STATE OF TENNESSEE
DEPARTMENT OF CONSERVATION
DIVISION OF GEOLOGY
WALTER F. POND, State Geologist

BULLETIN 47

GEOLOGY AND PETROLEUM RESOURCES OF CLAY COUNTY, TENNESSEE

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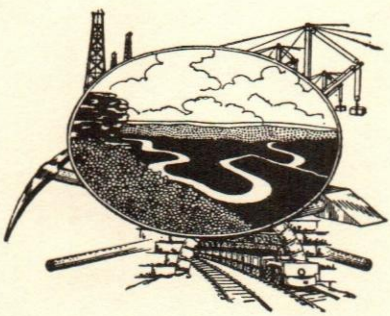

NASHVILLE, TENNESSEE
1939

Library Catalog Card

Tennessee. *Division of geology.*

. . . Geology and petroleum resources of Clay county, Tennessee, by Kendall E. Born . . . and H. B. Burwell . . . Nashville, Tenn. [Rich printing company], 1939.

xii, 188 p., 16 plates including 1 folded map in back pocket, 7 tables including 1 folded in front pocket. 23 cm. (Tennessee. Department of conservation. Division of geology. Bulletin 47.)

Bibliographical foot-notes.

1. Petroleum—Tennessee, Clay county. 2. Geology—Tennessee, Clay county. I. Born, Kendall E. II. Burwell, H. B.

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FOREWORD

Oil drilling in Clay County has been largely confined to the eastern part of the county, no doubt owing to earlier reports of this Division in which a farm line and structure map of only that part of the county was published. The present report with its more complete structure map will no doubt extend exploration to the western part of the county and there is no known reason why equally well-defined structures there should not have a good chance of production.

The State Geologist again emphasizes the fact that the structure contours on the county map are preliminary and that they should be checked by a competent geologist before they are used as a basis for drilling. It is not considered a function of a State Division of Geology to map structure in such a large area on private lands in accurate detail, but rather to indicate the type of structure which may be found, its relation to oil, and the places which seem most favorable for finding such structure.

An important part of this report, and one which is of wider application and consequence than appears at first thought, is the carefully worked out microscopic characteristics of well cuttings. Microscopic studies make it possible to definitely determine many subsurface geologic horizons which would otherwise be missed or viewed only with uncertainty. This is especially true when the cuttings are treated with acid to remove the limestone and other carbonate minerals, thereby leaving an "insoluble residue" consisting of shale, chert, sand grains and other forms of silica, which in many formations have characteristic textures and mineral content which determine the geologic horizon or position in the rocks, with certainty. Geologic science and the oil industry in particular owe a great debt to H. S. McQueen who so ably worked out the principles and early application of the method under Dr. H. A. Buehler, State Geologist of Missouri.

The work in preparation for this report and the report itself have been done in much more detail than is customary in an area with oil and gas production of this type. This is because cooperation of operators and drillers in saving well cuttings for this Division has accumulated a large fund of subsurface information and the report will serve as a type for the region. Shorter papers will, therefore, be sufficient for surrounding areas.

Too much cannot be said for the splendid cooperation which has been received from all concerned in collecting the information and the people of Clay County may well feel that they have had an important part in its preparation. Even the child who has given road directions has done his bit.

The main object of this report is to gather and place at the disposal of operators a vast fund of scattered information, in the hopes and expectation that it will further promote development of the mineral resources of the State in this and surrounding regions.

WALTER F. POND,
State Geologist.

ABSTRACT

Clay County is located in the northeastern part of the Middle Tennessee political division and is a part of the greatly dissected Highland Rim Plateau near the boundary of the northern and eastern units. Most of the drainage is into Cumberland River, which traverses the County in a general north-south direction and swings in entrenched meanders 400 to 600 feet below the general Highland Rim level.

The county is largely agricultural. Celina, with a population of less than 1,000, is the only incorporated town. There are no railroads, but the area is served by a good network of highways.

Rocks, ranging in age from the lowermost part of the Catheys limestone of the middle Ordovician (Trenton) to the Cypress sandstone of the upper Mississippian (Chester), outcrop in Clay County. At least 180 feet of Ordovician beds are exposed. These strata constitute a lithologic unit consisting of thin- to thick-bedded, gray, dense- to coarse-grained limestones with many calcareous shale beds. They are widely distributed in the valleys of Cumberland and Obey rivers and their tributaries. The Ordovician is succeeded by the widespread Chattanooga black shale which marks the base of the Mississippian. The lower Mississippian consists of approximately 200 feet of siliceous and cherty limestones, shales, and siltstones and is overlain by the Warsaw and St. Louis limestones of the middle Mississippian which form the surface rock of the Highland Rim over a considerable part of the County. The higher uplands are surfaced with the Fredonia (Ste. Genevieve) and Gasper oolites, and the youngest consolidated formation is the Cypress sandstone. The youngest rocks exposed are isolated patches of terrace gravels, probably of Tertiary age, and the alluvium along the present day streams.

Subsurface studies of samples from the deeper wells demonstrate the presence of the following formations: Hermitage formation, Carters limestone, Stones River group (Lebanon, Ridley, Pierce, and Murfreesboro), a unit (Zone B), possibly of Canadian age, and a section of cherty dolomites lithologically similar to the upper Knox dolomite group of the Appalachian region. No beds have been observed on the subsurface which are suggestive of the St. Peter sandstone.

The Upper Cumberland district is located in the Cincinnati geanticlinal structural province. The Nashville dome axis plunges gently to the north in extreme western Clay County. The regional dip is east-southeast. Other major structural features include: the Moss structural low, Bennetts Ferry upwarp, Celina arch, Peterman Bend trend, Mill Creek-Fox Springs anticline, and the Willow Grove terrace. The regional dip off the Nashville dome axis is interrupted throughout the county by many small sharp domes and synclines generally with closures of less than 30 feet. Approximately 80 of these small structures have been mapped.

Oil has been known in the Upper Cumberland district for over 100 years and several old wells, drilled for brine, encountered flows of oil and gas. It was not, however, until 1923 that commercial production was obtained in Clay County. Since that time, more than a dozen producing areas have been discovered, and the developments have been essentially a story of sporadic drill-

ing. The small initial capital required for shallow testing has resulted in numerous wildcat drilling operations with little accurate data to justify these explorations. Consequently, there has been an unusually high percentage of dry and near-dry holes. The more important fields include: Tinsleys Bottom, Mill Creek, Celina, Kettle Creek-Pine Branch, Peterman Bend, Fox Springs-Mitchell-Creek, Willow Grove-Irons Creek, and the Ashburn Creek-Jouett Creek areas. More than 350 wells have been drilled in the area covered by this report. While accurate production figures prior to 1935 are not available, the area is conservatively estimated to have produced slightly less than 300,000 barrels of oil. The oil is of high gravity, ranging from 38° to over 44° Baumé. Drilling has shown a close relationship between commercial accumulation of oil and geologic structure. While not all anticlines have produced there has been no significant production in areas definitely known to be structurally low.

The producing horizons are, almost without exception, dense- to medium-grained limestones ranging in age from the upper part of the Knox dolomite group to the Cannon limestone inclusive. The more important horizons have been the upper and lower Sunnybrook zones of the middle Cannon and Hermitage formations respectively, the lower part of the Carters limestone, the Lebanon limestone, and the upper part of the Ridley limestone.

The source of the oil in this region is believed to be the Ordovician rocks and no extensive migration is suggested. The greater part of the porosity seems to have been developed by fracturing with subsequent solution. Several producing horizons suggest an intimate relationship with unconformities.

In the shallow testing to date cable tool rigs have been used. The last fresh water is generally found at depths of 150 feet or less, and, although salt water is often present in the Trenton section, water does not present a major problem in this area. Usually, very little water is encountered from the base of the Trenton to the top of the Canadian, where mineralized waters often occur in the upper part of the Knox dolomite group. Shooting good shows or small pays is a common practice. Practically no acidizing has been attempted to date.

Geology and Petroleum Resources of Clay County, Tennessee

BY

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AND

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INTRODUCTION

LOCATION AND EXTENT OF THE AREA

Clay County is located in the northeastern part of the Middle Tennessee political division and comprises 254 square miles. It is bounded on the north by Monroe, Cumberland, and Clinton counties, Kentucky; on the east by Pickett County; on the south by Overton and Jackson counties; and on the west by Macon County. Locally, this group of counties is referred to as the Upper Cumberland district.

The entire county is covered by topographic quadrangles of the United States Geological Survey and, with the exception of the Standingstone sheet (scale 1/125,000), this mapping was a cooperative project with the State Division of Geology. All of the quadrangles except the Standingstone covering Clay County are comparatively recent and are on a scale of approximately one inch to one mile. In 1937 a new base map of the county, showing culture and drainage, was prepared by the Tennessee Division of Geology with the cooperation of the Tennessee Valley Authority and the Works Progress Administration. This map has been used as a base for the present report. The Cumberland and Obey rivers survey maps of the War Department have been used as a base for the sketch maps of the individual oil fields except the Mill Creek area.

FIELD WORK

The field studies upon which this report is based were initiated by the senior author in the spring of 1935 and have continued, with interruptions, to the present. The junior author has spent the major part of his time since April 1936, in Clay County. The greater part of this time, however, has been directed toward keep-ing in touch with current drilling activities and collecting data on the older wells drilled in the area. The actual writing of the report is the work of the senior author, although he has been assisted throughout by the field notes and discussions of the junior author.

Approximately 26 square miles in the Tompkinsville quadrangle were mapped structurally by the altimeter method during the summer of 1938 by John Webb, a temporary assistant of this Division.

SCOPE OF THE PRESENT STUDY

The present report has three principal objectives: (1) A general discussion of the stratigraphic and structural geology of Clay County, especially as it affects the possible accumulation of oil and gas; (2) a review of the past oil and gas developments in the area; and (3) as a guide for future oil and gas prospecting.

This publication is the first attempt to compile data on the oil and gas developments in Clay County. A number of the wells were drilled more than 15 years ago and over one-half of them are more than 10 years old. Since there is no law in Tennessee requiring drilling permits and the filing of logs and production figures, it has been difficult to obtain accurate information on many of the older tests. In many cases it became necessary to secure data from the best local information. The chances for errors by such methods are obvious. The State Division of Geology will appreciate any information regarding errors in the present report in order that these mistakes may not be perpetuated in revisions.

PREVIOUS WORK

Although oil seeps had been noted in the Upper Cumberland district for over 100 years and numerous wells in that region drilled for brine encountered oil and gas in varying amounts, the first detailed geologic work done on the oil and gas possibilities in this area was in 1918 by Charles Butts.[1] This report covered a very small part of southeastern Clay County along the headwaters of Mill Creek.

In 1923 a structural map of the Lillydale quadrangle was prepared by Gene Perry for the State Geological Survey. This map included the eastern half of Clay County and the western edge of Pickett County, and was issued along with a press bul-

[1]Butts, Chas. Geology and oil possibilities of the northern part of Overton County, Tennessee, and of adjoining parts of Clay, Pickett, and Fentress counties: Tenn. Geol. Survey, Bull. 24-2A, 1919.

letin late in 1925.[2] A more detailed manuscript outlining the general stratigraphic and structural conditions in Clay County accompanied the map, but this manuscript was never published. Perry's farm-line map was revised by W. F. Bailey in 1927, and the revised map was accompanied by a short press bulletin.[3]

The discovery well on the E. D. Marcum lease near Willow Grove was discussed by Jillson[4] in 1923, and by Nelson[5] the following year.

In 1924, Bassler mapped the Tennessee portion of the Lillydale quadrangle which included approximately the same area as Perry's structural farm-line map of 1923. The Chattanooga outcrop belt was the work of Perry. Bassler's map and a four-page stratigraphic summary were published in 1932.[6]

The discovery of oil in Tinsleys Bottom along the Jackson-Clay County line was reported by Nelson in 1925.[7] The following year Roberts discussed the developments and the general geologic and structural conditions in the Tinsleys Bottom field.[8] A farm-line map with some structural contours accompanied this report. In the same year Miser published a short note on the first Peterman Bend producer.[9] During the summer of 1926 field studies were carried on by R. G. Lusk in the Gainesboro quadrangle, which included a narrow strip along the southern edge of Clay County. This publication will be issued in the near future as Bulletin 45 of this Division.

In 1927, Lusk, in demonstrating the relation of structure to the accumulation of oil in Tennessee, briefly discussed the Tinsleys Bottom and the Celina fields as examples of this relationship.[10] In 1928 the Tennessee Division of Geology issued sketch maps of the Peterman Bend and Mill Creek oil fields, both in Clay

[2]Geologic structure map of the Lillydale quadrangle embracing eastern Clay County and parts of Overton and Pickett counties, Tennessee: Tenn. Geol. Survey, Press Bulletin, Dec. 14. 1925.

[3]Geologic structure map of the Lillydale quadrangle embracing eastern Clay County and parts of Overton and Pickett counties, Tennessee: Tenn. Div. Geol., Press Bulletin, May, 1927.

[4]Jillson, W. R. New Tennessee oil pool: Pan-Amer. Geol., vol. 40, pp. 197-202, 1923.

[5]Nelson, W. A. Oil and gas conditions in Kentucky and Tennessee during 1923: Production of Petroleum in 1923 (A. I. M. E.), pp. 133-134, 1924.

[6]Bassler, R. S. Stratigraphy of the Central Basin of Tennessee: Tenn Div. Geol., Bull. 38, pp. 180-183, geologic map in pocket, 1932.

[7]Nelson, W. A. Review of oil and gas conditions in Kentucky and Tennessee during 1924: Production of Petroleum in 1924 (A. I. M. E.), pp. 108-109, 1925.

[8]Roberts, J. K. The Tinsleys Bottom oil field, Clay and Jackson counties, Tennessee: Tenn. Geol. Survey, Press Bulletin, March 15, 1926.

[9]Moulton, G. F., Miser, H. D., and Logan, W. N. Petroleum developments in the Mississippi Valley region during 1925: Petroleum Development and Technology in 1925 (A. I. M. E.), pp. 650-651, 1926.

[10]Lusk, R. G. The significance of structure in the accumulation of oil in Tennessee: Bull. Amer. Assoc. Petroleum Geologists, vol. 11, pp. 905-917, 1927.

County. The recent oil developments and production in Clay County have been discussed by Born.[11]

ACKNOWLEDGEMENTS

The writers thank Mr. Walter F. Pond, State Geologist, for his suggestions and criticisms, both in the course of the field work and during the writing of the manuscript. The drafting has been done by George Hager and the chemical analyses have been made by D. F. Farrar, both members of the Tennessee Division of Geology.

Locations and general information on a number of the older wells have been supplied by Hampton and Tony Maxey, J. S. Arms, Bryan Davis, and J. H. Overstreet, all of Celina; A. G. Greenup of Glasgow, Kentucky, and the late J. H. McClurkin of Horse Cave, Kentucky. Valuable subsurface data have been furnished by the late J. H. McClurkin, Art Pratt of Murphysboro, Illinois, H. Z. Clark of Clay, Kentucky, William Horn of Marietta, Ohio, and J. H. Overstreet of Celina. In the individual fields aid was given by Amos Smith in Tinsleys Bottom, Allan Boles in the Mill Creek district, J. H. Overstreet for the Kettle Creek-Pine Branch area, Carlie Greenwood in the vicinity of Willow Grove, and Joe D. Moredock for the Ashburn Creek field. The drillers have extended excellent cooperation in the way of samples and well records, especially Jack Read, Ted and Lon Heckathorn. Malcolm Dillingham, Clay Eubanks, and Grover Evans. The writers are indebted to all of these and others who have kindly supplied data. Such cooperation is most desirable, especially in this State, which has no law requiring the filing of drilling permits, logs, and production figures. Without this aid very little information could have been assembled on the oil and gas developments in Clay County prior to 1935.

[11]Born, K. E. Oil and gas developments in Tennessee in 1935: Trans. A. I. M. E., vol. 118, pp. 349-350, 1936.
Born, K. E. Oil and gas developments in Tennessee in 1936: Trans. A. I. M. E., vol. 123, pp. 449, 451-452, 1937.
Born, K. E. Oil and gas developments in Tennessee in 1937: Trans. A. I. M. E., vol. 127, pp. 495-497, 1938.
Born, K. E. Oil and gas developments in Tennessee in 1938: Trans. A. I. M. E., vol. 132, pp. 403-405, 1939.

PHYSIOGRAPHY

GENERAL

Tennessee, because of its extreme east-west extension, crosses three major physiographic provinces of the United States and, consequently, presents a variety of land forms. Extending from the Great Smokies of the Appalachians westward to the Mississippi River, the State includes eight well-defined physiographic divisions, most of which extend unchanged into states lying north and south. These physiographic units conform remarkably well to the geologic structure of the underlying rocks; thus, the plains and plateaus have been developed on areas of essentially horizontal rocks and the highly folded and faulted strata have given rise to the mountainous areas of eastern Tennessee.

PHYSIOGRAPHIC DIVISIONS OF MIDDLE TENNESSEE

Central Basin.—The most conspicuous topographic feature of Middle Tennessee is an oval-shaped depression, ranging from 500 to 700 feet above sea level, whose major diameter trends N. 30° E. through Rutherford County, the approximate geographic center of the State, and which has been known for many years as the Central or Nashville Basin. This unit comprises some 5,000 square miles and is extremely irregular in outline. The Basin is entirely surrounded by the Highland Rim escarpment, some 400 or more feet higher than the Basin floor. Outliers from the Highland Rim, in the form of spurs and isolated remnants, extend far out into the Basin. In addition to these, the Basin is dotted with many small rounded, residual knobs rising 200 to 300 feet above the general level—remnants which clearly indicate that the Highland Rim formerly reached entirely across the present area of the Central Basin. The resistant Mississippian rocks, which offer protection to the present day Rim surface, once extended across the Basin, forming a surface of a former plain. The arching of these strata, due to the uplifting of the Nashville dome, hastened erosion near the crest of the uplift and once the resistant Mississippian rocks were removed the more soluble underlying Silurian and Ordovician limestones were attacked readily by both surface and subsurface waters with the ultimate formation of the present Central Basin.

Within the Basin proper two geomorphically distinct units may be recognized. These areas have been termed the "inner basin" and the "outer basin" by Theis.[12] This distinction is lithologic, topographic, and stratigraphic.

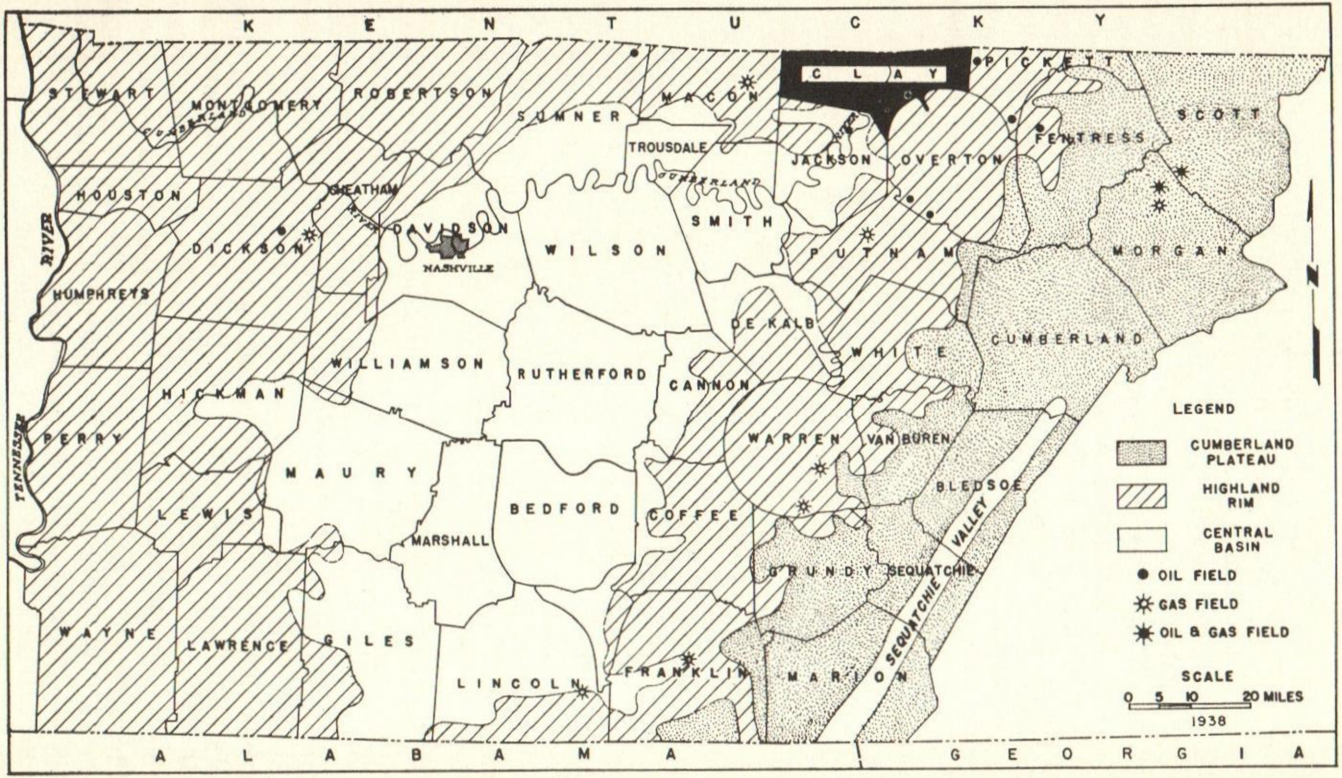
The inner basin centers in Rutherford County near the apex of the Nashville dome, and covers a considerable area in DeKalb, Wilson, Williamson, Maury, Marshall, and Bedford counties. Topographically, this area represents that part of the Central Basin in which base leveling was most highly perfected; the relief is small. The outcropping rocks are dense to fine-grained, light- to medium-gray limestones of the lower Ordovician Stones River and Black River groups.

The outer basin, as the name suggests, surrounds the inner basin at a somewhat higher elevation. The medium- to coarse-grained, dark-gray limestones and shales of the Middle and Upper Ordovician are widely distributed within this unit. It is in this area that the large Highland Rim remnants occur, and it is this part of the Basin which is projected as long, ramifying fingers into the Upper Cumberland district.

Highland Rim.—Completely surrounding the Central Basin is the Highland Rim plateau region, a slightly undulating plain, whose eastern boundary is the foot of the Cumberland Plateau, and whose western terminus is the high ridges overlooking the Western Valley of Tennessee River. It is the largest physiographic division in the State, with an area of nearly 11,000 square miles. In Tennessee the plateau reaches a maximum elevation of nearly 1,400 feet near the southeastern corner of Rutherford County, with an average altitude of slightly less than 1,000 feet. The Rim region throughout is capped by limestones, shales, and cherts of Mississippian age. The Highland Rim province in Tennessee is subdivided according to its relation to the Central Basin into the eastern, northern, and western Highland Rims.

The eastern Rim is a general plain averaging 1,000 feet in altitude and extending from the base of Cumberland Plateau escarpment westward to the common boundary with the Nashville Basin, where the Rim is deeply trenched by many subparallel drainageways which have given rise to a maze of flat-topped linear ridges and outliers. The northern part of the eastern Highland Rim is trenched to a depth of 250 to 600 feet by Cumberland River and its major tributaries whose ingrown meanders swing laterally between 2 and nearly 8 miles. This general area includes Clay and adjoining counties, and it presents the most rugged and picturesque scenery in Middle Tennessee.

[12]Theis, C. V. Ground water in south-central Tennessee: U. S. Geol. Survey, Water-Supply Paper 677, p. 13, 1936.



Sketch map of middle Tennessee showing the location of Clay County in relation to past and present producing areas in the State.

LOCAL

General Features.—As previously outlined, Clay County is a part of the greatly dissected Highland Rim physiographic division near the boundary of the northern and eastern Highland Rim units. With the exception of a small area in the northwestern part, the entire county lies within the drainage of Cumberland River, which traverses the area in a general north-south direction and swings in entrenched meanders 400 to 600 feet below the general Highland Rim level. The larger tributaries, especially Obey River, are also deeply incised and have meandering courses.

Topographically, the lowest part of the county is at the southern edge where the floodplain of Cumberland River is approximately 500 feet above sea level. The valleys of the larger tributaries are only slightly above this elevation. Pilot Knob, 3½ miles northeast of Celina, is the highest point in the county, with an elevation of 1,398 feet above sea level. The topographic relief is approximately 900 feet.

In general the Highland Rim level ranges between 850 and 1,000 feet above sea level. While the county as a whole is rugged and highly dissected, especially near the major streams, there are several interstream areas which are essentially flat uplands with relief of less than 100 feet. The most marked of these are in the western part of the county in the vicinity of Moss; immediately north of Richville; one mile south of Cherry Crossroads; and south of Dentons Crossroads and Pine Hill School. In the central and eastern parts of the county there are several square miles of "flatwoods" north of Pea Ridge, east of Chowning Knob, and northeast of Fairview Church.

These interstream tracts of the Highland Rim are remarkably even-topped. Drainage is essentially ephemeral and the streams usually display flat longitudinal and transverse profiles. In areas of relatively soluble middle and upper Mississippian limestones, sinkholes are well developed.

A few remnants of an older topographic surface above 1,000 feet are preserved, among which are Pilot Knob, northeast of Celina; the higher hills east and northeast of Pea Ridge; and Chowning Knob in the southeastern part of the county, west of the headwaters of Irons Creek. These topographic features are local landmarks and offer testimony that the present Highland Rim physiographic surface in Clay County was not brought to its present position in a single and short unit of geologic time.

In the central, eastern, and southwestern parts of the county the Cumberland River and its tributaries, especially the Obey, have carved their valleys some distance below the Highland Rim level. In many places this erosion has proceeded to approximately the general level of the "outer" Nashville Basin. Indeed, this downcutting has resulted in an extension of the physiographic surface of the "outer" Basin into Clay County as a long, meandering topographic feature with many ramifications. This surface coincides, of course, with the present and older meander belt of the Cumberland River and its principal tributaries.

The intricate dissection below the Highland Rim level has given rise to sharp, steep-sided valleys separated by narrow, winding ridges which have numerous long, irregular fingers. These fingers usually branch off at large angles and serve as drainage divides for the smaller streams. This extreme dissection in most of the area is well shown by a topographic cross-section which consists essentially of a tiring and monotonous succession of steep climbs to the tops of rounded spurs or narrow, flat-topped ridges, each followed by an abrupt plunge to the bottom of a sharp, deep valley.

In addition to the uplands or "flatwoods" of the interstream areas on the Highland Rim, the only level surface in the county is along the Cumberland and its major tributaries. The flood plain of the major stream varies from less than a mile to more than two miles in width. In places Obey River has developed its flood plain more than a mile wide, although the average is much less than this figure. The lower reaches of other tributaries such as Irons, Ashburn, Mitchell, and Proctor creeks, have narrow flood plains. In general, however, the relief in the area, and consequently the gradients of the tributary streams, is such as to give the streams impetus to cut downward at a rapid rate with little or no development of alluviated valleys.

Terrace Gravels.—Lusk[13] has described two small patches of gravel on the Highland Rim in southern Clay County, $5\frac{1}{2}$ miles south of Celina and 2 miles east of Baptist Ridge School on the Butlers Landing-Hilham road. The areal distribution of these gravels is only 2 or 3 acres. Here the pebbles occur in a matrix of reddish sand, silt, and clay, and range in size from less than $\frac{1}{4}$ inch to about $1\frac{1}{4}$ inches in the long dimension. They are composed essentially of clear to milky quartz, and most of them are quite smooth. While the larger pebbles are subangular to well-

[13]Lusk, R. G. Gravel on the Highland Rim plateau, and terraces in the valley of Cumberland River: Jour. Geol., vol. 36, pp. 164-170, 1928.

rounded, the smaller ones are usually well-rounded. Lusk[14] suggested that these gravels represent remnants of a general gravel sheet deposited at the time Cumberland River was entrenching itself in the Highland Rim plateau. The remnants are less than 4 miles from the present river. The present writers have not noted additional preservations of such gravels on the Rim, although detailed work would undoubtedly add to these occurrences.

It was not within the scope of the present study to carry on detailed work on the terraces along the present Cumberland River and its major tributaries. The Upper Cumberland district, however, offers a fertile field for students of the geomorphological history of the Cumberland River in Tertiary and later times. Within the meander belt of the larger streams hills occur which are composed essentially of alluvial material. Many of them stand as high as 100 to 200 feet above the present flood plain. This is especially true of the hills just west of Seven Sisters Bluff along Cumberland River in southern Clay County. Here, in one locality, a section of nearly 30 feet of well-laminated clays and clay sand, with small amounts of gravel, is exposed at least 100 feet above the present level of the river. A similar terrace is preserved at about 700 feet elevation in Barksdale Bend of Obey River, 5 miles east of Celina. Careful work would show the presence of many others, especially at or about the 700-foot level. The preservation of these terraces point conclusively that the Cumberland, during the past, has flowed across a general region level enough for it to develop meanders. After the development of the meander belts the area was gently uplifted and the Cumberland and its tributaries, thus quickened by increased gradients, continued to carve downward into the underlying rocks with the preservation of much of its earlier channel. As these streams became incised, successive terraces were developed which show that this process of entrenchment was not a steady one, nor was it accomplished in a relatively short unit of time.

DRAINAGE

Except for a small area in the northwestern part, Clay County lies within the Cumberland River drainage. The region is well supplied with water. From 1904 to 1930, inclusive, the average rainfall at Celina was 52.63 inches per year. Precipitation is fairly well distributed throughout the year, the fall months receiving the least amount.

[14]Idem., p. 166.

Cumberland River, in its north-south course across the county, is the largest stream. Its most important tributary is Obey River, which flows in a sinuous course across the eastern part of the county and joins the Cumberland at Celina. The main tributaries to Obey, in Clay County, are Wolf River, Ashburn, Sulphur, Irons, Mitchell, and Neeley creeks, all in the eastern half of the county. In addition to Obey, the Cumberland is fed directly by Kettle, Proctor, Knob, Dry, Turkey, Mill, Brimstone, and smaller creeks. The drainage in the southwestern part of the county is directly into Jennings Creek, which enters the Cumberland north of Gainesboro in Jackson County. Trace and Line creeks are the major drainage ways in northwestern Clay County.

In addition to surface streams, subsurface waters are locally important means of water discharge. Springs are numerous throughout the area and in many of the valleys the springs constitute the only source of water for domestic use. Most of the springs are of the gravity type; that is, they percolate from permeable beds or flow under the force of gravity from openings in the rocks. In general, the springs are of the seepage class. In many of the valleys water issues from minute joints and bedding planes near or at the top of the Chattanooga black shale, although their water is probably derived, for the most part, from weathered zones in the overlying limestones, shales, and cherts of lower Mississippian age. The base of the Chattanooga is also characterized in many places by small seepage springs.

In the eastern and southeastern parts of the county, a calcareous sandstone at the top of the Warsaw formation (Garretts Mill) is often so pervious to waters that this zone may be recognized by the abundance of springs. Springs are also present in the middle and upper Ordovician limestones in many of the valleys.

Although analyses have not been made, the springs are known to differ greatly in the chemical character of their water. Those which issue from thoroughly weathered and leached zones usually contain little dissolved material, those that seep by slow percolation from partly leached limestones yield water that is relatively highly concentrated and hard. The bedding plane and joint springs in the Chattanooga shale are often of the sulphur water type.

While the development in sinkholes in Clay County is not as pronounced as in the adjoining counties to the east and southeast, numerous sinks do occur. In the general area west of Moss, in the western part of the county, the relatively pure limestones of the Warsaw formation and the St. Louis have given rise to a local karst topography. The sinks are roughly elliptical in outline, generally less than 40 feet deep, and some of the larger ones approach one-half mile in their longest dimension. Smaller sinks occur in the St. Louis and Warsaw limestones in the general upland along Pea Ridge, and on these same formations in the eastern part of the county.

The almost entire restriction of sinkholes in Clay County to the more soluble Mississippian limestones of Warsaw and St. Louis ages, points toward a well-developed karst topography at the time when these formations were more extensive over the county. Such a condition exists at present in parts of Pickett and Overton counties and throughout the Highland Rim areas where the middle Mississippian limestones have their greatest areal distribution. It is, perhaps, a significant factor in the physiographic history of the Highland Rim region that the development of karst is generally arrested when downward percolating waters contact the siliceous shales and cherty limestones of the Ft. Payne formation. Sinkholes in the Ordovician limestones of Clay County are not common.

GEOGRAPHY

CULTURE

Clay County was erected in December 1870, from nearly equal parts of Jackson and Overton counties. The county was named in honor of Henry Clay. Celina was selected as the county seat over Butlers Landing and Bennetts Ferry, and has remained the center of county government and activities. The county now comprises four civil districts.

The 1930 population was 9,577, with a density of 37.7 persons per square mile. Celina, with a population of 756, is the largest and only incorporated town. It is located on the east bank of Cumberland River near the geographical center of the county. It is the most important trading center and has good stores, schools, a bank, and a hotel. Willow Grove and Lillydale are small settlements in the eastern half of the county. In the western part Hermitage Springs and Moss are trading centers. Butlers Landing serves a sizeable area in the southern part. In addition to these, there are many smaller settlements scattered throughout the county, each with less than a dozen houses, a church, a school, and usually a store or two.

INDUSTRY

Clay County is almost wholly agricultural, 7,657 persons of the 1930 population of 9,577 living on farms. In 1930, nearly 83 per cent of the total land was in farms with the average farm consisting of 92.4 acres. The value of farm lands and buildings totals over $3,000,000.

The soils and climate of the county would support a widely diversified agriculture, but the lack of good transportation facilities in the past has retarded expansion. Tobacco, potatoes, corn, and hay crops are the principal products. Vegetables, with the exception of those for domestic consumption, are of little commercial importance. Grapes, apples, peaches, pears, and cherries are the principal fruits. In general, fruit-growing is neglected. The raising of live stock is important on most farms and considerable poultry is marketed.

Clay County comprises three major soil divisions which correspond remarkably well to the physiography and stratigraphy. The surface soils of the Highland Rim upland are generally gray, due to weathering and leaching. Yellow and red are the prevailing colors of the subsoils. This type of soil was mapped in Jackson County, which immediately joins Clay County on the south, as the Clarksville series and consists of silt loam, gravelly loam, and stony loam phases.[15] Chert occurs abundantly in this soil, being derived, for the most part, from the siliceous lower Mississippian rocks, with additions from cherty zones in the overlying middle Mississippian formations. The Clarksville series are not considered strong soils and are used mostly for corn and small grain.

The Hagerstown soils occupy the slopes below the Clarksville loams and consist essentially of soils derived from the lower part of the Ft. Payne formation, the Chattanooga shale, and the upper part of the Ordovician limestones. It is a more fertile soil than the Clarksville, but because of severe erosion on the hill slopes probably less than 50 per cent of this type is tilled, the remainder being largely in pasture.

The soils of the bottom lands and flood plains are classed in the Huntington series and are light brown in color and there is usually little change in color or character of the material from

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[15]Rogers, R. F. and Derden, J. H. Soil survey of Jackson County, Tennessee: U. S. Dept. Agri. (Bur. of Soils), pp. 14-29, 1915.

the surface down.[16] These soils are composed of alluvial materials washed chiefly from limestone. This type of soil is very productive and is practically all under cultivation, almost entirely in corn.

Lumbering, an important industry in Clay County in the past, is now of secondary importance. At one time the county was heavily forested with many varieties of hardwoods, but practically all of the walnut and most of the poplar has been removed. Lumbering is still carried on in many parts of the area, the hardwood varieties receiving the most attention.

TRANSPORTATION

There are no railroads in Clay County, a condition which has retarded the development of the county's resources to a large extent. The closest railroad shipping points are on the Tennessee Central Railroad at Algood or Double Springs in Putnam County, both of which are about 36 miles from Celina.

Excellently maintained State highways cross the county. Graveled Highway 53 offers transportation from Gainesboro north through Butlers Landing to Celina, and thence east through Willow Grove, joining with Highway 42 near Byrdstown in Pickett County. Highway 52 from Livingston crosses the county and passes through Celina, with which it connects Red Boiling Springs. This Highway is paved, with the exception of the stretch between the junction with Highway 51 and Red Boiling Springs. A few miles west of Moss, Highway 51 joins 52 and provides a good road to Tompkinsville, Kentucky, and other points to the north and northwest. There is a bridge across the Cumberland at Celina.

In addition to these state highways most parts of the county are reached by gravel and dirt roads, which range in condition from well-maintained highways to certain types of roads on the Highland Rim and up the creek bottoms that are practically impassable for automobiles. The comparatively recent policy of removing the roads from near or actually in the stream beds has made these roads passable in nearly all kinds of weather. In general, the roads of Clay County are above the average for this part of Tennessee.

Cumberland River was the chief route of travel in earlier days and some of the heavier freight is still transported by water, during the time of the year when the river is navigable.

[16]Idem, pp. 23-28.

Log rafts are constructed in the vicinity of Celina and are floated down the river. Barges are loaded with staves to be used for automobile spokes and transported down the river to suitable mills with railroad facilities. During the past, small amounts of crude oil have been barged from Clay and Jackson counties.

CLIMATE

This section of Tennessee has a rather mild climate. The summers are moderate, with occasional hot periods during which the temperature reaches between 90° and 100° F. Usually the winters are short and mild, accompanied by light snows, few of which remain on the ground for more than a week.

There is no Weather Bureau station in Clay County, but figures are available for Carthage, the county seat of Smith County, located about 30 miles southwest of Celina. At Carthage the average maximum temperature is 71.9° F., and the average minimum temperature is 47.9° F. The average date of the last killing frost in the spring is in early April and the first killing frost in the fall is during the last of October. The growing season approximates 200 days.

STRATIGRAPHY

INTRODUCTION

The rocks outcropping in Clay County, as well as those penetrated thus far by drilling, are all of sedimentary origin. This class of rocks includes those which have originated as sediments transported from land by water, wind, or ice, and spread out as great layers or sheets on the bottom of shallow seas which covered parts of the continent during the geologic past. The rocks of this class include sandstones, clays, shales, limestones, dolomites, and many others. In Clay County, limestones, shales, and sandstones are the most common; limestones predominate and sandstones occupy a relatively small part of the rock section.

A study of sedimentary rocks, including their position, order of deposition and relative age, is called *stratigraphy*. Stratigraphic studies over the world have definitely established that our present continental areas have been invaded repeatedly by shallow seas during the past. Streams, originating on higher lands bordering these continental seas, carried immense amounts of sediments from the border lands to the sea, and these sediments were laid down, either along the shore or farther out, as great stretches of sand, silt, mud, and other materials. The death of organisms of the sea with their calcareous shells contributed to the calcareous oozes on the sea floor. Later these sediments were buried beneath younger sediments and as the land continued to sink, the waters covered more land and the sediments became more deeply buried. The pressure of the overlying materials compressed or consolidated the original sediments into hard rocks which are classed as sedimentary rocks; that is, the limy oozes and calcareous materials were compacted into limestone, the sand grains were cemented into sandstones, and the muds and silts were compressed into shales.

Essentially the same conditions of sedimentation have occurred repeatedly throughout geologic time with a deposition of similar beds of sedimentary rocks. Therefore, in order to distinguish between these and for the purpose of mapping, a name is given to each group of beds which are composed of essentially the same type of rock. Such a group of strata is called a *formation,* and it has become customary to name them after some geographical locality, usually where they are especially well developed or exposed or where they were first studied. Thus, the Chattanooga shale, so widespread on the slopes in Clay County, has been named from the city of Chattanooga, where it is well exposed.

In most areas the sequence of formations is not complete, due to the absence of great thicknesses of rocks that were deposited in certain regions and not deposited in others. For example, in Clay County the Chattanooga shale is underlain by the Leipers formation of Ordovician age. In other parts of the United States there are over 10,000 feet of rocks of the upper Ordovician, Silurian, and Devonian ages present between these two formations. This thick section of rocks is definitely known to be older than the Chattanooga shale and younger than the Leipers formation. Therefore, in Clay County the plane of contact between the Chattanooga shale and the Leipers formation is termed an *unconformity*. Several other unconformities are known in the exposed rock section in Clay County.

The practical value in the study of rock formations lies in the fact that a large part of the economic products of any region have definite relations to the rock formations. Thus, the coals of Tennessee are found only in rocks of Pennsylvanian age; most of the zinc deposits of Tennessee are found only in rocks of Pennsylvanian age; most of the zinc deposits of East Tennessee are restricted to certain zones within the Knox dolomite; and the oil and gas horizons in the Upper Cumberland district occur in certain groups of rocks of Ordovician age. Therefore, the study of these formations, their character and distribution, serves as a basis for the mineral development and is just as fundamental as the foundation of a building is essential to support the superstructure.

RESUME OF STRATIGRAPHY

Rocks, ranging in age from the upper part of the Knox dolomite group of the lower Ordovician (Canadian) to Recent, are definitely known to occur in Clay County. The Canadian, Stones River, Black River, and lower Trenton formations do not outcrop anywhere in the county, but they have been studied and correlated by microscopic examinations of well samples.

The oldest outcropping formation is probably the Cannon limestone of Trenton age, which is believed to outcrop during low water of Cumberland River just west of Tinsleys Bottom along the Clay-Jackson County line. The Cannon, Catheys, Leipers, and locally a formation of Richmond age, represent the Ordovician system. At least 180 feet of strata are exposed below the base of the Chattanooga shale in Clay County. These formations consist essentially of thin- to thick-bedded, gray, dense to coarse-grained limestones with many calcareous shale beds. They are widely distributed in the valleys of Cumberland River and its tributaries.

The Ordovician is succeeded by the widespread Chattanooga black shale. Rocks of Silurian and Devonian ages are absent and the Ordovician-Mississippian contact is the most pronounced plane of unconformity in the Upper Cumberland district. The Mississippian system of rocks is well represented in Clay County. The distinctive Chattanooga shale is succeeded invariably by approximately 200 feet of siliceous and cherty limestone, shale, and siltstone. In the present report this entire unit has been assigned to the Fort Payne formation. The Warsaw and St. Louis limestones of the middle Mississippian overlie the Fort Payne and form the surface rock of the Highland Rim plateau over a considerable part of the county. The higher uplands are surfaced with the Fredonia (Ste. Genevieve) and Gasper oolites (Monte Sana group of E. O. Ulrich) and the youngest consolidated formation is the Cypress sandstone of lower Chester age. These formations have a very limited areal distribution, being restricted to the higher knobs in the area north and northeast of Celina.

The youngest rocks exposed in Clay County are the terrace gravels, probably of Tertiary age, and the alluvium of the present day streams.

TENNESSEE DIVISION OF GEOLOGY BULLETIN 47, PLATE III

SYSTEM	SERIES	FORMATION	COLUMNAR SECTION	THICK.	CHARACTER OF ROCKS	DISTRIBUTION IN CLAY COUNTY
MISSISSIPPIAN		CYPRESS SANDSTONE		20'	WHITE TO BROWN, COARSE SANDSTONE.	CAPPING HIGHEST HILLS NORTHEAST OF CELINA.
	UPPER (CHESTER)	MONTE SANA GROUP OF E.O. ULRICH: GASPER OOLITE		150'	LIGHT GRAY, USUALLY PURE OOLITIC LIMESTONE WITH SOME DARKER GRAY FINE-TO MEDIUM-GRAINED LIMESTONE. SHALE LOCALLY PRESENT NEAR THE BASE.	CAPPING HIGHER HILLS AND UPLANDS NORTHEAST OF CELINA. WELL EXPOSED IN THE VICINITY OF PILOT KNOB AND ALONG PEA RIDGE. ALSO EXPOSED ON CHOWNING KNOB IN SOUTH-CENTRAL PART.
	MIDDLE (MERAMEC)	MONTE SANA GROUP OF E.O. ULRICH: FREDONIA OOLITE		150'	GRAY TO BLUE-GRAY OOLITIC LIMESTONE WITH CONSIDERABLE AMOUNT OF DARK MEDIUM-GRAINED LIMESTONE. GENERAL LITHOLOGY VERY SIMILAR TO OVERLYING GASPER OOLITE.	PRACTICALLY THE SAME AS THE OVERLYING GASPER OOLITE.
		ST. LOUIS LIMESTONE		140'	DARK BLUE TO BLUE-GRAY, FINE TO MEDIUM-GRAINED LIMESTONE. CHERT COMMONLY PRESENT. SHALE LOCALLY DEVELOPED ESPECIALLY NEAR THE BASE.	SURFACE FORMATION OVER MOST OF INTER-STREAM DIVIDES IN EASTERN HALF. SMALL AREA OF RESIDUAL ST. LOUIS PRESENT CAPPING HIGHEST HILLS IN WESTERN PART IN THE VICINITY OF MOSS.
		WARSAW FORMATION		80'	GRAY TO BLUE, GRANULAR LIMESTONE WITH SOME GRAY SHALE. THIN, MASSIVE SANDSTONE (GARRETTS MILL) DEVELOPED AT TOP IN EASTERN PART.	WIDESPREAD IN EASTERN PART OCCUPYING UPPER PARTS OF VALLEYS BELOW THE ST. LOUIS. CAPS GENERAL UPLAND IN VICINITY OF MOSS.
	LOWER	FT. PAYNE FORMATION		230'	LITHOLOGY VARIABLE. DARK GRAY, FINE-TO MEDIUM-GRAINED, SILICEOUS AND CHERTY LIMESTONE, BLUE-GRAY, SILICEOUS SHALE AND GRAY CRINOIDAL LIMESTONE (NEW PROVIDENCE). BLUE-GREEN SILICEOUS SHALE (RIDGETOP). GREEN PHOSPHATIC SHALE PRESENT AT BASE (MAURY) GREEN SHALE.	MOST WIDELY EXPOSED FORMATION IN COUNTY. FORMS MAJOR PART OF VALLEYS IN EASTERN PART AND OCCUPIES MOST OF THE GENERAL UPLAND AND HEADS OF VALLEYS WEST OF CUMBERLAND RIVER.
		CHATTANOOGA SHALE		20'	BLACK, CARBONACEOUS, FISSILE SHALE SAND OCCASIONALLY AT BASE.	INVARIABLY PRESENT IMMEDIATELY BELOW FT. PAYNE FORMATION.
ORDOVICIAN	CINCINNATIAN	RICHMOND		0-10'	CLAY LIMESTONE WITH MUCH CHERT.	RESTRICTED AREA WEST OF CELINA.
		LEIPERS FORMATION		100'	GRAY-BLUE, NODULAR, ARGILLACEOUS LIMESTONE WITH INTER-BEDDED GRAY SHALE. LIMESTONE USUALLY THIN-BEDDED.	WELL DEVELOPED ALONG CUMBERLAND, OBEY AND THEIR MAIN TRIBUTARIES THROUGHOUT THE COUNTY. MOST WIDESPREAD ORDOVICIAN FORMATION.
	MOHAWKIAN	CATHEYS FORMATION		80+	GRAY-BLUE, IMPURE, USUALLY EVEN-BEDDED, FINE-TO MEDIUM-GRAINED LIMESTONE WITH GRAY SHALE BEDS.	LIMITED TO VALLEYS OF THE CUMBERLAND AND ITS IMMEDIATE TRIBUTARIES NORTH AND SOUTH OF CELINA.

Columnar stratigraphic section of rocks exposed in Clay County.

TABLE 2. STRATIGRAPHIC SYNOPSIS BASED UPON SAMPLES STUDIED FROM TYPICAL WELLS IN CLAY AND ADJOINING COUNTIES.

WELL NAME	No.	LESSEE	Location		Total Depth (Feet)	MAYSVILLE	TRENTON			BLACK RIVER		STONES RIVER				CANADIAN (?)	CANADIAN	
			Plate	No.		Leipers	Catheys	Cannon	Hermitage	Upper Carters	Lower Carters	Lebanon	Ridley	Pierce	Murfreesboro	Zone B	Zone C	Zone C_1
Anderson, Cora......	1	Dewey Mong..........	I	1	650	0–100		100–350	350–405	405–415	415–505	505–630	630–650	....	....	....	....	....
Arney, B. C.........	1	Doctors Syndicate.....	XIV	17	560	27–245		245–485	485–545	545–555	555–560	....	....	....	....	....	....	....
Brown, Rebecca.....	1	John Kerzan et al......	I	28	769	144–356		356–604	604–680	680–690	690–763	763–769	....	....	....	....	....	....
Cherry, O. N........	1	W. P. Clements et al...	I	37	663	No samples		Base at 300	300–360	360–370	370–450	450–575	575–663	....	....	....	....	....
Clay County Farm...	1	Mich-a-Tenn Oil&GasCo	XI	50	645	0–164		164–380	380–439	439–450	450–520	520–645	....	....	....	....	....	....
Donaldson Heirs....	1	Jesse Ashby et al.....	I	85	1456	....	0–70	70–285	285–336	336–352	352–429	429–564	564–691	691–707	707–1087	1087–1173	1173–1252	1252–1456
Fletcher & Brown...	2	A. G. Greenup et al....	I	102	1136	No samples			Base at 405	405–417	417–495	495–783		783–789	789–1136		....	....
Hargrove, John.....	2	Doctors Syndicate.....	XIII	117	851	No samples	130–212	212–436	436–495	495–510	510–586	586–729	729–837	837–851	....	....	....	....
Hull, Cordell........	1	Overstreet & Miller.....	X	138	631	No samples		Base at 355	355–415	415–425	425–500	500–604	604–631	....	....	....	....	....
Jackson, S. S........	1	W. P. Clements et al...	I	141	772	30–250		250–495	495–566	566–573	573–639	639–753	753–772	....	....	....	....	....
Langford, Lewis.....	1	Peeler et al...........	I	171	800	No samples			Base at 473	473–488	488–565	565–700	700–800	....	....	....	....	....
Lynn, G. H.........	5	Dafoe & Dafoe.........	VIII	180	1319	....	0–281			281–288	288–1040					1040–1120	1120–1145	1145–1319
Moredock, Joe D....	1	Carnahan Oil Co........	XIV	235	820	0–204		204–444	444–500	500–517	No samples					....	....	....
Moredock, Joe D....	2	Carnahan Oil Co........	XIV	236	1451	No samples			Base at 495	495–511	511–602	602–725	725–850	850–875	875–1125	1225–1267	Absent	1267–1358
Smith, H. L.........	1	Shamrock Oil & Gas Co.	VIII	296	522	....	0–214		-214–273	273–281	281–351	351–480	480–522	....	....	....	....	....
Williams, Mary E....	5	Ava Oil & Gas Co......	XII	349	1187	....	0–305		305–362	362–381	381–1060					1060–1080	Absent	1080–1187
Wright, Ed.........	1	Doctors Syndicate.....	I	352	850	85–300		300–535	535–590	590–600	600–685	685–805	805–850	....	....	....	....	....

CANADIAN SYSTEM OF E. O. ULRICH*

KNOX DOLOMITE GROUP

GENERAL STATEMENT

The oldest rocks pierced by the drill in the Upper Cumberland district are a part of the Knox dolomite group of Cambro-Ordovician age. This group outcrops over wide areas in the Great Valley of East Tennessee, where it is composed essentially of white, gray, light- and dark-blue limestones, magnesian and dolomitic limestones, and gray to brown dolomites. Cherts are abundant at certain horizons and sandstones and shales are locally developed. The thickness of this group of beds reaches more than 4,000 feet. To the west the Knox passes beneath younger beds, but at Murfreesboro, in Rutherford County, near the top of the Nashville dome, the Knox was encountered at 290 feet in a test well. About 75 miles northwest of Nashville, in the Wells Creek Basin in southeastern Stewart County, the Knox again appears at the surface in a local intensely disturbed area.[17]

In the area covered by this report 15 test wells have entered the Knox group (Table 3). The deepest well, stratigraphically, is the New Domain Oil and Gas Company's A. Phillips No. 2 (273),** drilled in 1906 in the northwestern part of Pickett County. Unfortunately, no samples are available from this test, but during 1938 Jesse Ashby et al., Donaldson Heirs No. 1 (85) reached a depth of 1,456 feet and penetrated more than 1,300 feet of rocks which are not exposed in this general region. Samples from this test, located just northeast of Celina, in central Clay County, allowed a detailed microscopic study of the character of the older rocks that underlie the Upper Cumberland district at depths below 1,000 feet (pp. 100-105). Samples have also been studied from the Ava Oil and Gas Company's Mary Williams No. 3 (347), Carnahan Oil Company's Joe D. Moredock No. 2 (236), and Dafoe and Dafoe's G. H. Lynn No. 5 (180). Valuable subsurface data on the pre-Stones River rocks in this region have also been obtained by sample studies of W. F. Carter et al., Thomas Scantland No. 1 and Clay Richardson No. 1 and L. G. Welsh et al.,

*In 1911 E. O. Ulrich (Bull. Geol. Soc. Amer., vol. 22, pp. 647-679, plate 27) proposed systematic rank for the Canadian. The Canadian was considered as a system on the 1933 edition of the Geologic Map of Tennessee and that classification is followed in the present report. The senior author, feeling that the question is still in the controversial stage, accepts the systematic rank of the Canadian only with reservations, preferring to delay a definite decision until more evidence is available. A decision is not essential to the usefulness of this report.—K.E.B.

