McLOUTH GAS AND OIL FIELD, JEFFERSON AND LEAVENWORTH COUNTIES, KANSAS

By

WALLACE LEE and THOMAS G. PAYNE

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Investigation conducted under cooperative agreement between the State Geological Survey of Kansas and the United States Geological Survey

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FOREWORD

The data presented in the following report are of more widespread importance than is implied by its title, "McLouth Gas and Oil Field, Jefferson and Leavenworth Counties, Kansas." The McLouth field is unique in that it is the only gas field in northeastern Kansas in which the relation of the structure of the gas sand in the Pennsylvanian to the underlying Mississippian is known. It is also unique in this area in that cuttings or samples of the rocks penetrated have been saved from nearly all of the wells drilled in the field and have become available for study. Thus the McLouth field has been a "laboratory" for the study of structural relations in gas and oil fields in northeastern Kansas.

Some of the structural relations discovered to be true in the McLouth field can be used as a guide in the future exploration for and development of oil and gas deposits in other areas in northeastern Kansas. This is particularly true of the relation of surface structures to the deeper underlying anticlines or domes that actually yield the oil and gas. Mr. Lee and Mr. Payne clearly point out that the crest of the deep structure does not conform to the crest of low anticlines at the surface, as the crest reflected in the surface rocks has been displaced by the tilting that gave rise to the regional dip. They also show that the dip of the rocks on the flanks of the anticlines increases in depth and that oil or gas traps may occur below gentle "warps" or "noses" in the surface rocks. Furthermore, it is shown that the gas in the Pennsylvanian producing sand is sealed in the structure down dip by desiccated oil or tar and that the contacts between gas and tar occur at a lower level on the west side of the pool than on the east. These facts may guide and assist the future discovery and development of oil and gas pools in northeastern and east-central Kansas.

Analyses of oil and gas from the McLouth field are given in this report and are compared with analyses from several other pools. These analyses furnish a basis for judging the type of oil and gas that may be found in other parts of the Forest City basin.

The regional stratigraphy and structure of the Kansas part of the Forest City basin, which contains the McLouth field, have been studied by Mr. Lee. The results of this regional investigation have recently been published as Bulletin 51 by the State Geological Survey of Kansas, to which the reader is referred for general stratigraphic and structural data on this part of the state.

JOHN C. FRYE.

McLOUTH GAS AND OIL FIELD, JEFFERSON AND LEAVENWORTH COUNTIES, KANSAS

By

Wallace Lee and Thomas G. Payne

ABSTRACT

This report is an expansion of an earlier report on the McLouth gas and oil field published in 1941 and includes developments to April 1, 1943. The report discusses the McLouth field and its relations to the Forest City basin and to the structure of the region as a whole.

On April 1, 1943, the McLouth field included three pools, the North McLouth, McLouth, and Ackerland, comprising an area of 4,610 acres yielding oil and gas. The area of oil production comprises 550 acres. The field was discovered in November, 1939, and there were 90 wells yielding gas and 21 wells producing oil on April 1, 1943.

A normal sequence of Pennsylvanian rocks starting with the Lecompton limestone is encountered in wells. The Cherokee shale, which includes the McLouth sand, consists of alternating deposits of shale and impure sandstone. The McLouth sand is composed of sandstone and shale zones of variable character and porosity, and its productivity is controlled by porosity and structural conditions. The McLouth sand immediately overlies the eroded and beveled edges of low-dipping Mississippian limestone formations.

The Mississippian rocks include St. Louis, Spergen, Warsaw, undivided Burlington and Keokuk (which includes the main oil-producing zone of the field), Gilmore City, and Chouteau limestones. Clastic black shale occurs in caverns in the Mississippian at irregular stratigraphic intervals.

The Mississippian limestones are underlain in descending order by the Chattanooga shale, Devonian limestone, Maquoketa (= Sylvan) shale (of local occurrence), Kimmswick (=Viola) limestone, St. Peter sandstone, and Arbuckle limestone, the top of which has been penetrated in two wells in the field.

There are three producing zones in the McLouth field. The first is the McLouth sand, of early Pennsylvanian age, from which all of the gas and minor amounts of oil are produced. This gas and oil are produced from porous erratically spaced sand bodies on anticlines. The second zone consists of porous weathered limestone at the top of the Mississippian which has yielded small amounts of gas and shows of free oil. The third zone consists of porous dolomite approximately 150 feet below the top of the Mississippian. The porosity of the dolomite is seemingly a result of an unconformity during the period of deposition of the undivided Burlington and Keokuk limestones. There are several potential producing zones, as yet unproductive in the McLouth field, which yield oil in other pools in Kansas and in parts of southeastern Nebraska. These zones occur at the top of the Devonian where shows of oil have been encountered in the McLouth field, at the top of the

Kimmswick, in the St. Peter sandstone, and at the top of the Arbuckle limestone. None of these zones has been adequately explored in the McLouth field and, in general, in northeastern Kansas.

During pre-St. Peter time, the Ozark region was subsiding and southeastern Kansas was rising. After deposition of the St. Peter sandstone across the eroded edges of the earlier rocks the structural movements were reversed, and until the end of Chattanooga time parts of southeastern Nebraska were subsiding and the general area of the Ozarks was rising.

Unconformities at the base of the Pennsylvanian rocks, at the base of the Chattanooga shale, and at the base of the Devonian rocks are important. Before the deposition of the Devonian rocks, the older strata were tilted to the northwest toward the area of subsidence in southeastern Nebraska and were subjected to erosion and beveling. All the Silurian rocks and most of the Maquoketa shale were eroded in the McLouth field, and the Devonian rocks were deposited upon the beveled edges of the older formations. After deposition of Devonian limestones, a similar tilting of the surface toward the northwest occurred. This was followed by erosion and beveling of the Devonian limestones and older rocks. The Chattanooga shale was deposited upon this beveled surface. There is much variation in porosity of rocks at the top of the Devonian in different areas. The occurrence of impermeable rocks in the upper part of the Devonian in one anticline thus does not mean that similar impermeable conditions prevail elsewhere.

The Mississippian limestones were deposited upon the Chattanooga beds without marked angular unconformity. At the end of Mississippian deposition, the region was re-elevated and the northeasterly trending Nemaha anticline and other subsidiary parallel structures were developed. The surface of the beveled Mississippian formations was reduced to a peneplain; it was then re-elevated and a fault escarpment on the east side of the Nemaha fold was developed. At the same time, gentle subsidence warped the surface east of the escarpment and produced the Forest City and Cherokee basins which trend south from northeastern Kansas to Arkansas and Oklahoma. These basins probably were at first separated by the Bourbon arch, a broad low structural divide trending northwest from Bourbon county, Kansas. The earliest Pennsylvanian deposition in northeastern Kansas was in the deepest part of the Forest City basin, but as regional subsidence continued the Bourbon arch was submerged. The McLouth sand was deposited approximately at the time the Forest City and Cherokee basins were united.

During deposition of the Pennsylvanian rocks, the Forest City basin continued to subside by differential movements, and structural features that were initiated after deposition of the Mississippian rocks continued to develop. After deposition of the Permian rocks, the surface of Kansas and parts of adjoining states was tilted toward the northwest and the exposed rocks were beveled and ultimately buried by deposits of Cretaceous age. The development of the westerly regional dip in the Pennsylvanian rocks had an important effect on the expression of the structure of the gently dipping surface rocks.

The McLouth sand was deposited upon the beveled and warped surface of the Mississippian which had not previously been submerged in the area of the McLouth field. The gentle structure of the surface rocks overlies steeper structure in the underlying rocks because of continued differential warping. The regional tilt modified the expression of the weak surface structures and in many places decreased the areas of closure and shifted the positions of the crests of the surface anticlines in the McLouth field. The structural features of the older rocks were steeper than those of the younger rocks, and although the regional dip resulted in alteration of the closure, no perceptible change in the positions of the crests occurred.

The McLouth sand ranges from clay through coarse sand and intraformational conglomerates. It ranges in thickness from 15 to 95 feet. The variations in the thickness of the McLouth sand are due to the topographic relief of the underlying surface and the gentle structural deformation which was active before and during its deposition. Seven lithologic zones have been recognized. Four of these are predominantly sandy, and three are shaly. The zones are extremely variable laterally and almost all contain carbonaceous material. It is believed that this variability is due to deposition upon a slowly subsiding plain of aggradation at or slightly below sea level.

The gas reservoirs are sealed on the flanks of the anticlines by tar and dried oil which fill the interstices of the sand and thus exclude water. The planes of contact between the tar and the gas and between the water and the tar conform to the regional dip. When regional dip is eliminated, the gravitational distribution of the water, tar, and gas in the anticlines is essentially symmetrical with the structure of the anticlines before development of the regional dip. It is concluded, therefore, that oil and tar entered the anticlines in a fluid state before regional tilting and that later desiccation of the oil prevented gravitational readjustment of the oil and gas after regional tilting. The original accumulation of hydrocarbons in the reservoir thus took place at a time when the only areas that could contribute to the pools were adjoining synclinal areas. Therefore, the oil and gas in this case did not migrate long distances up the regional dip. Because the oil is desiccated and because the original closed pressure in the gas fields is lower than might be expected, one is led to speculate as to the possibility that large amounts of gas may have escaped from the anticlines from time to time when structural movements occurred.

The cumulative gas production to April 1, 1943, from the three pools was approximately 7 billion cubic feet. The calculated ultimate production from the developed area is slightly more than 9 billion cubic feet. Declines of pressure in the three pools of the McLouth field indicate a short life for these pools. The cumulative production of oil to April 1, 1943, was approximately 176,000 barrels. The peak of oil production had not been reached at that date. The oil is produced principally from a small area of Mississippian rocks on the crest of a dome underlying a part of the much larger gas-charged area in the McLouth sand. Oil in the McLouth sand comes from several isolated areas in the three pools. The Bankers Life pool with six wells and an area of 120 acres is the largest.

Hempel analyses reveal that oil from the McLouth sand and oil from the Mississippian dolomite are almost identical. There can be little doubt that oil has migrated upward from Mississippian rocks into the McLouth sand in the Bankers Life pool which is bounded on the north by a fault. Scattered wells in the other gas pools yield oil of the same character as that in the Bankers Life pool. It is believed, therefore, that concealed faults or perhaps only joints and crevices have permitted leakage of oil from below into the McLouth sand at other points than in the Bankers Life pool and that Mississippian oil pools of limited areal extent will be found beneath other structural crests in the McLouth field.

The character of the oil in the McLouth field is unusual, as indicated by the curves of correlation indices calculated from Hempel analyses. Such curves also reveal that oils from the Devonian and Kimmswick limestones of the Falls City pool of southeastern Nebraska are similar to those in the McLouth field. This suggests that the source beds of both areas were similar, that both had a similar dynamic history, and that the oil in the McLouth field may have been derived from source beds at least as old as the Kimmswick limestone. It seems possible, however, that the tar and dried oil bordering the gas reservoir in the McLouth sand and the original accumulations of gas may have been derived from the McLouth sand but that the undesiccated oil found locally in the McLouth sand came from a deeper source. Part of the gas may also have migrated upward through the same channels.

Conditions in the McLouth field increase the hope that oil and gas will be found in similar relations in extensions of the McLouth field and also in other places in northeastern Kansas. It may be expected that at least some of the anticlinal gas pools of northeastern Kansas, when drilled to Mississippian rocks, may yield oil on the crests of Mississippian anticlines, and that some anticlines now apparently condemned, when tested with due consideration of the shifting of the crests of weak surface structures, may be found to be productive.

INTRODUCTION

A preliminary report on the McLouth field (Lee, 1941), published by the State Geological Survey of Kansas, describes the development of the field prior to August 15, 1941. The present report discusses geological developments and production information of the field to April 1, 1943. The investigation that yielded these reports was undertaken by the State Geological Survey of Kansas and the Federal Geological Survey and represents part of a cooperative project having as its purpose the study of the relationship of oil and gas to stratigraphy and structure in the Forest City basin in Kansas. Another result of this cooperative investigation is a more general report on the stratigraphy and regional structure of the Forest City basin in Kansas which has been published as Bulletin 51 of the State Geological Survey. The work on the Pennsylvanian rocks of the McLouth field was done mainly by Thomas G. Payne who contributed the chapters on the stratigraphy of the Pennsylvanian, on the lithology, thickness, and lithologic zones of the McLouth sand, and on the environment and paleogeography during its deposition. The nomenclature and classification used in this report follow the usage of the State Geological Survey of Kansas. The use of adjectival endings on series names is not the preference of the senior author.

Location and Topography

The McLouth gas and oil field is situated in northeastern Kansas between Kansas City and Topeka, 15 miles north of Lawrence (fig. 1). The field is named for the village of McLouth, in southeastern Jefferson county, on the southwestern edge of the original gas pool. On April 1, 1943, the field included three pools in Jefferson and Leavenworth counties—the McLouth, the North McLouth, and the Ackerland pools (see pl. 3). These pools include parts of 21 sections in the southern part of T. 9 S., R. 20 E., the north half of T. 10 S., R. 20 E., and a small area in the northwestern corner of T. 10 S., R. 21 E. On April 1, 1943, the area of the three pools from which oil and gas were being produced was 4,610 acres, of which 550 acres yielded oil. At that date there were 90 gas wells and 21 oil wells.

The field is near the southern boundary of the submaturely to maturely dissected till-plains section of the Central Lowland physiographic province. The upland area of the field ranges in altitude from approximately 1,100 feet to a maximum of nearly 1,200 feet in the southwestern part, and is mantled by Pleistocene glacial deposits of till, sand, and gravel. This upland plain has been dissected, especially in the northern and eastern parts of the field, by the headwaters of northeastward and eastward-flowing tributaries to Stranger creek, which flows southward and joins Kansas river. The well altitudes in this dissected and topographically lower portion of the field range from 969 to nearly 1,100 feet. Thus, the topographic relief of the producing area is roughly 225 feet.

The McLouth field lies on the southeastern side of the Forest City basin, a low broad structural feature whose central area lies in northeastern Kansas and whose margins extend into the adjoining parts of Nebraska and Missouri and into Iowa. The basin was formed by regional warping of the pre-Pennsylvanian rocks, and it was originally both a topographic and a structural feature in which the earliest Pennsylvanian rocks of this part of Kansas were deposited. The McLouth field is approximately 40 miles southeast of the deepest part of the basin and 50 to 60 miles east of the Nemaha anticline which confined the basin on the west.

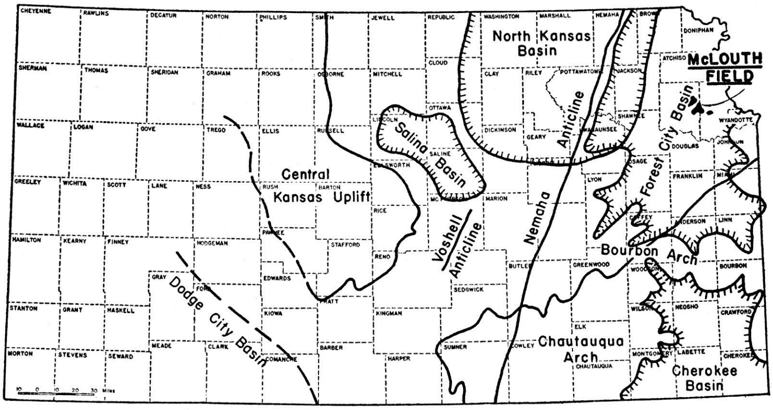


FIG. 1 Map of Kansas showing McLouth gas and oil field and outlines of principal structural features of Kansas. The Chautauqua arch is indicated by pre-Chattanooga outcrops of top of Simpson sandstone (after McClellan, 1930); trends of Nemaha and Voshell anticlines and position of Salina basin are indicated by thickness of Mississippian rocks (Lee, 1939); Central Kansas uplift is shown by absence of Mississippian limestone (Lee, 1939); outline of Forest City basin from thickness map of pre-Hertha Pennsylvanian rocks (this report); outline of Cherokee basin from thickness map (Bass, 1936); North Kansas basin from thickness map of Chattanooga shale (Lee, 1940); and Dodge City basin after McClellan (1930). The development of all these structural features was not contemporaneous. The Chautauqua arch and the North Kansas basin are the oldest structural features outlined on the map, and the Forest City basin and the Cherokee basin are the youngest.

History of the Field

The geological work which led to the development of the field was done in April, 1939, by Huntsman Haworth and C. B. Taylor, consulting geologists of Wichita. Gas was discovered in the McLaughlin and Sons No. 1 fee well, in the NE¼ NW¼ sec. 4, T. 10 S., R. 20 E., early in November, 1939. This gas was found in what is called the McLouth sand, an irregular body of sandstone and shale at the base of the Cherokee shale which is the oldest Pennsylvanian rock in Kansas. This well was originally gauged at 8½ million cubic feet of gas per day from sand at a depth of 1,426 to 1,440 feet. As there was no market for the gas, the well was deepened to explore the possibilities for oil production. An increase in gas was reported at depths from 1,450 to 1,475 feet. Casing was set and cemented at the top of the Mississippian rocks at a depth of 1,475 feet. Small amounts of oil and gas were reported at the top of the Mississippian, and heavily oil-stained porous limestone and dolomite were encountered in four other zones in the Mississippian beds between 1,475 and 1,645 feet below the surface (170 feet below the top of the Mississippian). Water was reported at depths of 1,635 and 1,650 feet.

Limestone of Middle Devonian age ("Hunton") was encountered at 1,875 feet and drilled to 1,915 feet below the surface. Shows of gas were reported in the Devonian, but efforts to shut off the water that filled the hole proved unsuccessful. Drilling was stopped at 1,915 feet and the well was plugged back to the base of the Pennsylvanian where gas was later produced from the McLouth sand.

The second well in the field, Young and Longwell No. 1 McLeod, in the S½ NW¼ SW¼ sec. 4, T. 10 S., R. 20 E., was started on April 7, 1940. This well penetrated the same sequence of Pennsylvanian rocks as the discovery well except that the gas sand was represented by impervious silty and sandy shale with thin streaks of dense oil-stained sandstone. Prompted by the encouraging shows of oil in the discovery well, the operators deepened the second well to test the Mississippian limestones. Some free oil was found in the top of the Mississippian rocks at a depth of 1,469 feet, and many samples of dolomite and limestone to a depth of 1,594 feet were oil stained. Between depths of 1594½ and 1,596 feet, the well filled 1,200 feet with black oil of 20.7° Bé. gravity. Seventy-two barrels of oil were pumped from the well during the first 24 hours of a test and 32 barrels were pumped during the ensuing 30 hours, but production from this well declined rapidly.

The discovery of oil in the Mississippian limestone in the second well in the field, although not in itself of great importance, led to the deeper drilling of many other tests which have revealed the structural relations of the pre-Pennsylvanian rocks to those of the Mississippian. The Young and Longwell No. 1 McLeod well (the second well) also revealed pre-Pennsylvanian faulting which is indicated by the local absence of certain limestone beds and by the shortening in this well of the upper part of the Mississippian section.

Two other gas wells were drilled shortly thereafter, one of which, the McLaughlin and Sons No. 1 Dark well in the NW¼ SW¼ NW¼ sec. 4, T. 10 S., R. 20 E., was gauged at over 13 million cubic feet of gas per day. The other, the McLaughlin and Sons No. 2 Dark well, offsetting the No. 1 Dark well, was gauged at 3.8 million cubic feet per day. The fifth well, Stark No. 1 Ragan, in the N½ NW¼ NE¼ sec. 4, was favorably located near the crest of the surface anticline, but found the McLouth sand composed of impervious sandy shale and thin streaks of impervious sandstone. The Mississippian producing zone contained water. This location had been considered for the first well; if chance had not directed the first test to another location, the anticline would have been abandoned and the surrounding areas condemned.

At this time, gas production seemed to be so spotty that a pipeline connection seemed unwarranted. However, owing largely to persistent drilling by D. W. McLaughlin and his associates in spite of the disappointing results from some of the early wells, sufficient gas reserves were developed to insure the construction of 10 miles of pipe line to the Cities Service main line at Tonganoxie. The pipe line was connected on March 18, 1941.

Expansion of the field resulted in a series of important developments. In May, 1941, the Longwell No. 1 Bankers Life well, in the NW¼ SW¼ sec. 3, T. 10 S., R. 20 E., discovered oil in the McLouth sand in the depressed area south of the fault (fig.8.). This and other wells later drilled in this section revealed a small oil pool on a faulted anticline, the crest of which had been lowered by the fault below the gas sand on the upthrow side. In July, 1941, the discovery of gas in the Anderson No. 1 Woodhead well, in the NE¼ SW¼ sec. 32, T. 9 S., R. 20 E., outside the area of structural closure of the surface rocks, led to the hypothesis that porosity of the sand body rather than structure was the controlling factor of accumulation. This conclusion is now known to have been erroneous, for, as will be shown later, the structure at the surface imperfectly reflects the structure in the deeper rocks.

The Anderson No. 1 McLeod-Wisdom well, in the SW¼ NW¼ sec. 29, T. 9 S., R. 20 E., drilled in July, 1941, opened the North McLouth gas pool, which at that time was believed to be an extension of the original pool. However, a number of holes drilled later revealed a sharp intervening syncline conforming in trend to the shallow structural trough shown on Haworth and Taylor's map of the surface structure (pl. 2). The Ackerland gas pool was opened in October, 1941, by the Mosbacher et al. No. 1 Bell Estate well, in the NW¼ NE¼ NE¼ sec. 12, T. 10 S., R. 20 E., 2½ miles west of the village of Jarbalo in Leavenworth county. Development of this pool was retarded for a time because the well made only slightly more than 1 million cubic feet of gas per day. More productive wells were drilled later. The pool, although small, was still being extended toward the east on April 1, 1943.

Another interesting well, the Anderson No. 1 Dick well in the SE¼ SW¼ sec. 17, T. 9 S., R. 20 E., found oil in the McLouth sand in the North McLouth pool in October, 1941. The Mosbacher No. 1 Dolman well, in the NW¼ NW¼ SE¼ sec. 27, T. 9 S., R. 20 E., drilled in September, 1941, found the McLouth sand impermeable but had a show of gas in the St. Louis limestone at the top of the Mississippian. This limestone was acidized and the flow was increased to a reported 2.8 million cubic feet of gas per day.

The Apperson No. 1 Bower well, in the SE¼ SE¼ NE¼ sec. 5, T. 10 S., R. 20 E., a rotary well on the crest of the McLouth anticline, was drilled to the Arbuckle limestone in the autumn of 1941. This well is structurally the highest well in the pool in the Mississippian limestone. The Mississippian producing dolomite was cored in this well, revealing a spongy condition in the cores recovered (pl. 5). The top of the Devonian ("Hunton") was also cored. This core consisted of sucrose dolomite which was heavily stained with oil, but it lacked porosity adequate for oil accumulation. After drilling to the Arbuckle limestone, the hole was plugged back to the pay zone in the Mississippian and a good oil well was developed. Traces of oil in the upper zone of the "Hunton" in this well and traces of oil in the lithographic limestone at the top of "Hunton" in the McLaughlin No. 1 Thorpe well, in the NE¼ NE¼ sec. 27, T. 10 S., R. 20 E., which had been drilled earlier, indicate that oil pools probably will be discovered in the Devonian at places where both porosity and structure are favorable. The Jackson No. 1 Shughart well, in the SW¼ SW¼ sec. 6, T. 9 S., R. 20 E., drilled in December, 1941, found porosity in oil-stained dolomite in the upper Devonian rocks, but the well was unfavorably located structurally.

Three wells in secs. 28, 29, and 32, T. 8 S., R. 20 E., drilled by McLaughlin and Sons during 1942, failed to yield commercial production but demonstrated the occurrence of structural features in the southern half of T. 8 S., R. 20 E. which give promise of a northern extension of the McLouth field.

On December 20, 1941, 32 rigs were operating in the McLouth field. At the end of January, 1942, only 14 rigs were operating and by the first of March, 1943, only 6 wells were being drilled. During the summer of 1942 the number of wells being drilled at one time rarely exceeded 14 and frequently fell below 10. On April 1, 1943, only 8 wells were being drilled.

Drilling and Operating Practices

SPACING OF WELLS

It has been the practice to space each gas well on a 40-acre tract, but there are several gas wells on town lots at the north edge of the town of McLouth, in the NE¼ NW¼ sec. 8, T. 10 S., R. 20 E., where at one time it seemed that a town-lot drilling campaign might develop.

Oil wells were originally drilled on 10-acre tracts. The six oil wells in the SW¼ sec. 3, T. 10 S., R. 20 E. and a few gas wells in secs. 4 and 5 were irregularly spaced because of the irregular shape of land subdivisions. Limitations prescribed by the Office of Production Management for the drilling of oil wells to the Mississippian dolomite in secs. 4 and 5 have complicated the spacing of oil wells in these sections. Conservation Order No. M68, dated December 23, 1941, restricted the drilling of gas wells to one in 640 acres and oil wells to one in 40 acres. Provisions for obtaining exceptions to the conservation order later were promulgated and relief was secured which permitted the resumption of drilling. Regulations as of April 1, 1943, permit the spacing of gas wells on 40-acre tracts as before the conservation order, but the spacing of oil wells is restricted to 20-acre locations at a distance of at least 660 feet from oil wells and 330 feet from gas wells and property lines.

DEPTHS TO PRODUCING ZONES

Most of the wells reach the gas sand at depths between 1,400 and 1,550 feet; because of structure and topography, however, extremes of depths as shallow as 1,365 feet and as deep as 1,625 feet have been drilled. The oil zone in the Mississippian dolomite is reached at depths of 1,596 to 1,682 feet in the McLouth oil pool depending upon the local topography and structure.

DRILLING PRACTICES

The wells in the field have been drilled with drilling machines of various makes; standard tools were used in a few wells. Rotary tools were used in drilling only one well. This well, the Apperson No. 1 Bower well, in the SE¼ SE¼ NE¼ sec. 5, T. 10 S., R. 20 E., was drilled to a depth of 1,955 feet with rotary tools. At this depth, circulation was lost in a crevice or cavern in the Devonian limestone. Standard tools were then installed and the well was completed at 2,288 feet in the Arbuckle limestone. This experience and the shallow depth of the producing zones discouraged the use of rotary equipment.

Wells to the McLouth sand require an average drilling time of 18 to 20 days. A few wells were drilled in 10 days but many have required a much longer period because of fishing jobs, caving-shale, water, and in some cases inadequate equipment. The average contract price is $1.35 per foot exclusive of pipe which is furnished by the operator.

Three to four strings of casings are run. Ordinarily, one to three joints of 10-inch surface pipe are set and a string of 8¼-inch pipe is run through the Hertha limestone, which is penetrated at depths of 800 to 1,000 feet. In many wells this is followed by a string of 6⅝-inch pipe cemented at the top of the gas sand. Where caving-shale or water-sand is encountered in the Cherokee shale, however, 6⅝-inch pipe is run at depths ranging from 1,100 to 1,400 feet. Where 6⅝-inch pipe is set in the Cherokee shale, 5 3/16-inch pipe is cemented on top of the gas sand. In some gas wells 2-inch tubing is run. In oil wells in the McLouth sand, 2-inch tubing is run; in oil wells in the dolomite zone, 2½ to 3-inch tubing is used.

It is not the practice to shoot gas wells in the McLouth sand. Oil wells in the McLouth sand, however, have been shot with 40 to 60 quarts of nitroglycerine. The first oil well in the dolomite zone was acidized, but the great increase in water discouraged the acidization of other early wells in the dolomite. The development of the field revealed that the discovery well in the dolomite was an edge well and that the Mississippian limestone in this well was faulted. Late in 1942, one of the oil wells higher on the structure was acidized and an important increase of oil resulted. Since that time all but one or two of the dolomite wells have been acidized with 1,000 to 2,000 gallons of acid. Acidizing doubles or triples the initial production of oil, but it also increases water production. The amount of water accompanying the oil in the dolomite wells of the McLouth pool varies greatly. In many wells more water than oil is pumped. The average production of water on April 1, 1943, was reported to be about 60 percent of the fluid pumped. The water is run to earthen evaporating ponds.

The Mosbacher No. 1 Dolman well, in the NW¼ SE¼ sec. 27, T. 9 S., R. 20 E., an edge well, encountered gas in St. Louis limestone. The open flow is reported to have been gauged at 360,000 cubic feet per day before acid treatment. The flow of gas increased to 759,000 cubic feet per day after a first acid treatment and to 2,800,000 cubic feet per day after a second acid treatment. The amount of water, however, also increased and the well was never put on production.

All of the oil wells of the field are equipped with individual pumping units. A few of the oil wells made brief initial flows but the first successful oil well, the Young and Longwell No. 3 McLeod well, in the NE¼ SE¼ sec. 5, T. 10 S., R. 20 E., a well producing from the dolomite, was unique in that it flowed by heads for several months. Very little gas accompanies the oil. Gas used for pumping wells which produce oil from the dolomite is drawn from nearby gas wells. Enough gas to operate the pumps accompanies the oil in wells in sec. 3 producing from the McLouth sand. The oil is heated to 150° F. and chemically treated in the field to separate the water.

DISPOSAL OF GAS AND OIL

Gas from the McLouth area is piped from the field through two pipe lines, both of which have Cities Service connections. The first, a 6-inch line connected March 18, 1941, is owned by the A and B Pipe Line Company of Wichita. The second, an 8-inch line connected December 16, 1941, is owned by Walter S. Fees of Iola, Kansas.

The A and B line runs southeast from the field to Tonganoxie, Kansas, where it delivers gas to the Cities Service pipe line at a pressure of 300 pounds per square inch. The Cities Service line runs northeast from Tonganoxie, and supplies the cities of Leavenworth and Atchison, Kansas, and St. Joseph, Missouri. The Fees line runs slightly northwest from the field and delivers gas at a pressure of 170 pounds per square inch to a former distributing line of the Cities Service Company built north from Topeka to supply the towns of Oskaloosa and Valley Falls. The direction of flow in this line is now reversed and McLouth gas is now conducted through Oskaloosa to Topeka, where most of the gas from the Fees line is consumed. The average field pressure had declined before April 1, 1943, to less than 150 pounds per square inch in all pools (fig. 20), and compressor plants are now operated by both companies to maintain pipe-line pressures.

The A and B Pipe Line Company pays 7 cents per thousand for gas at the wells; the Fees pipe line pays 7½ cents per thousand. The Cities Service is reported to pay the pipe-line companies 12 cents per thousand delivered in Tonganoxie and at the line near

Oskaloosa. The volume of gas is computed at 2 pounds above atmospheric pressure and at a temperature of 60° F.

The Marson Oil Company of Kansas City buys most of the oil from the field. It is transported by truck mainly to Kansas City where it is used as fuel oil without further treatment. The oil was sold at 85 cents per barrel at the well until early in 1943 when the price was raised to 95 cents per barrel. About 5,000 barrels of oil were disposed of locally and in adjoining counties for road surfacing. Minor amounts of oil have been utilized as fuel for drilling operations.

Study of the Field

The McLouth field is unique in that it is the only gas field in northeastern Kansas in which the relation of the structure of the gas sand in the Pennsylvanian to that in the underlying Mississippian rocks is known. This came about through the discovery of oil in the Mississippian rocks early in the development of the field. Most of the wells are drilled into the McLouth sand; if this proves to be dry, the wells are deepened to test the porous zone in the Mississippian rocks. The conditions revealed by a study of the data from the upper part of the Mississippian, which will be discussed later in this report, have an important bearing on the development of future deep production in northeastern Kansas and give hope for production in the deeper rocks below other gas pools in Pennsylvanian rocks in places where the accumulation of the gas was controlled by structure.

Only six wells in the field have been drilled below the middle beds of the Mississippian limestones so that the relation of the surface structures to the important oil-producing zone at the top of the Devonian limestone is still undetermined.

EXAMINATION OF SAMPLES

In the course of this work, nearly complete sets of samples have been collected from all wells in the field. Samples were usually taken at 5 to 10-foot intervals. In some wells the taking of samples at intervals of 15 to 30 feet or more has interfered with the accurate determination of the depth to key horizons. Samples of the McLouth sand ordinarily were taken at 5-foot or smaller intervals, but no satisfactory samples of the producing gas sands have ever been caught. The water used in drilling the gas wells is blown out of the hole by the gas and the wells necessarily are drilled in dry. Consequently, the gas sands become pulverized and are ejected as fine angular quartz dust which does not represent the character of the reservoir sand. Samples of the sand from oil wells, wells yielding water, and wells in which the sand is argillaceous or clogged with desiccated oil or tar, however, have been studied. Chunk samples recovered from oil wells in the McLouth sand have been of value in the study of the lithologic character of the sand (pl. 8), but these samples probably represent the less porous parts of the McLouth sand.

Many of the depths to key horizons used on the contour maps are not in accord with the drillers logs. Some of these differences are due to corrections resulting from sample examination. Others are due to the correction of drilling depths by steel-line measurements. Corrections are, for the most part, of only a few feet and rarely over 10 feet, but corrections up to 25 feet were made in a few wells. In well logs where the correction of depth occurs below one of the key horizons the depth of the key horizon has been adjusted proportionally to the distance up the hole to a previous check measurement. The shorter the distance between the key horizon and the correction point, the more nearly does the adjustment equal the correction. Unfortunately, it is probable that in a few cases depths were corrected without notation in the log book. The depths to key beds in all wells in the McLouth field are given in table 1 with corrected depths where these differ from the drillers log.

WELL NAMES

Table 27 gives a list of wells drilled in the McLouth field and on its borders. Much difficulty has been encountered in naming the wells. Many of the wells were drilled as joint enterprises with two or often several owners. It is obviously impossible to name all those interested as owners and it has been the practice to name the wells for the operator who seemed to hold the dominant interest at the time the well was started, and to continue this name even when there were later changes in the dominant ownership of the well and lease. Where such changes in ownership have attained current usage, the new name has been added in parentheses. For instance the Magnolia leases were subleased in part to Hatcher and Fisk and in part to others with the condition that the lease should revert to Magnolia in case oil were discovered. Thus, the name Magnolia in parentheses has been added in some cases.

The transfer of fee interests has been equally confusing. The authors have preferred to continue the use of the established name under which the well was drilled rather than to add confusion by changing the lease name. However, where current usage has adopted the name of the new fee owner, this name has in some cases been placed in parentheses. Thus, Longwell and others drilled an oil well on land leased from the Bankers Life Company, but the land was thereafter transferred to Bessie McLeod. The name Bankers Life was continued in naming wells subsequently drilled, but the name of the new fee owner has been placed in parentheses. Many changes in both fee and lease ownership have been ignored, however, to avoid confusion of nomenclature and because changes in ownership could not always be verified.

Acknowledgments

The study of an area like the McLouth field with divided ownership of leases can be prosecuted only with the cooperation of a large number of people upon whose continuing help the assembling of the data depends. This cooperation has been given fully by drillers, contractors, geologists, and operators.

It is a pleasure to acknowledge the help of all the operators in the field, particularly that of D. W. McLaughlin in securing the interest and cooperation of other operators in the early development. Especial thanks are tendered to the drillers and contractors who saved and labeled the samples, and whose careful logs in many instances have given more accurate determination of stratigraphic breaks than is possible from a study of samples alone.

The original map of the field by Haworth and Taylor showing the structure as indicated by the surface rocks is here published by permission of Huntsman Haworth to whom the writers are indebted also for altitudes, detailed information on current developments, and for the use of other structure maps in outlying areas (pl. 2.). The personal contacts established by James C. Clark, Gene Maxwell, and Hugh Crain in collecting samples and other information in the field have contributed in no small measure to the successful prosecution of the enterprise.

The writers are indebted to L. L. Armstrong of the A and B Pipeline Company for production figures, well pressures, and gas analyses; and to Walter Fees of the Fees Pipeline Company for data on gas production. Data on oil production have been contributed by George B. Willhoite of McLaughlin and Sons, Ray

Anderson, the Magnolia Petroleum Company, and the Marson Oil Company.

Analyses of oil from the Falls City pool made by the Bureau of Mines at Bartlesville were provided by Edward A. Huffman, District Geologist for the Skelly Oil Company. Samples of oil from the McLouth pool were analyzed by J. G. Crawford of the U.S. Geological Survey. N. W. Bass contributed a discussion of the Hempel analyses of oils from McLouth and Falls City. W. F. Earl of the Ohio Oil and Gas Company assisted by contributing samples and in other ways.

Most of the work on the Pennsylvanian samples was done by Thomas G. Payne, co-author of the report. Ada Swineford ably continued the examination of the Pennsylvanian cuttings after the transfer of Payne to other work. Miss Swineford is responsible also for the tedious compilation of well data and for the production and other charts. The drafting of the illustrations was done by Dorothea Weingartner, Eileen Martin, and others under their direction. The manuscript was edited by H. D. Miser, John C. Frye and Edith Lewis to whom thanks are tendered.

STRATIGRAPHY

A composite stratigraphic section of rocks penetrated by drilling in the McLouth field is shown in figures 2 and 3. The key horizons used in the structure and isopachous maps are indicated by the letter K at the right of the columnar sections. The reference horizons used in well-to-well correlation and as controls for picking the key horizons are indicated by the letter R. The positions of the gas- and oil-producing zones and of the most prominent unconformities are shown by standard symbols.

Pennsylvanian Rocks

Pennsylvanian rocks penetrated by drilling in the McLouth field are described in detail in a report by Moore (1936) on the Pennsylvanian rocks of Kansas. The nomenclature and stratigraphic classification used in discussing Pennsylvanian stratigraphic units follow the usage of the Kansas Geological Survey.

Virgilian series.—The Pennsylvanian formations that crop out in the area of the McLouth field are, in descending order, the Lecompton limestone, the Kanwaka shale, and the Oread limestone of the Shawnee group in the middle part of the Virgilian series of late Pennsylvanian age. They are, however, mantled in many areas by deposits of glacial till, clay, sand, and gravel of Pleistocene age.

The rocks of the Lecompton limestone and the Oread limestone consist chiefly of different types of limestone interstratified with shale. The Kanwaka shale consists chiefly of shale divided by the Clay Creek limestone, much of which is soft and shaly in the McLouth area. The shales above and below the Clay Creek are in part sandy. As pointed out by Moore (1936), the rocks of these and other Pennsylvanian formations were deposited in cyclic succession during the alternating advance and retreat of marine water.

The Douglas group, also a part of the Virgilian series, lies below the Shawnee group but does not crop out in the area of the McLouth field. Unlike the Shawnee group, which is partly of marine origin and contains numerous limestone beds, the Douglas group is largely of nonmarine origin and, with the exception of the marine Haskell limestone (fig. 2), does not contain much limestone. The Douglas group includes the Lawrence shale and the Stranger formation and consists predominantly of shale, sandy shale, sandstone, siltstone, and massive clay beds; there are also minor beds of coal, underclay, clay ironstone, and nonfossiliferous and probably nonmarine sandy limestone. The Douglas group contains beds of channel sandstone (fig. 2), including the Ireland sandstone in the lower part of the Lawrence shale and sandstone developed at variable positions in the Stranger formation, commonly referred to as the Tonganoxie sandstone. The beds of the Douglas group show marked vertical lithologic variations and few of the beds are laterally persistent. The Haskell limestone was deposited upon an irregular surface and is not a trustworthy datum bed for the mapping of structure.

Missourian series.—The Douglas group is underlain by the Lansing, Kansas City, and Bronson groups, which are part of the Missourian series and consist of alternating beds of limestone and shale (fig. 2). The lowest persistent limestone of the Bronson group is the Hertha limestone, the base of which is used as a key horizon for structure contour mapping. It is described later under the heading entitled *Base of Hertha limestone.* That part of the Missourian series below the Hertha limestone is the Bourbon group. It consists largely of silty to sandy shale; locally, at the base, there is a thick sandstone deposit, and in places there are extensive sandstone beds in the middle and upper parts of this group.

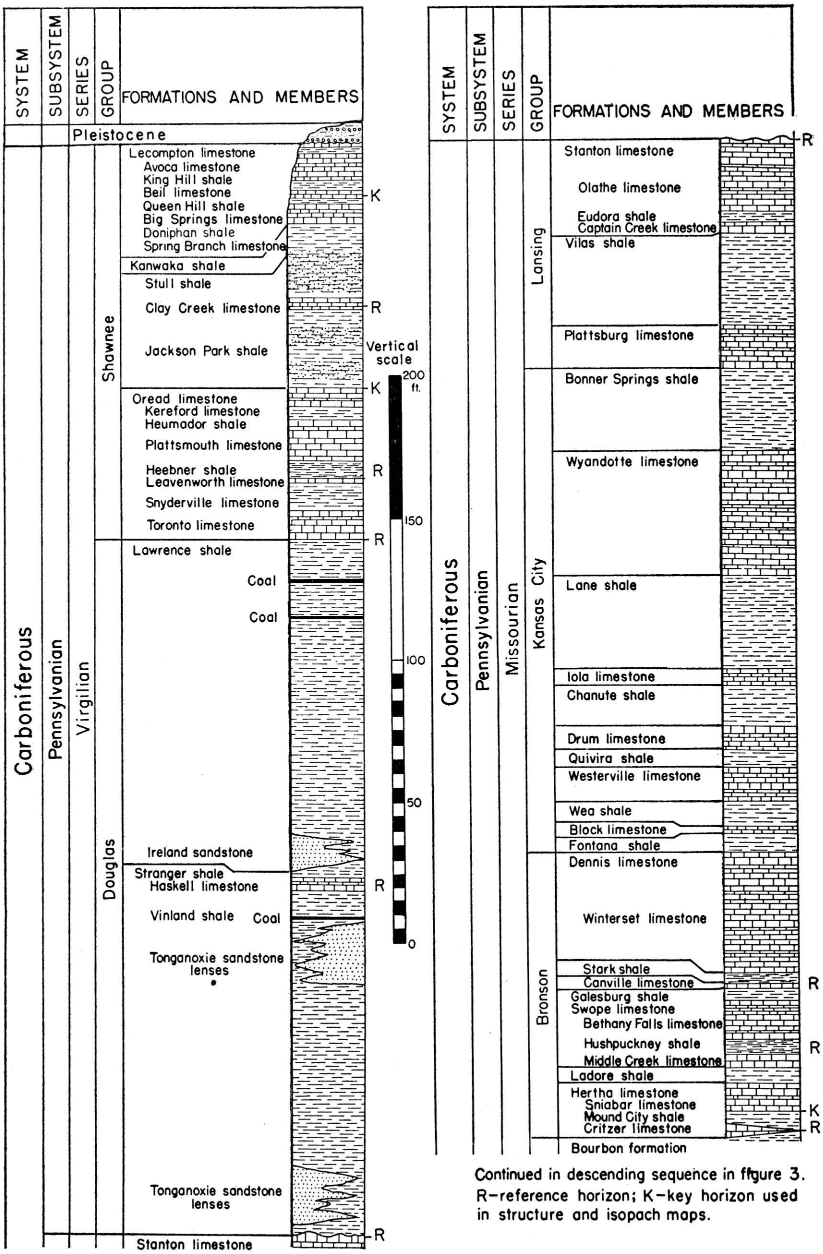


FIG. 2. Composite columnar section of Pennsylvanian rocks from the base of the Hertha limestone to the top of the Lecompton limestone exposed at the surface in the McLouth field. Only the more important members of the formations are shown.

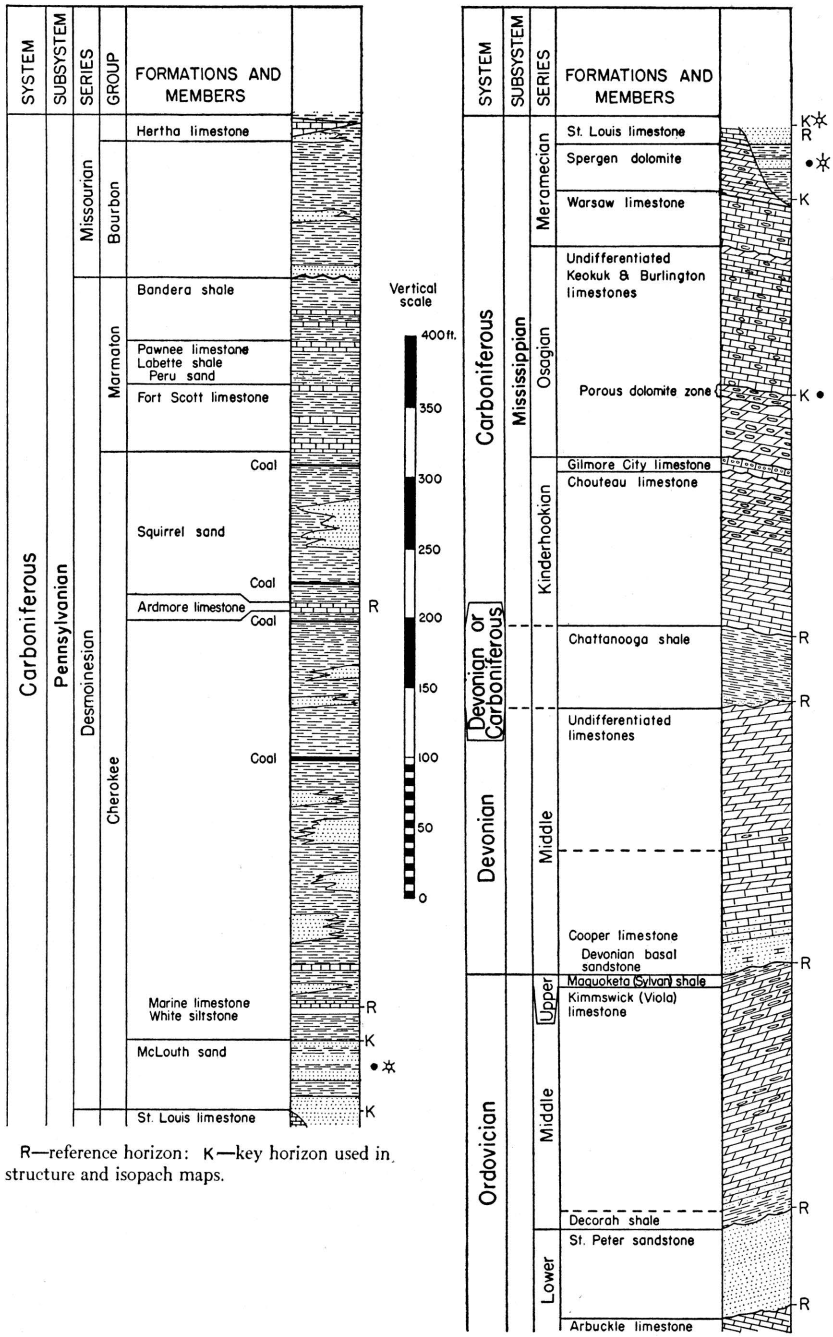


FIG. 3. Composite columnar section of upper Ordovician, Devonian, Mississippian, and lower Pennsylvanian rocks in the McLouth field. Pennsylvanian section continued from figure 2.

Desmoinesian series.—The Desmoinesian series, which lies below the Missourian, consists of an upper part, the Marmaton group, and a lower part, the Cherokee group. The Marmaton group consists chiefly of alternating beds of shale and limestone and also contains persistent thin coal beds and sandstone beds. The sandstone beds of the Marmaton, known loosely as "Peru sand," yield gas in many places in eastern Kansas but are unproductive in the McLouth field. The limestones of this group are thin in the McLouth area and are not consistently logged by all drillers. They cannot be differentiated where samples have been taken at long intervals, and consequently they are unsatisfactory for correlation in the McLouth field. The most prominent formation of the Marmaton, the Fort Scott limestone, is a good datum bed in most places in Kansas, but it is thin in the McLouth field and cannot be identified in all wells. The Cherokee shale (fig. 3) includes strata of diverse lithologic types from the base of the Fort Scott limestone of the Marmaton group down to the base of the Pennsylvanian. Within the Cherokee there are cyclic successions of sandstone, shale, coal, and in some places thin limestone beds; these successions are not as well developed as those in the Shawnee, Lansing, Kansas City, and Bronson groups and differ in character from those beds. The predominant type of rock in this formation is shale, of which there are many varieties including clay shale, silty micaceous shale, and sandy shale. Black carbonaceous shale is common. There are also beds of massive clay, sandstone, and siltstone, and thin beds of coal, clay ironstone, and limestone. The sandstone beds lack lateral persistence. Some grade laterally into sandy shale; others fill ancient channels or perhaps, as in other parts of eastern Kansas, represent offshore bars (Bass, 1936). A zone of discontinuous sandstone beds in the upper part of the Cherokee, 50 to 100 feet below the base of the Fort Scott limestone, is known to gas operators as the "Squirrel sand." It has yielded gas in many fields in eastern Kansas, but is not productive in the McLouth field. With the exception of certain of the limestone beds, the group is dominantly of nonmarine origin. The most prominent limestone, the Ardmore limestone (fig. 3) which occurs in the upper middle part of the Cherokee, probably does not exceed 5 feet in thickness. The Ardmore should constitute a valuable reference or datum bed. However, it is not always logged by drillers, and samples from this part of the stratigraphic section are taken at such long intervals in many wells that the exact depth of the Ardmore is locally uncertain even when material from it is recognized in the samples.

The McLouth sand, a variable sequence of shale and sandstone which constitutes the basal part of the Cherokee group and overlies Mississippian rocks, is described in detail in a subsequent part of the report. This sand constitutes the gas- and oil-producing zone of the Pennsylvanian rocks in the McLouth field.

PENNSYLVANIAN DATUM BEDS

The Pennsylvanian beds that have proved most useful as datum beds in the study of structure are described below. The term "key horizon" is used to refer to datum beds which were used in the preparation of structure and thickness maps. Reference beds are those that have been useful in confirming the identification of key beds but which have not been of direct use in structural studies.

Top of Oread limestone.—The uppermost key horizon used in structure contour mapping in the McLouth field is the top of the Oread limestone formation. This horizon (fig. 2), at the contact between the Oread limestone and the overlying Jackson Park shale, is recognized by drillers and is easily identified by means of sample studies.

The Kereford limestone member, the topmost member of the Oread (fig. 2), is an impure, very fine-grained, fossiliferous limestone, with very light brownish-gray coloration. Its thickness is variable within the field and ranges from 5 to 10 feet. Fusulinids, crinoid stem plates, and molluscan remains are abundant. The insoluble residue, ranging up to 11 percent by weight, consists primarily of silt composed of quartz and mica. Locally, the Kereford member contains oölites which stand out as dark-gray patches on the surfaces of rock fragments in well cuttings.

The Jackson Park shale (fig. 2) overlies the Kereford member of the Oread limestone and is generally 25 to 30 feet in thickness. It consists of calcareous and carbonaceous fine sandstone and siltstone composed dominantly of quartz and mica grains cemented by calcite. The rock is light buff-gray as seen under the binocular microscope. Fossil remains consist of abundant carbonized fragments of land plants.

In addition to the above-described rocks, there are several reference beds used in well-to-well correlation and as controls for determining this key horizon. The Clay Creek limestone which is 2 to 4 feet thick and overlies the Jackson Park shale is represented in most drillers logs. The base of this fusulinid-bearing, brownish-gray, fine-grained argillaceous limestone is 25 to 30 feet above the top of the Oread limestone. Another important reference bed is the Heebner shale member of the Oread formation. This black, carbonaceous, hard and very fissile shale, logged as "black slate" in many records, averages less than 5 feet in thickness. Its top lies about 30 feet below the top of the Oread. The Toronto limestone member, the lowermost member of the Oread formation, averages 8 feet in thickness and is light buff-gray in color and fine- to medium-grained. It is rather impure fossiliferous limestone, containing a residue of silt and very fine sand composed of quartz and a minor amount of mica. The base of this member commonly is 55 to 60 feet below the top of the Oread.

Base of Hertha limestone.—The second key horizon in the McLouth field, the base of the Hertha limestone (fig. 2), ranges from 630 to 680 feet below the top of the Oread limestone, but in most wells is 650 to 670 feet below the top of the Oread. As described by Jewett (1932, p. 100) and as recognized by the Kansas Geological Survey, the Hertha along its belt of outcrop in Kansas and Missouri consists of two limestone members separated by a shale which averages 5 feet in thickness. The upper limestone member, the Sniabar limestone, is the most persistent and the most distinctive lithologically of the two members; its base represents a good key horizon. The lower member, the Critzer limestone, in the subsurface is highly variable and is not laterally persistent. The base of the Hertha as used in this report is at the base of the Sniabar limestone member of the revised classification. The Critzer is thin and variable and occurs only locally. The writers have retained the name "Hertha limestone" in its original sense for this key horizon inasmuch as it is commonly so termed by drillers and operators. In wells in which the Critzer limestone is found, drillers confuse the base of Hertha, as here used, with the base of the Critzer.

The Sniabar member of the Hertha limestone averages 10 feet in thickness and varies considerably in lithology. Characteristically, it is a nearly white to light-buff, impure, fine- to medium-grained dolomitic limestone; the impurities, as shown by insoluble residues, consist mostly of silt and very fine sand composed of quartz and mica. The rock varies laterally from highly dolomitic to highly calcitic. Fossils are not abundant, but samples from several wells contain a few crinoid remains and fragments of corals and brachiopods. Coarse oölite phases were noted in samples from several wells. In some places the oölites have been in part removed by solution, leaving a highly porous water-bearing rock. In a few samples the oölites have been dolomitized.

The Sniabar member of the Hertha limestone is underlain by the Mound City shale (fig. 2), which varies greatly in lithology in different parts of the field and averages 5 feet in thickness. Commonly it is a light- to dark-gray clay shale, but in several wells the Sniabar limestone is underlain by a shaly carbonaceous quartz siltstone. The Critzer limestone member underlies the Mound City shale and, although not everywhere present, it is a valuable reference bed. In the McLouth field the Critzer is thin, ranging to 3 or 4 feet in thickness where present, and is a hard, sublithographic, dolomitic limestone. It commonly is brownish-gray in color and is very impure, yielding a large residue of quartzose and micaceous silt.

There are two important reference beds above the Hertha limestone. The Hushpuckney shale, the base of which is about 20 feet above the base of the Hertha limestone, is recorded in most drillers logs. This shale bed is 3 to 4 feet in thickness; the lower part consists of black fissile shale and the upper part is bluish-gray clay shale. The Stark shale (fig. 2) lies 20 to 25 feet above the Hushpuckney shale and also is valuable in well-to-well correlation. It is 2 to 4 feet in thickness and is for the most part black and fissile.

Top of McLouth sand.—The top of the McLouth sand constitutes a reliable key horizon in the lower part of the Cherokee (fig. 3). The lithology of the McLouth sand is described in a subsequent part of the present report. A persistent white siltstone bed a short distance above the McLouth sand is generally recognized by drillers and provides a valuable marker indicating the proximity of the top of the sand. It is logged by drillers as "white shale" and its top is 15 to 25 feet, usually 20 feet, above the top of the McLouth sand. The bed averages less than 4 feet in thickness and consists of nearly white to very light buff-gray micaceous quartz siltstone which commonly contains reddish-brown siderite spherulites ("pellets") averaging 0.5 mm in mean diameter. The siltstone is overlain by an even more persistent reference bed, a medium to very dark-gray fossiliferous argillaceous limestone (fig. 3) which is recorded by drillers in some logs as "shell limestone." It leaves a large insoluble residue of dark argillaceous bituminous material and is easily overlooked because of its very dark color. The thickness of this limestone bed cannot be determined accurately from drillers logs and from examination of samples; it is probably only 1 to 2 feet thick in general, but in a few wells it is 4 feet thick. The limestone contains crinoid remains (mostly stem plates) and brachiopods. Inasmuch as the Cherokee shale shows indications of nonmarine origin, this limestone represents only a brief invasion of marine waters in a region of dominantly continental sedimentation.

