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STATE GEOLOGICAL SURVEY *of* KANSAS

RAYMOND C. MOORE, State Geologist
KENNETH K. LANDES, Assistant State Geologist

BULLETIN 12

THE GEOLOGY OF COWLEY COUNTY, KANSAS

With Special Reference to the Occurrence of Oil and Gas

By N. W. BASS

Prepared in coöperation with
The United States Geological Survey

Printed by authority of the State of Kansas

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The Geology of Cowley County, Kansas,

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By N. W. Bass.

INTRODUCTION.

IN continuation of the policy of studying the geology of Kansas by county units, followed for several years by the State Geological Survey and the United States Geological Survey in coöperation, Cowley county was selected as the unit for this report. It is one of the larger counties in Kansas, has recently featured prominently in the development of the oil and gas resources of the state, contains active building-stone quarries and gravel and sand pits, and embraces considerable thickness of strata cropping out at the surface. Its selection by the state geologist thus afforded a wide variety of subjects for study.

The present report describes both the strata that crop out in the county and those that occur beneath the surface, although the surface beds are treated more fully, for it is believed it is in them that geologists working in the region will be most interested. The physiographic features of the county are pictured in a general way, including a discussion of asymmetric stream valleys, a feature common to a wide region, including Cowley county. The water supply and industries other than oil and gas are briefly described, but the larger part of the report relates to the oil and gas fields of the county. Each field is treated separately, including a history of the field and a description of the rocks and their structural attitude, in so far as data are available for publication. A few analyses of oil and gas are quoted, and the available production statistics are given. The data pertaining to many fields are incomplete, so that the description is necessarily generalized; for some fields more complete reports were possible.

Field Work.

The field study of the area extended throughout the summer of 1926. A geologic map of the county showing the location of the outcrops of the principal rock beds was prepared and is shown as Plate 1. A large part of this map was compiled from maps of small areas that had been prepared by geologists of oil companies operating in the region. Later about a month was spent in the field checking the compiled map and mapping rock outcrops in the areas not covered by the oil-company maps. Some of the maps obtained from companies resulted from very careful work and show the delineation of the rock outcrops in minute detail; on others the outcrop positions were sketched with less precision. The supplementary field mapping was done by free-hand sketching from the section-line roads. For this work the county engineer's county base map, on a scale of 1 inch to the mile, showing roads and section lines, and the county soil map, on approximately the same scale, published by the United States Bureau of Soils, were used.

A hasty study of the rocks exposed in the county was made prior to and during the field mapping. Most of the beds that crop out in the county were named many years ago by geologists working on Cottonwood river and elsewhere in east-central Kansas. In order to correlate the strata of the two regions the rocks of the divisions in the central part of the exposed stratigraphic section were studied at the localities in east-central Kansas from which they were named —that is, the type localities—and were visited also at two places between the Cottonwood river region and Cowley county. The type localities of the beds in the upper and lower parts of the section were not visited.

The material for the chapters describing the buried rocks, the subsurface structure, and the oil- and gas-producing beds was procured largely through a study of records of wells drilled for oil and gas and from compiled data derived from similar studies by oil-company geologists operating in the region, generously supplied by the company representatives. Much of the summer of 1926 was occupied in compiling well records and other data. The office work on the report was done in the winters of 1926-'27 and 1927-'28.

ACKNOWLEDGMENTS.

So many companies and individuals contributed maps, well logs, data on production, and other information for use in the report that it is impossible to make acknowledgments for all kindnesses and services rendered. Only a few will be mentioned here, although the services given by many others are equally appreciated. The writer is deeply indebted to M. W. Baden, of the Trees Oil Company, of Winfield, who supplied much information, including well logs, altitudes, and geologic maps of a large part of the county, and gave his hearty support to all parts of the work. Joe Bailey, of the same

company, supplied many data. R. B. Rutledge, of the Barnsdall Oil Company, also furnished many logs, altitudes and suggestions. E. L. Jones, of the Roxana Petroleum Corporation, generously supplied well cuttings, maps and other data. G. M. Clark, of the Marland Oil Company, furnished maps of the Rainbow Bend and Graham pools, and A. F. Melcher, of the same company, supplied chunk sand samples for study. A. M. Ambrose and W. L. Walker, of the Empire Gas and Fuel Company, supplied geologic maps of much of the county, and also maps and other information concerning the Eastman pool. Luther H. White, of the J. A. Hull Oil Company, and Everett Carpenter, of the Mississippi Valley Oil and Gas Company, furnished many of the data on the Winfield pool. J. K. Knox and C. D. Sherwood, of the Phillips Petroleum Company supplied areal maps of parts of the county and detailed information about the Falls City pool. L. M. Neumann, of the Carter Oil Company, furnished areal maps for a portion of the southeastern part of the county, and the Tidal Oil Company also supplied part of the surface mapping.

GEOGRAPHY.

Cowley county is one of the southernmost tier of counties of the state of Kansas. (See Fig. 1.) It is one of the larger counties, being 35 miles from north to south by 34½ miles from east to west. It is traversed by several railroad lines—two branch lines of the Atchison, Topeka & Santa Fe Railway, the St. Louis-San Francisco Railway, the Midland Valley Railroad, and the Missouri Pacific Railroad. The county is crossed by a number of well-graded dirt roads, which are shown on Plate I. A paved highway extends northward through Arkansas City from the state line to a point several

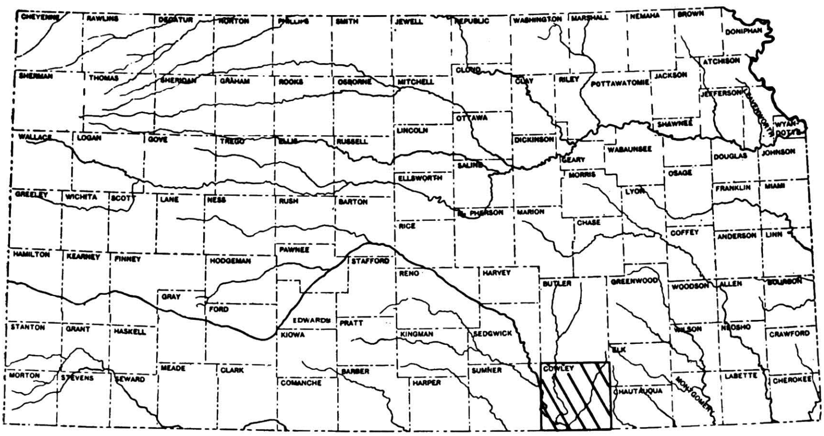

FIG. 1.—Index map of Kansas, showing the location of Cowley county.

miles beyond the city limits. The two largest towns are Arkansas City, which has a population of 12,000 and ranks fifteenth among the cities of the state, and Winfield, which has a population of 10,000 and ranks nineteenth.[1] The total population of the county is 37,000. The chief occupation is agriculture. Dairy products, alfalfa hay, live stock, winter wheat, corn, oats and kafir are the principal farm products. The operation of stone quarries and gravel pits and the oil industry, including refineries and gasoline absorption plants, furnish employment for an appreciable proportion of the inhabitants.

Most of the surface of Cowley county is covered by a good stand of native grasses and is used for the grazing of stock, principally

1. Mohler, J. C.: Kansas State Board Agr. Rept.; 1923.

cattle. The eastern part of the county, particularly the Flint Hills region, is used almost entirely for grazing. The broad bottom lands of Arkansas and Walnut rivers and the narrower stretches along Dutch, Timber, Silver and Grouse creeks are used for cultivated farm crops, such as alfalfa, corn, sorghums, wheat and truck. Extensive areas of the uplands in the central part of the county are farmed, but the crops sometimes fail, particularly in tracts where the soil directly overlies limestome. Back from the rocky edges of the uplands, where the soil overlies shale of the next higher formation, crops withstand a summer drought more successfully. The degrees of success attained in raising cultivated crops on various types of soil in the county exhibit a remarkable parallelism with the geology. The later part of the summer of 1926 was exceedingly dry in Cowley county, and it was possible to outline the general areas of crop failures from the geologic map. For instance, in the east-central part of the county there is a wide strip of upland near the outcropping edge of the Wreford limestone where erosion has stripped most of the overlying Matfield shale from the limestone beds and only a thin soil covers the rocks. Throughout this strip the growing crops were the first to suffer from the lack of rainfall. The upland bordering this area on the west is underlain by the lower part of the Matfield shale, and the growing crops there withstood remarkably well the long period of drought. Crops that were growing on the bottom lands along the streams, of course, withstood the dry weather much longer than those on either of these types of upland.

General Surface Features of Kansas.

The surface of Kansas is characterized by broad expanses of almost level uplands that trend slightly east of north and west of south across the state, and rise in steplike succession progressively westward. The extreme southeastern part of the state has a nearly level lowland surface; from this lowland westward to the western part of Cowley county the surface consists of a series of benches like great steps with abrupt slopes facing eastward, each bench surface tilted gently westward to the foot of the steep slope of the succeeding step. West of this area is an extensive plain occupying western Cowley county, Sumner and Sedgwick counties, western Butler and Harvey counties and some adjacent areas, and thence becoming narrower toward the north. An area about 100 miles wide from east to west having a surface similar to the benched area of eastern Kansas borders this plain on the west; still farther west, and extending for long distances into Colorado, Nebraska, Oklahoma and Texas is a broad, practically level area known as the High Plains. In a relatively small area in the south-central part of the state the surface is deeply dissected.

Probably the most rugged surface feature of Kansas is a range of hills that trends a little west of south across the state and into the northern part of Oklahoma, situated near the western edge of the benched area of eastern Kansas. Early writers in Kansas referred to these hills as the Kansas Mountains, but they later became known as the Flint Hills. They cross the eastermost part of Cowley county. Their existence is due to the abundant occurrence of chert (often called flint) in some of the limestone beds that crop out at the surface. The chert is much more resistant than the limestone and shale beds that make up the other strata of the region; consequently erosion destroys the limestone and shale more rapidly than the chert beds. The inevitable result is the formation of broad benches or uplands floored by the resistant rock and bordered by steep slopes of the softer beds. The upland surfaces slope gently westward, because the rock layers that form their floors are tilted slightly to the west. This same process has produced the steplike surface that characterizes so much of the state; in the Flint Hills region the addition of chert to the limestone has merely accentuated the resistance of the hard layers and likewise magnified the results. The Flint Hills present an eastward-facing steep slope 200 feet or more high, capped by the chert-bearing layers. The slope is not everywhere one great step, but more commonly two to three closely spaced steps or shoulders, the intervening slopes rising with steep gradients to the highest bench, which everywhere forms a broad upland. As a traveler approaches from the west the ascent toward the east is so gradual that it is not perceptible, and he comes abruptly and without warning upon the eastern edge of the upland. To the traveler approaching from the east, however, the Flint Hills stand out prominently, and he is struck by their pronounced relief. The upland surface is not everywhere floored by the same formation. In the central Kansas Flint Hills region the Florence flint provides the capping rock layers, as is finely exhibited on the Eureka-El Dorado highway a few miles east of Rosalia in eastern Butler county; farther south, throughout much of Cowley county, even the Florence flint has been removed by erosion, and the Wreford limestone, which also contains much chert and lies 60 feet beneath the Florence flint, remains to form the principal upland and rim of the Flint Hills;

still farther south in Cowley county, near the Kansas-Oklahoma boundary, the chief bench has dropped down to the Foraker limestone, which lies about 300 feet beneath the Wreford.

Surface Features of Cowley County.

Cowley county is so situated that it embraces parts of several of the state's physiographic divisions. The eastern part of the county includes a portion of the Flint Hills; the central part is occupied by the typical steplike surface; and the westernmost sixth embraces the eastern part of the central Kansas plains.

The surface features of Cowley county are directly and almost entirely attributable to the variations in types of rock that crop out. The entire county except the extreme western tier of townships is occupied by outcropping layers of alternating limestone and shale. The limestone beds, which are more resistant to erosion than the shale beds, form the benches, and the shale beds, which are relatively soft and are readily disintegrated, form the steep eastward-facing slopes between the limestone ledges. The western sixth of the county is underlain by soft clay shale, which is readily broken down by the agencies of weathering and forms an almost level surface.

Reference to the columnar section and geologic map, both on Plate I, will show the close relationship between the surface features of the county and the outcropping strata. The Emporia limestone and the sandstone beneath it form a rock terrace along the highway near Cedarvale, Chautauqua county, about two miles east of the eastern boundary of Cowley county, and extend westward nearly to the county boundary in T. 34 S., R. 8 E. In the southeasternmost part of the county the Admire shale, composed of relatively soft rocks, forms the steep eastward-facing slope of the Flint Hills, which are capped by the resistant cherty Foraker limestone, and the alternately hard and soft beds above the Foraker form low rock terraces ascending westward. In the northeastern part of the county the rim of the Flint Hills is formed by the Wreford limestone, and the several limestone units in the shale beds below form shoulders in the eastward-facing slope. The Foraker is the most prominent of these limestones and constitutes a definite subsidiary step in the Flint Hills throughout much of the region. Westward from the Flint Hills are the several steplike terraces or benches formed by the beds of limestone succeeding the Wreford, of which the Herington limestone forms the topmost step. The intervening slopes are made by the softer shale formations. The area west of the crop line of the

Herington is a nearly level plain carved in the soft shale beds of the Wellington formation.

Although not so intricately dissected as the Wreford upland (see Pl. I) the area floored by the Florence flint and Fort Riley limestone is the widest in the county, occupying most of the central part. On the surface of the eastern part of this upland are abundant fragments of residual chert derived from the Florence flint. Very shallow circular basins or filled sink holes 30 feet, more or less, in diameter are noteworthy features in the northern part of the upland floored by the uppermost beds of the Fort Riley limestone. Many of the basins are rimmed by weathered fragments of the uppermost limestone beds of the Fort Riley, and their surface contains scarcely any vegetation. Plate III is a view of one of these basins in sec. 4, T. 30 S., R. 5 E., near the northern line of the county. The Winfield limestone forms a relatively narrow bench west of Walnut river, but the flat-topped buttes capped by this formation east of the Walnut bear witness to a former much more extensive table-land. The bench formed by the Herington limestone is much less pronounced than that of the Winfield throughout most of the county; it is most prominent in the vicinity of Arkansas City.

The surface of Cowley county ranges in altitude above sea level from 900 feet near the southeast corner of the county, where Rock creek crosses the county boundary, to a little above 1,500 feet in the northeastern part. Much of the county has an altitude ranging between 1,150 and 1,350 feet. The most abrupt differences in altitude occur in the eastern part of the county in the Flint Hills region, where the relief is commonly as great as 300 to 350 feet in a mile.

The stream valleys vary in shape and depth with their location in the county. The streams in the Flint Hills have deep, precipitous channels lined with outcropping rock ledges, and their beds are strewn with angular fragments of limestone. The valley bottoms widen at the eastern edge of the Flint Hills, however, but are bordered by steep-sided divides that rise 300 feet above the valley floors. The channels of the small intermittent streams flowing southeastward from the vicinity of Hooser illustrate the characteristics common to the stream channels in this part of the county. There stream beds are incised in narrow boxlike channels in the upper reaches, but at the points where the streams have cut through the Foraker limestone and entered the Admire shale the valleys immediately open out, and a little farther east they widen even more and have gently sloping sides. The streams in the central part of the county have widened their valley floors somewhat, but the valley walls, although receding to a considerable distance from the stream beds, are still steep and lined with ledges of limestone and rise to heights of 50 to 150 feet. The major streams in the western part of the county flow sluggishly within broad flood plains spread upon wide, shallow valleys.

The Arkansas and the Walnut, which joins the Arkansas near Arkansas City, are the only two large streams in the county, and they are both in the western part and drain the western third. The Arkansas flows southeastward across the southwest corner of the county, and the Walnut flows almost due south. Timber creek, a tributary of the Walnut, drains much of the north-central part of the county. Grouse creek and its principal tributary, Silver creek, drain the central part and discharge into the Arkansas near the state line. The extreme eastern part of the county is drained by eastward-flowing tributaries of Caney river.

Origin of the Asymmetrical Stream Valleys.

It has long been noted by many observers that streams in Kansas that flow from west to east are eroding their south banks, that the northward-facing slopes are relatively much steeper than the southward-facing slopes, and that the profiles of the interstream areas are decidedly asymmetrical, the northern slope being the shorter. These facts were observed by early workers in Kansas[2] and have been mentioned also in more recent state reports;[3] they were called to the writer's attention and discussed at length by W. W. Rubey while working in western Kansas in 1924. In the course of reconnaissance trips about the state, which have included parts of all counties except four or five in the extreme northeastern part, the writer has observed this phenomenon of asymmetrical stream valleys and interstream areas. It appears to prevail so generally in eastward-flowing streams in this region that stretches in any stream course that fail to exhibit this feature are believed to be merely exceptions constituting a small percentage of the total course of the stream.

The Kansas river valley has a steep, in places precipitous, south slope and a relatively gentle north slope throughout its course eastward across Riley, Wabaunsee, Shawnee, Douglas and Johnson

2. Haworth, Erasmus: Kansas Univ. Geol. Survey.

3. Rubey, W. W., and Bass, N. W.; The geology of Russell county, Kansas: Kansas Geol. Survey Bull. 10, p. 10; 1925. Bass, N. W.; Geologic investigations in western Kansas: Kansas Geol. Survey Bull. 11, p. 13; 1926.

counties. Other streams that show this same phenomenon are Republican river between the 100th and 98th meridians in southern Nebraska; White Rock river across Jewell county; Saline river across Trego, Ellis and Russell counties; Smoky Hill river across Russell county and parts of Ellis and Ellsworth counties; Walnut creek across most of Ness and Rush counties; Arkansas river throughout parts of its course in western Kansas, but with notable exceptions through extensive parts; Medicine Lodge river in western Barber county; Fall river in Greenwood county; Cottonwood river

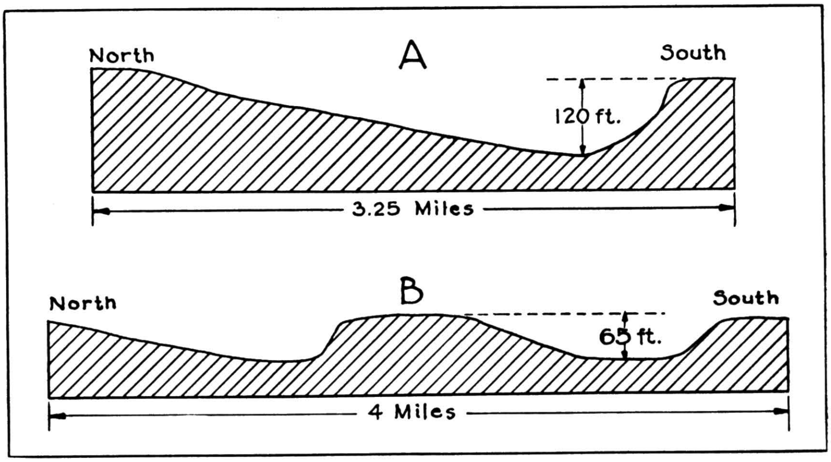

FIG. 2.—North-south profile of an eastward-trending stream valley near Pomona, Franklin county (above), and westward-trending valleys near Leon, Butler county (below).

in most of its course across Chase county; Neosho river in Coffey county; Dragoon creek, Salt creek and Osage river in Osage county; and Wakarusa creek across Douglas county. The valleys of these streams constitute simply examples of this phenomenon, which is believed to be the prevailing characteristic of practically all similarly directed streams in the region.