[17]Safford, J. M. Geology of Tennessee: Nashville, p. 147, 1869.

Bucher, W. H. Cryptovolcanic structures in the United States: XVI Intl. Geol. Cong. Rep't., vol. 2, pp. 1066-1070, 1936.

**Numbers in parentheses refer to well record numbers on Table 1.

Sallie Read No. 1, and from Jesse Ashby et al., Cinda Sells No. 1 in central Pickett County.

Although the Knox group has been drilled into many times in Middle Tennessee, considerable difficulty has been experienced in subsurface correlation of the lower Ordovician section. This difficulty is particularly pronounced in an interval between samples lithologically characteristic of the Stones River group of limestones and the cherty dolomites previously considered representative of the upper part of the Knox group. In the past, this interval, has been considered as transitional between the Stones River and the Knox.[18]

In an attempt to obtain more definite information on the lithology and stratigraphic relationships of this interval, the senior author has begun detailed subsurface investigations including correlation by the insoluble residue method.[19] While these studies are not complete, considerable data have been obtained on the general distribution, lithology, and relationships of the pre-Stones River rocks of the Highland Rim areas and the Central Basin.

Previously considered as a single formation, recent detailed studies by Oder[20] have indicated the presence of at least seven distinct formations in the "Knox dolomite" of earlier stratigraphers. Since Clay County is located more than 100 miles west of the outcrop area of the Knox in East Tennessee, no attempt has been made in the present study to introduce Oder's formational names to the pre-Stones River subsurface units other than general suggestions as to possible correlations with the standard lower Ordovician section of the Appalachian region. Therefore, until both surface and subsurface studies are more complete, the pre-Stones River units of Clay and adjoining counties are considered as zones and have been assigned alphabetical designations (Plate IV). These zones have been based entirely upon the microlithology of original well samples and microcharacteristics of insoluble residues. There is a strong suggestion, however, that throughout most of Middle Tennessee these individual zones do have stratigraphic significance. The general lithologic character of original samples and insoluble residues from the pre-Stones River rocks in Clay County is shown in Plate IV. Detailed sam-

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[18]Andrews, T. G. Insoluble residues as an aid in stratigraphic studies of limestone of central Tennessee: Tenn. Div. Geol., unpublished manuscript.

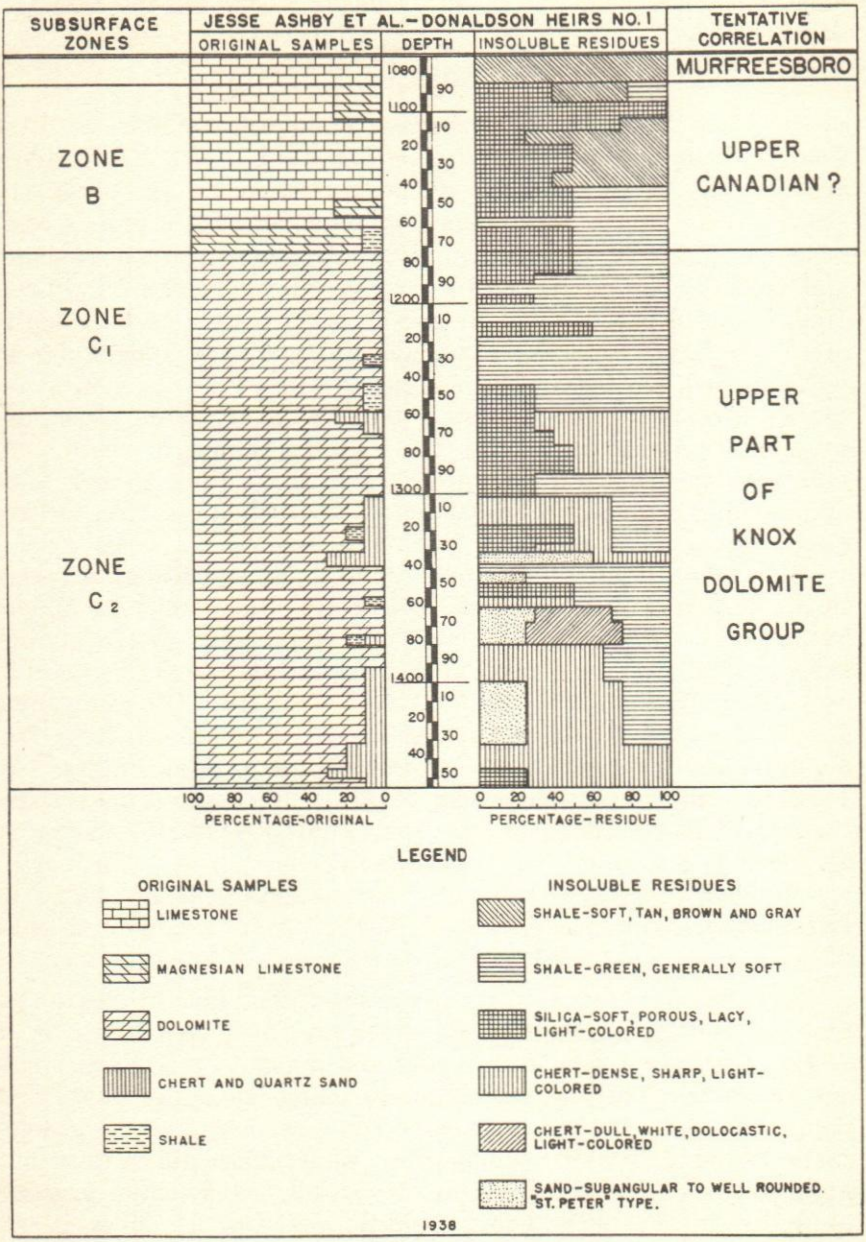
[19]With the exception of minor deviations generally necessary in local areas, the procedure used in the insoluble residue studies is the same as developed and described by McQueen. See McQueen, H. S. Insoluble residues as a guide to stratigraphic studies: Missouri Bur. Geol. and Mines, 56th Bien. Rep't., pp. 104-107, 1931.

[20]Oder, C. R. L. Preliminary subdivisions of the Knox dolomite in East Tennessee: Jour. Geol., vol. 42, pp. 469-497, 1934.

TABLE 3. STRATIGRAPHIC SUMMARY OF KNOX WELLS IN THE AREA.

WELL NAME	No.	LESSEE	LOCATION		Elevation (Feet)	Base of Pencil Cave	Top of Knox	Pencil Cave-Knox Interval	Total Depth	Source
			Plate	No.						
Boles, J. C.	1	Pierce et al.	IX	23	349	349′	....	....	1365′	....
Davis, A. T.	2	Dickson et al.	XI	75	586	421′	1179′	758′	1327′	Log
Donaldson Heirs	1	Jesse Ashby et al.	I	85	530	348′	1087′	739′	1456′	Samples
Holman, L. J.	1	W. S. Raydure	I	135	620	527′	1315′	788′	1385′	Log
Lynn, G. H.	5	Dafoe and Dafoe	VIII	180	540	288′	1045′	757′	1319′	Samples
Moredock, Joe D.	2	Carnahan Oil Co.	XIV	236	601	511′	1225′	714′	1451′	Samples
Nevins, W. J.	2	Spain et al.	I	255	595	445′	1225′	780′	1480′	Log
Osgathorpe, J. J	1	Dafoe and DeGive	I	256	521	300′	....	....	1300′	....
Pennington, J. W.	2	Ohio Oil Co.	IX	269	670	405′	....	....	1255′	....
Pennington, J. W.	3	Ohio Oil Co.	IX	270	784	528′	....	....	1350′	....
Phillips, A.	1	New Domain Oil & Gas Co.	I	272	614	605′	1320′	715′	1502′	Log
Phillips, A.	2	New Domain Oil & Gas Co.	I	273	613	585′	....	....	1725′	....
Phillips, Andrew	1	Robinson Oil Co.	I	274	624	579′	1315′	736′	1402′	Log
Short, Arch	3	Powell Oil Co.	X	290	620	535′	....	....	1333′	....
Williams, Mary E.	3	Ava Oil & Gas Co.	XII	347	548	381′	1060′	679′	1187′	Samples

TENNESSEE DIVISION OF GEOLOGY BULLETIN 47, PLATE IV



Graph of original samples and insoluble residues of the pre-Stones River rocks in Jesse Ashby et al., Donaldson Heirs No. 1.

ple descriptions of four wells which have been drilled into the Knox dolomite group are given on pages 86-88, 100-105, 121-123, and 143-146.

ZONE C_2

Original Samples.—The deepest samples available in Clay County, from Jesse Ashby et al., Donaldson Heirs No. 1 (85), are 369 feet below the base of the Murfreesboro limestone. In the original samples the section from 1,252 to 1,456 feet is composed of light- to dark-brown, fine- to coarse-grained dolomite and dolomitic limestone with a considerable amount of light-colored, dense to porous, angular chert. A soft, light-green shale is often associated with the chert and dolomite and subangular to well-rounded, frosted and pitted, quartz grains are common at intervals throughout this section. Chemical analyses of these lowest samples almost invariably show a magnesium carbonate content varying from approximately 10 to more than 40 per cent, approaching a theoretical dolomite. The insoluble matter, largely chert, varies from less than 5 to more than 60 per cent.

Subsurface studies indicate a corresponding lithology at practically the same stratigraphic position in other wells in Middle Tennessee. In the area covered by this report sample studies show that this zone has been drilled in the Ava Oil & Gas Company's Mary Williams No. 3 (347), the Carnahan Oil Company's Joe D. Moredock No. 2 (236), Dafoe and Dafoe's G. H. Lynn No. 5 (180), and in the Robinson Oil Company's Andrew Phillips No. 1 (274). Sample studies from other wells in the Upper Cumberland district indicate it has been entered by W. F. Carter et al., Thomas Scantland No. 1 and Clay Richardson No. 1 in northern Jackson County; Jesse Ashby et al., Cinda Sells No. 1 in central Pickett County; and in H. A. Cotton et al., Granville Cooper No. 1 in Fentress County, 7 miles southwest of Jamestown.

Insoluble Residues.—Chert is the most abundant insoluble residue in the samples below 1,252 feet in the Donaldson Heirs No. 1 (85). The colors vary from white and milky to tan; darker colors are rare. The chert is angular, sharp, generally dense and translucent. In the lower part of the section the chert is dolocastic, often dull white and porous. This dolocastic variety has been developed by acid solution of well-formed dolomite crystals imbedded in the dense chert. Oolitic varieties are present, although they are seldom common. A few of the fragments show concentric banding. Chert makes up from over 20 to nearly 60 per cent of the residue.

Associated with the chert is a light-green, soft, thinly-laminated, usually rounded, soft shale with a dull luster, and which appears very similar under the microscope to many of the shale fragments in the overlying Pencil Cave zone. There is a suggestion that this shale is bentonitic, although no biotite or mica fragments have been observed in it. In many of the samples a second type of shale is present in minor amounts. This shale is usually greenish-gray in color, dolocastic and hard.

Sub-angular to well-rounded, pitted and frosted, quartz grains occur at many horizons in this unit, especially at 1,332-1,337 feet in this particular well. This may represent the "St Peter" horizon (pp. 29-31).

Thickness.—The base of this zone has not been reached in any well in the Upper Cumberland district from which samples are available. The greatest thickness is in the Donaldson Heirs No. 1 (85), where 199 feet of beds are assigned to it. In other parts of Middle Tennessee thicknesses of more than 400 feet have been observed in subsurface studies. More detailed studies of this zone will probably show the presence of characteristic residues which will allow further subdivisions.

Correlation.—The lithology of the samples from Zone C_2 throughout Middle Tennessee is identical with that of the upper part of the Knox dolomite group (Cotter-Powell beds of Oder) of Canadian age which outcrops in the Appalachian region of East Tennessee and with rocks of Canadian age exposed at the center of the Wells Creek Basin in southeastern Stewart County. The residues of this zone compare remarkably well with those described by Oder[21] from the Cotter-Powell beds of Canadian age in the Appalachian Valley region of East Tennessee, but until additional subsurface data are available, which will allow more definite correlations, this unit will be designated as Zone C_2 of the Knox dolomite group. Studies to date indicate that it is a widespread unit underlying Middle Tennessee, and it has been traced on the subsurface from the Western Valley of Tennessee River to the western part of Cumberland Plateau.

ZONE C_1

Original Samples.—In most of the wells drilled into the Canadian in Middle Tennessee Zone C_2 is directly overlain by a group of beds composed of light-gray to greenish-gray, tan and brown, fine to coarse-grained dolomite and light-gray magnesian lime-

[21] Oder, C. R. L. The stratigraphy, structure, and paleontology of the zinc-bearing Knox dolomite, between Jefferson City and Bristol, Tennessee: Tenn. Div. Geol., unpublished manuscript.

stone. The dolomite appears identical with that in the underlying Zone C_2. Chert is practically absent, which is in striking contrast with the underlying section. This same general lithology characterizes this zone in samples from tests in the Upper Cumberland district. It is locally absent in at least two wells, the Ava Oil & Gas Company's Mary Williams No. 3 (347) and the Carnahan Oil Company's Joe D. Moredock No. 2 (236), where the typical cherty dolomites of Zone C_2 are directly overlain by the light-gray, magnesian limestones of Zone B. It has been observed in its usual development in the G. H. Lynn No. 5 (180) and the Donaldson Heirs No. 1 (85). It is also well developed in several wells in Fentress, Pickett, Overton, and Jackson counties in this general region.

Insoluble Residues.—Green shales are the characteristic residues of Zone C_1. The shales are of two types: (1) a light- to dark-grayish green, soft, thinly laminated shale with the dull luster, which has been described above in Zone C_2; and (2) a dark-green to bluish-green, dense, hard, often dolocastic shale. This latter type is often studded with small sub-angular to well-rounded quartz grains. Associated with these green shales are other shale fragments which may be light-gray to brown, often dolocastic, and generally soft. Minor constituents include quartz fragments and soft, lacy, light-colored silica. Sponge-like pyrite is common in some of the samples. By volume the residues from Zone C_1 average less than 15 per cent of the original samples.

Thickness.—Zone C_1 varies considerably in thickness throughout Middle Tennessee. As stated above, it is absent in the Mary Williams No. 3 (347) and the Joe D. Moredock No. 2 (236), although these are the only two wells in the State where this zone is definitely known to be absent. In the Donaldson Heirs No. 1 (85), 79 feet of beds above Zone C_2 have been referred to this zone. Twenty-five feet are present in the Lynn No. 5 (180) in the southern part of the area, although this incomplete sample set does not allow definite correlations.

Correlation.—On the basis of the predominance of dolomite, Zone C_1 is correlated with the upper part of the Knox dolomite group. It is undoubtedly of Canadian age. Green shales, almost identical with those described above, have been observed interbedded with dolomite and dolomitic limestones on the outcrop of the Cotter-Powell beds in East Tennessee. It is probably the "green lime" unit described by Bailey.[22]

[22]Bailey, W. F. Notes on sub-surface stratigraphy of middle Tennessee: Jour. Tenn. Acad. Sci., vol. 6, p. 82, 1931.

CANADIAN SYSTEM OF E. O. ULRICH (?)

KNOX DOLOMITE GROUP (?)

ZONE B

Original Samples.—In all wells drilled below the base of the Stones River group in Middle Tennessee, the dark-gray limestones, which are characteristic of the lower part of the Murfreesboro formation, give away rather sharply below to generally light-colored limestones. The limestones are dense and vaughnitic to fine-grained, although a few fragments may be coarse-grained. Many of the dense limestones show clear calcite inclusions not unlike the typical "birdseye" structure of the Carters limestone. Light-gray and tan are the predominating colors. Shale and chert are rare and are seldom observed in untreated samples. Clear and white calcite and selenite are the most common minor constituents. No fossils have been observed in this unit.

In most of the wells minor amounts of magnesian and dolomitic limestone are present, although no true dolomites have been observed. A series of analyses through this zone in Jesse Ashby et al., Donaldson Heirs No. 1 (85), show a maximum of 5.67 per cent magnesium carbonate. The 1,225-foot sample from the Carnahan Oil Company's Joe D. Moredock No. 2 (236) analyzed 9.52 per cent magnesium carbonate and 8.56 per cent is present in the 1,064-foot sample from the Ava Oil & Gas Company's Mary Williams No. 3 (347).

Insoluble Residues.—Quantitatively the insoluble residues from Zone B are in sharp contrast with those above and below this unit. By volume they seldom exceed 5 per cent of the original sample; the average is about 3 per cent and many samples yield practically no residue. The characteristic residues of Zone B are shales and minor amounts of silica. The shales are of two types: (1) a soft, light-colored, usually gray to green, porous, lumpy shale, somewhat similar in general appearance to certain of the gray shale residues of the overlying Stones River group; (2) a hard, light-gray to green, siliceous shale, much of which shows minute dolocasts.

Soft, porous, lacy and fragile, light-colored silica is the most characteristic residue of Zone B, although quantitatively it is subordinate to the shales. The original rock which gives rise to this diagnostic residue has not been definitely observed, but the source appears to be small amounts of light-gray, calcareous and siliceous shale. Minor constituents include pyrite and a gray, porous siltstone, much of which is probably decanted in the preparation of the residues.

Thickness.—In the Upper Cumberland district Zone B varies in thickness from 20 feet in the Mary Williams No. 3 (347) to a maximum of 86 feet in the Donaldson Heirs No. 1 (85). Sample studies of wells in Pickett, Fentress, and Overton counties suggest an average thickness of about 70 feet.

Correlation.—The exact relationship of Zone B to the overlying Stones River group and the underlying rocks, definitely of Canadian age, is not well understood. Previously these beds have been considered as transitional between Stones River and Knox dolomite groups.[23] The marked unconformity at the top of the Canadian throughout the Appalachian region does not support a theory of gradational relationship between the Canadian and Chazyan on the subsurface in Middle Tennessee.

In Bledsoe and Sequatchie counties in Sequatchie Valley, a distinctive series of light-colored, generally light-gray, thick- to thin-bedded, dense to vaughnitic and fine-grained limestones overlie a section of dolomite and dolomitic limestone—definitely a part of the upper Knox dolomite group—and underlie dense to fine-grained, very dark-gray limestone correlated by Wilson[24] with the Murfreesboro limestone of the Central Basin. In three sections measured this light-colored, dense limestone unit averaged 160 feet in thickness. Lithologically, this unit has much in common with samples examined from Zone B in Middle Tennessee.

This pre-Stones River limestone in Sequatchie Valley may be a part of the Newala limestone, which is present in northern Alabama, or it may represent a previously unrecognized formation.* In Alabama the Newala limestone is described by Butts[25] as a "thick-bedded, compact or non-crystalline or textureless, dark-gray, pearl-gray, and bluish-gray" limestone. It is composed of much limestone and proportionately little dolomite. On the basis of its fauna, the Newala is correlated by Butts[26] with the Cotter formation of upper Canadian age.

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[23]Andrews, T. G. Op. cit.

[24]Wilson, C. W., Jr. Stones River and Black River groups in central Tennessee: Tenn. Div. Geol., unpublished manuscript.

*Since the completion of the major part of this report the senior writer has revisited the outcrops of this unit in the Sequatchie Valley with Dr. E. O. Ulrich. In the field Dr. Ulrich recognized similarities of these limestones with the Everton formation of lower Ordovician age (Buffalo River group of E. O. Ulrich) of northern Arkansas. Very recent identifications of fossils collected from this unit have shown the presence of ostracods, gastropods, and a pelecypod, all of which are in the Everton collection from Arkansas. (Letter from E. O. Ulrich, June 23, 1939.)

[25]Butts, Chas. Geology of Alabama: Geol. Survey of Alabama, Spec. Rep't. 14, p. 93, 1926.

[26]Butts, Chas. Ibid., pp. 98-99.

While more detailed surface and subsurface studies will be necessary before a definite correlation may be made, Zone B is here tentatively correlated with the pre-Murfreesboro limestones in the southern part of Sequatchie Valley. The presence of magnesian limestones and soft, greenish-gray shales, typically developed in the underlying Knox dolomite group, suggests that Zone B is more closely related to the Canadian than to the overlying Stones River group. Until further data are available, therefore, Zone B will be considered as the top of the Knox dolomite group in Tennessee, although it is admitted that no undeniable evidence has been observed to date which would preclude the possibility of a post-Canadian age for this unit.

"ST. PETER" HORIZON[27]

GENERAL STATEMENT

A number of the deeper wells in the Central Basin and Highland Rim areas of Tennessee have penetrated sandy horizons in the lower Ordovician at depths ranging from 1,250 to 1,600 feet below the Chattanooga shale and from approximately 600 to 950 feet below the base of the Trenton limestones. These horizons, which average less than 10 feet in thickness, are composed of subangular to well-rounded, glassy, pitted and frosted quartz grains associated with white to gray and brown, granular, often cherty, magnesian limestones and dolomites. This unit has been tentatively and questionably correlated by some geologists[28] with the St. Peter sandstone of the Mississippi Valley and the term has become firmly entrenched in the vocabulary of the oil fraternity in the State.

SANDY HORIZONS ("ST. PETER") IN THE UPPER CUMBERLAND DISTRICT*

Subsurface studies to date have shown the presence of arenaceous horizons in the pre-Stones River rocks of the Upper Cumberland district. Twelve sets of well samples from this interval

[27]Born, K. E. Lower Ordovician sandy horizons ("St. Peter") in middle Tennessee: Paper read before the American Association of Petroleum Geologists, New Orleans meeting, March 17, 1938. Manuscript in preparation.

[28]Bailey, W. F. Notes on subsurface stratigraphy of middle Tennessee: Jour. Tenn. Acad. Sci., vol. 6, p. 81, 1931.

Piper, A. M. Ground-water in north-central Tennessee: U. S. Geol. Survey, Water-Supply Paper 640, p. 61, 1932.

Theis, C. V. Ground-water in south-central Tennessee: U. S. Geol. Survey, Water-Supply Paper 677, pp. 79-80, 1936.

*The Tennessee Division of Geology recommends abandoning the name "St. Peter sandstone" for producing zones in rocks of pre-Stone River age in the Upper Cumberland district. (See pp. 153-154.)

have been examined from this general region, four of which are described in the present report (pp. 86-88, 100-105, 121-123, and 143-146). That these zones have a certain amount of porosity is evidenced by the numerous salt water, sulphur water, oil and gas shows, and small amounts of oil production. Microscopic examinations of available well samples from these tests have failed to show the presence of a true sandstone in any part of the pre-Stones River section in Clay and adjoining counties.

There has been a tendency among drillers in the southern Cincinnati arch region, especially in the Upper Cumberland district, to give the name "St. Peter sandstone" to any porous horizon which occurs at least 500 feet below the base of the Pencil Cave. For example, the 1,176-1,187-foot samples from the Ava Oil & Gas Company's Mary Williams No. 3 (347) are described in the driller's log as "white sand, loosened up, and looks like St. Peter sand" (page 121). Under the microscope these samples are gray to tan and brown, medium- to coarse-grained dolomites with a considerable amount of dense, white, translucent chert and minor amounts of glassy, angular quartz (page 122). Very few of the quartz grains are well-rounded, pitted or frosted.

Subsurface studies by the senior author of 24 well sample sets in the Central Basin and Highland Rim areas of Middle Tennessee have shown that well-rounded, pitted and frosted quartz grains are commonly present in small amounts throughout the upper part of the Knox dolomite group. This sand seldom constitutes more than 5 per cent of any single sample, although in some wells concentration of sand grains may reach about 25 per cent. Such zones generally have porosity and have been termed "St. Peter sand." The thickness is seldom more than 5 feet. Such a sandy horizon was penetrated from 1,332-1,337 feet in Jesse Ashby et al., Donaldson Heirs No. 1 (85), where well-rounded quartz grains of the "St. Peter" type constitute approximately 25 per cent of the sample. The sand is associated with a light-brown, medium- to coarse-grained dolomite. The driller reported no oil or gas show or water in this zone.

CORRELATION

Subsurface investigations, especially by the insoluble residue method, carried on by this Division have made it possible to subdivide the upper part of the Knox dolomite group into definite lithologic zones which are believed to have stratigraphic significance (pp. 20-29). In a number of pre-Stones River samples studied from wells in the Central Basin and Highland Rim regions, concentrations of rounded quartz grains, generally found in a single 5-foot sample, were observed. These sandy horizons invariably occur below the top of the Canadian and they are always associated with dolomite and often with green shale and typical Knox chert. These porous zones do not appear to occupy a definite stratigraphic position with reference to any subsurface datum plane. For example, the sandy horizon penetrated at 1332-1337 feet in the Donaldson Heirs No. 1 (85) is in the upper part of Zone C_2, 245 feet below the base of the Murfreesboro limestone. Approximately 15 miles to the south, in W. F. Carter et al., Thomas Scantland No. 1 in northern Jackson County, a sandy horizon occurs 99 feet below the base of the Murfreesboro limestone. In the 24 sample sets studied to date throughout Middle Tennessee, the greater percentage of these arenaceous zones occur in zone C_1, although they are not restricted to any particular stratigraphic position within that zone. In other parts of the State the so-called "St. Peter sand" occurs from a few feet to as much as 160 feet below the top of Zone C_1.

Present studies, therefore, on the "St. Peter" horizon in Middle Tennessee indicate: (1) while sandy horizons consisting essentially of dolomite and minor amounts of well-rounded quartz grains, do occur in the pre-Stones River rocks, no true quartz sandstones have been encountered in drilling to date; (2) these sandy zones occur in the upper part of the Knox dolomite group, which definitely fixes a Canadian age for the "St. Peter" horizon; and, (3) these horizons do not occupy any definite stratigraphic position with reference to established subsurface markers. The conclusion is forced that the so-called "St. Peter sandstone" of the Upper Cumberland district are sporadically developed sandy horizons in the upper part of the Knox dolomite group. Such a correlation was suggested by Fanny Carter Edson[29] in 1935.

ORDOVICIAN SYSTEM

CHAZYAN SERIES

STONES RIVER GROUP

GENERAL FEATURES

In 1851 Safford[30] applied the name Stones River to the group of limestones well exposed along Stones River in Rutherford and adjoining counties in Middle Tennessee. Safford's original de-

[29]Edson, Fanny Carter. Resume of St. Peter stratigraphy: Bull. Amer. Assoc. Petroleum Geologists, vol. 19, pp. 1118-1119, 1935.

[30]Safford, J. M. The Silurian basin of middle Tennessee, with notices of the strata surrounding it: Amer. Jour. Sci., 2nd Ser., vol. 12, p. 352, 1851.

scription included the Carters limestone, which was transferred to the Black River group by Bassler[31] in 1915, whose studies, in collaboration with E. O. Ulrich, indicated that the limestone above Lebanon in the Central Basin of Tennessee was a part of the widespread Lowville limestone of Black River age. In the present classification the Stones River group is divided into four formations. These are, in ascending order: Murfreesboro limestone, Pierce limestone, Ridley limestone, and the Lebanon limestone.

In Middle Tennessee the Stones River group attains a maximum thickness of 318 feet on the outcrop.[32] The section is predominantly gray to dark gray, tan and brown, dense to medium-grained limestones. Thin, gray, calcareous shale beds are commonly present between limestone beds, but they make up a relatively small part of the unit. Chert is present, but not common.

Subsurface studies of well samples from the deeper tests in the Upper Cumberland district have indicated the presence of approximately 625 feet of Stones River beds between the base of the Carters limestone and the top of the Knox dolomite group. Lithologically, this section is remarkably similar to the Stones River rocks exposed in the Central Basin.

The marked lithologic similarity of this group on the subsurface in the Upper Cumberland district, together with its generally unfossiliferous nature, makes it difficult to subdivide the Stones River group into its component formations. Certainly the section from the Pencil Cave horizon at the top of the lower member of the Carters limestone of the Black River group to the top of Zone B constitutes a single lithologic unit. Since the greater number of the producing horizons in the Upper Cumberland district are in formations of the Black River and Stones River groups, the subdivision of these groups into their respective formations is decidedly advantageous. Insoluble residues appear most promising and widespread subsurface zones have been recognized as characteristic stratigraphic markers. The formational determinations in the correlated sample logs and the stratigraphic synopsis (Table 4) have been based entirely upon the microlithology of original samples and the microcharacteristics of insoluble residues. In all except the Lebanon-Ridley contact, check residues have been made on outcrop samples in the Central Basin. These formational determinations probably will be revised as both surface and subsurface studies progress on the

[31]Bassler, R. S. Bibliographic index of American Ordovician and Silurian fossils: U. S. Nat. Mus., Bull. 92, vol. 2, correlation table, 1915.

[32]Galloway, J. J. Geology and natural resources of Rutherford County, Tennessee: Tenn. Geol. Survey, Bull. 22, p. 30, 1919.

Stones River group in Tennessee. For the present, however, it is believed that units described below and shown in Table 4 will be of value in guiding future deeper drilling into the pre-Trenton rocks of the Upper Cumberland district.

MURFREESBORO LIMESTONE

Lithology.—On the outcrop in Rutherford County the Murfreesboro consists of heavy beds of dark- to medium-gray, bluish-gray, to drab and brownish, dense to medium-grained limestone. Individual beds range in thickness from less than 6 inches to more than 4 feet and are often separated by thin beds of argillaceous gray shale. Generally chert is not common, although small fragments of white to reddish brown and nearly black chert often occurs in residual Murfreesboro soils. At several exposures in Middle Tennessee dark chert is present in the upper few to 25 feet of the formation. The limestones of the Murfreesboro are usually brittle and when freshly broken or rubbed together emit a distinctly petroliferous odor. This feature is characteristic of many of the limestones of the Stones River group and small vugs containing oil are not uncommon.

Original Samples.—Microscopic examination of samples from the deeper test wells in Clay and adjoining counties show that the Murfreesboro consists of gray to brown, dense to medium-grained limestone with a small amount of argillaceous gray shale. Dark-gray is the predominating color. In the few analyses available the calcium carbonate content ranges from about 75 per cent to more than 90 per cent. The shales present in the samples are usually medium- to dark-gray, tan and brown, and generally thinly laminated. Minor constituents include calcite and gypsum, some white to dark, dense, sharp chert, and small amounts of pyrite.

Insoluble Residues.—After digestion in hydrochloric acid the residuals of the Murfreesboro limestone consist essentially of gray, tan and brown, thinly-laminated, soft, porous shales and dense to slightly porous chert grading in color from nearly white to very dark brown and nearly black. The shales, especially in the lower part of the formation, are sometimes dolocastic, although the dolocasts are smaller and not as pronounced as those in the underlying Knox group.

The most diagnostic residue marker in the Murfreesboro is a zone of dense, angular, vitreous chert. The color range is from light-gray to nearly black, the darker colors predominating. A chert zone at the top of the Murfreesboro limestone has been ob-

TABLE 4. LITHOLOGIC SUMMARY AND BASIS FOR CORRELATION OF BLACK RIVER AND STONES RIVER GROUPS IN CLAY AND ADJOINING COUNTIES

(Based on sample studies)

ORIGINAL SAMPLES	INSOLUBLE RESIDUES	BASIS FOR CORRELATION	Thickness (Feet)	Correlation		
Limestone; white to light-gray and tan, medium- to coarse-grained. Chert; light-colored, generally dense and angular.	Chert; white to light-tan and brown, generally dense and angular. Silica; white, soft, porous, lacy. Shale; gray, soft, porous. Average residue 20% by volume.	Sharp break from the dark-gray, very shaly and impure limestones of the overlying Hermitage formation. Base of the Hermitage well-marked by dull, brownish, soft, bentonitic (?) shale (Mud Cave of drillers). Sudden appearance of light-colored cherts in residues marks the upper member of the Carters. Checks outcrop section in Central Basin.	5-15	UPPER	CARTERS	BLACK RIVER
Limestone; white to light-gray and tan, dense to medium-grained. Shale; bentonitic, pale light-green, soft, thinly laminated, often biotitic (Pencil Cave of drillers).	Shale; bentonitic, soft, thinly laminated (Pencil Cave). Shale; light-gray, soft. Chert; rough, white, dolocastic—best developed in lower half. Residues less than 10%.	Top of lower member of Carters drawn at the first appearance of bentonitic, green shale (Pencil Cave). Upper 35 feet marked by general absence of chert. Well-developed zone of rough, white, dolocastic chert is a definite horizon marker of the lower Carters. Checks outcrop section in the Central Basin.	65-90	LOWER	CARTERS	BLACK RIVER
Limestone; light-gray to tan and brown, dense to medium grained. Shale; gray and tan, calcareous. Chert; gray and brown, dense, smooth, angular.	Chert; gray to dark-brown, dull, dense, smooth, angular. Silica; light to dark, brown, cavernous. Shale; gray to brown, soft, porous. Residue 10% by volume.	Top of Lebanon marked by the abrupt appearance of dark-colored cherts in the residues and the absence of white, rough, dolocastic cherts of the lower part of the Carters. Lower Lebanon characterized by increase in shale and decrease in chert in residues. Checks outcrop section in the Central Basin.	105-143		LEBANON	STONES RIVER
Limestone; gray and tan to brown, dense to medium grained. Shale; gray, tan and brown, soft, calcareous, porous. Lithologically same as overlying Lebanon.	Silica; white to dark gray and brown, porous, fragile, secondary (?). Shale; gray and tan to brown, soft. Chert; gray to brown with small rounded specks of darker colors—appears approximately 50 feet below top. Residues average about 10% by volume.	Lebanon Ridley contact is the most difficult to determine in Stones River section. Contact in present report is assumed at the first appearance of the secondary silica. Speckled chert horizon very diagnostic of middle part of the formation.	108-130		RIDLEY	STONES RIVER
Limestone; gray to tan and brown, dense to medium grained. Shale; gray, tan and brown and calcareous. Lithology similar to Lebanon and Ridley.	Shale; usually very light gray to nearly white, fluffy, soft, porous. Generally lighter in color than other Stones River shale residues. Absence of chert. Average residue 20-25% by volume.	Sudden increase in shale residues from less than 5 to more than 25 per cent is here considered to mark the top of the Pierce. Shales generally lighter in color than other Stones River shales. Checks outcrop section in Central Basin.	8-25		PIERCE	STONES RIVER
Limestone; generally dark gray to drab brown, dense to medium-grained. Chert; dark-gray to nearly black, dense, vitreous, angular, best developed near the top.	Shale; gray, tan, and brown, soft porous. Chert; generally dark-gray to black, dense, vitreous, near top. Average residue about 15% by volume.	Widespread dark-colored, vitreous chert horizon is here considered to mark the upper part of the Murfreesboro. Shales of the lower part quite similar to those of the Lebanon and Ridley, but generally darker in color than those of the Pierce.	350-380		MURFREESBORO	STONES RIVER
Limestone; light-gray to tan, generally dense to fine-grained, often slightly dolomitic.	Shale; gray to greenish-gray, porous, soft, lumpy, with some light-gray to green, hard, siliceous, minutely dolocastic shale. Silica; white, soft, lacy, porous. Average residue less than 5% by volume.	Abrupt change in lithology from generally dark-colored fine- to medium-grained limestones characteristic of the Murfreesboro into light-gray, dense, magnesian limestones.	20-86		ZONE B	CANADIAN?

served by the senior writer at several places in the Central Basin and it is believed to occupy essentially the same stratigraphic position in residues prepared from subsurface samples in Clay and adjoining counties. Detailed subsurface studies throughout Middle Tennessee indicate a widespread distribution for this chert. Since it is an excellent subsurface marker, this zone of dark chert has been assigned to the top of the Murfreesboro limestone. It seldom exceeds 10 feet in thickness. Below the chert zone gray, tan, and brown shales become the most abundant residue, although minor amounts of dense, angular, dark chert are present. Residues vary from less than 10 to about 25 per cent of the original samples from the Murfreesboro limestone.

Thickness.—In the type area of the Murfreesboro in Rutherford County approximately 70 feet of the formation outcrops, the base not being exposed at any part of the Central Basin. The Basin Oil & Gas Company's Henry Harrell No. 1, at the edge of the city of Murfreesboro, started near the top of the Murfreesboro limestone and drilled 290 feet of that formation before entering Zone B, here considered as representing the top of the Knox dolomite group.

In Clay County the maximum thickness recorded for the Murfreesboro limestone is in Jesse Ashby et al., Donaldson Heirs No. 1 (85), where 380 feet of beds have been assigned to this formation. In the eastern part of the county, the Carnahan Oil Company's Joe D. Moredock No. 2 (236) penetrated 350 feet of Murfreesboro and 349 feet of the same formation was drilled in northern Jackson County by W. F. Carter et al. in the Thomas Scantland No. 1. In Cox, Spivy, and Greenup's Fletcher and Brown No. 2 (102), 331 feet of Murfreesboro were drilled without reaching the base. Incomplete sample sets on Dafoe and Dafoe's G. H. Lynn No. 5 (180) and the Ava Oil & Gas Company's Mary Williams No. 3 (347) indicate a thickness of more than 250 and 204 feet respectively.

PIERCE LIMESTONE

Lithology.—In the Central Basin the dense, massive limestones of the Murfreesboro are succeeded by the Pierce limestone consisting of bluish-gray to dark-gray and brown, platy, and thinly-bedded limestone. The individual beds are seldom more than a few inches thick and are almost invariably separated from each other by bluish-gray, argillaceous and calcareous shale. The shale partings vary in thickness from a mere film to about one inch.

Original Samples.—Well samples in Clay County immediately above the dark chert horizon at the top of the Murfreesboro consist of gray to tan and brown, generally dense limestone with minor amounts of medium-gray, calcareous shale. In the Carnahan Oil Company's Joe D. Moredock No. 2 (236), this unit is considerably more shaly than the average.

Insoluble Residues.—After digestion in hydrochloric acid the shaly nature of the Pierce from the underlying and overlying Murfreesboro and Ridley, respectively, is demonstrated by the increased percentages in residues. Pierce residues often constitute 25 per cent of the original, which is in striking contrast with the shale residues of less than 10 per cent in the underlying Murfreesboro and overlying Ridley. The shale residues of the Pierce are generally light-gray—in contrast to the darker grays and tans of the other Stones River shale residues—and are usually soft and porous.

Thickness.—Galloway[32a] gives a maximum thickness of 28 feet for the Pierce limestone in Rutherford County. In the Jesse Ashby et al., Donaldson Heirs No. 1 (85), in Clay County, well samples assigned to the Pierce indicate a thickness of 16 feet for that formation and in the Thomas Scantland No. 1 in northern Jackson County, 4 miles south of the Clay County line, the Pierce is 19 feet thick.

RIDLEY LIMESTONE

Lithology.—In the Central Basin the Ridley is a gray to slightly brownish-gray, massive, dense to medium-grained limestone with little chert. While dense beds are common in the Ridley, the formation as a whole is more crystalline than the Murfreesboro. In general, however, the Ridley and Murfreesboro are so similar in their lithology that they may be differentiated satisfactorily only on the basis of their fauna.

Original Samples.—Samples are available on more than 30 wells in the Upper Cumberland district which have entered the Ridley limestone. The formation is predominantly limestones which are gray to light-tan and brown, dense to medium-grained. Most of the samples show a dense to subcrystalline texture. Small amounts of gray to brown chert are present, but it is seldom observed in untreated samples. The lithology in general is strikingly similar to the underlying Pierce and Murfreesboro and overlying Lebanon limestones.

32a Galloway, J. J. Op. cit. p. 36.

Insoluble Residues.—The residuals of the Ridley limestone are silica, shale, and chert. The Lebanon-Ridley contact is the most difficult one to determine in the entire pre-Trenton section. In the present study the first appearance of a white to dark-gray and brown, porous, fragile, siliceous aggregate is assumed to represent the top of the Ridley. This silica, which is undoubtedly secondary, is restricted to the Ridley and appears abruptly at about 200 feet below the base of the Pencil Cave. About 50 feet below the first appearance of the silica, a characteristic chert is present in the residues; it is dense, angular, and gray to brown, with very small rounded specks of darker colors. It has been found convenient to call it the "speckled chert" zone. This zone has been found in all wells which have penetrated the Ridley. It is particularly well developed in the Peeler et al., Lewis Langford No. 1 (171) at 750 feet, in the Jesse Ashby et al., Donaldson Heirs No. 1 (85) at 598 feet, and in W. P. Clements et al., O. N. Cherry No. 1 (37) at 600 feet. This chert horizon appears to be a definite stratigraphic marker, from 235 to 260 feet below the Pencil Cave, and approximately 100 feet above the dark chert zone at the top of the Murfreesboro limestone. The shale residues of the Ridley are gray to tan and brown, soft, and are similar to the other Stones River and Black River shale residues. The base of the Ridley is well marked by the sudden increase of light-colored shale residues, characteristic of the Pierce limestone.

Thickness.—In Rutherford County, Galloway[33] reports a maximum thickness of 115 feet for the Ridley. In four wells, which have penetrated the formation in Clay County, the thickness ranges from 108 to 125 feet.

LEBANON LIMESTONE

Lithology.—On the outcrop in Middle Tennessee the Lebanon, the youngest formation of the Stones River group, consists of blue to gray and dove-colored, dense to medium-grained limestone that weathers gray. The beds are generally less than 6 inches thick. Wilson[34] has recognized a massive bed about 30 feet below the top of the formation on the outcrop in the Central Basin.

Original Samples.—Subsurface samples from the Lebanon in the Upper Cumberland district consists of light-gray to tan and brown, dense to medium-grained limestone, with minor amounts of gray, calcareous shale. Minor amounts of gray and brownish-gray, dense, angular chert are present in some of the samples.

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[33]Galloway, J. J. Op. cit., p. 41.
[34]Wilson, C. W., Jr. Op. cit.

Like other formations of the Stones River group, raw cuttings show no lithologic characteristics which would serve as a basis of differentiating the Lebanon from the other Stones River limestones.

Insoluble Residues.—Microscopic examination of Lebanon limestone residues show the presence of a characteristic dark-gray to brown, smooth, dense, sometimes dolocastic chert in the upper part of the formation. This same type of chert has been observed in the upper part of the Lebanon at several outcrops in Middle Tennessee. In the present report the abrupt appearance of this chert is considered to represent the top of the Lebanon on the subsurface in Clay and adjoining counties. A second diagnostic residue of the Lebanon is the presence of light- to dark-brown, cavernous, vitreous silica, which has not been observed above the dark cherts which mark the top of the formation. The shale residues of the Lebanon are generally quite similar to others in the Stones River. They are present throughout the formation, but become abundant in the lower part. This increase in shale is usually accompanied by a decrease in the amount of dark-colored cherts.

Thickness.—In 15 detailed studies of samples from wells which have penetrated the entire Lebanon section in Clay and adjoining counties, this formation ranges in thickness from a minimum of 104 feet in Overstreet and Miller's Cordell Hull No. 1 (138) to a maximum of 143 feet in the Doctors Syndicate, John Hargrove No. 2 (117). The average thickness is about 125 feet, which compares favorably with Galloway's[35] maximum thickness of 120 feet on the outcrop.

MOHAWKIAN SERIES

BLACK RIVER GROUP

CARTERS LIMESTONE

Lithology.—Throughout the Nashville Basin area the widespread Carters limestone of the Black River group succeeds the Lebanon. Recent studies have made it possible to divide the Carters into two members on the outcrop.[36] The lower member is defined as that part of the Carters limestone between the persistent bentonite bed (Pencil Cave horizon of the driller) and the top of the underlying Lebanon limestone. Lithologically, this member consists of light- to dark-gray, dense to medium-grained

[35]Galloway, J. J. Op. cit., p. 43.
[36]Wilson, C. W., Jr. Op. cit.

limestone, some of which is magnesian. Bedding is generally massive. On the outcrop this unit reaches a maximum thickness of 69 feet along Cumberland River in Wilson County, but the average throughout Middle Tennessee approaches 50 feet.

The upper unit as defined by Wilson[37] consists of beds from the top of the bentonite to the base of the Hermitage. It is thinly bedded, dense to fine-grained, and almost invariably light-gray in color. Ten feet is the average thickness.

Original Samples.—On the subsurface in the Upper Cumberland district the persistent bentonite horizon allows the division of the Carters limestone into its two members as recognized in surface sections. Cuttings from the lower member are white to light-gray and tan, dense to medium-grained limestones. The top is sharply marked by the pale green, dull, soft, thinly-laminated clay shale (Pencil Cave). White, dense, rough cherts are characteristically present in the lower part of this unit.

In the original samples the upper member of the Carters consists of white to gray and tan, medium- to coarse-grained limestone, usually accompanied by light-colored, generally dense and angular cherts.

Insoluble Residues.—Residuals from the Carters limestone are very diagnostic. The first sample from the lower member always shows the characteristic Pencil Cave horizon. Shales are the most common residue of the upper 30 feet of this member; they are light-gray to tan in color, and usually soft and porous. The lower 50 feet of the Carters is sharply marked by a well established residue zone. This zone consists of white to light-gray, sometimes dark-gray to nearly black, rough, generally coarsely dolocastic chert, which persists through the lower Carters until the abrupt appearance of the dark-colored, smooth cherts, here considered to define the top of the Lebanon.

Insoluble residues from the upper member of the Carters are chert, silica and shale. The chert is white to light-tan and brown in color, generally dense and angular. The silica is light-colored, usually white, soft, and lacy. The residual shales are gray to tan, soft, and porous. Quantitatively, the upper member gives the larger residue.

Thickness.—The average thickness of the lower member of the Carters limestone on the subsurface in Clay and adjoining counties is approximately 80 feet. The upper member is almost invariably 10 feet thick, although in John Kerzan et al., Rebecca Brown No. 1 (28) the Mud Cave, representing the base of the

[37]Idem.

Hermitage, and the Pencil Cave at the top of the lower member of the Carters, occurred in the same 5-foot sample.

Bentonite Beds.—Over fifty years ago drillers in the Upper Cumberland district of Tennesse and Kentucky noted a distinctive green clay shale in wells which were drilled to depths of 500 feet or more below the base of the Chattanooga shale. This clay shale, which has become the most valuable subsurface marker for the driller in this general region, is seldom more than 2 feet thick, although greater thicknesses are indicated in the drillers' logs. The tendency of this green shale to break into pencil-shaped fragments and to cave into the hole has given rise to the drillers' term Pencil Cave, which has become firmly entrenched in the terminology of drillers, operators and geologists in the Upper Cumberland district.

In 1922 Nelson[38] described the occurrence of this green shale on the outcrop near Singleton, Bedford County, Tennessee. Analyses of fresh material by Larsen[39] indicated a bentonitic clay formed by the decomposition of rhyolitic ash that had been altered, immediately following eruption, into a material apparently related to leverrierite. Mineralogically, the green clay shale was found to contain orthoclase, quartz, apatite, zircon, and mica. Ross[40] has proposed the term metabentonite for these altered volcanic materials and this term has been used by Kay [41] and Allen[42] for thin beds in the Ordovician of the Appalachian region and in the upper Mississippi Valley, which are considered indurated bentonites.

Recent work by Wilson[43] has shown a widespread surface distribution for the persistent metabentonite which occurs approximately 10 feet below the base of the Trenton. It is well-developed on the subsurface throughout Middle Tennessee, and it has become the most reliable subsurface marker in the Upper Cumberland district. Although sometimes very thin, as in the Russell Producing Company's Addie Stafford No. 1 (302), the Pencil Cave is not known to be absent in any well in Clay and adjoining counties, which has penetrated the upper member of the Carters.

Studies by Wilson[44] in the Central Basin indicate the presence

[38]Nelson, W. A. Volcanic ash beds in the Ordovician of Tennessee, Kentucky, and Alabama: Bull. Geol. Soc. Amer., vol. 33, pp. 605-616, 1922.

[39]Ibid., pp. 613-614.

[40]Ross, C. S. Altered Paleozoic volcanic materials and their recognition: Bull. Amer. Assoc. Petroleum Geologists, vol. 12, p. 143, 1928.

[41]Kay, G. M. Stratigraphy of the Ordovician Hounsfield metabentonite: Jour. Geol,. vol. 39, pp. 361-376, 1931.

[42]Allen, V. T. Ordovician altered volcanic material in Iowa, Wisconsin, and Missouri: Jour. Geol., vol. 40, pp. 259-269, 1932.

[43]Wilson, C. W., Jr. Op. cit.

[44]Wilson, C. W., Jr. Op. cit.

of two older metabentonites in the lower member of the Carters limestone at depths of approximately 20 and 35 feet below the Pencil Cave horizon. These lower metabentonites are thin and locally absent. They have not been definitely recognized in well samples in Clay and adjoining counties.

The bentonitic clay on the subsurface in the Upper Cumberland district offers no particular drilling problem. Because of caving it is strongly recommended that casing be set immediately below the Pencil Cave (page 171). In sample sets from wells in which this horizon was not cased off, the green shale ravels considerably and presents difficulties in drilling and production.

A characteristic dark-gray to brown and greenish-brown, soft shale, with a dull luster (Mud Cave of drillers), probably bentonitic in origin, occurs at the base of the Hermitage formation. This shale is discussed in more detail under the description of that formation.

TRENTON GROUP

HERMITAGE FORMATION

Lithology.—The widespread Hermitage formation, marking the base of the Trenton group in Middle Tennessee, unconformably overlies the Carters limestone in the Central Basin. At the type locality, near Hermitage Station, in Davidson County, the formation consists of about 67 feet of thin-bedded, siliceous and argillaceous, blue limestone, which weathers light-brown with thin interbedded shales.[45] The formation is constant in its lithology throughout the Central Basin. It is commonly between 40 and 60 feet in thickness.

Original Samples.—The Hermitage is one of the most sharply defined formations encountered in well samples in Middle Tennessee. In Clay County it consists of dark- to bluish-gray, fine- to coarse-grained limestone with a considerable amount of gray, argillaceous, sandy shale. Fossil fragments are common, especially of *Dalmanella,* the index fossil of the formation. In many wells the top of the Hermitage is marked in samples by a light greenish-gray shaly limestone. Shale is common throughout the formation, but the lower half is usually the more shaly. A light- to dark-brown, sometimes greenish-gray, thinly laminated, pyritic, soft shale, which breaks into long, narrow fragments quite similar to the underlying Pencil Cave, occurs at the base of the Hermitage formation. This is the drillers' Mud Cave, and al-

[45]Bassler, R. S. Stratigraphy of the Central Basin of Tennessee: Tenn. Div. Geol., Bull. 38, pp. 73-80, 1932.

though no biotite has been observed in this shale, its striking resemblance to the Pencil Cave strongly suggests a bentonitic origin. The similarity between the two is so marked that the Mud Cave has been mistaken for the true Pencil Cave. The Mud Cave is an excellent horizon marker and its occurrence in samples with characteristic Hermitage lithology indicates that it belongs in the base of the Trenton.

The second or lower Sunnybrook horizon of the driller occurs in the Hermitage formation. This zone has produced oil in Clay and adjoining counties and is discussed in more detail on pages 149-151.

Insoluble Residues.—Although generally it is not necessary to prepare residues to distinguish the Hermitage formation, its residues are characteristically arenaceous shales which are dark-gray in color and may be porous or dense, lumpy or rounded. Very small, angular quartz grains, less than 0.1 millimeter in size, occur with the shale and also free in the residues. Quantitatively, the Hermitage yields the largest shale residue in the Ordovician section, a characteristic which sharply marks it from the overlying Cannon and the Carters limestone below. Residues constituting 60 per cent of the original are not uncommon, although the average is considerably less than this figure.