The interval from the base of the white siltstone reference bed down to the top of the McLouth sand consists, for the most part, of dark-gray to black carbonaceous shale; locally, there are beds of massive clay as well as black shale and traces of coal and clay ironstone.

The top of the McLouth sand is determined in the samples by the first appearance of sand below the above-described reference beds. This key horizon is generally about 20 feet below the top of the white siltstone or below the base of the marine limestone, and one or the other of these reference beds, usually both, is nearly always represented in the drillers logs or cable-tool cuttings. Samples from some of the wells indicate that in places a thin layer of nearly white dense quartzitic sandstone lies above the more porous sandstone of the top of the McLouth; this silica-cemented nonporous sandstone is erratic in its position and occurrence and is not considered as part of the McLouth sand.

WATER-BEARING ZONES IN PENNSYLVANIAN ROCKS

Several water-bearing zones are encountered in drilling the Pennsylvanian rocks in the field. Zones that yield water in sufficiently large amounts to interfere with drilling operations in some wells are dry in others, and the volume of water entering the wells from most of the zones varies materially from well to well. The Jackson Park sandy shale member (fig. 2) of the Kanwaka formation (Shawnee group) has yielded a few barrels of water per hour in several wells. The Stranger formation of the Douglas group has a sandstone phase, commonly known as the Tonganoxie sandstone (fig. 2), which is highly variable in position and thickness. Ordinarily this sandstone phase is developed in the upper part of the Stranger, where it is separated from the Haskell limestone by a few feet of Vinland shale. This sandstone yields several barrels of water per hour in many wells in the field. In several wells the sandstone occurs in the lower part of the Stranger, just above the Stanton limestone, and is separated from the upper sandstone by the brownish siltstone typical of the Stranger formation. This lower bed yields from a few barrels to a hole full of water.

Several minor water-bearing zones are present in the limestone and shale section of the Bronson, Kansas City, and Lansing groups. Drillers logs of individual wells commonly show a few barrels of water per hour from one or more of these zones and in occasional wells a hole full of water. Several wells have encountered water at the Eudora shale in the Lansing group approximately 30 feet below the top of the Stanton limestone. Small amounts of water, probably from the upper part of the Wyandotte limestone of the Kansas City group, have been reported in a few wells. A more persistent water-bearing zone occurs near the base of the Kansas City group. A few drillers logs show water in the Bronson group at the depth of the Hushpuckney shale and also below the Hertha limestone.

Sandstone in the Bourbon group yields water in a few wells. Locally the presence of water in one or more sandstone beds ("Peru" sand) in the Marmaton group is indicated on logs. The Cherokee shale contains several water-bearing sands, flow from which has hampered drilling operations in some wells. A flow of water from a sand zone (Squirrel sand) in the upper part of the Cherokee, between the base of the Fort Scott limestone and the Ardmore limestone, has resulted in a hole full of water in a few wells. Between the Ardmore limestone and the top of the McLouth sand in the Cherokee, sporadic water sands have yielded from a few barrels per hour to a hole full of water. The occurrence of water in the McLouth sand in the McLouth field is rare and is discussed in another chapter.

LOG OF PENNSYLVANIAN WELL

The following excellent log of a well drilled by Dave Wilson, contractor, is representative of the Pennsylvanian rocks in the McLouth field. Nearly all the named units of the Pennsylvanian are identifiable in this log.

TABLE 1. *Log of McLaughlin & Sons No. 2 Dark well, SE¼ NE¼ sec. 5, T. 10 S., R. 20 E., Jefferson county, Kansas.*

(Altitude above sea level at mouth of well, 1,114 feet. Drilling began July 23, 1940; completed August 7, 1940. Production, 3 million cu. ft. per day.)

	Thickness (feet)	Depth (feet)
Quaternary system		
Pleistocene series		
Soil and yellow clay	10	10
Quick sand	8	18
Blue shale	7	25
Quick sand	9	34
Carboniferous system		
Pennsylvanian subsystem		
Virgilian series		
Shawnee group		
Lecompton limestone		
Limestone	6	40
Shale	3	43
Limestone	9	52
Kanwaka shale		
Shale	26	78
Limestone (Clay Creek limestone member)	3	81
Dark shale	13	94
Sand	10	104
Dark shale	7	111
Oread limestone		
Limestone	7	118
Shale	3	121
Limestone	19	140
Black slate (Heebner shale member)	4	144
Limestone	3	147
Dark shale	5	152
Light shale	6	158
Limestone	7	165
Missourian series		
Douglas group		
Lawrence shale		
Shale	40	205
Sandstone	7	212
Shale	78	290
Haskell limestone		
Limestone	3	293
Stranger formation		
Light shale	17	310
Sandstone	5	315
Sandy shale	65	380
Dark shale	20	400
Gray shale	35	435

TABLE 1. *Log of McLaughlin & Sons No. 2 Dark well, continued*

	Thickness (feet)	Depth (feet)
Lansing group		
Stanton limestone		
Sandy lime, water	9	444
Light shale	2	446
Limestone	12	458
Dark shale	4	462
Limestone	4	466
Viola shale		
Dark sandy shale	19	485
Plattsburg limestone		
Limestone	19	504
Kansas City group		
Bonner Springs shale		
Black shale	2	506
Red shale	4	510
Shale	22	532
Wyandotte limestone		
Limestone	10	542
Light shale	28	570
Limestone	13	583
Lane shale		
Light shale	19	602
Iola limestone		
Limestone	6	608
Shale	2	610
Limestone	2	612
Shale	6	618
Limestone	8	626
Chanute and Quivira shale (Drum limestone not identified)		
Shale	25	651
Westerville limestone		
Limestone	3	654
Wea shale		
Shale	15	669
Block limestone		
Limestone	5	674
Fontana shale		
Dark shale	5	679
Bronson group		
Dennis limestone		
Limestone (Winterset limestone member)	32	711
Black shale (Stark shale member)	4	715
Swope limestone		
Limestone (Bethany Falls limestone member) (water)	30	745

TABLE 1. *Log of McLaughlin & Sons No. 2 Dark well, continued*

	Thickness (feet)	Depth (feet)
Black shale (Hushpuckney shale member)	5	750
Limestone	3	753
Dark shale	3	756
Hertha limestone		
Limestone (Sniabar)	12	768
Dark shale	7	775
Sandy limestone (Critzer)	5	780
Bourbon group		
Sandy shale	92	872
Sandstone	7	879
Desmoinesian series		
Marmaton group (undifferentiated)		
Red shale	4	883
Limestone	4	887
Black shale	4	891
Limestone	1	892
Black shale	4	896
Shale	17	913
Limestone	6	919
Shale	14	933
Sandy limestone	5	938
Light shale	7	945
Dark shale	10	955
Limestone	2	957
Dark shale	11	968
Limestone	4	972
Shale	20	992
Sandy limestone	5	997
Light sandy shale	4	1,001
Limestone	2	1,003
Cherokee group		
Light shale	6	1,009
Sandstone	21	1,030
Dark shale	70	1,100
Light shale	24	1,124
Limestone (Ardmore limestone member)	2	1,126
Shale	44	1,170
White shale	15	1,185
Red shale	3	1,188
Blue shale	47	1,235
Sandstone (a little water)	12	1,247
Red shale	8	1,255
Dark shale	17	1,272
Sandstone	8	1,280
Dark shale	17	1,297
Shale	17	1,314

TABLE 1. *Log of McLaughlin & Sons No. 2 Dark well, concluded*

	Thickness (feet)	Depth (feet)
Sandstone	7	1,321
Sandy shale	8	1,329
Dark sandy shale	21	1,350
Light sandy shale	5	1,355
Black shale	14	1,369
Sandstone	9	1,378
Black shale	8	1,386
Light shale	4	1,390
Black shale	15	1,405
Black sandy shale	5	1,410
Black shale	5	1,415
Light shale	5	1,420
Dark shale	11	1,431
McLouth sand		
Sandstone (gas)	15	1,446
Shale and sandstone (increase of gas)	6	1,452
Shale	14	1,466
Mississippian subsystem		
Meramec group		
Spergen limestone		
Silty dolomite	4	1,470 T.D.

MISSISSIPPIAN ROCKS

The Mississippian limestones as shown in the columnar section (fig. 3) underlie the Pennsylvanian from which they are separated by an angular unconformity. During the time interval represented by the unconformity, the Mississippian rocks were gently folded and peneplaned. Peneplanation in northeastern Kansas, however, was less complete than in central Kansas and some broad valleys of low relief are revealed by plotting the thickness of the formations above and below this surface. Partly on account of the folding and beveling of the limestones and to a minor degree on account of local erosional relief of the surface, different Mississippian formations underlie the Pennsylvanian in different parts of northeastern Kansas. Rocks of St. Louis, Spergen, and Warsaw limestone have been identified at the top of the Mississippian in the McLouth field (fig. 17).

The Ste. Genevieve limestone is the youngest Mississippian formation represented in this part of Kansas. It is preserved only in structurally low areas where only a part of the formation survives. The Ste. Genevieve consists of fine well-sorted calcareous sand and finely sandy limestone. Some of the beds are oölitic or pseudo-oölitic. The Ste. Genevieve formation seems to overlie the St. Louis limestone conformably. It has been identified with certainty only in areas north and east of the field.

The St. Louis limestone characteristically consists of dense gray lithographic or sublithographic limestone, although some wells reveal thin interstratified beds of semigranular fossiliferous limestone. The St. Louis limestone is noncherty and most samples leave no insoluble residue when treated with acid. Some samples, however, contain a little fine silt and a few enclosed sand grains at the base.

The St. Louis limestone was eroded from the central part of the McLouth field but is preserved on the east side of the field (see fig. 14) where it is the youngest local Mississippian formation that survived the period of peneplanation. Several wells west of the field (Sifers No. 1 Leonhard well, in the SE¼ SW¼ sec. 9, T. 10 S., R. 19 E., and others) reveal St. Louis limestone in areas surrounded by wells that penetrated Spergen limestone at the top of the Mississippian. The St. Louis limestone has survived in this area because it caps low pre-Pennsylvanian hills.

The St. Louis limestone has a maximum observed thickness of 36 feet in the McLouth field. It is unconformable below the Pennsylvanian except where the Ste. Genevieve intervenes. It seems to be conformable with the Spergen, but abnormal thicknesses of the Spergen in a few wells and the occasional occurrence of grains of sand in basal St. Louis beds suggest a disconformity.

The Spergen dolomite is the formation generally encountered on the pre-Pennsylvanian surface of the McLouth field. It consists of gray silty dolomite with minor amounts of chert. In some localities the Spergen is greenish-gray and contains so much silt and so many sponge spicules that the insoluble residues form a loosely coherent mass. In some places the dolomite is interstratified with semigranular microfossiliferous limestone in which the foraminifer *Endothyra baileyi*, a characteristic Spergen fossil, has been observed.

The insoluble residues of the Spergen generally are less than 5 percent chert but the enclosed silt and sponge spicules in some samples amount to 25 percent. The chert includes opaque gray, brown, or salmon-colored chalcedonic crusts and semiopaque and opaque microfossiliferous chert like that in the underlying Warsaw. Some of the chert in the insoluble residues is pitted with minute casts from which fragments of calcareous micro-organisms have been leached.

The Spergen dolomite rarely exceeds 30 or 35 feet in thickness, and where the St. Louis limestone has been eroded the thickness is generally less. In a few wells, the Spergen is 50 feet or more thick and rests upon the Warsaw limestone with which it seems to be conformable. This local thickening of the Spergen, which is greater than where it is overlain by the St. Louis, suggests that there may be an obscure disconformity between the Spergen and St. Louis formations. Nothing has been observed to indicate that there is an unconformity between the Spergen and the underlying Warsaw limestone.

The Warsaw limestone consists essentially of cherty semigranular fossiliferous limestone. In some zones, fossil fragments of crystalline limestone are incorporated in a matrix of sucrose dolomite that can be traced short distances from well to well. The insoluble residues consist mainly of gray chert crowded with silicified remains of broken microfossils of different sizes. The amount of insoluble residue in the samples ranges from 10 to 50 percent by volume. The base of the fossiliferous cherty limestone is regarded as the base of the Warsaw formation. The Warsaw limestone, which normally is overlain by the Spergen limestone, had been exposed by channeling in a few places on the flanks of the field before the Mississippian rocks were covered by Pennsylvanian rocks.

The average thickness of the Warsaw limestone is 35 feet but there is some variation. Thicknesses of 10 to 15 feet greater or less than the average have been observed. Except for these variations in thickness, no evidence has been noted indicating unconformities between the Warsaw and the overlying and underlying formations. In other parts of Kansas, however, an important disconformity exists below the Warsaw, but this break in sedimentation is not apparent in the McLouth field.

Undifferentiated Keokuk and Burlington limestones underlie the Warsaw limestone. In this part of Kansas these formations consist of two members which are distinguishable lithologically, but these members are not known to represent the respective formations. The upper member is predominantly limestone; the lower member is predominantly dolomite.

The top of the upper or limestone member is placed arbitrarily at the top of a gray sparsely cherty bed of sucrose dolomite, 2 to 10 feet thick. This bed is lithologically different from both Warsaw and Keokuk and might be included in either. The small insoluble residues of this bed consist of crumbs of spongy spicular silt similar to some insoluble residues of the Spergen limestone. The remainder of the upper member of the undivided Keokuk and Burlington is mainly semigranular fossiliferous limestone, but some samples consist of dolomite in which broken calcareous fossils are distributed. The dolomitic zones can be traced locally from well to well but have no extended continuity.

The amount of chert in the upper member is variable and constitutes 2 to 60 percent of the samples. The chert in the upper part of this member is gray, dense, opaque, and massive. Much of it has a microscopically grainy texture which aids in identifying the upper member of the Burlington and Keokuk. In the lower part of the limestone member there is much microfossiliferous chert which is superficially similar to that in the Warsaw but differs in that fragments of fossils have been replaced by vitreous translucent chalcedony or by quartz. Some zones are nearly free of chert and serve as convenient reference beds within limited areas. The thickness of the limestone member is 95 feet.

The lower or dolomitic member of the undivided Keokuk and Burlington limestones is composed of coarsely sucrose very cherty dolomite which contains coarse cavities at the top. A core taken from this zone in the Apperson No. 1 Bower well, in the SE¼ SE¼ NE¼ sec. 5, T. 10 S., R. 20 E., shows that the openings are due to leaching of crinoid stems and fragments of other fossils originally incorporated in a coarsely sucrose dolomite matrix. The leaching seems to have been the result of exposure and weathering and, therefore, indicates an unconformity, but no erosional relief has been detected in the McLouth area. This porous zone is the reservoir rock of most of the oil from the McLouth field. It is recognizable in most wells in northeastern Kansas where its regional porosity is shown by the fact that it yields large amounts of water.

The entire dolomitic member of the undivided Burlington and Keokuk beds has been drilled in only six wells in the McLouth field. In these wells the dolomite below the porous zone at the top is dense and impervious. The insoluble residues are gray, opaque to semiopaque, massive chert and make up 25 to 85 percent of the samples. The lower or dolomitic member is 55 to 60 feet thick.

The total thickness of the undivided Keokuk and Burlington limestones is about 150 feet. No marked local variation of thickness was noted. These limestones unconformably overlie the Gilmore City limestone, but the Gilmore City is cut out in some places and locally the undivided Keokuk and Burlington rests unconformably on the Chouteau limestone.

The Gilmore City limestone is a gray to white semigranular fossiliferous limestone. In some zones fragments of fossils are imbedded in a soft calcareous matrix which is easily pulverized in drilling. The fine-grained fragments are lost in washing so that samples of Gilmore City limestone from wells drilled by cable tools are small. Some beds of the Gilmore City contain irregularly shaped and sparsely distributed oölites, some of which are black. Oölitic beds, although characteristic, are a subordinate part of the formation. Insoluble residues are generally less than 2 percent by volume. The Gilmore City in the McLouth field is about 25 feet thick, but it is absent in some places in the surrounding region. It lies unconformably below the Burlington and unconformably above the Chouteau limestone. In some places in northeastern Kansas it replaces the upper member of the Chouteau.

The Chouteau limestone consists of three members: a noncherty or sparsely cherty buff to brown sucrose dolomite at the top, as much as 20 feet thick; a very cherty impure dolomite about 70 feet thick in the middle; and a sparsely cherty limestone member about 40 feet thick at the base. The Gilmore City limestone has replaced part or all of the eroded upper member of the Chouteau limestone in the McLouth field so that this member has a variable thickness and may be absent locally. The dolomite of the middle member, like the top, is sucrose, generally buff or brown, but it contains ash-gray, rough or grainy chert which is uniquely characteristic of the Chouteau. Insoluble residues amount to as much as 75 percent of some samples, although the average is probably less than 40 percent. The limestones of the basal member are, for the most part, noncherty and semigranular, but there is some argillaceous and sublithographic limestone at the bottom. Oölitic limestone has been noted at the bottom of the Chouteau in one well near the McLouth field (Continental No. 1 Berridge well in sec. 8, T. 9 S., R. 17 E.). The total thickness of the Chouteau formation is about

120 feet in the McLouth field. It lies unconformably on the Chattanooga shale, but the unconformity is not obvious locally.

Cave Deposits in Mississippian Rocks

Rocks of probable early Pennsylvanian age have been found enclosed in upper Mississippian rocks in at least half of the deep wells in the McLouth field and in many other wells in northeastern Kansas. The rocks consist chiefly of fine fragments and grains of black, dark, and gray shale deposited in a matrix of dark clay or black silty clay. The shale fragments include many types of black, micaceous, silty, and carbonaceous shale most of which have their counterparts in deposits of the Cherokee group. Occasional flakes of carbonized wood have been recognized. Grains of coarse and fine sand sparingly incorporated in dark clay, although rare, have been observed in the cuttings of some wells. Pitted and weathered chert embedded in a clay matrix is also present locally. Some of the samples from wells in which the Pennsylvanian rocks have been cased off consist largely of laminated black and dark clay shale and dark finely micaceous shale which is indistinguishable from Cherokee shale. Pyrite in varying amount is common. Among the more striking constituents present in minor amounts are thinly disseminated grains and coarse pellets of green clay resembling pale glauconite and minute aggregates of fine opaque white powdery silica. The siliceous aggregates are thinly distributed in the black silty shale. This material resembles white silt, but its characteristics suggest incipient and incompletely coalesced chert. These siliceous aggregates and the green clay particles, although thinly distributed and not everywhere present, are the most striking elements of the clastic shale (pl. 7).

The cuttings from the upper part of the cave deposit in two wells consisted almost entirely of spongy black pyrite. In one of these (Apperson-Stark et al. No. 1 McLaughlin well, in SW¼ NW¼ NW¼ sec. 4, T. 10 S., R. 20 E.) about 15 feet of black oil-stained spongy pyrite occurs at the top of the cave deposit. This is underlain by black carbonaceous shale with scattered fragments of carbonized wood beneath which is the more typical clastic dark silty shale with disseminated grains of pale-green clay. The lower 3 feet of the deposit consists mainly of pitted and weathered chert which is seemingly a residual deposit in clay. The shale deposit in this well is 35 feet thick and is overlain by 40 feet of Spergen and Warsaw limestones. In most wells, however, the shale deposits consist chiefly of clastic silty shale less than 15 feet thick. All the known cave deposits occur in the upper part of the Mississippian above the porous dolomite zone of the undivided Burlington and Keokuk limestones, which is water bearing throughout most of northeastern Kansas. Only six wells in the field have been drilled below the dolomite zone. None of these wells nor wells elsewhere in northeastern Kansas reveal cave deposits in the lower Mississippian, although they may occur.

It was at first believed that these black shales were cavings from the lower Pennsylvanian, in spite of the fact that casing was reported to have been set at the top of the Mississippian. It was soon recognized, however, that their lithology is somewhat unique and that the deposits include fragments of rocks not observed in the overlying Pennsylvanian. Other attempts to explain these deposits include the hypotheses (1) that they represent accumulations of Cherokee deposits in open fissures or along fault breccias; (2) that they are intraformational deposits in the Mississippian; or (3) that they are deposits filling solution chambers in the Mississippian limestone.

One of the first wells in which these clastic shales were noted was the Young and Longwell No. 1 McLeod well in which a fault in Mississippian rocks was recognized. This fault gave support to the first theory, but it was soon evident that the deposits occur also in many other wells in which there is no evidence of faulting or sharp deformation. The black shales do not represent deposits interstratified with Mississippian limestones, for they are found in all the stratigraphic units of the upper Mississippian, they cannot be correlated from well to well, and, although absent in many wells, they are found in some wells at two or more levels between the St. Louis limestone and the dolomite zone of the Burlington and Keokuk. No evidence is known which conflicts with the theory that the deposits represent filling of caverns in the upper Mississippian rocks.

During the period of re-elevation and warping of the post-Missippian peneplain when the Forest City and Cherokee basins were formed, the surface of the McLouth field and adjoining areas, particularly toward the east and southeast, was raised gradually above the bottom of the Forest City basin and probably high above parts of the Cherokee basin in eastern Oklahoma. Rocks in the area of the Nemaha anticline were re-elevated at this time and a fault escarpment was formed west of the Cherokee and Forest City basins. The crest of this escarpment gradually rose several hundred feet above the basin, for the northern part of its crest was not covered until Bronson or Kansas City time.

The cave deposits in the McLouth field are found to depths of approximately 150 feet below the top of the Mississippian. There could therefore, have been only a low ground-water gradient from the McLouth field to the bottom of the Forest City basin. Toward the south in the deeper parts of the Cherokee basin, both the surface and the ground-water table must have been much lower. Almost the entire region was underlain by thick limestones of Mississippian age. Conditions of lithology and topographic relief were, therefore, favorable to the establishment of underground drainage, and the caverns could have been developed during the period of re-elevation of the post-Mississippian peneplain. The character of the material filling the caverns, however, throws doubt on the theory that the development of the caverns took place after the post-peneplain re-elevation.

Deep pre-Pennsylvanian solution has been observed elsewhere in this region. On the Nemaha anticline west of the escarpment, oil wells have revealed what seem to be deep pre-Pennsylvanian sink holes in which almost the entire Mississippian section has been replaced by weathered conglomeratic chert (Lee, 1940, p. 76). One of several of these wells is the Tidal No. 1 McCutcheon well in sec. 33, T. 34 S., R. 2 E., in which the zone of weathered chert extends to a depth of 163 feet below the present top of the Mississippian rocks of that area. In the central Ozark region, deposits of sandstone, coal, fire clay, and shale of Pennsylvanian age are found in solution openings in the pre-St. Peter dolomites, some of which occur at depths at least 500 feet below the base of the earliest stratified Pennsylvanian deposits (Lee, 1913, p. 69). Similar phenomena have been reported by others in other parts of the region.

The materials found in the caverns in the Mississippian limestone seem to be of Pennsylvanian origin because of their carbonaceous character, but the deposits contain constituents, for instance the green clay granules, which are not present in the lower part of the Cherokee shale. Sand, on the other hand, which is common in much of the basal Cherokee of this locality, is rare in the cave deposits, and the spherical brown siderite "pellets" common in the lower Cherokee have not been observed.

It is improbable that sediments could be carried into the remote and devious passages in the limestone by gravity alone when the solution chambers were filled with stagnated water after the submergence of the region in the Cherokee sea. At this time, also, Cherokee deposition was taking place, whereas the cave deposits indicate disintegration of the source beds. At the end of the period of peneplanation and during the subsequent period of re-elevation, almost the only rocks exposed in a vast territory in Kansas and adjoining states were limestones, mainly of Mississippian age. No shales and clays were available as sources of the material in the cave deposits.

The only period during which disintegrating surface materials could have been sluiced into their present position seems to have been a period of elevation prior to the end of peneplanation. It is probable that the underground chambers were formed during the unrecorded time represented by the development of the post-Mississippian peneplain. There might have been a period or several periods of re-elevation during this interval and at times a greatly depressed and probably fluctuating water table. If the caverns and passages were formed at such a period and before some hypothetical overlying shale beds were completely denuded, the disintegrating deposits could have been carried by descending surface water into the lower caverns through widespread sink holes.

No Mississippian rocks younger than the Ste. Genevieve limestone are known in the subsurface of eastern Kansas, but rocks of suspected Chesterian age have been reported by H. S. McQueen and others from the subsurface of northwestern Missouri. Robert Roth [quoted by McClellan (1930, p. 1548)] and Glenn S. Dille (1932) have reported Chesterian beds in the subsurface of southwestern Kansas where they consist of gray shales and limestone. The Chesterian rocks of Illinois and southeastern Missouri consist of alternating beds of gray silty shales, sandstone, and limestone. None of the known Chesterian deposits in the areas mentioned are likely to have furnished the material of the cave deposits which are uniformly dark to black and, in some cases, carbonaceous shales. The black Fayetteville shale of Chesterian age in northeastern Oklahoma and Arkansas could have provided some but not all of the material. The lithology of parts of the Morrowan rocks of earliest Pennsylvanian age in Arkansas and eastern Oklahoma corresponds to that of the cave deposits. The materials might represent deposits of Chesterian or Morrowan age which were perhaps once hypothetically present in the region and later completely removed during a cycle of sedimentation not otherwise here recorded.

Whatever the source beds of these deposits, they call attention to the chambered character of the Mississippian rocks. The chambers seem to be almost completely closed to circulation by the shale and clay filling. No oil has been found in any of them in the McLouth oil field, but the spongy pyrite in the upper part of the large chamber in the Apperson-Stark No. 1 McLaughlin well is heavily stained with oil. Some water has been found in shale-filled caverns in wells, which, when deepened, yielded oil from the dolomite zone below. The water from these caverns is soon exhausted. A few wells drilled off structure have reported "hole full of water" from different parts of the Burlington and Keokuk rocks which are normally dry. These wells, however, were abandoned without deeper drilling, so that it is not known whether these erratic bodies of water have any relation to solution chambers or cave deposits, although it seems probable that they do. Open caverns on structure, if any exist, might yield prolific amounts of oil.

Mississippian or Devonian Rocks

The age of the Chattanooga shale is uncertain. It has not been satisfactorily proved whether the Chattanooga is of early Mississippian age or of late Devonian age as it does not contain diagnostic fossils. This shale has been correlated by Condra and Reed (1943, p. 62) with the Sheffield shale member of the Lime Creek formation of Devonian age in north-central Iowa, but evidence for this correlation was not presented. The Chattanooga of northeastern Kansas is essentially equivalent to the Grassy Creek shale of northeastern Missouri.

In the McLouth field, the Chattanooga shale consists mainly of gray to greenish-gray micaceous and slightly silty clay shale. The lower part is dark to almost black. Plant spores occur sparingly in the upper part of the formation and are abundant in the dark shales at the bottom. Sandy shale equivalent to the Misener sandstone member of Oklahoma is locally present at the base of the Chattanooga. The red shales and the flaxseed hematite zone in the upper part of the Chattanooga shale or in younger rocks farther north, which are reported by Condra and Reed (1943) and by some other geologists, are not present in the McLouth field.

The Chattanooga shale is 60 feet thick near McLouth, but its thickness increases toward the northwest and decreases toward the southeast. The Chattanooga was deposited upon underlying limestone of Devonian age after a long period of erosion during which the exposed rocks were tilted toward the northwest, beveled, and reduced to an approximate peneplain.

Devonian Rocks

The Devonian limestones of north-central Missouri have been correlated by Branson (1923, p. 2) with the Grand Tower limestone of Middle Devonian age. The Devonian rocks in northeastern Kansas cannot be differentiated. However, the Cooper and Callaway limestones of north-central Missouri and probably also even younger Devonian rocks are believed to be represented in the Devonian of the McLouth field.

The term "Hunton" limestone of oil geologists and operators is a convenient name for whatever limestone formations are present between the Chattanooga shale and the Maquoketa shale (=Sylvan shale). Inasmuch as these formations differ from place to place, including only formations of Devonian age in one place, only formations of Silurian age in other places, and in some places both, the term has no meaning as a formational name. In the McLouth field only rocks of Middle Devonian age occur between the Chattanooga shale and the Maquoketa shale (the northern equivalent of the Sylvan shale of Oklahoma). None of the older Devonian or Silurian rocks are present.

The Devonian rocks drilled in the McLouth field are made up of alternating beds of limestone and dolomite. Individual zones are 15 to 40 feet thick. Most of the limestones are gray, dense, and lithographic and the insoluble residues contain only faint traces of quartz, sand, or chert. There are some very cherty beds, however. The dolomite is chiefly medium to finely sucrose, although some beds are coarsely crystalline and porous. The samples from a zone about 30 feet thick and 80 feet above the base of the Devonian rocks yield insoluble residues composed of drusy quartz and quartzose semitranslucent chert. The samples from the upper beds of this zone yield 30 to 50 percent residues, but the proportion of chert decreases rapidly toward the bottom. The basal part of the Devonian rocks in the McLouth field consists of 15 to 20 feet of slightly dolomitic sandstone resting unconformably upon a pre-Devonian eroded surface which is approximately a peneplain. In nearby areas, however, the basal zone of the Devonian beds consists of sandy limestone.

The Devonian rocks are 173 feet thick in the vicinity of McLouth. Because of the northwestward tilting and subsequent beveling of the originally horizontal Devonian rocks, the thickness increases toward the northwest and decreases toward the southeast where the older parts of the Devonian finally wedge out. Thus, progressively younger limestones lie at the top of the Devonian assemblage toward the northwest. The upper part of the Devonian beds in the Jackson No. 1 Shughart well, in sec. 6, T. 9 S., R. 20 E., which consists of coarsely crystalline porous dolomite, is the youngest Devonian rock in the field that has been penetrated by drilling. The uppermost Devonian rocks in the Apperson et al. No. 1 Bower well, in the SE¼ NE¼ sec. 5, T. 10 S., R. 20 E., which consist of finely porous sucrose dolomite, are older. The rocks at the top of the Devonian in the McLaughlin and Sons No. 1 Thorpe well, in the NE¼ NE¼ sec. 27, T. 10 S., R. 20 E., 4 miles distant, are sublithographic limestone older than the dolomite at the top of the Devonian in the Bower well.

Ordovician Rocks

Only a small part of the Maquoketa shale (=Sylvan shale), which was originally more than 50 feet thick, remains in the McLouth field. Before deposition of the Devonian rocks the surface was tilted gently toward the northwest and Silurian limestones and other pre-Devonian rocks were eroded and worn down to a nearly flat surface. Less erosion occurred in the lowered region toward the northwest than in the elevated region toward the southeast where Silurian rocks, Maquoketa shale, Kimmswick limestone, St. Peter sandstone, and the upper part of the Arbuckle limestone were progressively removed. In the Apperson No. 1 Bower well, in sec. 5, T. 10 S., R. 20 E., 7 feet of Maquoketa shale was found, but in the McLaughlin No. 1 Thorpe well, in sec. 27, T. 10 S., R. 20 E., the Maquoketa, together with about 20 feet of the underlying Kimmswick, is entirely absent.

The Maquoketa shale encountered in the Bower well consists of soft gray dolomitic shale which originally formed the base of the formation. The upper part of the Maquoketa, which was eroded from this locality but is present toward the northwest, includes much siliceous dolomitic shale and shaly dolomite. The insoluble residues of the upper beds are composed mainly of dolocastic chert. Where the Maquoketa shale is present above the Kimmswick limestone it seems to be conformable with the Kimmswick. Actually the contact is disconformable, for a great thickness of rocks younger than the Kimmswick limestone and older than the Maquoketa shale is present in some places in the upper Mississippi valley.

The Kimmswick limestone (called the Viola limestone in Oklahoma) has been penetrated in the McLouth field only in the two deep wells already mentioned. It consists of two very cherty zones of dolomite alternating with slightly cherty to noncherty dolomite. Some samples from the upper cherty zone, which is 40 feet thick, contain more than 80 percent chert. The underlying sparsely cherty zone is 30 feet thick and includes less than 10 percent chert. The lower cherty zone is 30 feet thick and the samples average about 40 percent chert. The lower noncherty zone is 30 feet thick and yields residues of less than 3 percent chert. This bed grades downward into a zone, about 25 feet thick, of slightly sandy dolomite interstratified with gray flaky shale and clay shale. Some geologists regard this zone as the equivalent of the Decorah shale of eastern Iowa, but there is a possibility that in this part of Kansas it is merely a slightly clastic and impure basal dolomite member of the Kimmswick formation. The Kimmswick chert is opaque and gray. Much of it is sparsely peppered with microscopic black pyritiferous particles. A large part encloses silicified fragments of microscopic fossils and sponge spicules. The chert in the basal beds, although smaller in quantity, is of the same character as that in higher beds.

The total thickness of the Kimmswick rocks including the doubtful Decorah is 156 feet in the Apperson No. 1 Bower well, and 125 feet in the McLaughlin No. 1 Thorpe well where the upper beds were eroded. The Kimmswick lies disconformably on the St. Peter sandstone, for in southeastern Missouri several hundred feet of rocks of formations older than the Kimmswick lie above the St. Peter.

The St. Peter sandstone consists of clean white grains of quartz sand. The cuttings include a large proportion of rounded and frosted grains. Much of the sand is angular, but the angularity of some of the grains represents crystalline growth after deposition. The sand at the top of the St. Peter formation is commonly weakly cemented by silica and in some wells is very hard. The St. Peter is about 70 feet thick in the McLouth field. Slight variations in thickness may be expected, for the St. Peter is separated from the Kimmswick above and the Arbuckle below by obscure but important unconformities which are represented in other regions by several hundred feet of limestones.

The St. Peter sandstone occupies the same position in the stratigraphic section in northeastern Kansas as the Simpson group in Oklahoma, which includes in the upper part the productive Wilcox sand, a term that has been applied by some oil operators indiscriminately to one or more sandstones in the upper part of the Simpson. Several geologists have traced the Simpson group in the subsurface from its outcrops in Oklahoma to southeastern Kansas. Others have traced the St. Peter sandstone from the outcrops in Minnesota and eastern Missouri to the borders of northeastern Kansas. The St. Peter sandstone of northeastern Kansas differs from sand of Simpson age in central Kansas which includes green shale and limestone. For this reason and because of the unconformities at the top and bottom of the St. Peter, its relation to the Simpson of central Kansas is uncertain. The St. Peter sandstone may be equivalent to a part of the Simpson or may be younger than any part of it.

The Arbuckle limestone consists of coarsely crystalline dolomites and some sandstones of Lower Ordovician age. Most of the dolomites are characterized by large amounts of chert. Some similar deposits of late Cambrian age that lie between the Arbuckle dolomite of Ordovician age and the pre-Cambrian metamorphic and granitic rocks are commonly but incorrectly included in the term Arbuckle. Many unconformities occur within the Arbuckle, which is about 700 feet thick near McLouth. The combined thickness of the rocks below the top of the Arbuckle limestone decreases toward the northwest and increases toward the southeast. This relation is the reverse of that of rocks between the Mississippian and the St. Peter, all of which thicken toward the northwest.

PRODUCING ZONES

Three zones in the McLouth field (fig. 3) yield oil or gas: (1) the McLouth sand, (2) the weathered zone at the top of the Mississippian rocks, and (3) a zone of porous dolomite in the undifferentiated Burlington and Keokuk limestones, about 150 feet below the top of the Mississippian beds. Potential producing zones which have yielded oil and gas in other parts of Kansas occur at the top of or in the upper part of the Devonian rocks at the top of the Kimmswick limestone, in the St. Peter sandstone, and at the top of the Arbuckle limestone (fig. 3). These zones have not been tested adequately in the McLouth field.

McLouth Sand

Most of the gas production in the McLouth field comes from a body of basal Cherokee sediments termed the *McLouth sand.* Several wells yield oil in small amounts from the McLouth sand, but the area of oil production is small compared with that of gas production.

The McLouth sand overlies the eroded and structurally deformed surface of the Mississippian limestone and consequently has a variable thickness which has a known range of 15 to 95 feet within the area of the McLouth field. The McLouth sand consists of various types of sandstone interstratified with siltstone, clay, and shale. It includes also clay ironstone, coal, and intraformational conglomerate in minor amount. The McLouth sand is frequently referred to as Bartlesville sand with which it has nothing in common except that in some places the Bartlesville also lies near the base of the Cherokee shale. The Bartlesville sand in Oklahoma is a lenticular body of sandstone deposited along the western shore of the Cherokee basin. As the sea advanced northward into the basin, similar shoestring sandstones were deposited along both its eastern and western shores (Bass, 1934; 1936). Sandstones corresponding to the Bartlesville in lithology and stratigraphic position on the eastern side of the basin in Vernon county, Missouri, have been reported by Greene and Pond (1926) and in Crawford and Cherokee counties, Kansas, by Pierce and Courtier (1938). In these places the top of the sand lies 225 to 250 feet below the Ft. Scott limestone. The top of similar shoestring sands in Greenwood county, Kansas, which were studied by Bass, lies about 200 feet below the Fort Scott limestone. The McLouth sand, on the contrary, was deposited in another basin (Forest City), is 450 feet below the Fort Scott, and consists of highly variable sandstones interstratified with various types of shale.

The basal member of the McLouth sand is more nearly equivalent to the Burgess sand which was the earliest deposit of the Cherokee shale in the Cherokee basin. The Burgess sand consists of coarse sand which includes conglomerate in many places. The lowest member of the McLouth sand is similarly composed of coarse angular sand but does not include much conglomerate. It and the Burgess sand are similar in lithology, and both were the earliest deposits of the Pennsylvanian in their respective areas. The McLouth sand, however, includes several productive sand members higher in the section which are separated from each other and from the basal sandstone by beds of shale. The term McLouth sand is, therefore, more inclusive than the term Burgess.

Lithologic zones of two general types are distinguished in the McLouth sand: (1) shale zones consisting mostly of clay shale and micaceous silty shale but also containing beds of clay, siltstone, clay ironstone, and coal, and (2) sandy zones composed of sandstones that show marked lateral variation from well-sorted, porous sandstone to highly argillaceous sandstone. Where the sandy zones consist principally of fine-grained sediments rather than sandstone, they nevertheless contain sandy laminae or thin layers of argillaceous sandstone. These two general types of lithologic zones alternate vertically in the McLouth reservoir (pl. 4) and suggest that cyclic sedimentation occurred. The sandy zones are neither lenticular nor shoestring sands, but are widespread blanket deposits of variable character.

The McLouth sand includes four sandy zones, three of which yield gas or oil from well-sorted porous sandstone facies of the sandy zones where these occur in favorable structural positions. Several wells in favorable structural positions on the crests or high on the flanks of anticlines or domes failed to produce gas or oil from McLouth sands because they penetrated argillaceous facies of the sandy zones. Thus, although structure is the major factor in determining the localization of gas and oil in the McLouth sand, the accumulation and local distribution of gas and oil on the anticlines or domes and the volume of production and open flow of gas are controlled largely by lateral variations in the porosity and permeability of the sandy zones. Each sandy zone tends to act as a unit so far as the distribution of oil and gas is concerned. Thus, a certain well may produce gas from one zone and have a show of oil in a deeper zone in the McLouth, an example being the O. J. Connell No. 1 Edmonds well (SW¼ NE¼ sec. 21, T. 9 S., R. 20 E.). In practically all wells that yield both gas and oil, the oil comes from a deeper sand.

A more complete discussion of the McLouth sand is presented later in this report after the discussion of structure on which some of its characteristics depend.

Top of Mississippian Limestone

The top of the Mississippian is an erosional surface, as has already been pointed out. As a result of structural distortion, peneplanation, and mild dissection, different Mississippian formations were exposed in different areas on this surface when it was submerged and covered by Pennsylvanian deposits. Most of the wells in the McLouth and North McLouth pools find Spergen dolomite on the old surface, but wells in the Ackerland pool and on the east side of the McLouth field find St. Louis limestone on the old surface. A few wells in T. 10 S., R. 19 E. on the west side of the field also revealed St. Louis limestone at the top of the Mississippian. The Warsaw limestone forms the surface of the Mississippian in a few wells on the margins of the field.

Weathering and disintegration of the surface of the Mississippian rocks developed irregular porosity in the exposed rocks. In some localities the openings provided a reservoir for oil and gas. However, neither the dense lithographic St. Louis limestone nor the sucrose silty dolomite of the Spergen which lie at the surface of the Mississippian lend themselves to the development of porosity, and not much gas or oil have come from the weathered zone in the McLouth field. Solution of the dense St. Louis limestone takes place mainly along joints and cracks without developing much porosity. Only one well is known to have found gas in this formation. The Mosbacher No. 1 Dolman well, in the NW¼ SE¼ sec. 27, T. 9 S., R. 20 E., found no oil or gas in the impermeable sand at the base of the McLouth, but a small amount of gas entered the hole from the top of the St. Louis limestone. This zone was acidized and the flow of gas was reported to have increased from 360,000 cubic feet to nearly 3 million cubic feet of gas per day. Traces of oil-stained St. Louis limestone were encountered at the top of the Mississippian in the Miller No. 2 Jim Bell well, in the SW¼ NW¼ sec. 7, T. 10 S., R. 21 E., but no oil was developed.

The Spergen limestone is composed of dense silty dolomite, but weathering of this formation in some places has developed "pin hole" porosity visible under the microscope. Some wells that yielded gas in small amount in the McLouth sand have shown increased gas production when drilled into the underlying Spergen dolomite. This was the case in the McLaughlin and Sons No. 2 Bartlett well, in the SE¼ SW¼ sec. 33, T. 9 S., R. 20 E., which yielded 4,246,000 cubic feet of gas per day in the McLouth sand and increased to 6,100,000 cubic feet per day in the first 10 feet of the Spergen, a gain of 1,754,000 cubic feet. Gas was found in both Spergen dolomite and the McLouth sand in the McLaughlin No. 2 Dark well, in the SE¼ NE¼ sec. 5. The McLaughlin No. 1 Ragan well, in the NW¼ NW¼ sec. 3, also had an increase of gas in the top of the Spergen. Gas gauged at 500,000 cubic feet was reported from the top of the Spergen in the Smythe et al. No. 1 Jacobson well, in the SW¼ NW¼ sec. 27, T. 9 S., R. 20 E., and a show of gas was reported in the top of the Spergen in the Smythe et al. No. 1 Miller well, in the NE¼ SE¼ sec. 22, T. 10 S., R. 20 E.

Free oil was first noted in Spergen dolomite at the top of the Mississippian in the Young and Longwell No. 1 McLeod well, in the NW¼ SW¼ sec. 4, T. 10 S., R. 20 E., but efforts to increase the production by acidizing the well were unsuccessful. The Gordon and Poole No. 1 Knudson well, in the SE¼ NW¼ sec. 33, T. 9 S., R. 20 E., which is reported to have had only 1 million cubic feet of gas in the McLouth sand, was deepened to the Spergen dolomite where a show of free oil was found. This well was not connected to a pipe line and the well is now reported to have filled with oil which drowned out the gas. Several other wells have encountered shows of free oil in the top of the Mississippian. It is not unusual to find the dolomite and limestone of the Spergen oil stained, particularly in structurally high areas, but no oil has been produced from this zone as yet.

Porous Dolomite Zone of the Burlington and Keokuk

Streaks of oil-stained limestone and dolomite occur in the upper 150 feet of the Mississippian in many wells in areas that are structurally high. The oil stains occur in minutely permeable beds of dolomite and limestone which do not seem to have any regularity of porosity or infiltration. About 150 feet below the top of the Mississippian and 121 to 135 feet below the top of the Warsaw limestone a coarsely crystalline bed of very cherty dolomite which is porous over a large part of northeastern Kansas is encountered. On the structurally high parts of the McLouth anticline this zone yields oil.

Plates 5 and 6 are photographs of a rotary core recovered from this zone in the Apperson No. 1 Bower well, in the SE¼ NE¼ sec.

5, T. 10 S., R. 20 E. The core consists of coarsely sucrose dolomite. The cavities are molds of crinoid stems and other broken fossils up to three-eighths of an inch in diameter. The fossil fragments were originally incorporated in the dolomite but because of their solubility they have been leached from the rock, leaving the dolomite pitted and cavernous. Inasmuch as the immediately overlying limestone has not been affected by solution, it is probable that the dolomite was subjected to surface weathering at the time when the calcareous elements were removed and before its burial by the overlying limestone. A disconformity, therefore, seems to be indicated at the surface of the porous zone, but there was so little erosion on its surface that topographic relief has not been recognized. The cavities in the dolomite of the cores are lined with fine bright crystals of dolomite. The darker areas in plate 6 represent cavities that originally contained oil but the intervening light-colored bands, although pitted with similar voids, were not penetrated by the oil.

A thickness of 10 feet of dolomite was cored in the Bower well, of which about 3 feet is unstained or slightly stained with oil and obviously unproductive. It is assumed that the more porous and spongy parts of the cores were broken up in coring and that about 7 feet of dolomite is productive in this well. The thickness of the productive zone in other wells is probably variable but seems to range from 5 to 10 feet.

The dolomite zone was first penetrated in the field in the McLaughlin No. 1 fee well, in the NE¼ NW¼ sec. 4, T. 10 S., R. 20 E., where it was heavily oil stained but probably carried water. The Young and Longwell No. 1 McLeod well, in the NW¼ SW¼ sec. 4, T. 10 S., R. 20 E., the second well in the field, was the first well in which oil was found in this zone. Black oil of 20.7° gravity Bé. filled the well to a height of 1,200 feet. The gravity of this oil was lower than that found in subsequent wells producing oil from the dolomite. This may be due to the fact that this well penetrated a fault through which the lighter constituents of the oil escaped. Its initial production probably was about 25 barrels per day, but the production declined rapidly. The second well in which oil was discovered in the dolomitic zone was the Young and Longwell No. 2 McLeod well, 660 feet to the north, and in which oil of slightly higher gravity was found in April, 1940. The production of oil from this well was irregular because of mechanical difficulties. In

February, 1943, the well was acidized and is now reported to be pumping more than 100 barrels of oil per day. The third well, the Young and Longwell No. 3 McLeod well, NE¼ SE¼ sec. 5, T. 10 S., R. 20 E., found oil of 23.5° gravity that flowed by heads for several months. This well yielded approximately 100 barrels of oil per day, and is reported to have yielded over 40,000 barrels of oil in two years. It has not been acidized. In March, 1943, 70 barrels of oil per day were pumped, although 79 feet of cavings are reported in the well.

Other Potential Producing Zones

The Devonian rocks (fig. 3) were deformed and beveled by pre-Mississippian peneplanation and they were covered by the Chattanooga shale in much the same way that the beveled Mississippian rocks later were covered by the Cherokee shale. This beveling left progressively younger Devonian rocks beneath the Chattanooga toward the southeast. In consequence the same rocks occur at the top of the Devonian only in the direction of the pre-Chattanooga strike of the Devonian beds; that is, toward the northeast. *A well testing the top of the Devonian at one point will not encounter the same bed as that in another well drilled toward the northwest or southeast,* and, except along the pre-Chattanooga strike of the Devonian, wells will penetrate different beds at the top of the Devonian on different anticlines.

During the long period of exposure that preceded Chattanooga deposition, weathering of the Devonian rocks caused solution and development of porosity in the surface beds similar to that at the top of the Mississippian limestones. The Devonian rocks consist of zones of dense and porous dolomite and semigranular fossiliferous limestone and lithographic limestone. Consequently, there is great difference in the character of weathering and the amount of disintegration of the rocks on the ancient surface, so that the permeability and porosity of the eroded surface rocks vary according to the nature of the beds exposed. The lithographic limestone that predominates in the lower part of the Devonian assemblage is similar to the St. Louis limestone and is much less susceptible to the development of porosity under weathering conditions than some of the semigranular limestones and dolomites in the upper part of the Devonian. *The failure to encounter porous reservoir rocks in the upper part of the Devonian on one anticline,* *therefore, does not imply that similar unfavorable conditions occur on others.*

The top of the Devonian rocks has been penetrated in only six wells in the McLouth field. The well that penetrated the oldest rocks at the surface of the Devonian is the McLaughlin and Sons No. 1 Thorpe well, in the NE¼ NE¼ sec. 27, T. 10 S., R. 20 E., which encountered dense lithographic limestone lacking in porosity and unstained by oil. Three wells which penetrated slightly younger Devonian rocks have been drilled in the McLouth field. The Apperson No. 1 Bower well, in the SE¼ SE¼ NE¼ sec. 5, T. 10 S., R. 20 E., a rotary well, is structurally the highest in the field and the one most favorably situated to test the Devonian. Twenty feet of dolomite at the top of the Devonian was cored. The core consists of sucrose dolomite, in part heavily stained with oil. The porosity, however, was microscopic and the dolomite failed to yield oil. This zone, however, was not acidized. Gas was reported from Devonian rocks in the discovery well, the McLaughlin and Sons No. 1 fee well. The hole, which was drilled on the flank of the Mississippian dome, was full of water when drilled into the Devonian and some observers have expressed doubt as to the source of the gas. The cuttings consist of slightly porous dolomite like that in the Bower well but there were no indications of oil. The third well drilled to the Devonian in the McLouth pool, also below the crest of the dome, is the Young and Longwell No. 1 McLeod well, in the NW¼ SW¼ sec. 4, T. 10 S., R. 20 E. The Devonian rocks, in a zone 12 to 25 feet below the top, consist of microscopically pitted lithographic oil-stained limestone. The overlying Devonian beds are dense impervious unstained dolomite.

The Smythe et al. No. 1 Miller well, in the NE¼ SE¼ sec. 22, T. 10 S., R. 20 E., penetrated unstained dense lithographic Devonian limestone. The Jackson No. 1 Shughart well, in the SW¼ SW¼ sec. 6, T. 9 S., R. 20 E., 6 miles north of the McLouth pool, penetrated coarsely crystalline porous dolomite stained with oil at at the top of the Devonian. The oil stains were lighter in color than those noted elsewhere in the McLouth field. This well was definitely not on anticlinal structure, but the dolomite of the cuttings seemed to be sufficiently porous to provide a reservoir under favorable structural conditions.

In addition to these wells, the following wells in northeastern Kansas are known to have found oil stains and shows of oil in the upper rocks of the Devonian: McCain No. 1 Doane, sec. 34, T. 12 S., R. 22 E.; Kerlyn No. 1 Wise, sec. 28, T. 12 S., R. 20 E.; Forrester No. 1 Altenbernd, sec. 35, T. 12 S., R. 20 E.; Schiltz No. 3 Davis, sec. 33, T. 18 S., R. 18 E.; and Roxane No. 1 Fisher, sec. 19, T. 11 S., R. 22 E. These occurrences are significant because they imply that oil once circulated in the weathered zone at the top of the Devonian. Structural or lithologic conditions favorable to the accumulation of oil evidently were absent at the places drilled. Other oil pools similar to those in the Falls City field of Nebraska probably will be found in the Devonian in northeastern Kansas on anticlines where the top of the Devonian is porous. Structural conditions were favorable in the Bower well but the dolomite lacked porosity. Porosity seemed adequate in the Shughart well but there was no anticlinal structure. In the other wells mentioned, porosity was inadequate to form a reservoir and so far as known anticlinal structure was also lacking.

The basal part of the Devonian in most areas adjoining the McLouth field consists of very sandy limestone. The basal beds consist of slightly dolomitic sandstone in the two wells which have been drilled through this zone in the McLouth field, the Apperson No. 1 Bower well and the McLaughlin No. 1 Thorpe well. In the Bower well, traces of tar were noted in the coarse sandstone cuttings. It is possible that somewhere this sandstone may be found sufficiently free from calcareous or dolomitic cement to provide a suitable reservoir.

The Kimmswick limestone (the Viola limestone of Oklahoma) is productive of oil in central Kansas and in the Dawson pool of the Falls City field on the northwest side of the Forest City basin. The Bower well penetrated coarsely crystalline dolomite with medium-sized voids at the top of the Kimmswick. The Thorpe well penetrated dense sucrose dolomite. Neither well showed oil traces.

The St. Peter sandstone, which is similar to the Wilcox sand of Oklahoma but probably of slightly different age, contained water in the Bower and Thorpe wells. Sand from the top of the St. Peter formation in the Thorpe well showed faint indications of oil when tested with chloroform, and a show of oil was reported by the operator. A trace of tar was observed in St. Peter cuttings and in cuttings of sandy dolomite 40 feet below the top of the Arbuckle limestone from the Apperson well. These shows of tar were so small, however, that they may be the result of contamination.

STRUCTURE

Resumé of Structural History of Northeastern Kansas

Inasmuch as the development of the regional structure of northeastern Kansas has been presented in detail in Bulletin 51 (Lee, 1943), only a brief resumé of the regional structure will be given here as a background for understanding the structural conditions of the McLouth field.

From late Cambrian time to the end of Arbuckle time the central Ozark region of Missouri was subsiding and southeastern Nebraska was rising. These movements were intermittent, and deposition and erosion alternated many times. The whole region was at times exposed, but exposure was more frequent and erosion greater toward the rising area to the northwest. Submergence was also general over the whole region at times, but it was more frequent and deposits were thicker in the central part of the Ozark basin than toward its northwestern margin. These events resulted in a great accumulation of sediments more than 3,000 feet in thickness in the central Ozarks, and a wedging out of the deposits toward southeastern Nebraska. The McLouth field occupies a position between the subsiding area in southern Missouri and the rising area in southeastern Nebraska. The deposits from the granite to the top of the St. Peter sandstone have a thickness of about 700 feet in the McLouth field.

From the end of St. Peter time through the deposition of Chattanooga shale the relation of rising and sinking areas was reversed. Southeastern Nebraska was sinking and the Ozark region was rising. Most of the formations deposited within this time interval thicken toward the northwest. The beginning of the Chautauqua arch, which is a broad westerly to northwesterly trending fold in southeastern Kansas, seems to have been initiated contemporaneously with this change in isostatic balance. The McLouth field occupies a position which during this period was again intermediate but between the rising area to the southeast and the subsiding area toward the northwest. The aggregate thickness of St. Peter, Kimmswick, Maquoketa, Devonian, and Chattanooga rocks in the McLouth field is 430 feet.

Two very important time breaks occurred during the deposition of these rocks. One preceded the deposition of the Devonian during which there was a pronounced elevation toward the southeast with beveling of all the older rock formations. The other, of similar character, preceded the deposition of the Chattanooga shale when similar re-elevation of the surface toward the southeast was followed by widespread beveling of the Devonian and further erosion of the earlier rocks to the southeast.

Only a small amount of structural deformation occurred during deposition of the Mississippian rocks, although the thickness and distribution of the Mississippian formations and overlap of the younger Mississippian rocks toward the north imply a slight subsidence of southern Kansas. The initial movement of the Nemaha anticline seems to have occurred early in Mississippian time, but folding along the Nemaha anticline was unimportant until after deposition of the Mississippian limestone, when the crest of this anticline was raised several hundred feet in some places. Several other less pronounced parallel anticlines of great importance in oil and gas accumulation, such as the Voshell anticline of central Kansas, were also developed at the same time. The erosion that followed the development of these anticlines beveled the tilted beds and reduced the greater part of Kansas to a broad flat peneplain. Before the deposition of the first Pennsylvanian sediments, the base-leveled surface was disturbed by renewed structural movements particularly prominent along the Nemaha anticline and on its eastern flank. Though renewed folding took place along its crest, the most important feature of the new movements was a downward displacement of several hundred feet on the east flank of the Nemaha anticline. This displacement resulted in an escarpment produced in some places by faulting and in others by sharp monoclinal dip. It was accompanied by gentle downward warping of the peneplaned surface east of the escarpment. These structural movements produced the Cherokee basin in southeastern Kansas (the northern extremity of a very deep structural trough in eastern Oklahoma) and the Forest City basin, a relatively minor depression in northeastern Kansas separated from, but in northward continuation with, the Cherokee basin.