The rocks in which the stream valleys are cut throughout much of the state consist of interbedded shale and limestone. A relatively small area in west-central Kansas is occupied by the Dakota sandstone, and the western third of the state is largely mantled by gravel, sand and clay beds cemented with lime carbonate. Asymmetry of cross sections prevails in valleys cut in all these rock types.

Further observations relative to stream-valley cross sections were made in the course of field work in Cowley county. Inasmuch as most of the major streams in Kansas flow eastward, most of the observations in the state have been made on eastward-flowing streams. However, Walnut river flows nearly due south, and some of its tributaries flow westward in Cowley county, thus offering new fields for observation.

Application of Ferrel's law: The fact that the right banks of the eastward-flowing streams are the steeper is in accord with Ferrel's law that all streams in the Northern Hemisphere, independent of their direction of flow, will by the influence of the rotation of the earth exert pressure on their right banks. Many of the streams on which this phenomenon was observed are small, and others intermittent and only a few miles in length—conditions under which, one would think, the influence of the rotation of the earth would be practically negligible. However, if Ferrel's law is applicable to the streams of this region, the right banks of southward- and westward-flowing streams should be steeper than the left banks. Study of Blue river, in northeastern Kansas, and of Walnut and Verdigris rivers and the lower part of the Neosho, in the southeastern part of the state, as shown on the topographic maps of the United States Geological Survey, shows that in general the east (left) slope is as steep as the west (right) slope. Westward-flowing tributaries of Walnut river were observed in Cowley county and southern Butler county in the field and on the topographic maps. The south (left) slope of these tributaries is as markedly steep and the north (right) slope as contrastingly gentle as in the eastward-flowing streams. Timber creek in north-central Cowley county is an example. It flows slightly south of west for 12 to 15 miles, passing near Floral, and practically throughout its course bluffs of Fort Riley limestone and Florence flint border its valley on the south, and relatively gentle slopes rise northward from the valley floor. Numerous short westward-flowing tributaries of Grouse creek in northeastern Cowley county exhibit like conditions, notably Cedar creek, south and southeast of Cambridge. Rock creek flows nearly due west throughout a distance of 5 miles in T. 29 S., R. 5 E., just north of the Cowley county boundary, and has produced the same result. Other tributaries of Walnut river farther north in Butler county have asymmetrical valleys similar to those just described. A noteworthy example is Hickory creek, a tributary of Little Walnut creek. It flows nearly due west for more than 15 miles in southern Butler county, about 10 miles north of the northern boundary of Cowley county, and maintains a steep northward-facing slope and more gentle southward-facing slope throughout most of its course. It appears, then, that the slope on the south side is the steeper in eastward-flowing and westward-flowing streams; in one group it is the right bank and in the other the left bank; in southward-flowing streams no marked difference in degree of slope exists. In the light of these data the conclusion that the principle of Ferrel's law is inapplicable to the stream valleys of this region is inevitable.

Migration of streams down the dip. In regions of steeply tilted strata streams often migrate down the dip, and in consequence gentle slopes prevail on the up-dip side, but in this region the departure of the strata from horizontality is extremely slight, rarely exceeding 100 feet in a mile and commonly being much less, and it is thought that this factor probably exerts but little effect upon the stream's action. Moreover, in western Kansas the rocks dip at a low angle northward, but the streams are crowding southward; in eastern Kansas the regional dip of the strata is westward, and the stream channels are migrating southward. In parts of western Kansas there are streams with channels cut wholly in flat-lying rocks of Tertiary age, and yet they exhibit asymmetrical valley cross sections similar to those of the stream valleys cut in the older stratified rocks. In places the contact of an eastward- or westward-flowing stream with tilted hard layers may have modified somewhat its course and tended to push the stream to the north rather than the south side of its valley. A case in point is Cottonwood river where it crosses an anticlinal fold near Cottonwood Falls and Strong City, in Chase county. In other localities, however, the streams follow their normal habit irrespective of minor folds in the strata. Polecat creek, in northwestern Cowley county, flows southeastward across the axis of the granite ridge over which the beds are greatly folded, but the southwest slope of the stream valley is markedly steeper than the northeast slope. A similar condition is present along Slate creek in southwestern Sumner county. However, the surface rocks of the two areas just mentioned are softer and their dips probably more gentle than in the Cottonwood Falls region. In summary, it appears that any influence that the dip of the surface strata has upon the habit of the streams is only local, and that the prevailing characteristics of the stream valleys are independent of this factor.

Southward tilting. A regional southward tilting subsequent to the time of formation of the present drainage system might tend to shift the streams southward and create the asymmetrical conditions that now exist in the channels of eastward- and westward-flowing streams. If southward tilting has occurred, streams that flow southward should show an increase in gradient and in downward cutting. These items have been given but little study. Very small gulches in Cowley county, that must be relatively young and that contain water only at times of rainfall, exhibit a marked contrast in steepness between north and south slopes, a fact that is difficult to explain by regional tilting, because of the extreme youth of the valleys. Although the little information at hand is insufficient to prove or disprove whether the region has been subjected to southward tilting, the meager facts cited contribute some evidence against the effects to be expected if such tilting had occurred.

Climatic factors. Certain climatic factors, not confined to Kansas but operating throughout this general region, appear to be ample to bring about the results observed. It is a well-known fact that in the Northern Hemisphere the southward-facing slopes are struck more directly by the sun's rays and consequently receive an appreciably greater amount of heat than the northward-facing slopes. The prevailing winds throughout the warm months are southerly in this region, and so strike the southward-facing slopes more directly than the northward-facing slopes. According to the state meteorologist's records,[4] these winds are commonly hot and dry, often "like the wind from a furnace, in extreme cases having been known to kill the bark and foliage on the south side of trees." Both of these factors—heat from the sun's rays and heat and absorption of moisture by the winds—tend to dry out the surface material of the southward-facing slopes more than that of the northward-facing slopes. In dry-farming areas, where the precipitation is so small that success or failure in the raising of crops depends almost wholly on the degree of success in retaining the little moisture received, experienced farmers have long known that the raising of successful crops is more certain on the northward-facing slopes.

Chemical action is accelerated by an increase of heat and retarded by decrease of moisture. The heating effect of the sun's rays during the warm months would operate to hasten the chemical processes that tend to destroy the rocks, but the drying of the surface materials would retard them. Both of these factors are accentuated on the southward-facing slopes. Inasmuch as the northward-facing slopes remain relatively moist, chemical action should be almost continuous there throughout the warm period of each year. During

4. Flora, S. D.; Summary of climatological data for the United States; 1917.

the winter the material on the northward-facing slopes remains frozen for months at a time, while that of the opposite slope is subjected to daily thaws throughout much of the period. Accordingly, chemical action would be greater on the southward-facing slopes during the cold season. No data as to the relative effects of chemical activity are available, and it is not known whether the total effect is more destructive on the north or the south slopes.

The more direct rays of the sun on the southward-facing slopes, however, bring about a notable physical effect. The daily range of temperature is much greater on the southward-facing slopes than on the opposite slopes. The physical disintegration of the rocks due to the repeated expansion and contraction resulting from cooling and heating, freezing and thawing, would consequently be more manifest on the southward facing slopes. Moreover, the high southerly winds of the summer not only raise the temperature and dry out the surface, but as they are often laden with sand and silt, they constitute an erosional agent that accomplishes more rock destruction on the southward-facing slopes, against which they blow directly, than on the northward-facing slopes, which are comparatively protected. Relatively strong northerly winds occur during the winter throughout much of the state, but at that time the surface material is frozen and but little abrasive material can be gathered.

The season in which most of the rainfall comes may be of some importance. This region receives its maximum precipitation, approximately three-fourths of the year's total, between April and September, which is the hot portion of the year. The rain falls on south and north slopes alike, and in itself may not have a direct effect in producing asymmetrical valleys, but its maximum fall during the time of the year when the surface materials are so frequently dried by the sun's heat and loosened by the high winds is thought to be significant, inasmuch as the run-off resulting from the rainfall removes the loosened material, thus exposing new rock surfaces to the destructive elements. Moreover, the relative sparseness of vegetation on the southward-facing slopes contrasted with that on the northward-facing slopes is of no little importance, inasmuch as plant roots serve to hold the soils, and the foliage forms a protective covering. The erosional effect of the surface run-off resulting from rainfall is therefore greater on the southward-facing than on the northward-facing slopes.

To summarize, it appears that the combined effect of the several climatic factors described may produce the asymmetrical cross sections in eastward or westward trending valleys and in valleys that have a pronounced east or west component in their trends. On eastward- or westward-facing slopes the combined effect of these several climatic factors should be more or less equalized, so that no pronounced difference in degree of slope of the valley walls should result.

It may be assumed that the beds of eastward- or westward-flowing streams, except for vertical cutting, remain fixed, and that the asymmetrical slope of their valleys is produced solely by the more rapid disintegration and removal of the material extending a considerable distance back on the north side of the stream. Probably this explanation accounts for the greater part of the operating process, but it is believed also that the streams actually migrate southward. It seems that this migration should result from the accumulation and consequent building out that should take place on the gently sloping north banks, over which move greater amounts of sediment than that of the south banks. It is true that the streams will carry away much of the material that is received by tributary streams and rivulets, but in times of moderate precipitation much of the incoming sediment would be temporarily deposited near shore upon entering the quieter water of the larger streams. Inasmuch as more material is brought in from the north sides than the south, the north banks would be built out into the stream, thus forcing the currents southward, resulting in greater erosion by undercutting on the south banks, which in turn would aid in maintaining steep slopes on the south sides.

Summary. Eastward- and westward-flowing streams in Kansas have asymmetrical valley cross sections, steep on the northward-facing and gentle on the southward-facing slopes. Northward- and southward-flowing streams have symmetrical valley cross sections. The evidence observed indicates that the influence of the rotation of the earth, a possible regional tilting, or the influence of the attitude of the strata fails to account fully for the phenomenon. A combination of climatic factors with the nature of the surface strata is believed to account for the more rapid tearing down and removal of material from the southward-facing slopes than from the northward-facing slopes, which in turn results in the deposition of more material on the north than the south banks, thus forcing the currents southward.

STRATIGRAPHY.

Buried Rocks.

No detailed study of the buried rocks was made in Cowley county, and the description of these beds is accordingly generalized. A correlation chart made by matching a series of well logs from Bourbon county, at the eastern edge of the state, where the lower Pennsylvanian beds crop out, westward to the western part of Cowley county, is shown on Plate II. The identification of some units within the stratigraphic succession was aided by choosing wells drilled near the outcrops of individual formations as shown on Haworth's geologic map of eastern Kansas,[5] reproduced in part on Plate II. It was not possible to identify individual formations throughout the region by this method, but units of group size were delimited. The precise boundaries are for the most part impossible of detection by this method, and a detailed study of drill cuttings may even show gross errors. Nevertheless, such a correlation chart as is given here is believed to be of value, in that it divides the stratigraphic succession into units that appear to correspond to divisions recognized and named at the outcrops, and the same names are carried through to the locality discussed, even though the beds lie far beneath the surface. A systematic plan of describing the stratigraphic units drilled through is thus provided.

Pre-Cambrian Rocks.

Several wells in Cowley county and a large number of wells elsewhere in eastern Kansas and northern Oklahoma have been drilled into rocks of Pre-Cambrian age,[6] consisting chiefly of granite and schist, but including also quartzite, quartz porphyry, diabase, and other rock types. Similar rocks crop out in widely separated areas outside the state, mostly at a considerable distance from it. Studies by geologists of the rocks constituting these distant exposures and of samples obtained from drilled wells within the state and the

5. Haworth, Erasmus; Special report on oil and gas: Kansas Univ. Geol. Survey, vol. 9, pls. 7*b* and *c*; 1908.

6. Moore, R. C., and Haynes, W. P.; Oil and gas resources of Kansas: Kansas Geol. Survey Bull. 3, pp. 81, 82, 140-173; 1917; Bull. 6, p. 9; 1920. Fath, A. E.; Geology of the El Dorado oil and gas field: Kansas Geol. Survey Bull. 7, pp. 25-27; 1920. Landes, K. K.; A study of the Pre-Cambrian rocks of Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 821-824; 1927.

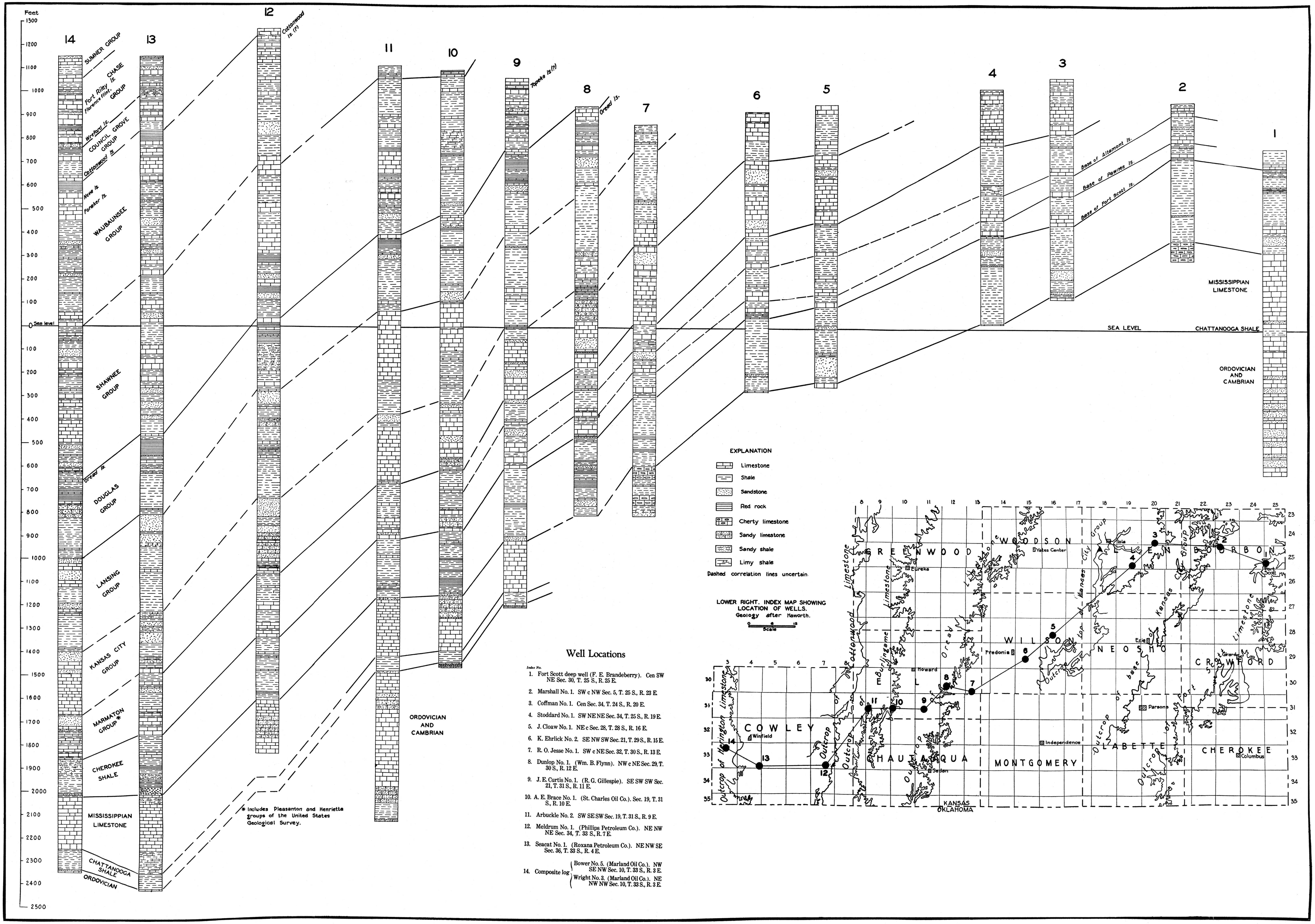

Plate II.—Well-log correlation in southeastern Kansas.

adjacent regions show that the sedimentary beds of Kansas are underlaid at widely varying depths by a metamorphic and crystalline complex constituting the floor upon which the sediments accumulated. Pre-Cambrian rocks were reported to have been encountered in Cowley county in the Eckhart well of the Phillips Petroleum Company, in the center of the SW¼, sec. 9, T. 35 S., R. 6 E., at a depth of 4,545 feet, or 3,300 feet below sea level; in the Smith No. 1 well of the Doric Oil Company, in the northwest corner of the SE¼ NW¼, sec. 18, T. 33 S., R. 7 E., at a depth of 4,005 feet, or 2,815 feet below sea level. Less than a mile west of the west boundary of the county granite was encountered in the W. A. Sleigh well, in the center of the SW¼ NW¼, sec. 36, T. 31 S., R. 2 E., at a depth of 3,420 feet, or 2,153 feet below sea level. This well is near the crest of a northeastward-trending buried ridge or mountain range of Pre-Cambrian rocks, known as the Nemaha mountains,[7] extending from Nebraska across Kansas into Oklahoma. The upper surface of the Pre-Cambrian rocks is nearer the present surface northeastward along the trend of the ridge, being at a depth of less than 600 feet in the northern part of the state. The ridge is believed to traverse the northwestern part of Cowley county, passing beneath the town of Oxford just west of the county boundary, thence northeastward, passing a short distance west of Udall and crossing the north boundary of the county in sec. 3, T. 30 S., R. 3 E. A number of the state's most valuable oil pools—the El Dorado, Augusta, Churchill, Oxford and others — overlie the ridge. Drilling for oil in recent years has indicated that other ridges of Pre-Cambrian rocks, in general paralleling the Nemaha range, lie buried in Kansas and that the Pre-Cambrian surface is one of decided relief.

Cambrian and Ordovician Rocks.

Deep wells in Cowley county and elsewhere in this region have penetrated a thick series of strata commonly reported as interbedded limestone, sandy limestone, sandstone, and minor amounts of shale, and believed to be of Cambrian and Ordovician age. These beds lie 50 to 100 feet beneath the Mississippian limestone and are separated from it by a unit of black shale of Mississippian age. The shale is not present everywhere in Cowley county, however, and in those localities where it is absent the differentiation between the Mississippian and Ordovician beds is difficult to make. Inasmuch as the

7. Moore, R. C., and Haynes, W. P.; Oil and gas resources of Kansas: Kansas Geol. Survey Bull. 3, p. 173; 1917. Moore, R. C., and Landes, K. K.; Underground resources of Kansas: Kansas Geol. Survey Bull. 13, fig. 54; 1927.