Thickness.—The Hermitage formation is not known to be absent anywhere in the Upper Cumberland district. In the area covered by this report the Hermitage is quite constant in thickness. A study of 24 sample sets from wells drilled in this region shows a minimum thickness of 45 feet for the Hermitage in Cox, Spivy, and Greenup's Fletcher and Brown No. 1 (101); a maximum of 76 feet was penetrated in the Rebecca Brown No. 1 (28); the average thickness for the Hermitage is 62 feet in Clay County.

CANNON LIMESTONE

Lithology.—On the western flank of the Nashville dome the Bigby limestone intervenes between the Hermitage formation and the Cannon limestone. East of the arch the Hermitage is overlain by the Cannon. This formation is composed of massive beds of fine-grained, brittle, dove-colored limestone; blue-gray crystalline limestone; and blue-gray granular limestone. Like the overlying Catheys and Leipers formations, the Cannon limestone is abundantly fossiliferous and the formation and its fauna have been well described by Bassler.[46] The Cannon limestone

[46]Bassler, R. S. Op. cit., pp. 85-106.

reaches its maximum thickness on the outcrop of over 200 feet on the east side of the Nashville dome, but it thins westward to an exposed minimum of 20 to 40 feet in an area south of Nashville.

With the possible exception of a small area in the vicinity of Tinsleys Bottom, which is discussed in more detail below, the Cannon limestone does not outcrop in the area covered by this report. It is at no great depth, however, along the valley of Cumberland River and its immediate tributaries. The upper part of the formation is well exposed in the southern part of the Gainesboro quadrangle, where it has been described by Lusk.[47]

Original Samples.—One the subsurface in Clay and adjoining counties the Cannon limestone consists of medium- to dark-gray and brown, dense to fine- and coarse-grained limestone and gray calcareous shale. Fossil fragments are common and in a number of samples studied there are many well-preserved ostracods, especially *Isochilina* sp. and *Leperditia* sp. The lower half of the Cannon is usually quite constant in its lithology; it is a gray to brown, medium-grained limestone with little shale.

Insoluble Residues.—Shales are the common Cannon residues. They are brown, gray, and tan in color and are usually quite porous, due to the digestion of the calcareous material by the acid. Light-colored to brown, angular, dense chert, undoubtedly secondary in origin, is a common constituent, although the chert is subordinate in amounts to the shale. In several wells the residues from the upper part of the Cannon show a considerable amount of clear, angular quartz. By volume the residues of this formation range from 5 to 25 per cent, an average approximating 10 per cent.

Distribution and Thickness.—The massive, gray, coarse-grained limestone exposed just west of Tinsleys Bottom at the foot of the bluff along the Cumberland River may represent the upper part of the Cannon limestone. Here the Cumberland has transected a part of the Tinsleys Bottom dome in which the Cannon has been brought above its normal position. There is no undeniable evidence, however, that these massive limestone beds do not represent the lower few feet of the Catheys formation.

The maximum thickness recorded to date for the Cannon in Clay County is in Dewey Mong's Cora Anderson No. 1 (1), in which 250 feet of beds are considered to be Cannon in age. An average thickness for the formation in this general area would

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[47]Lusk, R. G. Geology and oil and gas resources of the Gainesboro quadrangle, Tennessee: Tenn. Div. Geol., unpublished manuscript.

probably be between 200 and 225 feet. Relatively few complete Cannon sample sets are available.

CATHEYS FORMATION

Lithology.—Over the greater part of the Central Basin the massive beds of the Cannon limestone are succeeded by the limestones and shales of the Catheys formation. Lithologically, the Cannon and Catheys are very similar and throughout their outcrop area the two formations may be separated satisfactorily only on the basis of their respective faunas. In Clay County the Catheys is composed of thin to massive and even-bedded, dark-blue to dark-gray, coarse- to fine-grained and dense, argillaceous limestone and calcareous shale. Heavy beds of impure limestone are common, although the Catheys is generally less massive than the underlying Cannon limestone. On weathered outcrops nearly white to dark-gray chert is commonly present, but the formation is seldom cherty in fresh exposures. Gray and blue-gray, calcareous shales generally occur interbedded with limestone, but many of the shale beds approach 10 feet in thickness.

Fossils are common in the Catheys formation and Bassler[48] has zoned the formation on the basis of its fauna. Bryozoans and brachiopods are particularly abundant. The abundance of bryozoans in the lower part of the Catheys in Jackson County, suggests the presence of the *Constellaria emaciata* zone in the Upper Cumberland district. The zone of the large hydrozoan, *Stromatocerism pustulosum,* is present near the middle of the formation in the vicinity of Celina.

Relatively few subsurface samples are available from the Catheys in the Upper Cumberland district. Cuttings examined from this formation consist of light- to dark-gray, dense to coarse-grained limestone with a considerable amount of gray, limy shale. Certain zones show abundant fossil fragments. White calcite and gypsum are common minor constitutents; chert is not common. Dull, dark-gray to brown, lumpy, porous, soft shales, and white, porous, lacy silica are the most abundant insoluble residues. By volume Catheys residues constitute about 15 per cent of the original samples.

Distribution and Thickness.—The Catheys formation is well-developed along Cumberland River and its immediate tributaries. Excellent exposures of the upper part may be seen north and south of Celina, especially along the road leading down the west side

[48]Bassler, R. S. Op. cit., pp. 111-115.

of Cumberland River. Well exposed along the mouth of Obey River, the Catheys passes beneath the younger Leipers formation in Goodpasture Bend, about 5 miles east of Celina. It does not outcrop east of this point, but well samples from east Clay County indicate that the formation is present and typically developed on the subsurface.

North of Celina approximately 75 feet of Catheys beds are exposed without revealing the base, but a few miles to the west John Kerzan et al., Rebecca Brown No. 1 (28) penetrated 114 feet of strata referred to the Catheys. Older beds of the Catheys are present south of Celina, but in Clay County they are not well-exposed because of the alluviated valleys. It is probable that the formation is about 100 feet thick in the region around Tinsleys Bottom.

CINCINNATIAN SERIES

MAYSVILLE GROUP

LEIPERS FORMATION

Lithology.—Although rocks of Eden age are absent in Middle Tennessee between the Catheys and Leipers formations, there is no marked unconformity between the two.[49] In the field there are indications of the Cannon and Catheys facies of sedimentation continuing directly into the Leipers formation. The recurrent Trenton fauna adds to the difficulty of differentiation. In general, however, the marked shaly nature and distinctive bluish color of the Leipers aid in determining the Catheys-Leipers contact. The Leipers is less even-bedded than the underlying Catheys.

In the Upper Cumberland district the Leipers is made up of bluish-gray to light-blue, nodular, dense to medium-grained, argillaceous limestone with much interbedded bluish-gray, calcareous shale. On fresh exposures the Leipers is somewhat massive, but weathering produces the characteristic rubble of small rounded, earthy limestone chips. This feature is typical of weathered Leipers exposures throughout Middle Tennessee.

Like the underlying Trenton formations, the Leipers is abundantly fossiliferous. In general, the fauna is similar to the Cannon and Catheys, although the large brachiopod, *Platystrophia ponderosa,* is generally sufficient for the recognition of the Leipers in Middle Tennessee.

Most of the test wells in Clay County start below the Chattanooga shale, and since many drillers do not save samples above the

[49]Bassler, R. S. Op. cit., pp. 115-116.

depth of their first casing seat, very few Leipers cuttings are available. In John Kerzan et al., Rebecca Brown No. 1 (28) the Leipers is a blue and gray earthy and shaly limestone. Fossil fragments, especially bryozoans and brachiopods, are common. Insoluble residues are gray and brown, porous, soft shales which often make up 25 per cent of the original. They are not particularly different from those of the Cannon and Catheys formations.

Distribution and Thickness.—The Leipers formation outcrops extensively over the county, especially in the eastern, central and southern parts. It is not definitely known to be absent at any place in the region, although there are probably variations in thickness. Along Cumberland River, where the entire formation is exposed, the Leipers is approximately 100 feet thick and 94 feet of the formation are present near the mouth of Mill Creek, north of Butlers Landing. Near Gainesboro Lusk [50] measured 93 feet of Leipers.

Although conclusive data are not available, due largely to incomplete sample sets, there is a suggestion that in certain areas some of the upper beds of the Leipers have been removed by pre-Chattanooga erosion. This is tentatively believed to account for the short Chattanooga-Pencil Cave interval in certain areas such as the upper part of Mitchell Creek. This problem is discussed in more detail on pages 68-71.

RICHMOND GROUP

FORMATION OF RICHMOND AGE

Lithology.—At several localities in areas west and southwest of Celina, a thin unit, markedly different in lithology from the underlying Leipers formation, intervenes between the Leipers and the Chattanooga shale. Lithologically, this unit varies considerably, but in general it is a gray to bluish-gray, often slightly greenish, argillaceous and earthy limestone. Light- to dark-gray, dense chert is sometimes present as thin beds or elongated nodules along bedding planes. The beds are relatively unfossiliferous and to date no diagnostic fossils have been collected except a poorly preserved specimen of *Platystrophia*, probably *P. ponderosa*.

Distribution and Thickness.—These greenish-gray, earthy limestones appear to be restricted to the area west of Celina. They have been observed along Proctor Creek, and near the headwaters of Brimstone, Crabtree, Pine Lick, and Hudson creeks in the

[50] Lusk, R. G. Op. cit.

southern and southwestern parts of the county. This unit is also well-exposed along State Highway 52, 1.5 miles west of Celina, and along Trace Creek, south of Hermitage Springs near the center of the Hermitage Springs dome. It is believed to be present immediately below the Chattanooga shale in John Kerzan et al., Rebecca Brown No. 1 (28). This unit ranges in thickness from 5 to an observed maximum of 15 feet.

Correlation.—Although the Richmond group in the Central Basin of Tennessee has not been studied in detail, reconnaissance studies indicate that the Arnheim and Fernvale formations, so well-developed in the vicinity of Nashville, lose many of their lithologic characteristics to the north along the western flank of the Nashville dome. North of Gallatin in Sumner County, the senior writer has collected such typical Richmond fossils as *Rhynchotrema capax* in a very argillaceous limestone, lithologically different from either the Arnheim or Fernvale of the Nashville region. Richmond fossils have been noted in rocks of essentially the same lithology west of Red Boiling Springs in Macon County.

The argillaceous limestone and calcareous clay exposed immediately beneath the Chattanooga shale at several places in western Clay County are believed to be of Richmond age. Wilson[51] considers the pre-Chattanooga formation over most of western Clay County to be of Richmond age. These beds may well represent a southern extension of a group of relatively unfossiliferous rocks in southern Kentucky which were called the Cumberland sandstone by N. S. Shaler.[52] As pointed out by Foerste,[53] the name sandstone is inappropriate since the formation varies betwen a calcareous clay and a very argillaceous limestone. Foerste[54] found these beds present immediately north of Clay County in the vicinity of Burkesville, Cumberland County, Kentucky, and he found Richmond fossils from a limestone below the black shale, which he termed Fowler limestone. It is believed that detailed studies of the beds immediately below the Chattanooga shale in western Clay and Macon counties will demonstrate a rather widespread distribution of this Richmond unit.

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[51]Wilson, C. W., Jr. The pre-Chattanooga development of the Nashville dome: Jour. Geol., vol. 43, p. 450, 1935.

[52]Shaler, N. S. Kentucky Geol. Survey, 2nd Ser., vol. 3, pp. 152-155, 159-160, 387, 1877.

[53]Foerste, A. F. Silurian and Devonian limestones of Tennessee and Kentucky: Bull. Geol. Soc. Amer., vol. 12, p. 434, 1901.

[54]Foerste, A. F. Ibid., pp. 434-436.

MISSISSIPPIAN SYSTEM[55]

Lower Mississippian Series

KINDERHOOK GROUP

CHATTANOOGA SHALE

Lithology.—The Chattanooga shale is the most consistent and widespread stratigraphic unit in Tennessee. Throughout most of central Tennessee the Chattanooga consists of three members: (1) a thin, conglomeratic, phosphatic, dark-colored sandstone at the base (Hardin sandstone); (2) the ubiquitous black shale member; and (3) a thin, green, phosphatic, nodular, soft shale unit at the top (Maury green shale). In the Upper Cumberland district the Chattanooga is typically developed, although the basal Hardin sandstone is generally absent. The main part of the formation is a black, fissile, carbonaceous shale, the weathering of which into thin plates has given rise to the name "black slate" among the natives. In many exposures in Clay and adjoining counties there is a suggestion of a two-fold division of the black shale unit. An upper extremely fissile and chippy section and a lower less evenly laminated shale, which, in some localities, is actually blocky. These divisions, however, are seldom discernible in weathered outcrops.

The Maury green shale at the top of the black shale is generally well-developed in this region. It is a green to gray-green, soft, argillaceous shale with many rounded and elongated phosphatic nodules. The green color is due to the presence of glauconite. The Maury is seldom well laminated. In most of the sections studied the typical black shale grades imperceptibly into the overlying Maury. In Clay County this unit seldom exceeds 2 feet in thickness.

Distribution and Thickness.—The Chattanooga shale is present throughout the entire Upper Cumberland district, where it varies in thickness from about 15 to 25 feet. In one area, 6 miles south of Gainesboro in Jackson County, Wilson and Born[56] have reported a thickness of more than 200 feet of black shale. Here the Chattanooga has filled pre-Mississippian depressions, believed to be cryptovolcanic in origin. In Clay County the thickness of the black shale varies but little between 20 and 25 feet.

[55]The age of the Chattanooga shale in Tennessee has long been controversial, although Swartz (Amer. Jour. Sci., vol. 7, pp. 28-29, 1924) concluded that the shale in central Tennessee is wholly of earliest Mississippian age. The State Division of Geology accepts a Mississippian age for the Chattanooga shale in Middle Tennessee.

[56]Wilson, C. W., Jr., and Born, K. E. The Flynn Creek disturbance, Jackson County, Tennessee: Jour. Geol., vol. 44, pp. 815-835, 1936.

Use as a Datum Plane.—The distinctive lithologic chaarcter, together with its constant thickness, has long permitted the use of the Chattanooga as a datum plane for stratigraphic and structural studies in Middle Tennessee. Practically all structural work done in the Upper Cumberland district in connection with oil and gas explorations has been done on either the top or base of this formation. In the Highland Rim areas it is the most important subsurface marker.

The largest and most widespread unconformity in Middle Tennessee occurs at the base of the Chattanooga and the contact of the black shale with the underlying Ordovician limestone is generally quite sharp. In many places small fragments of the limestone are incorporated into the lowest beds of the shale. East of Willow Grove a two-inch silicified sandstone is present at the base of the shale. Chertification of the limestone for a short distance below the contact is common and pyrite and glauconite are often developed among this unconformity. Within local areas the top of the Ordovician shows practically no relief. Along State Highway 56, just south of Butlers Landing, irregular channels in the Leipers formation, some of which are 5 feet deep, have been filled with black shale. Because of the bench-forming character of the sub-Chattanooga limestone, there are better exposures of the lower contact than the upper one and the greater part of the mapping in this region has been done on the base of the Chattanooga. The striking lithologic contrast of the beds above and below this contact adds to the facility in determining the base of the black shale.

As previously stated, the black shale unit of the Chattanooga grades imperceptibly into the greenish, soft, phosphatic, nodular Maury shale above. In some Maury sections typical black shale may be observed interbedded with the green shale. The contact of the Maury with the overlying Osage rocks, especially where the latter are shaly, is not sharp and often may be found with difficulty. Because of slump the contact is seldom well-exposed. However, the occurrence of a layer of phosphatic nodules in a hill slope may be usually assumed to mark the top of the Chattanooga formation. Although the base of the shale is generally used as a datum plane, in areas where the lower contact is not exposed, it is necessary to take elevations on the top of the Chattanooga. The relatively constant thickness of the formation allows the use of both the top and bottom in structural mapping without the usual chance for error due to thickness variations.

Osage Group

FORT PAYNE FORMATION

Use of the Name.—In 1890 E. A. Smith[57] introduced the term Fort Payne chert for the siliceous beds between the black shale and the Oxmoor sandstones and shales in northeastern Alabama. Hayes[58] restricted the name to beds approximately equivalent to the present Fort Payne and the overlying Warsaw and St. Louis formations. It was later restricted to rocks of Keokuk and older ages and in the present classification the Fort Payne is considered to be mainly Keokuk in age.

Lower Mississippian of Middle Tennessee.—In 1912 Bassler[59] divided the strata between the Maury green shale unit of the Chattanooga and the Fort Payne chert in central Tennessee into two formations. The upper of these, consisting of soft, gray-green shales and crinoidal limestones, was correlated with the New Providence shale of Indiana, Ohio and Kentucky; the lower formation was named the Ridgetop shale and described as grayish-green to pale-blue, argillaceous and siliceous shale. Bassler[60] recognized and mapped these formations in the Lillydale quadrangle, which includes the eastern half of Clay County. Bassler's[61] sections show extreme variations in thickness for his Ridgetop and New Providence formations. Near Celina he recognized only New Providence between the Fort Payne and the Chattanooga, but eastward the New Providence became thinner and the Ridgetop intervened below the New Providence as a wedge thickening to the east until in western Pickett County the Ridgetop was believed to occupy the entire section between the Maury and the Fort Payne. To account for such variations Bassler postulated distinct embayments of deposition for these formations.

In 1936, Wilson and Spain[62] presented both faunal and lithologic evidence that the Ridgetop shale of Bassler in its type area is a facies of New Providence deposition. In the same publication Wilson and Spain[63] suggest facies deposition to explain the rapid variations in these units in the Lillydale quadrangle rather than the distinct embayments postulated by Bassler.

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[57]Smith, E. A. Geological structure and description of the valley regions adjacent to the Cahaba coal field: Geol. Survey of Alabama, Spec. Rep't. No. 2, p. 185, 1890.

[58]Hayes, C. W. Overthrust faults of the southern Appalachians: Bull. Geol. Soc. Amer., vol. 2, pp. 141-151, 1891.

[59]Bassler, R. S. The Waverlyan period of Tennessee: Proc. U. S. Nat. Museum, vol. 41, pp. 209-224, 1912.

[60]Bassler, R. S. Stratigraphy of the Central Basin of Tennessee: Tenn. Div. Geol., Bull. 38, pp. 180-183, 1932.

[61]Bassler, R. S. Ibid., pp. 148-152.

[62]Wilson, C. W., Jr., and Spain, E. L., Jr. Age of Mississippian "Ridgetop shale" of central Tennessee: Bull. Amer. Assoc. Petrol. Geol., vol. 20, pp. 805-809, 1936.

[63]Wilson, C. W., Jr., and Spain, E. L., Jr. Ibid., p. 807.

Detailed stratigraphic studies of the Lower Mississippian group of the eastern Highland Rim of Tennessee were begun in 1935 by Dr. Harry J. Klepser,[63] then of the Ohio State University. Klepser agrees with Wilson and Spain that the Ridgetop shale of Bassler is not a formational unit. Lithologic and faunal studies by Klepser also indicated a thinning of the typical New Providence shale of Indiana to 15 inches near Burkesville, Cumberland County, Kentucky. He believes that the true New Providence is completely absent in the eastern Highland Rim area in Tennessee, and that the term Fort Payne formation should be used for the stratigraphic interval between the Maury green shale and the Warsaw formation of the Middle Mississippian.

The present writers have no particularly convincing evidence to add to the existing and somewhat conflicting data on Lower Mississippian classification. Detailed stratigraphic studies of the Mississippian formations were not pertinent in the present study. In the absence of incontrovertible evidence it would seem advisable to consider all strata between the top of the Maury member of the Chattanooga shale and the base of the Warsaw formation as a unit. Since the name Fort Payne is so well established in this part of Tennessee, the Lower Mississippian is so designated on the geologic map (Plate I).

Lithology.—South from Pulaski County, Kentucky, through Clay County, Tennessee, and into Overton and Jackson counties, Klepser recognizes a facies of Fort Payne deposition, which he has named Greasy Creek from the stream of that name in Russell County, Kentucky. The general lithology of this facies is quite variable, ranging from silty shale and shaly siltstone to pure crinoidal limestone. While the major portion of this unit is Keokuk in age, Klepser reports Burlington fossils from the basal part. He considers the Lower Mississippian of Clay County to consist essentially of the Greasy Creek facies.

The present writers recognize the Lower Mississippian of Clay County as the most heterogeneous formation in the region, whose only constant lithologic characteristic is its siliceous nature. Variability is the rule rather than the exception; there are lateral gradations in lithology within relatively short distances. Whether a bed is called a cherty limestone, shaly siltstone, or siliceous shale depends, in many instances, upon whether or not the exposure is fresh. Cross-bedding and slumping are common features of this

[63]The writers wish to acknowledge with thanks Dr. Klepser's kind permission to quote his general conclusions regarding the Lower Mississippian stratigraphy of the eastern Highland Rim area.

unit and extreme care must be used in taking dip and strike readings upon these beds. Many so-called Fort Payne structures have failed to show comparable subsurface structural attitudes.

The following section, kindly furnished by Dr. Harry J. Klepser, shows the variations within the Fort Payne formation in Clay County:

Section along State Highway No. 52, two miles southeast of Celina.

WARSAW FORMATION:	
Limestone, crystalline and fossiliferous; gray to blue-gray, cross-bedded; contains bryozoa and other fossils (Upper Harrodsburg)	20
FORT PAYNE FORMATION (206½ feet exposed):	
Cover	18
Siltstone, siliceous and brittle, blue-gray to gray; weathers yellow-brown, shaly and cherty in part	50
Limestone, fossiliferous and cherty, slightly silty; blue-gray to gray; weathers yellow-brown	2½
Siltstone, dense and brittle, slightly limy, blue-gray, weathers yellow-brown; contains geodes	6
Limestone, crinoidal and cherty, blue-gray; chert completely replaces limestone laterally	5
Siltstone, limy and cherty, blue-gray, weathers drab and shaly; changes laterally to impure limestone, especially in lower part; crinoid stems scattered throughout; with geodes	52
Limestone, cherty and siliceous, gray, weathers brown	3
Shale, silty, gray	4
Limestone, cherty and siliceous, gray; weathers brown; with green specks	2
Shale, silty and limy, blue-gray to green-gray; limy zones due to concentration of fossils; bryozoa especially abundant	80
Limestone, cherty; gray; weathers brown	2
MAURY FORMATION:	
Shale, argillaceous, slightly silty, green-gray; contains phosphate nodules throughout	1
CHATTANOOGA FORMATION:	
Shale, black and fissile	20
ORDOVICIAN (LEIPERS) LIMESTONE	

In the vicinity of Celina and south along the Cumberland River the beds immediately overlying the Chattanooga shale are composed of gray, shaly and siliceous limestone with much chert. Locally, there are massive grayish-blue crinoidal limestones and gray shales (New Providence of Bassler). At other places, especially in the eastern part of the County, bluish-green, hard, siliceous shales make up the larger part of the unit (Ridgetop of Bassler). In the general vicinity of Hermitage Springs, in the western and southwestern parts of the County, heavy-bedded, dark-blue, shaly and chert limestones are present just a few feet above the Maury green shale.

The cherts of the Fort Payne are characteristically light- to dark-gray and tan, generally blocky and dense. In areas of poor exposures the typical gray, sandy soils, crowded with blocky, dense, chert fragments, may often serve as an aid in areal mapping. Geodes, partly filled with gypsum and calcite, are common in the Osage rocks in the Upper Cumberland district.

Distribution and Thickness.—Although differing considerably in lithology within relatively short distances, the Fort Payne is present immediately above the Chattanooga shale, throughout the entire region and has a greater areal distribution than any formation in Clay County. It occupies much of the general upland in the eastern half of the county. West of Celina the Fort Payne formation is widely distributed in the Highland Rim area except in the north-central part where the overlying Warsaw and St. Louis limestones have a considerable extent.

There are considerable variations in thickness of the Fort Payne in Clay County, but a minimum is slightly more than 200 feet. In the Willow Grove area Bassler[64] reports thicknesses of 242 and 284 feet for beds between the Chattanooga shale and the Warsaw formation. Approximately 250 feet are exposed up the east side of Pilot Knob, northeast of Celina, and poor exposures indicate a thickness of more than 200 feet in the western part of the County.

Middle Mississippian Series

MERAMEC GROUP

WARSAW FORMATION

Lithology.—In the Highland Rim region of Tennessee the widespread Warsaw formation succeeds the Fort Payne. The lower contact is one of the most difficult to determine in the State and in many places Osage deposition appears to have continued without a break into the overlying Warsaw. In the Highland Rim region the senior writer has used several criteria for determining the Fort Payne-Warsaw contact. Where exposures are good the basal Warsaw beds are almost invariably more calcareous than the underlying Osage. Upon weathering the lowest beds of the Warsaw appear as a yellowish-brown sandstone. Careful search immediately above this calcareous sandstone will usually be rewarded with such characteristic fossils as *Spirifer lateralis, S. bifurcatus, S. keokuk,* and *Rhipidomella dubia.* Typical fenestillid bryozoa are usually

[64]Bassler, R. S. Op. cit., pp. 150-151.

present in the lower part of the Warsaw. The soft, light-colored, fossiliferous cherts of the Warsaw are generally distinctive. In areas of deep weathering the abrupt appearance of a red to brownish-red, sandy soils in which Warsaw cherts are common, is often of value in determining the approximate contact of the Fort Payne and Warsaw; the soils of the Fort Payne are seldom red.

Because of deep weathering of the rocks in the Highland Rim region of Clay County, neither the middle nor upper Mississippian formations are exposed to good advantage. In general the Warsaw formation of Clay County is medium- to coarse-grained, gray to blue, granular limestone with blue and yellow shales, calcareous siltstones, sandy limestones, and local calcareous sandstones. On Pea Ridge, northeast of Celina, the formation consists of a lower part composed of alternating beds of gray-blue limestone, impure argillaceous and sandy limestones and calcareous shales, which underlies more massive, fossiliferous limestones. The sandy character of the lower unit is well-shown by cross-bedding on weathered outcrops. Although less cherty than the underlying Osage rocks, chert is generally present in the form of nodules and discontinuous layers. Like the Fort Payne, lateral gradations are common.

In Overton County the upper third of the Warsaw is predominantly sandstone, although some of the beds are highly calcareous and the upper few inches are ripple-marked. This is the Garretts Mill sandstone of Butts.[65] The same horizon is present in the southeastern part of Clay County, but it is generally not well exposed. The best exposures are found along narrow ridge roads, where heavy rains have removed the top soil. The top of the Warsaw, because of its sandy nature, is an important water horizon and its contact with the overlying St. Louis is usually dominated by springs and seeps.

The sandstone at the top of the Warsaw (Garretts Mill) has been used by some geologists as a datum plane for structural work in the upland areas of the Upper Cumberland district where the more reliable Chattanooga shale is buried. An interval of approximately 310 feet has been worked out between the top of the Chattanooga and the sandstone datum. However, the difficulty in locating this sandstone, together with the chance of mistaking other sandy zones for it, detracts considerably from its value as a datum plane. Careful work is demanded where it is used.

[65]Butts, Chas. Geology and oil possibilities of the northern part of Overton County, Tennessee, and of adjoining parts of Clay, Pickett and Fentress counties: Tenn. Geol. Survey, Bull. 24, 2-A, pp. 16-17, 1919.

Distribution and Thickness.—The Warsaw outcrops rather extensively over the uplands in southeastern Clay and western Pickett counties. In the more dissected central part it occurs as narrow bands near the tops of the higher hills. In the northwestern part of the County, the Warsaw is present but poorly exposed. The middle fossiliferous limestone member may be seen along State Highway 52 on the Highland Rim west of Celina.

The Warsaw appears to be quite constant in its thickness throughout eastern Clay County, varying between 80 and 90 feet. Approximately 80 feet of Warsaw is present at the base of Pilot Knob; it is 90 feet thick in the Willow Grove area and Butts[66] reports a rather constant thickness of 100 feet for it in northern Overton County.

ST. LOUIS LIMESTONE

Lithology.—The generally massive, gray to blue and dark-blue, fine- to medium-grained limestones of the St. Louis overlie the Warsaw formation. The basal beds of the St. Louis limestone are often more argillaceous than the upper part and cross-bedding is not uncommon immediately above the contact with the Warsaw formation. Thin, shaly, and sandy limestones are present between massive crystalline, relatively pure limestones.

Fossils are not uncommon in the St. Louis limestone. The silicified heads of the corals *Lithostrotion canadense* and *L. proliferum* are the most common, the former generally observed in the lower part of the formation. Crinoids and plates of *Melonites* are commonly present in the lower St. Louis.

Distribution and Thickness.—Due to the deep weathering over most of the higher parts of the Highland Rim area, the St. Louis limestone is not well-exposed in Clay County, but the characteristic chunks of yellowish, blocky to round, dense to slightly porous and sandy chert, often associated with *Lithostrotion*, is indicative of the St. Louis limestone. The formation underlies most of the general upland northeast of Celina in the Pea Ridge district and caps the broad drainage divide between Ashburn Creek and Irons Creek in the southeastern part of the County. West of the headwaters of Irons Creek, the St. Louis limestone is the surface rock on the upland surrounding the younger Mississippian formations which form Chowning Knob. In the western part of the County, in the vicinity of Moss, the St. Louis is present, but not generally well-exposed.

Although the top of the St. Louis limestone is seldom seen in Clay County, the formation probably reaches a maximum thickness

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[66] Butts, Chas. Op. cit., page 170.

of about 150 feet. Bassler[67] reports 140 feet on Pilot Knob, 4½ miles northeast of Celina and Butts[68] indicates thicknesses of 110 to 140 feet in the northern Overton County

MIDDLE AND UPPER MISSISSIPPIAN SERIES

MERAMEC AND CHESTER GROUPS

FREDONIA AND GASPER OOLITES

(MONTE SANA LIMESTONE OF E. O. ULRICH)

Lithology.—The higher knobs and uplands in Clay County are capped by a series of oolitic limestones which are definitely known to represent two formations, the Fredonia oolite member of the Ste. Genevieve limestone and the Gasper oolite, but which may be separated satisfactorily only on the basis of their fauna. Ulrich[69] has proposed the name Monte Sana for this combination in northern Alabama.

In Clay and adjoining counties this group is composed of light-blue to pearl-gray, predominantly thick-bedded, very pure, oolitic limestones. Some of the beds have a glassy texture. Locally the limestones become shaly, but in general shale and chert are rare. Although fossils are fairly common in these oolites, they are not often found weathered out in a condition which will permit accurate identification. Elliptical spiny stem plates and bases of the crown of the crinoid *Platycrinus huntsvillae* are common throughout the Fredonia and several species of *Pentremites* and the clustered coral, *Campophyllum gasperense*, are indicative of the Gasper oolite.

Correlation.—Since detailed work has not been done on the middle and upper Mississippian rocks of Tennessee, the Fredonia and Gasper oolites are treated together in the present report and were mapped together as the Monte Sana limestone by Bassler[70] in the Lillydale quadrangle. The two constitute a lithologic unit although a considerable thickness of beds is known to intervene between the two in southeastern Illinois and parts of western Kentucky. At the contact of the Fredonia oolite with the Gasper in the vicinity of Livingston, Butts[71] recognizes a thin shale bed directly overlain by a layer of limestone containing limestone pebbles. Essentially this same relationship has been observed by the senior

[67]Bassler, R. S. Stratigraphy of the Central Basin of Tennessee: Tenn. Div. Geol., Bull. 38, p. 149, 1932.

[68]Butts, Chas. Op. cit., p. 19.

[69]Ulrich, E. O. Revision of the Paleozoic systems: Bull. Geol. Soc. Amer., vol. 22, pl. 29, 1911.

[70]Bassler, R. S. Op. cit., Lillydale geologic map, in pocket.

[71]Butts, Chas. Op. cit., p. 20.

writer at several places in the eastern Highland Rim of Tennessee and detailed work may show a rather widespread distribution for this break in sedimentation.

The Tennessee Division of Geology will begin detailed investigation of the Chester group in the State in the near future, and until these studies are completed, the base of the Chester group in Tennessee is tentatively drawn at the top of the Fredonia member of the Ste. Genevieve limestone.

Distribution and Thickness.—The Fredonia and Gasper oolites have a relatively small areal distribution in Clay County. Although generally poorly exposed, they are present on the higher parts of the Pea Ridge upland northeast of Celina and on Chowning Knob, just west of the headwaters of Irons Creek.

Bassler[72] measured 310 feet of light-gray, thick-bedded oolitic limestones on the east side of Pilot Knob, northeast of Celina. This unit includes Fredonia and Gasper equivalents. In northern Overton County Butts[73] reports 240 feet for this oolitic limestone unit, the Fredonia making up the lower 100 to 130 feet, and the Gasper the upper 140 to 160 feet.

Upper Mississippian Series

CHESTER GROUP

CYPRESS SANDSTONE

Lithology.—The youngest consolidated formation in Clay County is the Cypress sandstone, definitely of Chester age. On Pilot Knob it is a grayish to yellowish, medium- to coarse-grained, fairly firmly cemented, generally thick-bedded sandstone. Cross-bedding and ripple markings are common features. The Cypress has been used in Overton, Pickett, and Fentress counties as a key-bed in structural mapping.

Distribution and Thickness.—The Cypress sandstone caps two of the highest hills in Clay County: Pilot Knob, northeast of Celina and the hill about three-fourths of a mile north of Thompson's Store and immediately south of the Kentucky-Tennessee line. The thickness of the formation on Pilot Knob is 20 feet.

TERTIARY SYSTEM

The Tertiary system is probably represented in Clay County by the two patches of gravels east of Baptist Ridge School on the

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[72]Bassler, R. S. Op. cit., p. 149.
[73]Butts, Chas. Op. cit., p. 21.

Butlers Landing-Hilham road. These gravels, discovered by Lusk[74], are discussed in more detail on pages 9-10.

QUATERNARY SYSTEM

The master streams in Clay County, Cumberland and Obey rivers, and the lower courses of their larger tributaries, are bordered by flood plains, which have a relatively flat transverse profile and terminate abruptly landward against the rock erosion slopes of the valley. These flood plains are composed of alluvium of Recent age and comprise beds of clay, silt, sand, and gravel. The coarser particles are for the most part derived from the cherty Mississippian formations and the sandstone and quartzite pebbles from rocks of Pennsylvanian age which cap the Cumberland Plateau region of Kentucky and Tennessee to the east. The alluvium thins rapidly toward the margins of the flood plains and since many of the immediate tributaries are flowing directly upon bed-rock, these Recent deposits are probably less than 50 feet thick throughout most of Clay County.

STRUCTURAL GEOLOGY

REGIONAL FEATURES

The Upper Cumberland district is located in the Cincinnati geanticline structural province. This linear upwarp in central Kentucky and Tennessee comprises three structural subdivisions: (1) the Nashville dome; (2) the Cumberland saddle; and (3) the Jessamine dome. Although a major structural feature of the Cincinnati arch province, a discussion of the Jessamine dome is not pertinent to the present report.

NASHVILLE DOME

The salient structural feature of central Tennessee is the Nashville dome, a broad, elliptical, upwarp, which represents the southern part of the Cincinnati arch. The axis of this major structure extends from Kentucky into the extreme western portion of Clay County and thence south-southwest into central Rutherford County where the major axis splits into two components. The southern extension of the Nashville arch in Tennessee has been outlined recently by Wilson and Spain.[75]

[74]Lusk, R. G. Gravel on the Highland Rim plateau, and terraces in the valley of Cumberland River: Jour. Geol., vol. 36, pp. 164-170, 1928.

[75]Wilson, C. W., Jr., and Spain, E. L., Jr. Upper Paleozoic development of Nashville dome, Tennessee: Bull. Amer. Assoc. Petroleum Geologists, vol. 20, p. 1077, 1936.

Near the apex of the Nashville dome, located in south-central Rutherford County, the Chattanooga shale reaches a sea level elevation of approximately 1,300 feet. From this point the rocks dip in all directions at very low angles. The dip on the flanks averages about 15 feet per mile, although locally it steepens considerably and often attains several degrees. Many small, subordinate folds are superimposed upon the gently dipping flanks of the dome. These flexures are generally small in areal extent and seldom reach 100 feet in structural relief.[76]

CUMBERLAND SADDLE

From the apex of the Nashville dome the Chattanooga shale dips gently to the northeast at a rate of 8-10 feet per mile into western Clay County where it averages 750-800 feet above sea level. A few miles to the north, in southern Cumberland County, Kentucky, the black shale is less than 600 feet above sea level.[77] This regional low, commonly termed the Cumberland saddle, is some 700 feet lower structurally than the crest of the Nashville dome and separates the latter from the higher Jessamine dome of central Kentucky.

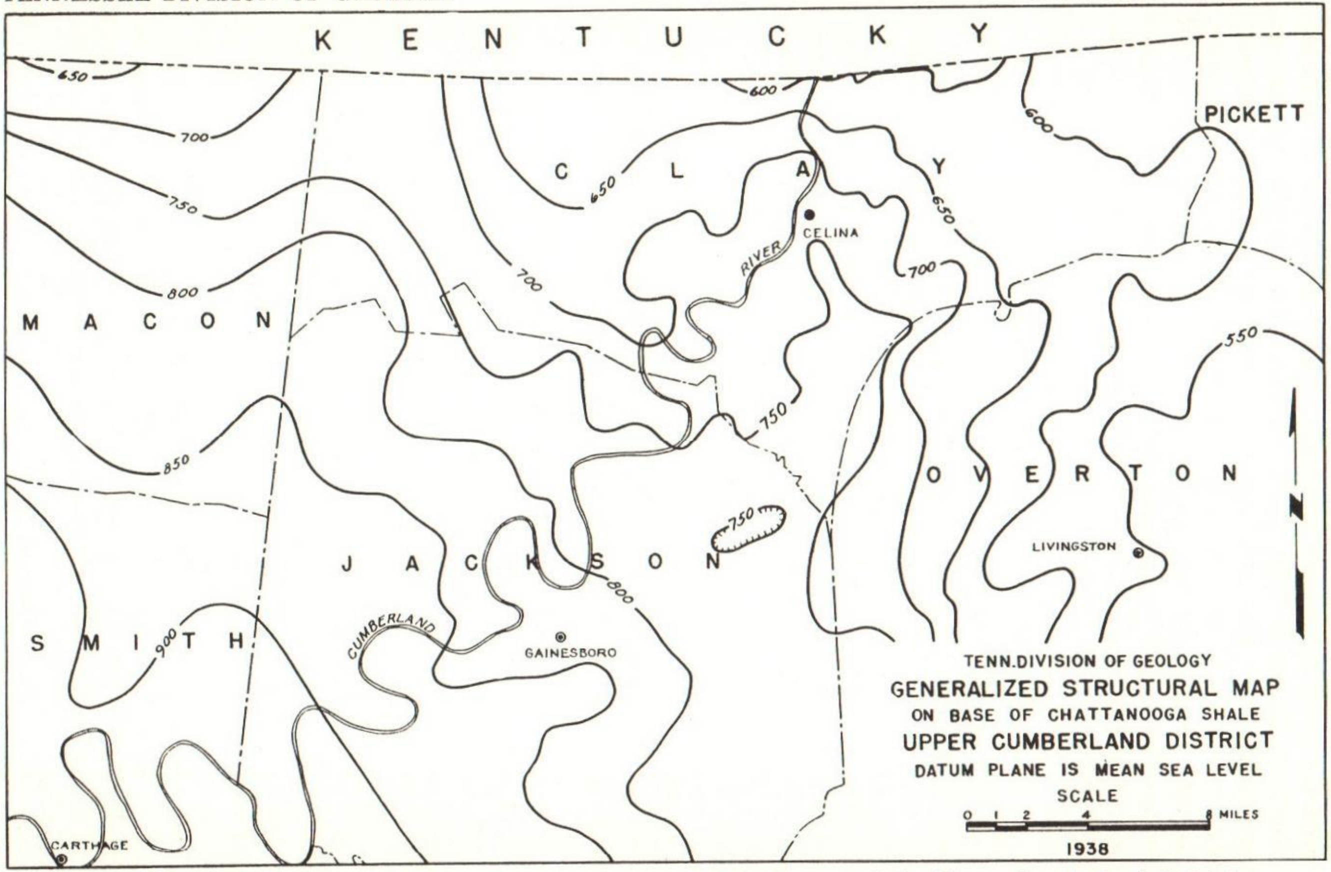
MAJOR STRUCTURAL FEATURES OF CLAY COUNTY

NASHVILLE DOME AXIS

Structural studies to date do not permit accurate geographic definition of the Nashville dome axis across the Upper Cumberland district. In western Clay County the Chattanooga shale, the most reliable datum plane, is generally covered by the Fort Payne and younger formations, and since only seven wells in this part of the County have reached the black shale or deeper subsurface markers, structural data at present are incomplete. Reconnaissance structural work in northeastern Smith, eastern Macon, and Jackson counties strongly indicates that in this region the Nashville dome is characterized by a series of structural shoulders and lows on which the Chattanooga shale locally attains higher sea-level elevations than on the main axis (Plate V). Intensive drilling activity, with its attendant valuable subsurface data, will be necessary before the structural details are known.

[76]For more detailed discussions of the Nashville dome, especially regarding its age and history, the reader is referred to: C. W. Wilson, Jr., The pre-Chattanooga development of the Nashville dome: Jour. Geology, vol. 43, pp. 449-481, 1935; and, C. W. Wilson, Jr., and E. L. Spain, Jr., Upper Paleozoic development of Nashville dome, Tennessee: Bull. Amer. Assoc. Petroleum Geologists, vol. 20, pp. 1071-1085, 1936.

[77]Jillson, W. R. Structural map of Kentucky: Kentucky Geol. Survey, Ser. VI, 1931.



Generalized structural map on the base of the Chattanooga shale in part of the Upper Cumberland district.

The highest Chattanooga shale in Clay County is in the extreme southwestern part where the base of that formation is approximately 820 feet above sea level. A generalized structural map on the base of the Chattanooga strongly suggests a major structural axis trending about due north from northeastern Smith County into southwestern Clay County, near Bakerton, thence north through the Chattanooga shale inlier south of Hermitage Springs into south-central Monroe County, Kentucky (Plate V). Until more surface and subsurface data are available, this general regional high will be assumed to approximately represent the trend of the Nashville dome axis through the northern part of the Upper Cumberland district.

The regional dip of the strata in Clay County is east-southeast. The base of the Chattanooga shale dips from a sea level elevation of approximately 800 feet in the vicinity of Hermitage Springs to 560 feet in the Doctors Syndicate, Ed Wright No. 1 (352)* about one mile northeast of Lillydale in the extreme northeastern part of Clay County (Plate VI). In the Jervian Corporation's Brier-Hill Collieries No. 1, 25 miles to the south-southeast, near Crawford in southeastern Overton County, the base of the Chattanooga was penetrated at 425 feet above sea level. Twenty-five miles farther east in Morgan County, 3 miles southwest of Sunbright, the Johnson-Messer Oil Company's Gilreath No. 1 logged the base of the black shale at an elevation of 257 feet above sea level.

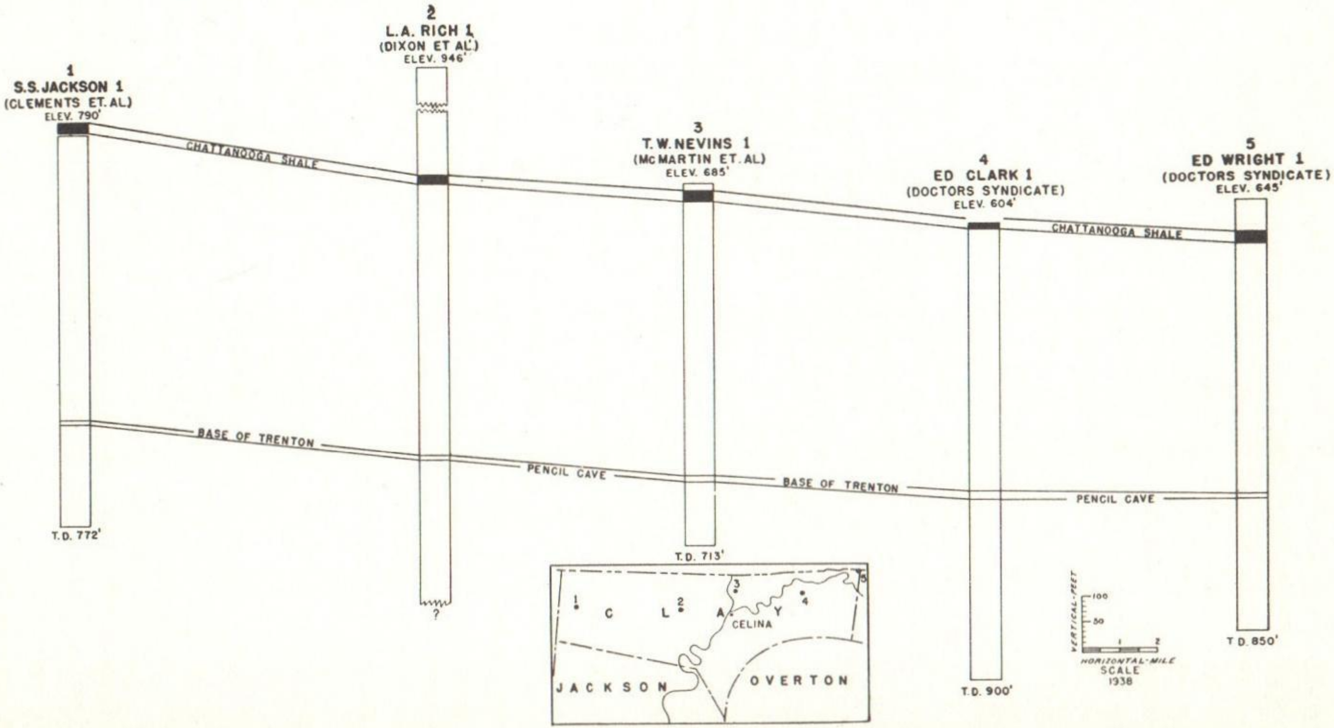
MOSS STRUCTURAL LOW

Present data suggest a broad structural low immediately east of the Nashville dome axis and in the general vicinity of Moss. The complete lack of subsurface data, together with the masking of the Chattanooga shale by younger rocks, do not allow precise definition of this structural feature. Undoubtedly future drilling will give subsurface information which will alter the present concept. The presence of this structurally low area is suggested by: (1) the preservation of younger Mississippian formations—the Warsaw and locally the St. Louis limestones; and (2) the occurrence of abnormally low Chattanooga shale in the headwaters of Brimstone Creek, south of Moss, and along McFarland Creek, 4 miles northeast of Moss. In the upper part of Brimstone Creek the base of the Chattanooga shale is generally less than 700 feet above sea level and along McFarland Creek elevations below 610 feet have been recorded.

*Numbers in parentheses refer to well record numbers on Table 1.

TENNESSEE DIVISION OF GEOLOGY

BULLETIN 47, PLATE VI



West-east cross-section in Clay County showing the regional dip of the Chattanooga shale and Pencil Cave.

A series of small domes, roughly aligned in a N. 40° E. trend, occur along the southeastern margin of the Moss low. The presence of sharp syncline to the northeast and southwest, together with the general lack of orientation of these small domes, does not seem to warrant regional consideration for these features. In general the Moss low is defined to the southeast by a series of synclines which form the western border of the Bennetts Ferry upwarp and the Celina arch.

BENNETTS FERRY UPWARP

One of the more conspicuous structural axes in the Upper Cumberland district strikes N. 45° E. from the northern part of Jackson County through Tinsleys Bottom and into south-central Clay County. Erosion by Cumberland River has removed much of the Chattanooga shale along this trend, but a regional high is indicated by available Chattanooga elevations, subsurface data on the Pencil Cave horizon (Plate 1-B), and dips as high as 5° to 6° in isolated Ordovician exposures. From Tinsleys Bottom the main upwarp continues N. 45° E. through Weaver Bottom to a point just north of Bennetts Ferry where the axis appears to split into two components, one of which swings about N. 60° E. through Peterman and Goodpasture bends, and the other trends N. 25° E. into what is described below as the Celina arch.

The Bennetts Ferry trend is not a continuous anticlinal axis, but rather it is a linear trend along which the base of the Chattanooga and the Pencil Cave are generally considerably higher than areas on either side. Structurally low areas transect this major axis. On the Pencil Cave horizon the structure has a maximum relief of 60 feet in the Tinsleys Bottom area.

The Tinsleys Bottom, Weaver Bottom, South Arcott, and lower Knob Creek domes are definitely associated with this regional high. Peterman and Goodpasture bends, both of which have been, or are, productive, may be related to this upwarp, although they are separated from the main trend by the southern end of the Celina syncline.

CELINA ARCH

A N. 25° E. trending axis, beginning just north of Bennetts Ferry, is here considered the southern part of a prominent structural feature, the Celina arch. The southern part of this upwarp is sharply defined on the southeast by the Celina syncline and to the northwest by the Harp Hollow and Knob Creek synclines. There is 70 feet of structural relief into the Knob Creek syncline and approximately 30 feet into the Celina low. Three well-defined domes are related to the southern part of this arch; the Harp Hollow dome, just north of the Harp Hollow syncline, the Plumlee dome, 1 mile northwest of Beech Bethany School, and the Kyle Point dome, centering 0.6 of a mile north-northeast of the Celina courthouse.

At Beech Bethany School, 1.5 miles north-northwest of Celina, the axis swings to N. 15° W. From this point it plunges gently to the north into the Solomon Branch syncline, just south of the Kentucky line, with 130 feet of structural relief in approximately 3 miles. This N. 15° W. trend is well-defined to the east by the southern extension of the Solomon Branch syncline and to the west by a structurally low area in the headwaters of Little Proctor Creek where the Chattanooga shale is as low as 625 feet above sea level.

The exact relationship of the Celina arch to the Bennetts Ferry upwarp is not well established due largely to the absence of the Chattanooga shale by erosion and the lack of subsurface records on the Pencil Cave horizon.

PETERMAN BEND TREND

On the lower Knob Creek dome, at the northern end of the main Bennetts Ferry upwarp, the Chattanooga shale dips to the northeast from 740 feet above sea level to less than 710 feet in the southern part of the Celina syncline. From this structurally low point the Chattanooga rises to a maximum of more than 740 feet on the Peterman Bend dome. Northeast of this dome the shale dips below 680 feet and then rises on the Goodpasture Bend dome. Although removed from the immediate area by erosion, the restored base of the Chattanooga shale at the apex of the Goodpasture Bend dome approximates 720 feet above sea level. This anticlinal trend merges northeast of Goodpasture Bend into the Willow Grove terrace. The Peterman Bend trend is well shown on the generalized structural map on the base of the Pencil Cave (Plate 1-B).

The southern extension of the Celina syncline is largely responsible for questioning the continuance of the main Bennetts Ferry upwarp into the Peterman and Goodpasture bends area. Drilling southwest of Celina will be necessary to prove a definite relationship. Present data, both surface and subsurface, merely suggest the possibility that Bennetts Ferry and Peterman Bend anticlinal features are related.

MILL CREEK-FOX SPRINGS ANTICLINE

Structural work on the Chattanooga shale by Lusk[78] in the Gainesboro quadrangle, including southwestern Clay and the major part of Jackson counties, shows a regional high beginning immediately northeast of the town of Gainesboro and trending N. 55° E. for approximately 9 miles to the Clay County line. Just northeast of the County line, in the southeastern part of the Mill Creek district, the main axis turns N. 35° E. and continues along the Overton County line into the Fox Springs-Mitchell Creek area. Where the strike changes, an anticlinal axis splits off the main trend and plunges gently N. 10° W. toward the Celina syncline.

The trend of the Mill Creek-Fox Springs anticline is roughly parallel to the main Bennetts Ferry upwarp, and like that structure, the axis plunges gently to the northeast. The relation between the two, however, is not well understood. The two anticlinal trends are separated by an area, 2 to 4 miles wide, in which the Chattanooga shale is as much as 70 feet lower than its position on the Bennetts Ferry and Mill Creek-Fox Springs axes. No name has been assigned to this structural low, but the southern part of the Celina low and the Butlers Landing syncline are pronounced structural depressions in this generally low area. Additional subsurface data are necessary to define its general configuration and areal extent.