A comparison of thickness maps of early Pennsylvanian rocks and of Mississippian rocks and the distribution of Mississippian formations indicates that the pre-Pennsylvanian surface in northeastern Kansas was marked by broad shallow valleys. It is uncertain whether this topography is the result of incomplete peneplanation or of erosion that occurred after deformation of the peneplaned surface. The drainage basins seem to have been eroded on an otherwise flat surface suggesting that they represent post-peneplain erosion. However, there are areas in which thin outliers of younger formations occur in places where the lower Pennsylvanian rocks are thin (fig. 17). This unquestionably indicates the survival of unreduced mounds on the surface of the peneplain. Erosion of drainage basins surviving on the peneplain was probably renewed after the deformation of the peneplain.

The deepest part of the Forest City basin received the oldest and thickest Cherokee deposits, and its configuration is roughly shown by the thickness of the interval between the base of the Hertha limestone and top of the Mississippian rocks (pl. 1). The crest of the Nemaha ridge was not completely submerged until Bronson or Kansas City time, for rocks of this age overlie granite on the northern part of its crest. The structural movements initiated by the re-elevation and deformation of the peneplaned surface continued active throughout Pennsylvanian time. The increments of structural deformation were small but are determinable by comparison of the structure of each successive datum bed, for, after each period of differential folding, the succeeding strata were deposited in essentially horizontal positions. These movements resulted in an increase in the sharpness of nearly all the structural features with depth so that very low anticlines in the surface rocks are found to overlie similar structures of greater closure in the older rocks.

The Forest City basin and the Cherokee basin were at first separated by a broad flat arch (Lee, 1939, pl. 2, p. 24), which will be referred to as the Bourbon arch. This arch extended northwest from Bourbon county, Kansas, and was approximately parallel to the Chautauqua arch which is not known to have been active at this time. The Bourbon arch was submerged in middle Cherokee time, and during the remainder of Pennsylvanian time the Forest City basin was merely the northern end of the Cherokee basin.

The final major structural event affecting northeastern Kansas, as well as the rest of Kansas and adjoining states, was a tilting of the whole region toward the northwest. The geologic cross section from western Missouri to western Kansas prepared by Betty Kellett (1932) shows that the westward-dipping beveled Permian and Pennsylvanian strata of central Kansas were covered by nearly horizontal Cretaceous rocks. Mohr (1939) has presented a north-south cross section from Texas to Nebraska. This cross section also shows beveled upper Permian rocks in Kansas overlain by Cretaceous rocks along a component of the regional dip.

The Kellett section shows very clearly the close parallelism of Permian and Pennsylvanian strata and the angular unconformity between Permian and Cretaceous rocks. The Cretaceous rocks are still essentially horizontal and it follows that the regional dip in eastern Kansas was developed during the hiatus between the Permian and the Cretaceous. Since the deposition of the Cretaceous, the whole region has been elevated several thousand feet without disturbing materially the original horizontal position of the Cretaceous, although local structures have been imposed upon it. The whole region has been subjected to long continued erosion during and since the elevation, for partial peneplains and river benches reveal many stages of re-elevation during the erosional period.

Relation of McLouth Field to Regional Structure

The position of the McLouth field in relation to the regional structure is shown in figures 4 and 5. Figure 4 shows by 50-foot contour lines the present structural configuration of the top of the Mississippian rocks. This surface was originally an approximately flat peneplaned surface although it was traversed in some parts of the region by broad shallow valleys. Its present configuration is the result of all the deformational movements that have occurred in this area from the completion of the peneplain to the present. These include the re-elevation and progressive growth of the Nemaha anticline and the escarpment on its east side, the subsidence of the Forest City basin, local folds, and the pre-Cretaceous regional dip which modified the expression of all the earlier structural features in relation to sea level.

Similarly, figure 5 shows the structural deformation of the originally horizontal base of the Hertha limestone. This datum plane has, however, been affected only by post-Hertha structural movements, most of which, except the regional dip, are the rejuvenation of earlier structural features.

Plate 1 shows the thickness of rocks between the base of the Hertha limestone and the top of the Mississippian rocks by 50-foot lines of equal thickness ("isopachs"). Inasmuch as the base of the Hertha was deposited upon an essentially flat surface, the thickness map shows the configuration of the Mississippian surface at the time the Hertha was deposited. The isopachous lines, there-

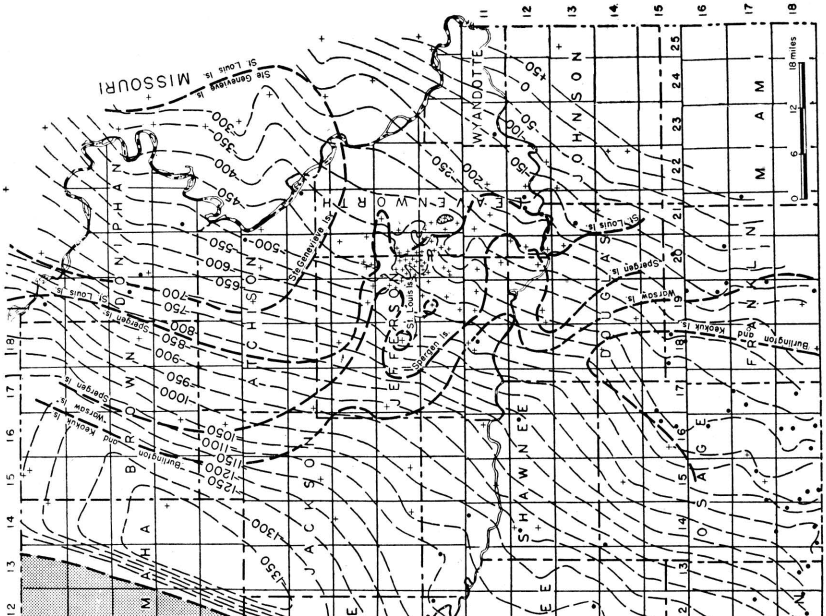


FIG. 4. Map of northeastern Kansas showing regional structure of the top of the Mississippian limestone and so far as known the distribution of Mississippian formations on the pre-Pennsylvanian surface in the eastern part of the area.

The approximate contacts between areas of outcrop of the different Mississippian formations in the eastern part of the area are indicated by heavy lines.

Contour interval, 50 feet. Crosses show the locations of wells from which samples have been studied. Dots show the locations of wells for which data are available from well logs.

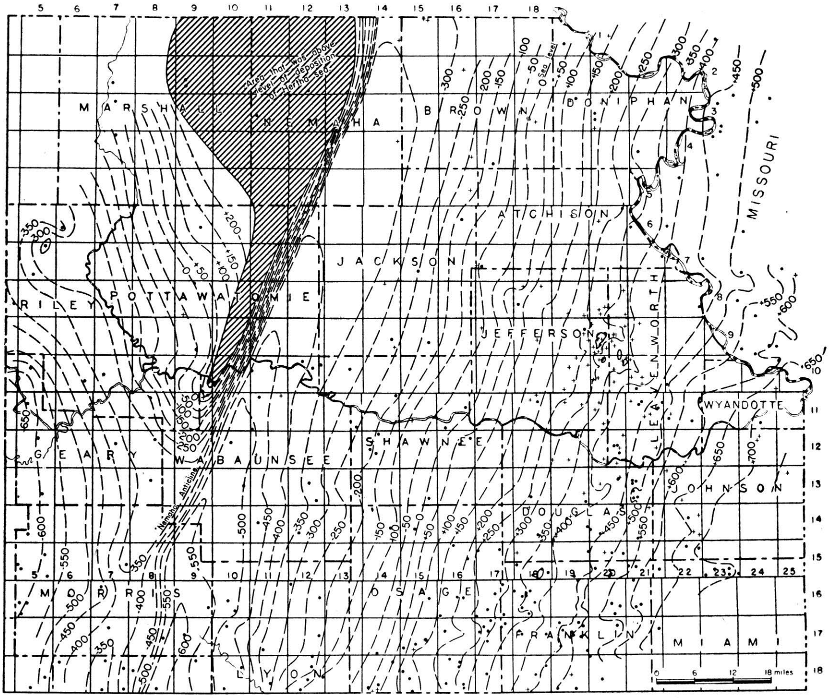


FIG. 5. Map of northeastern Kansas showing regional structure at the base of the Hertha limestone. The structure at the base of the Hertha represents only the structural deformation that occurred after the deposition of the Hertha limestone.

Contour interval, 50 feet. Broken lines indicate structure determined from scattered wells. Full lines, mainly in the McLouth field, indicate structure determined from closely spaced wells. Crosses indicate wells for which data are available from sample logs. Dots show the wells for which data are available only from well logs.

fore, express the deformation of the Mississippian surface from peneplanation to beginning of Hertha time, plus the gentle topographic features of this ancient surface. The deepest part of the Forest City basin thus indicated lies 15 to 25 miles east of the Nemaha escarpment. In the structure maps, however, the deepest part of the basin lies at the base of the escarpment. This change in the apparent position of the syncline in the structural maps is the effect of regional dip, which gave the reference plane of the thickness maps an altered relation to sea level. The original geographic position of the bottom of the Forest City basin syncline is indicated by the thickness map. The structure maps show the regional structure in relation to sea level after the development of regional dip.

The thickness map (pl. 1) also shows by 50-foot thickness lines a broad oval northward-trending area of thinning on the eastern side of the basin which represents a broad arch on the surface of the Mississippian. The study of the structure of the McLouth field, to be discussed later, reveals that the relief of the pre-Pennsylvanian surface in the field is mainly structural, the erosional elements being of minor importance. Inasmuch as the McLouth area lies at the crest of the arch, it is believed from analogy that the thinning of the lower Pennsylvanian rocks in Atchison, Jefferson, and Leavenworth counties represents in large part a structural arching of the Mississippian surface. Parts of the area of thinning, however, are not part of the arch. The Mississippian in these counties, as shown in plate 1, is underlain mainly by Spergen and St. Louis rocks beveled by post-Mississippian peneplanation, but outliers of St. Louis limestone occur west of the field in T. 10 S., R. 19 E. and in T. 9 S., R. 18 E. The thinning of the lower Pennsylvanian rocks over the St. Louis in these townships is, therefore, due to topographic relief and cannot be interpreted as the expression of structure.

The expression of the southern end of the arch is lost in an area of broad valleys shown on the lower Pennsylvanian thickness map by the dendritic pattern of the thickness contours in Douglas and Franklin counties. In this area the topographic features, which are reflected also in the areal distribution of the Mississippian formations, obscure the structural features as expressed by the thickness lines. After eliminating the areas of thinning in central Jefferson county due to outliers of the St. Louis limestone, the trend of the arch upon which the McLouth field is situated seems to be toward the north.

The structure map of the base of the Hertha limestone shows deformation that has taken place since the deposition of that formation. The contour lines represent both the amount of post-Hertha subsidence of the Forest City basin and local deformation, both of which have been modified by regional dip. The local deviations from regularity of dip are presumed to be the expression of low pre-Cretaceous folds modified by regional dip. The expression of most of these folds is vague and their configuration is uncertain, for the contour interval is large, the wells are sparsely distributed, and many of the wells were drilled without consideration of structural conditions. Restoration of this surface to its attitude prior to the development of the regional dip, as discussed in the chapter on the structure of the McLouth field, might reveal broad anticlinal areas worthy of detailed study to bring out local structural features of value in the search for oil and gas.

Examination of the contour lines reveals that there is a decrease in the rate of westerly dip in a belt 8 to 10 miles wide extending southward from Atchison county through the McLouth field into Douglas and Franklin counties. The flattening of the dip in this belt seems to be the expression of a low anticlinal fold which has been reduced by regional dip to a structural bench. Because of sparse control and the use of 50-foot contour lines, no great detail is revealed. In the McLouth field where many wells have been drilled local closure is shown. This structural bench traverses the same belt and has the same general trend as the structural arch suggested by the thickness map of the pre-Hertha Pennsylvanian rocks. It extends from Atchison county southward to Franklin county across the area in Douglas county in which the dissection of the Mississippian surface prevents its expression by thickness contours of the early Pennsylvanian rocks.

The recognition of a northerly anticlinal trend in both these maps is, to some extent, a matter of interpretation, but both lines of approach suggest that the McLouth field lies upon and is part of a northward- to northeastward-trending arch. Although this structural trend is more nearly toward the north than is the Nemaha anticline, the fact that folds in the McLouth field have a pre-Pennsylvanian history warrants the belief that the arch upon which the McLouth field lies was also initiated in pre-Pennsylvanian time and that it was contemporaneous with the Nemaha anticline. However, few wells have been drilled to the Devonian and older rocks in northeastern Kansas, and it is impossible to be certain that some of the structural features do not have a pre-Mississippian origin, although from what is known about the regional history of folding it seems improbable that folds trending toward the north or northeast are older than the Nemaha ridge.

Structure of the McLouth Field

The black lines of plate 2 show the structure of surface rocks in the McLouth field as mapped by Haworth and Taylor on outcrops of Lecompton limestone. The contour lines of the map represent the following features: a northeastward-trending fold with a closure of less than 20 feet in secs. 3, 4, and 5, T. 10 S., R. 20 E., the site of the McLouth pool; a broad flat northwestward-trending structural nose in secs. 20 and 21, T. 9 S., R. 20 E., the site of the North McLouth pool; and a small north-south anticline with less than 10 feet closure in sec. 1, T. 10 S., R. 20 E., where the Ackerland pool has been developed. In addition to these anticlines, there is a northwesterly structural projection of the Ackerland anticline in sec. 25, T. 9 S., R. 20 E., and a low unnamed anticline in secs. 16 and 17, T. 10 S., R. 20 E., neither of which has been tested.

The shallow syncline in the surface rocks trending northeast between the McLouth pool and the North McLouth pool has been proved by drilling operations. The structural depression shown on the map extending across secs. 8, 9, and 10, T. 10 S., R. 20 E., although based on scanty surface evidence, is confirmed by such drilling as has been done south of the McLouth pool. This area is particularly affected by concealed pre-Pennsylvanian faults, which will be discussed later.

Figures 6, 7, 8, and 9 show the structure at the top of the Oread limestone, base of the Hertha limestone, top of the McLouth sandstone, and top of the Mississippian limestone. The structure at the top of the Warsaw limestone (fig. 10) and at the top of the porous dolomite zone of the undivided Burlington and Keokuk limestones (fig. 11) is shown only in the McLouth pool because not enough wells have penetrated these datum beds to determine the detailed structure in a larger area. These maps were drawn from data determined by microscopic examination of complete sets of well samples and of insoluble residues below the Pennsylvanian rocks. In all, 202 sets of samples, which are now on file at the State Geological Survey, were collected and studied. Table 27 gives a list of all the wells completed in and adjacent to the field to June 15, 1943, and the depths and altitudes of the datum points used in drawing the structure maps.

This series of structure maps shows that the amount of folding increases with depth at least to the upper Mississippian rocks and that the folds were initiated in pre-Pennsylvanian time. Conversely, the maps show that during deposition of the Pennsylvanian rocks the folds were continually being revived by small increments of deformation. The vague amoeba-like pattern of the structure of the surface rocks represents only the distortion caused by structural movements that took place after the deposition of the Lecompton limestone.

Only six wells in the McLouth field have been drilled to the Devonian rocks, so the local structure of the pre-Mississippian rocks cannot now be determined. It is believed from the general relations that all the folds in the McLouth field originated after Mississippian time and will be found not to increase in intensity below the Mississippian. An angular unconformity separates the Devonian and older rocks from the Mississippian, however, and, although the amount of deformation of individual anticlines in the older rocks is the same as in the Mississippian, the expression of folding, as shown by the structural maps, may be modified below the angular unconformity by the pre-Mississippian regional dip toward the northwest.

INCREASE OF CLOSURE WITH DEPTH

The present closure of the anticline of the McLouth pool is less than 20 feet at the surface on the Lecompton limestone, but increases to 25 feet on the Oread limestone and to more than 30 feet on the base of the Hertha limestone. The closure on the top of the McLouth sand is more than 60 feet. The structural relief of the pre-Pennsylvanian rocks is even greater than on the McLouth sand (figs. 10, 11, and 13), and it is evident that well-defined structure was developed in the Mississippian rocks before the peneplanation that preceded Pennsylvanian deposition.

In the North McLouth pool no closure is shown in the surface rocks, but there are some areas with local closure of less than 10 feet at the top of the Oread limestone. The closure is more than 20 feet on the Hertha limestone and more than 30 feet on the top of the McLouth sand. The structural relief also increases in the Mississippian rocks on this anticline, but structural details on the crest are lacking. The Ackerland pool has a closure of about 20 feet in the surface rocks but the closure, as revealed by drilling, is at least 40 feet at the top of the McLouth sand.

RELATION OF SURFACE STRUCTURE TO PRODUCTION

It will be noted in plate 2 that the distribution of gas and oil wells is not very closely related to the anticlinal areas of the surface structures. On the west side of the McLouth pool, gas wells have been drilled in a wide area outside the area of closure of the surface rocks. The discovery well of the field was located on the crest of the anticline as indicated by the surface rocks. Later

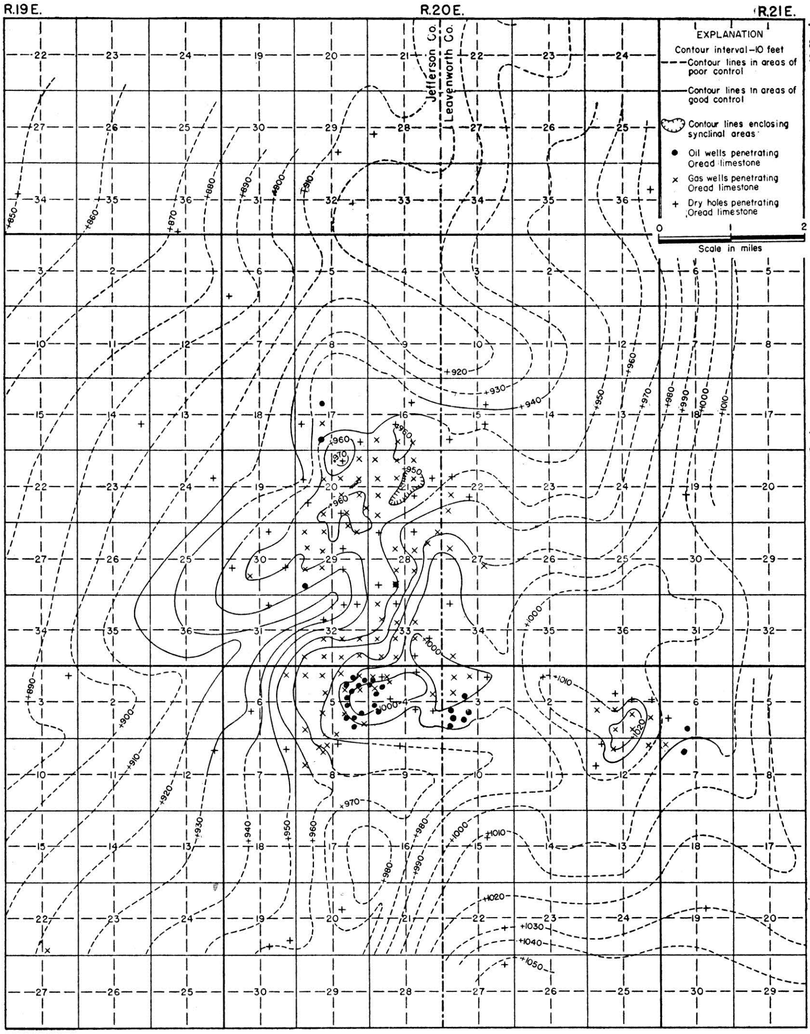


FIG. 6. Map showing the structure of the McLouth field contoured on the top of the Oread limestone. The structural relief is slightly greater than that on rocks exposed at the surface.

drilling showed that the crest in the surface rocks was nearly one-half mile from the crest in the Mississippian rocks. The surface crest is outside the area of Mississippian oil production on the crest of the subsurface anticline. The area from which gas is produced in the North McLouth pool shows no closure in the surface rocks, but only a structural nose. The McLouth sand in the subsurface shows well-defined anticlinal structure. Comparison of the structure of the surface rocks with the structure of the subsurface rocks thus reveals a shift both in the position of the crests of the anticlines and also in the areas of closure.

EFFECT OF REGIONAL DIP ON THE EXPRESSION OF STRUCTURE BY CONTOUR LINES

In order to explain the above-described anomalies it is necessary to consider the effect of regional dip upon the expression of structural features of varying degrees of relief. The effect of regional dip upon previously developed anticlines is shown diagrammatically in figure 12 by cross sections in the direction of the dip. Cross section A represents a low anticline in the surface rocks. The subsurface rocks are represented as having been more sharply deformed than the surface rocks, as is the case in the McLouth field. Cross section B shows the effect of regional dip on the surface and subsurface anticlines. It will be noted that the regional dip has not appreciably changed the position of the subsurface anticline and that the reverse dip has been reduced by the amount of regional dip. The regional dip, however, has produced a marked shift in the position of the crest of the low surface anticline and has reduced its closure by the amount of regional dip. The reverse dip of both surface and subsurface anticlines has been reduced by the same amount, but in the surface rocks the regional dip has almost eliminated the closure. A lower reverse dip at the surface or a steeper regional dip would destroy the closure and reduce the crest of the surface anticline to a structural bench.

The effect of regional dip on a low hypothetical dome represented by contour lines is shown in figure 13. The regional dip (B) imposed on the dome (A) has caused the crest of the dome to shift up dip, has reduced the closure of the dome, and has altered the configuration of the contour lines as shown in figure 13 (C). The same regional dip on deeper and consequently steeper structures reduces the amount of closure by the amount of regional dip but only slightly modifies the configuration of the contour lines. The shift in the position of the subsurface crest is negligible.

The regional dip thus induces a discrepancy between the position of the crest in low surface anticlines and its position in steeper anticlines of deeper rocks. It should be noted that the amount

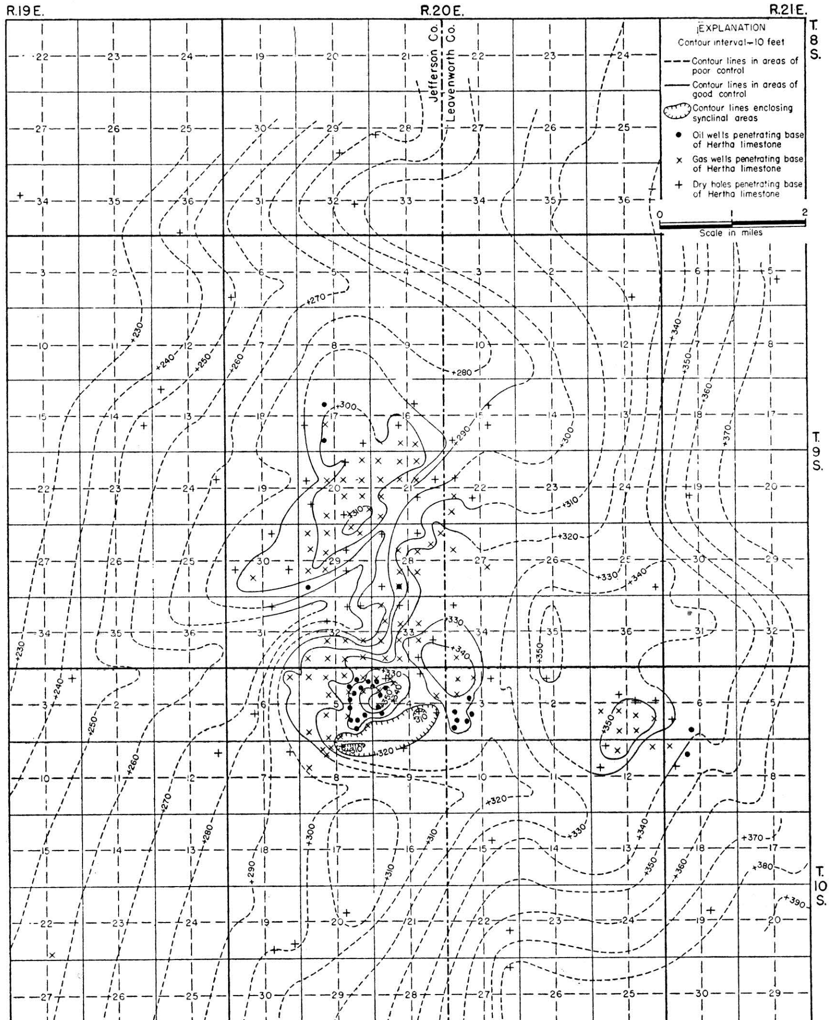


FIG. 7. Map showing the structure of the McLouth field contoured on the base of the Hertha limestone. The contours show structural relief greater than that on the top of the Oread limestone.

of deformation of the strata in relation to a plane surface has not been altered, but that it is the expression of the dome by means of contour lines that has been altered as a result of the changed relation of the structure to the horizontal plane.

The extraordinary effect that the regional dip may have under certain conditions in shifting the crest of low surface anticlines is shown in a paper dealing with another subject by Rich (1935, pp. 1540-1543). Illustrations for this article, partly reproduced in figure 18, show the structure of an area in Greenwood county in T. 23 S., R. 9 E. as indicated by the surface structure and as it appears with the regional dip eliminated. The crest of the principal anticline shown in this township has been shifted southeast from its original position in sec. 9 to sec. 27, a distance of nearly 3 miles. If structural relief in Greenwood county increases in depth in the same ratio as in the McLouth field, the crest of the anticline in the deeper rocks will be found 3 miles distant from its position as mapped on the surface rocks rather than beneath the crest of the surface anticline.

The imposition of regional dip on pre-existing structure involves the greatest change in the expression of structure by contour lines in the surface rocks where the reverse dips are low. Where the sharpness of structure increases in depth, the contours on the deeper rocks, although they receive the same amount of regional dip, suffer less distortion (fig. 12).

The steeper the structural slopes and the sharper the anticline, the less the crest is shifted by regional dip. The crests of anticlines with reverse gradients commensurate with the subsequently imposed regional dip always undergo an important shift in position unless the crests of the folds are narrow and paralleled the strike of the dipping rocks. In this connection, it is pertinent to point out that the bottom of the Forest City basin was shifted at least 15 miles by the regional dip (fig. 4 and pl. 1).

ALTERATION OF CONTOUR LINES IN THE MC LOUTH FIELD BY REGIONAL DIP

In order to determine the effect of regional dip on the structure of the McLouth field, the surface structure, as mapped by Haworth and Taylor, was recontoured to eliminate regional dip. The method used is described by Rich (1935, pp. 1538-1540) and illustrated in figure 13. The original position of the dome in A may be restored from C by considering C hinged on the zero-contour line of the regional dip and swinging the dip surface upward to a horizontal position. Corrections are made on the contour lines of the dome according to the amount of movement. No corrections are made on the hingeline. Elevations of points at the intersection of structure contours of the dome with contours of the regional dip

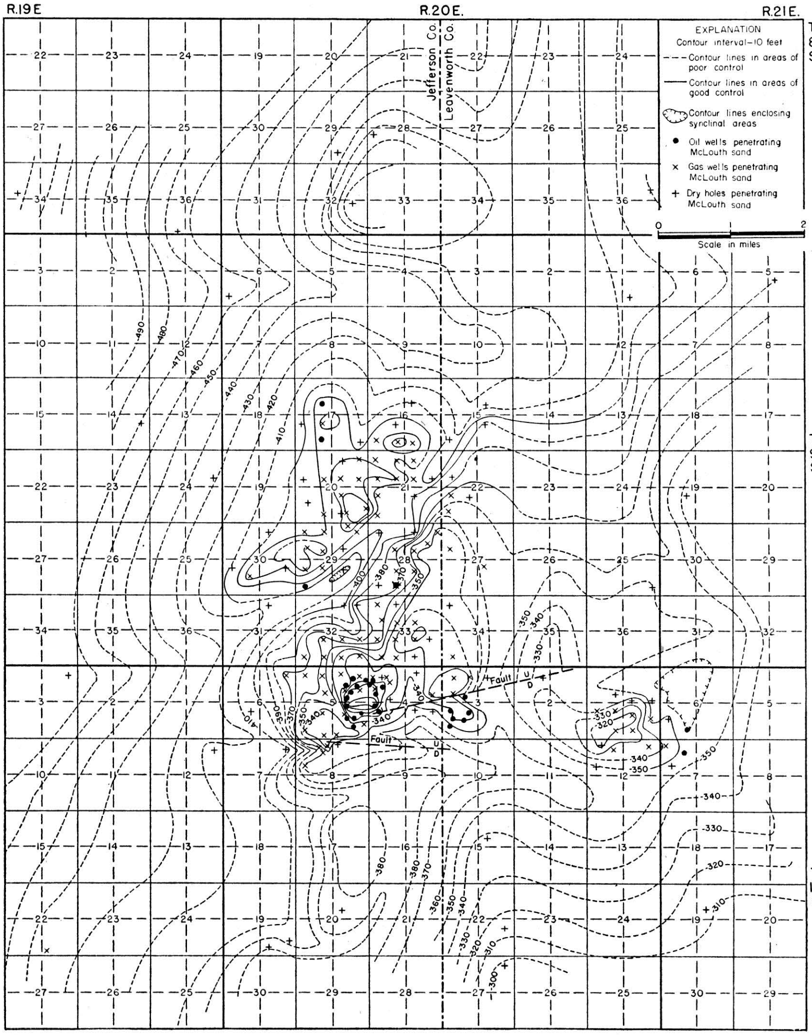


FIG. 8. Map showing the structure of the McLouth field contoured on the top of the McLouth sand. The contours show structural relief markedly greater than that on the base of the Hertha limestone.

are then made. The elevations at intersections of contours of the dome with 5-foot contours of the regional dip are increased 5 feet, those on the 10-foot contour are increased 10 feet, and so on. Restoration of the elevation of points on the dome between the contours may be determined by making similar but intermediate corrections.

The red lines of plate 2 determined in this manner represent the present surface structure of the McLouth field before development of regional dip. The actual local deformation of the strata has not changed but the contours, after regional tilting, have a different expression with respect to sea level. The regional dip in the McLouth field is about 15 feet per mile N. 70° W. in the surface rocks in the McLouth field. The dip was determined by averaging the dip across the field between wells far enough apart to eliminate the effect of local structure. The direction of strike was determined from the geological map of Kansas.

The surface structure of the McLouth field prior to the development of regional dip as represented by the red lines of plate 2 included many elements with lower or only slightly greater gradients than the regional dip. The regional dip caused a considerable shift in the position of the crest of the McLouth anticline and decreased the area of closure. The North McLouth anticline had original reverse surface dips so low that the regional dip reduced the fold in the surface rocks to a structural nose. The surface closure of the Ackerland anticline, only part of which has been tested at this date (April 1, 1943), was greatly restricted by the regional dip.

It has been pointed out that the area yielding gas in the McLouth pool (pl. 2, black lines) is eccentric to the present area of closure of the tilted surface beds and that gas wells on the west side extend far outside the closing contour. In plate 2 (red lines) which shows surface structure corrected for regional dip, all the gas wells lie within the area of closure represented by the 1,125-foot contour line of the structure in its original attitude. This line corresponds closely in position to the —375-foot contour of the structure on the McLouth sand (fig. 8). The original area of closure of the surface rocks and the distribution of gas thus correspond closely to the structural expression at the top of the McLouth sand (fig. 8) but differ sharply from the uncorrected surface structure with the imposed regional dip. Had this relation been recognized during the early development of the field, the extension of the producing area beyond the area of surface closure might have been anticipated.

The surface structure of the North McLouth pool, centering in secs. 20 and 21, T. 9 S., R. 20 E., is merely a broad anticlinal nose

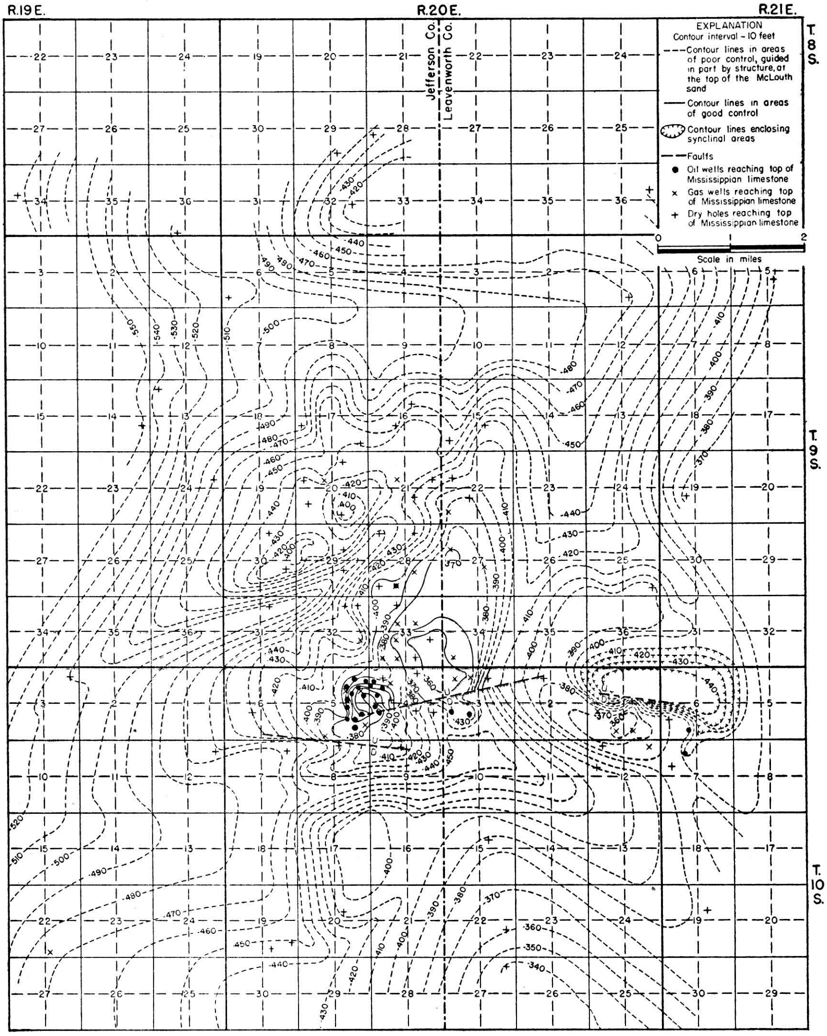


FIG. 9. Map showing the structure of the McLouth field contoured on the top of the Mississippian limestone. The structural expression on the top of the Mississippian limestone is distinctly greater than that on the top of the McLouth sand, but is modified by mild pre-Pennsylvanian erosion.

trending northwest without closure in the surface rocks. The restoration of this surface structure to its original horizontal position as shown in plate 2 (red lines) reveals an original low anticline. All but three of the gas wells lie within the 1,130-foot con-

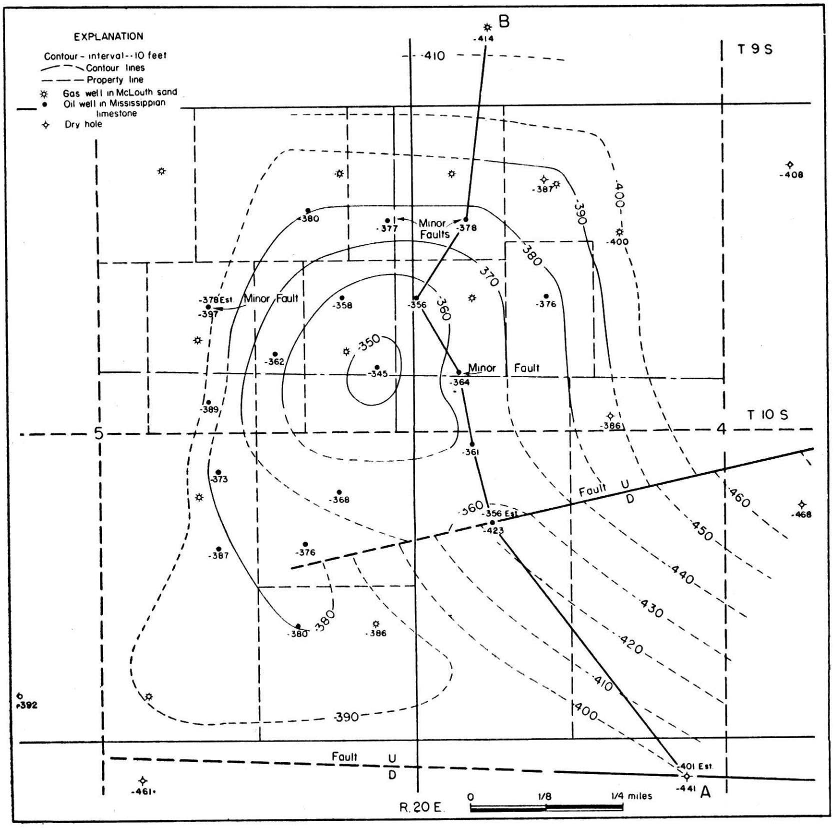


FIG. 10. Map showing structure of the McLouth pool contoured on the top of the Warsaw limestone. The structural relief is greater than that on the McLouth sand.

tour of the restored structure map. This line corresponds closely to the —395-foot contour of the McLouth sand. The lack of complete agreement is due in part to imperfections of mapping where there were no outcrops and in part to the fact that there was some deformation of the sand reservoir after accumulation of the gas. This factor will be discussed later. It should be pointed out, however, that where there is poor control for mapping the surface structure the corrected lines also will lack accuracy. This difficulty is illustrated on the west side of the North McLouth anticline where control for mapping the surface beds was inadequate.

The Ackerland pool, in sec. 1, T. 10 S., R. 20 E., lies on the eastern end of a surface anticline that has a closure of about 20

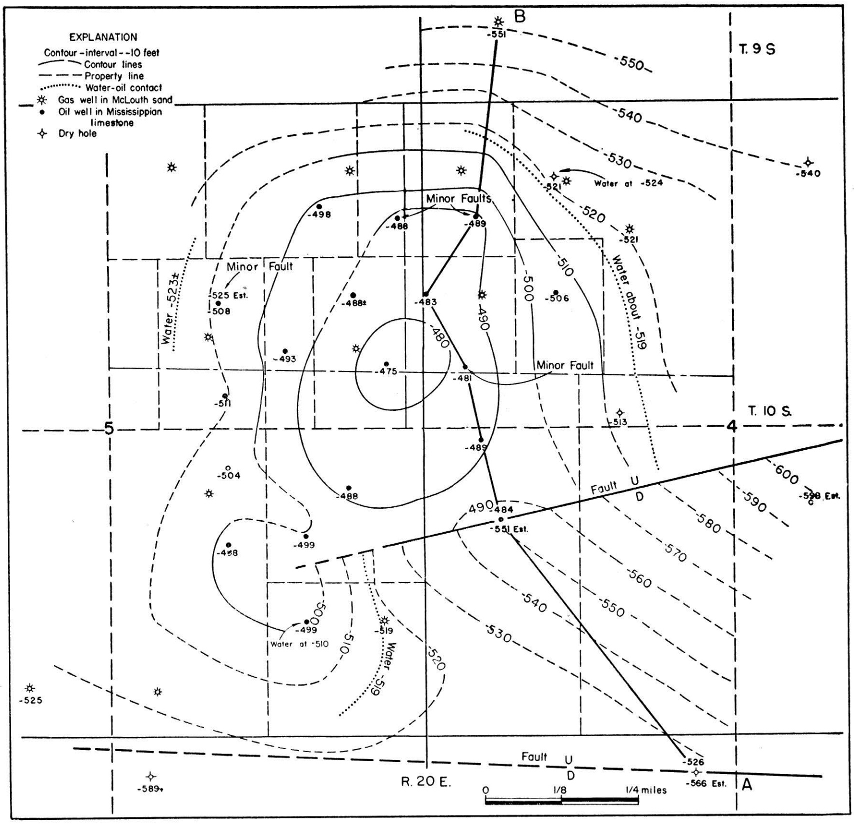


FIG. 11. Map showing structure of the McLouth pool on the top of the productive dolomite zone of the undifferentiated Burlington and Keokuk limestones. The structural relief differs from that at the top of the Warsaw because several wells reveal shortened intervals of 12 to 17 feet between the Warsaw limestone and the dolomite zone. These shortened intervals are believed to represent minor tension faults in the Mississippian, but neither the strike nor the direction of displacements is known.

feet. The surface structure of this anticline seems to be well authenticated by numerous outcrops. Correction for regional dip in this area greatly enlarges the area of closure which may have two crests. Only the eastern end of this anticline has been tested at this date (April 1, 1943). The restored contours in the Ackerland pool reflect the subsurface structure of the McLouth sand, so far as developed, more accurately than the unrestored surface structure.

The importance of determining the original attitude of the structure is well illustrated in the McLouth pool by the Mississippian dolomite. The crest of the dome that yields oil from the Mississippian dolomite was shifted so far from the subsurface crest that the well drilled on the surface crest lay outside of, and missed, the producing area (pl. 2). If the well drilled on the apparent crest had been the only test drilled to the Mississippian, it would probably have been concluded that the Mississippian rocks were unproductive.

The crests and areas of closure of structures in the subsurface and the areas of production of oil and gas are thus in close agreement with the original surface structure as revealed by the elimination of regional dip. They do not agree with the surface structure as contoured in their present relation to sea level. Weak surface structures recontoured with elimination of regional dip are, therefore, a more trustworthy guide to the development of weak surface structures than is their present attitude. Where anticlines are strongly developed in the surface rocks and trend in the direction of regional strike, as in central Kansas, these considerations are of no importance; however, under conditions prevailing in northeastern Kansas, they have an important bearing on the localization of producing areas.

In view of the structural relations existing at McLouth, no structural features in northeastern Kansas expressed in the surface rocks by low gradients, irrespective of the actual amount of closure, should be condemned or drilled until they have been evaluated by restoring the contour lines to their originally horizontal attitude.

FAULTING IN THE MC LOUTH FIELD

Faulting has been determined in the Mississippian rocks in two wells south of the McLouth field. It does not seem to be very strongly developed in the lower Pennsylvanian, either because of declining activity or because faults tend to die out in the incompetent shales of the Pennsylvanian. The Young and Longwell No. 1 McLeod well, in NW¼ SW¼ sec. 4, T. 10 S., R. 20 E., drilled through a fault having a displacement of 62 feet in the Mississippian. This fault was recognized by the fact that the interval from the top of the Warsaw limestone to the top of the dolomite zone was 62 feet less than the normal interval in other wells of the field. A normal or tension fault is indicated by the shortening of the interval between the datum beds. The downward displace-

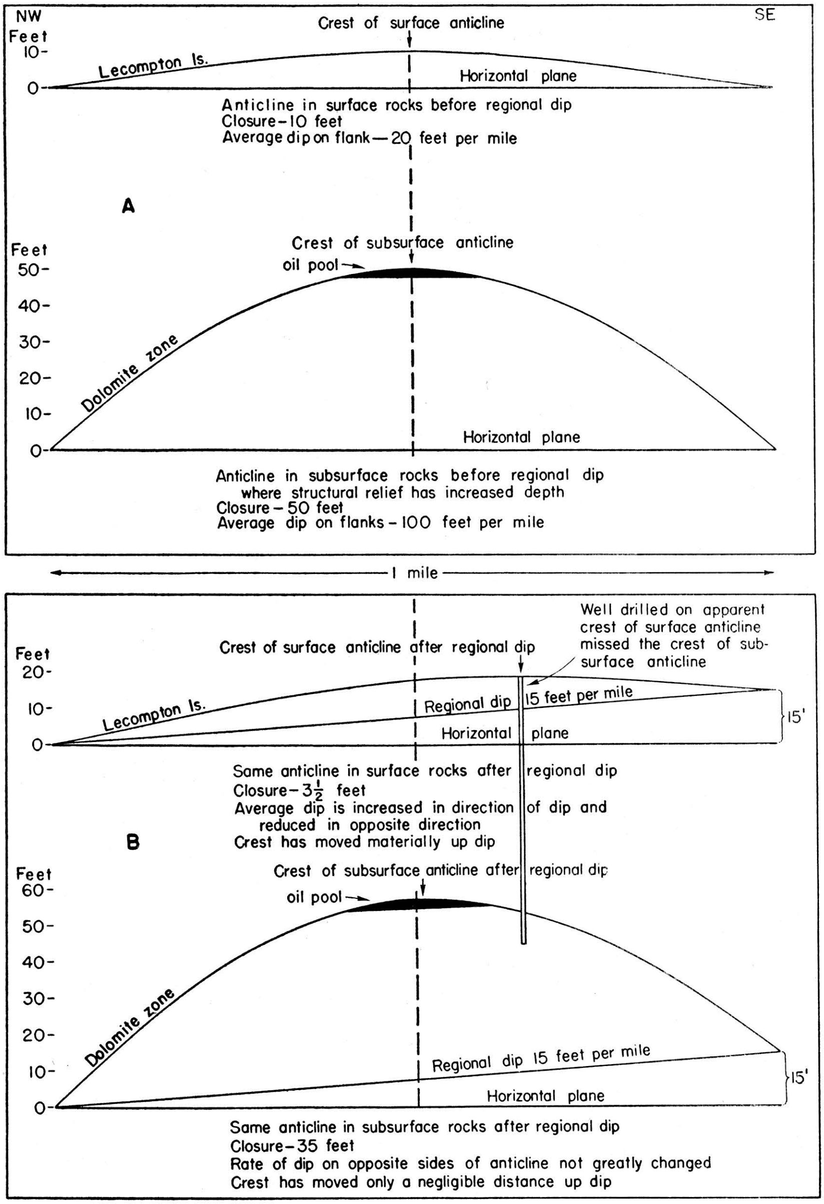


FIG. 12. Cross-sectional diagrams with exaggerated vertical scale to show: (A) relation of surface and subsurface anticlines in regionally horizontal rocks where structural relief increases with depth, and (B) altered relations of surface and subsurface anticlines and shift in position of crest of surface anticline after development of regional dip.

ment of the rocks on the south side is shown by the structural relations of nearby wells; the strike is shown by the attitude of the Mississippian limestone and the McLouth sand in wells in the S½ sec. 4, T. 10 S., R. 20 E. The fault seems to die out in the SE¼ of sec. 5, but may extend toward the east into the NW¼ of sec. 2.

Another normal fault that caused a shortened interval in the Mississippian rocks was revealed by the Apperson No. 1 McLeod (Hunter) well, in the NE¼ NE¼ NW¼ sec. 9, T. 10 S., R. 20 E. The downward displacement caused by this fault is 45 feet. The control, however, is at present inadequate to determine with confidence the strike and direction of displacement although the fault is shown tentatively on the maps (figs. 9, 10, 11) as trending slightly north of west with a downward displacement on the south. Several other wells on the McLouth anticline have shown shortened intervals in the Mississippian rocks. The Sherrod No. 2 Bower well, an irregularly-spaced well in the NE¼ SW¼ NE¼ sec. 5, T. 10 S., R. 20 E., found the interval between the top of the Warsaw and the top of the Burlington-Keokuk dolomite zone 17 feet shorter than normal. This shortened interval is believed to indicate a minor fault, but the strike and direction of displacement are uncertain. Some other shortened intervals that suggest minor faults in the Mississippian have been noted in other wells, but they may be the result merely of inaccurate measurements of depth or the result of depth corrections which have not been reported in the logs. One shortened interval in the Lansing group that has, however, been doubtfully accepted because of the location of the well occurs in the McNerney No. 1 Fidler well, in the NE¼ NW¼ sec. 2, T. 10 S., R. 20 E. In this well the Lansing group is 15 feet thinner than in the nearest wells. This well lies on the trend of the northeastern extension of the Young-McLeod fault. The possibility exists that the shortened interval may be the result of a correction of depth not reported in the log.

INTERPRETATION OF STRUCTURE FROM THE THICKNESS MAP OF THE MC LOUTH SAND

Some of the displacements along the faults seem to have occurred prior to peneplanation of the Mississippian but were not subsequently revived in earliest Cherokee time. These conclusions are reached by a study of the thickness of the McLouth sand as shown in figure 14. The relief of the Mississippian surface at the end of McLouth deposition is indicated roughly by the

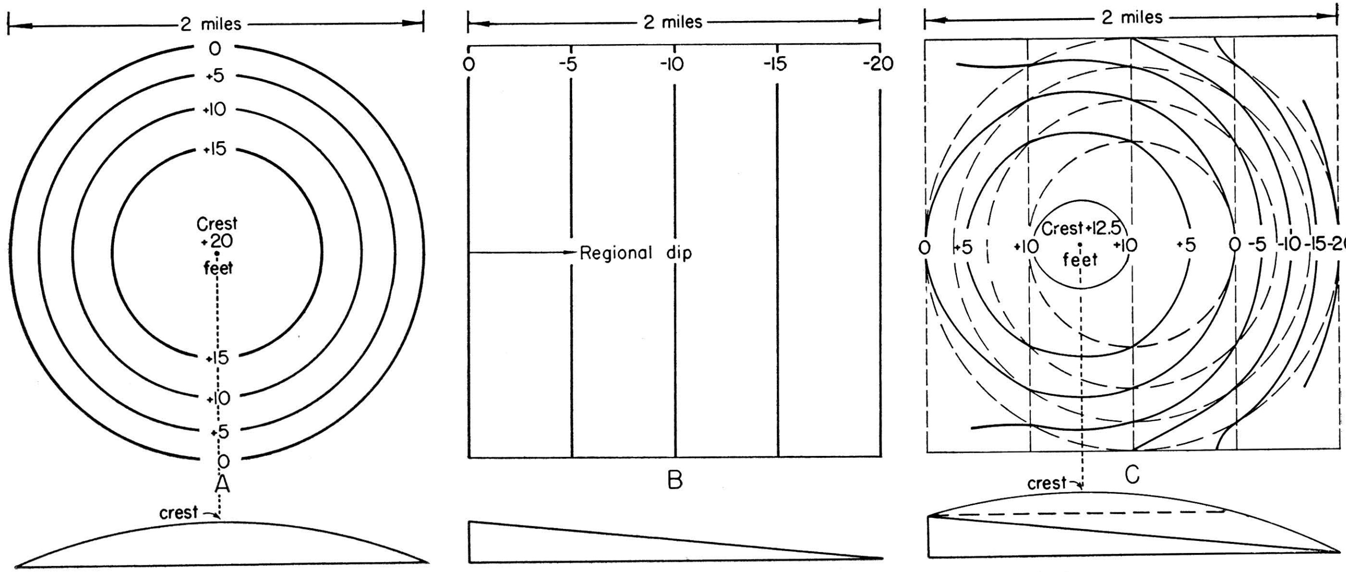


FIG. 13. Sketches to scale showing effect of regional dip on hypothetical dome with low relief.
A, Symmetrical dome with closure of 20 feet and average dips of 20 feet per mile. B, Regional dip of 10 feet per mile.
C, Effect of regional dip imposed on dome. Dotted lines show original dome; full lines show result of tilting.
Crest has moved one-fourth mile up dip and closure is reduced from 20 to 12½ feet.
Contour interval, 5 feet in all sketches.

thickness contours from the top of the McLouth sand to the top of the Mississippian limestone. The close parallelism of the top of the McLouth sand and the thin white siltstone, 20 feet higher, indicates that the top of the McLouth sand was essentially a flat surface when it was deposited. There has probably been slightly greater compaction of the sand and shale below the top of the McLouth in areas where the deposits of shale and sandstone were thick and less where these deposits were thin. The relief of the pre-Pennsylvanian surface referred to the top of the sand as shown by the thickness map (fig. 14) is probably slightly less than the actual relief when the McLouth was deposited by the difference in the amount of compaction that occurred over elevations and over depressions. The original relief, however, was essentially as shown on the thickness map. The thinnest deposits of McLouth sand on the McLouth anticline as shown by the isopachous lines follow the structural trend of the McLouth sand (pl. 2, red lines) northward from sec. 4, T. 10 S., R. 20 E. into sec. 22, T. 9 S., R. 20 E., and conform in a general way to the anticlinal trend of this pool in spite of the fact that parts of the Mississippian surface in sec. 5, T. 10 S., R. 20 E. and sec. 32, T. 9 S., R. 20 E. were obviously channeled. Similarly, the McLouth sand is thin over the anticline of the North McLouth pool and the thickness lines of the sand roughly conform to the structural pattern of that anticline (pl. 2, red lines). In the Ackerland pool, thin McLouth deposits overlie the crest of the dome. The deep narrow syncline between the McLouth and North McLouth pools is also clearly recognizable in the thickening of the McLouth deposits in that area.

The Mississippian rocks exposed in pre-Pennsylvanian time at the surface of the McLouth and North McLouth anticlines were entirely Spergen dolomite—a homogeneous, sparsely cherty, silty dolomite without contrasting hard and soft beds—unlikely to produce a topographic hill on the crest of an arch as a result of selective erosion. The thinning of the McLouth sand on the anticlines is thus due to the revival of the earlier fold and reveals one of the increments of the slowly developing structure which continued active at least through Lecompton time.

The intermittent development of some of the faults in the McLouth field is indicated at several points. The increase in the thickness of the McLouth interval on the down-throw side of the fault in the Young and Longwell No. 1 McLeod well from 30 feet north of the fault to 45 feet on the south, and to 75 and 89 feet in wells in the N½ SE¼ sec. 4, has already been mentioned in the chapter on thickness of the McLouth sand. This fault shows a displacement of 62 feet in the Young and Longwell No. 1 McLeod well, of which at least 34 feet took place prior to the deposition of the Pennsylvanian. It may have continued active even to Hertha time, as suggested in figure 15, but there is no indication of displacement in the upper part of the Pennsylvanian.

The Sherrod No. 1 Benne well in the NW¼ NW¼ NE¼ sec. 8, T. 10 S., R. 20 E., shows an abrupt increase in the McLouth interval from 49 feet in an offset well to 94 feet in the Benne well. Even greater displacement occurs in the Mississippian rocks of this well. The structural displacement was not materially, if at all, revived during later Pennsylvanian time. In the Apperson No. 1 McLeod (Hunter) well, in the NE¼ NE¼ NW¼ sec. 9, T. 10 S., R. 20 E., the McLouth sand zone has an average thickness of 39 feet on the downthrow side of the fault. Therefore, the displacement of 44 feet noted in the Mississippian rocks took place prior to peneplanation and was not revived appreciably during Cherokee time.

The abrupt increase in the thickness of the McLouth sand in the three dry wells in the N½ sec. 1, T. 10 S., R. 20 E. on the north side of the Ackerland pool is interpreted as indicating a fault. Chert fragments in shale in the McLouth sand 35 to 45 feet above its base in two of three wells north of the displacement suggest proximity to an escarpment of Mississippian rocks. This sharp fault or monocline was, however, not revived in the younger Pennsylvanian rocks, and the structure, as contoured on the Hertha, Oread, and Lecompton limestones, fails to give any indication of more recent displacement.

Known and suspected faults in the McLouth field have a general trend east and northeast. They do not seem to be parallel to each other but converge upon each other at sharp angles between northeast and east.