Cambrian and Ordovician strata lie deeply buried throughout this region they can be studied only from fragments or core samples procured in drilling wells. No studies of this type have been made in connection with this report, but extensive work by geologists in northern Oklahoma has resulted in the separation of this group of beds into a number of divisions, the characters and distribution of which are described in a recent report by Luther H. White.[8]

The chief divisions of these strata as described by White for the region bordering Cowley county on the south are, from the base upward, the Arbuckle limestone, commonly known as the "siliceous lime"; the Simpson formation (which he shows as including lower Simpson sandy shale at the base, overlaid by beds identified by him as "Burgen" sandstone, Tyner formation, and "Wilcox" sand); the Viola limestone; and the Sylvan shale. The names used by White are those applied to outcropping formations in central, southern and northeastern Oklahoma.

The principal historical events affecting these older beds are described as follows: After the deposition and lithification of these strata an extensive region, including northeastern Oklahoma and southeastern Kansas (including Cowley county) was arched by periodic earth movements into a broad southwestward trending nose; the sea withdrew, and the region became land; the surface beds were immediately attacked by erosion, and after a long period of time a great thickness of strata had been removed, reducing the region to a nearly level plane, thus exposing the lowermost beds (the "siliceous lime") in the higher part of the nose occupying part of northeastern Oklahoma and southeastern Kansas; the successively younger units of strata lying to the south and west formed broad bands trending in great arcs about this central area. The lower block in Figure 3 represents the surface of Oklahoma at the end of this period of erosion.

Practically the entire region was again submerged, and the Chattanooga shale, the Mississippian limestone, and finally the Pennsylvanian and Permian sediments, were deposited over and above the eroded edges of these strata. It is thus apparent that wells drilled through the Chattanooga shale and overlying beds will encounter beneath the Chattanooga shale beds of different ages in different wells, the particular beds depending upon the location. According to White's map the rocks lying beneath the Chattanooga shale strike slightly west of north and dip gently southwest at the north bound-

8. White, L. H.; Subsurface distribution and correlation of the Pre-Chattanooga ("Wilcox" sand) series of northeastern Oklahoma: Oklahoma Geol. Survey Bull. 40-B; 1926.

ary of Oklahoma, where it coincides with the south boundary of Cowley county, so that a well drilled in R. 8 E., in the southern part of the county, should pass from the Chattanooga shale immediately into the "siliceous lime"; wells in R. 7 E. should encounter the "Burgen" sandstone beneath the Chattanooga and then pass into the "siliceous lime"; a well drilled in R. 6 E. to R. 4 E. should encounter westward successively greater amounts of the Tyner formation before entering the "Burgen" sandstone and "siliceous lime"; wells drilled in R. 3 E. should find the "Wilcox" sand immediately beneath the Chattanooga shale, below which should be the Tyner formation, then the "Burgen" sandstone and the "siliceous lime." Differentiation of the several formations recognized by White in the area adjacent to Cowley county on the south is not possible on the basis of driller's records of wells drilled in Cowley county, but a study of well cuttings from these beds by workers familiar with these rocks throughout the region to the south should permit the correct projection of White's findings northward into Kansas. Inasmuch as many of these beds yield oil, it is highly important that their identification be made to prevent abandoning wells before all possibly oil-yielding beds have been tested. Oil is produced in this region from the rocks identified by White as Arbuckle limestone, Tyner formation, and "Wilcox" sand, and so a well that is drilled below the Mississippian should be continued until these strata are penetrated. On the basis of an arbitrary projection of White's mapping northward into Kansas, it appears that many wells in Cowley county reported to have tested the "Wilcox" sand and "siliceous lime" were actually abandoned a short distance above these beds, because many wells in the western part of the county, as well as elsewhere, have been abandoned after penetrating only a few feet of strata beneath the Chattanooga shale.

Only two wells in Cowley county are reported to have penetrated the entire thickness of these beds and entered the Pre-Cambrian rocks that form the basement upon which the Cambrian and later sediments rest. These are the Smith No. 1 well of the Doric Oil Company, near Dexter, in the northwest corner of the SE¼ NW¼, sec. 18, T. 33 S., R. 7 E., and the Eckhart No. 1 well of the Phillips Petroleum Company, in the center of the SW¼, sec. 9, T. 35 S., R. 6 E. The Cambrian and Ordovician beds as reported in the Smith well have a total thickness of 920 feet, and in the Eckhart well of 1,050 feet. The record of the Eckhart well shows the lowermost 500 feet to consist of thick beds of limestone with a few beds of sandstone; in the succeeding 250 feet thick beds of sandstone predominate; and in the uppermost 300 feet thick beds of limestone are interbedded with relatively thin beds of shale and some sandstone. Throughout the series the sandstone beds, and in places the limestone beds, carry an abundance of water that is strongly mineralized and emits a characteristic sulphurous odor. In the Doric well the uppermost 55 feet is reported to be sandstone and the remaining 865 feet sandy limestone.

White correlates the lowermost beds of this series of strata with the Arbuckle limestone of southern Oklahoma, and says that as revealed from well cuttings they consist "of medium or fine crystalline dolomitic siliceous limestone. After boiling in acid the residue will consist largely of quartz fragments, with an occasional quartz crystal. True sand grains are seldom found in average well samples, although the formation is known to contain some thin beds of sand." He states that these characteristics are persistent throughout an extensive region. The formation reaches a maximum thickness of 1,500 feet in northern Oklahoma. It is commonly called the "siliceous lime."

Several formations overlying the "siliceous lime" in regions where they have not been removed by erosion were recognized by White. According to his map at least the "Burgen" sandstone, Tyner formation, and "Wilcox" sand should be present in Cowley county. The "Burgen" is described as a tightly cemented and glassy white sandstone, in which the individual grains are "a heterogeneous mixture of very large and very small rounded grains with etched surfaces, with enough angular grains of various sizes thrown in to make it a good mixture." It is recognized by these characteristics and by its stratigraphic position above the horizon of the Arbuckle limestone, and in parts of Oklahoma by its position beneath the Tyner, which is composed of green sandy shale, thin beds of sandstone, some sandy dolomite, and thin beds of red shale near the middle. The dolomitic character of the lower beds is said to become more pronounced northwestward from Tulsa, Okla. The "Wilcox" sand, overlying the beds identified by White as Tyner in western Kay county, Oklahoma, which is adjacent to Cowley county on the south, is described as a much more uniform fine-grained sand than the "Burgen" sand. It is characterized by a high percentage of fine angular grains accompanied by a few large, rounded, etched grains and more small rounded grains. The characteristics of the "Wilcox" and "Burgen" do not differ widely enough to afford positive identification from single samples.

White describes a group of beds consisting of brown and gray sandy dolomitic limestones interstratified with some green shale and thin beds of sandstone lying above the "Wilcox" sand, in the uppermost part of the rocks which he identifies as Simpson formation in the extreme western part of Kay county, Oklahoma, several miles west of the southwest corner of Cowley county. It may be that these beds do not extend far enough east to be present in Cowley county. Above these beds, but present farther west and south, are rocks identified by White as the Viola limestone and Sylvan shale, both of Ordovician age, which still farther west and north are overlain by rocks that he correlates with the Hunton limestone of Silurian and Devonian age. A projection of White's mapping northward indicates that these higher rocks, if ever present, were removed by erosion from the Cowley county area prior to the submergence of the region in Chattanooga time, but owing to the lack of information concerning these beds in Cowley county it cannot be said that they are not present.

A thin veneer of sand of irregular thickness and patchy distribution is described as occurring upon the old erosion surface that lies on these rocks buried and preserved beneath the Chattanooga shale. Because of the subcircular shape and other characters of the sand bodies at this horizon, White believes that this sand was deposited by winds, the source of the material being the "Burgen" sandstone, Tyner formation, and "Wilcox" sand. It is known to the drillers as the Misener sand, and is correlated by White with the Sylamore sandstone member of the Chattanooga shale of eastern Oklahoma and Arkansas.

Figure 3 represents the facts presented above in a diagrammatic manner. The lower part of the figure shows a block or segment of the earth's crust that includes northeastern Oklahoma, indicating the rocks that occupied the surface at the end of the erosion period that immediately preceded the deposition of the Chattanooga shale. The reader must imagine that the Permian, Pennsylvanian and Mississippian beds that now cover this region have been cut away, exposing the underlying Ordovician strata. The block has been cut vertically along the Oklahoma-Kansas boundary, the cut edge revealing a vertical cross section of the strata. In the northern block the beds overlying the Ordovician rocks have not been removed, so that the complete section of strata is represented as it exists to-day.

Mississippian (?) Rocks.[9]

Chattanooga Shale.

Black carbonaceous fissile shale ranging between 50 and 100 feet in thickness, lying unconformably on older strata and locally entirely absent, composes the Chattanooga shale of Mississippian age. This shale unit is exceptionally widespread throughout Oklahoma and Kansas and is in general well known to the drillers. Its upper surface ranges in depth beneath the surface from 3,150 feet in the northeastern part of Cowley county to about 3,700 feet in the southwestern part. It is in general readily recognized in wells by its position beneath the Mississippian limestone and its softness and black color as contrasted with the hard gray beds above it. The Chattanooga shale appears to be absent in parts of Cowley county. Two deep wells drilled near Dexter failed to report it, although others near by reported it in normal thickness. The log of a well drilled 8 miles northeast of Dexter, another 11 miles southeast of Dexter, and three wells 1, 4 and 5 miles northeast of Cambridge do not record this shale. However, it is reported as being 70 feet thick in a well drilled 4 miles northwest of Cambridge and 85 feet thick in a well drilled near the county boundary 8 miles east of Cambridge. Its absence in certain localities may mean either that these places stood as islands in the Chattanooga sea and so were never covered by shale, or that the shale was spread over the entire region but locally removed by erosion prior to the deposition of the overlying Mississippian beds. The fact that after the deposition of the Chattanooga shale it was eroded to an uneven surface and in places entirely removed in northeastern Oklahoma, and its abrupt disappearance in wells at Dexter located near other wells that found the shale present with normal thickness, suggest that the second alternative is the true explanation of its absence in parts of Cowley county.

Mississippian Limestone.

A series of beds in Kansas, composed largely of limestone of Mississippian age, constitute probably the most widely known buried rocks in this region—the "Mississippi lime" of the drillers and operators. As a unit it is readily traceable by means of well records throughout an extensive part of the midcontinent region. In Cowley county it ranges in thickness from 225 to 400 feet and lies at depths ranging from 2,850 feet in the northeastern part of the county to

9. The United States Geological Survey classes the Chattanooga shale as Devonian (?).

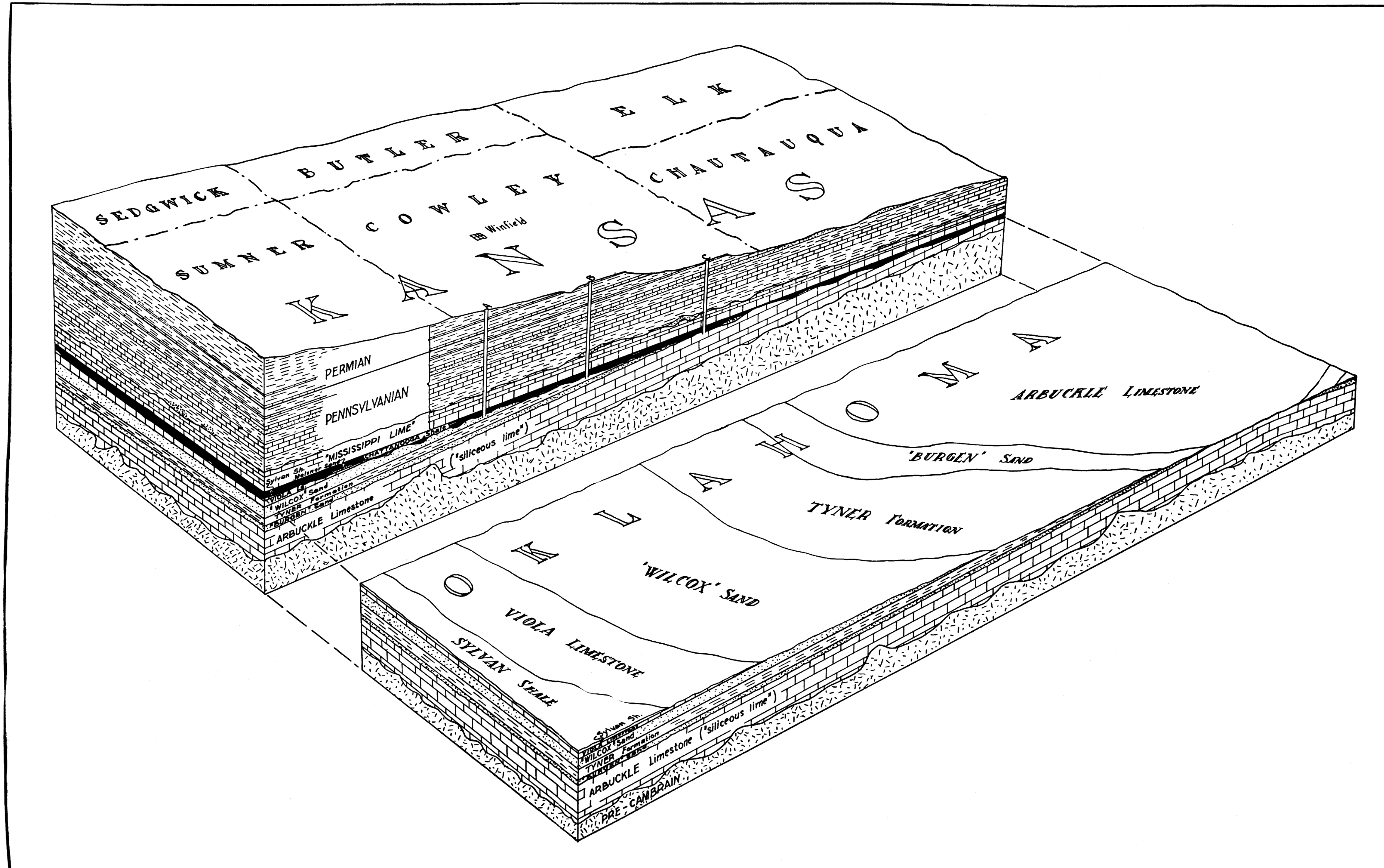

Fig. 3.—Block diagram showing Cowley county and adjacent region looking north. Block is cut along Kansas-Oklahoma line. All beds from Chattanooga shale upward have been stripped from the Oklahoma area, exposing the Pre-Chattanooga surface. The Kansas part represents the present surface and stratigraphic section. The Pre-Chattanooga formations are based on the correlations of Luther White. Well A penetrates "Wilcox" sand immediately beneath the Chattanooga shale; well B enters rocks correlated by White with the Tyner formation; and well C passes directly into the "siliceous lime" (Arbuckle limestone according to White).

3,350 feet in the southwestern part. It is noticeably thinner over structural "highs" and thicker over the "lows."

The Mississippian rocks crop out in northeastern Oklahoma, where they consist of a thick series of limestone and shale, in which the limestone beds make up the larger part of the total thickness. The strata there are divided into a number of formations, of which the Boone limestone, consisting of thick beds of cherty limestone, is much the thickest and probably the most widespread. In Cowley county and elsewhere in the adjacent region the Mississippian beds are reported by drillers as being composed largely of light gray to dark gray cherty limestone, probably representing in large part the Boone. A number of logs of wells drilled in Cowley county report beds of sandstone and shale interbedded with limestone in the upper part of the Mississippian strata. These beds may represent Mississippian formations above the Boone or may be beds within the Boone that do not maintain the most common characteristics of that formation. A similar condition is reported in the lower part of the Mississippian rocks in a number of wells drilled in Cowley county. Beds of green and dark shale interbedded with limestone are shown in these rocks in wells drilled in the central part of the county. A few well logs report red rock a short distance above the base of the Mississippian beds, and one well reports "chat" at this horizon. It is not known whether these lower shaly beds are equivalent to cherty limestone beds of the lower part of the Boone in northeastern Oklahoma or whether they are older. The entire unit between the Cherokee shale above and the Chattanooga shale below is commonly known as the "Mississippi lime." In many wells the entire thickness is reported as limestone. In most localities the "Mississippi lime" appears to rest conformably upon the Chattanooga shale, but in northeastern Cowley county the Chattanooga appears to be absent, and the Mississippian limestone beds lie directly upon Ordovician rocks. The upper surface of the "Mississippi lime" is irregular, owing to erosion throughout a long period prior to the deposition of the overlying Cherokee shale.

Pennsylvanian Rocks.

Interbedded limestone and shale and minor amounts of sandstone, having an aggregate thickness ranging from 1,200 to 1,800 feet, make up the Pennsylvanian rock section in Cowley county. In general the strata are characterized by a shale unit (Cherokee shale) in the lowermost part, overlain by a thick unit of interbedded limestone and shale (Marmaton[10] and Kansas City groups) in which the limestone beds form the larger part. Over this lies a thick unit composed largely of shale, but containing some sandstone near its middle (Lansing group and lower part of Douglas group), above which is a unit composed of interbedded limestone and shale (upper part of Douglas group and Shawnee group) constituting the uppermost part of the buried rocks. The Wabaunsee group overlies the strata just described and constitutes the uppermost group of the Pennsylvanian system. The beds of the Wabaunsee group crop out in Cowley county, and so its several parts are described under the heading "Surface rocks." The total thickness of the Pennsylvanian increases from northwest to southeast across Cowley county. This southeastward thickening continues across northern Oklahoma.[11] In Cowley county the change in thickness is comparatively irregular, as shown in Figure 4. The system is thin over the more pronounced anticlines and thicker on the synclines. The upper part of the Pennsylvanian beds is not present in the eastern part of the county, but the continuation of the divergence in that direction is indicated by a study of the interval between the Oread limestone and the base of the Cherokee, which comprises roughly the lower half of the Pennsylvanian. The thickness of this unit at the northwest corner of the county is 600 feet less than at the southeast corner, an average change of 14 feet to the mile. Reference to Figure 4 will show that in R. 4 E. the northward convergence of the entire Pennsylvanian system averages 12 feet to the mile. The maximum rate, which would be in a northwest rather than true north direction, would be somewhat greater than 12 feet to the mile.

Cherokee Shale.

Overlying the irregular surface of the Mississippian limestone is a relatively thick unit of strata composed largely of dark gray shale beds known as the Cherokee shale. In Cowley county it ranges in thickness from a little less than 300 feet in the eastern part to a little less than 125 feet in the northwestern part. The southeastward thickening is in general fairly uniform, but local variations, with notable small thicknesses over structurally high parts of the "Mississippi lime," are noteworthy. The Cherokee shale is composed predominantly of beds of shale, but locally beds

10. The Marmaton group of the State Geological Survey of Kansas is divided by the United States Geological Survey into two, called Henrietta and Pleasanton, which are not separable in the well logs in Cowley county.