More detailed surface work, together with subsurface data presented by future drilling, may show an intimate relationship of the Mill Creek-Fox Springs anticline with the east and northeast trending Dry Fork and Mitchell Creek anticlines mapped by Butts[79] in the northwestern part of Overton County.

The Mill Creek-Fox Springs anticline has a maximum relief in the Mill Creek area of approximately 60 feet on the base of the Chattanooga shale. On the subsurface the Pencil Cave horizon shows 70 feet of structural relief. In the Fox Springs district the general order of relief on the black shale is 30-40 feet, although data on the Pencil Cave indicates almost twice this amount (Plate 1B).

The Tidwell dome in the Mill Creek area and the New Salem Church and Fox Springs domes in the Fox Springs district, each of which have produced oil, are located on or near the Mill Creek-Fox Springs anticlinal axis.

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[78]Lusk, R. G. Op. cit., geologic and structural map.
[79]Butts, Chas. Op. cit., structural map.

WILLOW GROVE TERRACE

Surface work on the base of the Chattanooga shale and available subsurface data on the Pencil Cave horizon indicates a broad, poorly defined, structurally flat area from about the mouth of Mitchell Creek to the Pickett County line. Although local domes and basins are common throughout the eastern one-third of the County, from the general structural standpoint and with present subsurface information this general area must be contoured as a broad, relatively flat, structural terrace. It is in this general region that the Bennetts Ferry and Mill Creek-Fox Springs anticlinal trends lose their identity and the small individual upwarps and synclines mapped by Perry[80] do not appear to have a definite or oriented structural pattern.

The Willow Grove terrace includes strong local structures such as Stillhouse Creek, Iron Creek, Stamps, Lillydale, Ashburn Creek, and Jouett Creek domes, all of which have been, or are, productive.

FAULTING

Faulting is rare in the Upper Cumberland district. Although dips, locally as high as 20° have been noted, no faults were observed in the course of the field studies in Clay County. The nearest area of strong faulting is along Flynn Creek[81] in Jackson County, about 20 miles south-southwest of Celina.

DETAILS OF STRUCTURE

THE GEOLOGIC STRUCTURE MAP

Geologic structural work on the base of the Chattanooga shale was carried on during June and July, 1923, by E. S. Perry[82] in the Lillydale quadrangle, which includes the eastern half of Clay, the western edge of Pickett, and the northern border of Overton counties. Perry used the base of the Chattanooga shale as the structural key bed and elevations on this horizon were determined by an aneroid barometer and a hand level. In the upland areas sea level elevations were obtained on the ripple-marked sandstone (Garretts Mill) at the top of the Warsaw formation, and these elevations were converted to the Chattanooga elevations by subtracting 330 feet, his calculated interval between the base of the black shale and

[80]Perry, E. S. Geologic structural map of the Lillydale quadrangle, embracing eastern Clay County and parts of Overton and Pickett counties, Tennessee: Tenn. Div. Geol., Press Bulletin, May, 1927.

[81]Wilson, C. W., Jr., and Born, K. E. The Flynn Creek disturbance, Jackson County, Tennessee: Jour. Geol., vol. 44, pp. 815-835, 1936.

[82]Perry, E. S. Preliminary farm location map showing geologic structural contours of the eastern part of Clay County, Tennessee: Tenn. Geol. Survey, 1923.

the Garretts Mill sandstone. Since Perry's original map is not available in the files of this Division, the number and pattern of his elevations are not known. With the time available and the difficulties under which the work was done, the geologic structural map must be considered reconnaissance in nature.

In the present report and on the geologic structure map (Plate I) the present writers have incorporated Perry's work. The contour interval is 20 feet. In Perry's unpublished manuscript[83] and in the 1925 press notice[84] only locations of the more important domes are listed. Further reconnaissance studies by the present writers, together with the valuable subsurface data supplied by more than 200 wells drilled in eastern Clay County since the time of Perry's work, have given additional information and a check on the general structural conditions.

The present investigation has had as one of its major objectives the structural mapping of that part of Clay County west of Cumberland River and covered by parts of the Gainesboro, Tompkinsville, Carthage, and Red Boiling Springs topographic quadrangles of the United States Geological Survey. It was necessary, however, to do rapid reconnaissance work south of Celina to the Jackson County line and immediately east of the longitude of Celina on the Tompkinsville quadrangle to tie in with Perry's Lillydale structure.

In the area south of Celina, especially the Mill Creek area, reconnaissance structural work was augmented by several Chattanooga shale elevations furnished this Division by the late J. H. McClurkin, of Horse Cave, Kentucky. In a very small area just west of the Overton County line, the structural map of Butts[85] on the base of the Cypress sandstone was used by converting it to Chattanooga elevations by use of a constant interval.

More detailed structural studies were carried on in the area west of Cumberland River. Practically all of this work was done by the junior writer and John Webb, who mapped approximately 26 square miles of the Tompkinsville quadrangle between Proctor Creek and Tinsleys Bottom. The junior author completed the work.

The structural datum used in the western half of the County was the base of the Chattanooga shale. The altimeter method was used exclusively. A Paulin A-1 type instrument, which reads to

[83]Perry, E. S. Oil possibilities and geology of eastern Clay County, Tennessee: Tenn. Div. Geol., unpublished manuscript.

[84]Perry, E. S. Geologic structure map of the Lillydale quadrangle embracing eastern Clay County and parts of Overton and Pickett counties, Tennessee: Tenn. Geol. Survey, Press Bulletin, Dec. 14, 1925.

[85]Butts, Chas. Op. cit., structural map.

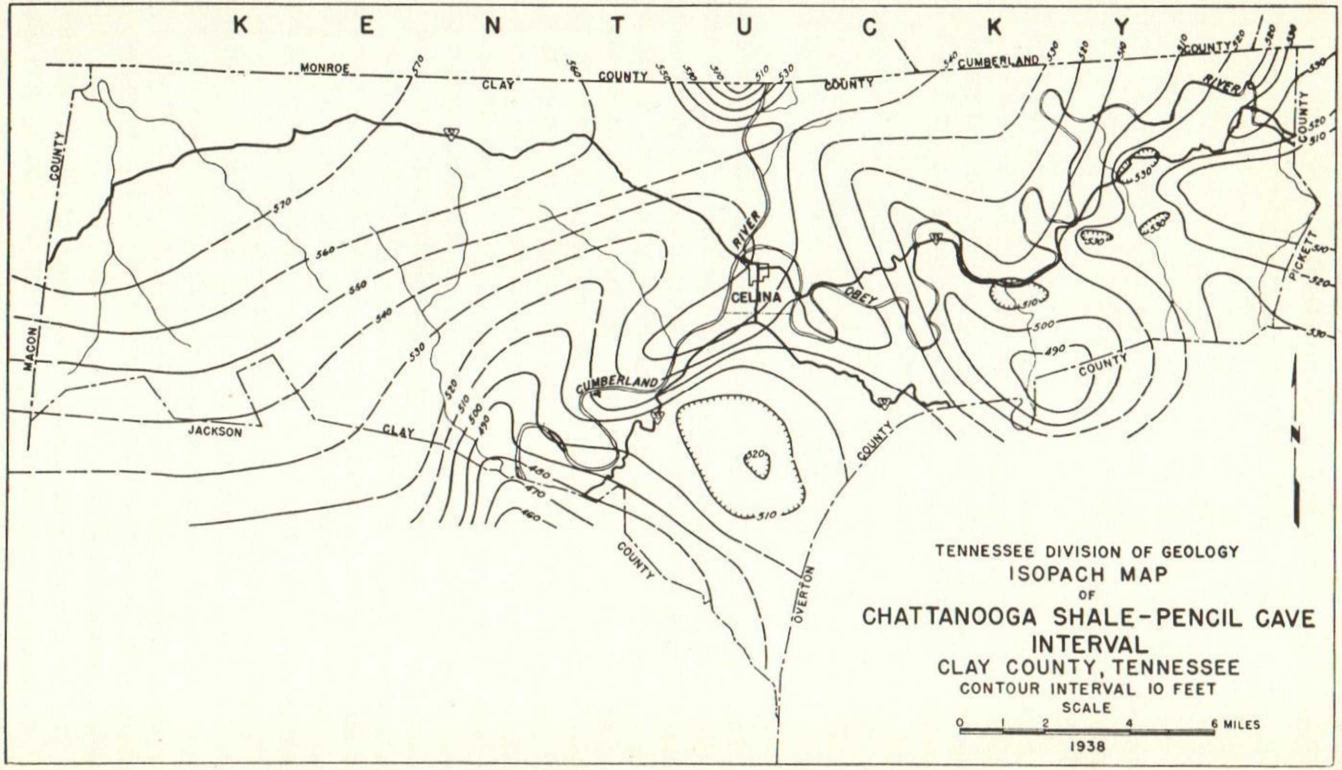
2-foot intervals, was used and corrections were made for atmospheric variations. The average accuracy of the work is believed to be at least 10 feet or less. Throughout most of the western half of the County an approximate quarter-mile grid was maintained, although in the southwestern part along Sycamore Fork, Brannon, Pine Lick, and Crabtree creeks, elevations were taken about one-half mile apart.

The geologic structure map shown on Plate I is not presented as a specific drilling location map. The errors that may be introduced by the method of mapping outlined above are obvious. Furthermore, the general structure in the Upper Cumberland district is characterized by small, sharp upwarps and downwarps with little vertical closure. In such areas extremely detailed work is imperative to definitely outline structures. Such careful work could not be done in the present study. It is hoped, however, that this generalized structural map of Clay County will serve as a guide to more intelligent prospecting and as an impetus to further detailed geologic work. Certainly all structures outlined on the map should be thoroughly checked by a competent geologist before they are tested by the drill.

THE CHATTANOOGA SHALE-PENCIL CAVE INTERVAL

In preparing the structural maps on the base of the Pencil Cave in three of the individual oil fields, Kettle Creek-Pine Branch area (Plate X), Peterman Bend (Plate XI), and the Willow Grove-Irons Creek district (Plate XIV), it was found practical to use a Chattanooga shale-Pencil Cave interval where actual Pencil Cave data were incomplete. The rather constant thickness of 500 feet for this interval has been recognized by drillers and operators for many years in the Upper Cumberland district. The plotting of this unit in individual wells throughout the County in the preparation of the Chattanooga-Pencil Cave isopach map (Plate VII) indicates a maximum variation of about 100 feet. This interval, however, is quite constant within restricted areas.

A maximum observed thickness of 573 feet for the Chattanooga-Pencil Cave interval was in W. P. Clements et al., S. S. Jackson No. 1 (141), drilled 1.5 miles south of Hermitage Springs in the extreme western part of the County. A minimum of 494 feet was present in Bryan Davis et al., G. L. Maynard No. 1 (227), in the Mitchell Creek area. Cox, Spivy, and Greenup's Fletcher and Brown No. 2 (102), in northern Overton County, had only 475 feet of beds between the base of the black shale and the Pencil Cave marker. Reconstructed intervals of approximately 480 feet



Isopach map of the Chattanooga shale-Pencil Cave interval in Clay County.

were obtained just west of Tinsleys Bottom and to the south, in Jackson County, this unit thins considerably.

Erosion rather than non-deposition is believed to explain the variations in thickness of the Chattanooga-Pencil Cave interval in Clay County. Subsurface studies of more than 20 sample sets show a remarkable constancy in thicknesses for the upper member of the Carters limestone and the Hermitage formation. While the Cannon limestone varies from 215 to 250 feet, an average of about 225 feet is common.

Since the drillers in this region seldom save samples before setting their 8¼-inch casing, little information is available on the thicknesses of the Catheys and Leipers formations throughout the County. While there is no marked physical break in the field, the plane of contact of these two formations represents a hiatus, since the intervening rocks of Eden age have not been recognized in Middle Tennessee. Incomplete studies, however, suggest a rather common thickness of slightly over 100 feet for the Catheys limestone.

The major unconformity in the exposed stratigraphic section in Clay and adjoining counties is at the Mississippian-Ordovician contact. There is no evidence that Silurian or Devonian beds were ever deposited in the Upper Cumberland district of Tennessee. During the time interval preceding the deposition of the black shales of the Chattanooga, this general area is believed to have had relatively little relief. It seems probable, however, that there were local areas that stood somewhat higher than the general land surface. Data are not at hand to prove whether these elevated areas were entirely topographic or due to pre-Chattanooga diastrophism, but the general structural parallelism of the base of the Chattanooga shale and the Pencil Cave does not suggest strong pre-Mississippian structural highs. Undoubtedly, a considerable amount of upper Ordovician strata was removed during the pre-Chattanooga erosional interval. This removal may explain the variations in thickness of the Chattanooga-Pencil Cave interval. Detailed sample studies of the Leipers and Catheys formations, when such samples become available, will be necessary to prove this suggested explanation. Data to date have failed to present any definite relationship between the thickness of this interval and the major structural features of the County.

The presence of 10 to probably as much as 30 feet of Richmond beds in local areas in the western part of the County has undoubtedly been reflected in the abnormal thickness of the Chattanooga-

Pencil Cave interval in W. P. Clements et al., S. S. Jackson No. 1 (141) and John Kerzan et al., Rebecca Brown No. 1 (28).

LOCAL STRUCTURE

The details of structure in Clay County are shown on the structural geologic map on the base of the Chattanooga shale (Plate I). For the purpose of enumeration and discussion it has seemed advantageous to divide the County into two parts, east and west of Cumberland River.

EASTERN CLAY COUNTY

The structural map of the Lillydale quadrangle, which covers most of eastern Clay County, has been available for over fifteen years. During this time the more promising structures have been drilled. No attempt, therefore, has been made to describe these structures in detail, although the majority of them have been briefly discussed in the section on individual fields. All local structures—anticlines with approximately 10 feet or more of closure, and synclines with closures of 20 feet or more—are enumerated below, from east to west. For the purpose of designation it has seemed advisable to assign names to these domes and synclines and, wherever possible, names with a geographic connotation have been chosen.

Name	*Location* Miles from Celina Courthouse	*Briefly Described* (Page)
Jouett Creek dome	13.5 E., 2.2 N.	146
Wilburn dome	13.5 E., 1.8 N.	146, 183
Rocky Branch syncline	13.1 E., 3 N.	137
State line dome	12.4 E., 5 N.	137
Ashburn Creek dome	12.4 E., 2 N.	146
Lillydale dome	11.7 E., 4.5 N.	137
Gamewell dome	11.4 E., 3.5 N.	137
Fairview School syncline	11.2 E., 0.7 S.	
Stamps dome	10.5 E., 3.7 N.	137-138
Sulphur Creek dome	9.8 E., 4.5 N.	138
Cedar Hill School syncline	9.4 E., 3.5 N.	138
Hogan Hollow dome	9.3 E., 1.4 N.	
Coalson Creek dome	9.2 E., 1.8 N.	130
Stover dome	8.8 E., 3.6 N.	
Wiley Fork dome	8.8 E., 0.5 N.	130
Irons Creek dome	8.7 E., 1.3 N.	130
Pusley Creek dome	8.6 E., 4.5 N.	

Name	*Location* Miles from Celina Courthouse	*Briefly Described* (Page)
Willow Grove dome	8.3 E., 2.7 N.	130
Stillhouse Creek dome	7.9 E., 1.4 N.	130
Keene Bend syncline	7.3 E., 1.2 N.	
Johnson Bend dome	7.2 E., 2.5 N.	
Neely dome	7.1 E., 0.3 S.	182-183
Holly Creek syncline	6.5 E., 2.5 N.	
New Salem Church dome	6.1 E., 0.7 S.	123
Fox Springs (Williams) dome	5.8 E., 0.1 S.	123
Grogan Hill dome	5.8 E., 3 N.	183
Galton Hollow dome	5.6 E., 1.2 N.	
Myers dome	5.2 E., 0.2 N.	183
Lick Run syncline	4.4 E., 2.4 N.	
Goodpasture Bend dome	3.8 E., 0.7 N.	64, 116
Smith Creek dome	2.7 E., 3.6 N.	183
County Line dome	2.6 E., 4.5 S.	
Walker Ridge dome	2.1 E., 1.7 S.	183
Skinniky Branch dome	1.3 E., 1.8 N.	
Peterman Bend dome	1.1 E., 0.7 S.	64, 114
Tidwell dome	1 E., 4.5 S.	65, 94, 96
Kyle Point dome	0.2 E., 0.6 N.	105-106
Celina syncline	0.1 E., 0.2 S.	106
Pine Branch dome	0.1 E., 3.3 N.	108-109
Oil Hollow dome	4.5 S.	94-95
Baptist Ridge dome	0.4 W., 5.1 S.	95
Pendleton Hollow dome	0.5 W., 3.7 S.	95
Bailey dome	1.8 W., 3.1 S.	
Weaver Bottom dome	3.6 W., 3.6 S.	63
Tinsleys Bottom dome	4.6 W., 5 S.	88-89

WESTERN CLAY COUNTY

One of the major objectives in the present study was the structural mapping of that part of Clay County which lies west of Cumberland River. The generally successful explorations in that part of the County east of the River strongly suggested the possibilities of extending this productive area west of the river. Commercial production in this region was found in W. P. Clements et al., O. N. Cherry No. 1 (37) during the spring of 1938. This was the discovery well in the Arcott School field (pp. 96-99). To the end of 1938, however, only 35 wells had been drilled in Clay County west of Cumberland River and the majority of these were located without regard to structural conditions.

Field studies were completed in this area late in 1938. Since that time and the writing of the greater part of this report, production has been extended from the J. H. Overstreet et al., Kyle and Vaughn No. 1 (160) across Cumberland River. This is the most active area in Clay County at present.

Since the present report contains the first published structural map of the western part of Clay County, it has been considered advisable to point out the more important features of each dome and each syncline with closures of approximately 10 and 20 feet, respectively. Here again the writers wish to emphasize the fact that this structural work is of the reconnaissance class; all structures briefly outlined below and shown on Plate I should be carefully checked before drilling.

McCauley dome

*Location:** 0.6 W., 4.5 N. *Vertical Closure:* 40+ ft. *Trend:* N. 10° E.

*Areal Extent:*** 275 acres. *Wells:**** 196, 197, 198.

Remarks: Good control. 8° southeast, 4° northeast dip. Strong dip to southwest.

Little Proctor Creek dome

Location: 0.9 W., 3 N. *Vertical Closure:* 10+ ft. *Trend:* N. 35° W.

Areal Extent: 65 acres. *Wells:* None.

Remarks: Good control to the south and east, fair to the north, poor to the northwest. Strong dips to north, east, and southwest. Super-imposed dome on northern end of the Celina arch.

Plumlee dome

Location: 1.2 W., 1.4 N. *Vertical Closure:* 20+ ft. *Trend:* N. 40° W.

Areal Extent: 75 acres. *Wells:* 276, 277.

Remarks: Good to fair control except to the southeast. Strong north dip. Two wells drilled (276, 277) do not appear to have been well located on the dome.

Solomon Branch syncline

Location: 1.3 W., 4.2 N. *Vertical Closure:* 20+ ft. *Trend:* N. 40° W.

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*In miles from Celina courthouse.

**Areal extent calculated by planimeter method within the closure. Figures given must be considered approximations.

***Numbers refer to well record numbers on Table 1.

Areal Extent: 550 acres. *Wells:* None.

Remarks: Fair to poor control. Strong southwest dip off McCauley dome. Defined on east by the Pine Branch dome and to the south by the Celina arch.

Harp Hollow dome

Location: 1.8 W., 0.2 N. *Vertical Closure:* 20+ ft. *Trend:* N.

Areal Extent: 375 acres. *Wells:* None.

Remarks: Good control except immediately to the northwest. Strong west dip into the Knob Creek syncline.

Proctor Creek-New Hope Branch dome

Location: 1.8 W., 1.3 N. *Vertical Closure:* 10− ft. *Trend:* N. 45° E.

Areal Extent: 50 acres. *Wells:* None.

Remarks: Good control. Strong west dip. Structure may represent a southeastern extension of the Plumlee dome.

Lower Knob Creek dome

Location: 2 W., 2 S. *Vertical Closure:* 10− ft. *Trend:* N. 45° E.

Areal Extent: 75 acres. *Wells:* None.

Remarks: Fair control except to east and southeast. Strong dips to the northeast and southwest in the Ordovician limestones may be seen along Cumberland River during low water.

Harp Hollow syncline

Location: 2.3 W., 0.7 S. *Vertical Closure:* 20+ ft. *Trend:* N. 30° E.

Areal Extent: 80 acres. *Wells:* 71.

Remarks: Poor control, especially to the northwest. Sharp southwest dip off Harp Hollow dome. Southeast dip may be seen along Knob Creek opposite mouth of Harp Hollow.

Knob Creek Ridge dome

Location: 2.6 W., 0.7 N. *Vertical Closure:* 10+ ft. *Trend:* N. 70° E.

Areal Extent: 150 acres. *Wells:* None.

Remarks: Good control to northeast and southwest, poor to northwest and southeast. Best definition to southwest by Knob Creek syncline. Chattanooga control in Proctor and Knob creeks; no Chattanooga control on ridge between the two creeks.

South Arcott School dome

Location: 2.7 W., 2 S. *Vertical Closure:* 10− ft. *Trend:* N. *Areal Extent:* 75 acres. *Wells:* 2, 27, 37, 198, 298.

Remarks: Chattanooga control only to the north. Closure assumed by strong north and west dips; and gentle south and east dips in the Catheys limestones. Closure substantiated by subsequent drilling. Dome responsible for accumulation in Arcott School field. Well 2 not well situated on structure.

North Arcott School dome

Location: 2.7 W., 1.4 S. *Vertical Closure:* 10+ ft. *Trend:* N. 55° E.

Areal Extent: 150 acres. *Wells:* None.

Remarks: Good control. Strongest dips to the west and northwest.

New Hope Branch dome

Location: 2.8 W., 2.1 N. *Vertical Closure:* 20+ ft. *Trend:* N. 10° E.

Areal Extent: 75 acres. *Wells:* None.

Remarks: Poor control to west and southwest. Strong dips to west and northwest.

Proctor Creek Ridge dome

Location: 2.9 W., 1.1 N. *Vertical Closure:* 10+ ft. *Trend:* N. 10° E.

Areal Extent: 25 acres. *Wells:* None.

Remarks: Fair control. 15 to 20 feet structural relief on base of Chattanooga in all directions.

Knob Creek syncline

Location: 3.1 W., 0.4 S. *Vertical Closure:* 40+ ft. *Trend:* N. 20° E.

Areal Extent: 550 acres. *Wells:* 70.

Remarks: Good control. Base of Chattanooga reaches a low point of 647 feet near center of the downwarp.

Proctor Creek dome

Location: 3.6 W., 1.3 N. *Vertical Closure:* 20+ ft. *Trend:* N. 15° W.

Areal Extent: 125 acres. *Wells:* None.

Remarks: Upwarp surrounded by abnormally low Chattanooga shale. Well-defined to the north. Poor control immediately to the east.

Upper Long Branch dome

Location: 3.7 W., 0.9 S. *Vertical Closure:* 10+ ft. *Trend:* N. 40° E.

Areal Extent: 100 acres. *Wells:* None.

Remarks: Good control. Strong north, east, and west dips, with gentle dip to the south.

Lower Long Branch dome

Location: 3.8 W., 1.7 S. *Vertical Closure:* 10– ft. *Trend:* N. 85° E.

Areal Extent: 100 acres. *Wells:* None.

Remarks: Poorly defined. Closure less than 10 feet.

Anderson dome

Location: 3.8 W., *Vertical Closure:* 10– ft. *Trend:* N. 55° E.

Areal Extent: 125 acres. *Wells:* 1.

Remarks: Good to fair control except to the west and southwest.

Upper Proctor Creek dome

Location: 4.2 W., 2.4 N. *Vertical Closure:* 10– ft. *Trend:* N. 50° E.

Areal Extent: 80 acres. *Wells:* None.

Remarks: Very gentle dips. Poor control to southwest.

Upper Knob Creek dome

Location: 4.6 W., 1 N. *Vertical Closure:* 10– ft. *Trend:* N. 50° E.

Areal Extent: 80 acres. *Wells:* None.

Remarks: Poor control.

Lower Dry Creek dome

Location: 4.7 W., 1.8 S. *Vertical Closure:* 10– ft. *Trend:* N. 55° E.

Areal Extent: 25 acres. *Wells:* None.

Remarks: Small dome superimposed upon a structural saddle between two shallow synclines to the northeast and southwest.

Middle Turkey Creek dome

Location: 4.8 W., 2.4 S. *Vertical Closure:* 10+ ft. *Trend:* N. 15° E.

Areal Extent: 100 acres. *Wells:* None.

Remarks: Good control except to the south. Strong north dip, with gentle dips to the east and west.

Dry Creek dome

Location: 5.1 W., 0.9 S. *Vertical Closure:* 20+ ft. *Trend:* N. 55° E.

Areal Extent: 575 acres. *Wells:* None.

Remarks: Includes two small closures on a larger dome. Good control in all directions. Strong dips to the northwest and east.

Long Hollow dome

Location: 5.4 W., 3.3 S. *Vertical Closure:* 10+ ft. *Trend:* N. 30° W.

Areal Extent: 75 acres. *Wells:* None.

Remarks: Good control. About 10-15 feet structural relief on the Chattanooga in all directions.

Upper Turkey Creek dome

Location: 5.6 W., 2 S. *Vertical Closure:* 10+ ft. *Trend:* N. 80° E.

Areal Extent: 225 acres. *Wells:* None.

Remarks: Good control. Strong dips to northeast, east, southwest, and south.

Left Fork of Turkey Creek dome

Location: 5.8 W., 2.7 S. *Vertical Closure:* 10− ft. *Trend:* N. 50° E.

Areal Extent: 100 acres. *Wells:* None.

Remarks: Poorly defined. No immediate control to the west.

Lower Brimstone Creek dome

Location: 6.1 W., 4 S. *Vertical Closure:* 10− ft. *Trend:* N. 10° E.

Areal Extent: 30 acres. *Wells:* None.

Remarks: Poorly defined. No immediate control to the west.

Pide Branch dome

Location: 6.6 W., 0.8 S. *Vertical Closure:* 10+ ft. *Trend:* N. 85° E.

Areal Extent: 225 acres. *Wells:* None.

Remarks: Poorly defined. No control to the east and immediately to the south. Fair northwest dip.

Right Fork of Brimstone Creek dome

Location: 7.5 W., 0.4 S. *Vertical Closure:* 10+ ft. *Trend:* N. 60° E.

Areal Extent: 65 acres. *Wells:* None.

Remarks: Good control except immediately to the north. 3° dip to the southwest, with strong dip to the east.

Brimstone Creek syncline

Location: 7.8 W., 1 S. *Vertical Closure:* 20− ft. *Trend:* N. 70° W.

Areal Extent: 300 acres. *Wells:* None.

Remarks: Good control. 2° dip to the northwest and southwest into this structural low. Chattanooga shale as low as 660 feet above sea level near the center.

Brimstone Creek dome

Location: 8 W., 1.7 S. *Vertical Closure:* 10− ft. *Trend:* N. 20° W.

Areal Extent: 200 acres. *Wells:* None.

Remarks: Gentle dips on all sides. Good control.

Left Fork of Brimstone Creek dome

Location: 8.2 W., 0.4 S. *Vertical Closure:* 40+ ft. *Trend:* N. 40° E.

Areal Extent: 975 acres. *Wells:* None.

Remarks: Good control. Dips of 2-3° to the south, 3° to the west 3° to the northeast, 4° to the southeast, and 1° to the east.

Sycamore Fork dome

Location: 9.3 W., 2.7 S. *Vertical Closure.* 10+ ft. *Trend:* N. 45° W.

Areal Extent: 100 acres. *Wells:* None.

Remarks: Fair control, poor immediately to the east. 6° dip to the southwest.

Sycamore Fork syncline

Location: 9.5 W., 2.8 S. *Vertical Closure:* 20− ft. *Trend:* N. 50° E.

Areal Extent: 30 acres. *Wells:* None.

Remarks: Good control except to the southeast. 6° southwest dip off the sycamore Fork dome.

Hermitage Springs dome

Location: 15 W., 0.2 N. *Vertical Closure:* 10− ft. *Trend:* N. 10° E.

Areal Extent: 100 acres. *Wells:* 141.

Remarks: Established largely upon the presence of the Chattanooga shale inlier. Good north dip on the surface, substantiated by subsurface data. Probably fairly strong west dip. Control to the south is poor. Wells 21, 174, 36, 34, 35 appear to be situated some distance down the north flank, probably off structure.

OIL AND GAS DEVELOPMENTS

HISTORICAL

EARLY PERIOD

Like many of the early discoveries in the eastern part of the United States, the first oil in the Upper Cumberland district of Kentucky and Tennessee was the result of generally discouraging attempts to find salt. The early history of the drilling in this general region has been traced briefly by Jillson.[86] In the year 1819, 40 years before Colonel Drake's discovery near Titusville, Pennsylvania, Martin Beatty of Abingdon, Virginia, completed the first oil well in Kentucky. The well was located on the South Fork of Cumberland River, in what is now known as McCreary County, just a few miles north of Scott County, Tennessee. Beatty was drilling for salt and when the well began to flow the dark-colored rock oil at a shallow depth, he quit the venture in disgust.

Munn[87] reported a well on Wolf River in 1820 about one mile above its mouth, near the Clay-Pickett County line. This well furnished sufficient oil to cover the river and, when set on fire, produced a "terrible conflagration." In 1829 a salt prospect well near Burkesville, Cumberland County, Kentucky, began flowing phenomenal amounts of oil from a shallow depth in the Ordovician.[88] This well, commonly referred to as the "Great American Well," was located less than 15 miles north of the Clay County line. The oil flowed into a small tributary into the Cumberland River to a point in Clay County, Tennessee, where reports have it, that the oil scum on the river became ignited by a grass fire and burned back to the mouth of the well. It is quite possible that this well produced the "terrible conflagration" quoted above by Munn. The oil was used for medicinal purposes and was sold in half-pint bottles for 50 cents as "American Oil."[89]

About 1837, shortly after the drilling of the "Great American Well," a hole was dug for salt in Clay County near the head of Sulphur Creek and Killebrew[90] reported that a large flow of oil was obtained.

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[86]Jillson, W. R. The oil and gas resources of Kentucky: Ky. Dep't. of Geology and Forestry, Bull. 1 (Ser. 5), pp. 3-9, 1919.

[87]Munn, M. J. Preliminary report upon the oil and gas developments in Tennessee: Tenn. Geol. Survey, Bull. 2-E, pp. 5-6, 1911.

[88]Jillson, W. R. Op. cit., pp. 5-6.

[89]Jillson, W. R. Op. cit., p. 6.

[90]Killebrew, J. B. Oil region of Tennessee with some account of its other resources and capabilities: Report of the Bureau of Agriculture, Statistics, and Mines, 1877-1888 (State of Tennessee), p. 63, 1878.

Sporadic drilling continued in the Upper Cumberland district until the eve of the Civil War. The records are almost entirely lost. After the war a number of wildcat wells were drilled in Jackson, Clay, Overton, Pickett, and Fentress counties and in the southern tier of counties in Kentucky. Impetus was given this activity by the success of the Drake well in 1859 in Pennsylvania and the discovery of oil in southern Overton County, Tennessee, along Spring Creek in 1866.[91] The few records available suggest that many of the wells were financed by northern capital and most of the tests were located near oil springs.

In 1888 Killebrew[92] discussed the oil springs in the Upper Cumberland district and the following concerning Clay County is of particular interest:

> Near the mouth of Ashburn's Creek, in Clay County, the rocks in the bed of the creek have a decided dip towards the north. They are much fissured, and oil is often made to rise to the surface by stirring the accumulated mud which fills the crevices.
>
> Numerous seeps occur in the margin of the stream for four or five miles above its mouth. The black shale forms the bed of the stream a short distance above its mouth, and appears to be saturated in an unusual degree with petroleum. Sulphur and chalybeate springs abound.
>
> Salt water with some oil was obtained up a hollow a half mile below the mouth of Ashburn's Creek, and one-fourth of a mile from Obey's River. The well was bored 178 feet deep, and about 10,000 bushels of salt were manufactured in the year 1867. Sixty gallons of water made a bushel of salt. The cost of making salt was 7½ cents per bushel, but bacon was then selling at 25 cents per pound, labor $1.50 per day. It could now be made at 3 cents per bushel.
>
> Near the salt well, up a branching hollow, is an oil seep. The calcareous shales which here have a great thickness, are saturated with petroleum. Oil has been found oozing out at several places in the vicinity.
>
> Wolf River enters the Obey's a few miles below Ashburn's Creek, but on the opposite side.
>
> Nearly opposite the mouth of Wolf River, a short distance below, the strata exhibit a beautiful synclinal, the length of which is probably a fourth of a mile. The rocks are grooved with a singular and pleasing regularity, making the bluff appear like the rock mouldings of an immense superstructure. Nearly opposite this synclinal Parsley's Creek comes in from the north. Upon this is an oil spring. On Wolf River, a mile above its mouth, a well was bored 60 years ago for salt water. Tradition tells of a greenish, oily fluid, highly odoriferous, running down the river, which was set on fire, producing a terrible conflagration.
>
> Sulphur creek comes in also from the north, three miles below the mouth of Wolf. Several oil springs occur on this stream, but within the State of

[91]Munn, M. J. Op. cit., pp. 6-8.

[92]Killebrew, J. B. Op. cit., pp. 62-64.

Kentucky. A well was dug near the mouth of Sulphur forty years ago by Mr. Trousdale, and a large flow of oil obtained.

At the mouth of Poor's Branch, which enters Obey's river ten and a half miles above Celina, oil in low water is seen upon the surface. This comes from the Nashville rocks, the black shale appearing thirty-five feet above in the bluff. Fossils abound in the limestone at this place. Indeed, some of the layers appear to be little else than a bed of fossils solidified. They are chiefly the *orthis lynx* and *orthis sinuata*.

A well was dug near this place for domestic purposes, but the water was so impregnated with petroleum as to be unfit for use.

On Mill Creek, below Celina, a well was bored in 1868 on the farm of L. B. Butler. A considerable amount of oil was obtained at this point and shipped, but I was not able to ascertain the precise number of barrels. The oil from this well came from the Nashville or Cincinnati rocks.

I have mentioned the oil spring on Franklin creek in Fentress county. Others are found on the western edge of that county in various places. There is a group of such springs near the mouth of Poplar Grove creek and several on East Fork, besides others reported, which are enough to confirm the existence of petroleum in this county.

In Clay county, on Brimstone creek, which is near the line which separates this county from Jackson, there are several places where the oil exudes from the earth.

On Mill Creek, in Clay county, petroleum oozes out from the Nashville rocks.

DEVELOPMENTS SINCE 1900

Although commercial oil was discovered at relatively shallow depths in the Ordovician at Spurrier in southeastern Pickett County in 1892 and near Riverton in southwestern Fentress County in 1896, activity did not reach beyond the western part of Pickett County (Plate II). Shallow Ordovician discoveries in adjacent parts of Kentucky were responsible for some drilling in Clay County between 1910 and 1920, but the maximum development was to follow.

The first commercial well in Clay County was completed in August, 1923, by A. A. Alexander et al. on the E. D. Marcum (Plate XIII, No. 202) lease (202)* immediately north of Willow Grove in the east-central part of the County. This test, located on a well-defined structure, came in flowing at a depth of 421 feet from a bluish-gray, porous, limestone. The producing zone was definitely in rocks of Trenton age. The well flowed freely under heavy gas pressure and because of insufficient storage about 500 barrels of oil were lost in the waters of Irons Creek.[93] The flush production was reported at 3,000 barrels.

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*Numbers in parentheses refer to well record numbers on Table 1.

[93]Jillson, W. R. New Tennessee oil pool: Pan-Amer. Geologist, vol. 40, p. 197, 1923.

The drilling in of Dafoe & Dafoe's G. H. Lynn No. 1 (176) in November 1924, in Clay County, near the Jackson County line, marked the discovery of the Tinsleys Bottom field, which has produced oil intermittently until the present. The Lynn No. 1 flowed oil at 430 feet, but much of it was lost on the first day before it could be controlled. On the following three days the well flowed 500 barrels per day, which filled the available tankage. The producing zone was 107 feet below the base of the Pencil Cave, probably in the upper part of the Lebanon limestone of the Stones River group. The Lynn No. 2 (177), with an initial daily production of 600 barrels and a flush production of 4,200 barrels, was the largest producer in the area.

The successful exploration at Willow Grove and in Tinsleys Bottom focused the attention of a number of drillers and operators toward the opportunity afforded in areas of possible shallow production in the Upper Cumberland district of Kentucky and Tennessee. More than 300 tests have been drilled since 1923 in Clay County alone. Within the past 15 years the history of oil and gas developments in Clay and adjoining counties has been essentially a story of sporadic drilling with the development of small, shallow pools. The small initial capital required for shallow testing has resulted in numerous wildcat drilling operations with little accurate field work to justify the exploration. Naturally this has been reflected in an unusually high percentage of dry and near-dry holes. During this time, however, commercial production has been found in several parts of the general region. In Clay County the more important productive areas are listed below:

TABLE 5. PRODUCTIVE AREAS IN CLAY COUNTY.

NAME	Discovery Date	Present Status
1. Willow Grove	1923	Abandoned
2. Tinsley Bottom	1924	Abandoned
3. Peterman Bend	1925	Producing
4. Lillydale	1926	Producing
5. Mill Creek	1926	Abandoned
6. Fox Springs	1926	Abandoned
7. Kettle Creek	1927	Abandoned
8. Ashburn Creek	1927	Abandoned
9. Irons Creek	1927	Producing
10. Celina	1928	Producing
11. Mitchell Creek	1929	Abandoned
12. Pine Branch	1937	Producing
13. Goodpasture Bend	1937	Producing
14. Arcott School	1938	Producing
15. Turkey Creek	1938	Producing

TINSLEYS BOTTOM AREA

(PLATE VIII)

Location.—Tinsleys Bottom, covering approximately 2 square miles, lies in a great westward bend, nearly an ox-bow, of Cumberland River on the Clay-Jackson County line, about 10 miles south-southwest of Celina and 2 miles southwest of Butlers Landing. The area lies just west of State Highway 53, which connects Gainesboro and Celina. Although not a part of the main bottom, an area north of the Cumberland along Turkey Creek is included in the present discussion (Plate VIII).

Physiography.—Tinsleys Bottom is an alluviated plain with an average elevation of about 550 feet above sea level. With the exception of drainage gaps, the area is almost completely surrounded by bluffs which reach an elevation of more than 900 feet above sea level. Seven Sisters Bluff projects into the northern part of the bottom and separates Tinsleys Bottom from the alluviated plain just west of Butlers Landing. The drainage on all sides is directly into the Cumberland River. Sink-holes are common.

Stratigraphy.—Alluvium from the Cumberland has masked many bedrock exposures in Tinsleys Bottom. The massive, gray, dense- to coarse-grained limestones, exposed at the foot of the bluff just west of the main bottom during low water stages of the Cumberland, may well represent the upper part of the Cannon limestone. Undeniable evidence for this correlation is not available at present. The oldest rocks exposed in the bottom proper are just north of the Dafoe & Dafoe, G. H. Lynn No. 7 (182). These are gray, impure limestones and represent the lower part of the Catheys limestone. They are certainly older than the Leipers to which they were assigned by Roberts[94] The Catheys, with its usual lithology, is exposed at several places in the bottom, especially north of the schoolhouse, about one-half mile west of State Highway 53. The shaly, fossiliferous Leipers formation overlies the Catheys and occurs near the base of the surrounding hills. The Leipers is about 100 feet thick.

The younger Mississippian formations are restricted to the hills which almost surround the bottom. The Chattanooga shale, 20 feet thick, is well exposed along State Highway 53 just north of the Jackson-Clay County line. The typical Fort Payne forms the upper third of most of the hills in the area.

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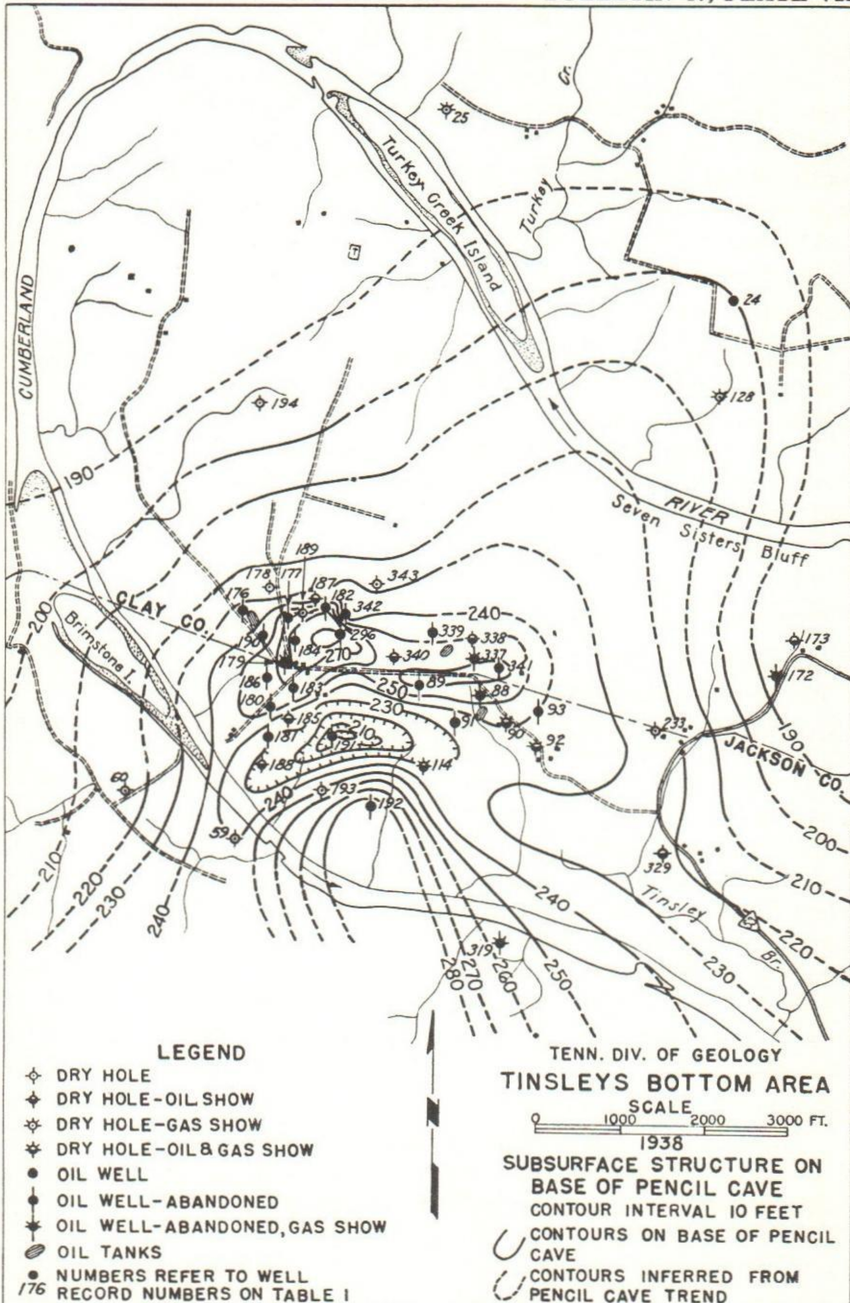
[94]Roberts, J. K. The Tinsleys Bottom oil field, Clay and Jackson counties, Tennessee: Tenn. Geol. Survey, Press Bull., p. 1, March 15, 1926.

TENNESSEE DIVISION OF GEOLOGY BULLETIN 47, PLATE VIII



Sketch map of the Tinsleys Bottom area showing well locations and subsurface structure on the Pencil Cave horizon.

Subsurface Stratigraphy.—The general lithology of the Trenton, Black River, and upper Stones River groups in Tinsleys Bottom is shown in the following sample log:

Shamrock Oil & Gas Company's H. L. Smith No. 1

LOCATION: Tinsleys Bottom. PLATE: VIII. WELL NO.: 296
COMPLETED: May 10, 1937. ELEVATION: 567 ft. TOTAL DEPTH: 522 ft.
PRODUCTION: Oil and salt water. PRODUCING FORMATION: Ridley (?) 484 ft.

Lithology	*From*	*To*	*Thick*
TRENTON GROUP (273 ft.):			
CATHEYS AND CANNON LIMESTONES (214 ft.):			
Limestone; light- to dark-gray, medium-grained	15	40	25
Samples missing	40	55	15
Limestone; medium-gray, medium-grained. Fragment of a tabulate coral and ostracod	55	60	5
Samples missing	60	85	25
Limestone; medium- to dark-gray, dense to medium-grained	85	90	5
Limestone; light-gray to light-brown, medium- to coarse-grained	90	135	40
Limestone; light- to medium-gray, fine- to medium-grained	135	156	21
Limestone; light-gray to brown, medium-grained	156	163	7
Limestone; medium-gray to brown, fine- to medium-grained	163	172	9
Limestone; light-gray to light-brown, medium-grained	172	176	4
Limestone; gray and brown, medium-grained	176	181	5
Limestone; white to light-brown, dense to fine-grained	181	186	5
Limestone; white to light-brown, fine-grained. Chert; light-colored, dense, angular. Shale; light-gray, calcareous	186	190	4
Limestone; light-gray to medium-brown, dense	190	194	4
Limestone; brown and gray, fine-grained	194	202	8
Limestone; gray to brown, fine-grained	202	206	4
Limestone; light-gray to light-brown, medium-grained	206	214	8
HERMITAGE FORMATION (59 ft.):			
Limestone; medium-gray, medium-grained. Shale; gray, siliceous, hard	214	240	26
Limestone; medium-gray, medium- to coarse-grained. Shale; medium- to dark-gray, siliceous, hard	240	268	28
Shale; gray-green, very soft, bentonitic (?), Mud Cave of drillers. Limestone; medium-gray, medium-grained	268	273	5

BLACK RIVER GROUP (78 ft.):			
CARTERS LIMESTONE—upper member (8 ft.):			
Samples missing	273	276	3
Limestone; white to light-gray, fine- to medium-grained. Chert; white to gray, dense to porous	276	281	5
CARTERS LIMESTONE—lower member (70 ft.):			
Limestone; light-gray to brown, dense to fine-grained	281	324	43
Limestone; white to light-brown, dense to fine-grained. Chert; white, dolocastic, angular	324	348	24
Samples missing	348	351	3
STONES RIVER GROUP (171 ft.):			
LEBANON LIMESTONE (129 ft.):			
Limestone; light-gray to brown, fine to medium-grained. Chert; dark-gray, dense, angular	351	405	54
Limestone; light-brown, fine- to medium-grained	405	410	5
Limestone; light-gray to light-brown, fine- to medium-grained	410	445	35
Limestone; gray and brown, fine-grained	445	480	35
RIDLEY LIMESTONE (42 ft.):			
Limestone; medium-gray to brown, medium- to coarse-grained. Shale; dark-gray, nearly black, hard, siliceous. Chert; light-colored, dense, sharp	480	490	10
Limestone; gray and brown, medium-grained	490	522	32

The deepest horizon tested to date in the Tinsleys Bottom area is the upper part of the Knox dolomite group in Dafoe & Dafoe's G. H. Lynn No. 5 (180). The following sample study, from an incomplete set of cuttings from this test, indicates the general lithologic character of the lower Stones River and upper Knox dolomite group in this region:

Dafoe & Dafoe's G. H. Lynn No. 5

LOCATION: Tinsleys Bottom. PLATE: VII. WELL NO.: 180.
COMPLETED: 1926. ELEVATION 540 ft. TOTAL DEPTH: 1319 ft.
PRODUCTION: Oil at three horizons in the Stones River limestones—350, 405, 437 feet.

Lithology	*From*	*To*	*Thick*
BASE OF TRENTON GROUP (driller's log) at 281 ft.			
STONES RIVER GROUP:			
MURFREESBORO LIMESTONE (250 ft.):			
Limestone; dark-gray, dense to fine grained	790	795	5
Samples missing	795	934	139
Limestone; dark-gray and brown, dense to fine-grained	934	975	41
Samples missing	975	1010	35

Limestone; very dark-gray, nearly black, dense to fine-grained	1010	1030	20
Samples missing	1030	1040	10
CANADIAN (?) (279 ft.):			
ZONE B (80 ft.):			
Limestone; light-gray, fine-grained; probably magnesian	1040	1045	5
Samples missing	1045	1065	20
Limestone; light-gray, fine-grained; probably magnesian	1065	1070	5
Samples missing	1070	1120	50
CANADIAN (199 ft.):			
ZONE C_1 (25 ft.):			
Dolomite and magnesian limestone; light-gray and tan, very coarse-grained	1120	1135	15
Same as above with minor amount of soft, dull, green, dolocastic shale	1135	1140	5
Dolomite and magnesian limestone; light-gray and tan, very coarse-grained	1140	1145	5
ZONE C_2 (174 ft.):			
Dolomite; gray, coarse-grained. Chert; white to milky, dense, sharp	1145	1150	5
Samples missing	1150	1179	29
Dolomite; gray, coarse-grained	1179	1184	5
Samples missing	1184	1194	10
Dolomite; very light-gray, fine-grained	1194	1199	5
Samples missing	1199	1202	3
Dolomite; light-gray, fine-grained	1202	1207	5
Samples missing	1207	1212	5
Dolomite; light-gray and tan, fine-grained. Small amount of soft, dull, green shale; a few well-rounded, frosted quartz grains	1212	1217	5
Dolomite; light-gray and tan, fine-grained	1217	1222	5
Dolomite; tan, fine-grained	1222	1227	5
Samples missing	1227	1237	10
Dolomite; brown, fine- to coarse-grained. Chert; dead white, angular, containing perfectly-formed dolomite crystals	1237	1242	5
Dolomite; tan and gray, fine-grained. Chert; white to milky, dense, sharp	1242	1247	5
Samples missing	1247	1252	5
Dolomite; light-gray, fine-grained	1252	1257	5
Samples missing	1257	1262	5
Dolomite; light-gray, fine- to medium-grained	1262	1267	5
Samples missing	1267	1275	8
Dolomite; light-gray and tan, very fine-grained. Chert; white to milky, dense, angular. Sand; quartz, well-rounded to sub-angular	1275	1280	5
Samples missing	1280	1290	10

Dolomite; gray, fine-grained. Chert; light-colored, dense, with many dolomite crystals and some oolitic varieties	1290	1300	10
Dolomite; tan, fine-grained. Chert; as above	1300	1305	5
Samples missing	1305	1309	4
Dolomite; tan, fine-grained. Chert; white to milky, dense, with many dolomite crystals	1309	1312	3
Dolomite; brown, fine- to medium-grained. Chert; same as above	1312	1319	7

The upper part of the Knox dolomite group was also tested in Dafoe & DeGive's J. J. Osgatharp No. 1 (256). An oil show was reported at 1190 feet, probably in the upper 100 feet of the Knox.

Structure.—The paucity of outcrops in Tinsleys Bottom, due largely to masking by alluvium, makes surface structural mapping difficult. However, drilling has outlined a major structural feature of the region, the Bennetts Ferry anticline, which plunges N. 45° E. across Tinsleys Bottom (see page 63). Subsurface data on the base of the Pencil Cave have shown the presence of three small, steep-flanked domes and one closed basin between them on the main Bennett Ferry axis. (See Plate VIII).

The dome just north of the home of G. H. Lynn shows a closure of 20^+ feet on the Pencil Cave. Thus structure has been the most productive in the area. Near the axis of this upwarp, just north of Dafoe & Dafoe's G. H. Lynn No. 7 (182), the Catheys limestone strikes N. 55° E. with a 6° dip to the northwest. The small dome, elongated east-west, lying immediately east of the Lynn dome, shows 10 feet of structural relief on the base of the Pencil Cave. A sharp structural low, which has approximately 30 feet of closure, borders these two domes just south of the Clay-Jackson County line. Subsurface data to date indicate the presence of an upwarp in the southern part of Tinsleys Bottom, although past drilling has not been sufficient to permit accurate definition of the structure. It may prove to be the largest dome in the area.