McLOUTH SAND

Lithology

The variable assemblage of lithologic types that constitutes the McLouth sand does not permit precise classification and description. Although this subdivision of the Cherokee is termed in the aggregate McLouth *sand,* only about one-half of the body of sediments actually is sand. A characteristic feature of the McLouth sand is intricate interlamination and interbedding of different lithologic types, some of which, in addition, are vertically and laterally intergradational. The outline classification (table 2) gives a breakdown into generalized lithologic types and varieties based largely on composition and grain size.

TABLE 2. *Classification of generalized lithologic types of the McLouth sand based on composition and grain size*

(The quantitative importance of the lithologic varieties is indicated by asterisks: *** abundant; ** common; * uncommon, but not rare; no arterisk indicates rare.)

A. Quartz sandstone
   1. Well-sorted, porous sandstone **
   2. Argillaceous sandstone ***
   Subvarieties formed by cementation of above varieties
      a. Quartzitic sandstone *
      b. Sideritic sandstone
      c. Pyritiferous sandstone
      d. Asphaltic sandstone *

B. Quartz siltstone
   1. Well-sorted siltstone **
   2. Sandy siltstone *
   3. Clayey siltstone **
   Subvarieties formed by cementation of above varieties
      a. Siliceous siltstone *
      b. Sideritic siltstone *

C. Massive clay (fireclay)
   1. Well-sorted, homogeneous clay **
   2. Silty clay
   3. Sandy clay

D. Shale
   1. Micaceous silty shale **
   2. Clay shale ***

E. Clay ironstone
   1. Clay ironstone *
   2. Red sideritic limestone

F. Coal *

G. Intraformational breccia phase of argillaceous sandstone **

Examination of large fragments shot from wells has indicated that the sandstone beds of the McLouth are not solid bodies of sand but contain thin layers of siltstone, clay, or shale. The presence of these layers is also indicated by study of well cuttings from sandstone zones, the larger fragments commonly showing contacts between sandstone and siltstone, clay, or shale. These thin layers of impermeable material probably have an important effect on the passage of fluids through the sandstone beds.

Another feature of the McLouth sediments that must have an important effect on the movements of gas and water is the tendency toward lateral variation in lithology and the intergradation between different lithologic types. The McLouth reservoir furnishes several examples of sandy zones that grade laterally from productive sandstone to nonproductive beds of sandy siltstone or shale containing only thin layers of argillaceous sandstone. Furthermore, the degree of cementation of the sandstone beds shows much lateral variation. Thus, lateral trends from permeable to nonpermeable rocks are common.

FOREST CITY WELL

Table 3 is a log of the basal 210-foot thickness of the Cherokee in the diamond drill hole on the W. F. Davis farm near Forest City, Missouri. This partial log, a result of the examination of cores, was taken from the report on the geology of northwestern Missouri by McQueen and Greene (1938). The sandstone and associated beds in the lower 119-foot section of this log have much in common with the McLouth sand and are believed to be its correlative. The two asterisks in table 3 mark the point believed to be the equivalent of the top of the McLouth sand. The dark, argillaceous, fossiliferous limestone reference bed of the McLouth field also is represented in this well. The greater thickness of the McLouth sand and of the interval between the top of the McLouth and the base of the limestone reference bed in this well, as compared with thicknesses in wells of the McLouth field, probably is due to the fact that the Forest City well is in a structurally deeper part of the Forest City basin where the entire Cherokee section is thicker and where differential subsidence was greater.

A notable feature of the McLouth sand in the Forest City well, similarly as in the McLouth field, is the abundance of carbonized wood and other plant remains, spores, and leaf imprints, and the generally carbonaceous character of the sediments. The presence in the Forest City well of linguloid shells and conodonts in black shale is significant of similar environmental conditions. Other features of the basal Cherokee of the Forest City well that indicate the similarity of the Kansas and Missouri sequences include

TABLE 3. *Log of the lower part of the Cherokee shale in the diamond drill hole on W. F. Davis farm, sec. 4, T. 59 N., R. 38 W., Forest City, Holt county, Missouri.*

(From report by McQueen and Greene, 1938, p. 174.)

Description of lithologic units	Thickness feet	Thickness inches	Depth feet	Depth inches
			1,403	
*Limestone, dark, argillaceous (calcareous shale to 1,412). Contains some shells	22	3	1,425	3
Sandstone; contains much woody material and large brown spores	9	9	1,435	
Shale, black	5		1,440	
Shale, gray, badly slacked. Some pseudo-oölites of siderite and plant fossils	26		1,466	
Shale, black, thin-bedded, some shells; much carbonized wood. From 1,465½ feet to 1,474½ feet very shaly coal. Pyritiferous badly slacked. Some sandy shale, black toward base	22	8	1,488	8
**Sandstone, tan, medium coarse-grained, plant fragments carbonized	1	9	1,490	5
Interbedded sandstone and darker gray shale. Sandstone is white, fine-grained, with glauconite, mica, and clay particles. Shale is mica-bearing and fissile	3	1	1,493	6
Shale, gray, badly slacked, with carbonized plant remains	1	10	1,495	4
Sandstone with interbedded shale and clay-filled cavities. Many plant remains, carbonized wood. Some siderite cement	11	2	1,506	6
Shale, dark gray to black with fossil plants, some linguloid shells, conodonts, and spores	11	8	1,518	2
Sandstone, fine-grained, with mica and plant remains; brown spores. Becomes shaly and more fine-grained with depth	6	10	1,525	
Grades into shale, gray, micaceous with some sand, spores, woody fragments	5		1,530	
Clay, soft, gray, with plant fossils, leaf imprints	4	6	1,534	6
Interbedded shale (micaceous), and sandstone, thin layers, with carbonized wood and plant remains, spores. Sandstone from 1,441 feet 10 inches to 1,442 feet 6 inches	21		1,555	6
Sand, fine-grained, irregularly bedded with cross-bedded appearance. Many plant remains	1	8	1,557	2
Shale, black, carbonaceous; some linguloid shells	2	10	1,560	

TABLE 3. *Log of the lower part of the Cherokee shale, concluded*

Clay shale, with leaf imprints. Irregular beds	5	1,565
Shale, black and dark gray, carbonaceous. Many plant remains. Sandy, conglomeratic at 1,580 feet to 1,582 feet. Sandy at 1,586½ feet to 1,587½ feet. Large brown spores. Some thin sand beds in lower 10 feet	48	1,613
Top of Mississippian rocks		

*Probably the correlative of the dark, argillaceous, fossiliferous marine limestone occurring approximately 20 feet above the top of the McLouth sand in the McLouth field.

** Probably approximately correlative with the top of the McLouth sand in the McLouth field.

the assemblage of lithologic types of the McLouth, as described in the present report, the presence of siderite cement, the interbedding and intergradation of sandstone and shale, and the conglomeratic character of certain beds.

CHARACTER OF SANDSTONE BEDS

The constituents of the sandstone beds of the McLouth reservoir have been determined by petrographic study of thin sections of shot fragments and by binocular microscopic examination of cuttings. These constituents may be grouped into three general categories: (1) detrital grains mostly of sand size, (2) minerals precipitated in place, primary, almost contemporaneous, or formed during later diagenesis, and (3) material of the clay "paste," which in the argillaceous sandstones partially or completely fills the interstices between the sand grains or forms a matrix in which the grains are set.

The detrital grains consist predominantly of quartz sand. Accessory detrital constituents comprise grains of feldspar, biotite, muscovite, and chert; heavy minerals, including grains of zircon, leucoxene, ilmenite, magnetite, and tourmaline; rock fragments through sand and pebble size composed of locally derived Cherokee siltstone and clay; and carbonized fragments and comminuted particles of land plants. Part of this detrital material, including the quartz, feldspar, biotite, muscovite, and heavy minerals, probably was derived from regions beyond the boundaries of the Forest City basin and was carried some distance to the area of McLouth deposition; whereas other constituents of the sandstone beds, including fragments of siltstone and clay and remains of land plants, probably were of local derivation and carried but a relatively short distance. Grains of detrital chert in the sands are common only at the base of the McLouth sand and probably were derived from residual material by weathering of cherty Mississippian limestones exposed in the Forest City basin region.

Quartz constitutes more than 95 percent of the detrital grains in sandstone beds of the McLouth sand. The grains vary considerably in average size and degree of sorting. Most of the sands show poor or only fair sorting and consist predominantly of fine sand (⅛ - ¼ mm) with admixtures of very fine grains (1/16 - ⅛ mm), medium grains (¼ - ½ mm), and locally contain quartz granules (2 - 4 mm) having irregular outlines and highly frosted surfaces. In samples from a few wells quartz sands having grains of two dimensions (grain-size distributions) were noted, a typical example being a very fine to fine sand containing an abundance of coarse sand grains ranging from ½ to 1 mm in mean diameter.

In general, very fine and fine sand grains are angular to subangular. Thin section studies indicate that in certain beds the angularity is due in part to secondary quartz growths. The coarse and very coarse sand grains, as a rule, have subangular or subrounded outlines, although a few are well-rounded; in the argillaceous sandstones this tendency toward roundness for the most part has been retained. In the nonargillaceous beds, however, the pore spaces have been partly filled with secondary quartz growths on the detrital grains, and angularity thus has been imposed, but the original subrounded or rounded outlines commonly may be detected by thin-section study. Thin sections reveal some medium and coarse grains whose outlines are in part angular and in part subround or round. They probably represent broken fragments of larger rounded grains.

There are several miscellaneous features of the quartz sand grains that are worth noting. Replacement of the margins by authigenic sericite, resulting in a serrated appearance, was found in several quartz grains. Most of the grains have few inclusions, and uniform extinction under crossed nicols probably represents normal igneous quartz. A large number, however, have marked undulose extinction and strain shadows and may represent metamorphic quartz; this conclusion is strengthened by the presence of a few subangular quartzite fragments of coarse sand size. In most of the sandstone beds the coarse sand grains show in thin section

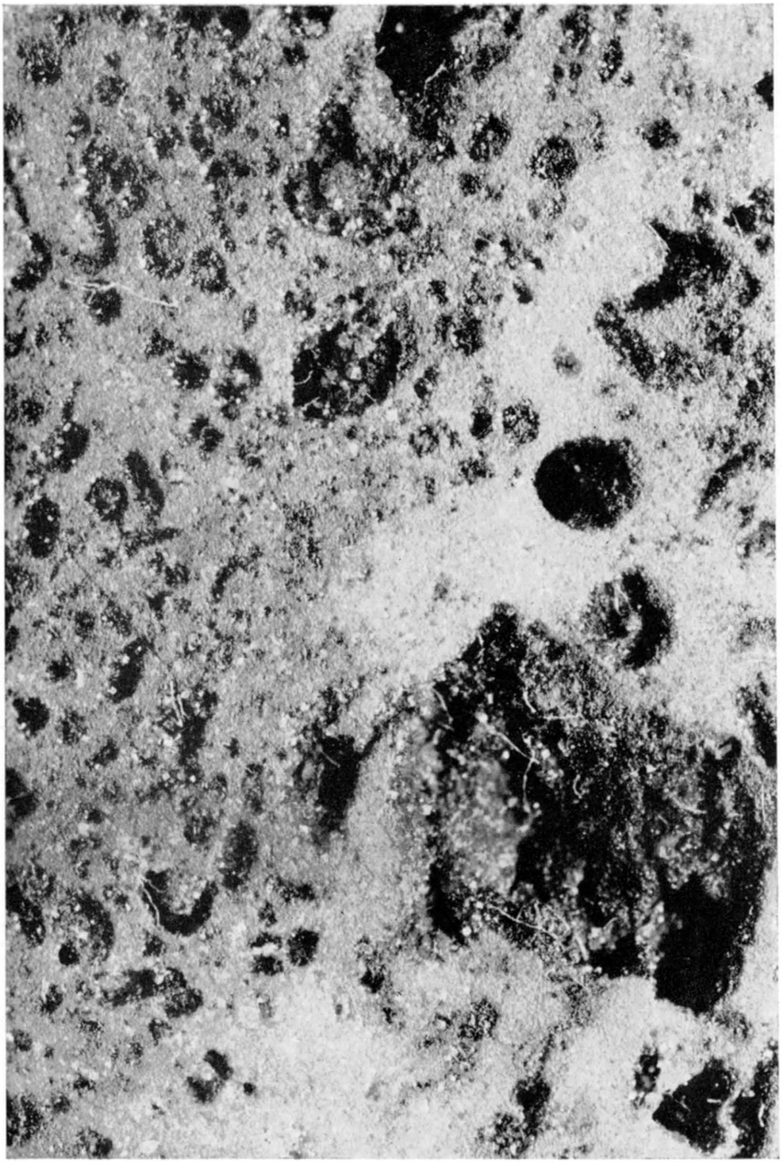


PLATE 5. Photograph of core (X 10) from dolomite yielding oil in undifferentiated Burlington and Keokuk limestones of Mississippian age. The core was taken at 1,595 feet in the J. B. Apperson et al. (T. W. Sowell) No. 1 Bower well, in the SE¼ NE¼ sec. 5, T. 10 S., R. 20 E.

The rock was originally a conglomerate of calcareous fossil fragments including crinoid stems, imbedded in a matrix of sucrose dolomite. The solution of the more soluble limestone fragments during a period of weathering left a porous mass of irregularly distributed cavities in the dolomite which constitutes the reservoir in which oil has accumulated.

at least a slight tendency toward preferred dimensional orientation, and in a sample from one of the very coarse basal sandstone beds preferred orientation was prominent.

Feldspar, comprising microcline and orthoclase, constitutes on the average about one-half of 1 per cent of the detrital grains seen in thin sections. The feldspar grains range from very fine to medium sand size. The larger detrital mica flakes, including both muscovite and biotite, are distinct from the minute mica flakes and shreds of the clay "paste" and average approximately 1 percent of the detrital material. They are partly concentrated in irregular laminae probably parallel to the stratification planes. Most of the biotite flakes are chloritized. The flakes of mica tend to be ragged in outline, and the larger ones commonly are bent around quartz grains.

Zircon and leucoxene are the most abundant heavy minerals in the sandstone beds of the McLouth sand. Other detrital species noted include magnetite, tourmaline, and ilmenite which usually is coated with a white crust of leucoxene. Taken together, detrital heavy minerals average only a fraction of 1 percent of the sands. Except for refractured grains, they commonly are well rounded and range in grain size from coarse silt through very fine and fine sand.

Rock fragments of local derivation are present in minor quantity in most argillaceous sandstone beds, and in several beds were found to constitute a major detrital constituent. They are composed largely of siltstone and clay, rock types indigenous to the McLouth sand, and range in size from 0.4 mm (mean diameter) through the coarse sand, granule, and pebble size grades. Locally, the larger fragments form breccia and conglomerate phases, the character and origin of which are described in a later section of the present report. That these siltstone and clay fragments were derived locally during McLouth time is indicated by the following facts: (1) they are the same rock types that occur elsewhere as beds in the McLouth, (2) they are for the most part angular to subangular, and (3) they consist of rather easily disintegrable material that could withstand transportation only over a very short distance. These fragments probably were derived from locally disrupted beds of partially lithified siltstone and cohesive clay.

Minerals of the second category, those precipitated in place,

PLATE 6. Photograph of core, sawed in half, (X 1¼) from dolomite yielding oil in undifferentiated Burlington and Keokuk limestones of Mississippian age. The core was taken at 1,595 feet in J. B. Apperson et al. (T. W. Sowell) No. 1 Bower well, in the SE¼ NE¼ sec. 5, T. 10 S., R. 20 E.

The illustration shows the distribution of cavities in the porous dolomite due to the solution of crinoid stems and fragments of other fossils, and also the irregular saturation by oil(dark areas) of the porous rock. This core probably does not represent the zone most productive of oil.

comprise quartz, siderite, calcite, dolomite, and pyrite, of which quartz and siderite are by far the most abundant. Quartz occurs in the form of secondary growths and as interstitial cement. Siderite occurs both as interstitial cement locally in sandstone beds and as a prominent constituent of certain of the argillaceous sandstone beds, in which it takes the form of irregular thin lenses and laminae and is associated with carbonaceous material. Thin-section studies have shown that the siderite lenses and laminae commonly contain siderite spherulites in the form of complete spheroids and sectors of spheres; these also occur outside of the lenses and laminae. The spherulites, averaging ⅛ - ¼ mm in diameter, consist of a radiate arrangement of crystal fibers about a common center and display a black extinction cross between crossed nicols. Some of the spherulites are separated, whereas others occur in clusters, the individual growths of which coalesce and are mutually interferent. Many of the spherulites completely enclose fine quartz grains or partially envelop large grains of sand size around part of which they have grown. Thus, it is evident that they were formed after deposition of the detrital quartz. Inasmuch as the siderite lenses and laminae constitute a large part of several of the argillaceous sandstone beds and are not merely interstitial, they are believed to have been primary or almost primary and laid down during intervals of quiet water between the times of sandstone deposition.

Calcite and dolomite occur in very minor quantities, constituting less than one-tenth of 1 percent in most sandstone beds, but in a few beds calcite serves as a minor cementing substance, constituting less than 1 percent of the rock mass. Where it is not in the form of cement, calcite occurs as tiny lenses and scattered irregular patches. Dolomite is limited in its mode of occurence to minute idiomorphic rhombs scattered at random through the rock mass. These carbonate minerals are authigenic and probably originated during penecontemporaneous or later diagenesis. Authigenic pyrite also is present in minor quantity, generally less than one-tenth of 1 percent, and is in the form of tiny cubes, pyritohedrons, and irregular patches. It is limited for the most part to sandstones containing carbonaceous material.

The clay "paste" of the argillaceous sandstone beds is composed of minute flakes and shreds of biotite, chlorite, and sericite, together with clay minerals and fine quartz silt. Whether the fine

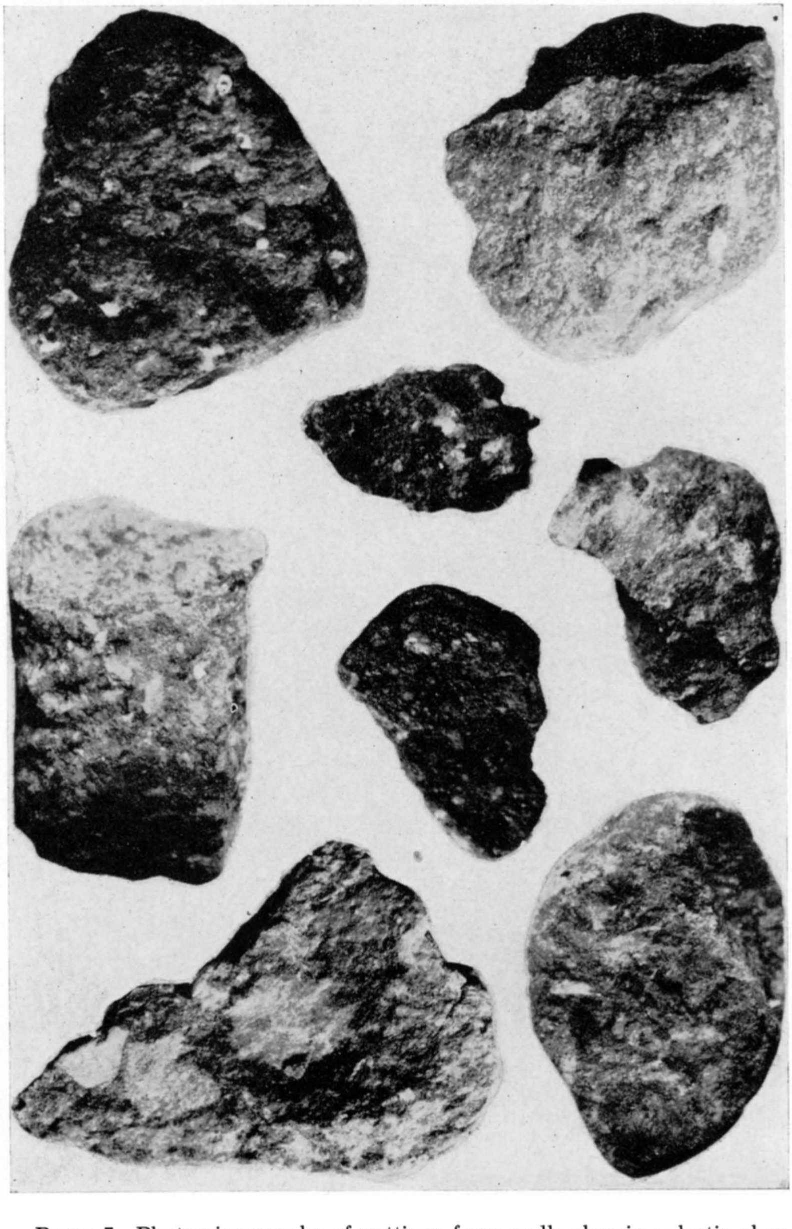


PLATE 7. Photomicrographs of cuttings from wells showing clastic character of black shale cave deposits in Mississippian limestones (X 10). The light-colored particles include grains of green shale, light-colored shale, particles of chert, and sand.

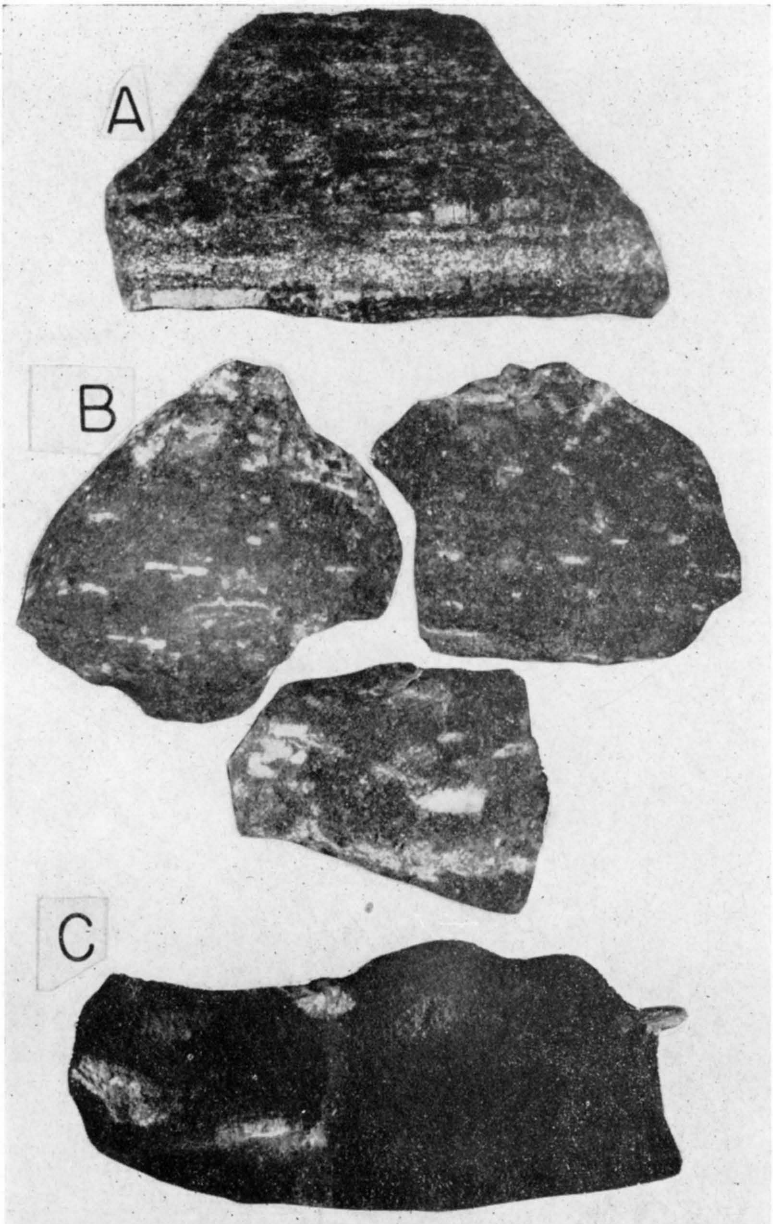


PLATE 8. Photographs of chunk samples of McLouth sand shot from wells. A, Oil-stained highly argillaceous sandstone with thin layers and laminae of silty clay (X 1½). B, Oil-stained argillaceous sandstone containing small pebbles and granules of silty clay (X 1½). C,Oil-saturated sandstone containing clay pebbles (X 1).

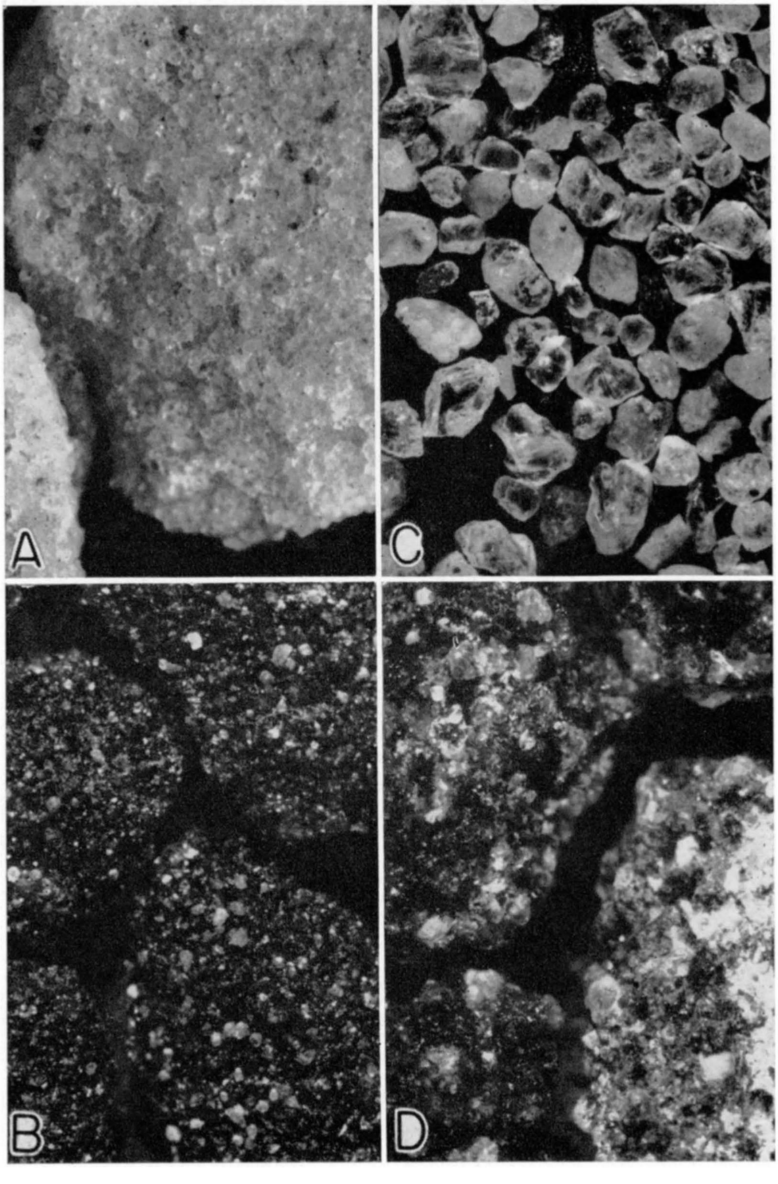


PLATE 9. Photomicrographs (X 12) of cable-tool cuttings of wells showing lithologic types represented in the McLouth sand. A, Fine-grained quartzitic sandstone. B, Oil-saturated fine sandstone. C, Quartz sand from poorly cemented coarse sandstone. D, Oil-stained poorly sorted fine to medium-grained argillaceous sandstone.

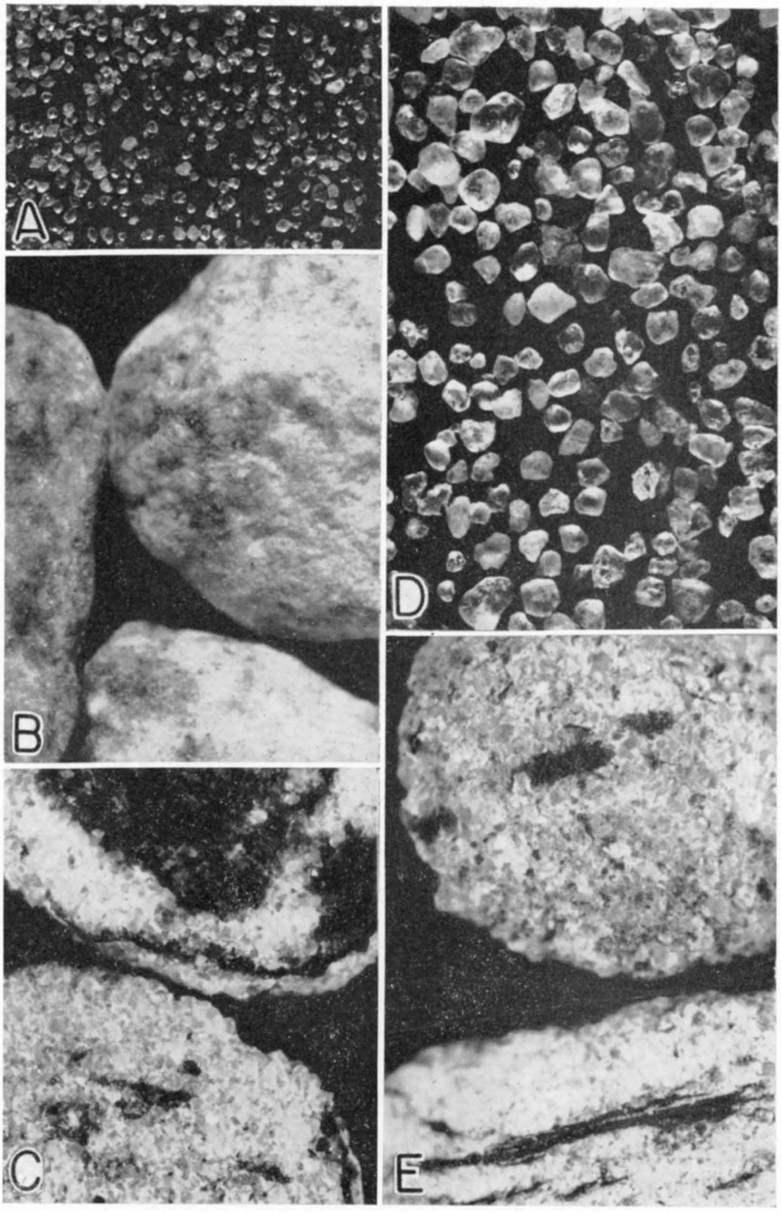


PLATE 10. Photomicrographs (X 12) of cable-tool cuttings showing lithologic types represented in the McLouth sand.

A, Well-sorted quartz sand from poorly cemented very fine sandstone. B, Slightly oil-stained siltstone. C, Argillaceous fine sandstone with coaly laminae and carbonaceous particles. D, Quartz sand from poorly cemented medium-grained sandstone. E, Argillaceous very fine sandstone with coaly laminae and carbonaceous laminae.

"hydromica" flakes are predominantly sericite or illite, a clay mineral, could not be determined. In argillaceous sandstones in which the quartz sand grains are for the most part in mutual contact the paste is interstitial and constitutes 10 to 15 percent of the rock mass. In some beds, however, the sand grains tend to be separated and are set in a matrix of clay paste, this material being partially concentrated in thin laminae and lenses.

CEMENTATION

The sandstone and siltstone beds of the McLouth sand vary greatly in degree of cementation and kind of cement. Silica in the form of quartz is the dominant cement; siderite, calcite or dolomite, and pyrite also are represented. In some beds, quartz cement is combined with siderite or a minor quantity of calcareous cement. Locally, siderite or pyrite is the sole cementing substance of sandstone beds, but in no case was calcite or dolomite found to constitute the dominant cement, calcareous material being present only in minor quantity in certain beds. This prevalence of silica cement and general lack of calcareous cement is a notable feature of McLouth sediments. In sandstone beds containing siderite cement, siderite spherulites commonly are present locally.

The degree of cementation in the sandstone and siltstone beds of McLouth sand varies from a poorly cemented condition, in which the rock is easily disintegrated to loose grains by drilling, to a tightly cemented condition, in which case only rock fragments are found in the cuttings. In most of the argillaceous sandstone beds relatively little precipitated cement is present, the sand grains being bound together largely by the clay paste.

WELL-SORTED POROUS SANDSTONE

Well-sorted porous sandstone occurs locally in the McLouth sand and grades laterally to argillaceous sandstone or quartzitic sandstone. It has intermediate to high porosity and permeability and yields gas, oil, or water in wells of the McLouth field. Off the flanks of the anticlines, wells that penetrated this type of sandstone in the McLouth sand filled with water. Examinations of well samples indicate that oil wells in the McLouth sand commonly produce from this type of rocks, and it is probable that the gas wells with large initial open flow and pressure derive gas from similar well-sorted porous sandstone.

Unlike the argillaceous sandstone variety, which generally contains a significant quantity of micas, siderite, and carbonaceous material as well as clay and silt, this type of sandstone consists almost entirely of quartz sand grains that tend to be of uniform grain-size. Accessory detrital minerals of the sand include feldspar, zircon, leucoxene, and others mentioned in the section on *Character of sandstone beds.* Although different beds are well-sorted, they show variation in grain-size from very fine sand to coarse sand. The sand grains in the fine and very fine sandstones tend to show some degree of rounding, but in many cases the subangular to subround condition has been masked by an imposed angularity produced by precipitation of secondary quartz growths in optical continuity on the surfaces of quartz grains after their deposition. The original rounded outlines of many grains can be detected in thin sections of shot fragments of the rock.

The porosity of this type of sandstone is dependent on the degree of cementation. In places, the rock evidently is poorly cemented, as indicated by the fact that it is completely broken up to loose grains during drilling. Elsewhere, it is fairly well cemented, and the well cuttings consist of aggregates of grains cemented by quartz. Commonly, the quartz cement is precipitated in the form of secondary growths. The name *quartzitic sandstone* is applied to that variety of sandstone which is rather completely cemented by quartz and therefore has low porosity and permeability. Locally and rarely the sandstone is tightly cemented by siderite or pyrite rather than quartz, in which case the terms *sideritic sandstone* or *pyritiferous sandstone* are applied.

Well-sorted porous sandstone varies greatly in hydrocarbon content, ranging from slightly oil-stained sands to sands that are partly or completely saturated with oil. In a few wells the sandstone was found to be impregnated with tar or asphaltic material which acts as a cement and greatly reduces the porosity and permeability; this kind of rock is termed *asphaltic sandstone.* In most of the oil-saturated sandstones the quartz sand grains show marked development of secondary growths; this suggests that the high porosity which permitted secondary growths also allowed the infiltration of oil.

ARGILLACEOUS SANDSTONE

In the argillaceous sandstone, the most common variety of sandstone in the McLouth sand, the pores between the quartz sand grains are partly to completely filled with silt and clay, and the rock thus is poorly sorted as to grain size. The fine interstitial or matrix material is termed clay "paste," as previously described, and may constitute as much as 30 to 35 percent of the rock mass. Argillaceous sandstone beds have intermediate to low porosity and permeability and usually do not yield water or oil in wells of the McLouth field. In numerous wells, however, this variety of sandstone yields gas, but the wells tend to have small open flows compared with those producing from well-sorted porous sandstone. In many wells, argillaceous sandstone, although unproductive, was oil-stained or even saturated with dead oil.

Argillaceous sandstone commonly contains flakes of mica (muscovite and biotite) and carbonaceous material. Carbonaceous material occurs in the form of scattered particles, representing comminuted plant remains, thin coaly laminae roughly parallel to the stratification, and carbonized remains of leaves, twigs, and other plant structures. Described in the section on *Character of sandstone beds* are other constituents, including feldspar, heavy minerals, and fragments of siltstone and clay, as well as siderite, that occurs in various forms as a prominent constituent of some argillaceous sandstones.

Argillaceous sandstone varies in grain size from very fine to very coarse sand. In some beds the quartz sand grains show fair sorting, although they were deposited together with silt and clay, but in other beds the sand grains are poorly sorted and heterogeneous in size. The grains of the fine and very fine sandstones tend to be angular; those of the medium and coarse sandstones commonly are subangular or subround. Unlike the well-sorted porous sandstones, in which the roundness of the coarse grains tends to be masked by secondary growths, the argillaceous sandstones maintain the rounded character of the grains and usually do not show secondary growths.

Certain beds of argillaceous sandstone evidently are poorly cemented, as indicated by the fact that the rock is partly or largely broken to loose grains during drilling. Most beds, however, are fairly well cemented by silica and clay paste, in which case well cuttings consist of fragments of the rock. The term *quartzitic argillaceous sandstone* is applied to the variety that is rather completely cemented by silica and is hard and resistant.

Argillaceous sandstone quite commonly is interbedded with or contains thin layers of siltstone, shale, clay, or even coal, and the contacts between layers tend to be sharp. Zones of argillaceous sandstone in the McLouth sand have been found to grade laterally to sandy siltstone, micaceous silty shale, or clay shale.

SILTSTONE

The beds of siltstone in the McLouth sand usually are nearly white, light buff, or very light gray. The silt particles are composed largely of quartz, although mica flakes are present in small quantities in most siltstones and are abundant in a few. Some siltstones contain sand grains and are related to and intergradational with argillaceous sandstone. In the variety termed *clayey siltstone,* the silt particles are set in a matrix of clay. The well-sorted siltstone variety seems to be somewhat porous and, where associated with oil sands, commonly is partly to completely stained or saturated with oil.

Siltstone beds that are hard and resistant as a result of being tightly cemented with silica are termed *siliceous siltstone* and are analogous to the quartzitic sandstone variety. The term *sideritic siltstone* is employed for siltstone beds partly or locally cemented with siderite. Siltstone beds very commonly contain abundant reddish-brown siderite spherulites about 1 mm in mean diameter.

Siltstone is interbedded with and is vertically and laterally intergradational with argillaceous sandstone and silty clay shale. Beds designated as siltstone are believed to be massive; well cuttings ordinarily do not give any indication of their having shaly structure.

MASSIVE CLAY

Beds designated as massive clay are common in the McLouth sand. They differ from clay shale in having a massive rather than a shaly or laminated structure. Furthermore, they do not have the microscopic micaceous appearance of most shales, a feature caused by the presence in shales of illite, the micalike clay mineral. Well cuttings from clay beds usually have conchoidal fracture and "slickenside" surfaces, features characteristic of fire clays. It is probable that most of the beds of massive clay in the McLouth belong in the category known to ceramists as *fire clay.* Some of these beds probably represent the underclays of thin coal streaks in the McLouth.

The clays vary in color from bed to bed but ordinarily they are some shade of light gray—very light neutral gray, light greenish-gray, buff-gray, or light brownish-gray. Some beds have a higher carbonaceous content and are dark gray, and a few are black. Carbonized plant remains are common. Some of the clays contain reddish-brown siderite spherulites. Beds of well-sorted or homogeneous clay are common in the McLouth sand, but the silty clay and sandy clay varieties are rare. In sandy clay the sand grains are disseminated in a clay matrix.

SHALE

The variety of shale designated *micaceous silty shale* is quite common in the McLouth sand. It is diagnostic of certain zones and has marked lateral persistence. It is composed dominantly of quartz-mica silt together with clay and carbonaceous material, and commonly has a laminated appearance due to the alternation of light-gray and dark-gray laminae and to the presence of microscopic partings composed of mica flakes and carbonaceous particles along which the rock tends to break.

Clay shale is the most abundant rock in the McLouth sand. It varies from silty clay shale to uniformly fine clay shale and is light to dark gray to black, depending on the carbonaceous content. Carbonaceous black shale is common. The micalike clay mineral *illite* is present and tends to give the shale a very fine micaceous appearance. Reddish-brown siderite spherulites are present in certain of the light-gray shale beds, and in some of the dark-gray and black shales pyrite occurs as disseminated grains or as clusters of crystals. Mica flakes are common, especially in the silty clay shales. Carbonized fragments of land plants and thin coaly laminae occur abundantly in certain of the clay shale beds.

CLAY IRONSTONE

Clay ironstone occurs in the form of thin beds that are uncommon but not rare in the McLouth sand. The clay ironstone is fine-grained, compact, and reddish-brown, and is composed of variable proportions of siderite, clay, silica, and calcium carbonate; carbonaceous material commonly is present. Of rare occurrence in the McLouth are thin layers of *red sideritic limestone,* a variety of clay ironstone which contains less siderite and more calcium carbonate and effervesces in acid. It leaves an insoluble residue of clay and silica, colored red by finely divided siderite.

COAL

Thin layers of coal occur locally at different horizons in the McLouth sand and are associated with massive clay, clay shale, siltstone, and clay ironstone. It is probable that with increase of clay content, the coals grade into black clay rock which is somewhat similar to black shale but contains so much carbonaceous material as to nearly constitute coal. This black clay was noted in several wells.

INTRAFORMATIONAL BRECCIA

Large shot fragments of McLouth sand obtained from several wells indicate that beds of argillaceous sandstone contain intraformational breccia phases. These consist of angular pebbles of clay and silty clay shale set in a matrix of argillaceous sandstone. The term *breccia* is not strictly applicable to this kind of rock inasmuch as the pebbles tend to be separated from one another in the sandstone matrix and in some specimens they are rather widely spaced. Thus, this phenomenon is considered to represent an intraformational breccia phase of argillaceous sandstone. Whether this breccia phase is widespread or only of local development was not determined, but it is represented in most of the shot fragments of argillaceous sandstone.

These breccias are truly intraformational in character inasmuch as the pebbles obviously once were part of continuous clay or silt layers that were broken up, reworked, and redeposited in a sandstone matrix. Argillaceous sandstone commonly contains thin layers of clay, siltstone, and shale. In some specimens these layers are undisturbed and unbroken, whereas in others they have been broken up to form breccias, the origin and depositional environment of which is described in the section on *Origin of the McLouth sand.*

The pebbles range in mean diameter from 4 to 20 mm or more. The silty shale pebbles are distinctly tabular in shape and tend to show preferred orientation which is probably parallel to the surface of deposition. The massive clay pebbles are less tabular and more spheroidal or irregular in shape.

THICKNESS

The top of the McLouth sand is a conformable surface and a reliable key horizon, but the top of Mississippian rocks was a deformed and eroded surface when the McLouth sand was deposited. As a result, the McLouth sand has an irregular thickness which ranges from 15 to 95 feet in the McLouth field, as shown by the isopachous map (fig. 14). This variation in thickness is due to two factors: (1) the depositional filling of topographic lows caused by erosion and deformation of the surface of the Mississippian rocks prior to McLouth deposition, and (2) gentle folding and faulting during McLouth time which resulted in local differential subsidence and differential accumulation of McLouth sediments.

It is probable that the greater part of the deformation of the eroded Mississippian surface occurred before the beginning of McLouth sedimentation inasmuch as it was preceded by a long period during which the whole region was re-elevated, important structural movements took place, and the region was again lowered to or near sea level. Differential structural movements, however, continued during deposition of the McLouth sand, but the local deformation was probably so gentle that sedimentation kept pace with subsidence without giving much if any relief to the surface of sedimentation. The irregularities of the surface of the Mississippian are in part residual drainage channels on the peneplaned surface and in part are due to erosion that took place after the re-elevation of the region.

It is difficult to isolate and differentiate the results of erosion and deformation on the old pre-Pennsylvanian surface. In some places the influence of one or the other was dominant, but in most areas both are reflected in the thickness of the McLouth sand. In some parts of the field, however, the character and thickness of the underlying Mississippian rocks provide a means of differentiating their influence.

Three Mississippian formations, the St. Louis, Spergen, and Warsaw limestones, are present at the top of the Mississippian in the area of the McLouth field. The St. Louis limestone in the eastern part of the area was beveled toward the west. Its featheredge is indicated on the map (fig. 14) by the line indicating the boundary between it and the underlying Spergen dolomite, which is the uppermost Mississippian formation to the west and throughout the greater part of the McLouth field. The Warsaw limestone, which underlies the Spergen dolomite, was found at the top of the Mississippian in two wells: (1) the Jackson No. 1 Sheldon well (well 9), in the NE¼ SE¼ sec. 14, T. 9 S., R. 19 E., in which the McLouth sand is 87 feet thick, and (2) the V-8 Drilling Company No. 3 McLeod well (well 166), in the SE¼ NW¼ SE¼ sec. 5, T. 10 S., R. 20 E., in which the sand is 51 feet thick. Prior to Cherokee sedimentation, the surface of the beveled St. Louis, Spergen, and Warsaw formations dipped gently westward.

The local variations in thickness of the upper formations of the Mississippian rocks are generally low. The Spergen is thin on the crest of the McLouth anticline and generally thicker on the flanks. Irrespective of the thickness of the McLouth sand, the thinning of Mississippian strata on anticlinal crests indicates pre-Pennsylvanian beveling of pre-Pennsylvanian anticlines. Thinning of the Spergen rocks is not marked on the crest of the North McLouth anticline, probably because the structural relief of this anticline was low.

In places where the McLouth sand is thin and also overlies a thin section of Spergen limestone on a structural crest, the thinning of the McLouth is probably due to its deposition on an anticlinal surface that was rejuvenated before the deposition of the sand. An example of this condition occurs in the Young and Longwell No. 2 McLeod well, in the NW¼ NW¼ SW¼ sec. 4, T. 10 S., R. 20 E., on the crest of the McLouth anticline; in this well the McLouth sand, which is only 39 feet thick, overlies Spergen limestone only 24 feet thick. Similarly, where thick deposits of McLouth sand overlie thick deposits of upper Mississippian formations, synclinal movements or faults of pre-McLouth age are suggested, as in the Sherrod et al. No. 1 Momyer well, in the NW¼ SE¼ sec. 4, T. 10 S., R. 20 E., which penetrated 75 feet of McLouth sand overlying 40 feet of Spergen on the down-dropped side of a fault. An abnormal thickness of Spergen or upper Mississippian rocks overlain by a thin section of McLouth sand probably indicates a topographic high on the old surface. Such a condition occurs in the Sifers No. 1 Leonhard well, in the SE¼ SW¼ sec. 9, T. 10 S., R. 19 E., where the McLouth sand, 60 feet thick, overlies an outlier of St. Louis limestone at least 36 feet thick.

There are some areas where the Spergen is thin or absent and where the McLouth sand, even on structurally high areas, is thick. This condition indicates erosional relief. Thus, in the V-8 Drilling Company No. 3 McLeod well, in the SE¼ NW¼ SE¼ sec. 5, T. 10 S., R. 20 E., on the McLouth dome, the Warsaw limestone was exposed on the Mississippian surface and the McLouth sand is 51 feet thick. This condition is interpreted as being due to pre-Pennsylvanian erosion, in this case partly counteracted by pre-Pennsylvanian structural elevation.

The isopachous map of the McLouth sand (fig. 14) illustrates all phases of thickness variations caused by depositional leveling of the surface of the Mississippian. In general, there is an inverse relation between the thickness of the McLouth sand and the thickness of the Spergen limestone, which indicates in most cases, erosion of the Mississippian. On the McLouth anticline, in the Stark No. 1 Ragan well in the NW¼ NE¼ sec. 4, T. 10 S., R. 20 E., the McLouth sand is 29 feet thick and the underlying Spergen is 42 feet thick. Approximately half a mile to the west, in the McLaughlin No. 1 fee well in the NE¼ NW¼ sec. 4, the McLouth thickens to 49 feet and the Spergen thins to 28 feet. Anomalies in the thickness relations in two wells farther west in the NE¼ sec. 5, where the McLouth sand is 51 and 57 feet thick and the Spergen is 3 and 8 feet thick, respectively, are caused by differential deformation of the eroded Mississippian surface and differential accumulation of McLouth beds during McLouth time.

The thickness contours on the structurally high western side of the McLouth anticline indicate the presence of an erosional trough in Mississippian rocks which extends from secs. 7 and 8, T. 10 S., R. 20 E., northward through sec. 5 and into the northwestern corner of sec. 4. In the deeper parts of this trough the Spergen limestone ranges from 3 to 15 feet and averages only about 8 feet in thickness in nine wells, but it is absent in the V-8 Drilling Company No. 3 McLeod well, in the SE¼ NW¼ sec. 5. The overlying McLouth sand in these wells usually exceeds 50 feet in thickness. The McLouth is only 33 feet thick, however, in two wells in the E½ SE¼ sec. 5. These wells evidently are not in the erosional trough because the Spergen is only 8 feet thick and there is no compensating thickening of the McLouth sand. These wells are on the McLouth anticline. Therefore, thinness of the McLouth sand probably is due to the influence of local structural movements before or during McLouth time. Northward and eastward from the erosional trough, the Spergen thickens greatly and the McLouth sand thins to less than 30 feet; the McLouth thins in a westward direction also where, in the Richard No. 1 Sherman well in the NE¼ NE¼ sec. 6, T. 10 S., R. 20 E., it is only 32 feet thick.

Another example of the inverse relations of the thickness of the McLouth sand and the Spergen dolomite occurs in a structurally low area in the northwestern part of the isopachous map. The Spergen is 45 feet thick and the McLouth is 48 feet thick in a well in the SE¼ NE¼ sec. 24, T. 9 S., R. 19 E. About 1½ miles to the northwest, in the NE¼ SE¼ sec. 14, still lower in the structural basin, drilling encountered Warsaw limestone at the base of Pennsylvanian rocks, the Spergen evidently having been completely removed by erosion; here the McLouth has increased in thickness to 87 feet replacing the eroded Spergen. Other examples of this relationship are found on the North McLouth anticline.

The isopachous map furnishes several examples of variation in thickness of the McLouth sand caused by gentle folding and by faulting before and during McLouth sedimentation. Movements along the fault zone on the south side of the McLouth anticline in secs. 3 and 4, T. 10 S., R. 20 E. were evidently important in controlling the thickness of the McLouth sand (fault profile, pl. 4, and structure contour map of the top of the McLouth sand, fig. 8). In two wells in the N½ SE¼ sec. 4, on the downthrow side of the fault, the McLouth sand is 75 and 89 feet thick. Evidence that the fault was active during McLouth time lies in the fact that the upper zones of the McLouth carry across the fault but thicken on its downthrow side. Approximatley half a mile in a west-northwest direction from these wells, there is a well on the upthrow side of the fault (cen. W½ sec. 4) in which the McLouth sand is only 30 feet thick. This marked difference in thickness could not have been caused solely by filling of an area of erosional relief on Mississippian rocks because the Spergen dolomite is thicker on the downthrow side where the McLouth is thicker. Movement along the fault may have begun prior to McLouth sedimentation, in which case part of the 45 to 50 foot excess in thickness of the McLouth sand on the downthrow side was due to filling in of a topographic low along a fault scarp.

A similar condition exists on the north flank of the Ackerland pool in sec. 1, T. 10 S., R. 20 E. In a well in the SE¼ NW¼ sec. 1, the McLouth sand is 95 feet thick and is underlain by St. Louis limestone. The finding of St. Louis limestone at the top of Mississippian rocks in a well in which the McLouth is exceedingly thick is contrary to expectations, and the anomaly is increased by the fact that in structurally higher wells to the south the McLouth is 35 feet thick but still overlies the St. Louis limestone which has a maximum known thickness of 36 feet. The anomaly suggests the presence of a fault, which also is indicated by structure on the top of the McLouth sand (fig. 8).

The effect of gentle folding on the thickness of the McLouth sand is illustrated by wells on the North McLouth anticline treated in

TABLE 4.—*Relation of thickness of McLouth sand to structure*

Location of well in T. 9 S., R. 20 E.	Thickness of McLouth sand, feet	Altitude of top of McLouth sand, feet below sea level	Thickness of Spergen dolomite, feet
SW¼ SE¼ sec. 20	15	383	52
NE¼ SE¼ sec. 30	25	392	53
NW¼ NE¼ sec. 30	33	401	57

table 4. Inasmuch as the Spergen dolomite is of rather uniform thickness in these wells, the differences in thickness of the McLouth sand probably are the result of gentle folding during McLouth time rather than filling of erosional relief, for the several lithologic zones of the McLouth, which are thick in the structurally deeper wells, here carry across the structural high. In the second well in table 4, the top of the McLouth sand is 9 feet deeper and the McLouth is 10 feet thicker than in the first well; in the third well the top of the McLouth is 18 feet deeper and the McLouth is 18 feet thicker than in the first well. These observations lead to the conclusion that the structure shown by the top of the McLouth sand and its thicknesses are the result of structural movements that began before the close of McLouth deposition and were revived during later Pennsylvanian time, an assumption that is supported by evidence from other parts of the field.

The structure contour map of the top of the McLouth sand (fig. 8) shows a pronounced saddle between the McLouth anticline and the North McLouth anticline that extends northeastward from secs. 30 and 31 through parts of secs. 29 and 28, T. 9 S., R. 20 E. This structural saddle is represented on the isopachous map of the McLouth sand by a belt, trending in the same direction, in which the McLouth sand is up to 80 feet thicker than it is on the anticlines to the north and south.

Most of the producing wells of the McLouth field were not drilled completely through the McLouth sand, and the total thickness of the McLouth in them is not known. The actual thickness penetrated followed by a plus sign is shown on the isopachous map in some wells where the partial thicknesses are significant.

LITHOLOGIC ZONES

The subdivision of the McLouth sand into lithologic zones which, although showing lateral lithologic variation, may be traced throughout large parts of the field, has been made possible by the examination of cable-tool cuttings, usually taken at 5-foot or smaller intervals in the McLouth sand, and information from drillers logs. Sandy zones and shale zones alternate vertically in the McLouth. As shown by the block diagram (pl. 4), the McLouth contains four sandy zones, one or more of the upper three of which yield gas, oil, or water. They are designated as *sandy* zones because they are not everywhere represented by sandstone; locally, they consist of sandy siltstone or sandy shale or are represented by thin sandy laminae in beds of siltstone, shale, or clay. The four sandy zones are separated by three nonsandy zones composed of varying amounts of siltstone, clay, clay ironstone, coal, and several varieties of shale. Samples from the Sherrod and Workman No. 1 Seitz well, in the SW¼ NE¼ sec. 32, T. 10 S., R. 19 E., and the O'Dea No. 1 Borst well, in the SW¼ NE¼ sec. 1, T. 10 S., R. 20 E., indicate that in these wells the McLouth does not contain any beds of sandstone, the sandy zones being represented by thin sandy laminae in beds composed of fine clastic material. The distinguishable lithologic zones are designated from the bottom up by letters A to G.

The sandy zones of the McLouth are not shoestring sand bodies but are blanket deposits, although they wedge out and vary considerably in lithology within the McLouth field. The lowermost zone (A) is limited to the eastern part of the field and wedges out westward (pl. 4), whereas the second sandy zone from the bottom of the McLouth (C) is limited to the western and central parts of the field, where it produces gas, and pinches out eastward. The upper two sandy zones (E and G), which are separated by a thin shale zone, are present throughout the field; the top of the uppermost zone is the top of the McLouth sand, and provides a reliable key horizon for structure mapping. The intervening shale zones (B, D, and F) consist of shale, clay, and siltstone and are shown by solid black bands on the block diagram.

Detailed lithologic study and zonation of the McLouth make possible the lithologic interpolation between wells. This procedure is of potential value in guiding a drilling program. The well numbers used in the following description of lithologic zones refer to the well index numbers employed in the block diagram.