11. Levorsen, A. I.; Convergence studies in the midcontinent region: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 657-682; 1927.

of sandstone are present, and because they serve as reservoirs for the accumulation of oil and gas in numerous localities in the county as well as elsewhere in the region, they are of great economic importance. In general the sandstone is more abundant in the western half of the county than in the eastern half. Even in the western

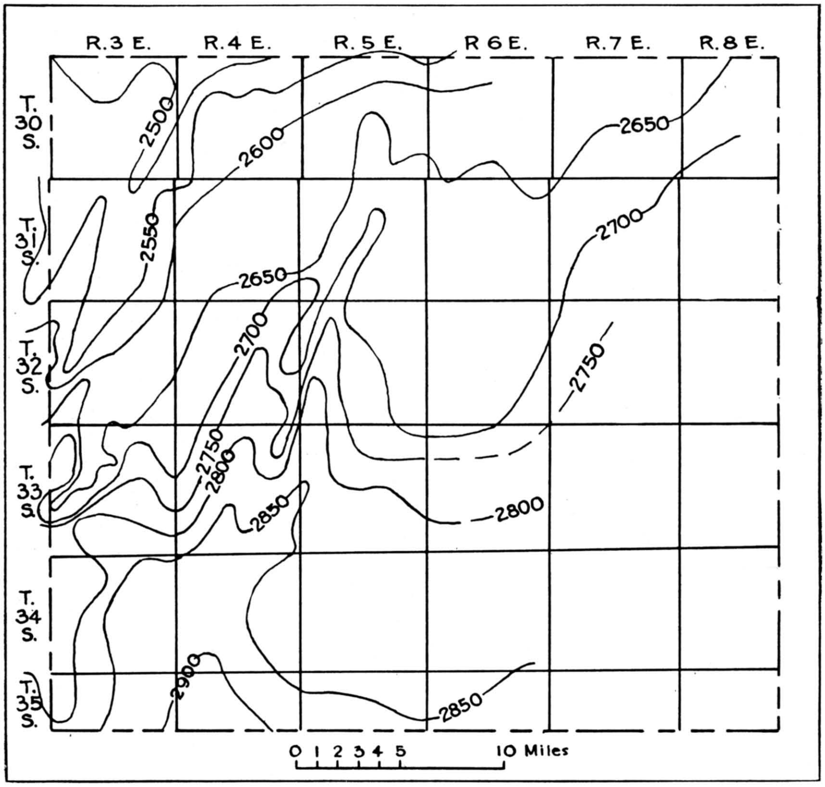

FIG. 4.—Map of Cowley county. The lines show thickness of the Pennsylvanian rocks.

half the sandstone beds are lenticular, being entirely absent in many localities. Thin beds of "red rock" are commonly present in the lower part of the Cherokee shale, but constitute only a very minor part of its total thickness in most places. Similar beds are present in the upper part in certain areas. The "red rock" reaches a maximum total thickness of 75 feet and is particularly abundant in the south-central part of the county. There appears to be no definite relation between the occurrence of sandstone lenses and that of the "red rock," nor does the distribution of the "red rock" appear to bear any definite relation to the structurally high areas in the Mississippian limestone.

Many well logs report "chat" from 1 to 50 feet thick immediately above the "Mississippi lime." This material is believed to be weathered rock fragments dislodged from the Mississippian strata during the period of erosion that followed the Mississippian sedimentation, the débris being buried later by the overlying shale beds. Its occurrence is patchy, but it increases in thickness and in number of occurrences westward toward the buried "granite ridge" that crosses the northwestern part of Cowley county. The "chat" is composed largely of rounded pebbles and sand grains of chert, with lesser amounts of other material. Because of crushing by the drill, it commonly comes from wells in sharply angular fragments of chert, resembling the chat used in road construction. It serves as a reservoir for oil and gas in some localities. It is herein described with rocks of Pennsylvanian age, because it is probably a product of weathering of Mississippian strata in early Pennsylvanian time. It may be in part residual and in part transported. The Mississippian beds formed the surface of a land mass and were subjected to erosion for a long time after the beginning of Pennsylvanian time, while the Pennsylvanian sea was spreading northwestward from the eastern Oklahoma region. The sea probably did not invade Cowley county until a great thickness of sediments had been deposited in eastern Oklahoma and Kansas.[12] It was during this early Pennsylvanian time that the "chat" of Cowley county is believed to have been formed.

Marmaton[13] and Kansas City Groups.

Interbedded limestone and shale occupy an interval of about 500 feet immediately above the Cherokee shale and are believed to belong to the Marmaton and Kansas City groups of eastern Kansas. These groups are readily divisible into a number of formations at their outcrops in eastern Kansas, and many members and formations are traceable by means of well records for long distances westward from their outcrops, but in Cowley county the distinction between the several subdivisions, as well as between the groups themselves, can not always readily be made from well records. The two groups are accordingly treated herein as a unit. The unit varies somewhat

12. McCoy, A. W.; A short sketch of the paleogeography and historical geology of the midcontinent oil district and its importance to petroleum geology: Am. Assoc. Petroleum Geologists Bull., vol. 5, pp. 541-584; 1921.

13. The term Marmaton group, as used in this report, includes the Henrietta and Pleasanton groups of the United States Geological Survey.

in total thickness in the county, being thickest in the southeastern part and thinning toward the north and west. In the morthern part of the county the upper part—the Kansas City group—is composed largely of gray limestone and is commonly recorded as solid limestone a little more than 200 feet thick. Sandstone beds make their appearance in the upper part of the unit 10 to 15 miles south of the northern boundary of the county and with some interbedded shale increase in thickness southward, until in the southern part of the county a large part of the upper two-thirds of the Marmaton and Kansas City groups is occupied by shale and sandstone. Limestone and shale in relatively thin beds form the lower third of the unit. Beds at numerous horizons in these groups yield oil and gas in Cowley county, but the beds of sandstone in the uppermost part of the Kansas City group, known as the Layton sand, are probably the most productive.

Lansing Group.

The Lansing group includes beds about 400 feet in total thickness succeeding the Kansas City group. In Cowley county it consists predominantly of shale, with minor amounts of sandstone and limestone. A relatively thick zone composed almost entirely of sandstone occupies the uppermost part of the group and is widespread throughout the county. This sandstone zone is a prolific water producer, but yields oil in one or two localities. The position of the boundaries of the Lansing group as shown on the correlation chart (Pl. II) is open to some question, but the general horizon of the group is believed to be correctly placed.

Douglas Group.

About 350 feet of shale, sandstone, red rock and limestone make up the Douglas group as correlated by well logs. In the uppermost part of the group several thin limestone beds underlain by interbedded red rock and shale are believed to represent the Oread limestone, the uppermost formation of the Douglas group as described from exposures in eastern Kansas. The zone containing the red beds is widespread in southern Kansas and northern Oklahoma, and inasmuch as there are no other red beds in the stratigraphic succession several hundred feet above and below this zone, it forms an admirable marker for correlation by means of well logs.

Shawnee Group.

Above the Oread limestone is a series of interbedded limestone and shale, with a few beds of sandstone, in all about 650 feet thick, that contains a much greater percentage of limestone than the underlying Douglas and Lansing groups. In eastern Kansas this group includes a number of formations, among them the Lecompton, Deer Creek and Topeka limestones, but these formations are difficultly differentiated in well records in Cowley county. The lower half of the group contains more limestone than the upper half.

Exposed Rocks.

The Paleozoic rocks exposed in Cowley county fall into three natural divisions if we classify them according to their lithology and their topographic expression. The lower division is composed of beds of shale and shaly limestone about 335 feet thick, the middle division is composed of alternately bedded thick limestone and shale more than 600 feet thick, and the upper division is composed of soft shale beds 80 feet thick. As described under "Surface features," the rocks of the lower division form grass-covered steep slopes in the east face of the Flint Hills, those of the middle division form rock "steps" or terraces ascending westward, and those of the upper division form an almost level plain in the westernmost part of the county. The beds have not been grouped on this basis, however, but they have been described for the most part under more or less arbitrary divisions defined and named by early workers in central Kansas and now well established. There are four of these divisions—the Wabaunsee group, of Pennsylvanian age, including eight formations, and the Council Grove, Chase and Sumner groups, of Permian age, including a total of eleven formations. The lowermost of the three natural divisions mentioned above comprises the lowermost four formations of the Wabaunsee group; the middle natural division comprises the uppermost four formations of the Wabaunsee group, the Council Grove and Chase groups, and the lowermost two formations of the Sumner group; and the uppermost natural division is made up of the uppermost formation of the Sumner group, only the lower part of which is present in the county.

*Geologic formations exposed in Cowley County, Kansas.**

System.	Series.	Group.	Formation and member.	Thickness in feet.	Character.
Quarternary.	Recent.		Alluvium and dune sand.	0–55 ± 0–50 ±	Stream deposits of sand, gravel, and clay beds. Wind-blown sand in southwestern part of county.
	Pleistocene.		Gravel and loess.	0–10 ± 0–30 +	Chert-gravel terraces chiefly bordering the Walnut and its tributaries 10 to 100 feet above stream beds. Wind-blown fine-grained reddish-brown material mantling surface in southwestern part of county.
Tertiary (?).	Pliocene (?).		Gravel.	0–20	Chert-gravel terraces 150 to 225 feet above streams.
Permian.		Sumner.	Wellington formation.	80+	Varicolored clay shale containing a few thin beds of gypsiferous limestone (lowermost 80 feet exposed).
			Herington limestone.	30	Light buff limestone and dolomite.
			Enterprise shale.	45	Greenish and bluish-gray shale.
			Luta limestone.	20	Thin-bedded light gray fossiliferous limestone. Because of poor exposures in this county it is for convenience mapped with the Enterprise shale.
		Chase.	Winfield limestone.	10	Light buff limestone, weathering dull gray, in two massive beds.
			Doyle shale.	85 ±	Varicolored shale with minor amounts of limy shale and limestone.
			Fort Riley limestone.	45–55	Thick and thin bedded light buff limestone.
			Florence flint.	11–35	Thick-bedded limestone containing layers of nodular chert.
			Matfield shale.	58–65	Varicolored shale interbedded with gray limestone.
			Wreford limestone.	33	Gray limestone containing chert.
		Council Grove.	Garrison shale including the Crouse limestone member.	140	Interbedded varicolored shale and gray limestone. Crouse limestone member, 4 to 6 feet thick, about the middle.
			Cottonwood limestone.	10	Gray limestone; upper part weathers nearly white.

* The United States Geological Survey classes Permian and Pennsylvanian as series in the "Carboniferous System."

GEOLOGIC FORMATIONS EXPOSED IN COWLEY COUNTY, KANSAS—CONCLUDED.

SYSTEM.	Series.	Group.	Formation and member.	Thickness in feet.	Character.
Pennsylvanian.		Wabaunsee.	Eskridge shale.	35–40	Gray and maroon shale, limy in upper part.
			Neva limestone.	22–28	Buff limestone; weathers dull gray, has sharply rough surface.
			Elmdale shale including the Red Eagle limestone member.	80	Maroon and gray shale, in part limy. Red Eagle member includes 20 feet of thin-bedded gray limestone near middle of formation.
			Foraker limestone including the Americus (?) limestone member.	50	Thick-bedded gray limestone containing chert and large Fusulinas and minor amount of shale. Americus (?) member consists of blue-gray limestone 2½ to 4 feet thick, occurring in the lowermost part of the formation.
			Admire shale.	265	Predominantly gray shale. Contains several brown-weathering beds of limestone and sandstone.
			Emporia (?) limestone.	15	Interbedded brown limestone and gray shale.
			Humphrey (?) shale.	45	Mostly shale beds. Contains some brown micaceous sandstone in upper part.
			Burlingame (?) limestone.	10	Brown limestone containing a thin unit of shale in the middle.

Pennsylvanian System.

WABAUNSEE GROUP.

The Wabaunsee group, comprising nearly half of the total thickness of the exposed rocks of Cowley county, is divisible into two parts on the basis of its lithology. A thick series of shale beds with minor amounts of limestone and sandstone occupy the lower three-fifths, and thick beds of limestone alternating with shale make up the upper two-fifths. The limestone and sandstone beds in the lower part weather brown, and those in the upper part weather light gray to white. In spite of including nearly half of the total thickness of the exposed stratigraphic section, the rocks of the Wabaunsee group occupy less than one-tenth of the surface of Cowley county, their outcrop being largely confined to Tps. 31 to 35 S., R. 8. E., and T. 35 S., R. 7 E. Compared with the moderate relief characteristic of the greater part of the state the topography of the area in which this group crops out is rugged. Relief of 350 feet within a mile is present in parts of this area. The surface is characterized by great terraces of bare limestone ledges, terminated on the east by a high, steep slope that descends to a broad plain stretching far to the east in Chautauqua county. The beds of the lower division of the group form the steep slopes of the lowermost great rise or step of the Flint Hills. In the southeastern part of the county the lowermost limestone formation of the upper part of the group, the Foraker limestone, caps the slope as a bare rock ledge and forms the top of the bench, the higher limestone formations forming lesser steps above it in the westward-rising slope. Streams that head west of the brink of the Flint Hills have cut steep-sided miniature gorges through the limestone beds of the upper part of the Wabaunsee group, but upon emerging into the soft rocks of the lower part the valleys immediately flare, in marked contrast with the narrow gulches upstream.

The Wabaunsee group has been divided in Kansas into eight formations, named, from the base upward, the Burlingame limestone, Willard shale, Emporia limestone and Admire shale, constituting the lower or shaly part of the group; and the Americus limestone, Elmdale shale, Neva limestone and Eskridge shale, constituting the upper two-fifths of the group, which is likewise the part that forms the rock terraces.* In Cowley county limestone beds immediately above the horizon of the Americus limestone are much thicker than further north, and the name Foraker is extended from northern Oklahoma to designate these strata; the basal bed of the Foraker is tentatively identified as equivalent to the type Americus limestone.

Inasmuch as the rocks of the lower shaly division occupy a relatively small area in the southeastern part of the county, an area which has attracted but little attention from the oil and gas operators, and which is not readily accessible because of scarcity of roads traversing it, less study was given to the details of the composition of its beds than to any other beds cropping out within the county. The beds below the Admire shale occupy a thickness of about 70 feet, and the Admire makes up the succeeding 265 feet. The identification of the separate formations in this part of the section is somewhat doubtful, as they were not studied at their type localities farther north in Kansas nor traced from known localities.

The Wabaunsee group of beds can be identified in most well logs of this general region as the thick series of shale and thin beds of

* G. E. Condra (Stratigraphy of the Pennsylvanian system in Nebraska, Neb. Geol. Survey [2], Bull. 1, 1927), after detailed consideration of the nomenclature of the lower Wabaunsee beds, concludes that the proper sequence of formations from the base upward is Burlingame limestone, Humphrey shale, Emporia limestone, Willard shale, Tarkio limestone, McKissick Grove shale, Admire shale, etc.—R. C. Moore.

limestone or shaly limestone, and in many localities thin beds of sandstone, that occur beneath the thick limestone beds in the several hundred feet next above. It is rarely possible to identify the precise position of the top or bottom of the group, however, or to identify its individual formations.

BURLINGAME (?) LIMESTONE.*

A threefold series of limestone and shale beds about 10 feet thick, tentatively correlated with the Burlingame limestone, crops out at the county boundary in the SE¼, sec. 9, T. 34 S., R. 8 E. It consists of two units of dense, brittle limestone separated by about 2 feet of shale. The upper limestone unit, which is 4 feet 10 inches thick, contains numerous specimens of fossil Cryptozoa, which are particularly abundant in the uppermost foot. The limestone surrounding the fossil forms has weathered away, displaying the fossils in relief on the surface of the bed. The lowermost foot of the upper unit is thin bedded and more or less shaly. The middle part of the upper unit occurs in two beds that are hard and brittle and break with conchoidal surfaces. Only 2 feet of the lower limestone unit is exposed, the remainder being concealed by alluvium, and so its total thickness is not determined. The exposed part resembles the limestone of the upper unit except that it lacks the fossil Cryptozoa. The rock of both limestone units is steel gray on freshly broken surfaces and weathers brown.

The Burlingame (?) limestone occupies so small a part of the surface of Cowley county that it is of relatively little importance. It can rarely be detected with certainty in logs of drilled wells. Its correlation with the Burlingame limestone, named by Haworth[14] from Burlingame, Osage county, Kansas, is by no means certain. Plate VII-*c* of Kansas University Geological Survey, volume 9, by Haworth and others, shows the outcrop of the Burlingame limestone crossing the Cowley county boundary in sec. 9, T. 34 S., R. 8 E. Its position as thus shown in section 9, however, and just east of the county boundary in the vicinity of Cedarvale appears to represent more nearly the position of the outcrop of a series of beds of limestone about 45 feet above the limestone beds herein correlated with the Burlingame. These higher beds are here provisionally correlated with the Emporia limestone. The same group of beds (Burlingame through Emporia) were examined at Madison, in north-

* Recent stratigraphic studies by me indicate that Mr. Bass has correctly identified the Burlingame, Humphrey and Emporia beds as described here.—R. C. Moore.

14. Haworth, Erasmus; Stratigraphy of the Kansas coal measures: Kansas Univ. Geol. Survey, vol. 3, p. 72; 1898.

eastern Greenwood county, where the outcrop of the Burlingame limestone is shown by Haworth, on Plate VII-*b* of the publication cited, as passing just south and west of the town. At that locality limestone beds containing Cryptozoa occur in the approximate position of the Burlingame limestone shown on Haworth's map, and the strata in the succeeding 60 feet closely resemble those succeeding the lowermost limestone in sec. 9, T. 34 S., R. 8 E., Cowley county. On this basis the lower limestone beds are correlated with the Burlingame limestone, and the succeeding shale and limestone beds are tentatively assigned respectively to the Humphrey shale and Emporia limestone.

HUMPHREY (?) SHALE.

Above the Burlingame (?) limestone is a steeply inclined soil-covered slope that presumably is composed largely of shale or other soft rocks. In sec. 9, T. 34 S., R. 8 E., the lowermost 3 feet is gray clay shale; the succeeding 35 feet is covered; above the covered interval is a ledge of weathered brown fine-grained micaceous quartz sandstone. The lowermost few inches of the sandstone bed is filled with fossils and is very limy, and the uppermost foot is also limy and fossiliferous. Succeeding the sandstone is 6 feet of gray shale that weathers brown and ocherous and contains a few lenses of fossiliferous limestone 1 to 2 inches thick. A particularly conspicuous slabby limestone bed that is literally crowded with fragments of crinoid stems occurs 2 feet above the base of this shale. This entire series of beds with an aggregate thickness of about 45 feet is tentatively correlated with the Humphrey shale.[15] The correlation is based on identification of the Burlingame and Emporia limestones, the evidence for which is set forth with the description of Burlingame (?) limestone. The Humphrey (?) shale occupies only a small area in the southeastern part of the county and was not mapped separately. The sandstone near the top of the formation, with the overlying limestone beds of the Emporia (?) limestone, forms a relatively prominent bench that is particularly conspicuous in the vicinity of Cedarvale, a few miles east of the Cowley county boundary, in T. 34 S., R. 8 E. It is this sandstone that is exposed in the street on the south side of the Cedarvale high-school grounds, and the limestone beds above it occupy the surface in the northwestern part of the town. This series of beds forms a pronounced terrace immediately south of Cedarvale south of Cedar creek. This forma-

15. G. E. Condra, Stratigraphy of the Pennsylvanian System in Nebraska, Neb. Geol. Survey [2], Bull. 1, 77, 1927.

tion is not readily identifiable in many well logs, although the sandstone in its upper part is recorded in some.