There are meager data on the structural conditions in the Turkey Creek area, immediately north of Tinsleys Bottom. Here the Chattanooga shale has been removed by erosion and the bed-rock covered by alluvium. The Bennetts Ferry upwarp strikes N. 45° E. through the area. R. W. Stafford's Milton Boles No. 1 (24) appears to be located on this regional structure, although accumulation here may well be in a closed dome.

The discovery and present knowledge of the structural conditions in the Tinsleys Bottom area have been revealed by subsurface data on the Pencil Cave. Elevations on the base of the Chattanooga shale, which almost completely surrounds the area, do not allow precise definition of the structure. The north and northwest flanks are poorly defined on this datum plane. Strong northeast, east, and southeast dips, locally as high as 5°, may be seen in the Chattanooga along State Highway 53. The restored Chattanooga base over the Tinsleys Bottom area would probably reach a maximum of approximately 760 feet above sea level.

Producing Horizons.—Although several oil and gas shows have been encountered in rocks of Trenton age in the Tinsleys Bottom area, the commercially productive horizons are restricted to rocks of the Black River and Stones River groups (Plate XV). Dafoe & Dafoe's G. H. Lynn No. 2 (177), the largest producer in the field, encountered oil in the upper part of the Lebanon limestone at a depth of 429 feet, 104 feet below the base of the Pencil Cave. The greater part of the production has come from the lower half of the Carters and the upper half of the Lebanon limestones (Plate XV). The deepest production obtained to date was in the Shamrock Oil & Gas Company's H. L. Smith No. 1 (296) at a depth of 484 feet in the upper part of the Ridley limestone.

The only producer drilled to date in the Turkey Creek area, immediately north of Tinsleys Bottom, is R. W. Stafford's Milton Boles No. 1 (24), which entered the pay at 450 feet, probably in the lower part of the Carters limestone.

Developments.—Although Dafoe & Dafoe's G. H. Lynn No. 1 (176) has been usually considered as the discovery well in Tinsleys Bottom, records in the files of the Tennessee Division of Geology indicate that production was obtained in this area as early as 1920. In that year C. H. Langdon and others found small production in their Edgar Williams No. 1 (337) at depths of 324 and 383 feet, probably in the Carters limestone. The well pumped about 2 barrels per day.

Intensive developments in Tinsleys Bottom began in 1924. In October of that year Dafoe & Dafoe completed their first well on the G. H. Lynn farm (176) as a small producer. Their No. 2 (177) on the same lease had an initial daily production of 600 barrels and a flush yield of 4,200 barrels. It was the largest producer drilled in the Tinsleys Bottom area. Intensive drilling was carried on during 1925 and 1926 and a pipeline was completed in October 1925. This line connected the 5,000-barrel storage in Tinsleys Bottom with the then existent Tennessee, Kentucky & Northern Railroad at Windle, Tennessee, from which it was shipped by tank car to the Stoll Refining Company at Louisville, Kentucky. The total length of the pipe line was slightly less than 15 miles. The relatively rapid decline in the production made it necessary to dismantle the pipe line in 1928 Production since that time has been moved by trucks.

The maximum developments in the Tinsleys Bottom area were in 1925 and 1926. Since that time the leases have passed through several organizations and the developments and production have been very sporadic. In 1936, after being pumped intermittently for about 10 years, a part of the old production was taken over by the Shamrock Oil & Gas Company. The results of efforts to revive the production were not particularly encouraging. Several of the old wells, some of which were 10 years old, were pumped with indifferent results. A few wells were acidized and responded poorly, although the condition of the holes and the actual technique of acid treatment are not known.

Since 1936 six wells have been completed in the field, but no lasting pay horizons have been found. Three of the more recent wells made small amounts of oil. The largest was 60 barrels per day, but the well was pumped dry after about 500 barrels were produced.

During the summer of 1938 a producing well was drilled, the Milton Boles No. 1 (24), in the Turkey Creek area just north of the main Tinsleys Bottom field. The initial production was 100 barrels per day.

The records in the files of this Division indicate that 42 wells have been drilled in the Tinsleys Bottom district, 23 of which have produced oil. The field at present is temporarily abandoned.

Production.—From the latter part of October 1925, when the pipe line to Windle was completed, to December 31, 1925, 8,694.4 barrels of oil were run from Tinsleys Bottom. Most of this production was from the Lynn No. 2 (177). During January 1926, 2,104 barrels were shipped from Windle, and the production for the year was about 7,000 barrels. From 1927 to 1935 inclusive, accurate figures are not available on the Tinsleys Bottom production. The wells were pumped intermittently and apparently no accurate figures were kept. In 1936 approximately 500 barrels of oil were produced. A slight revival of the old production, along with several new producers, increased the production to 2,005 barrels in 1927. The field was practically abandoned during 1938; probably less than 100 barrels were produced. From July to December 31, 1938, approximately 400 barrels of oil were produced from R. W. Stafford's Milton Boles No. 1 (24) in the Turkey Creek area.

While total production figures as high as 60,000 barrels have been reported on the Tinsleys Bottom area, the writers feel that perhaps one-half of this amount would more nearly represent the true production.

MILL CREEK AREA

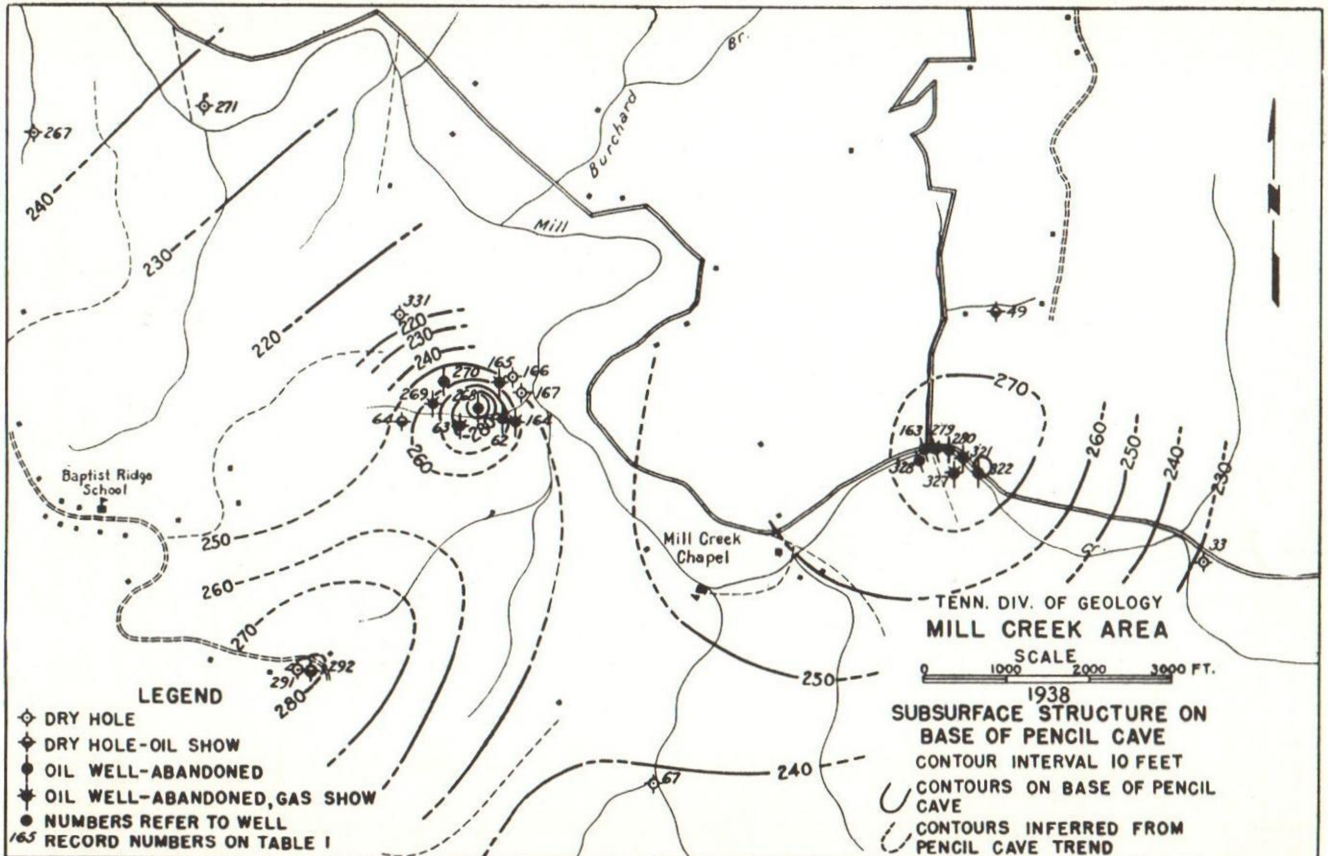
(PLATE IX)

Location.—The Mill Creek area is located in the south-central part of Clay County, centering approximately 4 miles south of Celina and 4 miles east of Butlers Landing. The area is easily accessible by two county roads; one which follows Baptist Ridge and the other along Mill Creek.

Physiography.—The Mill Creek district is a highly dissected part of the Highland Rim with topographic relief of more than 400 feet. The only flat land is along the flood plain of Mill Creek or along the relatively flat-topped Highland Rim. Mill Creek, a tributary of Cumberland River, drains the entire area. Most tributary streams to Mill Creek enter at large angles and have relatively steep gradients.

Stratigraphy.—Along the lower reaches of Mill Creek the usual dark-gray, medium- to coarse-grained, massive limestones of the lower part of the Catheys limestone are exposed. A maximum of about 100 feet is present without revealing the base. The Catheys is overlain by the characteristic blue and gray, argillaceous limestones of the Leipers formation, which is approximately 100 feet thick. Twenty feet of Chattanooga shale follows the Leipers, overlain, in turn, by the Fort Payne formation which caps the higher ridges. Although residual soils, strongly suggestive of the Warsaw formation, have been observed on some of the highest hills, no exposures of the unweathered Warsaw were observed in connection with the present study.

Subsurface Stratigraphy.—No samples are available from the earlier drilling in the Mill Creek area and the character and thicknesses of the unexposed rocks can only be inferred from the subsurface section penetrated in nearby wells. The following sample study of the Major Peeler et al., Lewis Langford No. 1 (171), located about 1 mile east-northeast of the development on the Tidwell dome, shows the general lithology of the lower Trenton, Black River, and upper Stones River groups in this general area:



Sketch map of the Mill Creek area showing well locations and subsurface structure on the Pencil Cave horizon.

Major Peeler et al., Lewis Langford No. 1

LOCATION: 2.3 miles east-northeast of Mill Creek Chapel. PLATE: I. NO.: 171.

COMPLETED: 1937. ELEVATION: 695 ft. TOTAL DEPTH: 800 ft.
PRODUCTION: Oil, estimated 1 barrel per day. PRODUCING FORMATION: Lebanon, 603 ft.

Lithology	*From*	*To*	*Thick*
MAYSVILLE AND TRENTON GROUPS (473 ft.):			
LEIPERS, CATHEYS, CANNON, AND HERMITAGE FORMATIONS (452 ft.):			
Samples missing	0	452	452
TRENTON GROUP (21 ft.):			
HERMITAGE FORMATION (21 ft.):			
Shale; gray, medium-grained, with dark-gray, medium- to coarse-grained limestone	452	469	17
Shale; drab-gray, soft (Mud Cave of drillers)	469	473	4
BLACK RIVER GROUP (92 ft.):			
CARTERS LIMESTONE—upper member (15 ft.):			
Limestone; light-tan to dark-gray, medium- to coarse-grained, with a small amount of tan, angular chert	473	482	9
Limestone; white to tan, dense to medium-grained	482	488	6
CARTERS LIMESTONE—lower member (77 ft.):			
Limestone; white to tan, dense to medium-grained, with light-green, soft, waxy, bentonitic shale (Pencil Cave of drillers)	488	493	5
Limestone; white to tan and light-gray, dense, with light-colored, dense, angular chert	493	510	17
Limestone; white to tan, fine-grained	510	530	20
Limestone; white to light-tan, fine-grained, with imbedded dolomite crystals	530	565	35
STONES RIVER GROUP (235 ft.):			
LEBANON LIMESTONE (135 ft.):			
Limestone; tan, fine-grained, with a small amount of very dark-brown, angular chert	565	575	10
Limestone; tan to gray, fine- to medium-grained	575	580	5
Limestone; tan and brown, fine- to medium-grained, with small amount of dark-gray, dense, angular chert	580	585	5
Limestone; white, tan, and brown, fine- to medium-grained	585	610	25
Limestone; tan and brown, fine- to medium-grained, with dark, dense, angular chert	610	660	50
Limestone; gray to tan, fine- to medium-grained, no chert	660	700	40

RIDLEY LIMESTONE (100 ft.):			
Limestone; tan, fine-grained, with a small amount of white, drusy silica	700	705	5
Limestone; white and tan, fine- to medium-grained	705	730	25
Limestone; white to gray and tan, fine-grained	730	750	20
Limestone; white to gray and tan, fine-grained, with small amount of tan and brown, speckled chert	750	765	15
Limestone; white to gray and tan, fine-grained, with some brown and black, rough, chert	765	770	5
Limestone; white to gray and tan, fine-grained, with a small amount of white, drusy silica	770	775	5
Limestone; gray to tan, fine-grained, with a small amount of dark-brown to nearly black shale	775	800	25

Structure.—In general the Mill Creek area is structurally high and appears to be related to a regional upwarp which begins just south of the town of Gainesboro in Jackson County and trends approximately N. 50° E. into the Mill Creek district (see page 65). Detailed structural studies were carried on in the Mill Creek district by the late J. H. McClurkin, whose Barlow Langford No. 1 (163), on what is here called the Tidwell dome, was the discovery well in this general area. Reconnaissance structural work on the base of the Chattanooga shale and subsurface data on the Pencil Cave horizon shows the presence of four pronounced structural features in the Mill Creek area. These are briefly described below from east to west:

A dome, with a closure of 10-20 feet on the base of the Chattanooga shale, has been mapped 0.6 of a mile northeast of Mill Creek Chapel. Subsequent drilling has demonstrated at least an equal amount of closure on the Pencil Cave horizon. Seven wells have been drilled within the 270-foot closure on the Pencil Cave, all of which were productive. The name Tidwell dome has been assigned to this small structure.

The Tidwell dome is bordered to the west by a gentle, elongated downwarp, the Mill Creek Chapel syncline. This structure shows 10 feet of closure on the Chattanooga and it trends almost north-south, extending from Beech Springs north to a point about 0.7 of a mile north of Mill Creek Chapel.

This syncline separates the Tidwell dome from a small, sharp upwarp, which centers in Oil Hollow, 0.8 of a mile northwest of Mill Creek Chapel. Although surface work indicates closure of only 10 feet, well records show more than twice this amount on the Pencil Cave. There is 75 feet of structural relief on the top of the lower Carters between the Ohio Oil Company's J. W. Pennington No. 1 (268), located near the crest of the Oil Hollow dome, and

Hughes-Rife Syndicate, W. C. Waddel (331), drilled approximately 1,500 feet to the northwest. The major developments on this dome were those of the Ohio Oil Company, 5 of their 6 tests being productive. In all, 10 wells have been drilled on the Oil Hollow upwarp, 7 of which were commercial wells.

Burman and Pierce's Charles Short No. 1 (291) found the Chattanooga shale and the Pencil Cave markers high in their test well located 0.9 of a mile southwest of Mill Creek Chapel and about 0.7 of a mile southeast of Baptist Ridge Church. This structure, here called the Baptist Ridge dome, is not well-defined, but it shows at least 10 feet of closure on the Chattanooga, and probably as much on the Pencil Cave. Two wells, Burman and Pierce's Charles Short No. 1 (291) and No. 2 (292), have been drilled on this structure. The No. 2 had a show of oil at 744 feet, probably near the Lebanon-Carters contact.

A small dome occurs near the mouth of Pendleton Hollow, 1.8 miles northwest of Mill Creek Chapel. There is 10-20 feet of closure on the base of the black shale.

Producing Horizons.—All of the production in the Mill Creek area has come from rocks ranging in depth from 35 to 434 feet below the Pencil Cave (Plate XV). Most of the production has been within a zone 37 to 130 feet below the Pencil Cave, in the lower half of the Carters and the upper part of the Lebanon limestones. The upper part of the Murfreesboro limestone has been productive in this district in the Ohio Oil Company's J. W. Pennington No. 3 (270), which flowed oil at 953-962 feet. Although samples are not available from this well, this pay is undoubtedly in the Murfreesboro limestone, probably as much as 50 feet below the top of that formation. This is the only persistent pay encountered to date in the Murfreesboro limestone in the Upper Cumberland district. This well was drilled 1,350 feet, and after finding the upper part of the Knox dolomite dry, it was plugged back to 1,100 feet and the 953-962 foot pay was pumped.

Developments.—Although Killebrew[95] reported production as early as 1868 on the L. B. Butler farm on Mill Creek, concerted developments in this area were begun with J. H. McClurkin's Barlow Langford No. 1 (163), which, on July 23, 1926, flowed 104 barrels of oil from the upper part of the Lebanon limestone at 421 feet. The well was located on a sharp upwarp mapped independently by

[95]Killebrew, J. B. Oil region of Tennessee with some account of its other resources and capabilities: Report of the Bureau of Agriculture, Statistics, and Mines, 1877-1878 (State of Tennessee), p. 64, 1878.

the lessee. When deepened to 450 feet another pay was found. A year later the well was flowing 1½ barrels per day.

After the discovery of oil on the Tidwell dome, the following two years witnessed the maximum developments along Mill Creek. Late in 1926 production was found about 1 mile due east of the discovery well on the Oil Hollow dome. The first well, the Ohio Oil Company's Lem Cunningham No. 1 (62), encountered production at 391 feet in the Carters limestone. Most of the developments in the Mill Creek district have centered around these two small domes. The Tidwell structure was developed by individual operators, while the Oil Hollow production was largely controlled by the Ohio Oil Company.

In 1927 the Paragon Development Company laid approximately 26,000 feet of 2-inch pipe-line from their Peterman Bend line into the Mill Creek area. This line has since been removed.

Production.—Based upon the very meager data available, the total production for the Mill Creek area is estimated at 25,000 barrels. No wells are being pumped in the district at present.

ARCOTT SCHOOL AREA

(PLATE I. WELLS NO. 2, 27, 37, 198, 298)

Location.—The Arcott School field is located on the west side of Cumberland River, 3.5 miles southwest of the Celina bridge and 2.5 miles north of Butlers Landing.

Physiography.—The present productive area is located at the south edge of a dissected part of the Highland Rim upland, which reaches an elevation of approximately 800 feet. The elevations of wells drilled to date range between 548 and 565 feet above sea level. The drainage is to the south, directly into Cumberland River.

Stratigraphy.—Most of the area is covered by the alluvium of Cumberland River and its tributaries. The Chattanooga shale and the overlying Fort Payne formation outcrop in the hills to the north. The Chattanooga rests unconformably upon the Leipers formation which is here about 100 feet thick and displays its characteristic lithology. The underlying Catheys formation, in which most of the wells start, is well exposed along the creek which drains the immediate area.

Subsurface Stratigraphy.—The general character of the strata not exposed in the Arcott School area is indicated in the following driller's log:

W. P. Clements et al., O. N. Cherry No. 1

LOCATION: Arcott School field. PLATE: I. WELL NO.: 37.
COMPLETED: April, 1938. ELEVATION: 565 ft. TOTAL DEPTH: 663 ft.
PRODUCTION: Oil at 452, 663 ft. AUTHORITY: Grover Evans, contractor.

Lithology	*From*	*To*	*Thick*
TRENTON GROUP (360 ft.):*			
CATHEYS AND CANNON LIMESTONE (300 ft.):			
Limestone; blue, hard	52	85	23
Water at 52 ft.; gas at 70-80 ft.			
Limestone; gray, hard	85	140	55
Gas at 140 ft.			
Limestone; brown, hard	140	180	40
Limestone; blue, hard	180	190	10
Limestone; gray, hard	190	195	5
Limestone; brown, hard	195	200	5
Limestone; gray, hard	200	205	5
Limestone; brown, hard	205	220	15
Limestone; gray, hard	220	225	5
Limestone; brown, hard	225	250	25
Limestone; gray	250	260	10
Water at 254 ft.			
Limestone; brown	260	270	10
Limestone; gray	270	290	20
Limestone; sandy	290	300	10
HERMITAGE FORMATION (60 ft.):			
Limestone; gray	300	340	40
Limestone; blue	340	355	15
Limestone; sandy	355	360	5
BLACK RIVER GROUP (90 ft.):			
CARTERS LIMESTONE—upper member (10 ft.):			
Limestone; blue	360	370	10
CARTERS LIMESTONE—lower member (80 ft.):			
Pencil Cave; green shale	370	375	5
Limestone; blue	375	385	10
Limestone; blue and gray	385	390	5
Limestone; gray	390	395	5
Limestone; brown	395	415	20
Limestone; gray	415	450	35
STONES RIVER GROUP (213 ft.):			
LEBANON LIMESTONE (125 ft.):			
Limestone; dark brown, coarse	450	460	10
Oil at 452 ft.; first pay.			
Limestone; sandy	460	465	5
Limestone; dark-brown, coarse	465	480	15
Limestone; light-brown	480	490	10
Limestone; brown, flaky	490	495	5
Limestone; light-brown, sandy, fine	495	500	5
Limestone; gray and brown, mixed	500	525	25

Limestone; dark-brown, coarse	525	545	20
Limestone; brown, coarse	545	571	26
Oil show at 545-550 ft.			
Limestone; dark-brown, fine	571	575	4
RIDLEY LIMESTONE (88 ft.):			
Limestone; gray and brown, mixed	575	590	15
Limestone; light-brown	590	600	10
Limestone; brown, fine	600	650	50
Gas at 615 ft.; oil show at 650 ft.			
Limestone; brown, sandy	650	655	5
Limestone; dark-brown, flaky	655	663	8
Oil at 650-663 ft.; second pay.			

*NOTE: Formational determinations below 180 feet made by microscopic examination of well samples.

Structure.—The production at Arcott School is located on the northwestern flank of the Bennetts Ferry anticline. The dip to the northwest off this regional upwarp is interrupted by a small dome which centers about 0.3 of a mile south of Arcott School (South Arcott School dome). Here the Chattanooga black shale has been removed by erosion, but well-defined dips in Catheys limestone indicate the presence of a reversal and it was upon the presence of these dips that the first test well, the O. N. Cherry No. 1 (37), was drilled. The dome was later substantiated by drilling. On the south and east the dips are not pronounced, but on the north and west flanks the dips steepen considerably and to the northwest strong dip is present for two miles. Extrapolations from nearby Chattanooga outcrops and the Chattanooga-Pencil Cave interval indicates that the base of the black shale restored over the O. N. Cherry No. 1 (37) would approximate 740 feet above sea level. In the hill just north of the area the base of the Chattanooga has a sea level elevation of 714 feet. indicating a closure on the black shale of approximately 25 feet. The strong northwest dip is well shown by 57 feet of structural relief on the base of the Pencil Cave between the Victor Oil Company's McCoglan Brothers No. 1 (198) and A. G. Greenup et al., Arcott School No. 1 (2).

Producing Horizons.—In the three producers the pays are from 84 to 105 feet below the base of the Pencil Cave (Plate XV.) A sample study of the O. N. Cherry No. 1 (37), which flowed oil at 452 feet, indicates the producing horizon is in the upper part of the Lebanon limestone of the Stones River group. Lithologically, the pay is a gray to tan, dense to fine-grained limestone, with minor amounts of gray, calcareous shale and medium- to dark-gray, dense, translucent chert. This well was later drilled to 663 feet, where small production was found in the Ridley limestone. The producing horizons in the W. P. Clements et al., Stone Smith No. 1 (298) and Lester Brown No. 1 (27) are 105 and 97 feet below the Pencil Cave respectively; the Smith No. 1 was later deepened to 601 feet without finding deeper production. The deepest horizon tested to date in the Arcott School area is in the Victor Oil Company's McCoglan Brothers No. 1 (198), which was abandoned in the upper part of the Murfreesboro limestone at 704 feet.

Development.—Oil was discovered in the Arcott School area by W. P. Clements et al., O. N. Cherry No. 1 (37) in April 1938. The well came in flowing approximately 50 barrels per day at a depth of 452 feet. To date 5 wells have been drilled, 3 of which are producing.

Production.—Approximately 4,000 barrels of oil were produced in the Arcott School field between April and December 31, 1938. Three wells were pumped intermittently during this time.

CELINA AREA

PLATE I, WELLS NO. 84, 85, 156, 157, 158, 160)

Location.—The Celina area is located about one mile north of the town of Celina and at the confluence of Obey and Cumberland rivers.

Physiography.—Wells drilled to date have been located on or near the flood plains of Obey and Cumberland rivers. A narrow, sharp ridge, which reaches an elevation of about 950 feet above sea level, separates the two streams and rises some 400 feet above the general level of the flood plains.

Stratigraphy.—With the exception of the ridge between the rivers, alluvium covers the entire area. The ridge is capped with about 200 feet of cherty limestones and shales of the Fort Payne formation, which is underlain by 20 feet of Chattanooga shale. The underlying Leipers formation shows its usual lithologic development and is about 100 feet thick. It is well exposed in both the Cumberland and Obey rivers bluffs. The oldest rocks exposed in the immediate area are the limestones of the Catheys formation, which may be seen along the lower part of the bluffs. The flood plains of the Obey and Cumberland have been developed upon this limestone.

Subsurface Stratigraphy.—The general character of the unexposed rocks in the Celina area is well shown by the following sample study of the Donaldson Heirs No. 1 (85). Since this is a most complete sample set, penetrating most of the Trenton and the entire Black River and Stones River sections, it has been used in this report as a key well. For that reason, descriptions of the insoluble residues, used in subsurface correlations, are included.

Jesse Ashby et al., Donaldson Heirs No. 1

LOCATION: Celina area. PLATE: I. NO.: 85.
COMPLETED: 1938. ELEVATION: 530 ft. TOTAL DEPTH: 1456 ft.
PRODUCTION: Dry. Gas shows in the Trenton.

Lithology	*From*	*To*	*Thick*
TRENTON GROUP (336 ft.):			
CATHEYS LIMESTONE (70 ft.):			
Samples missing	0	10	10
Limestone; medium-gray, medium-grained, with some gray and brown calcareous shale. *Insoluble residue:* Shale; medium-brown, porous, with a small amount of translucent, subangular quartz	10	16	6
Limestone; white to medium-gray, medium-grained. *Insoluble residue:* Shale; medium-brown, porous; quartz; translucent, subangular; chert; dense, milky, angular	16	46	30
Limestone; medium-gray, medium-grained. *Insoluble residue:* shale; medium-brown, soft, porous; quartz; translucent, subangular, with a small amount of white, angular chert	46	70	30
CANNON LIMESTONE (215 ft.):			
Limestone; medium-gray and brown, medium-grained. *Insoluble residue:* shale; gray, porous, soft; chert; light-colored to brown, dense, angular	70	82	12
Limestone; medium-gray to brown, medium- to coarse-grained. *Insoluble residue:* shale; brown, porous	82	88	6
Limestone; white to gray and brown, medium- to coarse-grained. *Insoluble residue:* quartz; translucent, sharp	88	100	12
Limestone; gray and brown, medium- to coarse-grained. *Insoluble residue:* shale; brown, soft, porous; silica; brown, porous, angular	100	112	12
Limestone; white to brown and gray, medium-grained. *Insoluble residue:* shale; brown and gray, porous	112	118	6
Limestone; brown and gray, medium-grained, with a considerable amount of gray, calcareous shale. *Insoluble residue:* shale; brown and gray, soft, porous	118	124	6

Lithology	From	To	Thick
Limestone; white to gray and tan, medium-grained. *Insoluble residue:* shale; brown and gray, porous	124	154	30
Limestone; brownish-gray, medium-grained. *Insoluble residue:* shale; medium-brown and gray, porous; silica; white, angular	154	161	7
Limestone; brownish-gray, medium-grained, with many ostracods. *Insoluble residue:* shale; brown; chert; brown, dense, angular	161	182	21
Limestone; white to gray and brown, medium-grained. *Insoluble residue:* shale; brown	182	196	14
Limestone; gray and brown, medium- to coarse-grained. *Insoluble residue:* shale; gray and brown	196	203	7
Limestone; white to gray and brown, medium-grained. *Insoluble residue:* shale; brown and gray	203	285	82
HERMITAGE FORMATION (51 ft.):			
Limestone; gray, coarse-grained. *Insoluble residue:* shale; gray; silica; white, porous	285	294	9
Limestone; gray to dark-gray, medium- to coarse-grained, with gray, calcareous shale. *Insoluble residue:* shale; gray	294	308	14
Limestone; dark-gray, medium-grained, shaly, with lighter-gray, calareous shale. *Insoluble residue:* shale; gray (more than 50% of the original)	308	329	21
Limestone; gray to brown, medium- to coarse-grained, with gray, calcareous shale. *Insoluble residue:* shale; gray and brown, soft, bentonitic (?) (Mud Cave of drillers); chert; white to brown, dense, sharp	329	336	7
BLACK RIVER GROUP (93 ft.):			
CARTERS LIMESTONE—upper member (16 ft.):			
Limestone; white to light-brown, medium- to coarse-grained, with gray, calcareous shale, and a small amount of white to dark-brown, dense, angular chert. *Insoluble residue:* shale; gray to brown, soft; chert; white to dark-brown, dense, angular	336	343	7
Limestone; gray to brown, medium- to coarse-grained. *Insoluble residue:* shale; gray to brown, porous to dense, angular; silica, white, lacy	343	352	9

Lithology	*From*	*To*	*Thick*
CARTERS LIMESTONE—lower member (77 ft.):			
Limestone; gray to brown, medium- to coarse-grained, with green to greenish-gray, soft, waxy, biotitic shale (Pencil Cave of drillers). *Insoluble residue:* shale; green, soft, dull, with biotite flakes; chert; tan, dense, angular	352	355	3
Limestone; tan to white and gray, medium- to coarse-grained. *Insoluble residue:* shale; white to gray; chert; tan, angular	355	381	26
Limestone; white to tan, dense to medium-grained. *Insoluble residue:* shale; tan, porous	381	399	18
Limestone; white to tan, dense to medium-grained. *Insoluble residue:* chert; white and tan, generally dolocastic, rough	399	429	30
STONES RIVER GROUP (658 ft.):			
LEBANON LIMESTONE (135 ft.):			
Limestone; gray to tan, medium- to coarse-grained. *Insoluble residue:* chert; gray to dark-brown, dense, smooth, angular; shale; brown, soft	429	447	18
Limestone; gray to tan, medium-grained. *Insoluble residue:* shale; brown, porous; chert; dark-brown, finely dolocastic	447	465	18
Limestone; brown and gray, medium- to coarse-grained. *Insoluble residue:* chert; brown, finely dolocastic, with some white, coarsely dolocastic chert	465	471	6
Limestone; gray to brown, medium- to coarse-grained. *Insoluble residue:* shale; brown and gray, soft, porous	471	483	12
Limestone; gray to brown, medium- to coarse-grained. *Insoluble residue:* shale; brown and gray, porous; chert; tan to brown, dense to finely dolocastic	483	519	36
Limestone; medium-gray to brown, medium- to coarse-grained. *Insoluble residue:* shale; tan and gray, porous	519	564	45
RIDLEY LIMESTONE (127 ft.):			
Limestone; white to brownish-gray, dense to medium-grained. *Insoluble residue:* silica; white to dark-gray and brown, porous; chert; brown, dense, angular; shale; tan to brown, porous	564	598	34
Limestone; light-gray to brown, dense. *Insoluble residue:* chert; gray to brown, with small rounded (oolitic?) specks of darker colors; shale; tan, porous	598	604	6

Lithology	*From*	*To*	*Thick*
Limestone; light-gray to tan, dense. *Insoluble residue:* shale; gray to tan and brown, soft, porous	604	609	5
Limestone; light-gray to tan and brown, dense to medium-grained. *Insoluble residue:* silica; white to dark-gray and brown; chert; white to brown, dense, sharp; shale; gray and tan	609	635	26
Limestone; gray and tan, dense to medium-grained. *Insoluble residue:* shale; brown, porous, siliceous	635	691	56
PIERCE LIMESTONE (16 ft.):			
Limestone; drab-gray to brown, dense to medium-grained. *Insoluble residue:* shale; light-gray, soft, porous	691	707	16
MURFREESBORO LIMESTONE (380 ft.):			
Limestone; tan and brown, dense. *Insoluble residue:* shale; dark-gray, porous; chert; dark-brown to black, angular, vitreous	707	712	5
Limestone; dark-gray to tan and brown, dense. *Insoluble residue:* shale; light-gray, soft, porous	712	742	30
Limestone; drab-brown, dense. *Insoluble residue:* shale, brown, porous, siliceous	742	830	88
Limestone; gray to drab-brown, dense to fine-grained. *Insoluble residue:* shale; light-gray, flaky, porous	830	848	18
Limestone; dark-gray, dense. *Insoluble residue:* shale; tan, siliceous	848	874	26
Limestone; brown and gray, dense. *Insoluble residue:* shale; tan and brown, siliceous	874	890	16
Limestone; brown and light-gray, dense. *Insoluble residue:* shale; tan, siliceous	890	930	40
Limestone; gray and brown, dense to fine-grained. *Insoluble residue:* shale; tan and brown, siliceous	930	935	5
Limestone; brown, medium-grained. *Insoluble residue:* silica; tan to dark-gray, porous; shale; tan, soft, porous	935	960	25
Limestone; gray and brown, medium- to coarse-grained. *Insoluble residue:* silica; light-gray, lacy	960	1087	117
CANADIAN (?) (86 ft.):			
ZONE B (86 ft.):			
Limestone; light-gray to brown, dense, magnesian (?). *Insoluble residue:* shale; grayish-green, hard, dense; shale; light gray, porous; silica; light-colored, soft, porous	1087	1095	8

Lithology	*From*	*To*	*Thick*
Limestone; light-gray to light-brown; dense. *Insoluble residue:* silica; light-colored, soft, porous; shale; gray, soft; shale; tan and brown, soft	1095	1110	15
Limestone; light-brown, dense. *Insoluble residue:* silica; white, soft, shale; gray, soft, waxy	1110	1131	21
Limestone; light-brown, very dense. *Insoluble residue:* shale; gray, soft; shale; tan and brown, very porous; silica; light-gray, porous, lacy	1131	1138	7
Limestone; light-tan to brown, dense to medium-grained. *Insoluble residue:* silica; white, soft; shale; light-gray, porous, soft	1138	1145	7
Limestone; light-gray to light-tan, dense to fine- and medium-grained, magnesian. *Insoluble residue:* silica; light-gray, porous	1145	1154	9
Limestone; light-gray to brown, medium-grained, with gray calcareous shale. *Insoluble residue:* shale; dull-green, soft	1154	1166	12
Shale; gray, calcareous with grey and brown limestone. *Insoluble residue:* shale, gray, slightly dolocastic; silica; light-colored, porous	1166	1173	7
CANADIAN (283 ft.):			
ZONE C_1 (79 ft.):			
Dolomite; white and light-gray, coarse-grained. *Insoluble residue:* shale; light-green, compact; silica; light-gray, dolocastic	1173	1190	17
Dolomite; light-tan, coarse-grained. *Insoluble residue:* shale; dark-green, dull, compact	1190	1194	4
Dolomite; light-tan to brownish, coarse-grained. *Insoluble residue:* silica; light-colored, dolocastic	1194	1200	6
Dolomite; light-tan, coarse-grained. *Insoluble residue:* shale; dull-green, soft	1200	1210	10
Dolomite; light-tan, brown, and dark-gray. *Insoluble residue:* silica; light-colored, dolocastic; shale; greenish-gray, soft, compact	1210	1217	7
Dolomite; light-tan, coarse-grained. *Insoluble residue:* shale; greenish-gray, soft	1217	1242	25
Dolomite; light-tan and light-gray, coarse-grained. *Insoluble residue:* shale; green, dull, soft; silica; light-gray to white, soft	1242	1252	10
ZONE C_2 (104 ft.):			
Dolomite; cream to steel-gray, fine- to coarse-grained, with some white, dense, sharp chert. *Insoluble residue:* silica; light-colored, dolocastic; chert; white and tan, dense, sharp	1252	1288	36

Lithology	*From*	*To*	*Thick*
Dolomite; light-tan, coarse-grained. *Insoluble residue:* silica; light-colored, dolocastic; shale; dark-gray to green, dull, compact	1288	1309	21
Dolomite; tan, coarse-grained. *Insoluble residue:* silica; gray, dolocastic; shale; green, soft; chert; white, smooth, sharp, dense	1309	1332	23
Dolomite; light-tan, coarse-grained. *Insoluble residue:* chert; white, dense, sharp; quartz sand; well-rounded, pitted, frosted	1332	1337	5
Dolomite; tan, fine-grained. *Insoluble residue:* shale; dull-green, soft; quartz sand; subangular to well-rounded; chert; white, dense	1337	1347	10
Dolomite; cream-colored, fine- to medium-grained. *Insoluble residue:* silica; white, porous; shale; greenish-gray, dolocastic	1347	1354	7
Dolomite; light-tan, coarse-grained. *Insoluble residue:* chert; dense, light-colored, sharp; shale; greenish-gray, dolocastic	1354	1360	6
Dolomite; cream-colored, coarse-grained. *Insoluble residue:* shale; greenish-gray, soft; chert; white, dull, dolocastic; quartz sand; angular to rounded, pitted, and frosted	1360	1380	20
Dolomite; cream-colored to light-tan, coarse-grained. *Insoluble residue:* chert; white to tan, generally dense, smooth, sharp, a few pieces oolitic; shale; green, soft	1380	1399	19
Dolomite; tan to cream and brown, coarse-grained. *Insoluble residue:* chert; white to tan, oolitic, smooth, dense, angular; shale; greenish-gray, soft, somewhat dolocastic; quartz sand; sharp to rounded, with pitted and frosted grains	1399	1433	34
Dolomite; brown, coarse-grained. *Insoluble residue:* chert; white, oolitic, somewhat dolocastic	1433	1445	12
Dolomite; brown to light-tan, coarse-grained. *Insoluble residue:* chert; white to tan, some pieces banded, generally oolitic, with a few pieces showing clear quartz grains	1445	1456	11

Structure.—The salient structural feature in the Celina area is a pronounced dome, the Kyle Point dome, which is well shown in the bluffs along Cumberland and Obey rivers, immediately north of town. Strong west dip of 5° to 7° may be observed in the Obey River bluffs facing the town of Celina. Dips as high as 4° are present to the south in the bluff and closure in that direction is evidenced by exposures of the Chattanooga shale at sea level elevations of 20 to 50 feet lower than those on the point between the rivers. In general the east and north dips are gentle. The apex of the Kyle Point dome lies just across Obey River in the bluff immediately north of town. From this point the anticline plunges gently to the north, where it appears to become a part of the Celina arch (pp. 63-64). To the south the Kyle Point dome is bordered by the Celina syncline, a broad, gentle downwarp with more than 20 feet of closure. The town of Celina is located near the center of this structural basin.

Producing Horizons.—Hughes-Rife Syndicate, Kyle Brothers No. 2 (157) is reported to have produced a small amount of oil from a depth of 645 feet, 158 feet below the Pencil Cave; this production was probably in the Lebanon limestone. J. H. Overstreet et al., Kyle and Vaughn No. 1 (160) is now producing from the middle part of the Cannon limestone at a depth of 240-242 feet. The deepest well in the Celina area, Jesse Ashby et al., Donaldson Heirs No. 1 (85) encountered 5 gas shows in the Trenton section between 205 and 305 feet, but there was no commercial production.

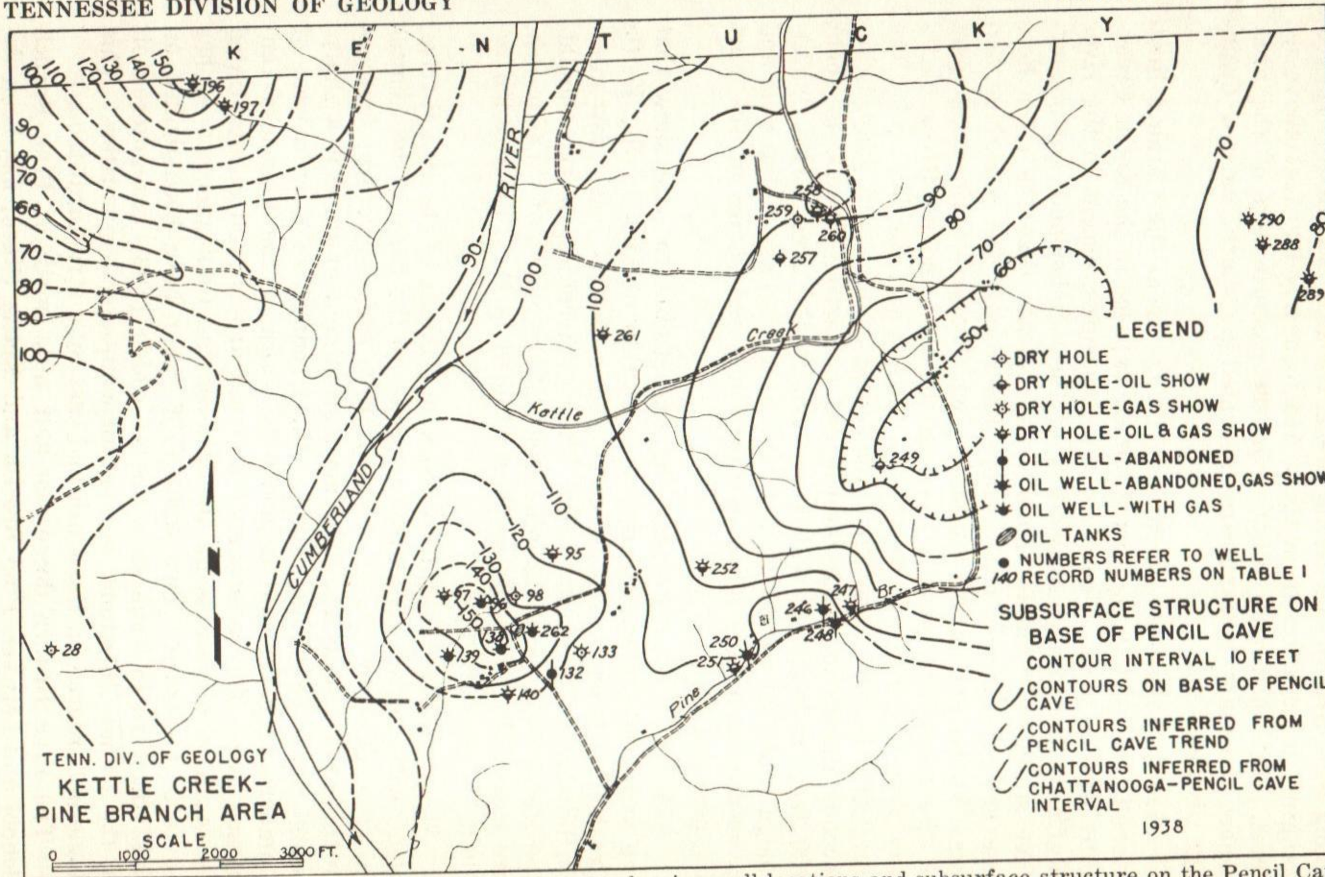
Developments.—Records in the files of this Division show that a small amount of oil was produced in 1928 from the Hughes-Rife Syndicate, Kyle Brothers No. 2 (157). In December 1938, J. H. Overstreet and others completed their Kyle and Vaughn No. 1 (160) as a 70-barrel producer from the Cannon limestone at 240-242 feet. This well has attracted considerable attention and since the writing of the major portion of this report two additional producers have been drilled. The production is from the Trenton limestones at depths of less than 250 feet.

Production.—No figures are available on the small production from this area prior to December 1938. From December 16, 1938, to January 1, 1939, the Kyle and Vaughn No. 1 (160) produced 285 barrels of oil.

KETTLE CREEK-PINE BRANCH AREA

(PLATE X)

Location.—The area here considered as the Kettle Creek-Pine Branch district includes approximately 5 square miles and lies between the mouth of Pine Branch, two miles north of Celina, and the Kentucky line. Most of the developments have been east of Cumberland River although in the present report the M. C. McCauley wells (196, 197) and John Kerzan's Rebecca Brown No. 1 (28) west of the Cumberland are included. The eastern boundary is the headwaters of Pine Branch.



Sketch map of the Kettle Creek-Pine Branch area showing well locations and subsurface structure on the Pencil Cave horizon.

Physiography.—Although most of the drilling to date has been along Pine Branch and Kettle Creek, the area is relatively rugged, ranging in elevation from about 515 to nearly 900 feet above sea level. The maximum relief is in the eastern part of the area, where the many streams are separated by sharp, narrow drainage divides.

Stratigraphy.—Rocks ranging in age from the Catheys limestone to the Fort Payne formation are exposed in the Kettle Creek-Pine Branch area. There are few exposures, except in the river bluffs, in the immediate vicinity of the Cumberland, but subsurface studies of samples from wells indicate that the river here has not cut through the Catheys limestone. The dark-blue and gray, knotty and earthy limestones, which make up the upper part of the formation, may be seen in the Cumberland River bluffs and along the lower parts of Pine Branch and Kettle Creek. The overlying Leipers formation, consisting of blue and gray, argillaceous limestones with interbedded calcareous shales, is about 100 feet thick and is widely exposed in the area. The Chattanooga shale, 20 feet thick, outcrops near the base of the hills and is succeeded by the siliceous limestones and shales of the Fort Payne formation.

Subsurface Stratigraphy.—Sample studies to date show that the same subsurface stratigraphic section obtains in the Kettle Creek-Pine Branch area as in the Celina district just a few miles to the south. The sample descriptions, therefore, on the Donaldson Heirs No. 1 (85), 2.5 miles south of the mouth of Pine Branch, are essentially the same as those studied in the Pine Branch region.

Structure.—Structural contours on the base of the Pencil Cave, along with surface structural mapping on the base of the Chattanooga shale, show the presence of three main structural features in this area (Plate X). The most prominent of these is a sharp, round dome (McCauley dome), three-fourths of a mile west of Cumberland River and immediately south of the Kentucky-Tennessee line. The presence of this upwarp is well substantiated by sea level elevations on the base of the Chattanooga. It has 50 feet of closure. Two wells (196, 197) have been drilled on this structure in Tennessee, one of which (196) encountered oil in the Ridley limestone, but not in commercial quantities. This dome is bordered on the south and east by a structural trough.

The Pine Branch dome, one-half mile north of Pine Branch School and between Pine Branch and Kettle Creek, has been defined by dips in the Ordovician limestones and later subsurface data. The structure has a closure of 30+ feet. Drilling has shown that the dips to the southeast are more pronounced than those to the northwest. The Pine Branch dome is separated from the one described above by a sharp structural saddle.

One and one-fourth miles northeast of the Pine Branch dome is a well-defined, elliptical, structural basin with a closure of about 20 feet. The southwest flanks of this structure are steep and the strike of the axis is approximately N. 40° E.

There is probably a small dome about 1,000 feet southeast of the home of J. H. Overstreet. The presense of this structure has been based upon J. C. Carpenter et al., J. C. Overstreet No. 1 (258), which was high on the base of the Pencil Cave.

Producing Horizons.—Two general zones have been found productive in this area, the lower half of the Trenton and the limestones of the Black River and Stones River groups (Plate XV). The Trenton has produced oil in J. C. Overstreet and Son's Sam Nevins No. 1 (246) at a depth of 340 feet, probably in the Cannon limestone. Small production was obtained from the lower Cannon in J. C. Carpenter's J. C. Overstreet No. 1 (258) and in J. C. Overstreet's own No. 1 (260).

The most productive horizons to date in this area have been in the lower part of the Carters and in the Lebanon limestones. Overstreet and Miller's two most productive wells, J. H. Overstreet No. 1 (262) and the Cordell Hull No. 1 (138), found their best pays in this zone, although the latter was later deepened to 631 feet and found production in the underlying Ridley limestone. Caillouette and Mannion's M. C. McCauley No. 1 (196) also found oil at 777 feet in the Ridley limestone, but the pay was not commercially important. If the general reports that the Powell Oil Company's Arch Short No. 3 (288) found production at 1,333 feet, this horizon is the deepest production to date in this district. No log or samples are available on this well, but the depth below the Chattanooga shale would almost certainly place this pay in the upper part of the Knox dolomite group.

Developments.—Although not a part of the Kettle Creek-Pine Branch area proper, the production on the Arch Short lease in 1924 marks the first developments in this general area. Although oil had been discovered a number of years before along Kettle Creek in Monroe County, Kentucky, it was not until 1928 that production was extended south into the lower part of Kettle Creek in Clay County, Tennessee. In that year J. C. Carpenter's J. C. Overstreet No. 1 (258) discovered small amounts of oil in the Trenton limestones at relatively shallow depths. From that date until August 1937, developments were sporadic and generally not encouraging in this area. In August 1937, Overstreet and Miller's Cordell Hull No. 1 (138) found an oil pay at 481 feet in the lower part of the Carters limestone. Approximately 50 barrels per day were pumped from this horizon for 2 weeks. When deepened to 516 feet, the well flowed an initial of 600 barrels per day, but the production soon leveled off at 120 barrels. Later drilling found another pay at 631 feet in the Ridley limestone. Two offset wells had a combined production of about 100 barrels per day. In January 1938, a 200-barrel producer was completed on the adjoining lease. All of these wells were located on the Pine Branch dome. Other attempts to find production in this area have not been particularly encouraging and the production has declined steadily during the past year.

The files of this Division show that 27 wells have been drilled in the Pine Branch district, 10 of which have produced. or are producing, oil in commercial quantities.

Production.—No figures are available on the older production in the Kettle Creek-Pine Branch area, but it is estimated at less than 2,000 barrels. Three wells on the Pine Branch dome produced 6,993 barrels of oil in 1937 and approximately 12,000 barrels were produced from 4 wells in the same area in 1938.

PETERMAN BEND AREA

(PLATE XI)

Location.—Peterman Bend is a southward swing, almost an ox-bow, in Obey River about one mile southeast of Celina. The area within the boot-shaped bend is bordered on the north by State Highway 53, but in the present report a small part of the surrounding area on all sides is included. The district covers 4 square miles.

Physiography.—Peterman Bend proper is an alluviated area, relatively flat, with elevations ranging from about 550 to 650 feet above sea level. With the exception of a narrow, deep valley cut by the Obey, the area is almost entirely surrounded by hills, some of which reach an elevation of over 1,000 feet. Drainage on all sides is directly into Obey River.