Zone A.—The lowermost subdivision of the McLouth sand, Zone A, is composed dominantly of argillaceous sandstone and is limited to the easternmost part of the field, where it overlies Mississippian rocks from which it is separated by an erosional uncon-

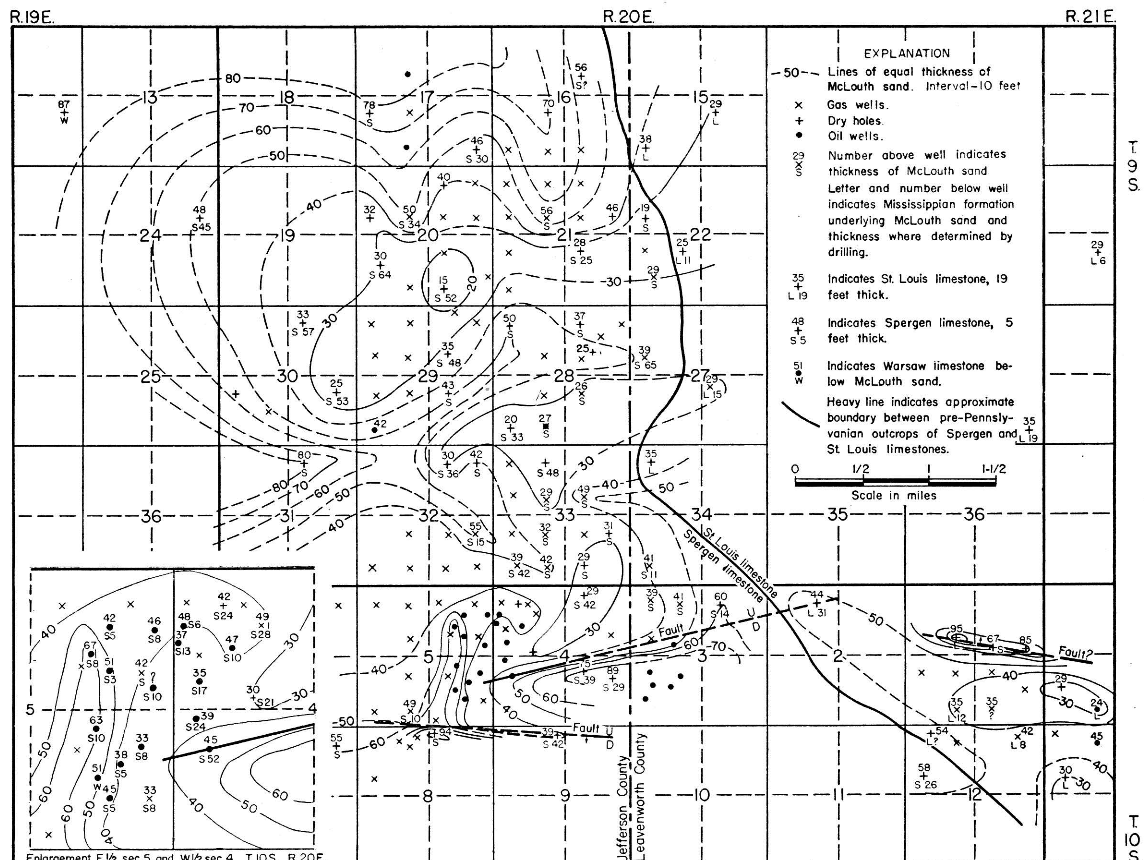


FIG. 14. Map of McLouth field showing variations in thickness of the McLouth sand by lines of equal thickness and the thickness of the underlying Mississippian formations where determined by drilling. Inset shows details in crowded area in E½ sec. 5 and W½ sec. 4, T. 10 S., R. 20 E.

formity. It was found in wells 105, 145, 181, 182, 183, and 194 (pl. 4) and in other wells not shown on the block diagram. This zone pinches out westward and is not present on the crests or flanks of the major anticlines on which the McLouth and North McLouth pools are situated. Where Zone A pinches out in a westward direction, the entire McLouth section tends to become thinner. This thinning is due in part to the wedging out of the basal sandstone zone. In well 194, in which the McLouth has a total thickness of 65 feet, Zone A is about 17 feet thick. This zone evidently pinches out westward from this well because in well 187 there is no basal sandstone and the McLouth totals only 46 feet. In well 183, the McLouth is 55 feet thick and Zone A is about 10 feet thick, whereas in well 186, approximately 2 miles to the southwest, the McLouth is only 18 feet thick, and the basal sandstone is absent. In wells 145 and 144, south of the fault on the south flank of the McLouth pool anticline, the McLouth sand is thick, 89 feet in well 145 and 75 feet in well 144. The difference in thickness of the McLouth in these wells is largely due to the fact that the basal sandstone is present in well 145 but is absent to the west in well 144, where black shale that commonly overlies Zone A rests directly on Mississippian rocks.

Zone A consists predominantly of argillaceous, very coarse-grained sandstone, the pores between the coarse quartz sand grains being largely filled with silt and clay material. In places, the argillaceous sandstone is partly cemented by silica and is somewhat quartzitic. This zone has not yielded gas, oil, or water, probably because of low permeability due largely to its argillaceous and in some places cemented or quartzitic character.

Zone A shows much lateral variation in lithology (pl. 4). In well 194 (SW¼ NE¼ sec. 19, T. 10 S., R. 21 E.) it is about 17 feet thick and consists chiefly of argillaceous, very coarse-grained sandstone which is poorly cemented and for the most part broken up during drilling to loose sand grains which are angular to subangular and show good size sorting. In the basal 5 feet, however, the sandstone evidently is interbedded with dark-gray to black clay shale and light-brownish-gray siltstone. Coarse weathered grains of chert were noted at the base of the zone. In well 183, 3 miles to the west-northwest, Zone A is about 10 feet thick and contains sand similar to that found in well 194; however, well samples indicate that the argillaceous sandstone here is interbedded with dark-gray to black clay shale, coal, massive clay, and

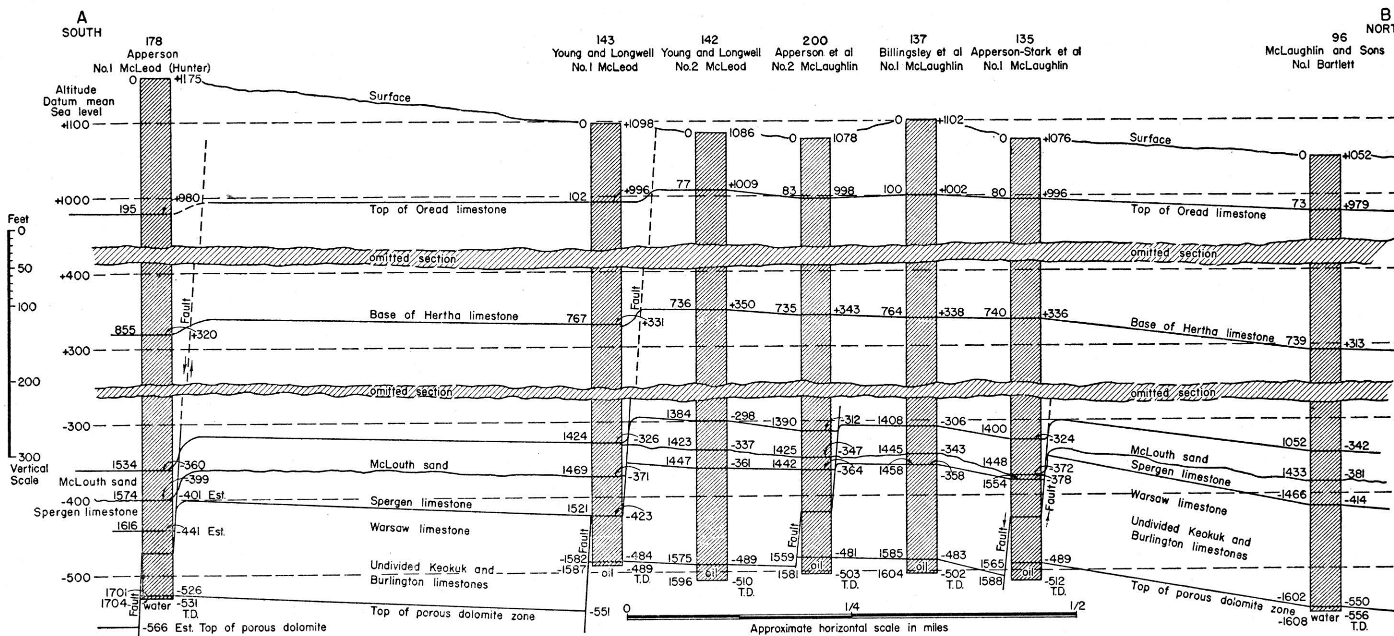


FIG. 15. Diagrammatic cross section of the McLouth field along line A-B (figs. 10, 11, pl. 3) showing structural relations of Pennsylvanian and Mississippian rocks. The structural relief increases with depth. Some faults in the Mississippian die out in the lower Pennsylvanian.

The numbers at right of well columns indicate altitudes above and below sea level. The numbers at left of well columns indicate depths below surface. The numbers above well names refer to the numbers of wells as listed in table 27.

minor beds of clay ironstone. In well 145 (NE¼ SE¼ sec. 4, T. 10 S., R. 20 E.), the basal sandstone zone is approximately 10 feet thick and consists of coarse-grained angular sand. The sandstone is less argillaceous here than elsewhere, contains beds of oil-stained siltstone, and is saturated with oil. This well is in the vicinity of oil wells producing from a higher zone in the McLouth sand and is a short distance south of and on the downthrow side of the fault zone on the south flank of the McLouth anticline. Here the basal sandstone zone contains abundant angular chert fragments, some of which show a banded structure typical of some of the chert in the Spergen dolomite. This chert may have been derived from residual material of the Spergen on the upthrow side of the fault to the north where the basal sandstone zone is absent. There is evidence that this fault was active during the deposition of the McLouth sand. In well 182, situated 3 miles to the east in NW¼ NE¼ NE¼ sec. 12. T. 10 S., R. 20 E., Zone A is about 15 feet thick and consists of highly oil-stained argillaceous coarse-grained sandstone with thin beds of oil-stained siltstone. A short distance southwest from this well, in well 181, Zone A is markedly different in lithology and is approximately 25 feet thick; the bottom part, about 10 feet thick, does not contain sand but consists of black carbonaceous clay, laminae of coal, and beds of siltstone and clay ironstone. The upper part of the zone, the remaining 15 feet, consists of layers of quartzitic silty coarse sandstone interlaminated with black shale and coal, massive clay, white siltstone with siderite spherulites, and clay ironstone. In well 105, more than 3 miles to the north, Zone A is only about 4 feet thick and consists of quartzitic silty slightly oil-stained sandstone.

Throughout the basal sandstone zone the quartz sand grains tend to be very coarse-grained and angular to subangular, although a few range through subround. Furthermore, they tend to be well-sorted or uniform in size, although the pores between them are filled with argillaceous material. Large quartz granules were noted at the base of the zone in several wells. Angular detrital chert grains, for the most part weathered and probably derived from Mississippian limestone, are present in the sand but are abundant only at the base.

Zone B.—This zone consists of several types of shale, clay, and siltstone, and, unlike Zone A, does not contain beds of sandstone. The rock types are nonporous and nonpermeable, and the entire zone is represented on the block diagram (pl. 4) by a solid black pattern. Zone B is present throughout the greater part of the McLouth field and directly overlies Mississippian rocks on the McLouth and North McLouth anticlines and elsewhere in the central and western part of the field. In the easternmost part of the field, however, it is separated from Mississippian rocks by the underlying sandstone and associated rocks of Zone A.

Zone B is characterized by marked lateral variation in lithology. Micaceous silty shale, composed dominantly of quartz-mica silt, clay, and carbonaceous material, is the diagnostic lithologic type. Medium- to dark-gray to black clay shale which contains carbonized leaves and other plant remains also is common, especially in the lower part of the zone. The black shale beds in places contain pyrite. Another important rock type is massive clay, some of which is black. In a few wells the zone is composed almost entirely of a single one of these lithologic types, but in most wells there is interbedding of other types. Minor rock types of this zone, described in the section on *Lithology,* include sideritic white siltstone and thin beds of clay ironstone and coal. Coarse angular grains of residual chert from the Mississippian and coarse quartz sand grains and granules are common at the base of Zone B where it overlies Mississippian rocks.

Zone B is 8 to 10 feet thick throughout the greater part of the McLouth field. In well 101, in the SW¼ SE¼ sec. 33, T. 9 S., R. 20 E. on the McLouth anticline, the zone is only 2 or 3 feet in thickness; in well 139, a quarter of a mile to the south in the NW¼ NE¼ sec. 4, T. 10 S., R. 20 E., Zone B is not represented, and the sandstone of Zone C containing a show of gas rests directly on Mississippian rocks. Zone B increases in thickness on the south or downthrow side of the fault on the south flank of the McLouth pool where in wells 145 and 183 it merges with Zone D, the sandstone beds of Zone C having pinched out (pl. 4).

Zone C.—This zone is present in the western half of the area shown in plate 4 and consists of sandstone with thin beds of shale and siltstone. This sandstone zone pinches out eastward in secs. 3 and 4, T. 10 S., R. 20 E. and in secs. 20, 28, 29, and 33, T. 9 S., R. 20 E. Westward from this area it ranges in thickness from 6 to 30 feet. The sandstone beds of Zone C vary from well-sorted porous sandstone to highly argillaceous sandstone, intermediate stages being present. In a few wells, part of the zone consists of quartzitic sandstone, but the sandstone beds are generally slightly cemented by quartz.

On the northwest flank of the McLouth anticline, Zone C is believed to form a stratigraphic trap from which comes most of the production of the numerous gas wells in the NW¼ sec. 4 and the N½ sec. 5, T. 10 S., R. 20 E. and along the southern border of sec. 32, T. 9 S., R. 20 E. In this area, Zone C, consisting of well-sorted porous sandstone, pinches out eastward on the McLouth anticline, as indicated by wells 53, 94, 99, 125, and 145 (pl. 4). In well 89, with an initial open flow of 12,250 M cubic feet, the upper part of Zone C was penetrated and yielded most of the gas. Southeast of this well, in well 131, most of the initial open flow of 10,200 M cubic feet came from the upper 16 feet of Zone C. Still farther southeast, in well 134 which had an initial open flow of 8,500 M cubic feet, the total thickness of Zone C, 24 feet of porous sandstone, was penetrated and yielded gas. In well 140, a little more than a quarter of a mile to the east from well 134, Zone C thins to about 5 feet of porous sandstone and had only a show of gas (88 M cubic feet); in well 121, about half a mile farther east, the zone is nonproductive and is represented by only about 3 feet of highly argillaceous sandstone. The gas production from this well comes from a higher sandstone zone in the McLouth. Thus, along the line of these wells, Zone C thins and becomes argillaceous and nonproductive in an eastward direction. The stratigraphic trap in this zone on the northwest flank of the anticline is indicated by other wells not shown on the block diagram.

Well-sorted, porous sandstone developed locally in Zone C yields gas, oil, and water in other parts of the field. In well 9, in the NE¼ SE¼ sec. 14, T. 9 S., R. 19 E., the cuttings from Zone C consist entirely of loose well-sorted grains of quartz sand. The zone is 30 feet thick and carries water. In well 101, in the SW¼ SE¼ sec. 33, T. 9 S., R. 20 E., there was an oil show in Zone C which here is 10 feet thick and consists of porous, oil-saturated sandstone. Eastward from this well, the sandstone of this zone pinches out, and in well 103, half a mile to the east, the zone is represented by oil-saturated sandy siltstone which gave a small show of oil.

Aside from the areas of porous productive sandstone described in the preceding paragraphs, Zone C consists largely of argillaceous sandstone which is commonly interstratified with layers of siltstone and shale. In several wells the argillaceous sandstone was oil stained but failed to produce oil.

Zone D.—The siltstone, shale, and associated beds of Zone D are similar to those of Zone B. This zone is present throughout the McLouth field and ranges in thickness from 4 to 10 feet. White siltstone, certain beds of which contain siderite in the form of spherulites and irregular shapes, is the characteristic lithologic type, especially in the eastern half of the area shown in plate 4. Some of the siltstone beds are sandy. Micaceous silty shale also is common in the zone throughout the field. Light- to dark-gray to black clay shale and beds of massive clay and clay ironstone are present locally.

Zone D directly overlies Zone B in the eastern part of the field, where the intervening sandy Zone C has thinned out. Inasmuch as these two shale zones are composed of similar lithologic types, it is impossible to distinguish them in this part of the field. Zone D increases in thickness on the south or downthrow side of the fault on the south flank of the McLouth pool, where it merges with Zone B to form a single body of shale, siltstone, and clay which is about 40 feet thick in wells 145 and 183.

Zone E.—The sandstone and associated beds of Zone E are present throughout the McLouth field and range in thickness from 4 to 16 feet, usually 6 to 8 feet. Argillaceous sandstone is the dominant lithologic type. The sands range widely in grain size from very fine to very coarse. The zone contains laminae and thin beds of siltstone and shale. Carbonaceous material in the form of scattered particles and coaly laminae is abundant.

Locally, where porous sandstone phases of the zone occur in favorable structural positions, wells drilled to this zone yield large initial open flows of gas. Oil is found in some localities. In most wells of the field the sands of Zone E are oil stained, and in several wells the sand is impregnated with asphaltic material. In well 194, in the SW¼ NE¼ sec. 19, T. 10 S., R. 21 E., the zone consists entirely of water-bearing well-sorted fine sand. Porous sandstone is developed only locally, however, and sand grades laterally into argillaceous sandstone which is commonly oil-stained but does not produce oil. Gas wells producing from argillaceous sandstone have smaller initial open flow than do wells that encountered porous sand in this zone.

In the North McLouth pool several wells found shows of oil, and two wells (21 and 23) in sec. 17, T. 9 S., R. 20 E. produce oil from Zone E. In the oil wells south of the fault zone on the south flank of the McLouth pool (sec. 3, T. 10 S., R. 20 E.), Zone E is thick and consists of well-sorted coarse porous sandstone containing thin layers of siltstone and shale. In these wells oil is produced from Zone E and from Zone G.

Zone F.—Black clay shale is the dominant rock type of Zone F, which extends throughout the area of the field and averages only about 5 feet in thickness. White siltstone and dark-gray to black massive clay occur locally, either interbedded with black shale or comprising the entire thickness of the zone. Well samples indicate that Zone F thins to 2 feet or less in parts of the field. The difference in oil and gas content of the sandstone in the underlying Zone E and the sandstone in the overlying Zone G indicates that the shale of Zone F forms an effective barrier between these producing zones. In several wells in the northern part of the North McLouth pool (secs. 17, 20, and 21, T. 9 S., R. 20 E.), the uppermost zone (G) produces gas or gives shows of gas, whereas in the same wells Zone E produces oil or gives shows of oil. In numerous wells in other parts of the field, Zone E produces gas, and Zone G is nonproductive.

Zone G.—The sandstone and associated beds of Zone G are present throughout the McLouth field and form the top of the McLouth sand, a reliable key position for structure mapping. This zone averages about 5 feet in thickness and consists almost entirely of fine- to medium-grained argillaceous sandstone containing laminae and thin beds of dark-gray to black shale. The sandstone beds are carbonaceous and commonly contain carbonized plant fragments and coaly laminae. Locally, the sandstone beds are partly cemented by quartz and are somewhat quartzitic. In many wells of the field, this zone was found to be capped by a thin layer of nearly white quartzitic sandstone; this cap rock is dense and nonpermeable and has remarkable lateral persistence.

The sandstone beds of Zone G commonly are oil stained or saturated with dead oil, and in a few wells shows of oil were obtained from this zone. Production of oil from this zone is limited to the wells in sec. 3, T. 10 S., R. 20 E., south of the fault zone. Because of the argillaceous character of the sandstone, only shows of gas were obtained from Zone G throughout the greater part of the field. Zone G is the principal gas-producing zone, however, in the northern part of the North McLouth pool and in the Ackerland pool (secs. 1 and 12, T. 10 S., R. 20 E.) where the sandstone beds are less argillaceous and more porous.

PALEOGEOGRAPHY AND ENVIRONMENT OF THE FOREST CITY BASIN DURING EARLY CHEROKEE TIME

At the beginning of Cherokee time, the Forest City basin was a detached northern extension of the Cherokee basin of Oklahoma from which it was separated by the Bourbon arch, a broad low structural feature underlain by Mississippian limestone. A similar arch north of the Ozark region in Missouri separated the Forest City basin from the Illinois basin to the east. The region of the Ozark uplift, southeast of the Forest City basin, was a land mass of low elevation underlain mainly by cherty dolomites of late Ordovician age flanked by beveled Mississippian limestones. The re-elevation of the Nemaha anticline had formed an eastward-facing escarpment which was the western boundary of both the Cherokee basin and the Forest City basin. Areas of granite not exceeding 1,400 square miles, bordered by early Paleozoic rocks, were exposed on the beveled crest of this anticline in northern Kansas and southeastern Nebraska, but toward the south early Paleozoic and Mississippian limestones were exposed on the crest. The elevated region west of the escarpment was underlain mainly by Mississippian and Devonian limestones but still farther west, in the area of central Kansas, Ordovician dolomites with local outcrops of granite were exposed (McClellan, 1930, p. 1542). Toward the north and northeast, a land area seems to have existed in Minnesota, Wisconsin, and adjoining areas to the north, for the Cherokee rocks become thinner in this direction. Mississippian and older Paleozoic rocks also wedge out on pre-Cambrian rocks in the same direction (Ballard, 1942, p. 1571). Part of the land area of igneous and metamorphic rocks probably drained into the Forest City basin and thus could have been the source of at least a part of the Pennsylvanian sediments of that area.

The Cherokee basin of southeastern Kansas is the northern extension of the much deeper Ouachita basin of southern Arkansas and southeastern Oklahoma. The Ouachita basin is bordered on the south by the Ouachita mountains which were rising contemporaneously with the subsidence of the basin. There seems to be no reason to doubt that the sediments accumulating in the Ouachita basin were derived mainly from the Ouachita mountains. It seems probable, therefore, that most of the early sediments introduced into the Cherokee basin were derived also from this source, although to reach the northern end of the Cherokee basin the materials must have been carried across the aggrading Ouachita basin and into the northern reaches of the narrowing tributary Cherokee basin. After the burial of the Bourbon arch, however, sediments from the north probably mingled with those from the south.

The upper and middle Cherokee sediments of the Forest City basin extend southward through eastern Kansas and western Missouri into the Cherokee basin in southeastern Kansas and eastern Oklahoma. The Cherokee deposits are thinner on the broad divide (Bourbon arch) than in the basins to the north and south, as shown by the isopachous map in the report by Bass (1936, pl. 1) on the shoestring sands of Greenwood and Butler counties, Kansas. Similar relations occur in northern Missouri on the slightly higher divide between the Forest City basin and the Illinois basin. Thus, although the Forest City basin is believed by the senior writer to have been at first a separate structural and topographic depression, sedimentation was in progress during late Cherokee time from the Illinois basin westward through northern Missouri and southern Iowa to the Forest City basin, and thence southward through eastern Kansas and western Missouri to the Cherokee basin.

The early deposits in the deep central part of the Forest City basin consist of black shale with very small amounts of sand or sandy shale. Above the black shale, the Cherokee sediments consist largely of quartz sand, silt, mica, and clay. Grains of feldspar also occur and beds of arkose were deposited especially in the western and central parts of the basin. Most of the land draining into the Forest City basin was underlain by limestones and dolomites from which the mica, quartz sand, and feldspar of the Cherokee could not have been derived. The relatively small area of granite exposed on the crest of the Nemaha anticline is inadequate to account for the vast quantities of quartz sand and mica of the Cherokee, although the arkose was probably derived at least in part from the Nemaha anticline. The region of the Central Kansas uplift, although underlain in some places by granite, does not seem to have drained into the Forest City basin. Much of the early clastic deposits of the Forest City basin, except possibly the arkose, may have been derived, therefore, from the area toward the north if the Bourbon arch actually formed a topographic barrier confining the Forest City basin.

The development of the Forest City basin between post-Mississippian base leveling and deposition of the Fort Scott limestone is clearly revealed by the evidence now available. The detailed steps by which the Nemaha anticline was faulted and re-elevated and the surface of the post-Mississippian peneplain depressed to form the Forest City basin are still obscure partly due to lack of adequate well samples and partly because no broadly recognizable datum beds have yet been established in the lower Cherokee rocks.

The senior writer advocates the theory that both the Forest City basin and the Cherokee basin were developed by a long series of minor movements deforming the peneplain east of the Nemaha anticline escarpment. Greater depression resulted in the areas north and south than on the Bourbon arch. It is presumed that the slowly developing Cherokee basin drained into the much larger Ouachita basin toward the south and that at first no sediments accumulated in this basin in Kansas. The Forest City basin north of the Bourbon arch, on the other hand, because of its closed character was almost contemporaneously filled with black shale deposits as the differential subsidence took place. When the Cherokee basin finally became filled with aggrading deposits advancing from the south, the Bourbon arch was buried and the Forest City basin merged with the Cherokee basin.

H. S. McQueen and some other geologists (oral communications) support a theory which implies that the beveled and peneplaned surface of the Mississippian limestones was widely covered by black shale deposits before the beginning of the Forest City and Cherokee basin movements. This theory assumes that the Nemaha anticline was rejuvenated after and not before the deposition of the black shale; that the shale was stripped from the crest of the ridge after re-elevation, thus re-exposing the granite areas at the north end of the anticline; and that the re-elevated granite areas were the source of the arkose which then spread out over the beveled surface of the black shale in the Forest City basin. This theory implies that neither of the basins nor the Bourbon arch were developed until after the deposition of the black shale and that the Forest City and Cherokee basins were never separate topographic entities. The theory is not without merit, but there is evidence to indicate that the early Cherokee sediments in southeastern Kansas advanced into a previously developed basin and that the earliest Cherokee sediments in the Cherokee basin differ markedly in content of sand and coal from those in the Forest City basin.

These two theories might be reconciled by assuming that the black shale accumulated in the differentially subsiding Forest City basin independently of the Cherokee basin, as in the first theory, but that at the close of the time of black shale accumulation in the Forest City basin an exceptionally strong uplift of the area to the west re-elevating the granite areas and a corresponding depression of the basin caused the flood of arkose overlying the black shale. In view of the present lack of detailed knowledge of the stratigraphy of the lower Cherokee in Kansas, particularly in the area of the Bourbon arch, this question must remain open. There is abundant evidence, however, to indicate that the McLouth arch, the Cherokee basin, and structural features of the Forest City basin were in existence and active prior to submergence. The senior writer, therefore, believes that the Forest City basin and the Bourbon arch were also developed before submergence and that topographic and structural barriers originally separated the Forest City basin from the Cherokee basin and from the Illinois basin. The McLouth sand seems to have been deposited at or shortly after the time when the surface of the Bourbon arch subsided below the level of deposition.

The occurrence of linguloid shells in black shale in the lower part of the Cherokee shale a short interval below the McLouth sand in the core of the Forest City well, as reported by McQueen and Greene (1938, p. 174), implies that in that area marine or at least brackish-water conditions prevailed briefly shortly before the deposition of the McLouth sand. Other extensive thin beds of marine argillaceous limestone containing crinoid and brachiopod remains occur above the McLouth sand and indicate that the region was extensively inundated by marine waters at infrequent brief intervals during the early cycles of sedimentation which characterize the Pennsylvanian.

After the deposition of the basal black shale deposits in early Cherokee time, the Forest City basin is believed to have been a flat, slowly subsiding plain of aggradation, at times partly inundated and occupied by shallow bodies of brackish or marine water and marshlands, and at other times at or slightly above sea level and occupied by numerous shifting and aggrading streams, flood plains, and associated lakes and swamps. The lithologic zones of the McLouth sand are of two general types which correspond with these two contrasted types of environment: (1) shale zones consisting mostly of clay shale and micaceous silty shale but containing also beds of clay, siltstone, and thin beds of clay ironstone and coal; and (2) sandy zones that show marked lateral variation from well-sorted porous sandstone and highly argillaceous sandstone to beds of clay, siltstone, and shale that are sandy or contain laminae of sand. Thus, although the sandy zones do not everywhere consist of sandstone, they contain quartz sand interlaminated and interbedded with finer grained sediments. The two types of deposits alternate in the McLouth sand and suggest cyclic sedimentation.

Environment and Origin of Shale Zones

During times when the Forest City basin was subsiding the region was partly or locally inundated by brackish or marine water, and it was in this environment that the lithologic types of the shale zones were deposited. Marine fossils have not been found in the McLouth sediments of the McLouth field but linguloid shells in shale beds of McLouth age have been found elsewhere in the Forest City basin. In the log of the Davis well near Forest City, Missouri (table 3), McQueen and Greene (1938, p. 174) report linguloids in black shale containing plant remains associated with lithologic types not of open-water marine origin. At the present time brachiopods of linguloid type live in brackish water marginal to the ocean as well as in the open seas. Fossil linguloids have been found in several parts of the stratigraphic column in beds ascribed to brackish-water deposition.

The assemblage of lithologic types in the shale zones includes beds of massive clay, clay ironstone, and coal. These deposits are not formed under marine conditions of the type prevailing in a broad open sea, but suggest deposition in partly restricted bodies of quiet water. The abundance of carbonized plant remains and other carbonaceous material in these sediments supports this contention. It is believed that the dark-gray to black clay shales were deposited on partly submerged plains in partly landlocked basins, embayments, or lagoons in which poor circulation resulted in deficiency of oxygen. This would account for the lack or extreme scarcity of the remains of marine organisms and for the highly carbonaceous character of the shales.

There is a total lack of ferric iron in well samples of the various rock types that constitute the McLouth sand, and the shales and clays are for the most part dark gray to black. This feature also suggests that deposition took place below water level in quiet shallow bodies of water under reducing or anaerobic conditions. Locally thin beds of clay ironstone were formed in the marshes or shallow quiet water of the partly inundated region. The iron is believed to have been brought to the places of deposition in solution as ferrous bicarbonate, and precipitated from solution as iron carbonate as a result of depletion of carbon dioxide by bacteria, algae, or other agencies in an environment of stagnant water deficient in oxygen. According to Twenhofel (1932, p. 447), "Such conditions are thought to obtain in the marshes and shallow waters of lakes, rivers, and the sea, where photosynthesis of vegetation extracts the carbon dioxide from the water and the decay of organic matter uses up the oxygen." Inasmuch as the clay ironstone beds are impure, the precipitation of iron carbonate took place in environments in which silt, clay, and organic matter were present. They are associated with thin coal seams and were probably deposited in swampy areas. Thus it would seem that there was extreme environmental differentiation in the region when the shale zones of the McLouth sand were deposited.

Environment and Origin of Sandy Zones

The sandy zones of the McLouth are not shoestring sand bodies such as those in the Cherokee of Greenwood and Butler counties, Kansas, described by Bass (1936), but are blanket sands (pl. 4) which show lateral lithologic variation and local wedging out. They are believed to have been laid down approximately at sea level under conditions of extensive aggradation by numerous shifting streams on partly inundated plains which supported abundant vegetation and were undergoing gentle subsidence. The assemblage of lithologic types of the sandy zones has much in common with that of the Mississippi delta and is interpreted as representing sedimentation in stream channels and broad flood plains and associated swamps, lakes, and embayments. The bodies of impounded water are believed to have ranged in character from shallow open-water lakes or embayments agitated by waves and currents to protected and restricted bodies of stagnant water, conditions which are consistent with the lithologic diversity of the sandy zones of the McLouth sand.

It is probable that during periods of floods, large areas received river sediments—argillaceous sands and silts—whereas during periods in which stream flow was less active, well-sorted fine sandstone, siltstone, clay, shale, clay ironstone, and coal were deposited in swamps and bodies of impounded water. This would account for the complex interbedding of different types of sediments in the sandy zones and for the lateral changes in lithology. The deposition of sand in quiet-water lake and swamp environments during floods would explain such peculiarities of the McLouth sand as the presence of sandy laminae in beds of massive clay. The bodies of poorly sorted argillaceous sandstone in the McLouth beds which are commonly interbedded with fine sediments are believed to have been deposited in shifting river channels and on broad flood plains during times of high water. Beds of siltstone and finally clay were laid down in the remaining quiet-water lakes when the waters subsided.

The flood plains of many present-day rivers, including Kansas river at Lawrence, Kansas, show interbedding of argillaceous sand, silt, and clay. A common associated feature in these river sediments is the presence of angular to subrounded pebbles of clay and clayey silt in the argillaceous sandstone beds. These pebbles are formed in Kansas river by the disintegration of sandstone layers interbedded with silt and clay. The resulting undercutting causes the breaking off of the overlying cohesive layers forming angular pebbles which are ultimately buried in sandstone when flood conditions return. Pebble-bearing beds of this type may be formed in other ways, such as by the breaking up and reworking during floods of thin mud-cracked layers of clay and silt exposed to the air on flood plains during times of low water. Similar intraformational conglomerates and breccias in sandstone in Lower Cretaceous beds (Moulton zone of the Kootenai) of the Cut Bank field, Montana, are attributed by Blixt (1941) to flood-plain sedimentation. The small tabular pebbles of silty clay which have been observed in shot fragments of McLouth sand (pl. 8) are interpreted as evidence of fluviatile sedimentation.

Examination of well cuttings has indicated that the well-sorted porous sandstone bodies of the McLouth sand have small lateral extent and commonly do not exceed 10 feet in thickness. In certain wells of the field, well-sorted sandstone was found to compose practically the entire thickness of one or the other of the two middle sandy zones (C and E, pl. 4), but in adjacent wells one-quarter of a mile distant the zone generally was found to be of different lithologic character and is composed of argillaceous sandstone alone or interbedded with clay, silt, shale, or coal. The shape, dimensions, and orientation of these well-sorted sandstone facies of the sandy zones could not be determined, but their length and breadth in most cases do not exceed a distance ranging from a quarter of a mile to half a mile. They commonly consist of a very fine to medium quartz sand, and the interstices between grains contain little silt or clay. Sands deposited by rivers in channels and flood plains commonly are of the argillaceous type and do not show the excellent size sorting characteristic of some of these local porous sand facies of the McLouth beds. In the Mississippi delta country R. J. Russell and R. D. Russell (1939) found that sand bodies that show such good sorting represent beach, dune, and open-water sands subjected to a long period of winnowing. It is possible that the porous sand facies of the McLouth sand represent deposition under similar conditions in shallow open-water lakes or brackish-water embayments where current and wave action resulted in sorting of sand carried in by streams.

The lateral lithologic gradation of the sandy zones indicates that there was simultaneous sedimentation in different parts of the region of (1) argillaceous sands and associated silts and clays by rivers, (2) well-sorted fine sands in current and wave-agitated open-water bodies, and (3) silts, clays, clay ironstone, and coal in restricted quiet-water bodies and swamps which at times of flood receive sand in the form of sandy laminae.

The general type of environmental conditions under which the McLouth sand was deposited prevailed throughout most of Cherokee time. Although sand is a prominent constituent of some zones higher in the Cherokee, sand deposition was less common in the McLouth area after McLouth time. The various lithologic types of the McLouth occur throughout most of the Cherokee section, and cyclical repetition of types is indicated. Thin fossiliferous marine limestone beds in the Cherokee suggest that at infrequent intervals of brief duration the Forest City basin region was invaded by the open sea.

The sedimentation represented by the assemblage of lithologic types of the McLouth sand is an important and rather common type. As already mentioned, it is represented in other parts of the

Cherokee group, including the Squirrel sand, in parts of the Bourbon group, in parts of the Douglas group, and in other subdivisions of the Pennsylvanian. The assemblage of lithologic types in the lower part of the Terra Cotta and in the Janssen clay members of the Dakota sandstone in Kansas (Plummer and Romary, 1942) is the same as that in the McLouth sand. The lithologic character of the Moulton zone of the Kootenai (Lower Cretaceous) in the Cut Bank oil and gas field, Montana, as described by Blixt (1941), has much in common with that of the basal Cherokee in the Forest City basin.

OIL AND GAS DISTRIBUTION IN THE McLOUTH FIELD IN RELATION TO STRUCTURE

Occurrence of Gas in McLouth Sand

At the time of the publication of the preliminary report on the McLouth field (Lee, 1941), the developments seemed to indicate that the porosity of the sand was more important than structure in controlling the distribution of the gas in the McLouth sand. This was suggested by the following observations: a number of wells located on the anticline had failed to find gas, or were very small producers because the sand bodies were either absent or impervious; some wells had penetrated good sand bodies, but the pores of the sandstone were clogged with tar or dried oil; and many gas wells, including some of the largest, lay far outside the area of structural closure as indicated by the surface rocks. The detailed structure of the deeper rocks for the entire field had not been definitely determined at that time. Subsequent development of the field disclosed that, although there are some areas on the anticline in which the sand conditions are unfavorable, there are no gas wells in areas of unfavorable structure. The areas from which gas is produced are definitely anticlinal and, although eccentrically related to the closure of the anticline as expressed in the surface rocks, are symmetrical with the subsurface structure of the sand.

RELATION OF GAS AND TAR IN MC LOUTH SAND

The areas of gas production are completely encircled by dry wells, most of which penetrated sand bodies saturated with tar or dried oil. Examination of the cuttings shows that many wells which found gas in the upper part of the McLouth sand found dried oil or tar or, in some places, small amounts of heavy oil in the lower part of the sand. The continued development of the McLouth pool and the discovery and development of the North McLouth pool revealed a close relation between the gas and tar sand areas and the structure of the McLouth sand.

The contact between the gas sand and the tar-stained sand is more sharply determinable on the west side of the McLouth pool, where more tests have been drilled along the margin of the gas-producing area than on the east side of the pool, where drilling has been discouraged because test wells have found the sand bodies absent or with low porosity and small production. On the east side of the McLouth pool the Longwell No. 1 Steenstry well, in the NE¼ NW¼ sec. 3, T. 10 S., R. 20 E. (shown on table 5), was a small gas well in sand overlying tar sand. The contact of the tar sand and gas sand is at -342 feet. The next test to the east, the Longwell No. 1 Moore well, in the NW¼ NE¼ sec. 3, was a low well with dried oil and tar in all the sand bodies (fig. 16). In the Aladdin No. 1 Edmonds well, in the SW¼ SW¼ sec. 34, T. 9 S., R. 20 E., a diagonal offset northwest of the No. 1 Steenstry well, the contact between gas and dried oil is at -351 feet.

On the west side of the McLouth pool, the Hatcher and Fisk No. 1 Myers well, in the SW¼ SW¼ sec. 32, T. 9 S., R. 20 E., found the contact of the gas and tar sand at -388 feet. The Hatcher and Fisk No. 2 Kimmel well, in the NW¼ NW¼ sec. 5, T. 10 S., R. 20 E., found the contact at -387 feet. The Archie No. 1 Shrader well, in the SE¼ SW¼ sec. 28, T. 8 S., R. 20 E., in which some heavy oil was reported, penetrated the gas-tar contact at -373 feet.

The regional dip of the surface rocks over large areas in northeastern Kansas is approximately 15 feet per mile N. 70 W. There is, however, a convergence of Pennsylvanian strata from the center of the Forest City basin southeastward toward its margin, representing the amount of subsidence that took place during deposition. At the time of deposition of the Shawnee group, the earliest Cherokee rocks had acquired a gentle dip toward the bottom of the Forest City basin (pl. 1). In the area west of the McLouth field this convergence ranges from 2 to 5 feet per mile. An additional average dip of 3 feet per mile is assumed. Thus, although the correction required to restore the originally horizontal position in the surface rocks is only 15 feet per mile, the correction required to restore the original horizontal attitude of the McLouth sand is approximately 18 feet per mile.

The following table shows the present altitude of the gas-tar contact in the various wells noted above and their relative positions in relation to the Myers well after elimination of regional dip.

TABLE 5.—*Present altitudes of gas-tar contacts in the McLouth pool and relative altitudes of the same points compared with the Hatcher and Fisk No. 1 Myers well after elimination of regional dip.*

No.	Well	Present altitude in feet below sea level	Altitude, in feet below sea level[1]
1	Hatcher and Fisk No. 1 Myers, SW¼ SW¼ sec. 32, T. 9. S., R. 20 E.	388	388
2	Hatcher and Fisk No. 2 Kimmel, NW¼ NW¼ sec. 5, T. 10 S., R. 20 E.	387	389
3	Archie et al. No. 1 Shrader, SE¼ SW¼ sec. 28, T. 9 S., R. 20 E.	373	388
4	Longwell et al. No. 1 Steenstry, NE¼ NW¼ sec. 3, T. 10 S., R. 20 E.	342	382
5	Aladdin No. 1 Edmonds, SW¼ SW¼ sec. 34, T. 9 S., R. 20 E.	351	384

[1] Corrected for regional dip to compare with No. 1 Myers.

It is obvious that the former position of the gas-tar contact was essentially horizontal and that the plane of contact was not altered after the development of regional dip. Cross sections A-B and C-D of figure 16 show the same relation, but slight deviations from a smooth plane of contact appear. These are believed to be caused in part by the heterogeneity of the McLouth sand which, as has been pointed out, consists of alternating zones of shale and sandstone, the porosity of which varies horizontally. It is probable that some irregularities are due to the fact that there were structural movements after the establishment of the gas-tar contact. Other deviations from a smooth plane of contact are probably due to errors in the measurement of depths which are inherent in all logs. Information provided by one well on the line of the cross section, the Archie No. 1 Brose well, in the NE¼ SE¼ sec. 32, T. 9 S., R. 20 E., has not been used because it presents a structural anomaly that is believed to be the result of incorrect depth records. The occurrence of tar and oil in the sands in the McLaughlin No. 2

Bartlett well is also anomalous, for the sand is high enough structurally to form part of the gas reservoir.

RELATION OF TAR AND WATER IN MC LOUTH SAND

Some irregularity of the surface of contact between the water and tar, due to irregular porosity and to alternation of sand and shale deposition, may be expected as is true of the contact between gas and tar. The plane of contact between oil and water in any pool is, of course, dependent upon the amount of gas and oil present in the anticlinal trap, and in separated pools no uniformity of the position of the plane of contact may be expected. The plane of contact, however, should be approximately uniform in individual pools.

Inasmuch as structurally low areas are avoided in oil and gas exploration, only a few wells have encountered water. They are nearly all outside the band of tar-sand wells encircling the gas areas. The distances between tar-sand wells and water wells are for the most part too great to determine the altitude of the plane of contact very sharply, but a few wells have passed through tar sand before encountering water, thus revealing the plane of contact between them locally.

In sec. 30, T. 9 S., R. 20 E., on the west side of the North McLouth pool, the contact between water and tar sand in the Hatcher and Fisk No. 1 Ray Kimmel well, in the NW¼ SW¼ sec. 30, as shown in table 6, is at -439 feet; in the Jackson No. 1 Shoemaker well, in the SE¼ SW¼ of the same section, the contact is at -431 feet. The only well which found water in the McLouth sand on the east side of the field is the Aladdin No. 1 Corlett well, in the SW¼ NE¼ sec. 19, T. 10 S., R. 21 E., in which water was encountered at -323 feet. Inasmuch as no tar sand was found in this well, the water-tar contact may be assumed to be somewhat higher. The distance between the Ray Kimmel well and the Corlett well projected on the direction of regional dip is 7.7 miles. The regional dip on the McLouth sand is approximately 18 feet per mile. The correction for dip is, therefore, 138 feet. The present altitudes of the water table in these three wells and their positions relative to the Ray Kimmel well after corrections for regional dip are shown as items No. 1, 2, and 6 in table 6. The other items show the present altitudes and the altitudes corrected for the dip of the bottom of known tar or oil sands in other low wells of the field where water was not encountered.

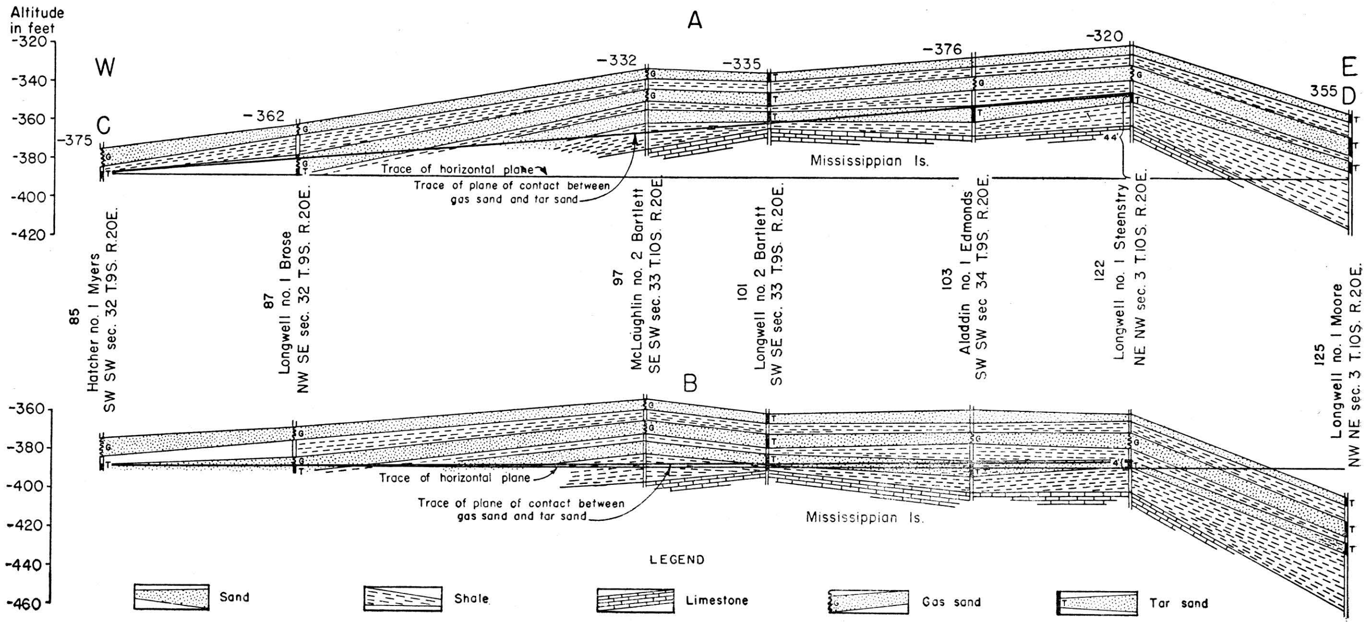


Fig. 16. Cross sections of McLouth sand on line C-B showing attitude of plane of contact of gas and tar before and after elimination of regional dip. A, Cross section of McLouth sand from samples of wells. B, Cross section of McLouth sand after elimination of regional dip. In A the gas-tar contact at right is 44 feet above horizontal plane. In B the gas-tar contact at right is only 4 feet above horizontal plane.

Numbers at left of wells show altitudes of top of sand below sea level.

Numbers above well names refer to numbers of wells listed in table 27.

TABLE 6.—*Present altitudes of the plane of contact between tar and water, the bottom of tar or oil sands in low wells in McLouth field, and relative altitudes of the same points compared with the water contact in the Hatcher and Fisk No. 1 Ray Kimmel well after elimination of regional dip*

No.	Well	Remarks	Present altitude in feet below sea level	Altitude, in feet below sea level[1]
		North McLouth pool		
1	Hatcher and Fisk No. 1 Ray Kimmel, NW¼ SW¼ sec. 30, T. 9 S., R. 20 E.	Water contact west side North McLouth pool	439	439
2	Jackson No. 1 Shoemaker, N½ SE¼ SW¼ sec. 30, T. 9 S., R. 20 E.	Water contact west side North McLouth pool	431	435
3	Jackson No. 1 Shrader-Haas, NW¼ SE¼ sec. 29, T. 9 S., R. 20 E.	Lowest tar sand, no water. South side N. McLouth pool	464	480
4	Magnolia No. 1 Mathew Woodhead, SW¼ SW¼ sec. 29, T. 9 S., R. 20 E.	Lowest tar sand, no water. South side N. McLouth pool	443+	461+
		Ackerland pool		
5	Miller No. 1 Jeannin, NE¼ NW¼ sec. 7, T. 10 S., R. 21 E.	Base of oil sand, no water. East side Ackerland pool	400	522
6	Aladdin No. 1 Corlett, SW¼ NE¼ sec. 19, T. 10 S., R. 21 E.	Top of water sand. Local structural relations uncertain. Water contact probably higher	323	461
		McLouth pool		
7	Luehring et al. No. 1 Fryhofer, NE¼ NE¼ sec. 7, T. 10 S., R. 20 E.	Water contact west side McLouth pool	438	464
8	Longwell No. 1 Moore, NW¼ NE¼ sec. 3, T. 10 S., R. 20 E.	Lowest tar sand, no water. East side McLouth pool.	384	453
9	Magnolia No. 1 Kell, NE¼ SE¼ sec. 4, T. 10 S., R. 20 E.	Lowest tar sand, no water. South of fault south side McLouth pool.	392	459

[1] Corrected for regional dip to compare with No. 1 Ray Kimmel well.

The relation of the plane of contact between tar and water in the Ray Kimmel well and the top of the water sand in the Corlett well suggests, in a general way, that the water-tar contact was established before the regional dip in the same manner that the gas-tar contact was established in the McLouth pool. The relations are inconclusive, however, for the Ray Kimmel well indicates the position of the water-tar contact on the west side of the North McLouth pool, whereas the Corlett well is on the east side of the field in a locality where the local structural features are uncertain.

No comparative figures are available to compare the relations of the water-tar contact on opposite sides of a single pool. The Luehring No. 1 Fryhofer well, in the NE¼ NE¼ sec. 7, T. 10 S., R. 20 E., found the water-tar contact on the west side of the McLouth pool at -438 feet (-464 feet corrected for dip). The Longwell No. 1 Moore well, in the NW¼ NE¼ sec. 3, T. 10 S., R. 20 E., on the east side of the McLouth pool, did not find water but showed tar sand to a depth of -384 feet (-453 feet corrected for dip). South of the fault on the south side of the McLouth pool, the Magnolia No. 1 Kell well in the NE¼ SE¼ sec. 4, T. 10 S., R. 20 E., found tar sand and traces of oil to a depth of -392 feet (-459 feet corrected for dip). In accordance with the evidence at hand, the contact of water and tar sand on the west side of the McLouth pool and the depths of the lowest known tar sands on the east and south sides of the McLouth pool (regional dip eliminated) are in essential agreement and conform to the structure of the pool as it is believed to have been prior to the development of regional dip. The exact depth of the water-tar contact on the east side of the pool has not been revealed by drilling.

The tar sand in the Jackson No. 1 Shrader-Haas well, in the NW¼ SE¼ sec. 29, T. 9 S., R. 20 E., on the southeast side of the North McLouth pool, was drilled to a depth of -464 feet (-480 feet corrected for dip) without encountering water. This depth is far below the plane of contact of water and tar in the Hatcher well west of the North McLouth pool (-439 feet corrected for dip). It is also below the water-tar contact in the Fryhofer well west of the McLouth pool (-464 feet corrected for dip) and seems to violate the theory of an originally horizontal plane of contact between tar and water sands, inasmuch as the corrected depth of tar sand in No. 3 is below the corrected depths of the water level in Nos. 1 and 7. The Jackson No. 1 Shrader-Haas well, however, lies in a sharp syncline between the two pools. This syncline was structurally active from the time of deposition of the McLouth sand until after deposition of the Lecompton limestone. The top of the McLouth sand in this well is 120 feet below the crest of the McLouth anticline and 45 feet below the crest of the North Mc-

Louth anticline. The top of the Lecompton limestone is only 45 feet below the crest of the McLouth anticline and 25 feet below the crest of the North McLouth anticline. The anomaly, therefore, is probably the result of downward warping of the McLouth sand in the syncline after the introduction of the now desiccated oil. The Magnolia No. 1 Mathew Woodhead well, SW¼ SW¼ sec. 29, T. 9 S., R. 20 E. (No. 4 of table 6), which also shows a low tar-water contact, is also in the syncline in the same relative position as the Shrader well.

The water level in the McLouth sand in the Ackerland pool has not yet been determined. The lowest known oil sand in the pool was drilled in the Miller No. 1 Jeannin well, in the NE¼ NW¼ sec. 7, T. 10 S., R. 21 E., where oil sand was drilled to a depth of -400 feet (-522 feet corrected for dip). The altitude of the base of the sand, corrected for dip, is considerably lower than that on the west side of either the McLouth or North McLouth pools. It is also lower than the corrected altitude of the water encountered in the sand in the Corlett well and is probably controlled by local structural conditions in the Ackerland pool not yet revealed.

The different altitudes of the water on the flanks of the pools, even after corrections for dip have been applied, indicate that the water level is dependent on the accumulation of oil and gas in each pool, and also may have been modified by structural distortion after establishment of the water-tar contact.

PERIOD OF GAS AND OIL ACCUMULATION

At the time when the oil entered the sands it must have had a mobility or fluidity which permitted it to enter the pores of the sandstones. It is evident that the oil has lost this mobility because in most wells the oil is too viscous to escape from the sand into the wells and is generally reduced to a tarry matrix or a dried oil cementing the sand grains. Since the development of regional dip, the oil has not invaded the gas area on the lower side of the tilted anticline, nor has the gas displaced the oil on the upper side of the anticline. The tar must have entered the sand before the pre-Cretaceous westward tilting of the region, for the gas-tar contact conforms to the pre-Cretaceous attitude of the strata.

The time when the oil lost its mobility is uncertain. It might be assumed that the desiccation occurred prior to the development of regional dip as the position of the tar in the sand does not conform to the altered symmetry of the anticline. This hypothesis assumes that the oil, if fluid, would rearrange itself gravitationally on the opposite flanks of the anticline. It may be doubted, however, that even relatively fluid oil, having attached itself to the enclosing sand grains, would alter its position in the sand on gentle slopes. It seem improbable that, with dips no greater than 18 feet per mile, the difference in gravitational pressure on opposite sides of an anticline would overcome the surface tension by which the oil is attached to the enclosing sand grains. The desiccation of the oil may, therefore, have occurred at a date later than the regional westward tilting of the oil- and gas-bearing rocks. It may be that the oil invaded the sand and established the gas-tar and tar-water planes of contact soon after its burial, for these planes of contact are more completely restored to horizontal by the use of a dip correction of 18 feet per mile, which includes the slope of the McLouth sand into the Forest City basin, than by the use of the regional dip of 15 feet per mile of the surface rocks. The difficulty of determining the various dips with complete accuracy, however, renders this hypothesis inconclusive. The low position of the tar-water contact in the syncline between the McLouth and North McLouth pools suggests that the tar-water contact was established before the end of Pennsylvanian deformation.

The asymmetry of oil zones under anticlines in Oklahoma and in central Kansas, where the oil is generally lowest on the west side, has been attributed by some geologists to the greater accumulation of oil on the side from which the oil reached the trap. They assume that the regional dip provided the conditions essential to the migration of oil and that the oil traveled long distances up dip before coming to rest in the anticlinal trap. This hypothesis implies that there was no accumulation of oil and gas in the anticlines until after the development of regional dip which occurred after Permian and before Cretaceous time. In the McLouth field the tar and gas in the McLouth sand, whatever their original source, seem to have reached their present position before the development of regional dip. Therefore, they did not migrate long distances up the dip, and the source materials must lie at lower altitudes within an area limited by nearby synclines.