The following fossils collected from the limy parts of the sandstone bed in the upper part of the formation were identified by G. H. Girty, of the United States Geological Survey:

U. S. G. S. No. 6155, collected near west quarter corner of sec. 10, T. 34 S., R. 8 E.:

Crinoid stems, etc.
Rhombopora lepidodendroides.
Derbya sp.
Productus cora.
Productus pertenuis.
Pustula nebraskensis.
Deltopecten occidentalis.
Myalina swallowi.

EMPORIA (?) LIMESTONE.

In the southeastern part of Cowley county above the Humphrey (?) shale is a series of interbedded limestone and shale, with an aggregate thickness of 15 feet, that is tentatively referred to the Emporia limestone. The basis for this correlation is given in the description of the Burlingame (?) limestone. In sec. 9, T. 34 S., R. 8 E., the following section was measured:

	Feet.
Weathered brown smooth limestone	3
Covered slope, probably limy shale	5
Mostly limestone. Lowermost 2 feet forms a ledge; weathers brown; contains some chert and fossils	8

The Emporia (?) limestone, with the sandstone underlying it in the upper part of the Humphrey (?) shale, supports a prominent bench at the foot of the lowest steep Flint Hills slope in the southeastern part of Cowley county and the western part of Chautauqua county. It is particularly prominent in the northwestern part of Cedarvale, in western Chautauqua county, and south of Cedarvale on the south side of Cedar creek.

The outcrop of the Emporia (?) limestone was not mapped in Cowley county, but was included with the next underlying and next overlying formations. This formation cannot be delimited in many logs of wells. Some logs record the sandstone immediately beneath it, and in those logs its position can be determined. Its beds are useful for surface mapping to a minor extent.

The following fossils collected from the Emporia (?) limestone were identified by G. H. Girty:

U. S. G. S. No. 6155*a*, collected about a mile west of Cedarvale, in the N. E. ¼, sec. 9, T. 34 S., R. 8 E.:

Enteletes hemiplicatus.
Productus cora.
Productus semireticulatus.
Pseudomonotis kansasensis.
Orthonema sp.

ADMIRE SHALE.*

The thickest division of strata composed predominantly of shale in Cowley county is the Admire shale, with an aggregate thickness of about 265 feet, based on measurements made with an aneroid barometer on the eastern county line in T. 34 S., R. 8 E. Little detail as to individual beds in the formation was obtained, in part because no detailed examination of the formation was made and in part because of a lack of extensive exposure. The prevailing softness of the beds manifests itself at the surface by soil-covered slopes lacking bare-rock exposures. The formation occupies the steeply inclined slope beneath the Foraker limestone that forms the first great bench of the Flint Hills, an area that contains some of the most rugged surface features in the state. These features are particularly well developed in the southeastern part of Cowley county. Practically no detailed knowledge of the lowermost 135 feet of the formation was obtained in the field. It is believed to be made up in general of shale with minor amounts of shaly sandstone and shaly limestone. A bed of micaceous sandstone that weathers rusty brown, estimated to be a little below the middle of the formation, crops out in a number of places in the extreme southeastern part of the county. It is represented in the columnar section on Plate I as being in the approximate position of sandstone "B," described by Heald[16] south and east of Cowley county, in the northwestern part of the Pawhuska quadrangle, Oklahoma, although its exact stratigraphic position was not determined in Cowley county. Several beds of limestone that are sufficiently persistent and prominent at the surface to constitute mappable units throughout areas of many square miles occur in the uppermost 130 feet of the formation. The rocks between the beds of limestone form sod-covered slopes and are presumably composed largely of shale. The limestone beds all weather tan or brown, in striking contrast with the prevailing gray and white of the limestone beds in the succeeding formations. Many of them are abundantly fossiliferous. The base of this uppermost unit of the formation is occupied by a bed of argillaceous limestone, only the upper 6½ feet of which was seen, and its full thickness was not determined. This limestone bed weathers brown, fractures into conchoidal chips, and is sparingly fossiliferous. From 20 to 25 feet above it is a dark gray hard

* As revised by G. E. Condra, "Admire Shale" as here used includes, in ascending order, Willard shale, Tarkio limestone (apparently absent in southern Kansas), McKissick Grove shale and Admire shale (restricted). The Kansas Geological Survey accepts this revised classification.—R. C. MOORE.

16. Heald, K. C.; Geologic structure of the northwestern part of the Pawhuska quadrangle, Oklahoma: U. S. Geol. Survey Bull. 691, p. 63; 1918.

crystalline even-bedded limestone 1 foot thick, that contains some fossils and weathers dull brown. Succeeding this thin bed and separated from it by an interval presumably occupied by shale, although not exposed, is a bed of limestone 6 feet thick that makes a fairly prominent ledge. It is underlain by sandstone 4 feet or more thick. The bed is marked in many places by springs, several of which are piped to stock tanks. The mass of the bed weathers tan and breaks down into conchoidally curved chips very similar to the 6½-foot limestone at the base of this division. In the uppermost few inches, however, is a slabby bed of blue-gray color that is crowded with fragments of crinoid stems, most of which are less than a quarter of an inch in diameter, although a few measure half an inch. The 45 to 55 feet of strata that succeed this limestone bed form a covered slope in most localities. The middle 20 feet is exposed in the northeastern part of the county, and there consists of limy shale and soft shaly limestone. Above the 55 feet of shaly beds is a bed of limestone 5 feet thick that weathers into porous honeycombed masses of yellow-buff color. It crops out in the slope 20 feet beneath the top of the Admire formation, or 20 feet beneath the blocky blue limestone bed of the Americus (?) limestone that is everywhere so prominently exposed, and marks the base of the thick gray limestone series of rock "steps" above. The uppermost 20 feet of the Admire shale forms a covered slope and is rarely exposed. Partial exposures and its topographic expression indicate that it is composed largely of beds of shale and shaly limestone.

The Admire shale is sharply defined above by the Americus (?) limestone member of the Foraker limestone, which is clearly exposed almost everywhere along its outcrop as a blocky bed of blue-gray limestone about 2½ feet thick—the lowermost gray-weathering limestone in the exposed rocks of the county. Although the base of the Admire shale is not so clearly exposed as the upper boundary, its approximate position is placed near the outer edge of the low bench formed by the Emporia (?) limestone.

The Admire shale was named by Adams[17] from exposures near Admire, in northern Lyon county, Kansas, and described as shale about 40 feet thick occurring between the Emporia and Americus limestones.

Although the precise top and bottom of this formation cannot be readily recognized in logs of wells drilled in Cowley county, the formation as a unit is determinable. It is commonly logged as

17. Adams, G. I., Girty, G. H., and White, David; Stratigraphy and paleontology of the upper Carboniferous rocks of the Kansas section: U. S. Geol. Survey Bull. 211, p. 53; 1903.

shale with a few thin sandstone and limestone beds. In the Waite Phillips well, H. Thurlow No. 7, in the SE¼, sec. 17, T. 33 S., R. 3 E., the Admire shale is believed to occupy the interval between depths of 705 and 980 feet. In the Roxana Seacat well, in sec. 36, T. 33 S., R. 4 E., it is believed to occupy the interval between depths of 555 and 817 feet.

The thin beds of sandstone that occur in the Admire shale are shown by records of wells throughout the county to be lenticular. These sandstone beds have supplied good yields of gas in a number of areas east and southeast of Winfield, north and northeast of Arkansas City, and near Dexter, Otto and Wilmot. The gas from these sands contains an unusually high percentage of helium in several localities. These beds are correlated with the prolific shallow gas sands of the Augusta and El Dorado fields of Butler county.

FORAKER LIMESTONE.

Thick-bedded limestone containing chert and a minor proportion of shale and shaly limestone with an aggregate thickness of 50 feet constitutes the Foraker limestone in Cowley county. Its most outstanding characteristic is the presence of abundant large sized specimens of the fossil protozoan *Fusulina** that occur in the limestone beds and in the chert. It is also characterized by the regularity and striking outcrop of several of its beds. The lowermost bed in the formation, which constitutes the Americus (?)† limestone member, is separated from an upper division of thick-bedded limestone by 10 to 13 feet of soft shale and crops out prominently, breaking into sharply bounded rectangular blocks that are everywhere present in the slope a few feet beneath the rock ledge of the thick-bedded part of the formation. Likewise in many localities a bed of limestone about 1 foot thick, 33 feet above the base of the formation, crops out as great slabs that lie upon a gently inclined slope that recedes upward from the rock ledge below. These features of the Foraker formation are well shown about a quarter of a mile north of the Winfield-Cedarvale highway in the SW¼, sec. 6, T. 34 S., R. 8 E. Although they are prominent characteristics of the formation they are secondary to the occurrence of the large specimens of *Fusulina* in the chert and limestone, which constitutes the most distinguishing characteristic of the formation, not only at the outcrop but in cores from drilled wells.

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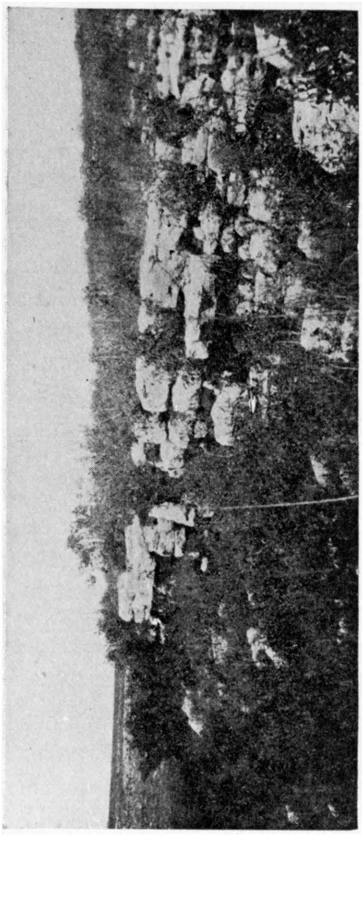
* Most of the fusulinids in the Foraker belong to the genus *Triticites* (see C. O. Dunbar and G. E. Condra, Neb. Geol. Survey [2], Bull. 2, 1928) but the upper beds contain numerous specimens of *Fusulina longissima*.—R. C. MOORE.

† Recent field work by G. E. Condra and me has shown definitely that the Americus limestone of the type locality extends southward and constitutes the basal part of the Foraker as described by Mr. Bass and by Heald and others in Osage county, Oklahoma.—R. C. MOORE.



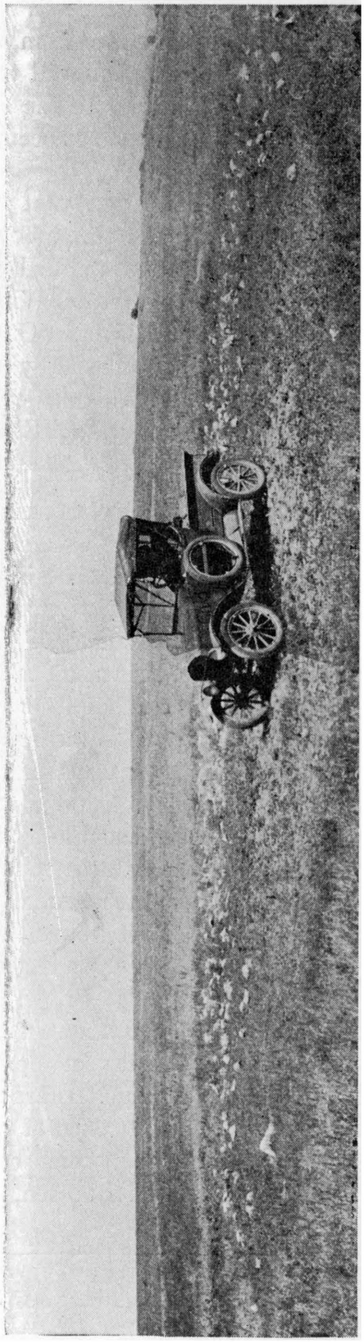


PLATE III.—Upper: A part of the Foraker limestone, showing beds 15 to 20 feet above the Americus (?) member, in the N. W. ¼, sec. 7, T. 34 S., R. 8 E. Lower: Upland floored by Fort Riley limestone, containing sunken basin near north quarter, corner of sec. 4, T. 30 S., R. 5 E.

From the base upward the formation comprises a bed of blue-gray limestone 2½ to 4 feet thick, the Americus (?) limestone member; 10 to 13 feet of shale, forming a covered slope in most localities; 2 feet of ocherous weathered limestone, not everywhere exposed; 11 feet of thick-bedded light-buff limestone (see Pl. III) and light tan and blue chert containing large specimens of *Fusulina* and forming a rock ledge capping the steep slope of the Admire shale, the limestone weathering white and the chert light tan; a covered gently graded slope composed of softer thin-bedded limestone forming a strip from 20 to 50 feet wide extending back of the rock ledge; great slabs about a foot thick of white, weathered limestone like that below; and thin-bedded limestone crowded with large *Fusulina,* in most localities forming a covered slope. Because of the position of the resistant Foraker limestone above the thick unit of soft shale of the Admire formation erosion has produced long, pronglike ridges capped by the Foraker beds. The steep slopes of the ridges rise 200 to 300 feet above the surrounding surface and project eastward from the Flint Hills rim, forming some of the most rugged topography in Kansas. Thus nearly everywhere along the outcrop of the Foraker formation in southern Kansas the topographic position and prominence of its outcrop are sufficient to identify the formation.

The following section of the Foraker limestone was measured in sec. 34, T. 30 S., R. 8 E.:

	Ft.	In.
Elmdale shale.		
Foraker limestone:		
Thin-bedded cream-colored limestone, in part crowded with large *Fusulina.* Forms covered slope	10	6
Massive light-cream sugary-textured limestone that weathers white and forms a ledge of enormous slabs. The uppermost real prominent bed in the formation contains *Fusulina* of large size,	1	..
Thin-bedded limestone, with *Fusulina,* relatively soft and weathers into rocky slope receding from bluff below	10	..
Thick-bedded light-buff sugary-textured limestone and interbedded tan and blue chert. Large *Fusulina* occur in the chert and limestone. Forms a bluff	11	..
Soft limestone; weathers in ocherous-brown thin slabs exposed in places at the foot of the bluff of light-gray limestone. Locally concealed. *Fusulina* present	2	..
Gray shale, in part limy	2	6
Hard, dense blue to blue-gray limestone (Americus [?] limestone member). Contains kidney-shaped nodules of chert 3 to 5 inches in diameter irregularly but not abundantly scattered through the bed. The lowermost few inches of the bed is abundantly fossiliferous. Large specimens of *Fusulina* occur in the limestone and a few in the chert	2	6
Total Foraker limestone	47	..
Admire shale.		

A section measured a short distance south of the state line on the Cedarvale-Foraker road, in about sec. 16, T. 35 S., R. 8 E., is as follows:

	Ft.	In.
Elmdale shale:		
Shale, drab; weathers light tan	8	..
Shaly limestone, weathering porous, and shale	5	6
Tan shale	2	..
Foraker limestone:		
Limestone, relatively soft, thin bedded; forms covered slope in most localities	14	..
Light-buff, fairly coarse-grained massive limestone; weathers in large slabs with total thickness of bed, and crops out in slope about 50 feet back of the bluff formed by the lower part of the formation	1	..
Slope of weathered, relatively thin-bedded limestone	8	..
Thick-bedded light-buff, weathered gray, fairly coarse-grained limestone, and some interbedded chert. Large *Fusulina* in limestone and chert. Forms bluff	13	..
Shale, in part limy, and covered	11	..
Americus (?) limestone member:		
Blue-gray dense limestone; abundant *Fusulina*	1	2
Blue limy shale; weathers tan	..	2
Blue-gray dense limestone; *Fusulina* and other fossils, most abundant 8 inches below top	2	7
Total thickness of Foraker limestone	50	11
Admire shale:		
Dark-gray shale	..	8
Shaly limestone, blue-gray; weathers tan	..	4
Gray shale	1	6
Shaly tan limestone	..	9

The large Fusulinas so characteristic of the Foraker appear to be present throughout the formation, although they are not everywhere conspicuous on weathered surfaces. The chert occurs mostly interbedded with the thick-bedded ledge. It is not as abundant as in the younger Wreford limestone and Florence flint, but is sufficiently abundant and widespread in occurrence to be conspicuous everywhere in this region, either in place or weathered upon the surface, thus marking the position of the Foraker. For the most part the chert occurs in thin nodular bands or lenses interstratified with limestone beds that are 6 to 18 inches thick. The chert layers commonly follow the bedding planes; some are nodular and some lenticular. Some lenses are 2 to 3 feet long and 4 to 6 inches thick. The chert is blue-gray on freshly broken surfaces but weathers to a light tan color. It can readily be distinguished from chert of other formations of the region by the presence of the well-preserved Fusulinas.

The lower boundary of the Foraker formation is sharply defined by the base of the Americus (?) limestone member, which is more resistant to weathering than the shale beds above and below it, and is in consequence widely exposed. The upper boundary of the Foraker is rarely exposed, as the uppermost limestone beds, which are soft and somewhat shaly, grade into the overlying shale beds and with them form a soil-covered slope. The massive limestone bed that forms large slabs about a foot thick occurs approximately 15 feet beneath the top of the formation, however, and is rather widely exposed, and by measurement from this bed the approximate position of the top of the formation can be located in the covered slopes.

The Foraker limestone can be recognized in most drill records in this general region as the thick limestone above a thick interval of limy shale (Admire) and a short distance below a series of red shale and limestone beds. In cores from core-drill holes it is readily distinguished by the abundance of large Fusulinas, parts of the formation being largely composed of the spindle-shaped tests about one-eighth of an inch in diameter and three-eighths of an inch long. The formation is prominently exposed near the eastern edge of the county in Tps. 32 to 35 S., R. 8 E.

The Foraker limestone was named by Heald,[18] from exposures near Foraker, Osage county, Oklahoma, about 10 miles south of Cowley county. In previous Kansas reports the strata of this formation except the lowermost 6 feet have been included in the Elmdale shale. The differentiation of the Foraker limestone in Kansas therefore necessitates a redefinition of the Elmdale shale. The Foraker has not been traced northward beyond the boundary of Cowley county, but it is exposed in central Chase county near the bridge spanning Cottonwood river east of Elmdale, and so it is assumed to be continuous between this locality and Cowley county. At the exposure seen near Elmdale the general features characteristic of the formation in Cowley county are present. It crops out as a thick-bedded limestone massed with large Fusulinas. No chert was seen at this locality, however, and the limestone beds are much softer here than in Cowley county. They are, therefore, readily

18. Heald, K. C.; The oil and gas geology of the Foraker quadrangle, Osage county, Oklahoma: U. S. Geol. Survey Bull. 641, pp. 21, 25; 1916.

decomposed, and as a result are covered by a mantle of soil in most localities in this region.*

The following stratigraphic section was measured a few hundred feet south of the bridge in the SW¼, sec. 26, T. 19 S., R. 7 E., near Elmdale, Chase county:

	Ft.	In.
Elmdale shale:		
Green-gray clay shale	6	..
Limy shale	11	..
Foraker limestone:		
Thick-bedded light-buff soft limestone containing abundant tests of large Fusulinas and some other fossils	20	..
Covered; some limestone exposed	8	..
Limy shale	3	..
Light-buff thick-bedded limestone, containing abundant large Fusulinas and other fossils	2	6
Greenish clay shale	5	6
Very limy shale	2	..
Blocky gray dense limestone. Contains abundant large Fusulinas in upper part of bed. Peculiar markings on upper surface. Lowermost 4 inches is massed with an assemblage of fossil shells (Americus [?] limestone member)	1	6
Total thickness of Foraker	42	6
Admire shale:		
Tan and gray clay shale	1	..