Stratigraphy.—Alluvium from the Obey River covers most of the area within the bend, but subsurface studies and isolated outcrops show the bed-rock to be the upper part of the Catheys

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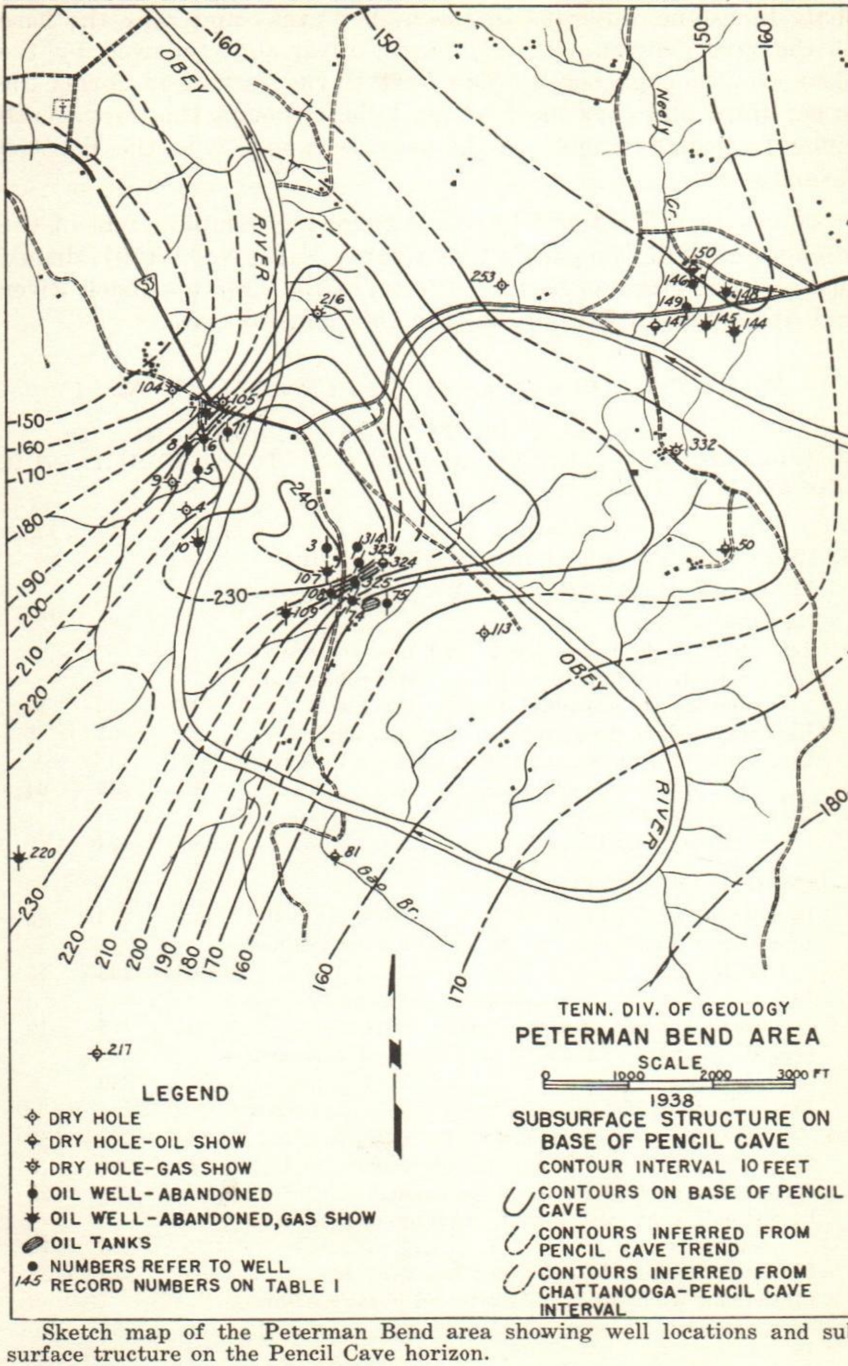


Sketch map of the Peterman Bend area showing well locations and subsurface tructure on the Pencil Cave horizon.

limestone. The Leipers formation, with its typical bluish-gray shaly limestone, outcrops in the higher areas and near the base of the river bluffs. It is, in turn, invariably followed by the black Chattanooga shale. The Fort Payne formation forms the upper third and caps most of the hills, although the north-south ridge, immediately south of the area, is capped with the Warsaw formation.

Subsurface Stratigraphy.—The following sample study of the Mich-a-Tenn Oil Company's Clay County Farm No. 1 (50), drilled just east of Peterman Bend, is typical of the Trenton, Black River and upper Stones River groups in this general area:

Mich-a-Tenn Oil Company's Clay County Farm No. 1

LOCATION: Peterman Bend PLATE: XI. WELL NO.: 50.
COMPLETED: 1938. ELEVATION: 629 ft. TOTAL DEPTH: 660 ft.
PRODUCTION: Dry.

Lithology	*From*	*To*	*Thick*
MAYSVILLE AND TRENTON GROUPS (439 ft.):			
LEIPERS AND CATHEYS FORMATIONS (164 ft.):			
Samples missing	0	80	80
Limestone; white to gray, medium- to coarse-grained. Large amount of light-colored angular chert, probably from up the hole	80	90	10
Limestone; dark-gray, medium-grained, shaly	90	95	5
Limestone; light-gray and white, medium- to coarse-grained. Some white, milky chert	95	159	64
Limestone; light-gray to white, some dark-gray, medium-grained	159	164	5
CANNON LIMESTONE (216 ft.):			
Limestone; dark-gray to brown, medium-grained	164	190	26
Limestone; dark-gray to brown, medium-grained, shaly	190	205	15
Limestone; white to dark-gray, medium-grained. Small amount of white, milky chert	205	215	10
Limestone; same as above with several ostracods (*Isochilina* sp.)	215	220	5
Limestone; white to dark-gray, medium-grained. Small amount of dark, angular chert	220	255	35
Limestone; same as above with ostracods	255	260	5
Limestone; dark-gray, medium-grained	260	285	25
Limestone; gray and brown, medium-grained with ostracods	285	295	10
Limestone; white to gray, medium-grained	295	320	25
Limestone; white to dark-brown and gray, medium-grained	320	330	10

Lithology	*From*	*To*	*Thick*
Limestone; white to gray and brown, fine-grained	330	370	40
Limestone; brownish-gray, fine-grained	370	380	10
HERMITAGE FORMATION (59 ft.):			
Limestone; light-gray to slightly greenish, medium-grained	380	385	5
Limestone; dark-gray, medium-grained, shaly	385	395	10
Limestone; light- to dark-gray, medium- to coarse-grained	395	430	35
Limestone; dark-gray, medium-grained, very shaly	430	439	9
BLACK RIVER GROUP (81 ft.):			
CARTERS LIMESTONE—upper member (11 ft.):			
Limestone; white to light-gray, medium- to coarse-grained	439	445	6
Limestone; same as above with a few fragments of brown, dense limestone	445	450	5
CARTERS LIMESTONE—lower member (70 ft.):			
Limestone; white to light-brown, dense to medium-grained. Light-green, soft, biotitic, clay shale (Pencil Cave)	450	453	3
Limestone; light-tan, dense	453	456	3
Limestone; brown and gray, dense	456	475	19
Limestone; white to light-tan, dense with some white, dense chert	475	500	25
Limestone; light-gray to tan, dense to fine-grained	500	520	20
STONES RIVER GROUP (125 ft.):			
LEBANON LIMESTONE (125 ft.):			
Limestone; medium-gray, medium-grained with small amount of dark-gray, dense, angular dull chert	520	545	25
Limestone; light- to dark-gray and tan, medium-grained	545	555	10
Limestone; light-gray to tan, dense to fine-grained	555	580	25
Limestone; dark-gray, fine- to medium-grained	580	600	20
Limestone; light-tan to gray, fine- to medium-grained	600	620	20
Limestone; light- to dark-gray and tan, fine- to medium-grained	620	625	5
Samples missing	625	640	15
Limestone; light-gray, dense to fine-grained	640	645	5

The deepest test in the Peterman Bend area is C. F. Dickson et al., A. T. Davis No. 2 (75), in which the driller reported "Knox dolomite cap rock" at 1,179 feet. Only two samples are available from this well; one marked 1,196 feet consists of a very light-gray, dense to fine-grained limestone with some dark-gray, medium-grained limestone. The light-gray limestone appears to be slightly magnesian and the general lithology is characteristic of the horizon which is called Zone B in this report. The dark-gray, medium-grained limestone is almost certainly Murfreesboro. It seems likely, therefore, that the Stones River-Upper Canadian (?) contact is represented in this single sample. The other sample at 1,208-1,223 feet is a light-gray and tan, medium- to coarse-grained dolomitic limestone, definitely a part of the Knox dolomite group.

The upper part of the Canadian was also drilled in J. L. Miller et al., Sam Keisling No. 5 (148), deepened in 1938 by A. G. Greenup et al. This test reached a depth of 860 feet below the base of the Trenton group.

Structure.—Oil accumulation in the Peterman Bend area is intimately related to a dome which may be a northward extension of the Bennetts Ferry anticline, which is here some 50 feet lower structurally than the highest dome in the Tinsleys Bottom field. Superimposed upon this regional upwarp, near the center of Peterman Bend, is a small, irregularly-shaped dome which has approximately 30 feet of closure on the base of the Pencil Cave. Subsurface data indicate sharp dips to the northwest and southeast. Strong northwest dip may be seen in the Ordovician limestones along State Highway 53, just west of the bridge across Obey River. With the exception of the production on the Keisling lease, which appears to be located on a terrace on the northeast flank of the Peterman Bend dome, the producing areas in this district seem to be confined to the steeper flanks.

Producing Horizons.—The most productive horizons in the Peterman Bend area are in the pre-Trenton rocks, especially in the Carters, Lebanon, and Ridley limestone (Plate XV). There has been no Trenton production, although two wells have produced oil from the upper member of the Carters limestone between the Mud Cave and Pencil Cave. The deepest production from the Stones River group was in the Clark-Hill Oil Corporation's J. M. Gray No. 3 (109), which found production at a depth of 619-630 feet, probably in the Pierce limestone.

Records in the files of this Division and the best local information indicate that C. F. Dickson et al., A. T. Davis No. 2 (75) made some oil from a depth of 1,208-1,223 feet, and the single sample studied from this depth (see above) definitely places this horizon in the upper part of the Knox dolomite group.

Developments.—Oil was discovered in the Peterman Bend area on December 5, 1925, by the Clark-Hill Oil Corporation in their J. M. Gray No. 1 (107), which has a reported initial production of 500 barrels per day from the upper member of the Carters limestone at 312 feet. Production was found soon after on the James Arms lease (3) by the H. Z. Clark Oil Company, and on the Sam Keisling farm (145) by J. L. Miller et al. Since the discovery well, 25 tests have been drilled in the Peterman Bend area, 14 of which have produced oil.

In 1927, when the area reached its maximum production, the Paragon Development Company of Toledo, Ohio, extended their Monroe County, Kentucky, pipe line south to gather the Peterman Bend production. In Tennessee this line consisted of 2,304 feet of 3-inch line and 36,668 feet of 2-inch line. Two power pumps were constructed in Peterman Bend. This line has since been removed.

With the exception of two wells (145, 148) on the Keisling lease, which are pumped irregularly, there is no production in the area at present and no drilling is in progress.

Production.—Like most of the productive areas in Clay County, no accurate production figures are available on Peterman Bend. The best local information indicates that more than 30,000 barrels of oil were produced in 1926, the year of maximum development. In 1927 and 1928, approximately 18,000 and 12,000 barrels, respectively, were marketed. Although a number of wells were pumped from 1928 to about 1934, no accurate figures are available since the removal of the pipe line. The total production in Peterman Bend from 1926-1938, inclusive, may have approached 100,000 barrels of oil.

GOODPASTURE BEND AREA

(PLATE I, WELLS NO. 22, 30, 31, 32, 153, 154, 155)

Location.—Goodpasture Bend lies in a northward swing of Obey River in its course across Clay County. It is located approximately 4.5 miles east-northeast of Celina. The area included within the bend proper is less than one square mile in extent, but in the present report nearby wells have been considered in the Goodpasture Bend area.

Physiography.—The area within the bend is a relatively flat, alluviated bottom. Like Peterman Bend, it is almost completely surrounded by hills that reach an elevation of 900 feet above sea level. The drainage is directly into the Obey, Long Branch and Lick Run being the largest tributaries.

Stratigraphy.—Goodpasture Bend approximately marks the most eastward outcrop of the Catheys limestone in Clay County. The limestones of this formation may be seen along Obey River near the bridge on State Highway 53, and they extend a short distance up Lick Run Creek. Although covered by alluvium, the Leipers formation is the bed-rock under most of the bend. The Chattanooga black shale and the Fort Payne formation are exposed in the higher hills on all sides of the bend and in the highest ridges to the north, toward Pea Ridge, the limestones of the Warsaw formation form the surface rock.

Subsurface Stratigraphy.—Samples are not available at present from any wells drilled in the Goodpasture Bend area, but drillers' logs indicate that the general subsurface section is similar to that in Peterman Bend (page 64). The deepest well to date in the area is the Norton-Stewart Petroleum Company's Charles Key No. 1 (155), which was drilled to a depth of 800 feet and probably ended in the upper part of the Murfreesboro limestone.

Structure.—The producing area in Goodpasture Bend is located upon a dome with small closure. Surface and subsurface data indicate dip in all directions from Bryan Davis et al., C. H. Buford No. 1 (30). This dome appears to be a northeast extension of the Peterman Bend trend, on which the Peterman Bend production is located.

Producing Horizons.—All the production to date in this area has been in limestones of the Stones River group. Bryan Davis et al., C. H. Buford No. 1 (30) found production at a depth of 465 feet in the upper part of the Lebanon limestone. When drilled deeper another zone of porosity was entered at 553, 205 feet below the base of the Pencil Cave, and probably near the contact of the Lebanon with the underlying Ridley limestone. Oil was found at 555 feet in Tom Irwin et al., Clarence Buford No. 1 (32); this production is in the Lebanon limestone.

Developments.—Oil was discovered in the Goodpasture Bend area late in November 1937, by Bryan Davis et al., C. H. Buford No. 1 (30). The initial production was reported at 4 barrels per hour. An off-set well on the same lease was dry at 151 feet below the base of the Pencil Cave. Tom Irwin et al., Clarence Buford No. 1 (30), drilled in 1938, produced 100 barrels per day on flush production. Seven wells have been drilled in what is here considered the Goodpasture Bend area, but attempts have failed to find production north and south of the Buford lease.

Production.—During December 1937, approximately 500 barrels of oil were produced from the discovery well. In 1938, 7,300 barrels were sold from this well and Tom Irwin et al., Clarence Buford No. 1 (32).

FOX SPRINGS-MITCHELL CREEK AREA

(PLATE XII)

Location.—The area here considered as the Fox Springs-Mitchell Creek district is located 4 miles southwest of Willow Grove and extends from the mouth of Carter Creek north along Mitchell Creek to the Obey River. Fox Springs School is located just south of State Highway 53 and near the confluence of Mitchell Creek and Obey River. The area is rectangular in shape and covers about 6 square miles.

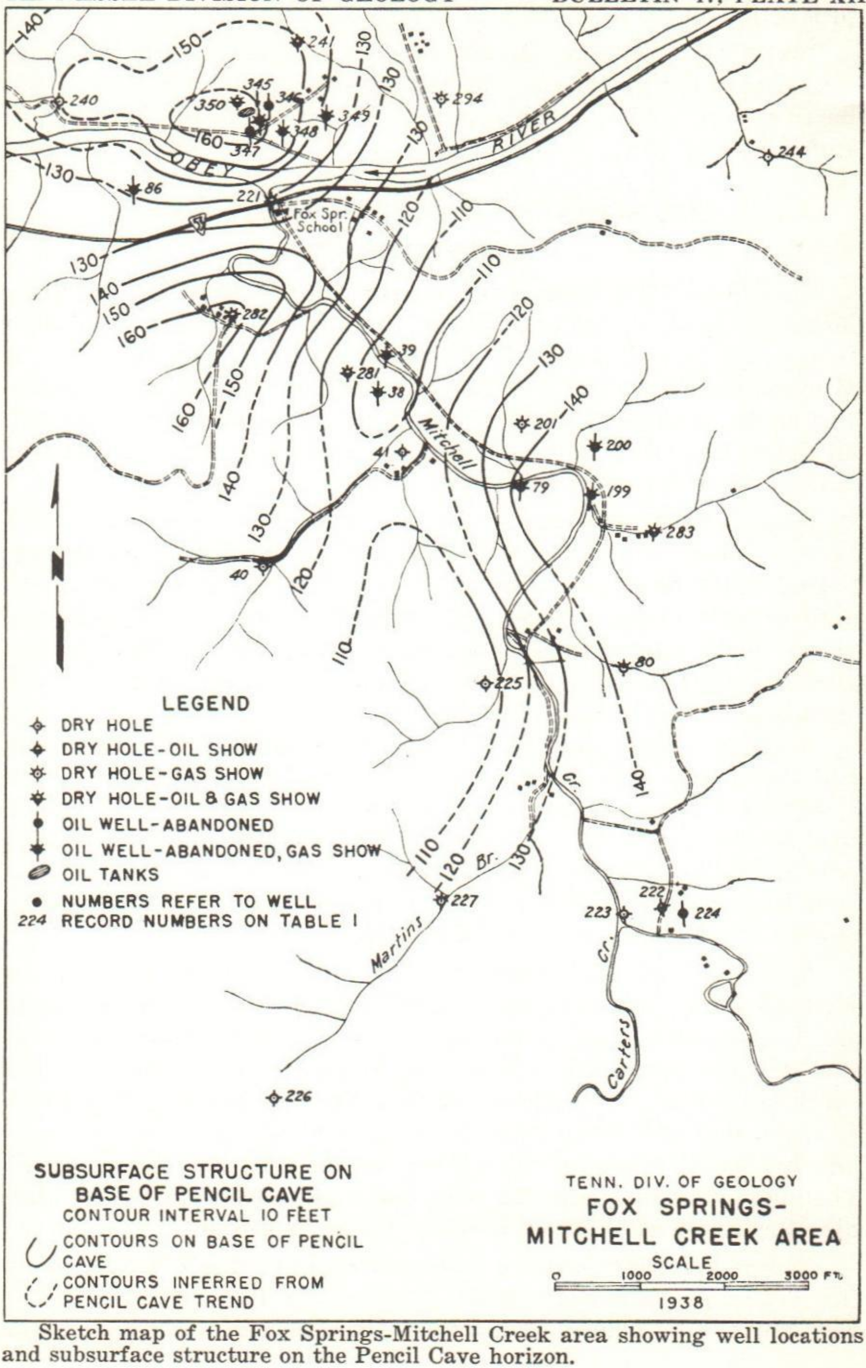
Physiography.—Most of the developments have been along Mitchell Creek and on the Williams lease just north of Fox Springs School north of Obey River. The Fox Springs area is along the alluvial plain of Obey River and Mitchell Creek, and it is bordered on the north, east and west by hills which rise more than 300 feet above the general level of the floodplain. Local outliers reach elevations of more than 1,100 feet.

Mitchell Creek and its tributaries, especially Carter Creek and Martins Branch, have carved their valleys below the general Highland Rim level, resulting in the usual intricate dissection that is so characteristic of most of Clay County. The only level land in the area is along the streams or on the flat-topped Highland Rim plain that borders the area on all sides. All drainage is directly or indirectly into Obey River.

Stratigraphy.—The oldest rocks exposed in the Fox Springs-Mitchell Creek area are the argillaceous limestones of the Leipers formation. This formation is well exposed along most of the streams, especially along the Mitchell Creek road leading south from State Highway 53 at Fox Springs School. The Chattanooga shale outcrops around the base of the hills and is overlain by the Fort Payne formation, which caps the lower ridges. The higher hills to the north, east, and west are capped by the Middle Mississippian Warsaw and St. Louis limestones.

Subsurface Stratigraphy.—No well samples are available from the Trenton, Black River and upper Stones River groups in the Fox Springs-Mitchell Creek area. Drillers' logs on most of the

TENNESSEE DIVISION OF GEOLOGY BULLETIN 47, PLATE XII



Sketch map of the Fox Springs-Mitchell Creek area showing well locations and subsurface structure on the Pencil Cave horizon.

Ava Oil & Gas Company's developments have been furnished this Division by Mr. Art Pratt. Samples are available from 856-1,187 feet on this company's Mary Ellen Williams No. 3 (347). The driller's log on this well is as follows:

Ava Oil & Gas Company's Mary Ellen Williams No. 3

LOCATION: Fox Springs PLATE: XII. WELL NO.: 347.
COMPLETED: 1935. ELEVATION: 540 ft. TOTAL DEPTH: 1187 ft.
PRODUCTION: Oil. AUTHORITY: Art Pratt.
OIL PAYS: 161, 196, 242, 690, 746 ft.
OIL SHOWS: 222, 331, 846-856, 865, 922-929 ft.
GAS SHOWS: 116, 190, 209, 295, 305, 325, 349, 381, 405, 443, 643, 683, 690, 949 ft.

Lithology	*From*	*To*	*Thick*
TRENTON GROUP (362 ft.):*			
CATHEYS AND CANNON LIMESTONE (305 ft.):			
Surface	0	20	20
Lime	20	199	179
Lime; dark-gray, open	199	209	10
Lime; dark-gray	209	210	1
Lime; dark-gray, hard	210	222	12
Lime; sandy	222	226	4
Lime; dark-gray, coarse, open	226	230	4
Lime; brown, drills to fine, angular sand	230	265	35
Lime; grayish-brown	265	275	10
Lime; grayish-brown, coarse	275	280	5
Lime; brown, fine	280	285	5
Lime; brown, medium-coarse	285	290	5
Lime; gray, light, fine, sandy	290	300	10
Lime; dark-gray	300	305	5
HERMITAGE FORMATION (57 ft.):			
Lime; flaky white in dark-gray	305	310	5
Lime; brown	310	315	5
Lime; blue	315	330	15
Lime; flaky white in blue	330	333	3
Lime; dark-gray, fine	333	345	12
Lime; blue, soft	345	350	5
Lime; coarse, gray	350	355	5
Mud Cave	355	362	7
BLACK RIVER AND STONES RIVER GROUPS (698 ft.):			
CARTERS, LEBANON, RIDLEY, AND MURFREESBORO LIMESTONES (698 ft.):			
Lime; light-gray, coarse	362	372	10
Lime; brown, hard	372	374	2
Lime; shaly, brown	374	379	5
Pencil Cave, green	379	381	2

Lithology	*From*	*To*	*Thick*
Lime; brown, shaly, hard	381	385	4
Lime; brown	385	408	23
Lime; brown, hard	408	443	35
Lime; brown	443	560	117
Lime; grayish-brown	560	575	15
Lime; gray	575	580	5
Lime; gray, brown, coarse	580	630	50
Lime; gray, brown, fine-grained	630	640	10
Lime; gray, brown, coarse	640	670	30
Lime; gray, brown, medium-fine	670	680	10
Lime; gray, brown, medium-coarse	680	690	10
Lime; fine, granular	690	697	7
Lime; brownish-gray, fine	697	701	4
Lime; dark-brown	701	708	7
Lime; light-gray	708	713	5
Lime; dark-brown	713	718	5
Lime; light-gray	718	731	13
Lime; dark-brown	731	739	8
Lime; light-brown	739	750	11
Lime; dark-brown	750	766	16
Lime; dark-blue	766	773	7
Lime; dark-brown	773	783	10
Lime; light-brown	783	794	11
Lime; dark-brown	794	846	52
Lime; gray, sandy	846	856	10
Lime; hard, brown, sandy	856	865	9
Lime; dark-brown, soft	865	870	5
Lime; dark-brown	870	875	5
Lime; dark-brown, hard	875	890	15
Lime; brown	890	901	11
Lime; dark-brown, hard	901	904	3
Lime; hard, brown	904	910	6
Shale; dark, sandy	910	918	8
Shale; hard	918	922	4
Shale; dark, hard	922	942	20
Lime; dark, hard	942	952	10
Shale; shelly, flaky, with white specks	952	988	36
Shale; flaky	988	993	5
Lime; dark, hard	993	1014	21
Lime; shelly, with fine flakes	1014	1018	4
Shale; dark	1018	1029	11
Lime; shelly	1029	1033	4
Shale; brown	1033	1047	14
Sand; dark	1047	1049	2
Lime; shelly, hard	1049	1051	2
Lime; dark, sandy	1051	1060	9
CANADIAN: (?) (127 ft.):			
ZONE B (20 ft.):			
Lime; dark, fine, hard	1060	1080	20

Lithology	*From*	*To*	*Thick*
CANADIAN: (107 ft.):			
ZONE C_2 (107 ft.):			
Lime; gray, hard	1080	1096	16
Lime; white, hard, sandy	1096	1114	18
Sand; brown, hard	1114	1124	10
Lime; gray, hard, sandy	1124	1136	12
Lime; gray with white flecks, hard	1136	1160	24
Lime; blue with white flecks, hard	1160	1176	16
Sand; white	1176	1178	2
Sand, white, like "St. Peter"	1178	1187	9

*NOTE: Formational correlations above 1060 feet from driller's log. (See below.)

A microscopic examination of samples from 856 to 1,187 feet from this test shows the general character of the lower Stones River and the upper part of the Knox dolomite groups:

Lithology	*From*	*To*	*Thick*
STONES RIVER GROUP (204 ft.):			
MURFREESBORO LIMESTONE (204 ft.):			
Limestone; gray, dense, iron-stained. A few pieces of gray, translucent, sharp chert	856	863	7
Limestone; medium-gray, dense to fine-grained	863	865	2
Samples missing	865	870	5
Limestone; medium-gray, dense to fine-grained	870	886	16
Limestone; medium- to dark-gray, dense to medium-grained	886	891	5
Limestone; very dark-gray, dense to medium-grained	891	901	10
Samples missing	901	904	3
Limestone; medium-gray, dense to fine-grained	904	925	21
Limestone; medium-gray, dense, with a small amount of gray, calcareous shale	925	929	4
Limestone; medium-gray, dense to fine-grained	929	932	3
Limestone; very dark-gray, medium- to coarse-grained with some dark-gray, calcareous shale and a few fragments of light-gray, dense limestone	932	936	4
Limestone; dark-gray, dense to medium-grained	936	942	6
Samples missing	942	946	4
Limestone; dark-grey, dense to medium-grained	946	952	6
Limestone; very dark-gray, medium-grained	952	955	3
Limestone; medium- to dark-gray, dense to fine-grained	955	972	17
Limestone; medium-gray, dense to fine-grained	972	988	16
Samples missing	988	993	5
Limestone; dark-gray, dense to fine-grained	993	1010	17

Lithology	*From*	*To*	*Thick*
Limestone; medium- to dark-gray, dense to fine-grained	1010	1037	27
Limestone; dark-gray to brownish, fine- to medium-grained	1037	1045	8
Samples missing	1045	1047	2
Limestone; very dark-gray, dense to fine-grained	1047	1060	13
CANADIAN (?) (127 ft.):			
ZONE B (20 ft.):			
Limestone; very light-gray, dense to medium-grained in which a number of the larger fragments show a sucrose texture. Some of the dense variety appear slightly dolomitic	1060	1064	4
Limestone; very light-gray, medium- to coarse-grained, dolomitic	1064	1068	4
Limestone; very light-gray to white, dense	1068	1072	4
Limestone; light-gray to white, dense to fine-grained, magnesian	1072	1080	8
CANADIAN (107 ft.):			
ZONE C_2 (107 ft.):			
Chert; white to light-gray, translucent, sharp with some light-gray, dense to medium-grained, dolomitic limestone	1080	1084	4
Dolomite and chert; dolomite, light-gray to brownish, medium-grained; chert, white to light-gray, sharp, with inclusions of dolomite crystals	1084	1088	4
Dolomite; light-gray to brown, medium-grained with minor amounts of dense to slightly porous, white chert	1088	1096	8
Dolomite; light-gray to tan, medium- to coarse-grained. Chert; white, dense, translucent, sharp. A few fragments of soft, dull green shale	1096	1110	14
Dolomite; tan, medium-grained	1110	1114	4
Dolomite; tan, medium-grained. Chert; white to light-gray, dense, translucent, sharp. A considerable amount of angular, glassy quartz	1114	1124	10
Dolomite; gray to tan, fine- to medium-grained	1124	1136	12
Dolomite; medium-gray to brown, medium-grained. Shale; dull green, soft	1136	1148	12
Dolomite; tan, medium-grained. Shale; dull green, soft. Chert; white to light-gray, dense, translucent, very angular. Quartz; glassy, sharp	1148	1157	9
Dolomite; tan, medium-grained. Shale; dull green, soft	1557	1160	3
Dolomite; same as above with a considerable amount of yellowish, spongy pyrite	1160	1167	7

Lithology	*From*	*To*	*Thick*
Dolomite; gray to tan and brown, medium- to coarse-grained. Shale; dull green, soft, dolocastic. Chert; white to medium-gray, some fragments oolitic, dense to slightly porous, translucent, very angular	1167	1176	9
Dolomite; gray and tan, medium-grained. Chert; same as above	1176	1187	11

It will be noted in this sample study that the Murfreesboro limestone rests directly upon Zone C_2, definitely of Canadian age, with the complete absence of Zone C_1, which is so well developed in the Dafoe and Dafoe's G. H. Lynn No. 5 (180) and Jesse Ashby et al., Donaldson Heirs No. 1 (85). Although data to date are not conclusive, the absence of Zone C_1 points strongly toward pre-Stones River erosion in this general area.

Structure.—Structural work on the base of the Chattanooga shale in the Mitchell Creek-Fox Springs area shows that the regional east dip is interrupted by two pronounced domes, one on the Williams farm, just north of the mouth of Mitchell Creek, and another north of New Salem Church. The Fox Springs or Williams dome has 20 feet of closure on the Chattanooga shale. Dips to the south, southeast, and east are relatively steep, reaching 5° to 6°. The north and west flanks appear to be more gentle, although control in those directions is lacking. This structure also closes on the base of the Pencil Cave, with a sea level elevation of 160 feet. The Fox Springs dome has been productive.

Immediately south of this structure, just north of New Salem Church, structural work on the base of the Chattanooga shows 40 feet of closure. Subsurface data are incomplete, and with available records it must be contoured as a structural nose, although it almost certainly closes to the west. Pencil Cave data to the south suggests the presence of a trough.

Relatively strong dips prevail along Mitchell Creek for some distance south of the New Salem Church dome, but they do not appear to arrange themselves into any definite structural pattern. The Chattanooga shale dips below 600 feet in a small structural basin just east of the junction of Carter and Mitchell creeks.

Producing Horizons.—Rocks of Trenton age, especially the upper or first Sunnybrook "sand" of the drillers, have been the most productive in the Fox Springs-Mitchell Creek area. The most prolific pays have been in the Cannon formation from 185 to 243 feet above the Pencil Cave. There has been no production from the lower or second Sunnybrook.

On the Fox Springs or Williams dome pays have been found in the underlying Stones River group of limestones; in the Ava Oil & Gas Company's Mary Ellen Williams No. 3 (347) at 690 feet, probably near the Pierce-Ridley contact, and in the same Company's Mary Ellen Williams No. 5 (349) at 795 feet, in the upper part of the Murfreesboro limestone.

Developments.—In 1926 the Ava Oil & Gas Company's Mary Ellen Williams No. 1 (345), located near the top of Fox Springs dome, found oil and salt water at a depth of 156 feet, 246 feet below the Chattanooga shale. When deepened, a 30-barrel per day pay was found at 186-191 feet in the upper part of the Cannon limestone. In all, 8 wells have been drilled in the Fox Springs area north of Obey River, 5 of which have produced oil.

One of the most phenomenal wells ever drilled in Clay County, the Ava Oil & Gas Company's T. V. Davis No. 1 (79), was located about 0.7 of a mile southeast of the Williams wells. According to the driller a rich, wet gas was encountered immediately above the pay horizon. The well began flowing during the night of June 26, 1928, from a depth of 185 feet in the upper part of the Cannon limestone. Before the tools could be lifted from the hole, backwaters along Mitchell Creek from Obey River covered the well with several feet of water. The oil and gas continued to flow through the water and a minimum of several thousand barrels of oil was lost. The well continued to flow and fill all storage from June 26 to August 28, 1928, before the tools could be lifted and the well properly tubed. Conservative estimates indicate a production of 15,000 to 20,000 barrels from this well. Of the 13 wells later drilled in the vicinity of the Davis No. 1, 6 were productive.

In 1928 a small amount of oil was found along the upper part of Mitchell Creek in Ackerman et al., G. L. Maynard No. 1 (222), but although several additional tests were drilled, including Bryan Davis' G. L. Maynard No. 1 (227) to the upper part of the Murfreesboro limestone, the production was not augmented.

At the time of the production in the Fox Springs area, this district was served by a pipeline of the Paragon Development Company. The entire area is now abandoned and all storage and equipment have been removed.

Production.—The Fox Springs-Mitchell Creek area has been the most productive district in the Upper Cumberland region. The Williams and Davis leases were, by far, the most prolific. Although accurate production figures are not at hand, the amount paid in royalty indicates a minimum production of 75,000 barrels with a strong possibility that more than 100,000 barrels have been produced from this area.

WILLOW GROVE-IRONS CREEK AREA

(PLATE XIII)

Location.—The Willow Grove-Irons Creek area comprises some 5 square miles. The town of Willow Grove is situated in the north-central part of the area. State Highway 53 crosses the northern half of the district in a general northeast-southwest direction.

Physiography.—The area is drained by Obey River, whose main tributaries are Irons, Coalson, and Stillhouse creeks. In the northern half of the district the surface is rolling with occasional erosion remnants projecting above the general level. Irons Creek has developed wider flood plains than nearby streams with comparable watershed areas. The area as a whole, exclusive of the flood plains, presents the usual rugged topography.

Stratigraphy.—The oldest rocks exposed in the Willow Grove-Irons Creek district are of Leipers age, which here exhibits its characteristic lithology. It is exposed on the crests of three small inliers, and forms the bed of Irons Creek from the mouth of Coalson Creek to Obey River. It is also exposed in the bluffs of Obey River in the northwestern corner of the area.

Immediately overlying the Leipers formation is the Chattanooga formation, with its typical lithology and thickness of approximately 20 feet. It is, in turn, overlain by about 200 feet of Fort Payne, which outcrops on the valley sides and caps most of the ridges. The Warsaw—the youngest formation in the area—is present on the highest ridges in the southwestern and southeastern parts of the area. It is probably not exposed anywhere in its full thickness of approximately 100 feet.

Subsurface Stratigraphy.—The following sample descriptions of the Doctors Syndicate, John Hargrove No. 2 (117) are typical of the Trenton, Black River, and upper Stones River groups as developed in this area:

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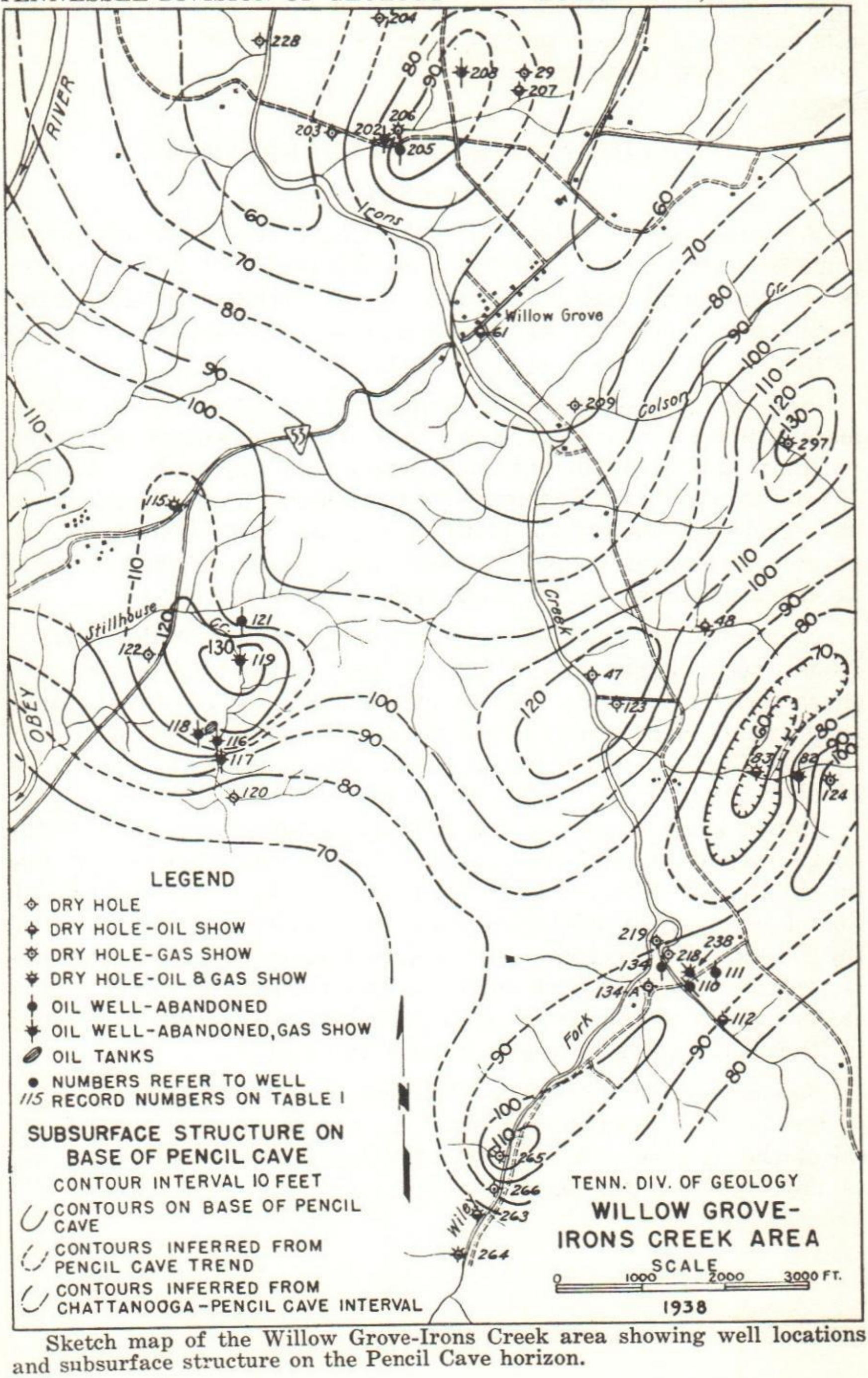


Sketch map of the Willow Grove-Irons Creek area showing well locations and subsurface structure on the Pencil Cave horizon.

Doctors Syndicate, John Hargrove No. 2

LOCATION: Willow Grove-Irons Creek area. PLATE: XIII. NO.: 117.
COMPLETED: Spring, 1937. ELEVATION: 600 ft. TOTAL DEPTH: 851 ft.
PRODUCTION: 100 barrels total. PRODUCING HORIZON: Hermitage, 455-490 feet.

Lithology	*From*	*To*	*Thick*
MAYSVILLE AND TRENTON GROUPS (510 ft.):			
LEIPERS AND CATHEYS FORMATIONS (212 ft.):			
Samples missing	0	130	130
TRENTON GROUP (365 ft.):			
CATHEYS LIMESTONE (82 ft.):			
Limestone; white to gray, medium-grained	130	135	5
Limestone; white to gray, medium- to coarse-grained	135	139	4
Limestone; white to gray, medium-grained	139	143	4
Limestone; white to gray, medium- to coarse-grained	143	147	4
Limestone; white to tan and brown, medium-grained	147	154	7
Limestone; white to brown and gray, medium-grained	154	163	9
Limestone; white to tan and gray, medium- to coarse-grained, with pyrite inclusions	163	167	4
Limestone; white to tan and gray, medium- to coarse-grained	167	212	45
CANNON LIMESTONE (224 ft.):			
Limestone; gray, medium-grained	212	217	5
Limestone; gray and brown, medium-grained, with small amounts of gray, calcareous shale	217	231	14
Limestone; light-brown and dark-gray, medium-grained	231	250	19
Limestone; white to light-tan and gray, medium- to coarse-grained, with many ostracods	250	255	5
Limestone; white to tan and gray, medium- to coarse-grained	255	259	4
Limestone; white to dark-gray and brown, medium- to coarse-grained	259	273	14
Limestone; tan and dark-gray and brown, medium-grained	273	277	4
Limestone; tan to dark-gray, medium-grained, with many ostracods	277	281	4
Shale; dark-gray, medium-grained, calcareous	281	286	5
Limestone; dark-gray, medium-grained	286	290	4
Limestone; light-brown and gray, medium- to coarse-grained	290	298	8
Limestone; brown and dark-gray, medium- to coarse-grained, with small amount of white, drusy silica	298	304	6

Lithology	*From*	*To*	*Thick*
Limestone; brown and dark-gray, medium- to coarse-grained, with gray, calcareous shale	304	308	4
Limestone; white and brownish-gray, medium- to coarse-grained	308	320	12
Limestone; light-tan and brownish-gray, medium- to coarse-grained, with small amount of white, drusy silica	320	324	4
Limestone; brown, medium-grained	324	344	20
Limestone; brown and gray, medium- to coarse-grained, with many ostracods	344	352	8
Limestone; brown and gray, medium-grained, with small amount of brown, dense, angular chert	352	356	4
Limestone; brown and gray-brown, medium- to coarse-grained, with many ostracods and a small amount of white and tan, drusy silica	356	360	4
Limestone; white and gray, medium-grained, with some gray, calcareous shale	360	364	4
Limestone; white to brown and gray, medium-grained	364	384	20
Limestone; white to tan and gray, medium- to coarse-grained, with some white, drusy silica	384	388	4
Limestone; tan and dark-gray, fine- to medium-grained, with some white, drusy silica	388	392	4
Limestone; tan to brown, medium-grained	392	408	16
Limestone; tan to brown, fine- to medium-grained	408	432	24
Limestone; tan to gray and brown, fine-grained, with some white, drusy silica	432	436	4
HERMITAGE FORMATION (59 ft.):			
Limestone; dark-gray, medium-grained	436	442	6
Shale; dark-gray, siliceous, with gray, medium-grained limestone	442	445	3
Limestone; dark-gray, medium-grained, shaly	445	455	10
Shale; light- to dark-gray, with gray, medium-grained limestone	455	470	15
Limestone; light- to dark-gray, medium- to coarse-grained, very shaly	470	475	5
Shale; drab-gray, calcareous	475	490	15
Shale; brownish-gray, calcareous, with many gray-brown, soft, elongated pieces (Mud Cave of the driller); some dark-gray, coarse-grained limestone	490	495	5
BLACK RIVER GROUP (91 ft.):			
CARTERS LIMESTONE—upper member (15 ft.):			
Limestone; white to brownish-gray, medium- to coarse-grained	495	500	5
Limestone; white to tan, medium-grained, with some tan, dense, angular chert	500	510	10

Lithology	*From*	*To*	*Thick*
CARTERS LIMESTONE—lower member (76 ft.):			
Limestone; tan and drab-gray, dense to fine-grained	510	532	22
Limestone; white to light-tan, dense to fine-grained, with some white to tan, roughly, angular chert	532	544	12
Limestone; light-gray to light-tan, dense to fine-grained	544	548	4
Limestone; light-gray to tan, dense to fine-grained, with some white to tan, angular chert	548	586	38
STONES RIVER GROUP (265 ft.):			
LEBANON LIMESTONE (143 ft.):			
Limestone; drab-gray to tan, dense to fine-grained, with a small amount of gray and brown, smooth, angular chert	586	598	12
Limestone; light-gray to tan and brown, fine- to medium-grained, with brown, dense, sharp chert	598	635	37
Limestone; light-gray to brown, fine- to medium-grained	635	655	20
Limestone; light-gray to tan and brown, fine-grained	655	665	10
Limestone; light-gray to tan and brown, fine- to medium-grained, with some tan and gray, dense, angular chert	665	677	12
Limestone; light-gray to tan and brown, fine- to medium-grained	677	729	52
RIDLEY LIMESTONE (108 ft.):			
Limestone; tan and brown, medium- to coarse-grained	729	767	38
Limestone; light-gray to tan and brown, medium-grained, with gray and brown speckled, dense, vitreous chert	767	782	15
Limestone; light-gray to tan and brown, medium-grained	782	827	45
Limestone; gray to tan and brown, medium- to coarse-grained	827	837	10
PIERCE LIMESTONE (14 ft.):			
Limestone; white to tan and brown, fine- to medium-grained, with a small amount of gray, soft, calcareous shale	837	851	14

The Doctors Syndicate, John Hargrove No. 6 (121) and E. G. Brandenberger's C. A. Greenwood No. 1 (110) are the deepest wells in the area. Both probably ended in the Pierce formation.

Structure.—The entire Willow Grove-Irons Creek area is a part of the Willow Grove terrace. This general structural feature shows very little regional relief. Locally, structural relief between the crest of the Irons Creek dome and the bottom of the structural basin just southeast of it approaches 70 feet. All prominent structural features in this area except the Stillhouse Creek dome are essentially sub-parallel and are aligned in a general northeast-southwest direction.

Data based on Chattanooga shale elevations indicate closure of approximately 20 feet in the Stillhouse Creek dome. Subsurface information on the base of the Pencil Cave show structural relief of 60+ feet to the south and a closure of 20+ feet. This dome forms the western end of a linear anticlinal feature which divides the area into approximate northern and southern halves.

The Coalson Creek dome, the eastern terminus of this linear feature, has a closure of approximately 20 feet. Intermediate between these two superimposed domes is the Irons Creek dome, which is transected by Irons Creek and has some 10+ feet of closure.

Another northeast-southwest trending upwarp is present in the southern half of the area. A dome known as the Wiley Fork dome is superimposed on this anticline. Data from the Chattanooga shale indicate an elongated dome centering about the mouth of Wiley Fork. Subsurface data, however, show that this structure is composed of two parts with a saddle between them.

Centering 0.5 of a mile northwest of Willow Grove School is an elliptical-shaped dome with 10 to 20 feet closure. This dome is known as the Willow Grove dome. The definitions of this structure from subsurface data and from Chattanooga shale elevations are essentially the same. Subsurface control immediately southeast of the dome is lacking.

Producing Horizons.—Production has been found in the Willow Grove-Irons Creek area in rocks ranging in age from the lower part of the Ridley to the lower half of the Cannon limestones (Plate XV). The deepest production found to date is in the Doctors Syndicate, John Hargrove No. 4 (119) in the Stillhouse Creek part of the area, at 762 feet, 320 feet below the base of the Pencil Cave and probably in the lower part of the Ridley limestone. The most shallow pay was in E. G. Brandenberger et al., C. A. Greenwood No. 2 (111) along Irons Creek, which entered a pay zone at 376 feet in the lower part of the Cannon limestone.

A pay, 70 feet above the Pencil Cave, was found in E. G. Brandenberger et al., C. A. Greenwood No. 1 (110) and in A. A.

Alexander et al., E. D. Marcum No. 1 (202), just north of Willow Grove. Although samples are not available on either of these wells, subsurface studies of samples from nearby tests indicate that this production was very near the Cannon-Hermitage contact. In general, the lower half of the Lebanon and the upper part of the Ridley limestones have been the most productive in this area. Two wells, A. A. Alexander et al., E. D. Marcum No. 7 (208) and E. G. Brandenberger et al., C. A. Greenwood No. 1 (110) were drilled to the upper part of the Murfreesboro limestone, the deepest horizon tested to date in this district.

Developments.—There has been sporadic oil production in the Willow Grove-Irons Creek area for more than 15 years. The discovery well, A. A. Alexander et al., E. D. Marcum No. 1 (202), located less than one mile north of Willow Grove, was drilled in on August 18, 1923. Production was found at 421 feet. The well has been discussed by Jillson:[96]

"During the first hour or two following the drilling in, the well flowed freely under heavy gas pressure uncontrolled; and it is estimated that about 500 barrels of oil were lost in the waters of Irons Creek, a northwestward flowing tributary of Obey River. After flow line connections to a 250-barrel gas-tight tank were made, the oil was conserved and the tank was filled within 4 hours. At the time the writer was engaged in making the reconnaissance of this field upon which this paper is based, August 24th to August 28, 1923, the Marcum No. 1 was driving petroleum under considerable gas head along weathered bedding planes in the upper Ordovicic limestones to points 1,000 feet distant, where it emerged along the adjacent waters of Irons Creek much like a fresh natural seepage and formed a bright "rainbow" on the flowing water. This discovery well is conservatively estimated at between 1,500 and 2,000 barrels of flush production."

Since 1923, 8 wells have been drilled in the area immediately north of Willow Grove, 3 of which produced oil in commercial amounts.

In March 1926, the Carnahan Oil Company's Petway Dennis No. 1 (82) found production in the lower part of the Lebanon limestone at 692 feet. This well was located in Hogan Hollow, 1.5 miles southeast of Willow Grove. Although the well was abandoned several years ago, it was probably the most productive single well in the area.

The following year, E. G. Brandenberger et al., C. A. Greenwood No. 1 (110), along Irons Creek, 2 miles south of Willow Grove, entered a pay horizon at 450 feet in the Trenton. The well had an initial of about 40 barrels per day. In August 1937, E. M. Ellis et al., Bud Morrow No. 1 (238), just north of the Green-

[96]Jillson, W. R. New Tennessee oil pool: Pan. American Geologist, vol. 50, p. 197, 1923.

wood No. 1 (110) came in flowing at 760 feet, 239 feet below the Pencil Cave. After flowing for 24 hours the well was put on pump without response. When deepened to 785 feet another pay zone was found. This well was pumped during 1938.

Early in 1937 the Doctors Syndicate, John Hargrove No. 1 (116), about one mile southwest of Willow Grove along Stillhouse Creek, came in flowing approximately 125 barrels per day at a depth of 671 feet, 195 feet below the Pencil Cave. The location was on a well-defined upwarp mapped by the Tennessee Division of Geology in 1923. For about two months approximately 100 barrels per day were pumped; the production then declined rapidly, and when the well was drilled deeper a 3-barrel pay was struck at 750 feet. During 1937 and 1938, 6 more wells were drilled on this lease, 3 of which produced oil from the Stones River limestones and one, Doctors Syndicate, John Hargrove No. 2 (117), produced a small amount from the lower Sunnybrook pay just above the Pencil Cave. Although the equipment has not been removed, the Stillhouse field is temporarily abandoned.

In all, 37 wells have been drilled in the Willow Grove-Irons Creek area. Twelve have produced oil.

Production.—No data are available which would allow more than rank speculation on the production in this district prior to 1937. The Carnahan Oil Company's Petway Dennis No. 1 (82), and the Doctors Syndicate, John Hargrove No. 1 (116) were the best wells drilled in the area. Perhaps as much as 12,000 barrels were produced before the discovery along Stillhouse Creek. In 1937 the Stillhouse or Hargrove pool produced 10,250 barrels from 5 wells, but the production in 1938 had declined to 1,250 barrels from 4 pumpers. E. M. Ellis et al., Bud Morrow No. 1 (238) has produced less than 1,000 barrels since 1937. The Willow Grove-Irons Creek area may have produced 25,000 barrels.

LILLYDALE AREA

(PLATE I, WELLS NO. 18, 44, 57, 103, 129, 130, 131, 135, 136, 137, 275, 285, 286, 287, 300, 303, 304, 305, 306, 307, 308, 309, 310, 311, 316, 317, 318, 352)

Location.—Scattered production in the general vicinity of the small village of Lillydale, in the northeastern part of Clay County, is here termed the Lillydale area. It is bounded on the east by Vans Branch in western Pickett County, to the north by the Kentucky state line, to the west by the Willow Grove-Irons Creek area (Plate XIII). The area embraces some 10 square miles.

Physiography.—Obey and Wolf rivers, the principal streams in this area, have cut their meandering courses some 400 feet below the highest hills in this part of the county. While steep-sided valleys are common, the general dissection of the Highland Rim is not as sharp in the Lillydale area as in many other parts of the county. There are many relatively flat valleys in the eastern part of the district.

Stratigraphy.—Rocks ranging in age from the Leipers formation to the St. Louis limestone outcrop in this area. The bluish-gray, shaly limestones of the Leipers are restricted to the valleys of Obey and Wolf rivers and their immediate tributaries. The overlying Chattanooga shale has relatively wide outcrops in the vicinity of the village of Lillydale and the black shale is overlain by the shaly and siliceous limestones of the Fort Payne formation. Warsaw limestones are present on the narrow ridges both east and west of Lillydale and north of Obey river. Although not well-exposed, the St. Louis limestone is preserved on the linear ridge in Pickett County west of Vans Branch.

Subsurface Stratigraphy.—Although four wells in this area (135, 272, 273, 274) have drilled into the upper part of the Knox dolomite group, no samples are available on these tests. A sample study of a test well, drilled 0.4 of a mile north of Lillydale School on the Tennessee-Kentucky line, illustrates the lithology of the lower Trenton, Black River, and upper Stones River groups in this area:

Doctors Syndicate, Ed Wright No. 1

LOCATION: 0.4 mile north of Lillydale School. PLATE: I. NO.: 352.
COMPLETED: 1937. ELEVATION: 645 ft. TOTAL DEPTH: 850 ft.
PRODUCTION: Dry.