DISTRIBUTION OF GAS, TAR, OIL, AND WATER IN MC LOUTH SAND

The absence of water in the McLouth sand in the McLouth pool was early noted and has been confirmed by drilling not only in the McLouth pool but also in the North McLouth and Ackerland pools. Water is present in the McLouth sand in low wells west of the McLouth and the North McLouth pools and southeast of the Ackerland pool. The disposition of the tar sands in wells encircling the gas areas and underlying the gas in flank wells accounts for the absence of water in the field. The tar constitutes an effective seal between the gas and the water and prevents the encroachment of the water as the gas is withdrawn and the pressure in the reservoir is reduced. It has already been pointed out that gas, tar, and water show an original gravitational adjustment and a symmetrical distribution in the anticlinal traps of the field after elimination of regional dip, but it is not clear why the sand in some areas yields oil and in others is cemented with tar or dried oil.

TABLE 7.—*Relative depths to oil and gas in sec. 34, T. 9 S., R. 20 E. and sec. 3, T. 10 S., R. 20 E. north and south of fault, and depths corrected to eliminate regional dip compared with the Hatcher and Fisk No. 1 Myers well, in the SW¼ SW¼ sec. 32, T. 9 S., R. 20 E.*

No.	Well	Remarks	Present altitude in feet below sea level	Altitude, in feet below sea level[1]
1	Hatcher and Fisk No. 1 Myers, SW¼ SW¼ sec. 32, T. 9 S., R. 20 E.	Reference point	388	388
	North of fault			
2	Aladdin No. 1 Edmonds, SW¼ SW¼ sec. 34, T. 9, S., R. 20 E.	Contact of gas and oil sand	351	384
3	Longwell No. 1 Steenstry, NE¼ NW¼ sec. 3, T. 10 S., R. 20 E.	Contact of gas and tar sand	342	382
4	Longwell No. 2 Steenstry, SW¼ NW¼ sec. 3, T. 10. S., R. 20 E.	Lowest gas sand	335	374
	South of fault			
5	Longwell No. 1 Bankers' Life, NW¼ SW¼ sec. 3, T. 10 S., R. 20 E.	Highest oil sand	342	382
6	Longwell No. 2 Bankers' Life, NE¼ SW¼ sec. 3, T. 10 S., R. 20 E.	Highest oil sand	338	381

[1] Corrected for regional dip to compare with the No. 1 Myers well.

The principal area of oil production from the McLouth sand occurs in the S½ sec. 3, T. 10 S., R. 20 E., where oil is produced from six wells on the faulted extension of a small dome on the southeast side of the McLouth anticline. The history of this fault has already been discussed. The first oil well drilled in the area south of the fault, the Longwell No. 1 Bankers Life well, in the NW¼ SW¼ sec. 3, T. 10 S., R. 20 E., found the top of the oil sand at -342 feet (-382 feet corrected for dip to compare with the Hatcher and Fisk No. 1 Myers well [table 7]). The highest well in this oil pool, the Longwell No. 2 Bankers Life well, in the NE¼ SW¼ sec. 3, found the top of the oil sand at -338 feet (-381 feet corrected for dip). Neither gas nor water has yet been encountered in the sand south of the fault.

The oil occurs in the McLouth sand on the south or downthrow side of the fault. On the north or upthrow side of the fault, wells yield gas from the sand zone which terminates at the fault and abuts against black shale above the McLouth sand on the south side (pl. 4 and fig. 15). The oil, therefore, occupies a fault trap. However, as shown in table 7, the highest oil sand south of the fault before the development of regional dip was slightly below or at the same altitude as the lowest known gas sand north of the fault. The gravitational distribution of oil in the area south of the fault, therefore, conforms to that of tar and oil in other parts of the McLouth pool. Consequently, it is concluded that the oil pool south of the fault in sec. 3 is an integral part of the McLouth pool in spite of the fault that separates it from the area yielding gas.

In the North McLouth pool, two wells yield oil from the McLouth sand. The first of these to be drilled was the Anderson No. 1 May Dick well, in the SE¼ SW¼ sec. 17, T. 9 S., R. 20 E. This well is an edge well and the oil comes from 15 feet of sand at the top of the McLouth. It was shot with 70 quarts of nitroglycerine and has yielded 12 to 6 barrels of oil per day for a year or more. The next well north, the Anderson No. 2 Dick well, found the McLouth sand 4 feet higher. This well yielded only one-half million cubic feet of gas and no oil. The next well north, the Hatcher and Fisk No. 1 E. Edmonds well, in the SE¼ NW¼ sec. 17, T. 9 S., R. 20 E., was similar to the No. 1 May Dick well in that oil with some water was found 20 feet below the top of the McLouth sand. Production is less than 6 barrels of oil per day.

In addition to these areas from which oil is being produced commercially, several scattered wells have found small but not commercial amounts of oil in the McLouth sand. The Aladdin No. 1 Edmonds well, in the SW¼ SW¼ sec. 34, T. 9 S., R. 20 E., found gas in the top of the McLouth sand and shows of heavy oil in the lower part. The well was gauged at 2.7 million cubic feet of gas and was completed as a gas well, but oil entered and filled the hole from the oil sand as the pressure declined. Some oil (less than 100 barrels) has been taken from this well. The Longwell No. 2 Bartlett well, in the SW¼ SE¼ sec. 33, T. 9 S., R. 20 E. (fig. 15), also revealed traces of oil in the McLouth sand. The oil shows in this well were from the top of the McLouth sand which yields gas at this altitude in other wells in the pool. All the sand drilled in this well below the free oil at the top was saturated with tar.

The Archie No. 1 Shrader well, in the SE¼ SW¼ sec. 28, T. 9 S., R. 20 E., an edge well on the north flank of the McLouth pool, entered the gas sand of the McLouth at a depth of 1,442 feet, 2 feet above the gas-tar contact. A small flow of gas gauged at 396,000 cubic feet was encountered in the upper 2 feet of the sand. Oil and tar were encountered in the sand from 1,444 to 1,460 feet. The well was reported to yield 7 barrels of oil per day at one time, but production has been small and intermittent.

The Hatcher and Fisk No. 1 Henry Kimmel well, in the SE¼ SW¼ sec. 5, T. 10 S., R. 20 E., reported a show of oil in the upper sand zone of the McLouth sand from 1,512 to 1,515 feet below the surface. This well is unusual in that gas was found in a lower sand zone below shows of oil and tar. After drilling black shale from 1,515 to 1,528 feet, gas sand was found from 1,528 to 1,543 feet. The well was completed as a gas well with an initial production of 4.5 million cubic feet per day.

The Anderson et al. No. 1 Woodhead Estate well, in the NE¼ SW¼ sec. 6, T. 10 S., R. 20 E., an edge well of the McLouth pool, penetrated oil sand from 1,529 to 1,582 feet immediately overlying the Mississippian. A show of oil led the operators to shoot the well with 40 quarts of nitroglycerine, but the results were unsatisfactory and the hole was plugged.

The Magnolia No. 1 Mathew Woodhead well, in the SW¼ SW¼ sec. 29, T. 9 S., R. 20 E., found oil in the upper sand zone and tarry sand in the lower sand zone of the McLouth sand on the southeastern side of the North McLouth anticline. This well was drilled in tar sand to a depth of -443 feet (-461 feet corrected for dip to compare with the tar-water contact in the Hatcher and Fisk No. 1 Ray Kimmel well [table 6]). The sand in this well was shot with 60 quarts of nitroglycerine and was reported to have had an initial production of 30 barrels per day of very low gravity crude. The well has produced oil for more than a year and is still producing at the rate of 6 barrels per day. The northwest offset of this well, the Hatcher and Fisk No. 1 Black well, NE¼ SE¼ sec. 30, also found a show of oil in the McLouth sand but there was no production. Viscous tar has been noted in the McLouth sand cuttings of several wells, notably among others the Smythe No. 1 Federal Land Bank well, SW¼ NE¼ sec. 29, T. 9 S., R. 20 E., the north offset of the Mathew Woodhead well, and in the Magnolia No. 1 Kell well, NE¼ SE¼ sec. 4, T. 10 S., R. 20 E.

In the Ackerland pool, the Miller No. 1 Jeannin well, NE¼ NW¼ sec. 7, T. 10 S., R. 21 E., found oil in the lower sand zone of the McLouth sand at depths from 1,386 to 1,412 feet. The oil sand, which is 26 feet thick, lies between altitudes of -374 and -400 feet (-489 to -522 feet corrected for dip to compare with the Hatcher and Fisk No. 1 Ray Kimmel well). The sand body is very coarse angular sand and immediately overlies the Warsaw limestone of the Mississippian. It probably corresponds to the Burgess sand of other areas. The presence of Warsaw limestone in this well, which was drilled in an area of St. Louis limestone, implies an erosion channel in the top of the Mississippian and suggests that this sand may be a channel deposit. The Miller-Magnolia No. 3 Jim Bell well, in the SE¼ SW¼ sec. 6, T. 10 S., R. 21 E., also found oil in this sand under similar conditions. Other wells in the Ackerland pool which reached the Mississippian found only black shale or sandy shale in the position of this sandstone.

No satisfactory explanation for the anomalous and seemingly erratic occurrences of oil in the McLouth sand presents itself. Some are at points structurally low on the anticline. Others, as in the Longwell No. 2 Bartlett well, occur in structurally high parts of the sand which yield gas in adjacent wells. It seems possible that the temporary opening of joints or minor faults during the long history of differential structural growth may have permitted the entry of oil into the gas sands from deeper zones (possibly from the Mississippian or even older rocks) where accumulations of oil were under greater hydrostatic pressure than the gas in the McLouth sand. Such joints and minor faults are, however, purely hypothetical in the localities of these occurrences. Some support is given to this theory because faults are known to occur in Mississippian rocks. The occurrence of the oil pool in the McLouth sand in sec. 3, in proximity to the faulted zone, fits into such a theory but it does not explain why the oil in the Magnolia No. 1 Kell well, offsetting the Longwell No. 1 Bankers Life well and in the same position in relation to the fault zone, is too viscous to produce. The reason for the desiccation of the oil in what must once have been a very extensive oil pool is also a mystery. Dried oil in Pennsylvanian rocks in contact with gas sands is known to occur in other parts of eastern Kansas, indicating that the conditions requisite for the desiccation are not unique to the McLouth field.

Occurrence of Oil and Gas in Mississippian Rocks

OIL AND GAS AT THE TOP OF THE MISSISSIPPIAN

The upper surface of the Mississippian which was exposed to weathering during the period of peneplanation is generally somewhat porous, but at the time of writing only small amounts of gas or oil have been found in it. The occurrence of oil and gas in the weathered zone is not determined by the pre-Pennsylvanian exposure of any particular formation. The Spergen dolomite was widely exposed on the pre-Pennsylvanian surface in the McLouth field and was thus susceptible to the development of porosity. It is, in consequence, the chief repository for the minor amounts of gas produced from the top of the Mississippian. Gas has been produced from the top of the Spergen in the McLaughlin No. 1 Ragan well in the NW¼ NW¼ sec. 3, T. 10 S., R. 20 E., which reported 3.7 million cubic feet of gas from the McLouth sand. After drilling through 20 feet of black shale and entering the top of the Mississippian rocks, this well made 4.5 million cubic feet, the additional gas coming from the top of the Spergen. Similarly, the McLaughlin No. 2 Bartlett well, in the SE¼ SW¼ sec. 33, T. 9 S., R. 20 E., found 4.3 million cubic feet of gas in the McLouth sand which increased to 6.1 million cubic feet when drilled into the top of the Spergen. The Mosbacher No. 1 Dolman well found the McLouth sand impervious and dry, but yielded 360,000 cubic feet of gas in the top of the St. Louis limestone. This flow increased after acidization, but the water also increased. The two wells yielding gas from the Spergen are flank wells on opposite sides of the McLouth anticline. The gas seems to have been trapped in the limestone in a porous part of the weathered zone where gas accumulated as though it were a part of the McLouth sand reservoir rather than a separate zone of accumulation in the Mississippian beds.

The weathered zone at the top of the Mississippian limestones is heavily oil stained in nearly all wells that are structurally high. Shows of free oil have been noted in several wells. Two of these wells, the Young and Longwell No. 1 McLeod well, in the NW¼ SW¼ sec. 4, T. 10 S., R. 20 E., and the Apperson-Stark No. 1 McLaughlin well, in the S½ NW¼ NW¼ sec. 4, had exceptionally promising shows of free oil. These wells were acidized but the results from this zone were unsatisfactory.

OIL IN THE DOLOMITE ZONE

Most of the oil in the field is produced from the porous dolomite zone in the undivided Burlington and Keokuk limestones of the Mississippian in a small dome about three-quarters of a mile in diameter in secs. 4 and 5, T. 10 S., R. 20 E., on the southwestern end of the McLouth anticline. This dome is outlined by structural contours on the overlying McLouth sand, but the structural gradients are steeper on the Mississippian rocks than on the McLouth sand. The dip on the top of the Warsaw on the northwestern flank of the dome is at the rate of 150 feet per mile; that toward the east is at the rate of 125 feet per mile. The corresponding dips in the top of the McLouth sand in the same area are at the rate of 120 and 100 feet per mile, respectively.

No commercial amounts of gas accompany the oil in the dolomite on the crest of the McLouth oil dome. Water occurs on the flanks. Table 8 shows the altitudes at which water has been encountered in flank wells of the oil pool. These wells show that the water contact in the porous dolomite zone in the McLouth Mississippian oil pool was originally at or near -519 feet. The dolomite zone on the flanks of the dome and elsewhere in the field is generally porous and charged with water.

Water was encountered in the Young and Longwell No. 4 McLeod well at -510 feet in April, 1943, 9 feet above the anticipated water level as indicated from a comparison of other wells in the pool. Several wells higher on the structure, however, had been drawing on the reservoir for a year or more before this well was drilled. The occurrence of water at -510 feet, therefore, probably indicates water encroachment on the flank of the dome.

TABLE 8.—*Altitudes at which wells encountered water in the McLouth Mississippian oil pool*

Well	Remarks	Altitude in feet below sea level
Apperson No. 1 McLeod NE¼ SE¼ SE¼ sec. 5, T. 10 S., R. 20 E.	Oil and water together at top of dolomite zone	519
Aladdin No. 1 McLeod Cen. S. line SW¼ SE¼ NW¼ sec. 4, T. 10 S., R. 20 E.	A few feet below the top of dolomite zone	518±
Sherrod No. 2 Bower NE¼ SW¼ NE¼ sec. 5, T. 10 S., R. 20 E.	Water about 16 feet below top of dolomite zone. This well found oil in dolomite at -508 but was drilled too deep.	523
Billingsley et al. No. 1 McLaughlin Cen. E½ NW¼ NW¼ sec. 4, T. 10 S., R. 20 E.	Water in top of dolomite zone	524
McLaughlin No. 1 Bartlett SW¼ SW¼ sec. 33, T. 9 S., R. 20 E.	Water in top of dolomite zone. This well was low on the north flank of the dome.	551
Hatcher and Fisk No. 1 Henry Kimmel SE¼ SW¼ sec. 5, T. 10 S., R. 20 E.	Water at top of dolomite zone. This well was on the southwest flank of the dome	532
Young and Longwell No. 4 McLeod SW¼ NE¼ SE¼ sec. 5, T. 10 S., R. 20 E.	Water 11 feet below top of dolomite zone.	510

The pre-Pennsylvanian attitude of the Mississippian rocks is difficult to determine. Prior to peneplanation, the Mississippian rocks in the McLouth area had been given a dip of about 5 feet per mile toward the east as shown by the Mississippian thickness map (fig. 17). The subsidence that formed the Forest City basin introduced on the east side of the basin a gentle westerly dip which, although it is more toward the northwest, approximately compensated for the earlier dip in the opposite direction. Prior to the development of the pre-Cretaceous regional dip, the attitude of the Mississippian rocks of the McLouth pool was consequently again essentially horizontal. Therefore, the effect of regional dip was to tilt the Mississippian dome of the McLouth pool toward the northwest at about 18 feet per mile, a dip not greatly different from that affecting the early Pennsylvanian rocks of the area. The pool is less than one-half mile wide in an east-west direction so that the correction for regional dip does not exceed 7 or 8 feet on opposite sides of the dome. The structural gradient is so high on the east flank of the dome that correction for regional dip produces no obvious effect on the position of the crest and no marked difference in the areal position of the water line. On account of the always present possibility that small errors have been introduced by inaccuracy in measuring depths of wells, too great reliance cannot be placed on minor variants in the depth to the top of the porous zone or depth to the oil-water contact. In any case, it seems probable in a reservoir honeycombed with coarse cavities that readjustment of the oil-water contact might occur after the development of regional dip.

The dome yielding oil from the Mississippian rocks on the southwestern end of the McLouth anticline is only one of several domes outlined by the structure of the McLouth sand on the three developed anticlines of the field (see fig. 8). This dome is the only one that has been tested for deeper production. Several wells have been drilled to the dolomite on the flanks of the other domes, but the areas on the crests that are most likely to produce from the dolomite have not been tested for pre-Pennsylvanian production because the wells that were drilled on the crests have been completed as gas wells. There seems reason to hope that some, if not all, of these domes may yield oil in the Mississippian. This probability is supported by the fact that oil occurs at so many points in the McLouth sand under conditions that suggest seepage from accumulations in deeper rocks.

PRODUCTION OF GAS AND OIL

Gas Production

The initial open flow and the production of wells in the McLouth field vary from well to well (table 9). These variations are due chiefly to the changing character and varying porosity and permeability of the productive zones in the McLouth sand, as discussed above.

The most productive well in the field, the McLaughlin No. 1 Dark well in the SW¼ NW¼ sec. 4, T. 10 S., R. 20 E., was one of the first four wells put in production. It had a reported initial open flow of 13.7 million cubic feet of gas per day. To April 1, 1943, it had yielded a total of 472.426 million cubic feet in 24½ months. The McLaughlin No. 2 Dark well, in the SE¼ NE¼ sec. 5 ,T. 10 E., R. 20 E., offsetting the No. 1 Dark well on the west, had an initial open flow of 3.8 million cubic feet per day. It was connected with the pipe line at the same time as the No. 1 Dark well, but had made only 108 million cubic feet at the time it was taken off production in January, 1943, after 22 months. Both of the Dark wells border an area in which the McLouth sand is impervious. The No. 2 Dark well probably penetrated the sand in the area of transition between the areas of coarsely porous and impervious sand. The position of the V-8 Drilling Company No. 2 McLeod well, in the SW¼ SE¼ sec. 5, T. 10 S., R. 20 E., in relation to the area of impervious sand is similar to that of the No. 2 Dark well. It was not completed until nearly 11 months after the Dark wells. The original open flow was reported as 3 million cubic feet of gas per day. In the 13½ months prior to April 1, 1943, this well had made only 55.748 million cubic feet but was still yielding gas at the rate of nearly 4 million cubic feet of gas per month or about the average rate of production for the first year.

The Anderson No. 1 Woodhead well, in the NE¼ SW¼ sec. 32, T. 9 S., R. 20 E., is an edge well on the northwest side of the McLouth pool. It was completed 5 months after production began in the pool. Its initial open flow was reported at 13.0 million cubic feet per day. In 20 months prior to April 1, 1943, this well had made a total of 176 million cubic feet. The offset well to the north was dry. The offset to the east, the Longwell No. 1 Brose well, yielded a total of only 14 million cubic feet of gas and was abandoned. The offset well to the south, the Magnolia No. 1 Myers, completed 4 months after the Woodhead well, had a reported initial open flow of only 7.6 million cubic feet of gas per day but had yielded a total of 206 million cubic feet of gas to April 1, 1943. The diagonal offset to the southwest, the Hatcher and Fisk No. 1 Myers well, had a reported initial open flow of 3.7 million cubic feet per day, but in 19 months prior to April 1, 1943, it had yielded a total of only 34.7 million cubic feet of gas.

Similar relations exist in sec. 3, T. 10 S., R. 20 E., where the Longwell No. 2 Steenstry well, in the SW¼ NW¼ sec. 3, which had a reported initial open flow of 16.8 million cubic feet, had yielded 24.9 million cubic feet of gas to April 1, 1943. The offset well to the north, the McLaughlin No. 1 Ragan well, in the NW¼ NW¼ sec. 3, which had been completed and put on production a few weeks earlier, was gauged at 4.9 million cubic feet per day, and on

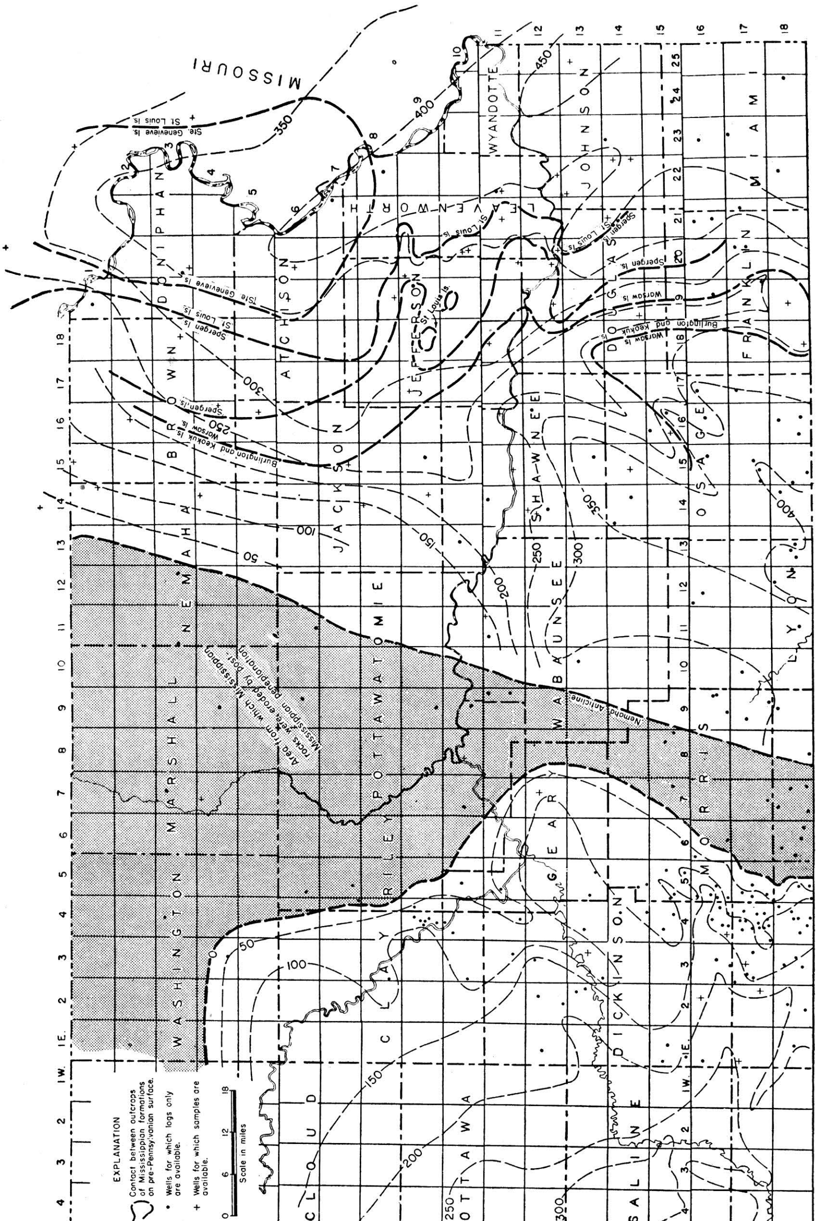
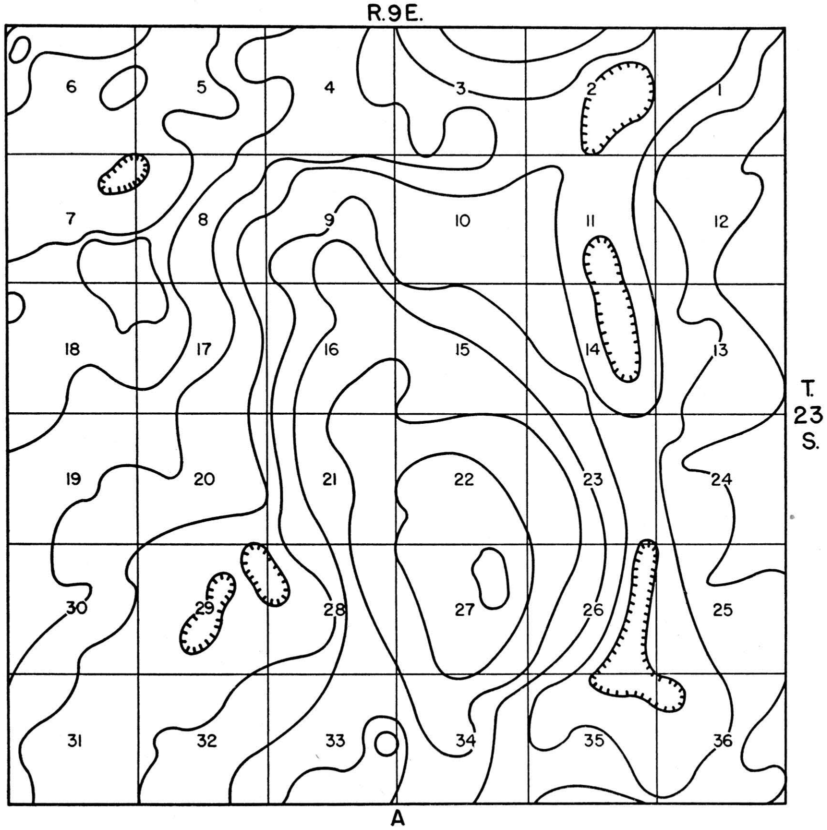


FIG. 17. Map of northeastern Kansas showing thickness of Mississippian limestones and approximate distribution of Mississippian formations on pre-Pennsylvanian surface. Lines connecting points of equal thickness are drawn at 50-foot intervals.

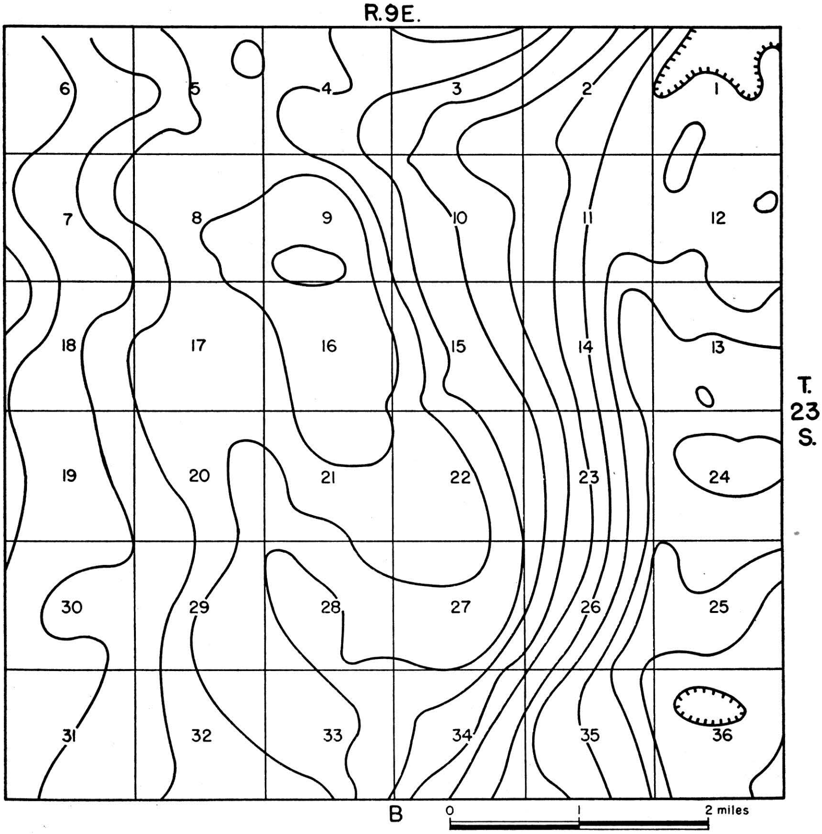


Structure of surface rocks of area in Greenwood County, Kansas

FIG. 18. Maps showing shifting of the crest of an anticline contoured on surface rocks in Greenwood county, Kansas, before and after elimination of the regional dip of 26 feet per mile. After John L. Rich (1935), republished by permission of the American Association of Petroleum Geologists.

April 1, 1943, had yielded 82 million cubic feet of gas. This production is approximately in proportion to the original open flow of the Longwell No. 2 Steenstry well, but the Longwell No. 1 Steenstry well, the diagonal offset to the northeast which had an initial open flow of 1.2 million cubic feet per day, had a yield to April 1, 1943, of only 44.6 million cubic feet of gas. The production from this well is greater in proportion to its initial open flow than the No. 1 Ragan or No. 2 Steenstry wells. Similar contrasts in productivity occur in all parts of the field.

FIG. 18.—*continued*



The same structure of surface rocks restored to its original attitude by elimination of regional dip

The crest of the anticline in its original attitude was in section 9 (figure B). The regional dip shifted the position of the crest to section 27 (figure A), a distance of nearly 3 miles.

Contour interval, 10 feet. The map as originally published does not show altitudes of contour lines.

PRESSURES

The average original pressure in the McLouth field in the first four wells connected to the A and B Pipe Line Company gathering line was 490 pounds per square inch. The initial closed pressure of each well for which the information is available is shown in table 9 and chronologically in figure 20. The initial pressures of the wells thus shown are local pressures at the time each well was completed. There was in every case a lag behind the decline of

Table 9.—*Initial open flow of gas in thousand cubic feet per day, initial and subsequent closed pressure in pounds per square inch, and production by wells in the McLouth field to April 1, 1943*

Well Name	Location	Date Completed	Open Flow in M cu. ft/day Initial	Open Flow Nov. 1941	Closed Pressure in lbs/sq. in Initial	Closed Pressure Nov. 1941	Closed Pressure 4-27 1943	Production in M cu. ft. 1941	Production 1942	Production 1943 to 4-1	Totals To 4-1 1943
McLouth Pool											
50. C. Miller No. 1 fee	NW SW 22-9-20	9-22-42	8,000		455				12,980	18,627	
52. McLaughlin & Sons No. 1 C. Miller	SW SW 22-9-20	11- 7-42	1,000								
53. Wm. O. Smythe et al No. 1 O. Jacobson**	SW NW 27-9-20	5-20-42	500		450				5,257	1,628	
54. E. W. Mosbacher No. 1 M. A. Dolman*	NW NW SE 27-9-20	11-28-41	360	759	450	468			5,554	0	
56. Hatcher & Fisk No. 2 F. J. Harwood	SE NW 28-9-20	11- 4-42	3,750		445				3,083	54,831	
57. Hatcher & Fisk No. 3 F. J. Harwood	NE SW 28-9-20	11-24-42	1,000								
59. O. J. Connell No. 3 T. C. Moseberger	NE NE 28-9-20	2-20-43	2,000								
60. McLaughlin & Sons No. 1 S. S. Miller	SW NE 28-9-20	7-17-42	2,480		460				26,460	8,780	
61. Don Allen et al No. 1 S. S. Miller	SW NE NE 28-9-20	9-11-42	2,750		461				22,733	22,431	
62. W. Archie et al No. 1 P. Shrader	SE SW 28-9-20	7-25-41	396						5,529	0	
64. H. Workman et al No. 1 Old Line Ins.	NW SE 28-9-20	9-11-42	800		421		121		1,950	5,711	
84. Ray Anderson et al No. 1 Grant F. Woodhead	NE SW 32-9-20	7-17-41	13,055	6,789	450	351		108,417	53,616	14,154	
85. Hatcher & Fisk No. 1 W. E. Myers	SW SW 32-9-20	1- 9-42	3,730						31,348	3,334	
86. Magnolia No. 1 W. E. Myers	SE SW 32-9-20	9- 3-41	7,643	8,285	356	356		2,929	184,903	18,329	
87. J. W. Longwell et al No. 1 S. Brose	NW SE 32-9-20	9-20-41	3,360	1,258	370	350		5,736	8,366	0	
88. Willard Archie et al No. 1 S. Brose	NE SE 32-9-20	8- 4-41	1,070	537	370	344		996	0	0	
89. Magnolia No. 1 W. W. Harris	SW SE 32-9-20	7-27-41	12,250	8,658	419	352		106.095	95,577	30,057	
90. Magnolia No. 1 Rachel Davidson	SE SE 32-9-20	6- 6-41	10,500	6,693	450	348		101,447	89,289	19,613	
91. I. H. Knudson et al No. 1 I. H. Knudson	SW NW 33-9-20	11- 5-41	5,890	4,252	421	421	117	3,266	63,900	4,511	
92. I. H. Knudson et al No. 2 I. H. Knudson	NW NW 33-9-20	11-24-41	11,450				115		101,200	11,174	
93. Gordon & Poole et al No. 1 I. H. Knudson	SE NW 33-9-20	1-17-42	1,000								
95. J. W. Sherrod et al No. 1 Lange Estate	SW NE 33-9-20	9-26-41	2,020	2,122	466	467	252	12,021	108,581	22,511	
96. McLaughlin & Sons No. 1 A. L. Bartlett	SW SW 33-9-20	4-16-41	7,000	DEAD	468		109	75,097	385	0	
97. McLaughlin & Sons No. 2 A. L. Bartlett	SE SW 33-9-20	5-21-41	6,136	2,158	440	337		60,319	62,809	9,909	
98. H. T. Wiedenman et al No. 1 A. L. Bartlett	NW SW 33-9-20	8-27-41	7,000	4,045	437	340		18,900	26,611	2,525	
99. J. W. Billingsley et al No. 1 A. L. Bartlett	NE SW 33-9-20	10-22-41	1,900	759	400	412	195	1,877	21,850	1,764	
100. J. W. Longwell et al No. 1 A. L. Bartlett	NW SE 33-9-20	7-30-41	5,458	2,422	482	342	110	37,367	49,236	6,846	
103. Aladdin No. 1 M. D. Edmonds	SW SW 34-9-20	7-26-41	2,700	576	407	362	240	12,117	19,532	1,461	
121. McLaughlin & Sons No. 1 H. D. Ragan	NW NW 3-10-20	10-14-40	4,960	583	491	354	116	60,988	19,214	2,676	
122. J. W. Longwell et al No. 1 W. H. Steenstry	NE NW 3-10-20	4-23-41	1,190	759	471	325	128	19,258	23,393	1,983	
123. J. W. Longwell et al No. 2 W. H. Steenstry	SW NW 3-10-20	5-14-41	16,839	4,294	467	307	104	117,717	113,138	18,126	
131. W.W. Stark et al No. 1 E. P. Dark (McLaugh.)	NW NW 4-10-20	10-15-40	10,200	5,291	494	339		213,982	99,848	9,856	
133. McLaughlin & Sons No. 2 fee	N½ NW 4-10-20	2-28-41	4,000	1,155	400	342		12,560	31,464	5,226	
134. McLaughlin & Sons No. 1 fee	NE NW 4-10-20	12-14-39	8,500	1,712	470	344	109	37,821	54,332	7,905	
138. McLaughlin & Sons No.1. E.P.Dark (McLaugh.)	SW NW 4-10-20	7-18-40	13,700	9,029	491		103	309,345	139,368	23,713	
141. Aladdin No. 1 H. B. Ragan	SE NE 4-10-20	6-25-41	6,070	2,965	370	306	104	17,072	58,681	7,828	
146. Hatcher & Fisk No. 1 C. Kimmel	NE NW 5-10-20	11-20-41	5,253	5,253		367					
147. Hatcher & Fisk No. 2 C. Kimmel	NW NW 5-10-20	12- 1-41	617		367			1,265	347,500	25,024	
148. Hatcher & Fisk No. 3 C. Kimmel	SE NW 5-10-20	12-20-41	13,686								
149. J. W. Longwell et al No. 1 D. E. Bower	NW NE 5-10-20	9-25-41	15,100	14,368	395	355	99	39,041	182,614	28,193	

150. Aladdin No. 1 D. E. Bower	NE NE 5-10-20	6- 8-41	6,018	3,918	453	347		87,460	60,631	4,887	
155. J. E. Sherrod et al No. 1 D. E. Bower	SW NE 5-10-20	6- 2-41	7,400	5,013	420	352		50,183	2,843	0	
157. McLaughlin & Sons No.2 E.P.Dark (Bower)	SE NE 5-10-20	8- 7-40	3,800	2,185	490			87,554	20,443		
159. Hatcher & Fisk No. 1 D. E. Bower	NE SW 5-10-20	4-29-42	6,250						56,085	17,964	
160. Hatcher & Fisk No. 2 Henry Kimmel	SW SW 5-10-20	4-28-42	4,500						47,546	13,188	
161. Hatcher & Fisk No. 1 Henry Kimmel	SE SW 5-10-20	12-29-41	800								
163. V-8 Drilling Co. No. 1 Bessie McLeod	NW SE 5-10-20	11- 3-41	7,600	7,536	350				77,141	3,041	
167. V-8 Drilling Co. No. 2 Bessie McLeod	SW SE 5-10-20	12-28-41	3,000		345		116		44,227	11,521	
170. John B. Richard et al No. 1 Kate Sherman	NE NE 6-10-20	8- 7-41	13,240	9,669	416	416		3,989	43,120	4,187	
173. J. B. Synhorst et al No. 1 McLeod-Wisdom	N½ NW 8-10-20	11- 8-41	19,029	19,029	400	429	110	16,394	260,827	26,296	
174. J. B. Synhorst et al No. 2 McLeod-Wisdom	SW NW 8-10-20	4-29-42	6,000				137				
175. Mosbacher, Kilness, et al No. 1 N. Vandruff	NE NW 8-10-20	9-20-41	13,250	11,888	428	428		18,405	70,344	15,693	
176. J. E. Sherrod et al No. 1 Alvin Means	NE NE NW 8-10-20	1-14-42	7,500						34,300	3,625	
Total								1,639,618	2,787,808	489,128	
Total of pool to April 1, 1943											4, 916,554

* Production from St. Louis limestone.
** Production from Spergen limestone

North McLouth Pool

17. Miller & Mosbacher No. 1 Rachel Edmonds	SE SW 16-9-20	7-14-42	10,100						97,874	32,361	
19. Anderson & Bradley No. 1 Rachel Edmonds	SW SW 16-9-20		4,344						66,538	18,317	
20. Hatcher & Fisk No. 1 Tabor Edmonds	SW SE 16-9-20		5,100		460				13,276	5,182	
24. Ray Anderson et al No. 2 May Dick	NE SW 17-9-20	6-24-42	1,500		500				7,575	16,104	
27. E. V. Jackson et al No. 2 Bank of McLouth	SE NW 20-9-20	7-22-42	1,200		450				2,934	4,200	
29. T. Fred Hodge No. 1 M. M. Zachariah	SW NE 20-9-20	11-20-42	3,790		246		122		8,665	15,252	
31. Ward Schooler et al No. 1 M. M. Zachariah	NE NE 20-9-20		6,386		500		122		278,265	32,816	
32. Ward Schooler et al No. 2 M. M. Zachariah	SW NE 20-9-20		8,200								
33. Hatcher & Fisk No. 1 W. N. Schwinn	SE SW 20-9-20		500						511	5,156	
34. Hatcher & Fisk No. 1 M. Hesse	NE SE 20-9-20	7- 1-42	2,750		475				42,252	7,081	
35. Hatcher & Fisk No. 4 M. Hesse	NW SE 20-9-20	11-24-42	4,900		430				11,637	10,945	
37. Miller, Smythe et al No. 1 C. E. Todd	NE SE SE 20-9-20	11-24-42	11,650		265				18,492	70,444	
38. Miller, Smythe et al No. 2 C. E. Todd	E½ SW SE 20-9-20	2- 3-43	4,500								
40. Hatcher & Fisk No. 2 Elijah Edmonds	SW NW 21-9-20	6-14-42	2,000		445				61,279	7,576	
41. Hatcher & Fisk No. 1 Ralph Edmonds	NE NW 21-9-20	4-29-42	6,103						43,592	10,450	
42. Hatcher & Fisk No. 2 Ralph Edmonds	SE NW 21-9-20	2-22-43	2,400								
43. O. J. Connell No. 1 Russell Edmonds	SW NE 21-9-20	12-20-41	2,800		502		116		44,992	8,106	
44. O. J. Connell No. 2 Russell Edmonds	NW NE 21-9-20		5,000		502		117		53,053	8,080	
46. Hatcher & Fisk No. 2 M. Hesse	NW SW 21-9-20	9-16-42	11,700		436				114,395	56,104	
47. Hatcher & Fisk No. 3 M. Hesse	SW SW 21-9-20	10- 7-42	10,000								
65. Ray Anderson et al No. 1 McLeod-Wisdom	SW NW 29-9-20	8- 4-41	15,230	12,464	486	486		7,155	118,850	18,652	
66. Ray Anderson et al No. 2 McLeod-Wisdom	NW NW 29-9-20	1-31-42	1,500								
67. Ray Anderson et al No. 1 R. E. Costigan	NE NW 29-9-20	12-20-41	14,000						141,453	11,082	
68. Ray Anderson et al No. 1 Alvin Means	SE NW 29-9-20	9-20-41	18,700	18,928	496	496		13,559	167,656	20,817	
69. Miller & Smythe No. 1 Fed. Land Bank	NE NW NE 29-9-20	12-20-42	10,600		265					36,209	
72. Hatcher & Fisk No. 1 J. W. Shrader	NW SW 29-9-20	12- 2-41	15,900					7,514	95,475	17,963	
73. Hatcher & Fisk No. 2 J. W. Shrader	NE SW 29-9-20	1-14-42	1,500						52,501	6,531	
78. E. V. Jackson et al No. 1 A. Shoemaker	SE SW 29-9-20	10- 1-41	1,070	1,659	477	477					
Total								28,228	1,441,265	419,428	
Total of pool to April 1, 1943											1,888,921

TABLE 9. *Initial open flow of gas, initial and subsequent closed pressure, and production by wells in the McLouth field, concluded*

Well Name	Location	Date Completed	Open Flow in M cu. ft/day Initial	Open Flow Nov. 1941	Closed Pressure in lbs/sq. in Initial	Closed Pressure Nov. 1941	Closed Pressure 4-27 1943	Production in M cu. ft. 1941	Production 1942	Production 1943 to 4-1	Totals To 4-1 1943
ACKERLAND POOL											
114. V. W. McKnabe et al No. 1 R. B. Kessinger	NW SW 1-10-20	11- 9-42	724		280					1,707	
115. Ward Schooler et al No. 1 L. H. Schmidt	NE SW 1-10-20	7- 2-42	3,220		472		136		34,867	9,712	
116. McLaughlin & McNerney No. 1 L. H. Schmidt	SE SW 1-10-20	7-28-42	1,260		460				13,316	5,699	
117. Miller, Cross et al No. 1 J. W. Bell	NW SE 1-10-20	6- 6-42	5,856				}				
118. Miller, Cross et al No. 2 J. W. Bell	SW SE 1-10-20	7- 8-42	900				} 131		114,900	42,230	
119. Miller, Cross et al No. 3 J. W. Bell	E½ SE 1-10-20	9-19-42	4,200				}				
180. W.T.McNerney et al No. 1 Fed. L. Bk. (Watson)	NE NW 12-10-20	6-11-42	3,500		465		150		31,687	7,943	
182. E. W. Mosbacher et al No. 1 J. Bell Estate	NW NE NE 12-10-20	10-28-41	1,036	1,036	470	474			14,968	0	
191. Charles E. Miller et al No. 1 J. A. Bell	NW NW NW 7-10-21	2-23-43	3,100		389		198			2,139	
Total								0	209,738	69,430	
Total of pool to April 1, 1943											279,168
Total of all pools by years								1,667,846	4,438,811	977,986*	
Grand total all pools to April 1, 1943											7,084,643†

* Total production of gas from all pools during year 1943 to Dec. 22 including production from 1 well in new pool discovered in August, 1943 was 2,534,973 M. cubic feet.

† Total production of gas from all pools to Dec. 22, 1943 was 8,667,516 M. cubic feet.

PRODUCTION BY COUNTIES

	1941	1942	1943 to 4-1	Totals To 4-1 1943
Jefferson County	1,457,766	4,030,005	864,055	6,351,826
Leavenworth County	210,080	408,806	113,931	732,817

pressures of wells already in production. The lag was dependent on the distance to producing wells, on the length of time the earlier wells had been on production, on the amount of gas already drawn from earlier wells, and on the porosity and continuity of the intervening sand bodies.

As was to be expected, wells that extended the pools several locations revealed initial pressures above the pressures near earlier wells but below the original pressure in the pool. Thus, the Anderson No. 1 Woodhead well, in the NE¼ SW¼ sec. 32, T. 9 S., R. 20 E., which was drilled 5 months after the pool was put on production and extended the pool three-quarters of a mile, showed a closed pressure of 450 pounds per square inch. However, the Sherrod No. 1 Bower well, in the SW¼ NE¼ sec. 5, T. 10 S., R. 20 E., which was drilled a month earlier and offsetting one of the original wells, had an initial closed pressure of only 420 pounds per square inch, 30 pounds less than the more distant Woodhead well.

The lag was greater than the average in areas where the intervening sands are relatively less permeable or where the gas comes from partly detached bodies of porous sand. The Sherrod No. 1 Lange Estate well, in the SW¼ NE¼ sec. 33, T. 9 S., R. 20 E., was drilled 8 months after production began and was nearer producing wells than the Anderson No. 1 Woodhead well, but its original closed pressure was 466 pounds per square inch. The initial pressure of the Woodhead well, drilled only 5 months after production started and at a greater distance from producing wells, was only 450 pounds per square inch.

Wells that had been drilled before November, 1941, were gauged by the State Corporation Commission and the closed pressure of each well was determined. No other pressures, except on new wells, were determined until April 27, 1943, when the compressor plant of the A and B Pipe Line Company was shut down for repairs for several days. During this period the wells connected to this pipe line were shut in and on April 27 and 28 the closed pressure of many of the wells was taken. The pressures taken by the Corporation Commission and by the A and B Pipe Line Company have been plotted on the chart in the appropriate place and provide the data for determining the pressure decline for a number of wells.

McLouth pool.—The available pressures for the McLouth pool (table 9 and fig. 20) show that there was a wide variation in the closed pressure of wells at the time they were drilled and much variation in pressure in November, 1941, owing to lag in equalization of pressures. By April, 1943, however, the pressure of most wells had equalized. The pressures of 12 of the 16 wells gauged in that month were between 99 and 117 pounds. The maximum difference in the pressures of these wells was only 10 pounds below and 8 pounds above the average of 109 pounds. The special conditions in the four wells not included in the average explain the failure of pressures in these wells to equalize with pressures in other parts of the pool. Two of these wells, the Sherrod No. 1 Lange Estate well, in the SW¼ NE¼ sec. 33, T. 9 S., R. 20 E., and the Longwell No. 1 Bartlett well, in the NW¼ SE¼ of the same section, were completed with higher pressures than the average on the date drilled. These wells are diagonal offsets of each other. The decline of pressure in these wells shows the same decline curve as the average of the field, but their pressures have remained consistently higher than other wells on the same date. There has not been any equalization of pressures with other parts of the field nor between these two wells. Examination of the logs of these wells indicates that both of these wells yield most of the gas from a sandy zone which is higher than the producing sand bodies in neighboring wells. Therefore, the pressures in these wells probably have not equalized with the pressures in other parts of the field because the producing sand bodies are at least partly cut off from the rest of the pool by less permeable zones of the sand.

The other two wells showing anomalous pressures also offset each other. The Aladdin No. 1 Edmonds well, in the SW¼ SW¼ sec. 34, T. 9 S., R. 20 E., is an edge well. It encountered a small amount of oil as well as gas. The accumulation of oil in the hole has interfered with the regular flow of gas and this has probably retarded the pressure decline in the area drained. The other well, the Longwell No. 1 Steenstry well, is a southeast diagonal offset of the Edmonds well. Its pressure is only 19 pounds per square inch above the average in other parts of the pool. The lag in equalization may reasonably be attributed to the influence of the Edmonds well and to the presence of an undrilled marginal area to the north and east.

In the calculations of ultimate production (table 10) the lag in pressure decline in these wells has been disregarded because the production is small,except in the Lange well, and the production of that well, although considerable, is small with respect to that of the whole pool.

North McLouth pool.—Fewer closed pressures have been taken in the North McLouth pool than in the McLouth pool, but those wells which have been tested on more than one date indicate a pressure decline conforming closely to the decline gradient in the McLouth pool. The initial closed pressure of the first wells drilled was 501 pounds per square inch, 11 pounds higher than the initial pressure in the McLouth pool. In April, 1943, the average closed pressure of four wells tested was 119 pounds per square inch. Although the data are less complete, it is probable that the average indicates a close approximation to pressures in other wells in the pool at the same date.

Ackerland pool.—In April, 1943, the Ackerland pool was much smaller than the other two pools in the field. The area of production is seemingly already outlined by drilling, but extensions of this pool may yet be developed. Inasmuch as some of the wells in this pool are of relatively recent date and as the porosity and occurrence of the sand bodies is more variable than in the other pools, the pressures of the wells have not yet equalized. The initial closed pressure of the Ackerland pool was 470 pounds per square inch (table 9 and fig. 20). The average pressure of the three wells in this pool which were gauged on April 27, 1943, was 139 pounds per square inch. There is a wider spread in the pressures of this date than in the other pools, as may be noted on the chart.

ESTIMATES OF ULTIMATE GAS PRODUCTION

Table 10 shows the production of gas from each of the three pools in the field as determined from the pipe-line runs of the two companies purchasing gas in the field. Volumes are calculated at 2 pounds above atmospheric pressure and at a temperature of 60° F. The total volume of recoverable gas in each pool has been calculated by Boyles law according to the formula

$$\frac{P\text{-}p}{p^1} \times V^1 = V$$

where P = the original closed pressure in the pool, p = the closed pressure at which production will be discontinued, p^1 = the closed pressure decline at a given date, V^1 = the cumulative volume of gas produced to the same date, and V = ultimate production of the pool.

Although the pressure at which it will become unprofitable to take gas from the pools is not now determinable, the abandonment

TABLE 10.—*Production of gas in the McLouth field by pools to April 1, 1943, calculated ultimate and future production, number of wells in each pool, and ultimate average production per acre.*

Pool	Cumulative production to April 1, 1943, M cu. ft.	Calculated ultimate production at gauge pressure of 10 lbs. per cu. in., M cu. ft.	Calculated future production after April 1, 1943, at gauge pressure of 10 lbs. per cu. in., M cu. ft.	Number of acres developed	Total ultimate average production per acre, M cu. ft.
McLouth	4,916,554.0	6,361,040.2	1,444,486.2	2570[1]	2,475.1
North McLouth	1,888,921.0	2,427,906.0	538,985.0	1220[2]	1,990.1
Ackerland	279,168.0	387,967.6	108,799.6	440[3]	881.7
Total	7,084,643.0	9,176,913.8	2,092,270.8	4230[4]	2,122.2

[1] Includes 170 acres yielding oil and gas; excludes 180 acres yielding oil only.
[2] Excludes 120 acres yielding oil only.
[3] Excludes 80 acres yielding oil only.
[4] Includes all areas yielding gas.

of production has been assumed to be at a pressure of 10 pounds per square inch. Gas is being produced from many wells in eastern Kansas at lower pressures where the distributing lines maintain a low pressure; because of the high pressures maintained in the Cities Service line to which the McLouth field is tributary, it is possible that the assumed end point of 10 pounds per square inch is too low. Table 10 shows the production to April 1, 1943, the calculated ultimate production, and the estimated future production of each pool.

The estimates of future production are probably more accurate for the McLouth pool than for either of the others because in that pool more decline pressures have been taken and because a greater equalization of pressures in different parts of the pool has taken place. The estimates for the Ackerland pool are least satisfactory because the equalization of pressures has not yet overcome the lag in the more recent wells. The possibility that this pool may be extended into areas where the pressures have not yet declined to the average pressure used in the calculation also casts doubt on the accuracy of the estimates.

The pressure decline in the McLouth field has been more rapid than in many gas fields. The absence of water drive in holding up pressures in the structurally higher parts of the pools is probably responsible in large part for the rapid decline. The absence of water in the productive sands, however, has made it possible, under stress of war demands, to draw on the pool more rapidly without damage from water encroachment than would have been possible if water advanced into sand with declining pressures.

Relation of Pressure in the McLouth Gas Pools to Overburden

The causes underlying the variations in initial pressures encountered in the gas pools of the McLouth field and in many other gas fields are uncertain, but it is permissible to speculate on the phenomena without arriving at a final conclusion.

Initial closed pressures of gas pools commonly are roughly in proportion to the depth of the reservoir rock below the surface, and the initial closed pressures of many pools approximate the hydrostatic head corresponding to the thickness of the overlying rocks. Initial closed pressures in gas pools, however, although in some cases greater than the hydrostatic head determined by the depth of the well, are generally somewhat less (Lilley, 1928). In this respect the low pressures of the McLouth field are not unusual.

The initial closed pressures of the three pools in the McLouth field, Ackerland, McLouth and North McLouth, were respectively 470, 490, and 501 pounds per square inch. The increase is in the direction of regional dip but this condition may not be significant. As shown in table 11, there appears to be no proportionate relation between the initial pressure of each pool and the overburden on the structural crest of the sand. Neither is there any proportionate relation between the pressures and the effective cover above the crest on other parts of the anticline. The hydrostatic head for these depths bears no relation to the actual initial pressures in the pools which were from 76 to 96 pounds per square inch lower than the minimum calculated hydrostatic heads for each pool.

If the pressures when the pools were discovered were dependent on or roughly proportionate to the stratigraphic cover, they were not established under present conditions. If the thickness of cover or hydrostatic head determines the pressure, the pressures in the several pools must have been much greater at the end of the Permian when rocks at least 2,000 feet thick lay above the rocks now exposed. At that time the rocks overlying the McLouth sand were at least 3,500 feet thick, or more than twice the thickness of the present cover.

TABLE 11.—*Relation of initial closed pressures to hydrostatic heads in pools of the McLouth field*

Pool	Initial closed pressure, lbs. per sq. in.	Altitude of McLouth sand on structural crest	Minimum thickness of overburden in well drilled to McLouth sand	Altitude of well	Hydrostatic head in well on crest of McLouth sand, lbs. per sq. in.	Thickness overburden from lowest point on surface to crest of sand on anticline	Hydrostatic head from lowest point on surface to crest of sand on anticline, lbs. per sq. in.
North McLouth	501	—360	1,348	969	584	1,329	576
McLouth	490	—310	1,310	978	591	1,288	558
Ackerland	470	—313	1,330	994	576	1,307	566

If an anticlinal reservoir had been completely sealed both against the escape of the gas transverse to the strata and against expansion in the reservoir sand (an improbable condition), the original pressures would be preserved during the erosion of the overburden and the pressures in the pools ("fossil pressures") would be disproportionately high for the reduced overburden. On the other hand, if the gas pressures in the reservoir had remained in balance as the overburden decreased, the excess gas must either have escaped transverse to the strata or expanded in the reservoir rock. In this case where the reservoir was sealed, the pressure in the reservoir would not fall below the pressure controlled by the thickness of the overburden or the hydrostatic head and would remain in balance with it. If the static pressure of the reservoir is expressed by the hydrostatic head, as some geologists have supposed, the pressures in the McLouth pools are below the pressures to be expected.

The McLouth field presents some features not known to be common in gas fields, although perhaps more common than generally recognized. The gas reservoirs are limited in volume by the tar and dried oil occupying the pores of the sandstone on the flanks of the anticlines, and the gas areas are thus sealed from the invasion of water farther down the dip and sealed against expansion into the gas sand. The pressures in the sand reservoir, therefore, might be expected to remain independent of the hydrostatic pressure exerted by the water in the sand.