The blocky bed at the bottom of the Foraker is apparently the lower bed of the Americus limestone as originally described[19] and exposed near Americus, about 25 miles northeast of this locality, and is believed to be continuous with the Americus (?) member of Cowley county.

Americus (?) *limestone member.* At the type locality of the Americus limestone, a short distance southwest of Americus, Lyon county, Kansas, the following section was measured:

	Ft.	In.
Blue-gray fossiliferous limestone, in part crystalline (flagstone bed)	..	6
Abundantly fossiliferous, weathered gray limy shale	6	6
Massive light-buff limestone. Lowermost 5 inches is crowded with fossils and fossil fragments. Uppermost few inches contains large Fusulinas abundantly. Quarried extensively in the years past	1	8

* The section east of Elmdale exhibits clearly all of the subdivisions of the Elmdale shale differentiated and named by Condra in Nebraska (Neb. Geol. Survey [2], Bull. 1, p. 84, 1927), with the Americus limestone at the base and Neva limestone at the top. The Foraker probably includes equivalents of the Americus limestone, Stine shale, Houchen Creek limestone, Hughes creek shale and Long creek limestone. In view of the known remarkable lateral persistence of minor stratigraphic units from Nebraska to central Kansas, it is likely that detailed stratigraphic work will afford basis for definite determination of the relations of the type Foraker to Americus and Elmdale.—R. C. MOORE.

19. Kirk, M. Z.; A geologic section along the Neosho and Cottonwood rivers: Kansas Univ. Geol. Survey, vol. 1, pp. 80, 81; 1896.

The light-buff limestone bed of this section is believed to be continuous with the lowermost limestone unit (about 4 feet thick) in the Foraker limestone in Cowley county. Although the member was not traced across the area intervening between the Americus type locality and Cowley county, exposures of it were seen at a few widely separated localities, and its identity is fairly well established. The upper limestone bed of the section measured near Americus appears not to be widespread. Aside from the fossils mentioned, the general appearance at the outcrop and the stratigraphic relation with beds above and below it, the Americus (?) limestone member has in many localities peculiar markings on its upper surface that resemble hoof imprints made by deer in soft mud and are believed to be significant. They were seen in abundance on the upper surface of the bed near the Cottonwood river bridge 1¼ miles east of Elmdale, Chase county; on the upper surface of what is believed to be the same bed in the railroad cut northeast of Grand Summit, Cowley county; and on Rock creek in the extreme southeastern part of Cowley county. As here used the Americus (?) limestone member is the lowermost limestone unit in the Foraker limestone. In Cowley county it ranges between 2½ and 4 feet in thickness, crops out extensively, and nearly everywhere along its outcrop breaks into rectangular blocks that conspicuously mark its position in the slope a few feet beneath the rock ledge formed by the beds in the middle division of the Foraker. Characteristic exposures of this sort were seen also at several localities outside of the county—in northern Oklahoma a few miles south of the southeast corner or Cowley county; in Greenwood county, Kansas, particularly a few miles west of Madison; and in west-central Lyon county southwest of Americus, at the type locality of the member. The Americus (?) limestone is hard and dense, is blue-gray when fresh, and weathers light buff to gray. It commonly contains kidney-shaped nodules of chert sparingly scattered irregularly through the member. In many localities the lowermost few inches of the member is crowded with fossils, and large Fusulinas are scattered throughout the limestone and chert, being particularly abundant near the top of the member.

A section of the Americus (?) limestone member and beds a few feet above and below it, well exposed in a recent road cut in the big hill in the NW¼, sec. 7, T. 34 S., R. 8 E., on the Winfield-

Cedarvale road about 2½ miles southeast of Hooser, is described below:

	Ft.	In.
Foraker limestone:		
Thick-bedded light-buff, weathered gray limestone in upper part and weathered ocherous-brown limestone in two beds in lower part. The lowermost foot is almost entirely made up of tests of large Fusulinas	2	..
Tan-weathered shale. The uppermost few inches is a mass of Fusulinas. At 2½ feet beneath the top is a limestone bed 2 inches thick that is massed with fossils, and 6 inches beneath is another similar bed	12	6
Americus (?) limestone member:		
Blue-gray, dense, hard, in part crystalline limestone; parts of bed contain abundant large Fusulinas	4	3
Admire shale:		
Dark-gray, finely laminated shale	1	10
Tan limestone	..	6
Gray limy shale	1	5
Tan fossiliferous shaly limestone	3	8

The Americus (?) limestone member constitutes an excellent key bed for structural geologic mapping in the area of its outcrop in Cowley county, because it is so extensively exposed, regular in thickness, and constant in appearance, and because the ledge forming part of the member varies only a few inches in its stratigraphic position.

ELMDALE SHALE.

As defined by Prosser[20] and subsequently used in Kansas, the Elmdale shale included a series of beds of shale and limestone above the Americus limestone and below the Neva limestone, with a total thickness of 130 feet. The strata between the same limiting beds are but little less than 130 feet thick in Cowley county, but the lower third of this total thickness combined with the Americus (?) limestone is herein called the Foraker limestone, thus restricting the name Elmdale shale to the strata between the Foraker and Neva limestones, having a total thickness of about 80 feet. The lowermost third of the Elmdale formation as thus defined is mostly shale and is succeeded by 20 feet of thin-bedded gray limestone, of which the uppermost 2 to 3 feet is deep buff and soft, the whole 20 feet constituting the Red Eagle limestone member, which forms one of the most prominent ledges in the eastward-facing slope of the Flint Hills. The uppermost two-fifths of the member is composed of red and gray shale, in party limy, containing a few beds of limestone.

20. Prosser, C. S.; Revised classification of the upper Paleozoic formations of Kansas: Jour. Geology, vol. 10, p. 708; 1902.

The Elmdale shale is exposed in the railroad cut $1\frac{1}{2}$ miles northeast of Grand Summit, where the following section was measured:

	Ft.	In.
Neva limestone.		
Elmdale shale:		
Gray limy shale, fossiliferous	5	6
Blue-gray, dense, massive limestone. Crops out in sharp-edged ledge. Large blocks broken from ledge are strewn along the outcrop line	4	..
Covered slope, probably shale	10	6
Thin-bedded light-gray limestone. Forms a band of thin slabs in the grassed slope	2	..
Covered slope	5	..
Red shale	10	..
Red Eagle limestone member:		
Deep-buff coarse-grained soft, massive limestone. Weathers in large rounded nodules conspicuous in slope immediately above the prominent thin-bedded ledge	3	..
Thin-bedded gray limestone, practically free from fossils	16	6
Gray shale, in part limy	18	..
Very limy gray shale	5	..
Total thickness of Elmdale shale	79	6
Foraker limestone.		

On the headwaters of Rock creek, in the extreme southeastern part of the county, in T. 35 S., Rs. 7 and 8 E., the shale beds of the formation are not well exposed, but the limestone beds form prominent outcrops. The thin-bedded gray limestone of the Red Eagle limestone member, 20 feet above the base of the formation, makes the most jagged-appearing rock ledge cropping out in the Rock creek slopes and is marked by a number of shrubs and trees. At its top and lying a few feet back up the slope from the main ledge is the deep-buff bed that forms the uppermost part of the member. This bed is not continuously exposed, but because of its striking buff color is unusually conspicuous. Above the buff bed, $17\frac{1}{2}$ feet of covered slope intervening, is a bed of weathered dark-gray limestone 1 foot or more thick that is dense, in part crystalline, and weathers with a very sharply rough siliceous surface. At 10 feet above it is a thin-bedded thin gray limestone that is not prominently exposed, but forms a narrow band of platelike slabs on the surface. The Neva limestone caps the slopes.

The Elmdale shale not only has a threefold division in its lithologic composition, but has also a threefold expression in the surface features it forms. On the divides the lower shale division occupies a broad, gently sloping surface; in the gulches it forms a narrow, steep slope between the Foraker limestone ledge below and the thin-bedded limestone of the Red Eagle member above, which in turn forms a prominent rock ledge or terrace. Next above, the upper half of the member forms a relatively broad band of sloping surface terminated above by the rock ledge of the Neva limestone. The Elmdale shale as a whole occupies a comparatively broad band of the surface, capping the lower of the two main benches of the Flint Hills, from the northern part of T. 32 S., R. 8 E., southwestward across Cowley county into Oklahoma. As a rule the formation is not clearly defined in well logs. In most logs the Elmdale formation is recorded as limestone and shale and is indistinguishable from the Foraker limestone below and the Neva limestone above. Some logs record red shale in parts of the unit occupied by this formation.

The following fossils, collected from the very limy shale in the uppermost few inches of the formation, in contact with the overlying Neva limestone, were identified by G. H. Girty, of the United States Geological Survey:

U. S. G. S. No. 6163, collected in the S. E. ¼, sec. 11, T. 34 S., R. 7 E.:
Productus cora.
Pustula nebraskensis.
Composita subtilita.

Red Eagle limestone member. The thin-bedded limestone 20 feet above the base of the Elmdale shale is one of the most conspicuous outcropping ledges in the Flint Hills slope. It is about 20 feet thick and consists throughout, except the uppermost 2 to 3 feet, of gray thin-bedded limestone. The top 2 to 3 feet is composed of deep-buff, rather coarse-grained massive limestone that weathers away easily and so is not exposed in all localities. Where present, this bed crops out as large rounded nodular masses, and because of its deep-buff color is unusually conspicuous on the slopes. The lowermost 5 to 10 feet of the member crops out typically as a series of gray beds, each 4 to 6 inches thick, forming a jagged rock ledge 5 to 8 feet thick. The upper part of the thin-bedded portion of the member forms a covered rocky slope capped by the deep-buff nodular bed lying in the slope a few rods back of the principal ledge. More shrubs and trees grow on the rock terrace formed by the Red Eagle limestone than on other beds above or below it.

The Red Eagle limestone was named by Heald[21] from exposures a few miles south of the Kansas-Oklahoma line, near Red Eagle schoolhouse, southwest of Foraker in northern Osage county, Oklahoma. The member was not traced northward beyond the boundary of Cowley county, but is believed to be continuous into central

21. Heald, K. C.; The oil and gas geology of the Foraker quadrangle, Osage county, Oklahoma: U. S. Geol. Survey Bull. 641, pp. 24, 25; 1916.

Kansas, because a limestone unit at the stratigraphic horizon of the Red Eagle member is exposed near the Cottonwood river bridge 1¼ miles east of Elmdale, Chase county.

NEVA LIMESTONE.

One of the most persistent limestone formations present in Kansas is the Neva limestone, the outcrop of which can be traced from north to south across much of the state and on southward for 75 miles into Oklahoma.[22] Characteristically it forms a ledge of dark-gray limestone that weathers to a very rough surface. On freshly broken unweathered surfaces it is buff, and in most localities a sufficient amount of the buff material is exposed in the face of the ledge to lend to the entire outcrop a slight buff hue when viewed from a distance and contrasted with other outcropping beds in the slope. It has not so deep a buff color, however, as the uppermost bed of the Red Eagle limestone, which lies about 35 feet below it. In some localities parts of the formation contain a relatively small amount of chert. The outcropping ledge is commonly only 3 to 6 feet thick, but the entire member has a total thickness of 22 feet in the northeastern part of Cowley county and 28 feet in the southeastern part. The measurement of 22 feet was obtained from an exposure in the railroad cut northeast of Grand Summit, in the SE¼, sec. 4, T. 31 S., R. 8 E., where the Neva limestone is exposed beneath the red shale in the lowermost part of the Eskridge shale. It consists of bedded buff-gray limestone, in part fossiliferous. Immediately below the Neva is 6 feet of limy shale containing a few thin beds of limestone, which is succeeded below by a massive bed of hard blue-gray limestone that forms a prominent ledge of sharp-edged blocks in this locality. The measurement of 28 feet was made in the railroad cut in the SW¼, sec. 12, T. 34 S., R. 7 E., 3 miles southeast of Hooser, where the Neva limestone is in part thin-bedded and in part thick-bedded dull-gray and buff limestone containing some chert. Some beds are fossiliferous. Beneath it is 5½ feet of very limy fossiliferous shale, succeeded below by a bed of dense blue limestone that may be the correlative of the "blocky" bed that is present at about this horizon near Grand Summit. Chocolate-colored clay shale occurs in the succeeding formation above the Neva in the southern as well as the northern part of the county, but is rarely exposed.

The Neva limestone is recognizable in logs of drilled wells in this part of the state as the limestone unit above the lowest red shale

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22. Miser, H. D.; Geologic map of Oklahoma: U. S. Geol. Survey; 1926.

in this part of the section. This lowest red shale is not reported in all logs, however. The red shale above the Neva in the lower part of the Eskridge shale also aids in the identification. The Neva limestone is one of the most readily recognized of the upper Pennsylvanian and Permian strata penetrated by the drill in Cowley county and can be identified in most of the wells. The formation is recorded as sandy lime in some logs, probably owing to the contained chert. Water is found in the Neva in many wells. The expression of the formation at its outcrop is that of a prominent ledge that lies near the foot of the upper slope of the Flint Hills in Cowley county, or it may be thought of as the highest prominent rock terrace of the lower main bench of the Flint Hills, which is formed mainly by the Foraker limestone below. The Red Eagle limestone and the Neva limestone form ledges or rock terraces at almost equal intervals above the Foraker limestone. Above the Red Eagle and Neva ledges another slope rises steeply to the ledge formed by the Wreford limestone, which caps an extensive plateau forming the crest of the Flint Hills.

Aside from the two localities of measured sections cited, the lower part of the Neva limestone is prominently exposed near the roadway just south of the west quarter corner of sec. 12, T. 34 S., R. 7 E.; near the head of Rock creek, in secs. 13 and 14, T. 35 S., R. 7 E.; and just east of the county boundary beside the highway in the W½, sec. 17, T. 31 S., R. 8 E. The outcrop of the formation as shown on Plate I was rather carefully checked and sketched in the southern half of the area that it occupies. Its position as shown in the northern half was generalized, being in part traced from mapping done by the Empire Gas and Fuel Company, and in part interpolated from the sketched outcrop lines of lower beds.

The Neva limestone was named by Prosser[23] from its exposures northeast of Neva station, on the north side of Cottonwood river at the mouth of Diamond Creek, Chase county, Kansas. The general characteristics of the formation exhibited at its type locality persist southward through Cowley county and into Oklahoma. At its type locality the Neva limestone, 11 feet thick, forms a prominent ledge. It is light gray with a light-buff hue, changes from a massive bed to bedded layers within a few rods along the outcrop, weathers to a pitted, sharply rough surface, and contains fossils in abundance grouped in masses irregularly distributed through the bed.

23. Prosser, C. S.; Revised classification of the upper Paleozoic formations of Kansas: Jour. Geology, vol. 10, p. 709; 1902. U. S. Geol. Survey Geol. Atlas, Cottonwood Falls folio (No. 109), p. 2; 1904.

ESKRIDGE SHALE.

Red to chocolate-colored, green and gray shale, in part limy, and a few thin beds of limestone, the whole about 35 to 40 feet thick, constitute the Eskridge shale of the Wabaunsee group, named from exposures in the vicinity of Eskridge, Wabaunsee county, Kansas.[24] It is the uppermost formation of the Pennsylvanian system in Kansas, and lies above the prominently exposed Neva limestone and beneath the Cottonwood limestone. Inasmuch as the Eskridge shale is a body of relatively soft rocks between two beds of hard limestone, it forms a soil-covered slope terminated below by the Neva limestone bench and above by the Cottonwood ledge, and is rarely exposed. Much of its lower half is reddish to chocolate-colored clay shale, and the upper half is greenish-gray and gray calcareous fossiliferous shale, increasing upward in lime content and abundance of fossils. Its uppermost few feet is crowded with fossils and contains many irregularly shaped tubelike limy concretions constituting its most prominent characteristic. These concretions serve as one of the chief means of identifying the Cottonwood limestone, which overlies the Eskridge shale. Much of the total thickness of the formation is exposed in the railroad cut about 1½ miles northeast of Grand Summit, where the following section was measured:

	Ft.	In.
Cottonwood limestone.		
Eskridge shale:		
Covered. (In other exposures in this region this part is yellow-gray to tan calcareous shale crowded with fossils, increasingly abundant upward. Contains many irregularly formed tubelike masses 1 to 1½ inches thick and 2 to 12 inches long)	13	..
Greenish-gray shale, in part calcareous	8	..
Reddish to chocolate-colored clay shale	5	..
Bluish-gray thin-bedded limestone	1	..
Reddish to chocolate-colored clay shale	8	..
Covered	1	..
Total thickness of Eskridge shale	36	..
Neva limestone.		

Southeast of Grand Summit, at the county line on state highway No. 12, the total thickness of the formation is 37 feet, and the uppermost 20 feet is well exposed. Parts of the formation are exposed about 3 miles south of Hooser, in the SE¼, sec. 11, T. 34 S., R. 7 E., and the uppermost few feet of the formation crops out in the SE¼, sec. 8, T. 35 S., R. 7 E. The uppermost beds are exposed in a number of localities, but except in a few places the remainder of the

24. Prosser, C. S., op. cit., p. 109.

formation is concealed. The most extensive outcrop of the Eskridge shale in Cowley county occupies a relatively narrow band extending a little west of south across the county in its extreme eastern part and lying in the eastward-facing slope of the Flint Hills.

The following fossils collected from the uppermost few feet of the Eskridge shale were identified by G. H. Girty:

U. S. G. S. No. 6162. Collected near the center of sec. 11, T. 34 S., R. 7 E.:

Fenestella tenax.
Pinnatapora sp.
Septopora biserialis.
Meekopora prosseri.
Derbya multistriata?
Meekella striaticostata.
Chonetes meekanus.
Pustula nebraskensis.
Composita subtilita.
Deltopecten occidentalis.
Deltopecten mccoyi.
Pinna peracuta.
Pseudomonotis equistriata.
Pseudomonotis kansasensis.
Griffithides sp.
Ostracoda indet.

U. S. G. S. No. 6164. Collected in the S. E. ¼, sec. 8, T. 35 S., R. 7 E.:

Fusulina sp.
Fusulinella sp.
Rhombopora lepidodendroides.
Derbya multistriata.
Derbya sp.
Meekella striaticostata.
Chonetes granulifer?
Productus semireticulatus.
Pustula nebraskensis.
Ambocoelia planiconvexa?
Deltopecten occidentalis.
Deltopecten mccoyi.
Euchondria neglecta?
Myalina kansasensis.
Schizostoma catilloides.