Lithology	*From*	*To*	*Thick*
LOWER MISSISSIPPIAN SERIES (85 ft.):			
FORT PAYNE FORMATION (63 ft.):			
Samples missing	0	63	63
CHATTANOOGA SHALE (22 ft.):			
Shale; black, fissile, carbonaceous	63	85	22
MAYSVILLE AND TRENTON GROUPS (505 ft.):			
LEIPERS AND CATHEYS FORMATIONS (215 ft.):			
Samples missing	85	300	215

Lithology	*From*	*To*	*Thick*
CANNON LIMESTONE (235 ft.):			
Limestone; dark-gray to tan and brown, medium-grained, with gray and brown, soft, calcareous shale	300	305	5
Limestone; light- to dark-gray, medium- to coarse-grained, with small amount of gray, calcareous shale	305	310	5
Limestone; light- to dark-gray, medium-grained	310	315	5
Limestone; dark-gray, medium-grained, with some dark-gray, calcareous shale	315	340	25
Limestone; very dark-gray, with white fragments, medium-grained, with dark-gray to brown, calcareous shale	340	380	40
Shale; gray, calcareous, with gray, medium-grained limestone, and some white, soft, porous silica	380	390	10
Limestone; gray to brown, medium- to coarse-grained, with dark-gray, calcareous shale	390	400	10
Limestone; dark-gray, medium-grained, with many ostracods (*Isochilina?*)	400	405	5
Limestone; dark-gray to tan and brown, medium-grained	405	425	20
Limestone; dark-brown and gray, medium-grained, shaly	425	435	10
Limestone; light- to dark-gray, medium- to coarse-grained, with a few pieces of brown, dense, sharp chert	435	445	10
Limestone; light- to dark-gray, medium-grained	445	475	30
Limestone; light-gray to brownish, medium- to coarse-grained	475	500	25
Limestone; dark-gray and brown, medium- to coarse-grained	500	535	35
HERMITAGE FORMATION (55 ft.):			
Limestone; medium-gray to light greenish-gray, medium-grained ("green lime" of the driller), with light-gray to greenish-gray, medium hard, siliceous shale	535	540	5
Shale; dark-gray, calcareous	540	545	5
Limestone; dark-gray, medium-grained, very shaly	545	570	25
Shale; gray, calcareous	570	575	5
Limestone; gray, medium- to coarse-grained	575	580	5
Shale; dark-gray to brownish, dull, soft (Mud Cave of drillers), with dark-gray, coarse-grained limestone	580	590	10
BLACK RIVER GROUP (95 ft.):			
CARTERS LIMESTONE—upper member (10 ft.):			
Limestone; light- to medium-gray, medium- to coarse-grained	590	595	5

Lithology	*From*	*To*	*Thick*
Limestone; light-gray to tan, medium-grained, with white to tan, dense to slightly porous, sharp chert	595	600	5
CARTERS LIMESTONE—lower member (85 ft.):			
Limestone; white to light-gray, fine-grained, with elongated fragments of green, biotitic, dull shale (Pencil Cave of the drillers)	600	605	5
Limestone; drab-gray, dense to fine-grained	605	625	20
Limestone; drab-gray to tan, dense to fine-grained, with light-gray, soft, calcareous shale	625	635	10
Limestone; light- to medium brownish-gray, fine to medium-grained, with gray to tan, dense, angular chert	635	660	25
Limestone; light-tan to gray and brown, fine- to medium-grained, with white to gray and tan, dense, sharp, rough chert; some of the chert carries very small crystals of dolomite	660	680	20
Limestone; light-gray to brown, fine- to medium-grained, with some light-colored, dense, rough, sharp chert	680	685	5
STONES RIVER GROUP (165 ft.):			
LEBANON LIMESTONE (120 ft.):			
Limestone; light-gray to tan and brown, dense to medium-grained, with a few pieces of very dark dense, smooth, sharp chert	685	695	10
Limestone; dark-gray, medium-grained	695	720	25
Limestone; gray, medium-grained, with gray, calcareous shale	720	735	15
Limestone; dark brownish-gray, medium-grained, with gray and brown, calcareous shale	735	790	55
Limestone; drab-gray, fine-grained	790	805	15
RIDLEY LIMESTONE (45 ft.):			
Limestone; drab- to dark-gray, medium-grained, with brown, porous silica, and a few pieces of brown, dense, angular chert	805	810	5
Limestone; drab-gray to brownish, medium-grained	810	830	20
Limestone; light-grayish brown, fine- to medium-grained	830	840	10
Limestone; gray to tan and brown, medium-grained, with some dark-gray and brown specked chert	840	850	10

Samples are not available on one of the deepest tests in this area, the Robinson Oil Company's Andrew Phillips No. 1 (274). Since oil was encountered in the upper part of the Knox dolomite group, much attention has been aroused by this test. The driller's log is given below:

Robinson Oil Company's Andrew Phillips No. 1

LOCATION: 2.5 miles east of Lillydale School. PLATE: I. NO.: 274.
COMPLETED: Dec. 15, '37 ELEVATION: 624 ft. TOTAL DEPTH: 1402 ft.
PRODUCTION: Oil. PRODUCING FORMATION: Upper part of Knox, 1383-1394 ft.

Lithology	*From*	*To*	*Thick*
Clay	0	35	35
Black shale (Chattanooga)	35	50	15
Lime	50	100	50
Gray lime	100	140	40
Gray and white lime	140	180	40
Gray lime	180	220	40
Brown and gray lime	220	280	60
Blue and gray lime	280	330	50
Blue lime	330	380	50
Brown lime	380	420	40
Gray lime	420	470	50
Brown lime	470	500	30
Gray lime	500	530	30
Blue and gray lime	530	575	45
Gray and brown lime	575	670	95
Pencil Cave at 577-579 ft.			
Brown lime	670	730	60
Brown and gray lime	730	820	90
Brown lime	820	850	30
Brown and gray lime	850	885	35
Brown lime	885	915	30
Brown and gray lime	915	1020	105
Brown lime	1020	1050	30
Gray lime	1050	1095	45
Gray and brown lime	1095	1125	30
Brown lime	1125	1160	35
Brown and gray lime	1160	1205	45
Brown lime	1205	1315	110
Light brown lime	1315	1330	15
Brown lime	1330	1375	45
Light brown lime	1375	1383	8
Brown and gray sand—oil	1383	1387	4
Brown and gray sand—oil	1387	1394	7
Light brown formation	1394	1402	8

Water at	Gas at
35 ft.	100 ft.
50	185
80	530
	760
	780

Casing record: 36½ ft. of 8¼-inch
168 ft. of 6¼-inch
Tubing record: 1385 ft. of 2-inch

Structure.—Data are incomplete to contour the Lillydale area on the Pencil Cave horizon, but structural work on the base of the Chattanooga shale shows several small domes and synclines. These are briefly discussed below from east to west:

From the crest of the Jouett Creek dome (Plate XIV) the rocks dip to the northwest into a local synclinal area the center of which is located approximately at the intersection of Rocky Branch and State Highway 53, and may well be called the Rocky Branch syncline. The strike of this downwarp is about N. 65° W. There is approximately 20 feet of closure.

A dome, with about 20 feet of closure, is located less than 1 mile northeast of the road intersection at Lillydale. The structure commonly known as the State Line dome trends N. 50° W. from northwestern Pickett County, through the extreme northeastern part of Clay County and into Kentucky. Three wells (275, 300, 57) have been drilled on this structure in Tennessee, none of which have produced oil, although gas was used for domestic purposes from the Clark-Thomas Oil Company's A. T. Speck No. 1 (57) and the Robinson Oil Company's G. D. Phillips No. 1 (275). Production was obtained below the Pencil Cave horizon in the Bell Brothers-Clark, J. T. Clark No. 1 (44) in Clinton County, Kentucky, a short distance west of the State Line dome, and just north of the Kentucky state line.

The Lillydale dome is a small upwarp with less than 20 feet of closure. Sharp dips are present to the north, especially in the Leipers formation along Wolf River just north of its junction with Obey River. One well, the Owens-Mitchell-Clark, F. A. Scott No. 1 (285), has been drilled on this structure. Only shows were recorded.

Strong dips in the Chattanooga shale to the east and west defines a dome located on the J. A. Gamewell farm, 0.3 of a mile southwest of the Edward Clark bridge across Obey River and approximately 1 mile south-southwest of Lillydale. The structure trends N. 20° W. Owens-Mitchell, J. A. Gamewell No. 1 (103), tested this structure to a depth of approximately 155 feet below the base of the Pencil Cave, with only gas shows.

The past production on the Stanford Stamps lease is located 1.2 miles due west of the Edward Clark bridge over Obey River. Accumulation here appears to be confined to the south end of a narrow dome which trends almost due north. Strong east dip may be seen along Obey River where this stream transects the northern part of the structure. Fairly strong dip is present to the south on the Chattanooga shale. Six wells (303, 304, 305, 306, 307, 137), three of which have been productive, have been drilled on this dome.

Strong north dips in the Leipers formation along Sulphur Creek immediately north of the mouth of this stream define a local structure here called the Sulphur Creek dome. The apex appears to center approximately one-half of a mile north of the confluence of Sulphur Creek and Obey River. The dome strikes N. 5° E. and has 10+ feet of closure. Two wells (129, 130) have been drilled on this structure, one of which, Read's C. Tom Hogan No. 1 (129) furnished gas for several years for domestic purposes.

From the top of the Sulphur Creek dome the Chattanooga shale and Leipers formation dip to the southwest into a structural low, the Cedar Hill School basin or syncline. The center of this downwarp is located 1.5 miles northeast of Willow Grove and 0.7 of a mile south of Cedar Hill School. The strike is N. 25° E. and the structure has closure of more than 20 feet. Johnson et al., J. S. Stover No. 1 (316), was drilled in the southwestern part of this low, and the A. A. Alexander et al., J. S. Stover No. 1 (318), produced 500 barrels flush at a depth of 755-760 feet, probably from the Ridley limestone; this well was located just south of Obey River at the western edge of the Cedar Hill basin.

Obey River transects a small closed dome immediately west of the Cedar Hill School basin and 1 mile north-northeast of Willow Grove School. Abnormal dips in the Ordovician limestone, approaching at least 15°, are present to the south. To the northwest the strata dip into a gentle syncline immediately east of Willis Bottom. Johnston et al., J. S. Stover No. 2 (317) was drilled in 1923 on this structure, but the well was lost at 518 feet, 10 feet below the base of the Pencil Cave.

Producing Horizons.—Although good shows of oil have been reported in rocks of the Trenton group in the Lillydale area, all of the production to date has been from formations older than the upper member of the Carters limestone (Plate XV). The deepest production was obtained in the New Domain Oil & Gas Company's A. Phillips No. 1 (272) from a porous horizon at 1,385 feet, 1,337 feet below the base of the Chattanooga shale, undoubtedly from the upper part of the Knox dolomite group. This same zone produced oil in the Robinson Oil Company's Andrew Phillips No. 1 (274). Stratigraphically, these two pays are the deepest in the Upper Cumberland district.

W. S. Raydure's L. J. Holman No. 1 (135) produced a small amount of oil at 675 feet from the Ridley limestone, and this same limestone was probably the productive formation in A. A. Alexander et al., J. S. Stover No. 1 (318). Two pay zones were found in the Lebanon limestone in the Bell Brothers-Clark No. 1 (44), just across the state line in Clinton County, Kentucky. Resser and Edward's Stanford Stamps No. 1 (303) and No. 2 (304) produced oil from the lower part of the Carters limestone, approximately 60 feet below the Pencil Cave.

Developments.—The New Domain Oil & Gas Company's A. Phillips No. 1 (272), located on Vans Branch in northwestern Pickett County, was the first commercial well in the Lillydale area. This test, which spudded in March 25, 1905, made approximately 500 barrels before it was ruined by a shot. The same Company's No. 2 (273), drilled in the fall of 1906, found only a show in the same horizon.

In Clay County, W. S. Raydure's L. J. Holman No. 1 (135), about 2 miles west of Lillydale, produced a small amount of oil in 1922 before it was abandoned. A test well (318) completed in May 1926, by A. A. Alexander et al., on the J. S. Stover farm, found oil at 755-760 feet. Two dry or near-dry holes (316, 317) had been drilled previously on this lease. A small amount of oil was sold from the Bell Brothers' J. T. Clark No. 1 (44) north of Lillydale in 1927, and when drilled deeper in 1937 by J. T. Clark the well flowed oil at 726 feet. The initial production was reported at 100 barrels per day.

In 1928, Resser and Edwards found a productive structure on the Stanford Stamps lease, 1.5 miles west of Lillydale. Six wells were drilled in the immediate vicinity of the discovery, but only three of them produced oil in commercial amounts.

The most significant well drilled in the Upper Cumberland district within recent years was the Robinson Oil Company's Andrew Phillips No. 1 (274), which was completed on December 15, 1937. The test was located very near the A. Phillips No. 1 (272), drilled in 1905 by the New Domain Oil & Gas Company. After recording several gas shows in the Trenton and Stones River groups, this test encountered saturation from 1,384-1,394 feet in what the driller recorded as a "brown and gray sand" (page 121). A few samples made available to this Division below 1,300 feet strongly suggests that this test entered the Knox dolomite group at about 1,310 feet and that the producing horizon is in rocks of Canadian age. This test has never been persistently pumped and its potential production is unknown. Early in 1939, after being temporarily abandoned for more than a year, there were reports that this well was to be cleaned out and put on pump.

Production.—The total production in the Lillydale area is estimated at approximately 5,000 barrels. The Bell Brothers-Clark, J. T. Clark No. 1 (44) produced about 2,000 barrels, 1,000 barrels of which were produced in 1937. The New Domain Oil & Gas Company's A. Phillips No. 1 (272) and the A. A. Alexander et al., J. S. Stover No. 1 (318) produced about 500 each before they were abandoned. The two wells on the Stanford Stamps lease may have produced 2,000 barrels.

ASHBURN CREEK-JOUETT CREEK AREA

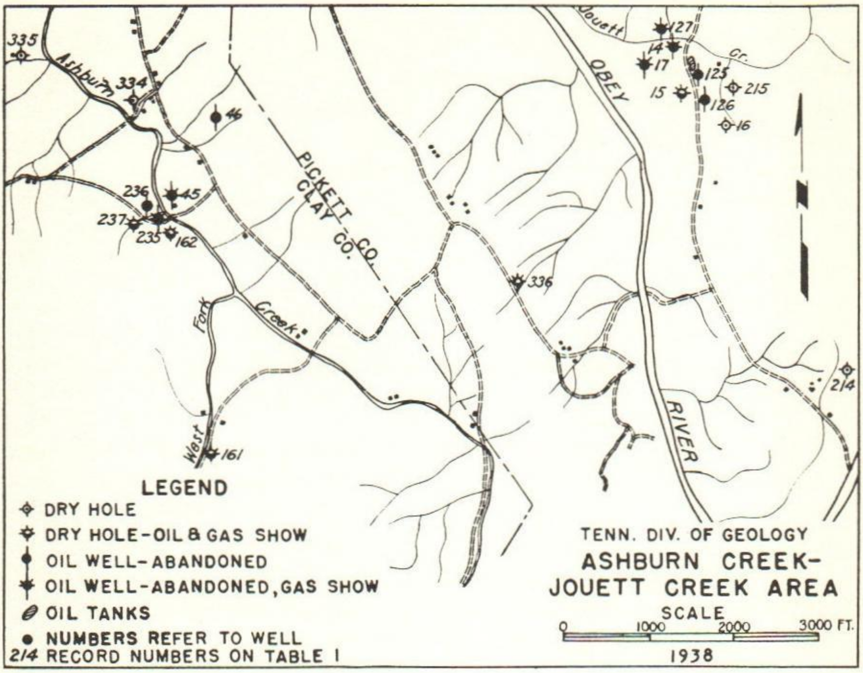
(PLATE XIV)

Location.—The Ashburn Creek-Jouett Creek area is located approximately 2.5 miles south of Lillydale along the Clay-Pickett County line. Ashburn Creek flows along the extreme eastern part of Clay County and Jouett Creek is in western Pickett County. Obey River serves as a boundary between the two areas. State Highway 53 skirts the northern edge of the general district, and the developments along Jouett Creek are located immediately south of this road. The Ashburn Creek area is accessible from State Highway 53 by a county road which leads south and thence east from St. John's School.

Physiography.—The developments in this area have been along the flood plains of Ashburn and Jouett creeks, which are immediate tributaries to Obey River. These streams, whose flood plains are generally less than 600 feet above sea level, are bordered by higher hills which range in elevation from less than 800 to more than 900 feet. In general, the dissection is not as sharp as in many other areas in Clay and adjoining counties.

Stratigraphy.—Ashburn and Jouett creeks have carved their valleys below the Mississippian into the underlying shaly limestones of the Leipers formation. The base of the Leipers is not exposed at any place in the immediate area. Approximately 20 feet of Chattanooga black shale are exposed along the streams and forms the valley floor near their headwaters. The cherty limestones and shales of the Fort Payne formation form the upper part and cap most of the uplands. The lower Warsaw limestones cap the linear ridge along the Clay-Pickett County line between Ashburn and Jouett creeks.

TENNESSEE DIVISION OF GEOLOGY BULLETIN 47, PLATE XIV



Sketch map of the Ashburn Creek-Jouett Creek area showing well locations and subsurface structure on the Pencil Cave horizon.

Subsurface Stratigraphy.—The general lithology of the Trenton rocks which underlie the Ashburn Creek-Jouett Creek district is shown in the following sample study:

Doctors Syndicate, B. C. Arney No. 1

LOCATION: Ashburn Creek-Jouett Creek area. PLATE: XIV. NO.: 17.
COMPLETED: Summer, 1938. ELEVATION: 655 ft. TOTAL DEPTH: 560 ft.
PRODUCTION: Oil, 20 barrels per day. PRODUCING FORMATION: Hermitage, 540-545 ft.

Lithology	*From*	*To*	*Thick*
LOWER MISSISSIPPIAN GROUP (27 ft.):			
FORT PAYNE FORMATION (5 ft.):			
Chert and soil	0	5	5

Lithology	*From*	*To*	*Thick*
CHATTANOOGA SHALE (22 ft.):			
Shale; black, fissile, carbonaceous	5	27	22
MAYSVILLE AND TRENTON GROUPS (218 ft.):			
LEIPERS AND CATHEYS FORMATIONS (218 ft.):			
Samples missing	27	245	218
TRENTON GROUP (300 ft.):			
CANNON LIMESTONE (240 ft.):			
Limestone; light- to medium-gray, fine- to medium-grained	245	250	5
Limestone; white to light-gray, medium-grained	250	265	15
Limestone; very dark-gray, fine- to medium-grained, with gray, calcareous shale	265	275	10
Limestone; medium-gray, fine- to medium-grained	275	285	10
Limestone; medium-gray, medium-grained, with some dark-gray, calcareous shale	285	295	10
Limestone; dark-gray, fine- to medium-grained	295	300	5
Limestone; dark-gray, medium-grained, with ostracods (*Isochilina* sp.)	300	305	5
Limestone; medium- to dark-gray, fine- to medium-grained, with dark-gray, calcareous shale	305	310	5
Limestone; medium-gray, fine- to medium-grained	310	315	5
Limestone; dark-gray, coarse-grained	315	325	10
Shale; gray and tan, soft, calcareous, with a considerable amount of dark-gray, coarse-grained limestone	325	335	10
Limestone; light- to dark-gray, fine- to medium-grained	335	345	10
Limestone; light- to medium-gray, medium-grained	345	355	10
Limestone; light- to medium-gray and brown, medium-grained	355	360	5
Limestone; light- to medium-gray, medium-grained	360	370	10
Limestone; gray to light-brown, medium-grained	370	405	35
Limestone; light- to medium-gray, fine- to medium-grained	405	430	25
Limestone; medium- to dark-gray and brown, fine- to coarse-grained	430	460	30
Limestone; gray to tan and brown, medium- to coarse-grained	460	470	10
Limestone; medium- to brownish-gray, fine to medium-grained	470	485	15
HERMITAGE FORMATION (60 ft.):			
Limestone; light-gray to greenish-gray, fine- to medium-grained ("green lime" of drillers)	485	490	5
Limestone; light- to medium-gray, fine- to medium-grained, with fragment of *Dalmanella*	490	500	10
Limestone; medium- to dark-gray, medium-grained, with considerable amount of dark-grey, argillaceous, calcareous shale	500	505	5

Lithology	*From*	*To*	*Thick*
Limestone; light- to medium-gray, medium-grained	505	510	5
Limestone; dark-gray, medium-grained, with gray, calcareous shale	510	520	10
Limestone; dark-gray, medium-grained, with considerable amount of medium-gray, hard, rounded, calcareous shale	520	530	10
Shale; light- to dark-gray, dense, hard, rounded, calcareous, with medium-gray, medium-grained limestone	530	535	5
Limestone; very dark-gray, medium-grained, with considerable amount of medium-gray, hard, rounded, calcareous shale	535	540	5
Limestone; medium- to dark-gray, fine- to coarse-grained, with brown to gray and brownish-green, soft, thinly-laminated shale (Mud Cave of drillers)	540	545	5
BLACK RIVER GROUP (15 ft.):			
CARTERS LIMESTONE—upper member (10 ft.):			
Limestone; very light-gray, fine- to medium-grained, with a small amount of white and gray, dense to slightly porous chert	545	550	5
Limestone; medium-gray to brownish-gray, fine- to coarse-grained, with white to gray and brown, dense, angular chert	550	555	5
CARTERS LIMESTONE—lower member (5 ft.):			
Shale; light-gray to greenish-gray, soft, greasy, with flakes of biotite (Pencil Cave of drillers), with light-gray, fine- to coarse-grained limestone	555	560	5

Samples are available from the top of the lower member of the Carters limestone to the upper part of the Knox dolomite group from the Carnahan Oil Company's Joe D. Moredock No. 2 (236). Sample descriptions on this test follow:

Carnahan Oil Company's Joe D. Moredock No. 2

LOCATION: Ashburn Creek-Jouett Creek area. PLATE: XIV. NO.: 236.
COMPLETED: Aug., 1928. ELEVATION: 601 ft. TOTAL DEPTH: 1451 ft.
PRODUCTION: Oil. PRODUCING FORMATION: Lebanon, 691-697 ft.

Lithology	*From*	*To*	*Thick*
BASE OF TRENTON GROUP (driller's log) at 495 ft.			
BLACK RIVER GROUP (107 ft.):			
CARTERS LIMESTONE—upper member (16 ft.):			
Samples missing	495	511	16

Lithology	*From*	*To*	*Thick*
CARTERS LIMESTONE—lower member (91 ft.):			
Limestone; light-gray to light-tan, dense to fine-grained, with green, dull, shale with biotite flakes (Pencil Cave of drillers), and light- to dark-gray, dense, angular chert	511	515	4
Limestone; medium-gray, dense to fine- and medium-grained, with some light-gray calcareous shale	515	522	7
Limestone; gray to dark-gray, fine- to medium-grained, with light-gray, calcareous shale	522	537	15
Limestone; light-gray to tan, dense to medium-grained	537	553	16
Limestone; tan to light-gray, dense to medium-grained, with light-colored, rough chert, some of which carries some dolomite crystals	553	579	26
Limestone; tan, dense to fine-grained	579	602	23
STONES RIVER GROUP (623 ft.):			
LEBANON LIMESTONE (123 ft.):			
Limestone; dark-gray, fine- to medium-grained, with a small amount of very dark-gray, dense, smooth, vitreous, angular chert	602	614	12
Limestone; gray to dark-gray, fine- to medium-grained, with some black, dense, sharp chert	614	618	4
Limestone; light-gray to light-tan, dense to fine-grained	618	638	20
Limestone; gray to dark-gray and brown, fine- to medium-grained, with gray, calcareous shale	638	645	7
Limestone; gray to dark-gray and brown, dense to fine-grained, with gray and tan, porous calcareous shale	645	663	18
Limestone; very dark-gray and tan, fine- to medium-grained, with gray and brown, soft, porous shale	663	691	28
Limestone; gray to dark-gray and brown, dense to fine-grained	691	697	6
Limestone; tan to very dark-gray, fine- to medium-grained	697	725	28
RIDLEY LIMESTONE (125 ft.):			
Limestone; tan to brown, fine- to medium-grained, with some brownish, soft, silica	725	750	25
Limestone; gray to dark-gray and brown, fine- to medium-grained	750	770	20
Limestone; gray to dark-gray, medium- to coarse-grained	770	780	10
Limestone; gray to dark-gray and brown, dense to fine-grained	780	800	20
Limestone; gray to dark-gray, fine- to medium-grained	800	825	25

Lithology	*From*	*To*	*Thick*
Limestone; gray to dark-gray and brown, fine- to medium-grained	825	850	25
PIERCE LIMESTONE (25 ft.):			
Limestone; light- to dark-gray and brown, dense to medium-grained, with a considerable amount of very light-gray, soft, calcareous shale	850	875	25
MURFREESBORO LIMESTONE (350 ft.):			
Limestone; very dark-gray, dense to fine-grained, with gray, nearly black, dense, sharp, vitreous chert	875	900	25
Limestone; very dark-gray, medium- to coarse-grained	900	925	25
Limestone; gray to dark-gray, fine- to medium-grained	925	1025	100
Limestone; very dark-gray, fine- to coarse-grained, with some light-gray and tan, soft, calcareous shale	1025	1075	50
Samples missing	1075	1100	25
Limestone; gray to dark-gray, fine- to medium-grained	1100	1125	25
Limestone; gray to dark-gray, dense to medium-grained	1125	1150	25
Limestone; light- to dark-gray, fine- to medium-grained, with brown, calcareous shale	1150	1200	50
Limestone; very dark-gray, dense to medium-grained	1200	1225	25
CANADIAN (?) (42 ft.):			
ZONE B (42 ft.):			
Limestone; light-gray, dense to fine-grained, magnesian, with greenish-gray, soft shale	1225	1267	42
CANADIAN (91 ft.):			
ZONE C_2 (91 ft.):			
Dolomite; light-gray to brown, with light-colored, dense, sharp chert, and some transparent, angular, glassy quartz	1267	1272	5
Dolomite; tan to brown, medium- to coarse-grained	1272	1280	8
Dolomite; tan to brown, medium- to coarse-grained, with some very dull white, soft, dolocastic chert	1280	1292	8
Chert; light-colored, transparent to translucent, generally dense, some dolocastic, sharp, with light-gray and tan, coarse-grained dolomite	1292	1300	8
Dolomite; tan to brown, medium- to coarse-grained, with dark-green, hard and soft, dolocastic shale, and white to cream, dense, angular chert	1300	1308	8
Dolomite; tan and brown, medium- to coarse-grained, with gray, very porous, probably dolocastic, chert	1308	1317	9

Lithology	*From*	*To*	*Thick*
Dolomite; light-gray to brown, coarse-grained	1317	1322	5
Dolomite; light-gray to tan, coarse-grained, with abundant white to milky, dense to dolocastic, angular chert	1322	1327	5
Dolomite; tan and brown, fine- to medium-grained	1327	1332	5
Dolomite; tan to brown, medium- to coarse-grained, with light-colored, dense, angular chert	1332	1342	10
Dolomite; brown, coarse-grained, with white, dense to porous chert	1342	1350	8
Dolomite; brown, fine- to medium-grained, with light-colored, dense to porous, angular chert	1350	1354	4
Chert; white, dull, dense to well-developed dolocastic varieties, sharp, generally translucent, with light-tan to light-brown, coarse-grained dolomite	1354	1358	4

Structure.—Structural work on the base of the Chattanooga shale shows the presence of three domes in the Ashburn Creek-Jouett Creek area. Restricted drilling to date and incomplete well records on past drilling do not permit structural contouring on the base of the Pencil Cave in this area.

A sharp, triangular-shaped dome, covering approximately 200 acres, centers along Jouett Creek, 0.3 of a mile south of State Highway 53 and 1 mile east of the Clay County line. Closure on the Chattanooga is 20+ feet. Strong dips of 4° to 5° may be seen in the Chattanooga shale and Leipers formation along Jouett Creek just east of the crest. This structure, which has been productive, is generally known as the Jouett Creek dome.

A N. 65° W. trending dome centers 0.6 of a mile due east of the confluence of Ashburn Creek and West Fork and 0.3 of a mile east of the Clay County line. Dips in the Chattanooga shale are fairly gentle in all directions, except to the south, where the beds dip sharply into a shallow syncline. One well, Harrison et al., Wilburn Heirs No. 1 (336), has been drilled on this upwarp. This test, however, was temporarily abandoned at 472 feet because of heavy gas pressure; it did not reach the lower Sunnybrook horizon which has been productive less than one mile to the northeast on the Jouett Creek dome.

The Ashburn Creek dome is located approximately 1 mile south of the junction of Ashburn Creek and Obey River and is a relatively sharp upwarp on which the southeast and northeast dips reach 4° to 5°. The trend of the structure is N. 70° E. The productive wells on the Joe D. Moredock (235, 236) and J. T. Clark (45) were located on this dome.

Producing Horizons.—Productive horizons in the Ashburn Creek-Jouett Creek area range in age from the upper Cannon of the Trenton in the Clark Oil Company's Harrison Heard No. 1 (127) to the lower part of the Lebanon limestone in the Carnahan Oil Company's Joe D. Moredock No. 2 (236).

Along Jouett Creek the most consistent and best producing horizons have been in the upper member of the Carters limestone, between the Mud Cave and Pencil Cave. In four wells (14, 17, 125, 126) in the Jouett Creek area the pays were found from 3 to 12 feet above the Pencil Cave. The Clark Oil Company's B. C. Arney No. 1 (14) produced from three horizons; the upper pay was at 385 feet, probably very close to the Cannon-Hermitage contact, the second productive horizon, in the upper member of the Carters, was encountered at 452 feet, and the lowest pay was drilled at 595 feet in the middle part of the Lebanon limestone.

In the Ashburn Creek area three paying horizons were found in wells (235, 236, 45) drilled by the Carnahan Oil Company. The upper one is probably in the lower Carters and the last two were in the Lebanon limestone. The deepest well in the Ashburn Creek-Jouett Creek area, the Carnahan Oil Company's Joe D. Moredock No. 2 (236), was completed at 1,451 feet in Zone C_2 of the Canadian. No oil or gas shows were reported below the producing zone in the lower part of the Lebanon at 691 feet.

Developments.—Oil was discovered in 1927 along Jouett Creek by the Clark Oil Company's B. C. Arney No. 1 (14), which found oil associated with salt water at a depth of 385 feet, probably at the Cannon-Hermitage contact. When deepened the well came in flowing 100 barrels per day natural at 452 feet in the upper member of the Carters limestone between the Mud Cave and the Pencil Cave. During the summer of 1937, after being temporarily abandoned for several years, Lon Heckathorn deepened the discovery well in the Jouett Creek area, the Clark Oil Company's B. C. Arney No. 1 (14), from 452 to 586 feet. At this depth the well was taken over by the Doctors Syndicate and a productive horizon was found in middle part of the Lebanon at 595 feet. The well flowed 250 barrels in 12 hours, and after being shut in for lack of storage, later failed to produce. The well was subsequently deepened to 775 feet. The most recent well drilled in the Jouett Creek area, the Doctors Syndicate, B. C. Arney No. 1 (17), found oil and salt water at 540-545 feet in the lower part of the Hermitage formation. The well, which had a flush of 20 barrels per day, is now abandoned. To date, 9 wells have been drilled in the Jouett Creek area, 4 of which have produced oil.

On the Clay County side of this district, along Ashburn Creek, the Carnahan Oil Company's J. T. Clark No. 1 (45) flowed oil on August 25, 1927. Saturation was found at 573 feet in the lower part of the Carters limestone. According to the driller the first evidence of the pay horizon was a wet gas issuing from the casinghead. Immediately after pulling the tools the oil had reached the top of the well and flowed 10 barrels per hour for the first 24 hours, filling two 100-barrel tanks. Since this discovery well 9 tests have been drilled in the Ashburn Creek area, only 3 of which produced oil in commercial quantities.

Late in 1927 the Paragon Development Company laid a 2-inch pipeline from their Clinton County, Kentucky, line south through the Lillydale area into the Ashburn Creek-Jouett Creek district. In Tennessee this line totaled 24,778 feet. It has since been removed.

Production.—The Paragon Development Company ran 6,892 barrels of oil from the Jouett Creek wells during 1927, but the production declined to 894 barrels the following year. During 1929 and 1930, less than 1,000 barrels were reported. Figures are not available from 1930 to 1937, probably not more than 3,000 barrels were marketed off the lease. In 1937 one well, the Clark Oil Company's B. C. Arney No. 1 (14), drilled deeper by the Doctors Syndicate, produced 530 barrels and in 1938 this well and the Doctors Syndicate, B. C. Arney No. 1 (17), had a combined total of 1,100 barrels.

No accurate figures on the Ashburn Creek production are available, but what are believed to be conservative figures, based upon the best local information, indicate that the Carnahan Oil Company's 3 productive wells produced approximately 10,000 barrels before they were abandoned. The Ashburn Creek-Jouett area is considered to have had a total production of approximately 25,000 barrels.

PETROLEUM GEOLOGY

STRATIGRAPHIC DISTRIBUTION OF PRODUCING HORIZONS

(PLATE XV)

Rocks ranging in age from the upper part of the Knox dolomite group to the upper part of the Cannon limestone, inclusive, have been commercially productive in this area.

TRENTON

In parts of Kentucky, especially in Cumberland County immediately north of Clay County, production has been found at depths of 160-190 feet below the base of the Chattanooga shale. This zone, locally known as the "Fannys Creek sand," is probably in the lower part of the Catheys formation. It has not been productive in the area covered by this report, although good shows were recorded from about this stratigraphic position in the Mill Creek, Kettle Creek-Pine Branch, Goodpasture Bend, Willow Grove-Irons Creek, and Lillydale areas.

The youngest productive horizon drilled to date in this area is in the upper half of the Cannon limestone; ranging from slightly less than 250 to about 300 feet below the Chattanooga shale. The name upper or first Sunnybrook became well established for this pay many years ago. Many tests throughout Clay County have recorded good shows of oil and gas or both in this horizon. Excellent production was obtained from it in the Fox Springs-Mitchell Creek district, although some of the pays were somewhat lower stratigraphically than the average upper Sunnybrook horizon.

The name "Anderson sand" has generally been used for a somewhat widespread zone of porosity which occurs from 325 to 375 feet below the black shale. Stratigraphically, it is about the middle of the Cannon limestone. The production at 340 feet in J. C. Overstreet and Son's Sam Nevins No. 1 (246)* in the Kettle Creek-Pine Branch area, and in E. G. Brandenberger et al., C. A. Greenwood No. 2 (111) and the J. D. Holman No. 1 (134), both in the Willow Grove-Irons Creek area, were probably in the Anderson. It has been, however, of very minor importance as a productive horizon in Clay County.

Very recent production in the Celina area comes from the lower part of the Cannon limestone, about 400 feet below the

*Numbers in parentheses refer to well record number on Table 1.

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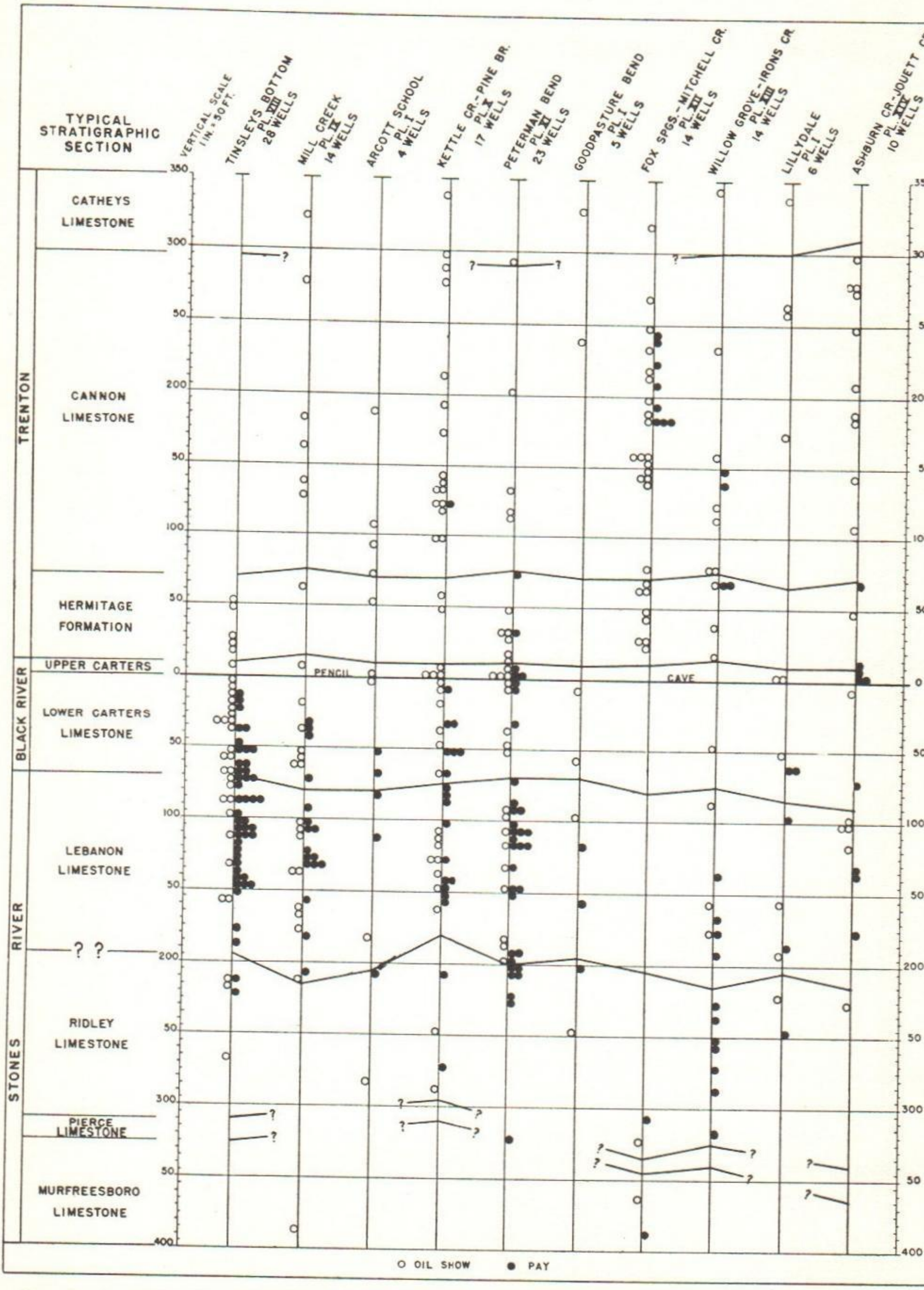

Graph showing the stratigraphic position and distribution of producing horizons.

Chattanooga. Except J. H. Overstreet et al., Kyle and Vaughn No. 1 (160), these wells have been completed since January 1, 1939, and are not included in the present report. Drilling to present, however, has shown a general zone of porosity in the Celina area between the Anderson and the lower Sunnybrook horizons. To the writers' knowledge no name has been suggested for this pay.

The second or lower Sunnybrook of the drillers occurs from 15 to about 50 feet above the Pencil Cave and from about 450 to over 500 feet below the base of the black shale. The true lower Sunnybrook is definitely within the Hermitage formation. It has produced oil in the Peterman Bend, Willow Grove-Irons Creek, and Ashburn Creek-Jouett Creek areas. Inspection of past drilling records shows that in some cases the pays in the upper member of the Carters limestone, between the Mud Cave and Pencil Cave, have been called lower or second Sunnybrook. It is here proposed to restrict this term to porous zones within the Hermitage formation.

BLACK RIVER-STONES RIVER

Most of the oil produced in the area covered by this report has come from limestones of the Black River and Stones River groups. No definite terminology exists as to the naming of these productive horizons. About 12 years ago a few of the local operators used the name "first, second and third Celina pays" for the production to approximately 250 feet below the Pencil Cave. These names, however, were not defined accurately and within recent years appear to have been abandoned. The senior writer[97] used the general term "Tinsleys Bottom pays" for the Black River and Stones River production in the area. More definite correlations, especially with reference to approximate stratigraphic equivalency, will be necessary before names may be assigned to these pays.

In the Peterman Bend and Ashburn Creek-Jouett Creek districts, production has been obtained from the upper member of the Carters limestone, between the two caves. As mentioned before, many operators considered this production as lower or second Sunnybrook. In Cumberland County, Kentucky, this pay is locally called the "fudge sand."[98]

The lower member of the Carters limestone has been productive throughout the entire area, ranging from immediately below

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[97]Born, K. E. Oil and gas developments in Tennessee in 1936: Trans. A. I. M. E., vol. 123, p. 449, Table 1, 1937.

[98]Beckner, Lucien. Cumberland County oil horizons: Trans. Kentucky Acad. Sci., vol. 2, p. 26, 1927.

the base of the Pencil Cave to the top of the Lebanon limestone of the Stones River group. Some of the best production in the Tinsleys Bottom area and in Peterman Bend was in the lower part of the Carters.

The most prolific horizon to date, in the Upper Cumberland district, is in the lower 25 feet of the Carters limestone and the upper 75 feet of the Lebanon limestone. Some of the best wells in the entire region, such as Dafoe and Dafoe's G. H. Lynn No. 2 (177), in Tinsleys Bottom, J. H. McClurkin's Barlow Langford No. 1 (163) in the Mill Creek area, W. P. Clements et al., O. N. Cherry No. 1 (37) at Arcott School, and Overstreet and Miller's Cordell Hull No. 1 (138) in the Kettle Creek-Pine Branch district, were very near the contact of the Lebanon and Carters limestones.

Except in the Arcott School and the Fox Springs-Mitchell Creek areas, the lower part of the Lebanon has produced oil in all of the fields in Clay County. This production, however, has been generally small compared with the upper part of the formation.

Oil has been found in the upper half of the Ridley limestone in the Tinsleys Bottom, Arcott School, Kettle Creek-Pine Branch, Goodpasture Bend, Willow Grove-Irons Creek, and Lillydale areas. The best wells were Bryan Davis et al., C. H. Buford No. 1 (30) in Goodpasture Bend, the Clark Oil Company's James Arms No. 1 (3) in Peterman Bend, and in Overstreet and Miller's Cordell Hull No. 1 (138) on the Pine Branch dome, which found its deepest production in this formation. Small pays occurred in the lower part of the Ridley limestone in the Fox Springs-Mitchell Creek and Willow Grove-Irons Creek areas. They were unimportant commercially.

No production is definitely known from the thin Pierce limestone. The Clark-Hill Oil Corporation's J. M. Gray No. 3 (109) in Peterman Bend found oil at 619-630 feet, 323 feet below the base of the Pencil Cave. No samples are available from this well, but based upon sample studies from nearby tests, this production may have been in the Pierce limestone or in the upper part of the Murfreesboro.

The Ohio Oil Company's J. W. Pennington No. 3 (270) in the Mill Creek area flowed 100 barrels initial at a depth of 953-962 feet, 434 feet below the Pencil Cave and undoubtedly from the Murfreesboro limestone, probably as much as 50 feet below the top of that formation. A small amount of oil was found at 746 feet in the Ava Oil & Gas Company's Mary Williams No. 3 (347) in the Fox Springs district; this production is probably from the upper part of the Murfreesboro. Sample studies of Cox, Spivy, and Greenup's Fletcher and Brown No. 2 (102), drilled in the northern part of Overton County, show that the few barrels pumped from 1,020 feet were in the Murfreesboro limestone, 231 feet below the typical dark-colored cherts which are here considered to mark the top of that formation.

KNOX DOLOMITE

Fifteen test wells have been drilled into the upper part of the Knox dolomite group in the area covered by this report (Table 3). Incomplete records indicate that production was obtained in 5 of the tests, no data are available on 3, and 7 were dry or near-dry holes. Good shows were reported in Dafoe's and DeGive's J. J. Osgathorpe No. 1 (256) and in the New Domain Oil & Gas Company's A. Phillips No. 2 (273). According to the records in the files of this Division, small production was encountered in the upper part of the Knox dolomite in the following wells: Dickson et al., A. T. Davis No. 2 (75), Spain et al., W. J. Nevins No. 2 (255), the New Domain Oil & Gas Company's A. Phillips No. 1 (272), the Robinson Oil Company's Andrew Phillips No. 1 (274), and the Powell Oil Company's Arch Short No. 3 (288). None of these pays were persistent producers and at the beginning of 1939 there was no commercial production from the upper part of the Knox dolomite group in Clay or adjoining counties.*

Based upon sample studies of individual wells or upon sample data from nearby tests, the productive horizons to date in the Knox dolomite are near the top of that group, ranging from 29 feet in Dickson et al., A. T. Davis No. 2 (75), to 68 feet in the Robinson Oil Company's Andrew Phillips No. 1 (274) below the base of the Murfreesboro limestone.

Since sample studies to date have failed to show the presence of the true St. Peter sandstone in the Upper Cumberland district, the continued use of this name is misleading and confusing. Because of convenience it seems advisable to assign a name to this pre-Stones River productive zone. After careful deliberation, the Tennessee Division of Geology recommends the term "deep pay" or, in Clay and adjoining counties, "Celina deep pay." This name is assigned with the definite understanding that it does not imply that these producing zones necessarily occupy the

*Since completion of the manuscript for this report commercial production has been found in the Lain Oil & Gas Company's T. W. Roberts No. 2 in the Celina field, 0.6 of a mile northwest of the Celina courthouse. The productive horizon was found at approximately 1110 feet in a cherty dolomite undoubtedly in the upper part of the Knox dolomite group.

same stratigraphic position throughout the area. Only future drilling and careful subsurface studies will demonstrate whether or not they are definite stratigraphic units. In the future, therefore, the name "St. Peter sandstone" will not be used by this Division, but will be supplanted by the general term "deep pay."

SOURCE BEDS

After a half century of scientific investigations, neither the exact nature of the source material nor the processes by which it is converted into the natural hydrocarbons is yet understood. While there has been a general acceptance of the organic theory for the origin of petroleum, there are many divergent theories advanced for accumulation and migration. The question of the source of the oil found in the Ordovician limestones of the Upper Cumberland district is one which has received but little consideration, due largely, as in many petroliferous areas, to the fact that no incontrovertible evidence has been found. As Rich[99] has pointed out, it has become a custom to consider the "source rock" to be the nearest likely-looking rock, preferably a dark, carbonaceous shale, but there is seldom a detailed discussion of the subject. In a review of the literature on the source rocks of petroleum, the conclusion is forced that there is no consistent position of the source rocks with regard to the reservoir rocks. In some productive areas logical conclusions suggest practically no migration of oil from its source to its present position; in others the source beds are considered above the pay horizon; and, in still others, below the productive beds. Current ideas regarding source beds have been recently summarized by Snider.[1]

1. Organic shales or limestones are almost unanimously held to be the source beds for the oils in the fields of the United States.

2. The majority of geologists evidently believe that source beds should be fossiliferous, although a minority believe that organic matter has been precipitated under conditions not favorable for the growth of organisms and that source beds need not be visibly organic.

3. Black or dark-colored marine shales are generally sought as source beds, and it is also generally believed that they should still be notably bituminous or carbonaceous or both, even though they may have yielded large quantities of oil to reservoirs.

4. In fields with no faults or unconformities, the dark-colored shale nearest the reservoir is generally suggested as the source bed.

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[99]Rich, J. L. Problems of the origin, migration, and accumulation of oil: Problems of Petroleum Geology (Amer. Assoc. Petroleum Geologists), p. 338, 1934.

[1]Snider, L. C. Current ideas regarding source beds for petroleum: Problems of Petroleum Geology (Amer. Assoc. Petroleum Geologists), p. 62, 1934.

5. Where the oil deposits are associated with faults or unconformities, there is a strong tendency to ignore any nearby beds and to seek some deep-seated source for the oil.

6. Faults are commonly regarded as avenues of migration of oil from deep-seated source beds into the reservoirs and, at the same time, as seals against the movement of oil from the reservoir to the surface.

7. The majority seem to believe that any marine, dark-colored shale may furnish enough oil for commercial deposits by migration to, and accumulation in, the reservoir. A few look for some particular type of shale as a source, but there is little agreement as to the type.

Due primarily to its highly carbonaceous and bituminous character, the Chattanooga shale has naturally received first consideration as a possible source bed for the oil in the Upper Cumberland district. The Chattanooga shale is still rich in oil. Distillation tests of this shale, reported by Nelson[2], indicates yields as high as 40 gallons per ton. Such a shale is an ideal source bed for petroleum and the possibility of this black shale as the source of the oil in the Upper Cumberland district has been suggested by Lusk[3] and St. Clair.[4]

While no conclusive data have been observed which would completely eliminate the Chattanooga shale as the source rock in the oil fields in the Upper Cumberland district, several facts may be considered that would not support this hypothesis. At least two general horizons in the Trenton group have produced oil in Clay and adjoining counties (Plate XV). These are the upper and lower Sunnybrook "sands" of the driller and occur approximately 250 feet and 475 feet, respectively, below the Chattanooga shale. Lithologically, the Trenton of Middle Tennessee is a limestone section with many interbedded shaly limestones and shales. Provided the source of the oil found in the Trenton is from the black shale, it would have been necessary for the oil to have migrated downward through many relatively impervious shales and impermeable limestones to have reached its present position. Howard[5] has shown that petroleum can not be passed through a limestone with a permeability much less than that required for commercial production. Such permeability is not believed to be widespread in the Upper Cumberland district. Relatively porous zones, on the outcrop certainly as

[2]Nelson, W. A. Oil horizons of Kentucky, northeastern Mississippi, and Tennessee: Bull. Amer. Assoc. Petroleum Geologists, vol. 8, p. 627, 1924.

[3]Lusk, R. G. Geology and oil and gas resources of the Gainesboro quadrangle, Tennessee: Tenn. Div. Geol., unpublished manuscript.

[4]St. Clair, Stuart. Oil and gas in Kentucky and Tennessee: Problems of Petroleum Geology (Amer. Assoc. Petroleum Geologists), p. 519, 1934.

[5]Howard, W. V. and Love, W. W. Some properties of limestone as a reservoir rock: Econ. Geol., vol. 25, p. 734, 1930.

porous as the Sunnybrook horizons, occur in the section above the upper Sunnybrook horizon. Furthermore, the proximity of these upper Trenton and Maysville zones to the Chattanooga would appear to add to the chances of accumulation, provided the black shale was the source rock; to date only oil and gas shows have been recorded in these rocks. Russell[6] does not believe that the Chattanooga was the source of the oil in the Sunnybrook horizons in Monroe, Cumberland, and Clinton counties in Kentucky, all of which join Clay County to the north.

Essentially the same argument holds for the production below the base of the Trenton and above in Knox dolomite group. In general the Black River and Stones River groups are more dense and less shaly than the Trenton. Production has been found in the Stones River as deep as 434 feet below the base of the Pencil Cave. The hypothesis of a Chattanooga source for this oil is further complicated by the presence of the widespread Pencil Cave horizon, a bentonitic clay, which is so impermeable as to constitute a barrier to the vertical movements of fluids. The present writers consider the existence of considerable amounts of oil below this horizon as significant in their conclusion that the pre-Trenton oil in the Upper Cumberland district has not come from the Chattanooga shale.

The entire Ordovician section, with the possible exception of the upper part of the Knox dolomite group, is here considered as possible source rocks. Dark-colored limestones and shales predominate in this part of the section throughout Middle Tennessee. Fossils are abundant. On the outcrop in Central Tennessee, some of these beds, especially the Cannon and the Stones River group of limestones, contain small vugs filled with oil or a tarry residuum; many of them emit a distinctly petroliferous odor when chips are briskly rubbed together. The writers believe that these beds would constitute an adequate source for the oil in this area.

The migration of oil through limestones, especially those in Clay and adjoining counties that are characterized by considerable differences in porosity and permeability within relatively short distances, offers a multitude of problems upon which little accurate data are available. Present information does not allow either acceptance or rejection of Howard's[7] theory that in limestone accumulation there has been no migration into the reser-

[6]Russell, W. L. Notes on origin of oil in Kentucky: Bull. Amer. Assoc. Petroleum Geologists, vol. 18, p. 1130, 1934.

[7]Howard, W. V. Accumulation of oil and gas in limestone: Problems of Petroleum Geology (Amer. Assoc. Petroleum Geologists), pp. 365-375, 1934.

voir, but rather only within the reservoir. The irregularity of porosity in the limestones of Clay and adjoining counties would seem to preclude the possibility of extensive lateral migration. It must be admitted, however, that if the conclusions of Howard and Love,[8] that a certain amount of fractionation takes place by the absorption of the lighter oils by the limestone, apply to the subsurface in Clay County, then the general absence of dark, heavy oils may be used as an argument for migration.