The tar and dried oil must have entered the pores of the sand while still fluid, but it has been a long time since their volatile constituents escaped. If the desiccation occurred before the development of regional dip, the gas in the pools accumulated under an overburden having a thickness of 3,500 feet or more and its pressure should have been much greater than prevailed when the pools were drilled. Inasmuch as the pressures are lower than might be expected from the present depth, large quantities of gas must have escaped from the reservoirs charged to a pressure represented by such an overburden and large quantities of gas must have escaped also from the now desiccated oil. The gas did not expand into the reservoir sand inasmuch as the gas has not readjusted its position in the reservoir sand since the development of the post-Permian dip. It seems likely, therefore, that if gas escaped it must have escaped transverse to the overlying strata.

The variations in gas pressure in widely separated gas fields and the occasional observation of pressures in excess of the hydrostatic heads show that factors other than the depth of cover are involved. In the McLouth field and generally in eastern Kansas and many other regions, a detailed analysis of the structural history reveals abundant evidence of repeated structural movements. This is particularly evident in the McLouth field where there were differential structural adjustments throughout the Pennsylvanian and probably well into the Permian. These structural adjustments could not have occurred without a long series of earth shocks and more or less violent seismic tremors. During development of the post-Permian regional dip other vibrations must also have occurred. It may reasonably be supposed that these adjustments would be accompanied by phenomena similar to those of modern earthquakes and would include the temporary opening of crevices and fissures with the expulsion of water and at times gas, accompanied in many cases by only very small or no measurable rock displacements.

Under quiescent conditions, gas pressures might be built up in anticlinal reservoirs by the breaking down of source materials to a pressure in balance with the pressure exerted by the temporary overburden or by the temporary hydrostatic head. During subsequent periods of structural adjustment, part or all of the accumulated gas might be dissipated. Cycles of accumulation and release of gas pressures might continue theoretically as long as source materials continued to replenish the reservoir or until structural adjustments ceased. The exhaustion of sources of gas might prevent subsequent refilling of a reservoir to the limit of the controlling maximum pressure. In some areas where the source materials were exhausted, the reservoirs might be left barren after the escape of gas. The repeated release of accumulated pressures might result in some places in the lowering of the gravity of the oil remaining in the reservoir. Pressures below the local maximum determined by the overburden, as in most pools, might represent reservoirs not yet recharged. Pressures above the local maximum pressure might be preserved in places where erosion has reduced the overburden but where the excess pressure has not yet been released.

In the McLouth field, the final desiccation of the oil in the McLouth sand must have marked the end of regeneration of gas from this source. Some accessions of gas could have escaped into the reservoir sand from deeper oils that have not yet lost their volatile constituents but without building up the pressure to the controlling maximum at which the gas would either escape or remain in solution in the oil.

Oil Production

Table 12 shows that the cumulative production of oil in the McLouth field from all wells to April 1, 1943, was 175,879 barrels. The figures given in the table represent monthly sales rather than monthly production. During cold weather the oil from some of the wells is too viscous to flow. Oil from such wells is left in storage on the lease until weather conditions have moderated. Other wells show irregularities of sales owing to stoppage occasioned by cleaning out, acidizing, and mechanical difficulties connected with pumping. Under the circumstances the sales curves are unsuitable for showing production decline although no proration has been practiced. Neither the Mississippian dolomite, from which most of the oil is produced, nor the McLouth sand has any regularity of thickness or porosity by which ultimate production might plausibly be estimated by assuming a nominal production per acre. In consequence, no attempts have been made to determine the future production of the oil pools. It seems probable that considerably more oil will ultimately be produced than was produced before April 1, 1943.

TABLE 12.—*Monthly sales of oil from wells in the McLouth field and production of oil, in barrels, by pools and by counties, to April 1, 1943*

No.	Well Name	1940	1-41 to 6-41	6-41	7-41	8-41	9-41	10-41	11-41	12-41	1-42	2-42	3-42	4-42	5-42	6-42	7-42	8-42	9-42	10-42	11-42	12-42	1-43	2-43	3-43	Totals
	McLouth Pool (Mississippian Dolomite)																									
143.	Young, Longwell et al No. 1 Bessie McLeod	3,867.30	429.70																							4,297.00
142.	Young, Longwell et al No. 2 Bessie McLeod			130.00	66.00	252.83	271.67	566.25	195.29	335.41	418.74	307.87	306.87	186.17	239.50	179.00	179.50		178.50	60.00					544.00	4,417.60
164.	Young, Longwell et al No. 3 Bessie McLeod			887.00	2,581.00	1,457.72	3,506.87	2,585.99	2,567.01	2,672.00	2,356.54	1,766.75	3,044.58	2,366.94	2,702.50	3,157.50	2,636.00	2,169.50	2,335.00	2,394.00	1,855.00	1,920.00	1,950.00	1,061.50	1,210.00	49,183.40
158.	J. B. Apperson (Sowell) et al No. 1 D. E. Bower									297.50	2,939.50	1,978.50	1,799.50	2,095.50	2,211.00	1,732.30	2,162.00	1,914.50	1,735.00	1,972.50	1,140.00	495.00	839.00	900.00	2,738.00	26,949.80
156.	T. B. Swan et al No. 1 D. E. Bower											340.24	1,199.00	1,436.93	1,135.27	1,376.50	929.00	922.00	900.00	1,020.00	820.00	705.00	802.00	588.50	894.00	13,068.44
136.	J.B.Apperson (Sowell) et al No. 1 McLaughlin																419.50	1,257.00	682.50	1,139.00	1,020.00	2,475.00	5,358.50	3,882.00	3,457.50	19,691.00
137.	J.W.Billingsley et al No. 1 D. W. McLaughlin																				660.00	735.00	1,034.00	1,354.00	2,007.00	5,790.00
135.	Apperson-Stark et al No. 1 D. W. McLaughlin																						60.00	129.00	1,496.00	1,685.00
155.	J. E. Sherrod et al No. 1 D. E. Bower																								60.00	60.00
	Totals McLouth Pool	3,867.30	429.70	1,017.00	2,647.00	1,710.55	3,778.54	3,152.24	2,762.30	3,304.91	5,714.78	4,393.36	6,349.95	6,085.54	6,288.27	6,445.30	6,326.00	6,263.00	5,831.00	6,585.50	5,495.00	6,330.00	10,043.50	7,915.00	12,406.50	125,142.24
	Number of wells on production	1	1	2	2	2	2	2	2	3	3	4	4	4	4	4	5	4	5	5	5	5	6	6	8	
	Average sales per well per month	3,867.30	429.70	508.50	1,323.50	855.28	1,889.27	1,576.12	1,381.15	1,101.64	1,904.93	1,098.34	1,587.49	1,521.38	1,572.07	1,611.32	1,265.20	1,565.75	1,166.20	1,317.10	1,099.00	1,266.10	1,673.92	1,319.17	1,550.81	
	Bankers Life Pool (McLouth Sand)																									
126-9.	J.W.Longwell et al Nos. 1, 2, 3, 4 Bankers Life (Bessie McLeod)			1,020.00	2,298.00	2,036.53	1,358.73	1,563.83	2,045.33	2,576.80	2,247.63	2,025.02	1,940.50	1,750.61	2,093.10	1,738.00	1,980.50	1,620.00	1,380.00	1,439.50	1,500.00	1,395.00	1,631.50	1,434.50	1,644.00	38,719.08
124.	Apperson, Pundt et al No. 1 W. H. Steenstry									120.00	60.00	238.50	59.50	60.00	179.50											717.50
130.	W.Schooler et al No. 1 Bankers Life (B. McLeod)												178.50	178.50	179.50	180.00			180.00	120.00	180.00	60.00	19.50	79.50	112.00	1,467.50
	Totals Bankers Life Pool			1,020.00	2,298.00	2,036.53	1,358.73	1,563.83	2,045.33	2,696.80	2,307.63	2,263.52	2,178.50	1,989.11	2,452.10	1,918.00	1,980.50	1,620.00	1,560.00	1,559.50	1,680.00	1,455.00	1,651.00	1,514.00	1,756.00	40,904.08
	Number of wells on production			1	2	2	2	2	3	5	5	5	6	6	6	5	4	4	5	5	5	5	5	5	5	
	Average sales per well per month			1,020.00	1,149.00	1,018.26	679.36	781.92	681.78	539.36	461.53	452.70	363.08	331.52	408.68	383.60	495.12	405.00	312.00	311.90	336.00	291.00	330.20	302.80	351.20	
	Scattered Wells in McLouth Sand																									
62.	Willard Archie et al No. 1 Perry Shrader					142.50	40.00		24.00	127.37							45.00									378.87
23.	Ray Anderson et al No. 1 May Dick									535.50	476.00	416.50	416.50	417.50	379.00	300.00	331.00	180.00	300.00	299.50	180.00	120.00	420.00	180.00	194.00	5,145.50
74.	Magnolia No. 1 Mathew C. Woodhead														93.00	271.00	200.00	246.00	184.00	187.00	151.00	164.00	81.00	223.00	154.00	1,954.00
21.	Hatcher & Fisk No. 1 Elijah Edmonds																123.00	129.00	365.00	253.00	254.00	236.00	207.00	175.00	195.00	1,937.00
190.	Miller-Magnolia et al No. 3 J. A. Bell																							67.00	185.00	252.00
193.	Miller-Magnolia et al No. 1 E. E. Jeannin																								166.00	166.00
	Totals scattered wells					142.50	40.00		24.00	662.87	476.00	416.50	416.50	417.50	472.00	571.00	699.00	555.00	849.00	739.50	585.00	520.00	708.00	645.00	894.00	9,833.37
	Number of wells on production					1	1		1	2	1	1	1	1	2	2	4 •	3	3	3	3	3	3	4	5	
	Average sales per well per month					142.50	40.00		24.00	331.44	476.00	416.50	416.50	417.50	236.00	285.50	174.75	185.00	283.00	246.50	195.00	173.33	236.00	161.25	178.80	
	Totals McLouth Field	3,867.30	429.70	2,037.00	4,945.00	3,889.58	5,177.27	4,716.07	4,831.63	6,664.58	8,498.41	7,073.38	8,944.95	8,492.15	9,212.37	8,934.30	9,005.50	8,438.00	8,240.00	8,884.50	7,760.00	8,305.00	12,402.50	10,074.00	15,056.50	175,879.69

Production of Oil By Pools
(barrels)

Pool	1940	1941	1942	1943 (3 mo.)
McLouth Oil Pool	3,867.30	18,802.24	72,107.70	30,365.00
Bankers Life Pool		13,019.22	22,963.86	4,921.00
Scattered Wells		869.37	6,717.00	2,247.00
Totals	3,867.30	32,690.83	101,788.56	37,533.00

Production of Oil By Counties
(barrels)

	1940	1941	1942	1943 (3 mo.)	Total
Jefferson	3,867.30	19,671.61	78,824.70	32,194.00	134,557.61
Leavenworth		13,019.22	22,963.86	5,339.00	41,322.08

MC LOUTH MISSISSIPPIAN OIL POOL

The McLouth oil pool in Mississippian rocks covers an area of approximately 230 acres with 16 oil wells either producing or drilling on April 1, 1943. The cumulative production of the pool to that date was 125,142 barrels. Since April 1, 1943, several wells not listed in the production table have been completed which, after acidizing, are reported to yield from 50 to 150 barrels of oil per day. These wells when put on production together with wells completed earlier will probably raise the production to 800 or 1,000 barrels of oil per day.

Some indication of water encroachment has been detected in the Young and Longwell No. 4 McLeod well, in the SW¼ NE¼ SE¼ sec. 5, T. 10 S., R. 20 E. This well, which was completed as an oil well in April, 1943, was drilled into water in the dolomite and was plugged back. The water was encountered at an altitude of -510, 9 feet higher than the water level in a well drilled on an adjoining lease to the south (the Apperson and Pundt No. 1 McLeod well) (fig. 11). This well and others drilled in 1941 found water in the dolomite at or near an altitude of -519. At the time the No. 4 McLeod well was drilled, the Young and Longwell No. 3 McLeod well, the nearest well up dip and the most productive well in the pool, had been on production 20 months and had yielded 49,000 barrels of oil. Other wells on the crest of the dome had also yielded considerable oil. The unexpectedly high position of the water level in the No. 4 McLeod well seems to be plausibly attributed to water encroachment.

None of the wells in the McLouth oil pool have been abandoned except the Young and Longwell No. 1 McLeod well. This well, an edge well drilled through a tension fault, was drowned out by water after having yielded 4,296 barrels of oil. None of the oil wells in the McLouth pool yield commercial amounts of gas.

BANKERS LIFE POOL

The Bankers Life pool in sec. 3, T. 10 S., R. 20 E. includes six wells yielding oil from the McLouth sand. The pool has a developed area of 130 acres. The cumulative production to April 1, 1943, was approximately 41,000 barrels. Production figures for individual wells were not kept separately, but the collective production has had a slow decline from 2,000 barrels to 1,600 barrels per month over a period of 21 months. In view of the history of some of the wells, it is probable that part of the lost production could be restored by cleaning out the wells. These wells make very little water and only enough gas to operate the pumps. The regularity of production of these wells implies that they may have a longer life than the more productive wells in the Mississippian rocks.

SCATTERED WELLS

The scattered wells, of which there are six listed in the production table, yield small amounts of oil from the McLouth sand, but the total production is small. The cumulative production of all these wells, two of which had been on production less than two months, was 9,833 barrels. The Archie No. 1 Shrader well, in the SE¼ SW¼ sec. 28, T. 9 S., R. 20 E., although not pumped during the winter months, has not been abandoned.

In April, two gas wells in the North McLouth pool were deepened in the McLouth sand by the Magnolia Petroleum Company and are making a small production of oil. These wells are the Hatcher and Fisk No. 2 Elijah Edmonds well, in the SW¼ NW¼ sec. 21, T. 9 S., R. 20 E., and the Hatcher and Fisk No. 2 Ralph Edmonds well, in the SE¼ NW¼ of the same section.

CHARACTER AND ORIGIN OF GAS AND OIL

ANALYSES OF OIL

Five Hempel analyses of oil from the McLouth field are presented in tables 13 to 17. Three of the samples are of oil from the McLouth sand, one from each of three pools. Two of the samples are of oil from the dolomite zone of the Mississippian limestone in the McLouth pool, one from a well on the crest of the pool and the other on the flank. These five analyses were made by J. G. Crawford in the laboratory of the U. S. Geological Survey at Casper, Wyoming, at barometric pressures averaging 630 mm. Three Hempel analyses of oil from the Falls City field in Richardson county, Nebraska, are presented in tables 18 to 20 for comparison. These analyses were made by the U.S. Bureau of Mines at Bartlesville, Oklahoma, at barometric pressures averaging 744 mm. Two of these samples are from Devonian limestone, one from the Falls City pool and the other from the Barada pool. The third sample is from the Kimmswick (=Viola limestone) of the Dawson pool.

TABLE 13.—*McLouth sand, McLouth oil and gas pool. Hempel analysis of crude oil in the Longwell et al. No. 1 Bankers Life (Fred McLeod) well, NW¼ SW¼ sec. 3, T. 10 S., R. 20 E., Leavenworth county, Kansas. Depth 1,438 to 1,450 feet.*

(Analysis by J. G. Crawford, Geol. Sur., Dept. of Interior, Casper, Wyo.)

GENERAL CHARACTERISTICS

Specific Gravity	0.905	A.P.I. Gravity	24.9°
Percent Sulphur	0.75	Pour point	5°F.
		Color	Black

Saybolt Universal Viscosity at 100° F., 424 sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry Distillation; Barometer, 634 mm; First Drop, 86° C. (187° F.)									
1	Up to 50	....	....	....	....				Up to 122
2	50- 75	....	....	....	....				122-167
3	75-100	0.8	0.8						167-212
4	100-125	2.1	2.9	.747	57.9				212-257
5	125-150	2.5	5.4						257-302
6	150-175	3.3	8.7	.754	56.2	16			302-347
7	175-200	4.5	13.2	.763	54.0	14			347-392
8	200-225	5.1	18.3	.774	51.3	13			392-437
9	225-250	5.8	24.1	.786	48.5	14			437-482
10	250-275	9.1	33.2	.802	44.9	16			482-527
Vacuum distillation at 40 mm									
11	Up to 200	0.1	0.1						Up to 392
12	200-225	4.7	4.8	.843	36.4	27+	45	30	392-437
13	225-250	4.1	8.9	.858	33.4	30	52	45	437-482
14	250-275	3.8	12.7	.877	29.9	36	69	60	482-527
15	275-300	6.2	18.9	.895	26.6	42	115	75	527-572

Carbon residue of residuum, 20.2 percent; carbon residue of crude, 10.3 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	0.8	......	......	
Total gasoline and naphtha	13.2	.754	56.2	
Kerosene distillate	20.0	.790	47.6	
Gas oil	5.6	.844	36.2	Below 50
Nonviscuous lubricating distillate	8.6	.854-.889	34.2-27.7	50-100
Medium lubricating distillate	4.7	.889-.906	27.7-24.7	100-200
Viscous lubricating distillate	......	......	......	
Residuum	46.0	1.019	......	
Distillation loss	1.9	......	......	
Base, Paraffin - intermediate.				

TABLE 14.—*McLouth sand, North McLouth oil and gas pool. Hempel analysis of crude oil in the Ray Anderson No. 1 May Dick well, SE¼ SW¼ sec. 17, T. 9 S., R. 20 E., Jefferson county, Kansas. Depth 1,464 to 1,479 feet.*

(Analysis by J. G. Crawford, Geol. Sur., Dept. of Interior, Casper, Wyo.)

GENERAL CHARACTERISTICS (Dehydrated oil)

Specific Gravity	0.924	A.P.I. Gravity	21.6°
Percent Sulphur	0.99	Pour point	10°F.
		Color	Black

Saybolt Universal Viscosity at 100° F., 2160 sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD (Dehydrated oil)

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry Distillation; Barometer, 622 mm; First Drop, 93°C. (199°F.)									
1	Up to 50	....	....	....	....				Up to 122
2	50- 75	....	....	....	....				122-167
3	75-100	0.5	0.5						167-212
4	100-125	1.7	2.2	.744	58.7				212-257
5	125-150	2.4	4.6						257-302
6	150-175	3.3	7.9	.750	57.2	14			302-347
7	175-200	4.2	12.1	.761	54.4	13			347-392
8	200-225	4.5	16.6	.773	51.6	13			392-437
9	225-250	5.9	22.5	.787	48.3	14			437-482
10	250-275	8.2	30.7	.802	44.9	16			482-527
Vacuum distillation at 40 mm									
11	Up to 200	....	....	....	....		....	....	Up to 392
12	200-225	4.3	4.3	.843	36.4	27	45	35	392-437
13	225-250	4.4	8.7	.859	33.2	31	53	45	437-482
14	250-275	6.0	14.7	.884	28.6	40	80	65	482-527
15	275-300	11.4	26.1	.900	25.7	44	116	80	527-572

Carbon residue of residuum, 21.3 percent; carbon residue of crude, 9.8 percent.

APPROXIMATE SUMMARY (Dehydrated oil)

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	0.5	.....	.....	
Total gasoline and naphtha	12.1	.752	56.7	
Kerosene distillate	18.6	.790	47.6	
Gas oil	5.0	.844	36.2	Below 50
Nonviscous lubricating distillate	11.5	.853-.893	34.4-27.0	50-100
Medium lubricating distillate	9.6	.893-.910	27.0-24.0	100-200
Viscous lubricating distillate	.....	.....	.....	
Residuum	41.6	1.047	.....	
Distillation loss	1.6	.....	.....	

Base, Paraffin - intermediate.

TABLE 15.—*Basal McLouth sand, Ackerland oil and gas pool. Hempel analysis of crude oil in the Miller No. 1 Jeannin well, NE¼ NW¼ sec. 7, T. 10 S., R. 21 E., Leavenworth county, Kansas. Depth 1,386 to 1,414 feet.*

(Analysis by J. G. Crawford, Geol. Sur., Dept. of Interior, Casper, Wyo.)

GENERAL CHARACTERISTICS

Specific Gravity	0.907	A.P.I. Gravity	24.5°
Percent Sulphur	0.86	Pour point	Below 5°F.
		Color	Black

Saybolt Universal Viscosity at 100° F., 427 sec.; (at 70° F., 975 sec.)

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry Distillation; Barometer, 627 mm; First drop, 89° C. (192° F.)									
1	Up to 50	....	....	....	....				Up to 122
2	50-75	....	....	....	....				122-167
3	75-100	0.8	0.8						167-212
4	100-125	1.7	2.5	.746	58.2				212-257
5	125-150	2.2	4.7						257-302
6	150-175	2.8	7.5	.753	56.4	15			302-347
7	175-200	4.2	11.7	.761	54.4	13			347-392
8	200-225	5.6	17.3	.771	52.0	12			392-437
9	225-250	6.2	23.5	.785	48.8	13			437-482
10	250-275	7.6	31.1	.799	45.6	15			482-527
Vacuum distillation at 40 mm									
11	Up to 200	....	....	....	....		....	....	Up to 392
12	200-225	5.0	5.0	.840	37.0	25	45	30	392-437
13	225-250	4.2	9.2	.855	34.0	29	51	40	437-482
14	250-275	4.2	13.4	.876	30.0	36	68	60	482-527
15	275-300	4.4	17.8	.894	26.8	41	109	75	527-572

Carbon residue of residuum, 20.0 percent; carbon residue of crude, 10.5 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	0.8	....	....	
Total gasoline and naphtha	11.7	.753	56.4	
Kerosene distillate	19.4	.786	48.5	
Gas oil	6.3	.842	36.6	Below 50
Nonviscous lubricating distillate	8.4	.852-.890	34.6-27.5	50-100
Medium lubricating distillate	3.1	.890-.903	27.5-25.2	100-200
Viscous lubricating distillate	....	....	....	
Residuum	48.0	1.017	....	
Distillation loss	3.1	....	....	

Base, Paraffin - intermediate.

TABLE 16.—*Mississippian dolomite, McLouth oil and gas pool. Hempel analysis of crude oil in the Young and Longwell No. 3 Bessie McLeod well, NE¼ SE¼ sec. 5, T. 10 S., R. 20 E., Jefferson county, Kansas. Depth 1,635 to 1,644 feet.*

(Analysis by J. G. Crawford, Geol. Sur., Dept. of Interior, Casper, Wyo.)

GENERAL CHARACTERISTICS

Specific Gravity	0.912	A.P.I. Gravity	23.7°
Percent Sulphur	0.77	Pour point	5° F.
		Color	Black

Saybolt Universal Viscosity at 100° F., 695 sec. B.S., mud and water (by centrifuge)

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	Sp. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry Distillation; Barometer, 635 mm; First Drop, 83° C. (181° F.)									
1	Up to 50	....	....	....	....				Up to 122
2	50-75	....	....	....	....				122-167
3	75-100	0.7	0.7						167-212
4	100-125	1.6	2.3	.741	59.5				212-257
5	125-150	2.3	4.6						257-302
6	150-175	3.3	7.9	.756	55.7	17			302-347
7	175-200	4.3	12.2	.764	53.7	14			347-392
8	200-225	4.9	17.1	.775	51.1	14			392-437
9	225-250	5.9	23.0	.788	48.1	15			437-482
10	250-275	9.8	32.8	.802	44.9	16			482-527
Vacuum distillation at 40 mm									
11	Up to 200	0.4	0.4						Up to 392
12	200-225	5.2	5.6	.847	35.6	28+	46	30	392-437
13	225-250	3.7	9.3	.863	32.5	33	55	45	437-482
14	250-275	3.8	13.1	.882	28.9	39	78	60	482-527
15	275-300	11.7	24.8	.897	26.3	43	136	75	527-572

Carbon residue of residuum, 21.3 percent; carbon residue of crude, 9.8 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	0.7	....	....	
Total gasoline and naphtha	12.2	.753	56.4	
Kerosene distillate	20.6	.792	47.2	
Gas oil	4.9	.846	35.8	Below 50
Nonviscous lubricating distillate	9.2	.854-.888	34.2-27.9	50-100
Medium lubricating distillate	10.7	.888-.908	27.9-24.3	100-200
Viscous lubricating distillate	....	....	....	
Residuum	41.8	1.022	....	
Distillation loss	0.6	....	....	
Base, Paraffin - intermediate				

TABLE 17.—*Mississippian dolomite, McLouth oil and gas pool. Hempel analysis of crude oil in the Apperson et al. No. 1 Bower well, SE¼ NE¼ sec. 5, T. 10 S., R. 20 E., Jefferson county, Kansas. Depth 1,595 to 1,605 feet.*

(Analysis by J. G. Crawford, Geol. Sur., Dept. of Interior, Casper, Wyo.)

GENERAL CHARACTERISTICS (Dehydrated oil)

Specific Gravity	0.916	A.P.I. Gravity	23.0°
Percent Sulphur	0.81	Pour point	5° F.
		Color	Black

Saybolt Universal Viscosity at 100° F., 1455 sec. B.S., mud and water (by centrifuge)

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry distillation; Barometer, 630 mm; First drop, 76° C. (169° F.)									
1	Up to 50	....	....	....	....				Up to 122
2	50-75	....	....	....	....				122-167
3	75-100	0.7	0.7						167-212
4	100-125	1.8	2.5	.739	60.0				212-257
5	125-150	2.2	4.7						257-302
6	150-175	3.1	7.8	.746	58.2	12			302-347
7	175-200	4.2	12.0	.756	55.7	11			347-392
8	200-225	4.3	16.3	.769	52.5	11			392-437
9	225-250	6.5	22.8	.784	49.0	13			437-482
10	250-275	8.2	31.0	.801	45.2	16			482-527
Vacuum distillation at 40 mm									
11	Up to 200	....	....	......	......	....	....	....	Up to 392
12	200-225	4.3	4.3	.840	37.0	25	44	35	392-437
13	225-250	4.2	8.5	.853	34.4	28	49	45	437-482
14	250-275	5.1	13.6	.875	30.2	35	68	60	482-527
15	275-300	6.9	20.5	.896	26.4	42	112	75	527-572

Carbon residue of residuum, 19.5 percent; carbon residue of crude, 10.0 percent.

APPROXIMATE SUMMARY (Dehydrated oil)

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	0.7	....	....	
Total gasoline and naphtha	12.0	.747	57.9	
Kerosene distillate	19.0	.788	48.1	
Gas oil	6.7	.843	36.4	Below 50
Nonviscous lubricating distillate	8.7	.854-.890	34.2-27.5	50-100
Medium lubricating distillate	5.1	.890-.908	27.5-24.3	100-200
Viscous lubricating distillate	....	....	....	
Residuum	46.0	1.032	....	
Distillation loss	2.5	....	....	

Base, Paraffin - intermediate

TABLE 18.—*Devonian limestone, Barada pool. Hempel analysis of crude oil in the Skelly Oil Company No. 1 H. Roesch well, CN½ NW¼ sec. 36, T. 3 N., R. 16 E., Falls City field, Richardson county, Nebraska. Depth 2,432 to 2,517 feet.*

(Analysis by Bureau of Mines, Dept. of Interior, at Bartlesville, Okla.)

GENERAL CHARACTERISTICS

Specific Gravity ....0.881 A.P.I. Gravity ....29.1°

Percent Sulphur ....0.41 Color ....Brownish-black

Saybolt Universal viscosity at 100° F., 140 sec.; at 130° F., 87 sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry distillation; Barometer, 747 mm; First drop, 72° C. (163°F.)									
1	Up to 50	....	....	....	....				Up to 122
2	50-75	....	....	....	....				122-167
3	75-100	0.4	0.4	.719	65.3	....			167-212
4	100-125	0.3	0.7	.720	65.0	12			212-257
5	125-150	0.4	1.1	.730	62.3	9.4			257-302
6	150-175	2.2	3.3	.743	58.9	8.8			302-347
7	175-200	3.3	6.5	.757	55.4	9.2			347-392
8	200-225	3.4	9.9	.773	51.6	11			392-437
9	225-250	4.6	14.5	.788	48.1	13			437-482
10	250-275	7.5	22.0	.803	44.7	15			482-527
Vacuum distillation at 40 mm									
11	Up to 200	5.3	27.3	.818	41.5	19	39	20	Up to 392
12	200-225	10.6	37.9	.827	39.6	19	43	35	392-437
13	225-250	7.2	45.1	.846	35.8	25	51	45	437-482
14	250-275	5.8	50.9	.866	31.9	31	75	65	482-527
15	275-300*	5.7	56.6	.882	28.9	....	115	80	527-572*

Carbon residue of residuum, 12.8 percent; carbon residue of crude, 5.5 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	0.4	.719	65.3	
Total gasoline and naphtha	6.5	.747	57.9	
Kerosene distillate	15.5	.792	47.2	
Gas oil	18.5	.830	39.0	Below 50
Nonviscous lubricating distillate	11.1	.844-.876	36.2-30.0	50-100
Medium lubricating distillate	5.0	.876-.890	30.0-27.5	100-200
Viscous lubricating distillate	....	....	....	Above 200
Residuum	42.8	.961	15.7	
Distillation loss	0.6	....	....	

*discontinued 297° C. (567° F.)

TABLE 19.—*Devonian limestone, Falls City pool. Hempel analysis of crude oil in the Pawnee Royalty Company No. 1 Bushels well, CNW¼ SW¼ sec. 17, T. 1 N., R. 16 E., Falls City field, Richardson county, Nebraska. Depth 2,217 to 2,230 feet.*

(Analysis by Bureau of Mines, Dept. of Interior, at Bartlesville, Okla.)

GENERAL CHARACTERISTICS

Specific gravity ....0.866 A.P.I. gravity ....31.9°
Percent Sulphur ....0.37 Color .... Greenish-black
Saybolt Universal viscosity at 77° F., 125 sec.; at 100° F., 84 sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	° A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry distillation; Barometer, 749 mm; First drop, 94° C. (201° F.)									
1	Up to 50								Up to 122
2	50— 75								122—167
3	75—100	0.1	0.1	.647	87.2	......			167—212
4	100—125	1.0	1.1	.694	72.4	0.1			212—257
5	125—150	1.8	2.9	.721	64.8	5.1			257—302
6	150—175	2.9	5.8	.741	59.5	7.8			302—347
7	175—200	4.0	9.8	.755	55.9	8.2			347—392
8	200—225	4.3	14.1	.769	52.5	9.3			392—437
9	225—250	6.2	20.3	.782	49.5	10			437—482
10	250—275	8.1	28.4	.794	46.7	11			482—527
Vacuum distillation at 40 mm									
11	Up to 200	5.9	34.3	.814	42.3	17	39	20	Up to 392
12	200—225	9.5	43.8	.826	39.8	19	42	35	392—437
13	225—250	6.7	50.5	.842	36.6	23	49	50	437—482
14	250—275	5.2	55.7	.862	32.7	29	68	60	482—527
15	275—300	6.1	61.8	.880	29.3	35	110	80	527—572

Carbon residue of residuum, 10.4 percent; carbon residue of crude, 4.0 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	° A.P.I.	Viscosity
Light gasoline	0.1	.647	87.2	
Total gasoline and naphtha	9.8	.757	60.5	
Kerosene distillate	18.6	.784	49.0	
Gas oil	19.2	.826	39.8	Below 50
Nonviscous lubricating distillate	9.8	.843-.875	36.4-30.2	50-100
Medium lubricating distillate	4.4	.875-.890	30.2-27.5	100-200
Viscous lubricating distillate	......	......	......	Above 200
Residuum	38.0	.956	16.5	
Distillation loss	0.2	......	......	

TABLE 20.—*Kimmswick (=Viola) limestone, Dawson pool. Hempel analysis of crude oil in the Skelly Oil Company No. 1 Wiltse well, sec. 10,T. 1 N., R. 14 E., Falls City field, Richardson county, Nebraska.*

(Analysis by Bureau of Mines, Dept. of Interior, at Bartlesville, Okla.)

GENERAL CHARACTERISTICS

Specific gravity ....0.880 A.P.I. Gravity ....29.3°
Percent Sulphur ....0.33 Color .... Brownish-black
Saybolt Universal viscosity at 100° F., 165 sec.; at 130° F., 96 sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	° A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry distillation; Barometer, 741 mm; First drop, 66° C. (151° F.)									
1	Up to 50								Up to 122
2	50— 75								122—167
3	75—100	1.3	1.3	.696	71.8				167—212
4	100—125	1.1	2.4	.716	66.1	10			212—257
5	125—150	2.3	4.7	.725	63.7	7.0			257—302
6	150—175	2.6	7.3	.744	58.7	9.2			302—347
7	175—200	3.9	11.2	.757	55.4	9.2			347—392
8	200—225	3.9	15.1	.770	52.3	9.7			392—437
9	225—250	5.3	20.4	.783	49.2	11			437—482
10	250—275	8.0	28.4	.795	46.5	12			482—527
Vacuum distillation at 40 mm									
11	Up to 200	4.1	32.5	.814	42.3	17	39	30	Up to 392
12	200—225	9.3	41.8	.823	40.4	17	43	40	392—437
13	225—250	5.9	47.7	.843	36.4	23	50	50	437—482
14	250—275	4.3	52.0	.863	32.5	30	70	65	482—527
15	275—300	4.5	56.5	.879	29.5	34	110	80	527—572

Carbon residue of residuum, 16.3 percent; carbon residue of crude, 7.0 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	° A.P.I.	Viscosity
Light gasoline	1.3	.696	71.8	
Total gasoline and naphtha	11.2	.736	60.8	
Kerosene distillate	17.2	.786	48.5	
Gas oil	16.4	.827	39.6	Below 50
Nonviscous lubricating distillate	8.4	.843-.875	36.4-30.2	50-100
Medium lubricating distillate	3.3	.875-.887	30.2-28.0	100-200
Viscous lubricating distillate	.....	.....	.....	Above 200
Residuum	43.0	.980	12.9	
Distillation loss	0.5	.....	.....	

TABLE 21.—*Devonian limestone, Dawson pool. Hempel analysis of crude oil in the Frank Powers No. 1A Albin Estate well, SW¼ NW¼ SW¼ sec. 10, T. 1 N., R. 14 E., Falls City field, Richardson county, Nebraska. Depth 2,220 to 2,230 feet.*

(Analysis by J. G. Crawford, Geol. Sur., Dept. of Interior, Casper, Wyo.)

GENERAL CHARACTERISTICS

Specific gravity	0.910	A.P.I. Gravity	24.0°
Percent Sulphur	0.27	Pour point	10° F.
		Color	Black

Saybolt Universal Viscosity at 100° F., 660 sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry distillation; Barometer, 632 mm; First drop, 154° C. (309° F.)									
1	Up to 50								Up to 122
2	50— 75								122—167
3	75—100								167—212
4	100—125								212—257
5	125—150								257—302
6	150—175	1.5	1.5	.767	53.0	....			302—347
7	175—200	2.5	4.0			....			347—392
8	200—225	3.0	7.0	.777	50.6	15			392—437
9	225—250	4.3	11.3	.787	48.3	14			437—482
10	250—275	8.5	19.8	.801	45.2	16			482—527
Vacuum distillation at 40 mm									
11	Up to 200	....	......	......	......				Up to 392
12	200—225	8.4	8.4	.834	38.2	22	45	35	392—437
13	225—250	6.0	14.4	.848	35.4	26	52	50	437—482
14	250—275	5.9	20.3	.867	31.7	31	73	65	482—527
15	275—300	10.9	31.2	.885	28.4	37	124	80	527—572

Carbon residue of residuum, 14.1 percent; carbon residue of crude, 7.2 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	° A.P.I.	Viscosity
Light gasoline	......	......	......	
Total gasoline and naphtha	4.0	.767	53.0	
Kerosene distillate	15.8	.793	46.9	
Gas oil	9.4	.835	38.0	Below 50
Nonviscous lubricating distillate	12.4	.844-.876	36.2-30.0	50-100
Medium lubricating distillate	9.4	.876-.897	30.0-26.3	100-200
Viscous lubricating distillate	......	......	......	Above 200
Residuum	47.2	.990	11.4	
Distillation loss	1.8	......	......	

Base, Paraffin - intermediate

TABLE 22.—*Devonian limestone, Shubert pool. Hempel analysis of crude oil in the Black Gold Operating Company No. 1 Smith well, E½ NW¼ NW¼ sec. 31, T. 3 N., R. 16 E., Falls City field, Richardson county, Nebraska. Depth 2,513 to 2,521 feet.*

(Analysis by J. G. Crawford, Geol. Sur., Dept. of Interior, Casper, Wyo.)

GENERAL CHARACTERISTICS

Specific gravity	0.884	A.P.I. Gravity	28.6°
Precent Sulphur	Less than 0.1	Pour point	5° F.
		Color	Black

Saybolt Universal viscosity at 100°F., 170 sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry distillation; Barometer, 636 mm; First drop, 135° C. (275° F.)									
1	Up to 50								Up to 122
2	50— 75								122—167
3	75—100								167—212
4	100—125								212—257
5	125—150	1.1	1.1	.755	55.9	....			257—302
6	150—175	2.7	3.8			....			302—347
7	175—200	4.0	7.8	.761	54.4	13			347—392
8	200—225	4.6	12.4	.771	52.0	12			392—437
9	225—250	6.1	18.5	.783	49.2	12			437—482
10	250—275	9.6	28.1	.797	46.0	14			482—527
Vacuum distillation at 40 mm									
11	Up to 200	1.2	1.2	.827	39.6	23	42	25	Up to 392
12	200—225	8.6	9.8	.831	38.8	21	44	35	392—437
13	225—250	6.2	16.0	.847	35.6	25	53	40	437—482
14	250—275	5.0	21.0	.865	32.1	31	72	60	482—527
15	275—300	7.5	28.5	.884	28.6	37	112	80	527—572

Carbon residue of residuum, 7.5 percent; carbon residue of crude, 3.4 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	° A.P.I.	Viscosity
Light gasoline	......	......	......	
Total gasoline and naphtha	7.8	.758	55.2	
Kerosene distillate	20.3	.787	48.3	
Gas oil	10.4	.831	38.8	Below 50
Nonviscous lubricating distillate	12.4	.842-.878	36.6-29.7	50-100
Medium lubricating distillate	5.7	.878-.896	29.7-26.4	100-200
Viscous lubricating distillate	......	......	......	Above 200
Residuum	41.8	.980	12.9	
Distillation loss	1.6	......	......	

Base, Paraffin - intermediate

TABLE 23.—*Devonian limestone, Barada pool. Hempel analysis of crude oil in the Skelly Oil Co. No. 1 Henry Roesch well, CN½ NW¼ sec. 36, T. 3 N., R. 16 E., Falls City field, Richardson county, Nebraska. Depth 2,439 to 2,488 feet.*

(Analysis by J. G. Crawford, Geol. Sur., Dept. of Interior, Casper, Wyo.)

GENERAL CHARACTERISTICS

Specific Gravity	0.882	A.P.I. Gravity	28.9°
Percent Sulphur	0.37	Pour point	15°F.
		Color	Black

Saybolt Universal Viscosity at 100°F., 138 sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Tempera-ture °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Vis-cosity at 100° F.	Cloud test °F.	Tempera-ture °F.
Dry distillation; Barometric pressure, 631 mm; First drop, 153° C. (307° F.)									
1	Up to 50								Up to 122
2	50— 75								122—167
3	75—100								167—212
4	100—125								212—257
5	125—150								257—302
6	150—175	2.3	2.3	.754	56.2	16			302—347
7	175—200	3.4	5.7	.764	53.7	14			347—392
8	200—225	3.9	9.6	.775	51.1	14			392—437
9	225—250	5.4	15.0	.788	48.1	15			437—482
10	250—275	8.6	23.6	.802	44.9	16			482—527
Vacuum distillation at 40 mm									
11	Up to 200	1.4	1.4	.825	40.0	22	41	20	Up to 392
12	200—225	9.4	10.8	.831	38.8	21	43	35	392—437
13	225—250	7.5	18.3	.843	36.4	23	50	45	437—482
14	250—275	5.1	23.4	.860	33.0	28	64	60	482—527
15	275—300	6.9	30.3	.879	29.5	34	101	75	527—572

Carbon residue of residuum,11.2 percent; carbon residue of crude, 5.3 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	° A.P.I.	Viscosity
Light gasoline	......	......	......	
Total gasoline and naphtha	5.7	.760	54.7	
Kerosene distillate	17.9	.792	47.2	
Gas oil	14.6	.833	38.4	Below 50
Nonviscous lubricating distillate	12.1	.843-.879	36.4-29.5	50-100
Medium lubricating distillate	3.6	.879-.890	29.5-27.5	100-200
Viscous lubricating distillate	......	......	......	Above 200
Residuum	43.9	960	15.9	
Distillation loss	2.2	......	......	

Base, Paraffin - intermediate

TABLE 24.—*Devonian limestone, Falls City pool. Hempel analysis of crude oil in the Harry Harper No. 1 Sibbernsen well, SE¼ NE¼ NW¼ sec. 20, T. 1 N., R. 16 E., Falls City field, Richardson county, Nebraska. Depth 2,210 to 2,236 feet.*

(Analysis by J. G. Crawford, Geol. Sur., Dept. of Interior, Casper, Wyo.)

GENERAL CHARACTERISTICS

Specific gravity	0.868	A.P.I. Gravity	31.5°
Percent Sulphur	0.13	Pour point	20°F.
		Color	Brownish-Black

Saybolt Universal Viscosity at 100° F., 86 sec.

DISTILLATION, BUREAU OF MINES, HEMPEL METHOD

Fraction No.	Temperature °C.	Percent cut	Sum percent	SP. Gr. of cut 60/60° F.	°A.P.I. of cut 60° F.	C.I.	S.U. Viscosity at 100° F.	Cloud test °F.	Temperature °F.
Dry distillation; Barometer, 635 mm; First drop, 124° C. (255° F.)									
1	Up to 50								Up to 122
2	50— 75								122—167
3	75—100								167—212
4	100—125								212—257
5	125—150	2.6	2.6	.749	57.4	20			257—302
6	150—175	3.2	5.8	.755	55.9	16			302—347
7	175—200	4.4	10.2	.765	53.5	15			347—392
8	200—225	5.2	15.4	.776	50.9	14			392—437
9	225—250	6.6	22.0	.789	47.8	15			437—482
10	250—275	9.5	31.5	.803	44.7	17			482—527
Vacuum distillation at 40 mm									
11	Up to 200	2.0	2.0	.825	40.0	22	40	25	Up to 392
12	200—225	9.5	11.5	.833	38.4	22	44	35	392—437
13	225—250	6.3	17.8	.848	35.4	26	51	45	437—482
14	250—275	5.5	23.3	.866	31.9	31	70	60	482—527
15	275—300	6.1	29.4	.884	28.6	37	106	75	527—572

Carbon residue of residuum, 9.3 percent; carbon residue of crude, 3.9 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	° A.P.I.	Viscosity
Light gasoline	......	......	......	
Total gasoline and naphtha	10.2	.758	55.2	
Kerosene distillate	21.3	.792	47.2	
Gas oil	13.8	.833	38.4	Below 50
Nonviscous lubricating distillate	11.6	.846-.881	35.8-29.1	50-100
Medium lubricating distillate	4.0	.881-.893	29.1-27.0	100-200
Viscous lubricating distillate	......	......	......	Above 200
Residuum	37.5	957	16.4	
Distillation loss	1.6	......	......	

Base, Paraffin - intermediate

COMPARISON OF MC LOUTH AND MISSISSIPPIAN OILS IN MC LOUTH FIELD WITH OILS FROM OTHER AREAS

A comparison of these analyses has been made by N. W. Bass at the request of the writers. Mr. Bass, who was a member of the committee of the Tulsa Geological Society to investigate the correlative index method for interpreting oil analyses proposed by H. M. Smith of the Bureau of Mines, has contributed the following discussion and the accompanying table 25 and chart (fig. 19).

Samples of oil from the McLouth sand and from the Mississippian limestone in the McLouth field were analyzed by the Hempel method. These analyses are compared herein with analyses, also by the Hempel method, of oils from the Falls City, Barada, and Dawson pools in the Falls City field, Nebraska, and with analyses of oils from two other fields in Kansas. The A.P.I. gravity, sulphur, carbon residue and residuum of the oils are listed in table 25. The average correlation indices for the oils are shown graphically in figure 19. The correlation index method for interpreting oil analyses (Smith, 1940) was developed recently during an investigation of the crude oils of Oklahoma and Kansas by a committee of the Tulsa Geological Society. As stated by that committee (L. M. Neumann and others, 1941, p. 1801), "This method employs a simple index number based on the boiling point-specific gravity relationships of pure hydrocarbons. The magnitude of the correlation index indicates certain characteristics of fractions of the crude oil distilling off at definite temperature intervals. The characteristics of these fractions depend in turn on the relative quantities of the various hydrocarbons present. These hydrocarbons belong to three main groups or types—paraffines, naphthenes, and aromatics. The index number increases in the same order; thus, low indices (10 or less) indicate paraffines, indices of 10 to 40 indicate mixtures of paraffines and naphthenes (in some, small amounts of aromatics are present), and indices above 40 indicate increasing amounts of aromatic compounds generally mixed with naphthenes."

A comparison of the parts of the analyses shown in table 25 and a comparison of the correlation indices determined by the analyses and shown in figure 19, reveal that in the McLouth field the oil from the McLouth sand is similar to the oil from the Mississippian dolomite. The greatest difference between the two oils is shown in the percent of sulphur but both oils have a large sulphur content when compared with other oils in Kansas. The differences between the oils shown by the curves of the correlation indices are so small that they may be attributed to experimental errors.

The oil from the McLouth field is peculiar among the oils of Kansas fields, however. This fact is strikingly shown by the items in table 25 and by the correlation index curves (fig. 19), where the oils of this field are compared with two oils that are fairly typical of many Kansas fields; one of these is from the Burbank (so-called Bartlesville) sand in the Madison field in Greenwood county and the other is from the Mississippian limestone in the Hazlett field in Butler county. The A.P.I. gravity of the oil from the McLouth field, which is between 23° and 24°, is much less than that of the oils from most Kansas fields, the gravity of which commonly ranges between 33° and 41°. The grav-

TABLE 25.—*Data obtained from analyses of oils from the McLouth field and three other fields*

	°A.P.I.	Sulphur, percent	Carbon residue of crude, percent	Residuum, percent
Average of three samples of oil from McLouth sand in McLouth field	23.7	0.87	10.2	45.2
Average of two samples of oil from Mississippian dolomite in McLouth field	23.3	0.79	9.9	43.9
Averages of three samples of oil, two from Hunton limestone and one from Viola limestone, Falls City field, Nebraska	30.1	0.37	5.5	41.3
Average of three samples of oil from Burbank (so-called Bartlesville) sand in Madison field, Greenwood county, Kansas	39.6	0.20	1.6	20.5
One sample of oil from Mississippian limestone in Hazlett field, Butler county, Kansas	40.4	0.13	1.6	15.0
Average of four samples of oil from Hunton limestone, Falls City field	25.6	0.22	5.0	42.6

ities of the oils from the Madison and Hazlett fields are 39.6° and 40.4°, respectively. The percent of sulphur in the five samples of oil from the McLouth field ranges from 0.75 to 0.99, which is much greater than in most oils from Kansas fields. The percent of sulphur in oils from most fields in Kansas is less than 0.25; in the Madison and Hazlett fields it is 0.20 and 0.13 percent, respectively. Moreover, the percent of carbon residue of the crude and the percent of residuum in the oil of the McLouth field is much greater than in the oils of most Kansas fields.

The correlation index curves show that the oil from the McLouth field is much more paraffinic than the oil from the Madison and Hazlett fields. Only in the last two fractions of the distillation do the indices of the oils from McLouth approach those of the oils from Madison and Hazlett. Only very small quantities of distillate were obtained in the first five fractions and none was obtained in the first two fractions during the distillation of the samples of the McLouth oils.

Analyses of two samples of oil from the Devonian limestone in the Falls City field and one sample from the Kimmswick (=Viola) limestone in the Dawson field, Nebraska, were examined. The analyses of the samples were so similar that they seem to represent similar oils, so the data are shown in table 25 and figure 19 as averages. These oils, although different from the oils at McLouth, show many features that, in a broad way, are similar. The gravities of the oils from the Nebraska fields are higher than those of the McLouth oils. The percent of sulphur, percent of carbon residue of the crude, and percent of residuum, although large, are less than in the McLouth oils. The correlation index curves show that some of the distillation fractions of the oils from the Nebraska fields are slightly more paraffinic than the corresponding fractions of oils from the McLouth field. The correlation index curves of the oils from the three pools in Nebraska and those from the McLouth field in Kansas, as well as the items shown in table 25 are roughly comparable, however, and suggest that these oils represent a group or class that is greatly different from another class such as one which would include the oils from the Madison and Hazlett fields.

COMPARISON OF OILS FROM THE MC LOUTH FIELD WITH OILS FROM THE FALLS CITY FIELD

The analyses of oil from the McLouth field, curves A and B of figure 19, were made at Casper, Wyoming, where the average barometric pressure is 635 mm. The correlation indices for McLouth oils have been taken from tables calculated for pressures of 635 mm by J. G. Crawford, associate petroleum chemist, U. S. Geological Survey, Casper, Wyoming (Crawford and Larsen, 1943). The analyses of oils from the Falls City field (curve C of figure 19) were made at Bartlesville, Oklahoma, where the average barometric pressure is 740 mm. The correlation indices for Falls City oils (curve C) have been taken from tables published for pressures of 740 mm by Harold M. Smith of the U. S. Bureau of Mines, Bartlesville, Oklahoma (1940). The correlation indices of oils thus analyzed at different atmospheric pressures are not strictly comparable. As pointed out in a letter from J. G. Crawford, "The lower boiling Hempel fractions at Casper contain heavier material and the specific gravities are correspondingly heavier than at Bartlesville. The indices at Casper pressures are from 1 to 3 points higher than those in use at Bartlesville." Inasmuch as the boiling points of the two sets of samples overlap, neither the volume of the fractions nor their specific gravities are strictly comparable. Fractions 11 to 15, however, which are separated in both laboratories by vacuum distillation at 40 mm, are comparable.

Although the index curves for oils from McLouth (A and B) and oils from Falls City (curve C) differ in the fractions distilled at atmospheric pressure, the curves for the two fields show a marked resemblance in the character of the low temperature fractions which in both fields are markedly paraffinic. Bearing in mind

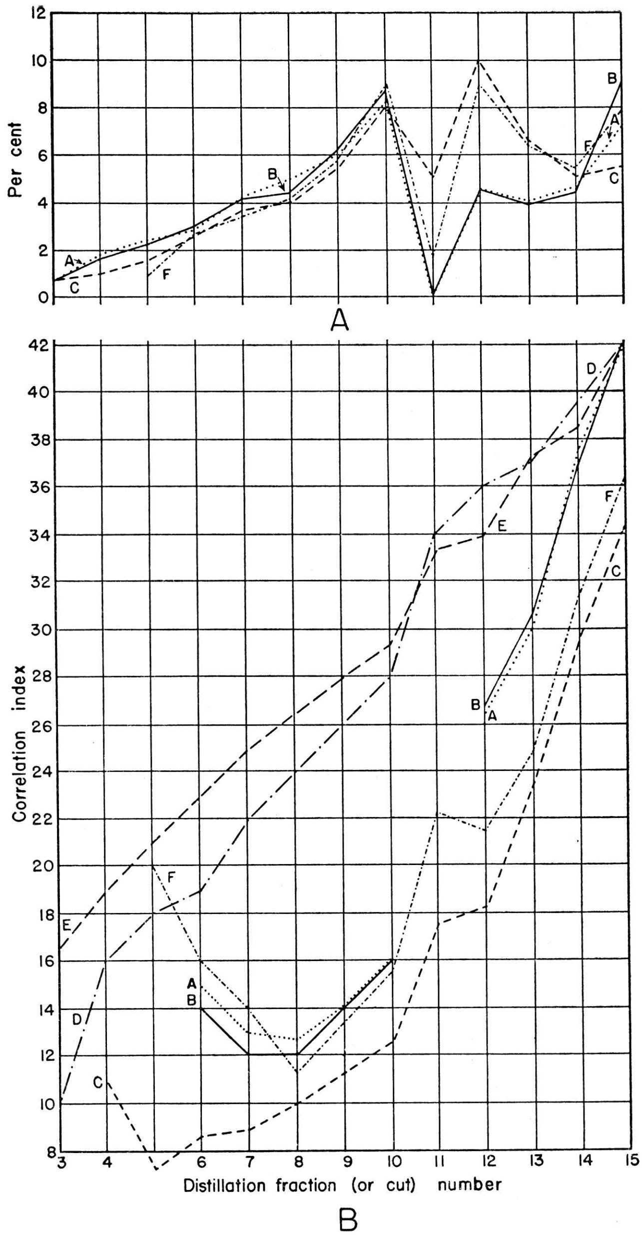


FIG. 19. A, Curves showing percentage of distillation fractions of Hempel analyses of McLouth and Falls City oils. B, Curves of correlation indices of Hempel analyses of McLouth and Falls City oils and comparison with correlation index curves of Burbank and Mississippian oils in southeastern Kansas.

that correlation indices of the oils analyzed at Casper are from 1 to 3 points higher than the corresponding fractions at Bartlesville, it is apparent that under identical pressures the index curve C would have shown a closer resemblance to curves A and B.

Since the discussion of the oil in the McLouth field was prepared by Bass, four analyses of oil from the Falls City field have been made in the laboratory of the Federal Geological Survey at Casper, Wyoming, by J. G. Crawford. These analyses are given in tables 21, 22, 23, and 24. The oils analyzed are all from the "Hunton" limestone — one each from the Dawson, Shubert, Barada, and Falls City pools. The average percentage volumes of the distillation fractions and the average correlation indices of the four oils are shown in figure 19 by the curves marked F. Although the averages represented by curve C include one sample of oil from the Viola limestone, a comparison of lines C and F shows approximately the difference in the correlation indices caused by distillation at Bartlesville at a pressure of 740 mm (curve C) and at Casper at a pressure of 635 mm (curve F). Curves A, B, and F are strictly comparable with each other, all the analyses having been made at pressures approximating 635 mm. Curves C, D, and E are also mutually comparable inasmuch as the oils represented were analyzed at pressures approximating 740 mm. The Falls City and McLouth oils, although showing some differences, are radically different from oils in other parts of Kansas.

The average volumes of separate distillation fractions of oils from the McLouth field and from the Falls City pools as determined by the Hempel analyses also are shown in figure 19. It will be noted that there is an approximate agreement especially in the

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A, Average of three samples of oil from the McLouth sand, McLouth field, Kansas. Analyzed at 635 mm at Casper, Wyo.

B, Average of two samples of oil from the Mississippian limestone, McLouth field, Kansas. Analyzed at 635 mm at Casper, Wyo.

C, Average of three samples, two from "Hunton" and one from Viola limestone, Falls City field, Nebraska. Analyzed at 740 mm at Bartlesville, Okla.

D, One sample of oil from Mississippian limestone, Hazlett field, Butler county, Kansas. Analyzed at 740 mm.

E, Average of three samples of oil from the Burbank (so-called Bartlesville) sand, Madison field, Greenwood county, Kansas. Analyzed at 740 mm.