Permian System.

Council Grove Group.

Varying but little from 150 feet in thickness, the lowermost group of strata in the Permian system, the Council Grove group, consists of alternate beds of shale and limestone. The well-known Cottonwood limestone occupies the lowermost 10 feet, and the succeeding 140 feet of the group is termed the Garrison shale. The limestone beds of the group are light gray to white on weathered surfaces; many are persistent across the county and form fairly conspicuous outcropping ledges. The shale beds range in color from gray or drab to tan, with a considerable proportion of maroon to chocolate-colored beds. In east-central Cowley county the Council Grove group crops out as a narrow band in the steeply sloping east face of the Flint Hills, its more prominent limestone beds forming blocky white ledges or shoulders in the slope. A bed of limestone near the middle of the Garrison shale forms a particularly prominent ledge that breaks down in rectangular blocks, which lie strewn along the line of outcrop. The Cottonwood limestone forms a pronounced shoulder or terrace in the slope, but rarely crops out as a ledge. In the northeastern part of the county, in Tps. 30 and 31 S., Rs. 7 and 8 E., and in the southeastern part, in Tps. 34 and 35 S., R. 7 E., the overlying Wreford limestone of the Chase group has been much more thoroughly dissected and removed by erosion than farther north in Kansas, leaving the underlying Council Grove group occupying broad areas of the surface.

The Council Grove group is difficultly distinguished in most well logs, although its approximate position can generally be allocated by interpolation from the Wreford limestone above and the Foraker limestone some distance below. The rocks of the Council Grove group are commonly reported by drillers as mostly gray limestone with breaks of red shale.

This group was named in 1902 by Prosser[25] from exposures in the bluffs of Neosho river, the uppermost part being exposed in the immediate vicinity of the town of Council Grove, Marion county, and the lower part about 6 miles downstream. These localities are about 80 miles north of the northeast corner of Cowley county.

COTTONWOOD LIMESTONE.

One of the most striking limestone divisions in the entire stratigraphic succession of beds in northern Kansas is the Cottonwood limestone[26]—striking because of its appearance at the outcrop as an unusually prominent ledge of yellowish-buff rock about 6 feet thick that is persistent with only minor variations in thickness and lithologic character throughout several counties in Kansas and into Nebraska. When traced southward, however, it abruptly loses its distinguishing features, and from southern Chase and Lyon counties southward it appears merely as one of a number of grayish weathered limestone beds cropping out low in the eastward-facing slope of the Flint Hills. In Cowley county the Cottonwood limestone has a total thickness of about 10 feet, but commonly only the lowermost foot or two crops out, the upper part forming a gently sloping soil-covered surface receding from the outcropping ledge. Even more commonly the formation makes only a pronounced shoulder in the general slope formed by the Garrison shale above and the Eskridge shale below, as shown in Plate IV, which is a typical view of its outcrop in the Flint Hills slope. It is less conspicuous in its surface expression than any one of a number of limestone divisions

25. Prosser, C. S.; Jour. Geol. vol. 10, pp. 709-711, 1902.
26. Prosser, C. S.; Jour. Geol. vol. III, pp. 697-705, 1895.

both above and below it—for example, the Crouse limestone member of the Garrison shale and the Wreford limestone above and the Neva, Red Eagle, and Foraker limestones below. In detail, however, the Cottonwood limestone has characteristics that distinguish it from other beds. The upper part is composed of fine-grained, rather soft limestone that weathers chalky white and which in most localities, although not all, contains some layers that are abundantly filled with small Fusulinas. In most localities this upper member

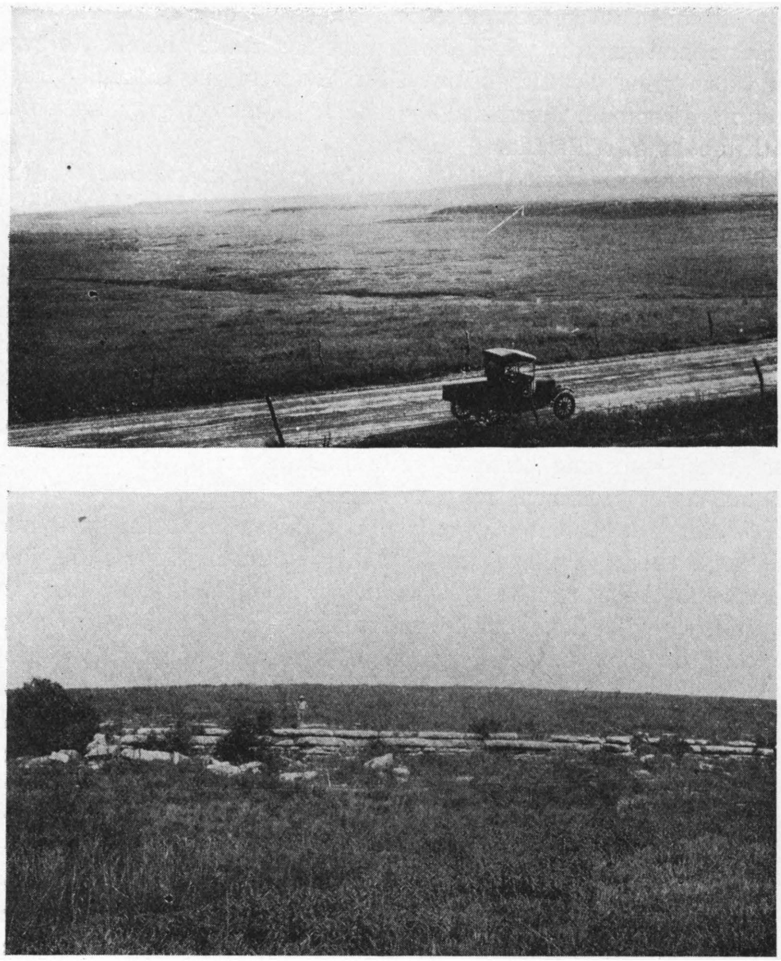


PLATE IV.—Upper: Bench formed by Cottonwood limestone (see arrow) in sec. 16, T. 31 S., R. 8 E. Lower: Outcrop of limestone beds in the lowermost 6 feet of the Florence flint near southwest quarter corner of sec. 26, T. 33 S., R. 5 E.

weathers into irregularly shaped nodules that are 2 to 3 inches in diameter and extremely white and fine grained, and that lie strewn upon the surface of the grass-covered bench or terrace formed by the formation. The lowermost 2 feet or more of the formation is somewhat more siliceous at the outcrop than the upper part, is of darker-gray color, and constitutes the ledge-forming part. It closely resembles weathered exposures of parts of the Neva limestone and one or two thin beds of limestone in the Garrison shale, in many localities being indistinguishable within itself from them. Immediately beneath the Cottonwood limestone is the abundantly fossiliferous shale in the upper part of the Eskridge shale. Abundant fossils were present at this horizon wherever it was seen exposed in the county; and associated with them are irregular tubelike calcareous concretions about 1 to 1½ inches thick and ranging from a few inches to a foot or more in length. In most localities of its outcrop either this fossiliferous shaly zone beneath the Cottonwood limestone or the chalky white limestone containing *Fusulina* of the upper part of the formation is present and serves to identify the formation. Because of poor exposures in a few localities, however, particularly parts of T. 35 S., R. 7 E., these criteria may not be sufficient for identification. In such localities it will be necessary to augment the study of the Cottonwood formation by measuring short stratigraphic sections of the lower part of the Garrison shale, which includes several limestone beds that are mappable locally. In short, although the Cottonwood limestone forms a sufficiently distinctive outcrop in most of its exposed area in Cowley county to make possible its identification under the usual field procedure for reconnaissance geologic mapping, there are some areas in which it is distinguishable with difficulty, being decidedly inconspicuous as contrasted with its unusual prominence in northern Kansas.

Probably the most complete exposure of the Cottonwood limestone seen in Cowley county is that on the county line near the northeast corner of the county, in the NE¼, sec. 5, T. 30 S., R. 8 E., where the following section was measured:

	Ft.	In.
Garrison shale.		
Cottonwood limestone:		
Thin-bedded light-gray limestone; weathers white, and produces small irregularly shaped white nodules. Several beds are fossiliferous	6	..
Light-buff limestone. Fairly large specimens of *Fusulina* abundant 6 to 10 inches above the base	1	8
Light-tan chert and gray siliceous limestone	..	5
Light-buff thick-bedded limestone; weathers gray	2	6
Total Cottonwood limestone	10	7

Eskridge shale:

Fossiliferous calcareous shale, containing many irregularly shaped tubular masses of limy shale 1 to 1½ inches thick and 4 to 10 inches long.

The Cottonwood limestone was described by Prosser* in 1894, more fully in 1895, and again in 1902, and was named by him from exposures on both sides of Cottonwood river near Cottonwood Falls and Strong City, Chase county, Kansas. In the latest of the three papers cited Prosser described the Cottonwood formation as "a massive light-gray to buff-colored foraminiferal limestone, frequently composed of 2 layers with a thickness of about 6 feet. It contains very few fossils, with the exception of *Fusulina emaciata* Beede, which is extremely abundant in its upper part and is called 'wild rice' by the quarrymen. It is the most important dimension stone in Kansas, and at various localities there are extensive quarries. Its constant lithologic character, with its line of outcrop frequently marked by a row of light-gray rectangular blocks filled with *Fusulina,* make it one of the most important stratigraphic horizons in the upper Paleozoic rocks for at least two-thirds of the distance across Kansas and into Nebraska."

GARRISON SHALE.

The Garrison shale, consisting of 140 feet of interbedded shale and limestone, comprises all but the lowermost 10 feet of the total thickness of the Council Grove group. It is rarely well exposed with the exception of a few of its limestone beds, particularly one and in places two that are near the middle of the formation. The uppermost 15 to 20 feet of the formation is clearly exposed in a number of localities by virtue of its position beneath the resistant Wreford limestone of the overlying Chase group. In general, the lower half of the Garrison formation contains much more limestone and limy shale than the upper half. The shale beds are in part very limy and throughout are varied in color, ranging through gray, tan, green, maroon and chocolate-brown, the last two colors predominating. The most conspicuous division in the formation is a light-gray limestone known as the Crouse limestone member, about 6 feet thick, that occurs near the middle, 65 feet above the base. Another limestone, 15 to 25 feet below the Crouse, is prominently exposed in the northeastern part of the county.

A generalized section of the formation, from the base upward,

* Prosser, C. S.; Kansas river section of the Permo-Carboniferous and Permian rocks of Kansas: Geol. Soc. America Bull., vol. 6, p. 40; 1895. The classification of the upper Paleozoic rocks of central Kansas: Jour. Geology, vol. 3, pp. 697-700, 1895. Revised classification of the upper Paleozoic rocks of Kansas: Jour. Geology, vol. 10, pp. 711, 712; 1902.

shows mostly shale beds in part of chocolate color in the lowermost 15 to 20 feet, overlain by a bed of gray limestone 3 to 4 feet or more thick. Above this, occupying an interval of about 35 feet, is alternately bedded shale, in part red, and gray limestone; two thin beds of limestone in this division are exposed in many localities in the southern part of the county, one a little less than 10 feet above the base and the other a little less than 10 feet below the top. Next above is the Crouse limestone member, consisting of gray limestone 4½ to 6 feet thick and constituting the most persistent and prominent limestone in the Garrison formation. It is prominently exposed 1½ miles south of Hooser. The beds above the Crouse member consist mostly of shale with some shaly limestone and have a total thickness of 75 feet. No complete exposures of this uppermost unit were seen, and so its composition in detail is not known. A considerable part of its upper half is maroon clay shale, but the uppermost 5 to 15 feet is composed of gray shale and thin beds of fossiliferous limestone constituting strata of somewhat transitional character, grading upward into the limestone of the overlying formation. The maroon color of the shale approaches nearer the top of the Garrison formation in the southern part of the county than in the northern part. Only about 4 feet of limy shale and shaly limestone intervenes between the red shale and the Wreford limestone in the northwest corner of sec. 29, T. 34 S., R. 7 E., a mile east of Otto, and but 5 feet of green shale and shaly limestone crowded with fossils occupies this interval in the center of sec. 14, T. 34 S., R. 6 E., 1½ miles northwest of Otto, in the southern part of the county. About 3 miles east of Burden, in the northeastern part of the county, near the northeast corner of sec. 31, T. 31 S., R. 7 E., the nonred rocks in the uppermost part of the Garrison have a total thickness of 14½ feet, made up of gray to tan shale containing several beds of abundantly fossiliferous limestone from 1 to 4 inches thick. At this locality 11 feet of maroon shale is exposed below the nonred unit, and 6 feet beneath the red material and separated from it by a covered slope is a thin light-gray limestone.

In the southern half of its outcropping area in Cowley county the red-shale unit in the upper part of the Garrison contains a lenticular body of sandstone in its upper part. Although the distribution of the sandstone was not studied in detail it was noted in several localities cropping out as a thick bed that thinned abruptly laterally. These characteristics suggest that the sandstone may be at least in part of stream-channel type—that is, formed by the filling of a stream channel in upper Garrison time. Inasmuch as the outcrops of the sandstone occur in most localities as ledges jutting out from sod-covered slopes, its unusually great thickness in scattered localities might satisfactorily be explained by lateral variation in the hardness of the bed, the portions that crop out in a thick bed being the harder parts that have better resisted the agencies of weathering, the softer parts having been more readily disintegrated at the surface and now remaining concealed from view by a mantle of soil. However, a channel-filling mode of origin is suggested in an exposure that was made in grading for the highway in the NE¼ SE¼, sec. 13, T. 34 S., R. 6 E., 6 miles due south of Dexter, where the sandstone and adjacent red clay have been cut through, revealing the body of sand abutting laterally abruptly against red clay. The sandstone here exposed is relatively fine-grained of light-tan color, weathering rusty brown, intricately cross-bedded, and about 10 feet thick where exposed 25 feet from its contact with the red clay. The sandstone crops out also near the northeast corner of sec. 36, T. 34 S., R. 6 E., where it is 10 to 12 feet thick and intricately cross-bedded; it thins southward within a few hundred yards to a thickness of 1½ feet. The bed is unusually thick in an outcrop just south of the center of sec. 12, T. 35 S., R. 6 E. Logs of wells drilled in the area immediately west of the region of outcrop of this sandstone do not record sand at its horizon, indicating that it is not widespread.

The Garrison shale is defined at the base and top by relatively abrupt changes in lithology. The rocks of the lowermost and uppermost few feet of the formation are composed of shaly limestone and shale with a sufficiently large shale content to give them a quite different character from the underlying Cottonwood limestone and the overlying Wreford limestone. These differences in lithologic character, however, are not sufficiently marked to be detected in wells drilled with churn drills. Much of the material that is called limy shale on a weathered outcrop is commonly recorded as limestone in well logs. The beds of red shale in the formation are readily detected in drill cuttings, and so in most logs the formation is recorded as alternately bedded limestone and red shale. The formation is usually allocated in a log by the position of the Wreford limestone, which overlies it, and the Foraker limestone, which lies below, although separated from it by other beds.

The following section of the Garrison shale was measured by hand level about 2 miles south of Hooser, in the NW¼, sec. 12,

T. 34 S., R. 7 E. It is only partly exposed but represents one of the better-exposed sections in the county:

	Ft.	In.
Wreford limestone.		
Garrison shale:		
Steep grass-covered slope	28	..
Weathered blocks of rusty-brown micaceous sandstone, not sure to be in place	3	..
Covered grassed slope	44	..
Crouse limestone member:		
Gray weathered limestone, light buff on freshly broken surface. Forms prominent ledge. Upper surface smooth except for vertical cylindrical pits about the size of automobile-engine cylinders. A few fragments of rod-shaped fossils etched upon the surface in places crops out as a single bed and in other places is split into two or three layers	3	4
Shaly fossiliferous limestone. Weathers more readily and so undercuts the bed above	1	..
Covered slope	8	6
Weathered brown limestone, composed almost entirely of fragments of fossils	1	..
Red clay	5	6
Covered grass slope	11	..
Blue-gray limestone; weathers gray-white; only partly exposed	..	4
Covered slope	9	..
Blue-gray thick-bedded limestone; weathers gray-white; forms slight shoulder in the slope	3	6
Covered slope. Some green and chocolate-colored shale exposed	17	6
Total of Garrison shale	135	8
Cottonwood limestone.		

A section of the formation measured in the railroad cut 1½ miles northeast of Grand Summit station, in the SE¼, sec. 4, T. 31 S., R. 8 E., follows:

	Ft.	In.
Wreford limestone.		
Garrison shale:		
Covered slope	75	..
Crouse limestone member: Gray limestone; forms ledge; weathers with a fairly smooth surface. Upper 2 feet breaks into large rectangular blocks	5	6
Covered slope. Some red shale exposed in the upper part, and some shaly limestone in the lowest part	33	..
Gray limestone	2	6
Covered slope; some reddish shale exposed in the lower part	13	..
Gray shale, in part limy	6	..
Total Garrison shale	135	..
Cottonwood limestone.		

The Garrison shale occupies a considerable part of the surface of Tps. 32 to 35 S., R. 7 E., and Tps. 30 to 31 S., Rs. 7 and 8 E., but its entire thickness was nowhere seen exposed. In the following localities the total thickness of the formation occupies the surface, but only parts of the strata are exposed: In sec. 11, T. 34 S., R. 7 E., 2 miles south of Hooser; along the east face of the Flint Hills in the E½, sec. 36, T. 32 S., R. 7 E.; near the west sides of secs. 7 and 18, T. 33 S., R. 8 E.; and in the railroad cut 1½ miles northeast of Grand Summit.

The formation was named by Prosser[27] from exposures in the valley of Big Blue river south of Garrison, Riley county, Kansas. Prosser described it as consisting of two parts in this northern region —a lower yellowish fossiliferous shale ranging from 2 to 13 feet in thickness, which he had earlier designated the Cottonwood shales and later named the Florena shales, and an upper unit of alternately bedded gray limestone and variegated shale to which he applied the name Neosho, the formation having a total thickness of 140 to 145 feet.

The following fossils were collected in Cowley county from the lower part of the Garrison shale and identified by G. H. Girty:

U. S. G. S. No. 6161. Collected on Winfield-Dexter highway in N. W. ¼, sec. 12, T. 33 S., R. 6 E.:

Derbya multistriata.
Deltopecten occidentalis.
Aclisina sp.