The few analyses available of oil from the upper part of the Knox dolomite group show that the oils are generally lower in gravity than the overlying oils, ranging from less than 30° to about 37° Baumé. A different source is assumed for this oil, but the position and nature of the source rock is not known.

There is an idea, somewhat generally accepted by the drillers and operators in the Upper Cumberland district, that the oil found to date in the Trenton, Black River, and Stones River groups has migrated upward from a deep-seated source. It must be pointed out that there are no data which substantiate such an assumption. Faults are commonly regarded as avenues for upward migration of oil from a deep-seat source; faults are unknown, either at the surface or on the subsurface, in Clay County. Furthermore, if samples studied from the deeper wells in Middle Tennessee are typical, the source bed possibilities of the pre-Stones River rocks must be considered much less favorable than the overlying strata.

While it is admitted that only meager data are at hand, the writers tentatively hold that: (1) very little, if any, of the commercial oil in the Upper Cumberland district has had its source in the Chattanooga shale; (2) the entire post-Knox Ordovician section is believed to be an adequate source for the oil discovered to date in this area; (3) there has been little migration, either lateral or vertical; and (4) the lower gravity oils from the upper part of the Knox dolomite group suggest a different source or history than the younger Ordovician oils.

RESERVOIR ROCKS

GENERAL

By far the majority of the past and present oil production in the Upper Cumberland district has come from limestones, in which the calcium carbonate content ranges from less than 75 to over 90 per cent (Table 6). While limestones constitute one of the most important rocks from which oil and gas are recov-

[8]Howard, W. V. and Love, W. W. Op. cit., pp. 721-722.

ered, probably no rock differs more radically in its properties as a reservoir rock for oil and gas accumulation. These variations are related in part to the mode of origin of the limestone and in part to the history of the rocks subsequent to their deposition as a calcareous sediment.

While porosity, the amount of open space per unit volume, is a most important property in the accumulation of oil and gas, in order that a limestone may become a reservoir rock these open spaces must be inter-communicating. Only by such relationship may commercial oil occur. Murray [9] has subdivided porosity into continuous porosity if the voids are connected with one another and discontinuous porosity if this inter-communication does not exist; the former renders the rock suitable for commercial accumulation; the latter does not. Both types of porosity are common in limestones.

Porosity in limestone may also be termed primary, originating at the time of or soon after the deposition of the calcareous ooze, or it may be secondary as the result of fracturing, solution, or recrystallization. As pointed out by Murray[10], primary porosity may be possessed by all limestones and varies directly with the uniformity of size of grain and inversely with the degree of induration and packing. Limestones with such porosity tend to be of the discontinuous type because of the filling in of the interstices between the grains or fragments with fine material and cement. For this reason Murray[11] concluded that limestones with primary porosity do not form important reservoirs for accumulation of oil and gas in commercial amounts.

The limestones, which are the productive horizons in the Upper Cumberland district, are generally dense to fine-grained with little or no primary pore-space visible to the eye other than minute openings in bedding planes. The shaly limestones of the Trenton have a certain amount of primary porosity, but the openings generally appear to be of the discontinuous type, and hence unimportant as a reservoir rock. According to Howard[12], chalk, oolitic limestone, primary crystalline limestone and dolomite, and coral limestone have appreciable primary porosity. Sample studies indicate that these types of rocks are not common in the area under consideration.

[9]Murray, A. N. Limestone oil reservoirs of the northeastern United States and of Ontario, Canada: Econ. Geol., vol. 25, p. 453, 1930.

[10]Murray, A. N. Ibid., pp. 454-455.

[11]Murray, A. N. Ibid., p. 455.

[12]Howard, W. V. A classification of limestone reservoirs: Bull. Amer. Assoc. Petroleum Geologists, vol. 12, p. 1155, 1928.

Secondary porosity includes those openings in limestone which have developed subsequent to the deposition and induration of the calcareous sediment. Limestones of this class form the great majority of commercial oil and gas reservoirs, since secondary pore-space is in a large part of the continuous type necessary for commercial reservoirs of oil and gas. Secondary porosity may be developed in limestones by: (1) fracturing, (2) solution, and (3) recrystallization. Recently Howard and David[13] have classified limestone reservoirs into two major groups:

1. Limestones with secondary porosity associated with former erosion surfaces;
   a. Strongly jointed
   b. Not strongly jointed
2. Jointed limestones without secondary porosity.

The important role of solution in the development of porosity in limestones is well established. Murray's[14] studies of a number of limestone reservoirs of the northeastern United States led him to the conclusion that erosion was responsible for the porosities in all of the areas studied.

Although many details are not definitely understood, the general process by which calcareous rocks are taken into solution by meteoric waters is well known. Carbonic acid has long been considered the most important solvent found in ground waters, although Murray and Love[15] concluded that organic acids, generated by soil bacteria, were probably responsible for much if not most of the solution of limestone. Howard and David[16] considered that the solvent action of these organic acids was of the order of 1 to 10 times as effective as that of carbonic acid.

Fractures and joints are obviously the most effective passageways for downward percolating waters charged with carbon dioxide, organic acids, and mineral salts. These solutions travel downward until the water table is reached, where they begin to travel laterally, or nearly so, toward some surface drainage system. Many factors, such as the surface relief, presence or absence of impervious beds, and the permeability of limestone, influence the depth to which water sinks before it begins its horizontal movement. Unless the passages are direct, the carbonic acid will have lost a certain amount of its solvent power before

[13]Howard, W. V. and David, M. W. Development of porosity in limestones: Bull. Amer. Assoc. Petroleum Geologists, vol. 20, pp. 1390-1391, 1936.
[14]Murray, A. N. Op. cit., pp. 458-469.
[15]Murray, A. N. and Love, W. W. Action of organic acids upon limestones: Bull. Amer. Assoc. Petroleum Geologists, vol. 13, pp. 1667-1675, 1929.
[16]Howard, W. V. and David, M. W. Op. cit., pp. 1392-1394.

the water table is reached. Since waters below the water table probably circulate slowly and have been charged with bicarbonates, it is commonly held that very little solution takes place great distances below the water table. For continuous solution it is essential that the ground water circulation be free, in order that the saturated waters may be continuously displaced by unsaturated water capable of taking the carbonates into solution.

The calcareous rocks differ considerably in their solubilities and hence differential solution or leaching is a major process in the development of porosity in limestone. Limestones vary in purity, common constituents other than calcium carbonate, including magnesian carbonate, silica, phosphate minerals, and clayey and sandy materials. These impurities change the solubility of the rock because they are themselves of different solubilities and also because they alter the conditions of equilibrium in the solution in which they dissolve.

During an erosion interval that follows an epoch of limestone deposition a system of solution openings may be formed, which may or may not be filled during the subsequent epoch of sedimentation. Murray[17] shows a close relationship between unconformities and oil accumulation in many of the oil fields in the northeastern United States. Such a relationship seems to exist in the Upper Cumberland district. The proximity of the Sunnybrook horizons and several of the pays below the base of the Trenton to unconformities is not believed to be merely coincidental. Breaks in sedimentation are definitely known to occur at the top of the Knox dolomite group, and at the top of the Lebanon, Carters, Hermitage, and Cannon formations. It is considered significant that the upper part of these formations, with the exception of the Canadian, have been important producers in the area under consideration. Middle Tennessee is believed to have been an area of low relief throughout the Ordovician. On such a land surface the slopes would be gentle and the streams sluggish. In addition to the usual processes of surface weathering, carbonic and organic acids in solution would percolate slowly downward. Such a condition would be almost ideal for the development of porosity by solution and leaching.

The present writers believe that much of the porosity in the Ordovician limestones of this area has been the result of fracturing and jointing due to deformational stresses. Certainly the forces which formed the small, sharp upwarps and downwarps

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[17] Murray, A. N. Op. cit., pp. 463-466.

were also responsible for some of the fracturing of the limestones on the subsurface. Undoubtedly these fractures and joints have been greatly modified by subsequent solution. The behavior of several adjacent wells indicates a type of inter-communication best explained by fractures and joints. In several fields there is a suggestion that the better production has been found on the steeper flanks of the small, sharp domes. Since fracturing is more intense on this part of the structure, this relationship is believed to be significant and is discussed in more detail on pages 169-170.

With a single exception, every hole drilled in the Upper Cumberland district in Tennessee has been with cable tools. No cores have been taken and no quantitative determinations of porosity have been made. The only source of information relative to possible subsurface conditions is from well cuttings. The following remarks on the reservoir rocks in Clay and adjoining counties have been based entirely upon sample studies of a number of the producing horizons and conclusions deduced from the general behavior and history of many of the wells.

TRENTON

The Trenton group in the Upper Cumberland district is composed essentially of gray, dense- to coarse-grained, fossiliferous limestones, many of which are argillaceous. Calcareous shales are commonly present throughout the section, especially in the lower part. Chert is uncommon. Although generally termed "sands" by the drillers, the calcium carbonate content of most of the productive horizons ranges from over 60 to more than 95 per cent. Analyses numbers 1-4 on Table 6 are probably representative of the chemical composition of the Trenton pays in this general area.

The generally thinly-bedded limestones of the Trenton section, usually separated by thin beds or partings of calcareous shale, suggest the presence of a certain amount of primary porosity in these rocks. This porosity is, for the most part, of the bedding plane type and it is probably not continuous over wide areas. Furthermore, these original bedding planes have undoubtedly been modified by subsequent solution. In the Trenton section in the Spurrier-Riverton district of Fentress and Pickett counties (Plate II), about 25 miles east-southeast of Celina, Butts[18] con-

[18]Butts, Chas. Geology and oil possibilities of the northern part of Overton County, Tennessee, and of adjoining parts of Clay, Pickett, and Fentress counties: Tenn. Geol. Survey, Bull. 24-2A, pp. 42-43, 1919.

TABLE 6. CHEMICAL ANALYSES OF PRODUCING HORIZONS.

No.	WELL NAME	No.	LESSEE	LOCATION Plate	LOCATION No.	DEPTH	FORMATION	LITHOLOGY	SiO_2	Fe_2O_3 and Al_2O_3	$CaCO_3$	$MgCO_3$
1	Hull, Cordell	1	Overstreet and Miller	X	138	290–295	Middle Cannon	Limestone; light-gray to light-brown, medium-grained	3.75%	.58%	95.45%	.30%
2	Smith, Stone	1	W. P. Clements, et al	I	298	253–257	Lower Cannon	Limestone; tan, dark-gray and brown, medium-grained, with small amount of brown, calcareous shale	3.92	1.38	92.89	1.67
3	Hargrove, John	2	Doctors Syndicate	XIII	117	455–460	Upper Hermitage	Limestone; white to dark-gray, medium-grained, conglomeratic, with dark-gray, calcareous shale	27.96	2.26	60.15	8.82
4	Arney, B. C.	1	Doctors Syndicate	XIV	17	540–545	Lower Hermitage	Limestone; medium- to dark-gray, fine- to coarse-grained with minor amounts of brown, calcareous shale	21.21	2.05	75.46	.88
5	Hull, Cordell	1	Overstreet and Miller	X	138	480–485	Lower Carters	Limestone; tan, fine-grained, oil-stained, with some tan, rough, dolomitic, sharp chert	7.98	.96	84.86	6.16
6	Hull, Cordell	1	Overstreet and Miller	X	138	500–503	Upper Lebanon.	Limestone; tan to brown, fine- to medium-grained, oil-stained, with some dark smooth, dense chert	5.34	1.07	92.70	.83
7	Cherry, O. N.	1	W. P. Clements et al	I	37	450–455	Upper Lebanon	Limestone; light-tan, fine-grained with some gray-brown, vitreous, smooth chert	9.11	2.04	87.84	.62
8	Hull, Cordell	1	Overstreet and Miller	X	138	511–516	Upper Lebanon	Limestone; white and light-tan to brown, medium-grained	2.00	.38	95.05	2.52
9	Lynn, G. H.	5	Dafoe and Dafoe	VIII	180	398–405	Upper Lebanon	Limestone; medium-gray to bluish-gray, medium- to coarse-grained	7.48	7.26	80.19	4.78
10	Lynn, G. H.	5	Dafoe and Dafoe	VIII	180	430–437	Middle Lebanon	Limestone; gray and bluish-gray, medium- to coarse-grained	7.26	1.84	86.23	4.38
11	Hull, Cordell	1	Overstreet and Miller	X	138	584–589	Lower Lebanon.	Limestone; light-tan to brown, medium-grained, with some brown, calcareous shale	8.72	2.12	77.18	11.92
12	Moredock, Joe D.	2	Carnahan Oil Company	XIV	236	691–697	Lower Lebanon	Limestone; gray to light-tan and brown, fine- to medium-grained with gray and tan, calcareous shale	4.57	1.41	91.85	2.03
13	Hargrove, John	1	Doctors Syndicate	XII	116	670–672	Lower Lebanon.	Limestone; drab gray and brown, fine- to medium-grained, with small amount of gray, calcareous shale	5.05	1.02	93.20	.74
14	Hull, Cordell	1	Overstreet and Miller	X	138	609–614	Upper Ridley	Limestone; tan to gray and brown, medium-grained, with some gray, calcareous shale	6.35	1.02	82.24	10.29
15	Morrow, Bud	1	E. M. Ellis et al	XIII	238	755–760	Upper Ridley	Limestone; light gray to tan and grayish-brown, fine- to medium-grained	19.89	3.06	75.42	1.31
16	Cherry, O. N.	1	W. P. Clements et al	I	37	659–663	Lower Ridley	Limestone; light-tan to brown and dark-gray, fine to medium-grained	1.81	.82	96.85	.40
17	Fletcher and Brown	2	A. G. Greenup et al	I	102	1017–1024	Middle Murfreesboro	Limestone; drab brown to dark-gray, fine-grained, with small amount of dark-gray, calcareous shale	7.66	1.70	83.47	6.96
18	Phillips, Andrew	1	Robinson Oil Company	I	274	1384–1390	Upper Knox (Zone C_2)	Chert; light-tan, smooth, dense, sharp, translucent, with light-gray and tan, fine-grained dolomite	58.14	1.22	30.50	9.85

sidered dessication along the bedding planes as an important factor in the formation of reservoir rocks in this group:

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. . . 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.

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. . . . .

Fossiliferous zones are invariably present in rock of the Trenton group on the outcrop in the Central Basin and fossil fragments are common constituents in samples from these formations in Clay and adjoining counties. At certain horizons fossils, usually brachiopods and bryozoans, are so abundant as to approach a coquina. The *Dalmanella fertilis* zone, for example, is crowded with fossils at nearly any exposure of the Hermitage formation in the Central Basin. Such zones display a considerable amount of porosity on the outcrop and it is apparent that a part of the pore spaces has been the result of leaching of the original shells and the remainder due to the interstices between the shells and fragments of shells. Such occurrences on the subsurface may account for some of the porosity in the Trenton rocks in the Upper Cumberland district, provided, of course, these openings had not been subsequently filled with calcite or other secondary materials.

Salt water is commonly associated with the oil in the Trenton rocks of the Upper Cumberland district. This water may be connate. Its presence is here considered as an indication of the possibility of some primary porosity in this group of rocks.

Undoubtedly induced porosity by fracturing and solution is the most common type in the Trenton section of the area under consideration. The high initial yields, closely followed by sharp declines in production, demonstrate the presence of very porous conditions. In some cases this porosity may be due to actual joints, fractures, and bedding planes, which may or may not have been subsequently enlarged by solution, or it may represent breaks in the sedimentary record. Definite stratigraphic hiatuses are known to occur at the top of the Cannon limestone and at the contact of the Cannon with the underlying Hermitage. The rather widespread porosity in the upper and lower Sunnybrook horizons, the most productive zones in the Trenton in Clay County, may be related to these stratigraphic breaks.

Although the general behavior of a number of wells implies considerable porosity within the Trenton, lateral gradations within relatively short distances are characteristic in this area. In the Arcott School field, for example, W. P. Clements et al., O. N. Cherry No. 1 (37) recorded no shows of oil in the Trenton, while the same group's Stone Smith No. 1 (298), drilled about 600 feet to the southeast, found oil at 255 feet in the lower part of the

Cannon. In the Celina area Jesse Ashby et al., Donaldson Heirs No. 1 (85) found only a small amount of gas at 205-210 feet in the lower part of the Cannon, while a 70-barrel producer was drilled by J. H. Overstreet et al. at approximately the same stratigraphic and structural position. The wells were about 0.5 of a mile apart. Essentially the same conditions existed in the Stillhouse Creek field in the Willow Grove-Irons Creek area where the Doctors Syndicate, John Hargrove No. 2 (177) produced oil from the lower Sunnybrook; four other tests on the same small structure produced from horizons below the Pencil Cave with no encouraging lower Sunnybrook shows.

Carefully recorded drilling notes show that the actual pay zones in the Trenton are characteristically thin and are separated by beds of barren rocks. After a test enters a small pay the oil will come up the hole and find a level until another saturated horizon is encountered. Several such zones may be penetrated before the well is put on pump. In the Celina area, for example, J. H. Overstreet et al., Kyle and Vaughn No. 1 (160) logged gas at 200, 218, and 224 feet, some oil occurring with the gas at the latter depth; thin beds carrying oil were penetrated between 224 and 242 feet, where the well was put on pump. This 18-foot interval did not represent a continuous pay horizon. For this reason it is very difficult to determine thicknesses of most of the productive zones in this general region.

BLACK RIVER-STONES RIVER

The Black River and Stones River groups as developed on the subsurface in the Upper Cumberland district consist of light- to dark-gray, tan and brown, dense to medium-grained limestones; dense and fine-grained textures predominant. Many of the formations, especially the Pierce and Murfreesboro, carry some gray and brown calcareous shale, but in general the shale content is considerably less than that of the overlying Trenton. Chert is well developed at several horizons, particularly in the upper member of the Carters limestone, the lower half of the Carters, and in the upper part of the Lebanon limestone. The producing horizons are all limestones ranging from about 70 to over 95 per cent calcium carbonate. Analyses number 5 to 17, inclusive, on Table 6 are probably representative of the chemical composition of the pays in these groups.

On the outcrop in the Central Basin the lower part of the Black River and most of the Stones River groups are medium- to thick-bedded limestones. Primary porosity in such beds is practically negligible. Although cores are not available, the same conditions probably obtain on the subsurface in Clay and adjoining counties. Certainly the microscopic examination of thousands of Black River and Stones River samples from this general area has failed to show anything other than very minute pore spaces, definitely too small to allow commercial accumulation.

Fracturing and solution have been chiefly responsible for the porosity in the limestones below the base of the Trenton. The limestones of this part of the section are relatively brittle, and hence fracture rather easily under conditions of stress. As has been suggested above, at least some of this fracturing is considered intimately associated with the deformational history of the area. Undoubtedly some of the wells in this area have encountered pre-existing joints, which may or may not have been subsequently enlarged by solution during the physiographic development of the region. The behavior of a number of wells can best be explained by such reservoir conditions.

The production from the upper member of the Carters limestone, immediately above the Pencil Cave, and at the top of the Lebanon limestone comes from a dense- to coarse-grained limestone, invariably associated with light- to dark-gray, tan, generally dense, chert. As suggested above, the porosity of these horizons is believed to be closely related to the unconformities at the top of the Carters and Lebanon limestones. Undoubtedly a considerable amount of porosity throughout the entire Ordovician section has resulted from breaks in sedimentation.

Similar to the overlying Trenton, the producing horizons of the Black River-Stones River groups are generally thin and separated by barren strata. A number of zones of saturation may be penetrated before the well is considered to be commercial. The following record on Overstreet and Miller's Cordell Hull No. 1 (138), kindly furnished this Division by Mr. J. H. Overstreet, is typical of many of the pays below the Pencil Cave in the Upper Cumberland district:

Partial Record of Overstreet and Miller's Cordell Hull No. 1

	Depth (feet)
Bottom of the Pencil Cave	427
Gas to	467
Show of oil	467
Put on pump (September 21, 1937)	481
Drilled deeper	
Flowed (October 27, 1937) at	505
Put on pump at	515
Flowed 25 to 30 bbl. per hour at	515
Flowed about one month	515
Drilled deeper (March 2, 1938)	
More oil at	535
Began flowing at	555
Put on pump at	564
Drilled deeper (May 4, 1938)	
Began flowing at	586
Salt water at	613
Drilled to	631
Put on pump at	631
Oil and gas at	640
Water at	660
Total depth (November 22, 1938)	674

KNOX DOLOMITE

The small production and encouraging shows recorded to date in the upper part of the Knox dolomite appear to be closely related to the unconformity at the top of that group. Studies by the insoluble residue method indicate that the Cotter represents the youngest Canadian present on the subsurface in the Upper Cumberland district. A considerable thickness of younger Canadian beds are known to be present in Missouri and Arkansas. It is perhaps significant that the oil in the Robinson Oil Company's Andrew Phillips No. 1 (274) and the recently completed Lain Oil and Gas Company's T. A. Roberts No. 2 is associated with cherty horizons in the upper part of the Knox dolomite group. For the most part these cherts appear to be definitely secondary in origin and many of them are minutely cavernous.

While subsurface studies of the Canadian rocks of middle Tennessee are far from complete, an unconformity of considerable magnitude is known to exist at the base of the Stones River group. In the Upper Cumberland district, Jesse Ashby et al., Donaldson Heirs No. 1 (85), encountered 165 feet of beds between the base of the Murfreesboro and the cherty dolomites of Zone C_2. In the Lain Oil & Gas Company's T. A. Roberts No. 2, located less than 1 mile to the northwest, only 68 feet of this interval is present; the lower part of Zone B and all of Zone C_1 is tentatively considered to be entirely missing. Zone C_1 is also absent in the Ava Oil & Gas Company's Mary Williams No. 3 (347) and the Carnahan Oil Company's Joe D. Moredock No. 2 (236) (pp. 122, 145).

RELATIONSHIP BETWEEN STRUCTURE AND THE ACCUMULATION OF OIL

GENERAL

A survey of the structural data in the past and present productive areas of Tennessee points conclusively toward the importance of geologic structure in the accumulation of oil and gas in commercial quantities. This relationship has been pointed out by Lusk[19] and the present study definitely supports his generalizations for the State. An inspection of the structural maps of the individual fields in Clay County, contoured on the base of the Pencil Cave horizon, demonstrates the intimate association of production and anticlinal conditions in the Upper Cumberland district. Practically all of the oil in this general region has come from small, sharp upwarps, with vertical closures of 10 to 20 feet and areal extent of 10 to about 100 acres. While not all domes have been productive, there has been no significant production in areas which are definitely known to be structurally low, with the possible exception of small production in the upper part of the Knox dolomite group. In some areas, such as Tinsleys Bottom, the structural conditions were poorly defined and only after drilling has progressed far enough to present valuable subsurface data was the production proved to be anticlinal. There have been no fields, however small, and very few productive wells in Clay and adjoining counties which have failed to substantiate the close relationship between commercial accumulation of oil to structural upwarps in the rocks.

TRENTON

Wells which have produced oil in commercial quantities from rocks of Trenton age have been, with few exceptions, located well up the flanks, if not on the crest, of the small, sharp, closed structures which are characteristic of this area. The Ava Oil & Gas Company's T. V. Davis No. 1 (79) produced oil from rocks of

[19]Lusk, R. G. The significance of structure in the accumulation of oil in Tennessee: Bull. Amer. Assoc. Petroleum Geologists, vol. 11, pp. 905-917, 1927.

Trenton age and, although definite data are not available, it is quite possible that this well was not on a closed upwarp. Other wells, such as J. C. Overstreet and Son's Sam Nevins No. 1 (246), in the Kettle Creek-Pine Branch area, have produced oil on structures which were not well defined. Good shows have been encountered in tests which were located off structure. F. T. Soper et al., B. Robbins No. 1 (283), in the Mitchell Creek district, found gas at 158 feet and a considerable amount of oil in the upper Sunnybrook at 209 feet. This test was structurally low on the base of the Chattanooga shale. In general, however, there has been a close relationship between structural upwarps and commercial Trenton production in this area.

The Trenton reservoirs in the Upper Cumberland district are in many cases "porosity locked." The lack of extensive water drive and the small total recovery as compared with high initial yields of oil seem to indicate reservoirs of restricted size. Some of these reservoirs are contained in rocks which are not horizontal. In such cases if water and oil were present in the same reservoir and if adequate continuous porosity were present in the rocks, the up-tilted part of the reservoir would be the productive part. This part would not necessarily bear any areal relationship to the axis or crest of an anticlinal feature. The production in the Ava Oil & Gas Company's T. V. Davis No. 1 (79) and J. C. Overstreet and Son's Sam Nevins No. 1 (246) might well have been the result of such a "perched reservoir."

In some cases it is possible that the differences in competency of individual limestone beds may have given rise to reservoirs in areas in which sharp reversals are present. This conclusion is based upon the two dimensional shape of many well samples from paying horizons in the Trenton section. If an incompetent bed which is immediately overlain by competent strata is subjected to warping or minor folding, a system or systems of joints or fractures, incipient or true, may be developed. In such a case the productive area would be limited in areal extent, and would probably be coincident with the area of local warping. Much of the Trenton production in this area suggests such a relationship between structure and accumulation.

BLACK RIVER-STONES RIVER

Like the overlying Trenton, most of the production below the base of the Trenton has been found on structures which are closed on the base of the Chattanooga shale or Pencil Cave. Commercial production, however, has been found on noses and terraces such as on the Keisling lease (145, 146, 148), just northeast of Peterman Bend, and in J. H. Overstreet and Son's Sam Nevins No. 3 (248) and T. W. Nevins No. 1 (250) in the Kettle Creek-Pine Branch district.

Microscopic examinations and chemical analyses (Table 6) have shown that the Black River-Stones River groups are characteristically pure limestones, with minor amounts of shale. Based upon outcrop sections in the Central Basin, these groups are believed to be relatively thick-bedded in the Upper Cumberland district, although thin beds undoubtedly occur. In such a section certain beds would fracture more easily than others under deformational stresses. Generally, the thick-bedded limestones would be the more competent. Since the producing horizons in these groups are generally thin (pp. 166-167), it is believed that there is a definite relationship between the fractured zones (paying zones) and the incompetent limestones. Cores will be necessary to establish this relationship.

As is the case in the Trenton production, there is a suggestion that the more productive wells have been located on that part of the dome in which warping has been more severe. Overstreet and Miller's Cordell Hull No. 1 (138), for example, was located very near the top of the Pine Branch dome and produced nearly 10,000 barrels of oil. Overstreet and Miller's B. G. Edens No. 2 (97) was only 6 feet lower structurally and was hardly a commercial producer.

KNOX DOLOMITE

Based upon the incomplete records of the few wells in the Upper Cumberland district that have encountered good shows or small production in the upper part of the Knox dolomite group, no definite relationship between geologic structure and accumulation in these lower horizons has been established. A sweeping generalization cannot be made at this time and there is no conclusive evidence that the general absence of encouraging shows in a number of tests, well located with respect to structure, was not due to conditions of porosity. It may be significant, however, that test wells into the Canadian located on such well defined structures as the Tinsleys Bottom, Oil Hollow, Kyle Point, Fox Springs, and Ashburn Creek domes have resulted in dry or near-dry holes. On the other hand, the good shows or small production in the Powell Oil Company's Arch Short No. 3 (290), Spain et al., W. J. Nevins No. 2 (255), the New Domain Oil & Gas

Company's A. Phillips No. 1 (272), and the Robinson Oil Company's Andrew Phillips No. 1 (274) have been in areas where no definite anticlinal conditions have been observed.*

METHODS OF EXPLORATION AND PRODUCTION

LEASING

The usual straight commercial lease is the standard oil and gas form used in Clay County. In a number of cases the leases carry drilling commitments within a year. The average lease, however, may be obtained by a minimum annual rental per acre and one-eighth royalty contract. In most cases the county records are good and lease titles may be certified quickly. On January 1, 1939, approximately one-half of Clay County was under lease.

DRILLING

Drilling problems in Clay and adjoining counties are essentially the same as those encountered in all areas in which a limestone section is drilled. The typical section drilled in this area offers no unique problems. Past experience has pointed toward only one part of the section which may prove to be troublesome. The driller should proceed cautiously as the Pencil Cave horizon is approached. The upper member of the Carters limestone, which lies directly below the easily recognizable Mud Cave horizon, is generally cherty and the most difficult to drill in the section above the Knox dolomite group. After drilling a few feet into this cherty limestone, ordinarily the bit will be worn out of gauge. When a full gauge bit is run in the hole, the tools are liable to stick. Several tests in this general area have been lost and in many cases progress has been retarded by fishing jobs at this horizon. Bits should be tested every 2 feet while drilling this zone.

Since the Pencil Cave is the most reliable and easily recognized horizon marker in the Ordovician section, this green, bentonitic clay shale is widely used as a datum plane to correlate the Black River and Stones River horizons. While this horizon marker may reach one to two feet in thickness, it is locally very thin. Particular care should be exercised to determine its presence and exact depth for future correlations of producing horizons, oil shows, and casing seats. It is strongly recommended that accu-

*The Lain Oil & Gas Company's T. A. Roberts No. 2, recently completed as a Knox producer in the Celina area, appears to be well located on structure.

rate steel-tape measurements be taken at the first appearance of this green, bentonitic shale in the samples.

In all cases, wells should be drilled with an oil-saver. Much oil in the past—in many cases in sufficient quantities to pay for the actual drilling of the well—has been lost by the neglect of this simple and inexpensive precaution. It must be kept in mind that many of the pays are unpredictable, except within rather broad limits, and high flush productions are common.

No definite spacing pattern has been followed in developments to date in the Upper Cumberland district, due largely to the extreme irregularity of productive areas. In a region characterized by abrupt changes in porosity, drilling patterns are not feasible. After a well is completed, whether or not commercial production is found, the location of offset tests is governed largely by the structural position and the behavior of the initial test. It has been the common practice, however, to drill wells 300 to 600 feet apart; the average location has been approximately 500 feet. Past experience definitely demonstrates that many small productive domes in Clay and adjoining counties have been overdrilled. In a number of cases the discovery well has gone dry or materially decreased in production upon the completion of a closely spaced second well. It appears probable that in several fields the total amount of oil recovered would have been obtained by one-half the number of wells drilled.

Too much emphasis cannot be placed upon the value of saving a complete sample set from all wells drilled. Cuttings should be saved from each bailing. Information obtained from these samples will enable the operator to compare one well with another. The customary practice of neglecting to save samples from above the first casing seat has added to the difficulty of correlating significant horizons in nearby wells. In most cases the rocks between the surface and the depth at which the last fresh water is encountered are barren of oil. It is possible, however, that rocks of the same age under considerable cover, no great distance away, would yield oil in commercial quantities. For this reason the writers urge the operators to save a complete set of samples from the surface to the bottom of the well. The Tennessee Division of Geology will gladly furnish sample sacks for the cuttings and a detailed log of the test well from the microscopic investigation of the samples. It is only by this cooperation that the subsurface details of any area may be ascertained.

It is also strongly recommended that each operator keep an accurate record of his well. The log book, furnished by this Division, should be kept at the rig and careful entries made after every screw. Such a record allows members of this Division to make intelligent reports to the operator and driller. It is well to keep in mind that the first well does not necessarily condemn a structure. Data from an accurate log book may be invaluable in determining the direction and position of the second test.

TYPES OF RIGS

For the average shallow well in Clay and adjoining counties, 2,000 feet or less, cable-tool rigs are most economical and efficient. The ordinary rig will drill 40 to 50 feet in 24 hours. The majority of rigs used at present in this area are of the spudding type and are powered by gasoline engines. A few of the rigs have walking beams and are powered by steam engines.

In the summer of 1938 a Sullivan J-2 core drilling rig was brought into the county. This type of drill drilled a 472-foot test on the Wilburn Heirs lease (336). The presence of heavy and numerous gas blowouts made it necessary for the operators to temporarily abandon this well. Circulation was lost at a number of places and indifferent drilling progress was maintained. If this operation be considered as typical, it is doubtful if a rotary machine of this type would be efficient in the Upper Cumberland district. No attempts have been made to drill the Paleozoic section of Middle Tennessee with heavy rotary equipment.

The average cost for drilling test wells in this area varies between $1.50 and $2.50 per foot. The usual price for reaming is one-half the drilling price per foot.

WATER HORIZONS

TRENTON

In most wells drilled in the Upper Cumberland district, especially those which start below the base of the Chattanooga shale, the last fresh water is usually encountered at depths of less than 150 feet. There are, of course, exceptions to this generalization, such as Overstreet and Miller's Cordell Hull No. 1 (138)*, in which fresh water, associated with oil, was logged in the Cannon limestone at 295 feet, and W. P. Clements et al., O. N. Cherry No. 1 (37), which entered a fresh water horizon at 254 feet. In general, however, waters encountered below 150 feet are more or less saline. The upper and lower Sunnybrook horizons in the lower Cannon and Hermitage, respectively, generally car-

*Numbers in parentheses refer to well record numbers on Table 1.

ry relatively strong salt water, often associated with oil and gas. Waters charged with hydrogen sulphide are not uncommon in the Trenton rocks in the Upper Cumberland district.

BLACK RIVER-STONES RIVER

Generally very little water is encountered between the base of the Trenton and the upper part of the Knox dolomite group in this area. While salt water has been encountered within this interval, it has not presented a major problem. A few wells in Clay County have produced salt water below the Pencil Cave horizon, such as the Overstreet and Miller, Cordell Hull No. 1 (138), the Ohio Oil Company's J. W. Pennington No. 3 (270), and the Clark Oil Company-Doctors Syndicate, B. C. Arney No 1 (14).

Relatively few of the wells in Clay County, producing below the Pencil Cave, go on salt water, although saline waters were encountered in the upper part of the Stones River group in several wells in the Pine Branch district.

KNOX DOLOMITE

Many of the wells drilled below the base of the Murfreesboro limestone in the Upper Cumberland district have encountered abundant water. While no chemical analyses are available, these waters are usually strongly mineralized. Hydrogen sulphide is a common constituent, and salt water has been noted. Saline waters were reported in Jesse Ashby et al., Donaldson Heirs No. 1 (85), at 1,456 feet, W. S. Raydure's L. J. Holman No. 1 (135) at 1,340 feet, and in Dafoe and Dafoe's G. H. Lynn No. 5 (180) at 1,300 feet. Incomplete records of the relatively few wells which have entered the Knox dolomite group in this area do not allow definite zoning of these waters.

CASING

Surface or fresh water should be cased off with at least 8¼-inch casing, in order that the upper and lower Sunnybrook horizons may be drilled with a minimum of water in the hole. The general absence of water in the Black River and Stones River groups allows the setting of 6¼-inch casing just below the Pencil Cave horizon to prevent it from sloughing down the hole. An oil string of 4⅞-inch casing should be set just above the pay on a packer. This last string is to prevent leakage in the open hole between the 6¼-inch casing-seat and the pay horizon.

In drilling offset wells care should be exercised in setting casing at the same stratigraphic levels to eliminate cross-watering. The practice of cementing casing is not followed in this area. Casing set just below the Pencil Cave usually seals itself within a relatively short time. If a well is to be treated with acid, the bottom joint of casing should be cemented to allow the introduction of acid under considerable pressure. If the last joint is the only one cemented, all casing except this joint may be recovered, provided, of course, this joint has not been set up too tightly.

TUBING AND PUMPING

There is no well-established method of tubing wells in this general area. Wells should be tubed so that the bottom of the working barrel is just above the top of the highest paying zone. The presence of a certain amount of paraffin in all of the oil makes it advisable to keep live oil over the pay zone to prevent the sealing of the pay by separation of the paraffin from the oil as it leaves the productive zone. It is quite probable that paraffin sealing has been a factor in the rapid decline in many wells in the Upper Cumberland district.

In most cases, after the production of the well has settled, the casing-head is left open to allow the escape of gas which is liberated from the oil. If this is not done, the back pressure resulting from the accumulation of this gas seems to interfere with the normal production of the well. Wells in which the oil rises to a considerable height in the hole must be carefully tubed. A small amount of agitation of the oil in the well will often result in a sudden flow with the consequent loss of oil. A considerable amount of the flush production of many wells in the Upper Cumberland district has been lost this way. As stated above, all wells should be drilled with an oil saver.

SHOOTING

Shooting of good oil shows is a common practice in the Upper Cumberland district. While it has generally helped the production, some wells have been ruined or the production materially lessened, probably due to the compaction which results from the shooting. In cases like these treatment with acid following the shot would probably reopen the producing zone.

A light shot with nitroglycerine is recommended in wells which enter a pay zone or a good show, with evidence of a considerable amount of gas pressure behind them, but only produce a small amount of oil per day. A light shot of 20 quarts or less is probably as effective as a heavier one. Limestone rocks are relatively soft and elastic, and for this reason a light shot would probably affect a zone nearly as far away from the well as a heavier one.

Based upon past records, it is urged that all shooting be done by a competent technician, preferably one who has had experience in shooting limestones similar to those present on the subsurface in Clay County.

ACIDIZING

The few attempts of acidizing producing horizons or good shows in Clay County have not been successful. In most cases the lack of accurate drilling records has probably contributed largely to these failures. It cannot be too strongly emphasized that before any intelligent acid treatment can be made, the operator must know the exact depth of the pay, shows, water zones, and casing seats. Much better results may be obtained if samples are available from the zone to be treated.

Since most of the producing horizons in the Upper Cumberland district are rather pure limestones, 75 to over 90 per cent calcium carbonate, there is no apparent reason why intelligent acid treatment would not materially increase production in a large number of wells. The technique of efficiently acidizing wells is best known by companies which specialize in this work, but it is only through the application and an understanding of the information supplied them that any degree of success may be attained. The few unsuccessful attempts to date are not considered evidence to condemn acid treatment in this region.

CHARACTER OF THE OIL

Unlike many limestone-producing areas, the crude oil in the Upper Cumberland district is of relatively high gravity, ranging from 38° to over 44° on the Baume scale. The color varies from dark-brown to green and light green, the latter color being the most common. The few analyses available show a sulphur content of less than 0.2 per cent. The gasoline content is high. Crude topping methods used in the area indicate 30 to 40 per cent of gasoline.

The few analyses on file of the pre-Stones River oil indicate heavier oils, ranging in gravity from about 30° to 38° Baume. These oils are generally dark-brown in color, considerably darker than those from the middle Ordovician.

Five fractional distillation analyses are given in Table 7.

TABLE 7. CLAY COUNTY CRUDE OIL ANALYSES.

Analyses Number	WELL NAME	No.	LESSEE	LOCATION		Color	Fluorescense	Gravity Be'at 15.5°C.	Specific Gravity	Sulphur	Initial Boiling Point	DISTILLATION TESTS												FORMATION
												Below 150° C.				150°-300° C.				Above 300° C.				
				Plate	No.							% By Vol.	% By Wt.	Sp. G.	Deg. Be'	% By Vol.	% By Wt.	Sp. G.	Deg. Be'	% By Vol.	% By Wt.	Sp. G.	Deg. Be'	
1	Marcum, E. D....	1	A. A. Alexander, et al.	XIII	202	Reddish Brown	Dark Green	40°	......	0.13%	47°C.	26.0	22.7	.7185	64.9°	35.0	34.3	.8061	43.7°	39.0	43.0	.9080	24.2°	Upper Hermitage
2	Gray, J. M........	1	Clark-Hill Oil Corp.	XI	107	Brown	Green	40.5°	0.8211	0.15%	......	26.5	23.1	.7173	65°	45.0	45.3	8266	39°	28.5	31.6	.9104	24°	Upper Carters
3	Lynn, G. H.......	7	Dafoe & Dafoe.	VIII	182	Brown	Green	44.5°	0.8023	0.18%	37°C.	32.5	29.0	.7154	66°	36.5	37.1	8157	42°	31.0	33.9	.8774	30°	Middle Carters
4	Lynn, G. H.......	2	Dafoe & Dafoe	VIII	177	Dark Brown	Dark Green	38°	0.8333	0.17%	......	25.5	22.4	.7319	61°	39.0	38.1	.8130	42°	35.5	39.5	.9285	21°	Upper Lebanon
5	Dennis, Petway...	1	Carnahan Oil Co....	XIII	82	Light Green	Green	40.4°	0.8232	0.14%	68°C.	24.5	21.9	.7347	61.1°	36.1	35.6	.8104	43.1°	39.4	42.5	.8894	27.6°	Lebanon

MARKETS

More than 40 miles of pipe lines were laid in Clay and adjoining counties during the developments in 1926-1928. The subsequent decrease in exploration, due largely to economic conditions, together with the steady decrease in production from the older fields, made it necessary to remove these pipe lines several years ago. At present the oil is transported from the area by tank trucks. Recently, the greater part of it has been trucked to Glasgow, Kentucky, 45 miles northwest of Celina, from where it is piped into a refinery at Louisville, Kentucky. Some of the oil is trucked to Algood, about 35 miles to the southeast, thence by tank cars over the Tennessee Central Railroad to a refinery at Nashville. Small amounts have been shipped to the refinery of the Russell Producing Company near Sunbright, in Morgan County.

The price of Clay County crude oil is governed largely by the posted price in western Kentucky. During the spring of 1939 the average price for this oil was $1.05 per barrel at the well.

RECOMMENDATIONS

GENERAL

Oil has been produced commercially in Clay County since 1923. Like in all producing areas, money has been made and lost. While the depths to production has precluded heavy expenditures, undoubtedly more intelligent drilling and handling of wells would have resulted in increased profits. The small initial capital required to test the shallow horizons has been largely responsible for numerous wildcat drilling operations with little or no consideration given to structural conditions. Naturally, such activity has been reflected in an unusually high percentage of dry and near-dry holes. It is to be regretted that in many cases no serious attention has been given to the reasons for success and failure in the past. Chances are greatly enhanced by carefully studying the methods of successful operators. There is a reasonable chance for success if intelligent methods of exploration and production are employed. Otherwise, chances depend almost entirely upon blind luck, and if the bitter experiences of many operators may be an example, it is an extremely slim one.

While each well may present individual problems, certain recommendations have been made throughout this report, especially on pages 171-177. It may be advisable, however, to reenumerate them.

(1) There is a definite relationship between structural upwarps and oil and gas accumulation in the area covered by this report. While not all domes and anticlines have produced oil, there has been no persistent production in areas known to be structurally low. There is a suggestion that the best production may be found on the steeper flanks of the sharp upwarps, very close to the "break-over," or crest.

(2) It has been repeatedly pointed out that the geologic structure map (Plate I) is not based upon data of sufficient accuracy to permit its use as an unqualified drilling location map. It is recommended that all structures be checked before they are tested by the drill.

(3) Take full advantage of the past experiences of others. Carefully study the reasons why some operations have been successful and others failures. Examine the records and subsurface data of wells in the general vicinity of your test.

(4) Keep an accurate record of your test well. This includes a complete sample set and detailed well log. Carefully measure, preferably with a steel-line tape, the depths of all significant horizons such as fresh and salt water, oil and gas shows, pays, Mud Cave, Pencil Cave, etc. Such information will materially assist in locating your second test and is necessary if the well is shot or treated with acid.

(5) Drilling recommendations:

a. While the area does not present major drilling problems, choose a competent driller, preferably one who has had local experience.

b. Do not buy inferior casing. Troublesome water problems have been introduced by such practice.

c. Make sure that the surface water has been completely shut off.

d. Proceed carefully as the Pencil Cave horizon is approached. The 10-foot section between the Mud Cave and Pencil Cave is generally cherty and ordinarily the bit will be worn out of gauge. When a full gauge bit is run into the hole the tools are liable to stick.

e. Drill all wells with an oil-saver. Much oil has been lost in the past because of neglect of this simple and inexpensive precaution.

f. Set casing immediately below the Pencil Cave horizon to prevent the bentonitic clay from sloughing down the hole.

g. In drilling offset wells, exercise care to set casing at the same stratigraphic position to prevent cross-watering.

(6) Do not overdrill small structures.

(7) A light shot with nitroglycerine is recommended for good shows and small pays. Shooting should be done by a competent technician.

(8) Carefully plug all abandoned wells.

DRILLING DEPTH

The question of drilling depth is at all times a perplexing problem. The enticing "just a few feet deeper" is ever present. To gracefully abandon a test well with no subsequent regrets is a faculty possessed by few. Each operator should definitely consider what horizon or horizons he considers the most promising and, unless there are developments in the course of drilling that make it advisable to alter his original plan, the test should be stopped when the objective has been reached. Many of the deeper tests in Tennessee have begun with a shallow depth as the objective. Past experience shows that it is generally unsound practice to drill deeper than the planned depth in any well which has not encountered encouraging shows, especially gas, in the upper part of the hole.

Since 1923, when oil was discovered at Willow Grove at 421 feet, about 100 feet above the Pencil Cave, production has been extended to a depth of about 800 feet below the Cave. Most of the production has come from depths of less than 250 feet below the base of the Trenton, although some oil has been found below this depth (Plate XV). Since relatively few wells have tested the section below the top of the Ridley limestone, there is, obviously, no conclusive proof that this section would not be as productive as the younger rocks. Certainly there is little lithologic difference between the upper and lower parts of the Stones River group.

DEEPER POSSIBILITIES

In any productive area there is naturally considerable interest in the deeper possibilities. This is especially true in Clay County. The Tennessee Division of Geology has received many inquiries relative to the deeper oil and gas possibilities of the region, especially of the lower part of the Knox dolomite group. The complete lack of samples from approximately 400 feet below the top of the Canadian, the distance the area of this report is removed from the Knox outcrop, and the absence of deep intervening wells are the chief factors contributing to the lack of adequate knowledge of the deeper possibilities of the area. Stratigraphically, the deepest pay found to date was in the Robinson Oil Company's Andrew Phillips No. 1 (247)* at 1,383 feet, 68 feet below the top of the Knox dolomite. The deepest well, the New Domain Oil & Gas Company's A. Phillips No. 2 (273), was drilled to 1,725 feet, but no encouraging shows were recorded below 1,390 feet.

In the outcrop area of the Knox dolomite group in the Valley of East Tennessee, the upper part of this group (Canadian system of E. O. Ulrich) ranges in thickness from over 500 to nearly 1,800 feet. These beds are composed of medium- to heavy-bedded light-gray to dark-bluish gray, fine-grained limestones and light- to dark-gray fine to coarsely crystalline dolomites with many thin sandy beds. Oder[20] has observed a widespread thin, light-gray, fine- to medium-grained sandstone, locally quartzitic, at the base of his Cotter-Powell beds, and many thin arenaceous zones occur sporadically from the base to above the middle of the Cotter-Powell beds. The lower Knox (Ozarkian system of E. O. Ulrich) reaches a maximum observed thickness of nearly 3,000 feet and consists of thin-bedded to massive light- to dark-gray, fine- to coarse-grained limestones with fine- to coarse-grained dolomites and subordinate arenaceous and sandy zones. Chert is a common constituent in the lower Knox section.

In the absence of samples, any remarks on the general lithologic character and thickness of the Knox dolomitic group, which underlies Clay County, must be considered as rank speculation. In Rutherford County, near the center of the Nashville dome, the Franklin Oil and Fuel Company's J. M. Alsup No. 1 entered the top of the Knox dolomite at 285 feet and drilled approximately 2,000 feet of beds belonging to this group. Sample studies indicate essentially the same type of lithology as in the outcrop area in East Tennessee. Definite formational subdivisions are not possible at the present time, although tentative correlations on this well do not suggest appreciable thinning of at least the Canadian part of the section. Furthermore, the Knox dolomite group exposed at the center of the Wells Creek Basin presents no striking lithologic difference with the upper part of that group

*Numbers in parentheses refer to well record numbers in Table 1.

[20]Oder, R. L. Preliminary subdivision of the Knox Dolomite in East Tennessee: Jour. Geol., vol. 42, p. 487, 1934.

in the Great Valley region. Perhaps an inference may be made that the Canadian and Ozarkian rocks which underlie Clay County are, in general, quite similar to exposures of these strata in the Appalachian region.

With no intention to depreciate the deeper possibilities, it must be admitted that the possibilities of Knox dolomite production in the Upper Cumberland district are entirely unknown. Certain arenaceous beds have been observed in the Knox, especially in the upper 750 feet on the outcrop in East Tennessee. Sandy horizons are known in the upper part of this group on the subsurface in Middle Tennessee (pp. 29-30). These zones undoubtedly have some continuous porosity and might well serve as reservoir rocks. The development of porosity in relation to unconformities might also be an important factor in the possibility of producing oil from the Knox dolomite. While subsurface studies on the Canadian rocks of Middle Tennessee are far from complete, examinations to date indicate a considerable amount of post-Knox erosion (pp. 167-168).

In summary, the presence of commercial oil or encouraging shows in the upper part of the Knox dolomite group is believed to justify testing the upper 500 feet of this section, which, over most of Clay County, will be penetrated at depths of less than 2,300 feet. Possibilities below this depth are entirely unknown. A carefully drilled exploratory well would present valuable data on the general possibilities of these lower horizons.

PROMISING AREAS

EASTERN CLAY COUNTY

Since the publication of the structural map of eastern Clay County in 1923, many of the more promising structures have been drilled. There remain, however, several areas which are considered worthy of further investigation. The areas listed below do not exhaust the possibilities of this part of the county. Detailed work would undoubtedly prove the presence of other meritorious structures. It is recommended that the following areas be investigated:

Peterman Bend.—Strong north dips shown in the eastern bank of Obey River suggest the possibility of drilling sites between State Highway 53 and the old drilling (Plate XI).

Neeley Dome.—According to the records in the files of this Division the V. D. Neeley No. 1 (224) was abandoned at 160 feet. The successful explorations at Fox Springs would seem to justify a deeper test provided, of course, the Neeley dome is checked before drilling.

Smith Creek Dome.—Strong dips, which bring the Leipers formation to the surface as an inlier, indicates closure in this area. The R. A. Coalson No. 1 (51) and the Riley Kerr (152) do not appear to have been well located, and it is probable that this structure has not been thoroughly tested. This dome deserves careful attention.

Myers Dome.—Checked against Perry's structural map of eastern Clay County, Owens-Mitchell et al., Jim Myers No. 1 (240), did not test the Myers dome. The closure is the same as on the Fox Springs dome, one of the most productive structures in Clay County.

Grogan Hill Dome.—The absence of any reliable datum plane leads the present writers to question the presence of this structure. One well, Baskin et al., Mrs. Estis Coffee No. 1 (52) has been drilled in this area. This Division has been unable to secure any data on this test other than the reported depth of approximately 800 feet. Shallow wells to the top of the Chattanooga shale may be the most efficient method to check this structure.

Wilburn Dome.—The presence of this structure is substantiated by strong dips in the Chattanooga shale. Harrison et al., Wilburn Heirs No. 1 (336), was temporarily abandoned at 472 feet because of heavy gas. This test was well located on structure. At least the lower Sunnybrook and Black River-Stones River horizons, which have been productive in the nearby Jouett Creek and Ashburn Creek domes, should be tested on this upwarp.

Walker Ridge Dome.—The Mich-a-Tenn Oil Company's Clay County Farm No. 1 (50) and Brown Brothers' J. K. Walker No. 1 (332) appear to have been located too far north to have tested this structure. The proximity of this dome to the Peterman Bend area recommends the possibilities of a test more favorably located on structure.

WESTERN CLAY COUNTY

The more important structural features of western Clay County, west of Cumberland River, are described on pages 72-78. The size and general configuration of the domes and anticlines in this part of the county are strikingly similar to those which have been, or are, productive in eastern Clay County. Because of more accessible control, certain of these structures are more sharply defined than others. It is recommended that the structural features of these upwarps be studied and checked in detail. As previously pointed out, there are no geologic reasons why the structures in the western part of Clay County should not be as productive as those in the eastern part of the county.

STATE COOPERATION

The Tennessee Division of Geology, located in Nashville, has for one of its major objectives cooperation in the development of the mineral resources of the State. While detailed geologic studies are not permitted on private properties, those interested in the oil and gas resources and general possibilities of any part of Tennessee are invited to confer with members of this Division. This Division has many unpublished data, especially well records, in its files and such information is available for inspection. An attempt is made to obtain complete samples, at five-foot intervals, and a driller's log on all test wells drilled within the State. Sample sacks for the cuttings and well record books will be forwarded on request. The Division will be pleased to furnish each operator a correlated sample log based upon the microscopic examination of cuttings from his well.