F, Average of four samples of oil from "Hunton" limestone, one from each of four pools, Falls City field, Nebraska. Analyzed at 635 mm at Casper, Wyo.

volumes of fractions in the earlier distillation cuts under atmospheric pressure although the fractions of the Falls City oils are consistently slightly lower in volume. The fractions distilled under a pressure of 40 mm have a greater range of volume but, in general, the increase and decrease in volumes occur in the same fractions.

The senior writer believes that the oil in the McLouth sand reached its present position from the dolomite zone of the Mississippian limestone, and that both the oil in the McLouth sand and that in the Mississippian were originally derived from a still deeper source. The unique character of the oil in the McLouth and Falls City pools revealed by the curve of correlation indices implies a similarity of source materials and a similar dynamic history. The fact that the oils from the Falls City pools were produced from pools in Devonian limestone and in Kimmswick (= Viola) limestone and the fact that in the McLouth field and elsewhere in the Forest City basin in Kansas shows of oil are not infrequent in dolomite in the upper part of the Devonian suggest that the oil in both fields may have been derived from source material at least as old as the Kimmswick limestone.

Analyses of Gas

Table 26 gives analyses of gas from the McLouth field. The first three samples show the results of analyses of samples of gas from the McLouth sand. Nos. 1 and 2 show analyses of gas from the McLouth pool, No. 3 of gas from the North McLouth pool; No. 4 is an analysis of gas from the St. Louis limestone, and No. 5 of gas accompanying oil from the Misssisippian dolomite zone. No. 6 is an analysis of gas from the upper part of the undifferentiated Burlington and Keokuk limestones above the dolomite zone from which oil is produced.

Most of the gas from the Pennsylvanian pools of southeastern Kansas includes larger amounts of ethane than the gas at McLouth, but the gas from many pools in northeastern Kansas consists almost entirely of methane. The ethane content of the gas in the McLouth field is therefore intermediate between that accompanying the high-gravity oil in the fields of central Kansas and that in the "shale gas" fields of the northeastern part of the state. It is of interest to note that the gas accompanying the oil from the Mississippian limestone in the McLouth pool has an ethane content of only 5.13 percent. H. C. Allen (1929) of the Department of Chem-

TABLE 26.—*Analyses of gas from the McLouth field*

No.	Well	Date	Carbon dioxide CO_2	Oxygen O_2	Methane CH_4	Ethane C_2H_6	Residue	Heating value*
1	McLaughlin and Sons No. 1 Dark[1] (McLaughlin) SW¼ NW¼ 4-10-20 E. (McLouth sand).	8-17-40	0.21	0.00	92.61	0.86	6.32	952
2	McLaughlin and Sons No. 1 Ragan,[2] NW¼ NW¼ 3-10-20E. (McLouth sand)	9-10-41	0.36	0.00	97.25	0.94	1.45	998
3	Hatcher and Fisk No. 1 Tabor Edmonds,[2] SW¼ SE¼ 16-9-20E. (McLouth sand)	9-10-41	0.48	0.00	87.45	3.41	8.66	943
4	Mosbacher No. 1 Dolman,[2] NW¼ NW¼ SE¼ 27-9-20E. (St. Louis limestone)	3-18-42	0.24	0.00	89.40	2.69	7.67	950
5	Apperson-Stark No. 1 McLaughlin,[2] SW¼ NW¼ NW ¼ 4-10-20E. (accompanying oil in Burlington-Keokuk dolomite)	6- 1-43	0.97	0.00	88.15	5.13	5.75	981
6	Jackson No. 1 Bowers,[2] NE¼ NE¼ SW¼ 5-10-20E. (upper part of Burlington and Keokuk)	9-16-43	0.39	0.00	89.65	1.84	8.12	937

* per cubic foot (dry) at 60° F. and 30 inches of mercury, B.t.u.

1 Analysis by V. M. Gustafson, Chemist, Kansas Light and Power Company, McPherson, Kansas.

2 Analyses by H. C. Allen, Department of Chemistry, University of Kansas, Lawrence, Kansas.

Analyses Nos. 1, 2, and 4 courtesy A. A. Armstrong, A and B Pipeline Company; No. 3 courtesy E. H. Hatcher.

istry, University of Kansas, has pointed out that the proportion of ethane in a gas pool varies directly with the distance of the gas from its contact with oil. This relation is substantiated by the few samples of gas available from the McLouth pools. Samples Nos. 1 and 2 which are on the crest of the McLouth pool contain respectively only 0.86 and 0.94 percent ethane. No. 3, with 3.73 percent ethane, is a well in the North McLouth pool two locations from wells yielding oil in the base of the McLouth sand. No. 4, with 2.69 percent ethane, is an edge well on the northeastern edge of the McLouth pool in the St. Louis limestone. The gas accompanying the oil in the McLouth pool, No. 5, contains 5.13 percent ethane. No. 6 is the analysis of gas from the upper part of the undifferenti-

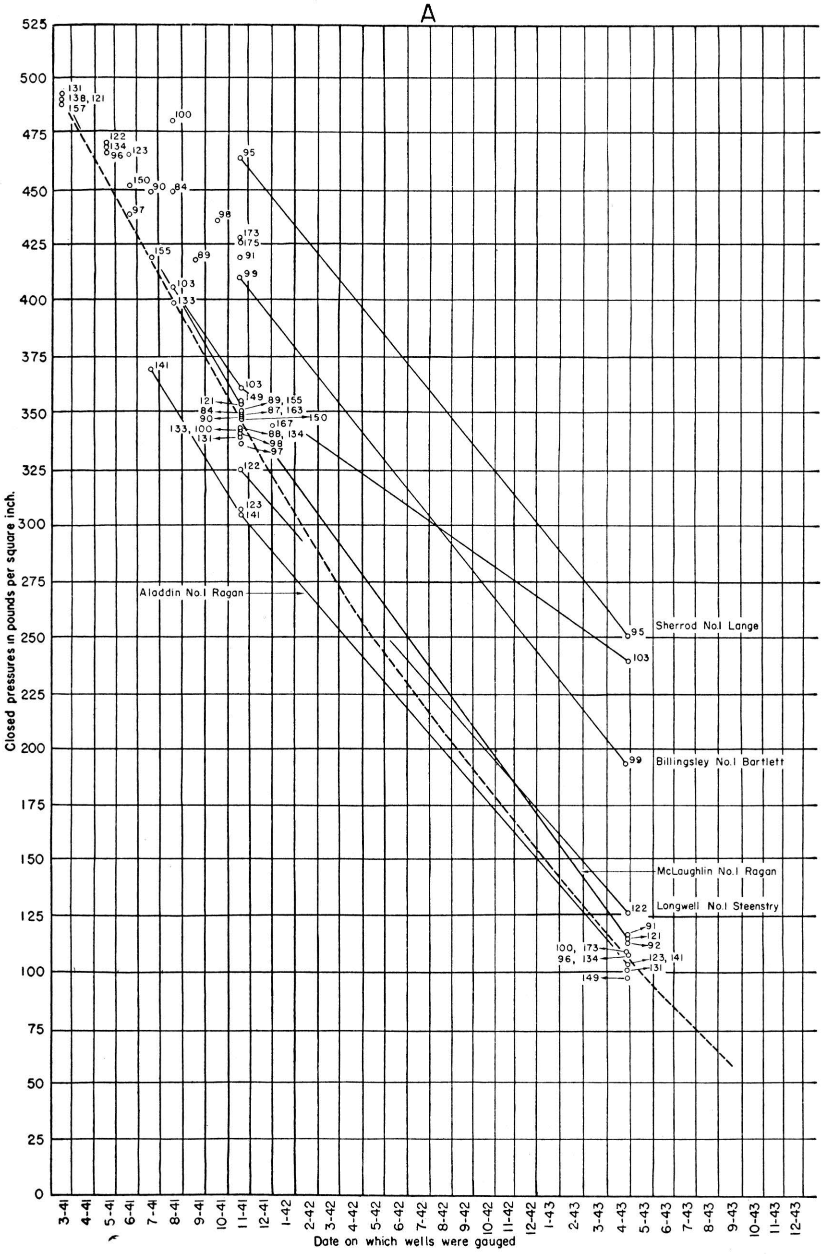

FIG. 20. Charts showing pressure decline in gas pools of the McLouth field.

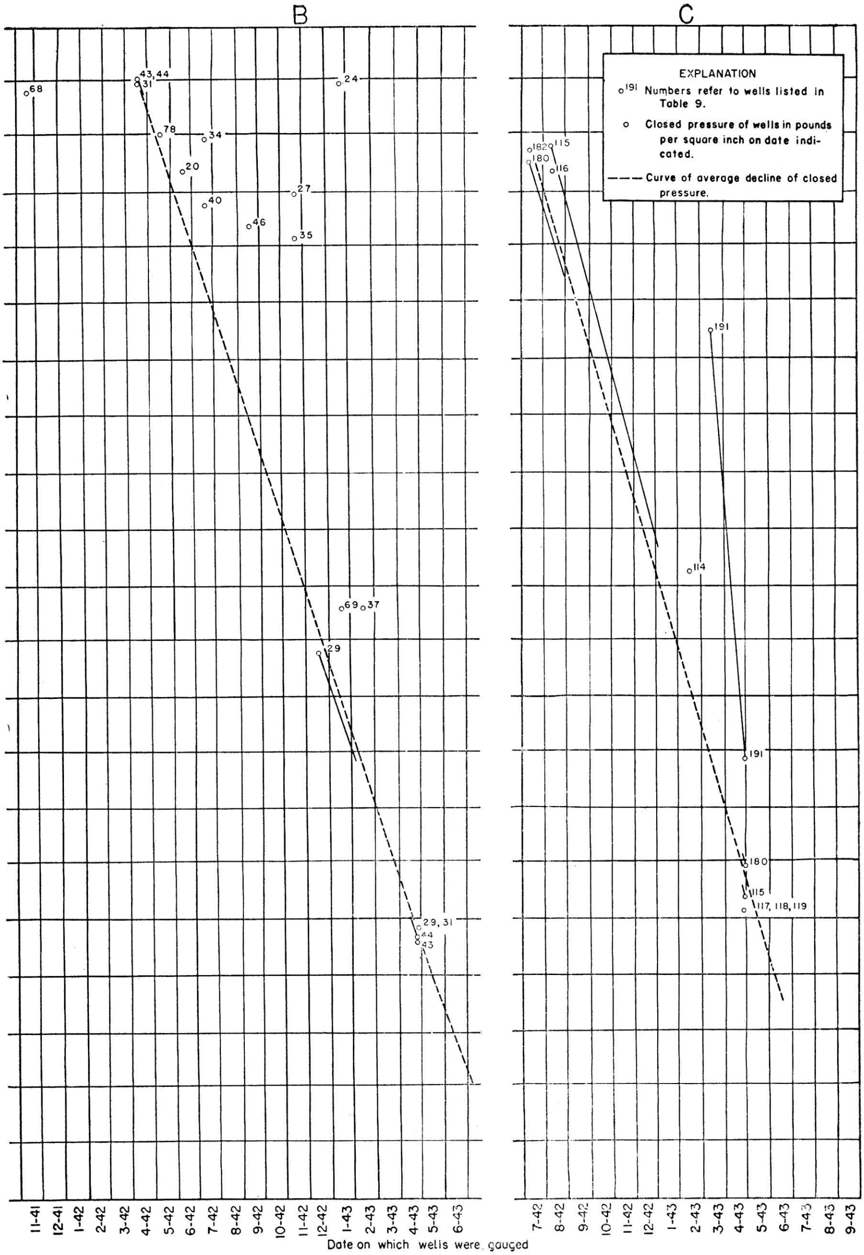

FIG. 20.—*continued*

A, Pressure decline curve of the McLouth gas pool. B, Pressure decline curve of the North McLouth gas pool. C, Pressure decline curve of the Ackerland gas pool. Numbers refer to wells listed in well index (table 27).

ated Burlington and Keokuk in the Jackson No. 1 Bowers well. This well was marginal to the oil pool and found water in the dolomite. The low ethane seems to reflect its distance from the oil. The incombustible residue (chiefly nitrogen) is relatively high but the helium content is low. Dr. H. P. Cady of the Department of Chemistry, University of Kansas, analyzed two samples of gas from the McLouth field, and found only 0.25 percent helium in one and 0.30 percent helium in the other. The relatively high incombustible residue, which varies from 1.45 to 8.66, results in a reduction of the heating value of the gas somewhat below that of other gas fields in eastern Kansas. The average heating value of the gas from the three wells representing the bulk of the gas run from the field is 964 B.t.u.

FUTURE DEVELOPMENT OF OIL IN THE McLOUTH FIELD

The oil-producing area in the McLouth sand in the Bankers Life pool (sec. 3, T. 10 S., R. 20 E.) is separated from the gas-producing area to the north in the same section by a structural displacement (either a fault or a monoclinal fold) in the Mississippian limestone. This displacement, initiated before Pennsylvanian time, was revived before the deposition of the McLouth sand and seems to have been active during its deposition and seemingly afterward also, although it dies out toward the surface.

The oil occurs on the lowered side of the displacement and, as has already been pointed out in the chapter on *Distribution of gas, tar, oil, and water in the McLouth sand,* the oil on the lowered extension of the semidetached dome in sec. 3 does not rise above the level of the contact of the gas and tar in other parts of the pool (regional dip eliminated). Gas accompanies the oil only in amounts sufficient to operate the pumps.

It is not known whether the Mississippian rocks underlying the Bankers Life pool contain oil, but if the oil-water contact was originally (regional dip eliminated) at the same level as in the Mississippian limestone in the McLouth oil pool, the limestone immediately below the Bankers Life pool is structurally too low for oil. The crest of the Mississippian structure north of the fault may, however, be productive. The sand in the Bankers Life pool abuts against the plane of displacement, and channels for upward migration of deeper-seated oil, either vertically or with lateral components, must have been available in the shattered zone. No oil is found in the McLouth sand above the fault in secs. 4 and 5 because in this area the sand is impervious and provides no reservoir directly above the fault for either gas or oil.

The May Dick well in the northern part of the North McLouth pool is 3½ miles distant from the Mississippian oil pool beneath the McLouth anticline. The oil in this well, as shown by the Hempel analyses, is similar to oil in the McLouth anticline. The oil is of slightly lower gravity but has a slightly higher pour point and a higher viscosity than oil from the McLouth pool. It seems probable that the oil from the May Dick well is also the result of escape from a deeper source, although the channels of escape have not been determined. Oil in small amount occurs in the McLouth sand in a number of other wells, most of which are on the flank of the gas area. In the Ackerland pool, three gas wells on the crest of the anticline are producing some oil from the McLouth sand and oil is being produced from the basal sandy zone in two wells low on the east flank. The Ackerland pool is bounded on the north by a sharp displacement.

It seems probable, therefore, that oil may be found in the Mississippian rocks beneath the Ackerland gas pool under conditions similar to those in secs. 4 and 5 and beneath at least some of the other structural crests revealed by the structure of the McLouth sand. It is probable, however, that not all the domes shown will be productive and that some will prove to be of limited areal extent. Possibilities for oil production in the Devonian limestone have not been exhausted.

CONCLUSIONS

The detailed study of structural and stratigraphic conditions in the McLouth field has revealed many important facts as to the occurrence of oil and gas and their relation to structural features. Some of these facts relate particularly to the McLouth field but others have a wider importance in the search for oil in other parts of northeastern Kansas. The most important conclusions brought out by the investigation are recapitulated below.

1. Gas, oil (tar), and water have a normal gravimetric arrangement in the anticlinal traps. This is true both in the McLouth sand and in the productive dolomite zone of the Mississippian. The occurrence of heavy oil in the McLouth sand in isolated small wells and the shows of oil in certain other wells are exceptions

which have not been fully explained. The oil in some of these wells occurs at or near the contact of the tar and gas, and it is perhaps in part oil locally protected, for some unapparent reason, from the desiccation which so generally reduced the oil to tar. In other wells, however, oil in small amounts has been obtained above the contact of the tar and gas. Because the analyses of oil from the sand so closely resemble those of oil from the underlying dolomite zone, it is probable that this oil entered the McLouth sand reservoir from below through faults, joints, and fissures after the period of desiccation of the oil originally trapped in the sand.

2. The accumulation of gas in the McLouth sand in anticlines is dependent upon the presence of porous sand bodies. There are many anticlinal areas in which the McLouth sand lacks porosity and, in consequence, does not yield gas. No gas, however, is found in porous sand bodies that do not occur in anticlines. Porous sand bodies not on anticlines carry water. No criteria have been determined by which the location or trend of porous sandstone zones in the McLouth sand can be predicted.

3. The oil that originally filled the pores of sandstones beneath and on the flanks of gas reservoirs in the McLouth sand has lost its volatile constituents and has been reduced to tar and hydrocarbon cement. This desiccated oil completely seals off the water on the flanks of the structures and prevents its encroachment into the gas reservoir as the gas is withdrawn.

4. The plane of contact between the gas and tar conforms to the plane of regional dip. The desiccation of the oil and the establishment of the limits of the gas reservoir are, for this reason, believed to have occurred prior to the development of regional dip during the interval between the deposition of the Permian and the Cretaceous rocks. The gathering areas for the desiccated oil in the sand must, therefore, have been in the adjacent synclines and the oil and gas did not migrate long distances up dip from remote source materials.

5. The structural deformation of anticlines and synclines increases with depth at least to the top of the Mississippian rocks. The earliest recognized local deformation warped the Mississippian limestones before the deposition of the first Pennsylvanian rocks in Kansas. The early structural features were increased by small increments of folding at intervals throughout Pennsylvanian time and possibly into the Permian. The oldest rocks were thus affected by all structural adjustments, but the younger rocks were affected

only by adjustments that occurred after their deposition. The weak anticlines and synclines revealed by the surface rocks, therefore, are the result only of the closing structural movements and generally indicate the position of similar but more pronounced structural features at depth.

6. The post-Permian tilting of the region toward the west, although it does not seem to have affected the structural relief of the local anticlines, had an important effect in changing the contoured expression of the anticlines in the altered relation to sea-level datum. The change in expression of the steeper anticlines in the deeper rocks from this cause was not pronounced, and consisted mainly in reducing the amount of reverse dip of the anticline by the amount of regional dip. The change in the position of the crest in the deeper rocks was negligible. The effect of the westward regional tilting of the Permian and older rocks was to reduce or wipe out the closure of the weak surface anticlines. Of equal importance in many places was the shift in the position of the crest of the anticline in relation to the new sea-level datum. Inasmuch as there was little, if any, shift in the postion of the crest in the more sharply folded anticlines in depth, the position of the crest in the surface rocks in some places is at considerable variance with that of the crest in the deeper rocks.

Where the dips in the surface rocks are low, the structure should be recontoured to eliminate the effect of regional dip and thus determine the unaltered position of the crest of the subsurface structure. The amount of shift in the position of the crest of the surface structure is in some places unimportant but in others it is enough to cause a test well to miss the productive area in the deeper anticlines.

Deviations from regularity of regional dip shown on the structure map of the base of the Hertha limestone (fig. 5) suggest areas favorable for exploration. The elimination of regional dip will show in a general way broad areas of anticlinal deformation not everywhere obvious on the structural map. Structural movements revealed in this way do not show local features, but detailed structural mapping of such areas may result in the discovery of local structures worthy of testing. The anticlinal nose in T. 8 S., Rs. 17 and 18 E. is an obvious structural feature on which detailed mapping may reveal more definite local anticlines.

7. The occurrence of oil in the Mississippian beneath an anticlinal gas pool in the Pennsylvanian at McLouth increases the hope

that other oil pools may be found in the Mississippian and older rocks in similar relations to gas production in other parts of northeastern Kansas. Many gas pools have been developed in counties south of Kansas river, and although some of them are reported to have produced from lenticular sand bodies independent of structure many others have produced from anticlines. Very few wells located on structure have been drilled in these counties below the local gas sands, and still fewer have tested the Mississippian rocks.

It should be borne in mind, however, that the McLouth oil pool in Mississippian rocks underlies a relatively small part of the area of the anticline producing gas, and that the oil pool in the Mississippian is eccentric to the weak surface structures as expressed on the dip slope. Similar relations will probably be found elsewhere.

8. The Devonian limestones were tilted toward the northwest, beveled by erosion, and subjected to surface weathering before being covered by the Chattanooga shale. These events resulted in the exposure of different parts of the Devonian in various parts of the area at the time the Chattanooga shale was deposited. The younger Devonian beds underlie the Chattanooga shale toward the northwest. Some of the Devonian limestones are dense and do not lend themselves to the development of porosity under weathering conditions. Other Devonian rocks do. Considerable variation, therefore, existed in the porosity of the beds exposed at the time they were covered by the Chattanooga shale.

The occurrence of dense impermeable rocks at the top of the Devonian beneath one anticline does not necessarily condemn the top of the Devonian in other anticlines where other rocks more susceptible to the development of porosity may underlie the Chattanooga.

9. Every discussion of the source beds for oil is subject to so many uncertainties that the conclusions are highly speculative. Nevertheless, the McLouth field provides some interesting, if not conclusive, data. As already pointed out, tar in the McLouth sand seems to have reached its present position prior to the development of regional dip. The source of the desiccated oil in the McLouth sand, therefore, lies in the synclinal basins adjacent to the pools, although the horizon of the source beds is not known. A large part of the McLouth sand, including beds of black shale and clay, is high in organic content. This fact, together with the conditions under which the junior author conceives the sediments to have been deposited, suggests that conditions suitable for the

accumulation of source materials of oil and gas may have prevailed during McLouth time. Younger beds in the Cherokee, however, indicate similar conditions, but there is no evidence that oil or gas is present or ever was present in sand beds in the upper part of the Cherokee rocks in the McLouth field. Gas and some oil have been found, however, in these beds in other parts of northeastern Kansas.

Although the McLouth sand may have provided a suitable source for the desiccated oil in that sand, it could not have been the source of the oil found in the underlying Mississippian limestones nor for the more or less frequent shows of tar in the still deeper Devonian. The data are insufficient to draw any conclusions in regard to the upward migration of oil from possible deeper source rocks. However, flecks of tar are not uncommon in vugs and in the cavities of fossils in all parts of the Mississippian limestone in the McLouth field and surrounding territory where there is no apparent relation to anticlinal structure. These occurrences imply either that the oil originated in the Mississippian or passed through it from older rocks. The Mississippian rocks in general give little indication of organic content adequate to provide source materials for oil. The Chattanooga shale has frequently been appealed to as a source for oil, but a source in the Chattanooga would not explain the presence of oil in the underlying Devonian rocks.

It seems possible that there may have been more than one source for oil. The desiccated oil in the McLouth sand may well have been indigenous. The Mississippian oil and its counterpart, the oil in the McLouth sand in the Bankers Life pool and in scattered wells in other parts of the field, may have had a common source in some as yet undetermined deeper rocks. The desiccated oil in the McLouth sand seems no longer capable of contributing much gas to the McLouth sand reservoir. Gas from the Mississippian oil, though not in large amount, is similar to the McLouth gas, which shows ethane in amounts ranging from 0.86 to 3.41 percent. A sample of gas accompanying the Mississippian oil contained 5.13 percent ethane. It seems possible, therefore, that the gas in the McLouth sand reservoir has emanated, at least in part, from deeper sources by way of the accumulations of oil in the Mississippian rocks and that gas from this source has replenished the McLouth sand reservoir from which large quantities of gas seem to have escaped from time to time.

Table 27.—*List of wells drilled in the McLouth field and bordering areas, by townships, locations and depths of wells, and depth and altitude of datum beds in each well.*

(The numbers identify the wells in figures 10, 11, 14, and 15, and plate 3)

Well Name	Location	Section	Depth top Oread	Alt. top Oread	Depth base Hertha	Alt. base Hertha	Depth top McLouth	Alt. top McLouth	Depth top Miss'pian	Alt. top Mississippian	Depth top Warsaw	Alt. top Warsaw	Depth B-K por. zone	Alt. B-K porous zone	Total depth of well
T. 8 S., R. 19 E.															
1. Bird & Sheedy No. 1 H. T. O'Neill	SE SW NW	34	315	+850	965	+200	1708	-543	1748	-583	1765	-600	1883	-718	2685
2. W. D. Dunn No. 1 N. W. Everett	S½ SE SW	36	210	+871	835	+246	1545	-464	1585	-504	1605	-524	1747	-666	1800
T. 8 S., R. 20 E.															
3. Max Cohen No. 1 M. L. Decker**	NW SW NW	12	41	+945	675	+311	1390	-404	1418	-432	1494	-508	1640	-654	1925**
4. McLaughlin & Sons No. 1 O. C. Bodde et al	NW SW	28	222	+916	857	+281	1542	-404	1583	-445	1630	-492			1770
5. McLaughlin & Sons No. 1 George Miller	SW SE	29	175	+912	808	+279	1510	-423	1544	-457	1612	-553	1740	-653	1750
6. McLaughlin & Sons No. 2 George Miller	NE SE	32	85	+928	717	+296	1395	-382	1427	-414	1460	-447			1535
7. Lebsack & Wamhoff No. 1 J. Maduska	SE NE	36	96	+972	738	+330	1458	-390	1497	-429					1505
T. 9 S., R. 19 E.															
8. Northern O. & G. No. 1 Edmonds (Winchester) (drillers log)	NW NW	13	......	....	820	+243	....	....	1590	-527	....	....	....	....	....
9. E. V. Jackson et al No. 1 J. P. Sheldon	NE SE	14	245	+896	888	+253	1612	-471	1699	-558	1685*	-644*			1749
10. Bradley & Jackson No. 1 NW. Mu. Life Ins. Co.	SE NE	24	196	+915	840	+271	1542	-431	1590	-479	1635	-524			1734
T. 9 S., R. 20 E.															
11. E. V. Jackson et al No. 1 N. Fevurly	SW SE	1	......	....	570	+321	1300	-409	1365	-474	1388	-497	1482	-591	1501
12. E. V. Jackson et al No. 1 C. Shughart**	SW SW	6	125	+882	758	+249	1468	-461	1521	-514	1554	-547	1686	-679	2007**
13. Frank Whitten et al No. 1 C. Courtney	SW NE	15	70	+938	715	+293									1392
14. McLaughlin & Sons No. 1 Tabor Edmonds	SW SW	15	118	+953	780	+291	1478	-407	1516	-445					1531
15. E. V. Jackson et al No. 1 Francis Houston	NW SE	15	70	+948	725	+293	1405	-387	1434	-416					1453
16. O. J. Connell No. 1 J. R. Locke	SW NE	16	1	+942	655	+288	1342	-399	1398+-	-455					1415
17. Miller & Mosbacher No. 1 Rachel Edmonds	SE SW	16	64	+961	720	+305	1385	-360							1410
18. Miller & Mosbacher No. 2 Rachel Edmonds	NE SW	16	64	+959	714	+309	1408	-385	1478	-455					1497
19. Anderson & Bradley No. 1 Rachel Edmonds	SW SW	16	15	+956	672	+299	1353	-382							1366
20. Hatcher & Fisk No. 1 Tabor Edmonds	SW SE	16	53	+960	710	+303	1387	-374							1399
21. Hatcher & Fisk No. 1 Elijah Edmonds	SE NW	17	130	+941	775	+296	1456	-385							1498
22. V-8 Drilling Co. No. 1 G. Makewski	NW SW	17	170	+934	814	+290	1510	-406	1588	-484					1605
23. Ray Anderson et al No. 1 May Dick	SE SW	17	130	+951	780	+301	1464	-383							1481
24. Ray Anderson et al No. 2 May Dick	NE SW	17	118	+943	760	+301	1440	-379							1456
25. Ward Schooler et al No. 3 M. M. Zachariah	SE SE	17	35	+956	685	+306	1388	-397	1434	-443	1464	-473			1586
26. E. V. Jackson et al No. 1 Bank of McLouth	SE NW SW	20	50	+952	703	+299	1398	-396	1428	-426	1492	-490	1590	-588	1600

27. E. V. Jackson et al No. 2 Bank of McLouth	SE NW	20	37	+953	694	+296	1378	-388	1428	-438	1462	-472			1520
28. E. V. Jackson et al No. 3 Bank of McLouth	SW NW	20	126	+930	774	+282	1450	-394	1482	-426					1487
29. T. Fred Hodge No. 1 M. M. Zachariah	SW NE	20	25	+954	675	+304	1356	-377							1373
30. T. Fred Hodge No. 2 M. M. Zachariah	NW NE	20	26	+974	700	+300	1380	-380	1420	-420					1422
31. W. Schooler et al No. 1 M. M. Zachariah	NE NE	20	15	+954	665	+304	1348	-379							1365½
32. W. Schooler et al No. 2 M. M. Zachariah	SW NE	20	20	+957	671	+306	1354	-377							1371
33. Hatcher & Fisk No. 1 W. N. Schwinn	SE SW	20	70	+962	727	+305	1422	-390							1444
34. Hatcher & Fisk No. 1 M. Hesse	NE SE	20	75	+962	730	+307	....	....							1423
35. Hatcher & Fisk No. 4 M. Hesse	NW SE	20	30	+956	683	+303	1357	-371							1370
36. William O. Smythe et al No. 1 C. E. Todd	SW SE	20	60	+960	713	+307	1403	-383	1418	-398	1470	-450	1543	-523	1558
37. Miller, Smythe et al No. 1 C. E. Todd	NE SE SE	20	100	+959	744	+315	1425	-366							1453½
38. Miller, Smythe et al No. 2 C. E. Todd	E½ SW SE	20	56	+960	707	+309	1378	-362							1404
39. Hatcher & Fisk No. 1 Elijah Edmonds	NW NW	21	40	+956	690	+306	1383	-387							1400½
40. Hatcher & Fisk No. 2 Elijah Edmonds	SW NW	21	80	+954	730	+304	1415	-381	1473	-439					1476
41. Hatcher & Fisk No. 1 Ralph Edmonds	NE NW	21	65	+960	720	+305	1416	-391							1424½
42. Hatcher & Fisk No. 2 Ralph Edmonds	SE NW	21	90	+954	745	+299	1424	-380	1480	-436					1484
43. O. J. Connell No. 1 Russell Edmonds	SW NE	21	128	+942	781	+289	1462	-392							1480
44. O. J. Connell No. 2 Russell Edmonds	NW NE	21	87	+955	741	+301	1424	-382							1431
45. O. J. Connell No. 3 Russell Edmonds	SE NE	21	134	+954	790	+298	1495	-407	1541	-453					1545
46. Hatcher & Fisk No. 2 M. Hesse	NW SW	21	93	+957	752	+298	1445	-395							1460
47. Hatcher & Fisk No. 3 M. Hesse	SW SW	21	116	+953	766	+303	1464	-395							1473
48. O. J. Connell No. 1 T. C. Moseberger	NW SE	21	95	+953	747	+301	1437	-389	1465	-417	1490	-442			1538
49. Dave Wilson et al No. 1 J. S. Martz	SW NW	22	93	+960	752	+301	1442	-389	1461	-408					1473
50. Charles E. Miller No. 1 fee	NW SW	22	98	+966	755	+309	1430	-366							1447
51. Charles E. Miller No. 2 fee	NE SW	22	70	+969	732	+307	1404	-365	1429	-390					1445
52. McLaughlin & Sons No. 1 Charles E. Miller	SW SW	22	45	+973	704	+314	1373	-355	1402	-384					1420
53. William O. Smythe et al No. 1 O. Jacobson	SW NW	27	20	+989	680	+329	1340	-331	1379	-370	1444	-435			1482
54. E. W. Mosbacher No. 1 M. A. Dolman	NW NW SE	27	50	+981	705	+326	1382	-351	1411	-380	1467	-436	1605	-574	1615
55. Hatcher & Fisk No. 1 F. J. Harwood	NW NW	28	100	+958	768	+290	1460	-402	1510	-452					1510
56. Hatcher & Fisk No. 2 F. J. Harwood	SE NW	28	47	+968	701	+314	1392	-377							1396
57. Hatcher & Fisk No. 3 F. J. Harwood	NE SW	28	85	+962	740	+307	1419	-372							1428
58. O. J. Connell No. 2 T. C. Moseberger	NW NE	28	15	+975	687	+303	1383	-393	1420	-430					1452
59. O. J. Connell No. 3 T. C. Moseberger	NE NE	28	......	....	651	+327	1310	-332							1332
60. McLaughlin & Sons No. 1 S. S. Miller	SW NE	28	78	+975	729	+324	1394	-341							1419
61. Don Allen et al No. 1 S. S. Miller	SW NE NE	28	12	+981	678	+315	1337	-344							1369
62. Willard Archie et al No. 1 Perry Shrader	SE SW	28	112	+959	767	+304	1442	-371	1469	-397					1472
63. Willard Archie et al No. 2 Perry Shrader	SW SW	28	60	+956	722	+294	1390	-374	1410	-394	1443	-427			1595
64. Hart Workman et al No. 1 Old Line Insurance	NW SE	28	100	+967	746	+321	1428	-361	1454	-387					1470
65. Ray Anderson et al No. 1 McLeod-Wisdom	SW NW	29	102	+951	759	+294	1434	-381							1453
66. Ray Anderson et al No. 2 McLeod-Wisdom	NW NW	29	117	+954	777	+294	1464	-393							1470
67. Ray Anderson et al No. 1 R. E. Costigan	NE NW	29	71	+957	724	+304	1418	-390							1434
68. Ray Anderson et al No. 1 Alvin Means	SE NW	29	98	+959	752	+305	1434	-377							1454
69. Miller & Smythe No. 1 Fed. Land Bank	NE NW NE	29	110	+953	748	+315	1440	-377							1459
70. Hatcher & Fisk No. 1 J. A. Black	NE NE	29	100	+963	760	+303	1454	-391							1473
71. William Smythe et al No. 1 Fed. Land Bank	SW NE	29	140	+952	795	+297	1485	-393	1520	-428	1568	-476	1662	-570	1676
72. Hatcher & Fisk No. 1 J. W. Shrader	NW SW	29	100	+950	752	+298	1422	-372							1431
73. Hatcher & Fisk No. 2 J. W. Shrader	NE SW	29	135	+948	790	+293	1474	-391							1495
74. Magnolia No. 1 Mathew C. Woodhead	SW SW	29	135	+942	795	+282	1478	-401							1520
75. E. V. Jackson et al No. 1 Shrader-Haas	NW SE	29	135	+939	793	+281	1495	-421	1538	-464					1557
76. O. J. Connell No. 1 Mary Garrett	NW NE	30	85	+946	744	+287	1432	-401	1465	-434	1522	-491			1530
77. Hatcher & Fisk No. 1 Ray Kimmel	NW SW	30	135	+942	790	+287	1487	-410							1530
78. E. V. Jackson et al No. 1 A. Shoemaker	SE SW	30	100	+952	760	+292	1438	-386							1483
79. Hatcher & Fisk No. 1 J. A. Black	NE SE	30	150	+950	803	+297	1490	-392	1515	-417	1568	-470	1684	-586	1687

TABLE 27. *List of wells drilled in the McLouth field and bordering areas, continued.*

Well Name	Location	Section	Depth top Oread	Alt. top Oread	Depth base Hertha	Alt. base Hertha	Depth top McLouth	Alt. top McLouth	Depth top Miss'pian	Alt. top Mississippian	Depth top Warsaw	Alt. top Warsaw	Depth B-K por. zone	Alt. B-K porous zone	Total depth of well
80. E. V. Jackson et al No. 1 C. W. Shrader	NW NE	31	165	+942	827	+280	1520	-413	1600	-493					1610
81. Hatcher & Fisk No. 1 E. Fowler	SE NW	32	165	+937	820	+282	....	....							1544
82. E. V. Jackson et al No. 1 Shrader-Haas	NW NE	32	156	+932	811	+277	1490	-402	1520	-432	1550	-462			1600
83. O. B. Kilness et al No. 1 Perry Shrader	NE NE	32	145	+948	798	+295	1460	-367	1502	-409					1520
84. Ray Anderson et al No. 1 Grant F. Woodhead	NE SW	32	168	+963	825	+306	1487	-356							1505
85. Hatcher & Fisk No. 1 W. E. Myers	SW SW	32	150	+970	805	+315	1495	-375							1510
86. Magnolia No. 1 W. E. Myers	SE SW	32	169	+974	827	+316	1502	-359							1531
87. J. W. Longwell et al No. 1 S. Brose	NW SE	32	174	+958	829	+303	1494	-362							1518
88. Willard Archie et al No. 1 S. Brose	NE SE	32	122	+962	798	+286	1460	-376	1515	-431	1530	-446			1575
89. Magnolia No. 1 W. W. Harris	SW SE	32	120	+976	776	+320	1430	-334							1450
90. Magnolia No. 1 Rachel Davidson	SE SE	32	85	+982	747	+320	1388	-321							1411½
91. Irving H. Knudson et al No. 1 I. H. Knudson	SW NW	33	80	+956	742	+294	1403	-367							1431
92. Irving H. Knudson et al No. 2 I. H. Knudson	NW NW	33	72	+952	735	+289	1393	-369							1408
93. Gordon & Poole et al No. 1 I. H. Knudson	SE NW	33	120	+979	780	+319	1444	-345	1473	-374					1503
94. Gordon & Poole et al No. 2 I. H. Knudson	NE NW	33	102	+966	757	+311	....	....	1460	-392	1508	-440	1602	-534	1606
95. J. W. Sherrod et al No. 1 Lange Estate	SW NE	33	60	+994	728	+326	1377	-323	1426	-372					1427
96. McLaughlin & Sons No. 1 A. L. Bartlett	SW SW	33	73	+979	739	+313	1394	-342	1433	-381	1466	-414	1602	-550	1608
97. McLaughlin & Sons No. 2 A. L. Bartlett	SE SW	33	110	+989	775	+324	1431	-332	1473	-374					1485
98. H. T. Wiedenman et al No. 1 A. L. Bartlett	NW SW	33	80	+962	747	+295	1403	-361							1433
99. J. W. Billingsley et al No. 1 A. L. Bartlett	NE SW	33	134	+985	790	+329	1449	-330	1481	-362					1492
100. J. W. Longwell et al No. 1 A. L. Bartlett	NW SE	33	105	+1002	768	+339	1425	-318							1462
101. J. W. Longwell et al No. 2 A. L. Bartlett	SW SE	33	95	+1004	760	+339	1434	-335	1463	-364					1469
102. Hatcher & Fisk No. 1 George Kell	NE SW	33	75	+998	738	+335	1396	-323	1427	-354					1448
103. Aladdin Oil Co. No. 1 M. D. Edmonds	SW SW	34	68	+998	720	+346	1392	-326	1433	-367	1444	-378			1447½
T. 9 S., R. 21 E.															
104. J. B. Apperson et al No. 1 C. Geisen	NW SE	5	......	....	625	+375	1332	-332	1380	-380	1417	-417			1549
105. Mosbacher & Miller No. 1 J. R. Locke	NE SW	19	1	+1000	640	+361	1338	-337	1367	-366	1394	-393			1505
T. 10 S., R. 19 E.															
106. E. V. Jackson et al No. 1 M. M. Chavanne	NE NE	3	190	+895	843	+242	1564	-479	1595	-510	1605	-520			1658
107. Earl Sifers et al No. 1 F. H. Leonhard	SE SW	9	245	+883	895	+233	1610	-482	1670	-542					1709
108. Frank Whitten et al No. 1 A. J. Meyer	NE NE	12	225	+930	880	+275	1570	-415	1616	-461					1620
109. Workman & Sherrod et al No. 1 E. T. Riling	SW SW SE	22	194	+923	860	+257	1551	-434	1589	-472					1604
110. Sherrod & Workman et al No. 1 C. J. Seitz	SW NE	32	220	+889	873	+236	1600	-491	1634	-525					1643
T. 10 S., R. 20 E.															
111. Magnolia No. 1 R. B. Kessinger	SE NW	1	5	+1014	670	+349	1365	-346	1460	-441					1470
112. George O'Dea et al No. 1 W. F. Borst	SW NE	1	45	+1010	705	+350	1405	-350	1472	-417					1502

113. McLaughlin & Sons No. 1 W. F. Borst	S½ SE NE	1	26	+1005	682	+349	1386	-355	1471	-440					1474
114. V. W. McKnabe et al No. 1 R. B. Kessinger	NW SW	1	15	+1016	685	+346	1371	-340							1386
115. Ward Schooler et al No. 1 L. H. Schmidt	NE SW	1	34	+1008	688	+354	1374	-332							1409
116. McLaughlin & McNerney No. 1 L. H. Schmidt	SE SW	1	47	+1022	717	+352	1390	-321	1425	-356	1437	-368			1452
117. Miller, Cross, et al No. 1 J. W. Bell	NW SE	1	5	+1023	670	+358	1341	-313							1368
118. Miller, Cross, et al No. 2 J. W. Bell	SW SE	1	17	+1022	685	+354	1365	-326	1400	-361					1405
119. Miller, Cross, et al No. 3 J. W. Bell	E½ SE	1	26	+1008	680	+354	1385	-351							1398
120. W. T. McNerney No. 1 A. Fidler	NE NW	2	......	....	640	+335	1348	-344	1392	-388					1454
121. McLaughlin & Sons No. 1 H. D. Ragan	NW NW	3	85	+1007	748	+344	1407	-315	1446	-354					1456
122. J. W. Longwell et al No. 1 W. H. Steenstry	NE NW	3	38	+1006	696	+348	1364	-320	1405	-361	1429	-385			1429
123. J. W. Longwell et al No. 2 W. H. Steenstry	SW NW	3	50	+1008	715	+343	1373	-315							1393
124. Apperson, Pundt, et al No. 1 W. H. Steenstry	SW SE NW	3	70	+1001	738	+333	1428	-357							1473
125. J. W. Longwell et al No. 1 W. F. Moore	NW NE	3	74	+1001	752	+323	1430	-355	1490	-415	1504	-429			1632
126. J. W. Longwell et al No. 1 Bankers Life (Bessie McLeod)	NW SW	3	100	+996	763	+333	1438	-342							1475
127. J. W. Longwell et al No. 2 Bankers Life (Bessie McLeod)	NE SW	3	50	+992	715	+327	1375	-333							1420
128. J. W. Longwell et al No. 3 Bankers Life (Bessie McLeod)	NW SW	3	80	+997	740	+337	1417	-340							1461
129. J. W. Longwell et al No. 4 Bankers Life (Bessie McLeod)	SW NE SW	3	70	+996	730	+336	1406	-340							1456
130. Ward Schooler et al No. 1 Bankers Life (Bessie McLeod)	SW SW	3	108	+996	772	+332	1455	-351							1491
131. W. W. Stark et al No. 1 E. P. Dark (McLaugh.)	NW NW NW	4	89	+993	746	+336	1410	-328							1442
132. J. W. Billingsley et al No. 2 D. W. McLaughlin	E½ NW NW	4	80	+999	738	+341	1400	-321	1442	-363	1466	-387	1599	-521	1607
133. McLaughlin & Sons No. 2 fee	N½ NW	4	88	+999	752	+335	1410	-323							1457**
134. McLaughlin & Sons No. 1 fee**	NE NW	4	95	+1008	763	+340	1426	-323	1475	-372	1503	-400	1624	-521	1915
135. Apperson-Stark et al No. 1 D. W. McLaughlin	SW NW NW	4	80	+996	740	+336	1400	-324	1448	-372	1454	-378	1565	-489	1576
136. J. B. Apperson (T. W. Sowell) et al No. 1 D. W. McLaughlin	NW SW NW	4	100	+1002	764	+338	1408	-306	1445	-343	1458	-356	1585	-483	1599
137. J. W. Billingsley et al No. 1 D. W. McLaughlin	NE SW NW	4	85	+1006	740	+351	1410	-319	1457	-366	1467	-376	1597	-506	1601½
138. McLaughlin & Sons No. 1 E.P.Dark (McLaugh.)	NW SW NW	4	69	+1005	730	+344	1378	-304							1411
139. Aladdin No. 1 Bessie McLeod (Bankers Life)	SW SE NW	4	135	+1004	800	+339	1474	-335	1504	-365	1525	-386	1652	-513	1682
140. W. W. Stark et al No. 1 H. B. Ragan	N½ NW NE	4	125	+997	783	+339	1459	-337	1488	-366	1530	-408	1662	-540	1665
141. Aladdin No. 1 H. B. Ragan	SE NE	4	105	+998	770	+333	1420	-317							1440½
142. Young, Longwell et al No. 2 Bessie McLeod	NW NW SW	4	77	+1009	730	+356	1384	-298	1423	- 337	1447	-361	1575	-489	1596
143. Young, Longwell et al No. 1 Bessie McLeod**	NW SW	4	102	+996	760	+338	1424	-326	1469	-371	1521	-423	1582	-484	1919**
144. J. E. Sherrod et al No. 1 E. R. Momyer	NW SE	4	155	+989	834	+310	1498	-354	1573	-429	1612	-468			1682
145. Magnolia No. 1 George A. Kell	NE SE	4	105	+999	775	+319	1450	-356	1539	-445	1568	-474			1645
146. Hatcher & Fisk No. 1 C. Kimmel	NE NW	5	171	+971	825	+317	1496	-354							1526
147. Hatcher & Fisk No. 2 C. Kimmel	NW NW	5	160	+974	820	+314	1503	-369							1530
148. Hatcher & Fisk No. 3 C. Kimmel	SE NW	5	182	+974	845	+311	1513	-357							1536
149. J. W. Longwell et al No. 1 D. E. Bower	NW NE	5	148	+981	815	+314	1464	-335							1500
150. Aladdin Oil Co. No. 1 D. E. Bower	NE NE	5	120	+997	790	+327	1442	-325							1473
151. Luehring-Aladdin No. 1 D. E. Bower	SW NE NE	5	152	+985	812	+325	1470	-333	1512	-375	1517	-380	1635	-498	1651
152. Apperson, Stark et al No. 1 Bower-McLaughlin	SE NE NE	5	112	+995	769	+338	1430	-323	1476	-369	1484	-377	1595	-488	1603
153. J. E. Sherrod et al No. 2 D. E. Bower	NE SW NE	5	145	+991	813	+323	1458	-332	1525	-389	1533	-397	1644	-508	1659½
154. J. B. Apperson et al No. 2 D. E. Bower	N½ SE NE	5	134	+999	788	+345	1445	-312	1483	-350	1491	-358	1623	-490	1628
155. J. E. Sherrod et al No. 1 D. E. Bower	SW NE	5	160	+997	827	+330	1482	-325							1501
156. T. B. Swan et al No. 1 D. E. Bower	SE NE	5	130	+1000	793	+337	1438	-308	1489	-359	1492	-362	1623	-493	1636
157. McLaughlin & Sons No. 2 E.P.Dark (Bower)	SE NE	5	111	+1003	768	+346	1424	-310	1466	-352					1470
158 J.B.Apperson (Sowell) et al No. 1 D. E. Bower**	SE SE NE	5	***	....	......	....	....	....	1440	-335	1450	-345	1580	-475	2288**
159. Hatcher & Fisk No. 1 D. E. Bower	NE SW	5	197	+980	848	+329	1508	-331							1544

TABLE 27. *List of wells drilled in the McLouth field and bordering areas, concluded*

WELL NAME	Location	Section	Depth top Oread	Alt. top Oread	Depth base Hertha	Alt. base Hertha	Depth top McLouth	Alt. top McLouth	Depth top Miss'pian	Alt. top Mississippian	Depth top Warsaw	Alt. top Warsaw	Depth B-K por. zone	Alt. B-K porous zone	Total depth of well
160. Hatcher & Fisk No. 2 Henry H. Kimmel	SW SW	5	215	+965	868	+312	1520	-340							1569
161. Hatcher & Fisk No. 1 Henry H. Kimmel	SE SW	5	200	+979	850	+329	1512	-333	1561	-382	1571	-392	1704	-525	1714
162. V-8 Drilling Co. No. 4 Bessie McLeod	NE NW SE	5	140	+1000	810	+330	1440	-300	1503	-363	1513	-373	1644	-504	1645½
163. V-8 Drilling Co. No. 1 Bessie McLeod	NW SE	5	152	+987	818	+321	1484	-345							1501
164. Young, Longwell et al No. 3 Bessie McLeod	NE SE	5	141	+1006	815	+332	1474	-327	1507	-360	1515	-368	1635	-488	1644
165. Young, Longwell et al No. 4 Bessie McLeod	SW NE SE	5	157	+992	817	+332	1475	-326	1513	-364	1518	-369			1659
166. V-8 Drilling Co. No. 3 Bessie McLeod	SE NW SE	5	152	+989	806	+335	1484	-343	1535	-394	1528	-387	1639	-498	1645
167. V-8 Drilling Co. No. 4 Bessie McLeod	SW SE	5	160	+983	825	+318	1479	-336							1533
168. Oscar Lofquist et al No. 1 Bessie McLeod	NW SE SE	5	170	+985	825	+330	1485	-330	1530	-375	1535	-380	1654	-499	1660
169. J. B. Apperson (T.W.Sowell) et al No. 1 Bessie McLeod	NE SE SE	5	135	+991	808	+318	1471	-345	1504	-378	1512	-386	1645	-519	1649
170. John B. Richard et al No. 1 Kate Sherman	NE NE	6	170	+966	818	+318	1504	-368							1518
171. Ray Anderson et al No. 1 Woodhead Estate	NE SW	6	180	+931	838	+273	1520	-409	1552	-441					1603
172. H. Luehring et al No. 1 Amiel Fryhofer	NE NE	7	215	+952	868	+299	1580	-413	1635	-468					1637
173. J. B. Synhorst et al No. 1 McLeod-Wisdom	N½ NW	8	220	+970	880	+310	1548	-358							1571
174. J. B. Synhorst et al No. 2 McLeod-Wisdom	SW NW	8	208	+958	860	+306	1520	-354							1553
175. Mosbacher, Kilness et al No. 1 Neal Vandruff	NE NW	8	220	+969	878	+311	1551	-362							1580
176. J. E. Sherrod et al No. 1 Alvin Means	NE NE NW	8	190	+977	840	+327	1499	-332							1536
177. J. E. Sherrod et al No. 1 Wm. F. Benne	NW NW NE	8	185	+977	856	+306	1516	-354	1610	-448					1623
178. J. B. Apperson et al No. 1 B. McLeod (Hunter)	NE NE NW	9	195	+980	862	+313	1535	-360	1574	-399	1616	-441	1701	-526	1706
179. Walter T. McNerney No. 1 Earl Chapman	E½ NW NW	12	40	+1008	694	+354	1367	-319	1421	-373					1428
180. W. T. McNerney et al No. 1 Fed. Land. Bank (Watson)	NE NW	12	14	+1020	682	+352	1368	-334							1385
181. W. T. McNerney et al No. 1 J. M. Williams	SW NW	12	32	+1006	695	+343	1390	-352	1448	-410	1474	-436			1495
182. E. W. Mosbacher et al No. 1 J. Bell Estate	NW NE NE	12	......	+1002	662	+332	1330	-336	1372	-378	1414	-420			1487
183. J. W. Billingsley et al No. 1 D. Wilkins	SW NE	15	30	+1011	703	+338	1370	-329	1425	-384	1460	-419			1575
184. Caufield & Sullivan No. 1 Ada Ragan	SW SE	19	160	+960	820	+300	1510	-390	1562	-442	1579	-459	1706	-586	1708
185. H. Luehring et al No. 1 S. A. Petrie	NE SE SE	19	148	+961	812	+297	1510	-401	1555	-446	1588	-479	1716	-607	1738
186. E. W. Mosbacher et al No. 1 C. L. Stroud	SW NE	20	40	+977	704	+313	1402	-385	1420	-403	1435	-418			1531
187. Wm. O. Smythe et al No. 1 Charles E. Miller**	NE SE	22	90	+1025	752	+363	1430	-315	1476	-361	1510	-395	1620	-505	1947**
188. McLaughlin & Sons No. 1 T. M. Thorpe**	NE NE	27	4	+1055	671	+388	1354	-295	1398	-339	1426	-367	1549	-490	2209**
T. 10 S., R. 21 E.															
189. Charles E. Miller No. 1 J. Bell Estate	S½ NW SW	6	55	+998	712	+341	1401	-348							1438
190. Miller-Magnolia et al No. 3 J. A. Bell	SE SW	6	36	+999	704	+331	1395	-360	1419	-384					1433
191. Charles E. Miller et al No. 1 J. A. Bell	NW NW NW	7	31	+998	695	+334	1370	-341							1384
192. Charles E. Miller et al No. 2 J. A. Bell	SW NW	7	......	....	612	+341	1305	-352	1335	-382					1342

193. Miller-Magnolia et al No. 1 E. E. Jeannin	NE NW	7	6	+1006	670	+342	1367	-355	1412	-400	1412	-400			1414
194. Aladdin Oil Co. No. 1 C. W. Corlett	SW NE	19	5	+1030	660	+375	1352	-317	1417	-382					1430
Wells completed April 1 to June 15, 1943															
T. 9 S., R. 19 E.															
195. B. O. Slottman et al No. 1 Bankers Life	SE SE	25	120	+934	780	+274	1467	-413							1473
T. 9 S., R. 20 E.															
196. O. B. Kilness et al No. 1 T. C. Moseberger	S½ NE SE	21	83	+957	738	+302	1414	-374							1417
197. Charles E. Miller No. 1. Tullis	SW SW SE	22	10		671		1349		1382						1421½
198. Charles E. Miller No. 1 Moses	SE SE	25	......	......	566	+349	1265	-350	1300	-385	1347	-432	1487	-572	1492
199. Byram et al No. 1 George Kell	NW NW	34	70	+993	735	+328	1402	-339	1437	-374					1441
T. 10 S., R. 20 E.															
200. J. B. Apperson (T.W.Sowell) et al No. 2 D. W. McLaughlin	SW NW	4	83	+995	735	+343	1390	-312	1425	-347	1442	-364	1559	-481	1581½
201. J. E. Sherrod et al No. 3 D. E. Bower	SE SW NE	5	140	+998	810	+328	1460	-322	1520	-382	1527	-389	1649	-511	1654
T. 10 S., R. 21 E.															
202. Charles E. Miller No. 3 J. Bell Estate	S½ SW SW	6	4		666		1345								1402

* Top of Warsaw estimated. Well entered Mississippian below top of Warsaw.

** Drilled below Mississippian, see supplementary table 27

*** Rotary well. No samples or log kept above top of Mississippian.

Supplement to Table 27, giving data on deep wells

	Depth top Gilmore City	Altitude top Gilmore City	Depth top Chouteau	Altitude top Chouteau	Depth top Chattanooga	Altitude top Chattanooga	Depth top Devonian	Altitude top Devonian	Depth top Maquoketa	Altitude top Maquoketa	Depth top Kimmswick	Altitude top Kimmswick	Depth top Decorah	Altitude top Decorah	Depth top St. Peter	Altitude top St. Peter	Depth top Arbuckle	Altitude top Arbuckle
3. Max Cohen No. 1 M. L. Decker	1680	-694			1801	-815	1874	-888										
12. E. V. Jackson et al No. 1 N. Fevurly	1743	-736	1770	-763	1870	-863												
134. McLaughlin & Sons No. 1 fee	1685	-582	1708	-605	1820	-717	1874	-771										
143. Young, Longwell et al No. 1 Bessie McLeod					1775	-676	1828	-729										
158. J. B. Apperson et al No. 1 D. E. Bower					1781	-676	1829	-724	2002	-897	2009	-904	2158	-1053	2165	-1060	2233	-1128
187. W. O. Smythe et al No. 1 Charles E. Miller	1688	-573			1821	-706	1872	-757										
188. McLaughlin & Sons No. 1 T. M. Thorpe	1606	-547	1624	-565	1734	-675	1794	-735			1953	-894			2088	-1029	2164	-1105

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