Crouse limestone member. One of the most conspicuously exposed limestone divisions cropping out in the eastern part of Cowley county is the Crouse member of the Garrison shale. It forms a prominent ledge of large white blocks about a third of the way below the crest of the slope extending west of the highway for 1½ miles southward from Hooser. At this locality the member consists of a lowermost division, 1 foot thick, of abundantly fossiliferous shaly limestone that has been eroded away more rapidly than the overlying beds and so forms a notch undercutting the main ledge-forming part of the member, which is 3 feet 4 inches thick. This upper part of the member consists of massive to indistinctly bedded limestone that is light buff on freshly broken surfaces, but weathers to a very light gray. The most characteristic feature of the member in the southern part of Cowley county is the presence of vertical or nearly vertical cylindrical pits ranging in diameter between ½ inch and 10 inches, but most commonly about 4 inches. The walls of the pits are vertical or nearly so, do not taper inward like the pits so abundant in the Wreford limestone, and are commonly lined with material

27. Prosser, C. S.; Jour. Geology, vol. 10, pp. 712, 713; 1902.

that appears to be largely silica. The pits are spaced from a few inches to a foot or more apart and in general resemble cylinders in an automobile engine. They are present in all exposures of the member seen in the southern third of the county and southward for many miles into Oklahoma, but are absent at most localities in the northeastern part of the county where the member was examined. The northernmost exposure seen to contain the pits is about 2 miles east of Cambridge, in the NE¼, sec. 35, T. 31 S., R. 7 E.

Although in the southern part of Cowley county the Crouse limestone member is readily recognizable because of its greater prominence of outcrop where contrasted with that of other limestone divisions of the Garrison formation and because of the presence of the cylindrical pits, in the northern part of the county it is not so easily determined. There are two limestone divisions, separated by an interval of about 20 feet, near the middle of the Garrison formation, that form prominent ledges in the northeastern part of the county, being particularly well exposed in the region about Cambridge. From the facts that a few cylindrical pits occur in the upper of these divisions and that its stratigraphic position corresponds closely to that of the Crouse member in southern Cowley county, it is believed that the upper division is the Crouse member, but its positive identification could not be made without more detailed tracing. The two limestone divisions, the lower one about 6 feet thick and the upper 5 to 8 feet thick, form the capping ledges of the Flint Hills from a point a short distance north of Grand Summit southward for several miles. Because of their regular thickness and abundant exposure, these beds in the northern part of the county and the Crouse member in the southern part of the county constitute excellent key beds for structural mapping.

Chase Group.

Alternately bedded limestone, in part cherty, and shale, with a total thickness varying slightly from 275 feet, constitute the Chase group in Cowley county. The two types of rock form about equal parts of the group. The limestone beds present light-buff, light-gray or white weathered surfaces, and the interbedded shale strata are drab, gray, chocolate-brown and maroon. The abundant chert, found chiefly in the lowermost and middle limestone formations, is probably the most characteristic feature of the group. The lowermost formation of the group is the cherty Wreford limestone, and the topmost formation is the Winfield limestone. These two formations are two of the best ledge formers and consequently most prominently exposed strata in Cowley county. The middle fifth of the group is composed of limestone that is divided into two formations—the Fort Riley limestone above and the Florence flint below. As indicated by the names the upper formation contains practically no chert and the lower formation, which is the thinner of the two, is abundantly cherty. The strata between the Wreford limestone and the Florence flint consist of gray limy shale, maroon clay, and relatively thin beds of gray limestone collectively known as the Matfield shale. The beds between the Fort Riley and Winfield limestones, known as the Doyle shale, are composed of material similar to that of the Matfield shale except that there is much less limestone. The limestone and cherty limestone beds of the group are widely exposed and sufficiently persistent in their chief characteristics to afford excellent horizons for mapping. In drill records the precise boundaries of the group cannot be readily determined, but its approximate position can be recognized by the red shale bands in the Matfield shale and by the Wreford limestone and Florence flint, which are usually reported as sandy limestone or sandstone carrying water.

The Chase group occupies about half of the surface of Cowley county, extending from the rim of the Flint Hills, in the eastern part, westward to the bluffs bordering the west side of the Walnut river bottoms in the western part, constituting a zone about 25 miles wide extending a little east of north across the county. The area is characterized by expansive but somewhat dissected uplands floored by the resistant limestone and cherty limestone divisions of the group. The uplands are terminated laterally by steep slopes formed by the softer shale beds. Isolated flat-topped buttes capped by the Wreford limestone are present in the eastern part of the county, and similar buttes capped by the Winfield limestone occur in the western half of the county, constituting surface forms that are typical of the region occupied by the Chase group.

The Chase group as a whole and its several divisions were described in detail by Prosser[28] in 1895 from field studies in Chase and Marion counties and contiguous areas. It is interesting to compare Prosser's compiled section of the group, derived from exposures in Marion, Chase, Morris and Geary counties, with the com-

28. Prosser, C. S.; Jour. Geology, vol. 3, pp. 771-786; 1895.

piled section in southern Cowley county. The two sections are shown diagrammatically in Figure 5. They indicate a striking continuity in thickness and lithologic character of individual beds, although separated by a distance greater than 50 miles.

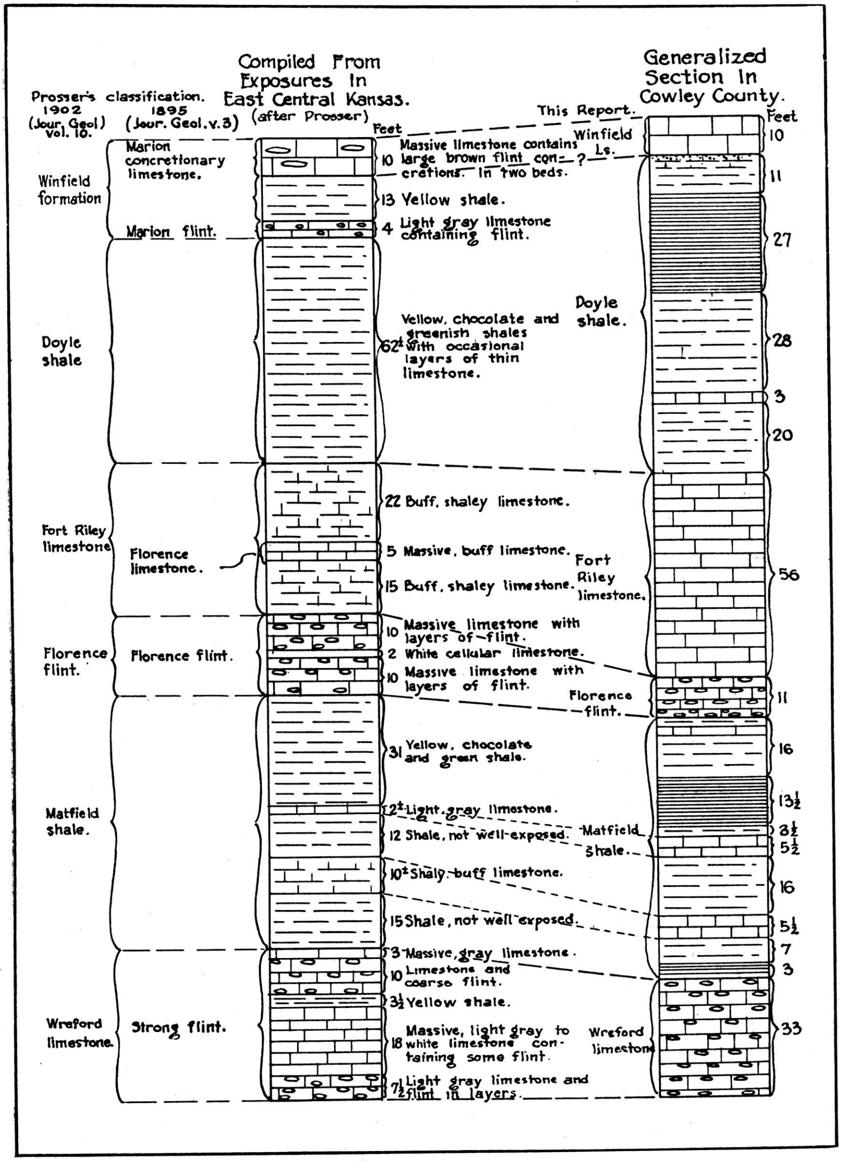


FIG. 5.—Sections of Chase group.

WREFORD LIMESTONE.

The lowermost formation of the Chase group, the Wreford limestone, is one of those rock divisions that exert a pronounced influence on the surface features of the state, for it forms the backbone of the Flint Hills throughout much of their extent, particularly in Cowley county. Its striking characteristics are its abundance of chert and its weathered light-gray to white, vertically pitted beds of limestone. In Cowley county the formation varies little from 33 feet in thickness and is composed almost entirely of beds of limestone and chert. The chert occurs most abundantly in regular layers interbedded with the limestone, but also as small, irregular masses or nodules unsystematically arranged within the limestone beds. The limestone occurs in beds that range from a few inches to 3 feet in thickness, is buff on freshly broken surfaces, and for the most part weathers to a very light gray or white, but the lowermost few feet weathers tan or light brown. The massive beds occur in the middle and uppermost parts of the member. The interbedded chert and thin-bedded limestone occupy a zone about 6 feet thick, occurring about a third of the way above the base of the formation, and another zone of about the same thickness 5 feet below the top. The greater part of the chert that occurs in irregular nodules within the limestone beds is in the lowermost 8 feet of the formation. The nodules are of irregular shape and range from 1 to 3 inches in diameter; the smaller ones are the more abundant. The bedded chert occurs in layers as much as 10 inches thick; it is light tan on its outer surfaces and blue and steel-gray on freshly broken surfaces. In many of the chert layers the individual nodules are separated by limestone, although continuous beds with wavy upper and lower surfaces, such as that shown in Plate V, are of more common occurrence.

The Wreford limestone is rather sharply defined lithologically at its base and top. It is true that the limestone in the lowermost few feet of the formation is somewhat shaly and transitional, characteristics that are accentuated by weathering, but in the uppermost part of the underlying Garrison shale the rocks are predominantly shale with thin beds of very fossiliferous limestone. The upper boundary of the Wreford is exposed in few places, because the uppermost bed of limestone is relatively soft and is readily eroded away. A few clean exposures, however, show that the rocks change in character abruptly from the buffish-white massive bed of limestone of the Wreford to clay shale, commonly maroon, of the succeeding formation. A compiled section of the Wreford limestone measured in a series of closely spaced exposures in recent cuts along the right of way of the Atchison, Topeka & Santa Fe Railway from 1½ to 2 miles east of Burden follows:

	Ft.	In.
Matfield shale.		
Wreford limestone:		
Massive light-buff limestone; weathers white and deeply pitted...	4	..
Interbedded limestone and chert; limestone weathers light gray and chert light tan. Limestone beds average about 4 inches thick and chert beds 4 to 8 inches. Uppermost limestone bed is 1 foot thick overlain by a layer of chert 3 inches thick.......	6	6
Covered	5	..
Massive light-buff to light-gray limestone; weathered surface is roughly pitted. Inconspicuous amount of chert in unsystematically arranged nodules through the limestone..............	3	6
Buff limestone, weathering gray, in beds 6 to 8 inches thick interbedded with chert, gray and blue on freshly broken surfaces and light tan on weathered surfaces, in beds 2 to 8 inches thick. Some chert irregularly distributed within the limestone........	4	1
Grayish-buff limestone. At base is the uppermost distinct layer of chert, about 2 inches thick, and 5 inches above the chert bed is a layer of flattish, siliceous nodules that weather brown and are commonly 6 to 8 inches thick and 1 to 2 feet long parallel with the bedding, although several are as much as 10 inches thick and 3 feet long. These nodules have a concentric banding that closely resembles the graining in wood. Many of the banded nodules contain smaller nodules of light-tan chert, similar to that which occurs in layers in other parts of the member, cutting cleanly across the banded structure......................	1	9
Dull-buff limestone with irregularly spaced nodules of chert 1 inch in diameter	4	1
Dingy-buff limestone	..	4
Tan limy shale	..	4
Dingy-buff limestone, containing silicified fossils; lowermost 8 inches shaly; small irregularly spaced nodules of chert in middle third	3	2
Total Wreford limestone	32	9
Garrison shale.		

Another section measured near the north quarter corner of sec. 10, T. 34 S., R. 6 E., 3 miles northwest of Otto, is as follows:

	Ft.	In.
Matfield shale (covered slope).		
Wreford limestone:		
Massive, deeply pitted dingy-white weathered limestone capping a covered slope	5	6
Massive, deeply pitted light-gray limestone with abundant rodlike fossil fragments (Bryozoa (?) and spines) etched upon the surface, capping a grassed slope strewn with abundant fragments of brown chert	6	..
Massive light-gray limestone weathered to a relatively smooth surface, capping a covered grassed slope........	5	..

Wreford limestone—*Concluded:*	Ft.	In.
Thick-bedded light gray limestone with no chert capping the bluff on the south side of the gulch	5	6
Interbedded light-buff limestone and tan chert	9	..
Weathered light-brown limestone with no chert	2	..
Total Wreford limestone	33	..

Garrison shale.

Several of the massive beds of limestone in the Wreford weather with deeply pitted surfaces, but a bed near the middle develops especially striking vertical pits, as shown in Plate V. This bed is conspicuously exposed on the south side of the highway about 1½ miles northwest of Dexter, in the NW¼, sec. 12, T. 33 S., R. 6 E.

The Wreford limestone forms the rim of the Flint Hills in much of their extent in Cowley county and far northeastward in Kansas, although erosion has removed it in much of the southern third and northeastern part of Cowley county. The broad dip slope of the Wreford, terminated abruptly on the east by a steep slope descending eastward, is typically developed in Tps. 32 and 33 S., R. 7 E.; in the south-central part of T. 30 S., R. 8 E., 3 miles northeast of Grand Summit; and in T. 34 S., R. 7 E., for 2 miles south of Hooser. Only the lowermost 10 to 15 feet of the formation commonly forms the immediate rim in these localities, the upper beds being concealed beneath a very gently inclined grass-covered slope. The relatively thin but persistent and resistant brown concretionary bed that occurs about 10 feet above the base of the formation appears to produce, more than any other single bed, the prominent surface features of the formation, although the chert beds, because of their relatively great resistance to the agencies of weathering, contribute materially to a like result. Most of the isolated flat-topped buttes that are so numerous in the northeastern part of the county and a number of the long, narrow prongs that extend out from the main Wreford plateau in the east-central and southern part (see Pl. 1) are capped by fragments of this bed of brown-banded concretionary chert, that lie upon the surface in sharp-edged blocks, ranging from a few inches to a foot or more in width and from 6 to 8 inches in thickness.

Aside from the two localities of the detailed sections above described, strata of the Wreford are clearly exposed on the west side of Grouse creek, west of the road just south of the Glenwood schoolhouse in the SW¼, sec. 28, T. 33 S., R. 6 E., and in the SW¼, sec. 3, T. 34 S., R. 6 E. The lowermost 20 feet of the formation is well exposed in the road cut in the steep hill just east of Dexter on the Dexter-Hooser highway.

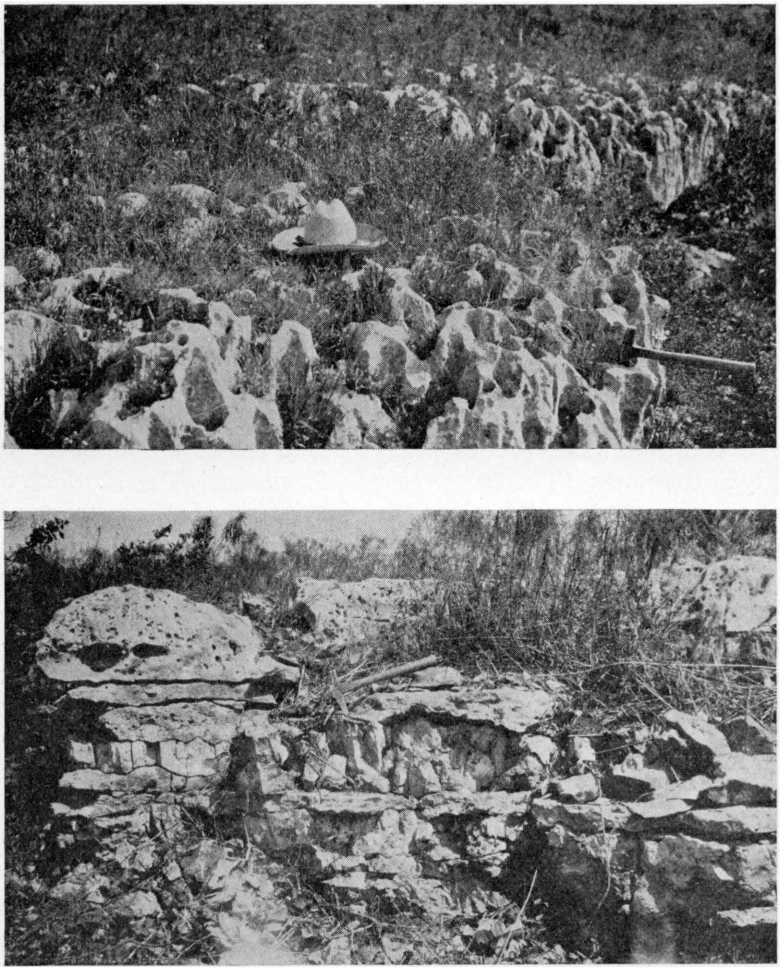


PLATE V. *Upper:* Deeply pitted limestone bed in uppermost part of Wreford limestone in western part of sec. 19, T. 32 S., R. 8 E. *Lower:* Interbedded limestone and chert in the Wreford limestone about 1½ miles east of Burden.

MATFIELD SHALE.

The Matfield shale consists of varicolored shale interbedded with gray limestone ranging in total thickness from 58 to 65 feet. In general it contains maroon and gray clay shale in the lowermost 10 feet, overlain by fossiliferous gray limestone about 6 feet thick; another gray fossiliferous limestone that is slightly thinner occurs a little below the middle of the formation, and the two are separated by gray shale, in part limy. These two limestone beds are remarkably persistent throughout Cowley county and presumably for many miles to the north, as a section measured by Prosser[29] near Matfield Green, in southern Chase county, shows two beds of fossiliferous gray limestone at the same horizons. In southern Cowley county more than 30 feet of shale, containing a few thin beds of limestone, the lower part of the shale of a maroon color, occupies the uppermost part of the formation. The maroon clay shale of this upper part is covered in the exposures of the formation seen in the northern part of the county, and the thickness of this upper division is somewhat reduced there. A bed of limestone about 3 to 4 feet thick is present 5 feet below the top of the formation throughout the northern part of the county, but was not seen in exposures in the southern part. Fossils occur abundantly in the two lower beds of limestone, in parts of the shale separating them, and in the shale and limestone beds in the upper 10 to 20 feet of the formation. The Matfield is usually reported in well logs as a series of interbedded limestone and red shale.

The upper boundary of the Matfield shale is placed below the lowest chert-bearing limestone bed of the Florence flint. The uppermost few feet consists of transition beds from limy shale to limestone, and grades into the limestone of the Florence flint, with no abrupt lithologic change except the appearance of chert. The base of the Matfield shale is more sharply defined, being rather abruptly terminated by the massive bed of white limestone constituting the top bed of the Wreford.

The total thickness of the Matfield formation decreases slightly northward in Cowley county. No definite statement as to the nature of this convergence can be made, but data disclosed by sections of the formation studied at three localities in the county suggest that it is accomplished by a transgression downward of the chert of the overlying Florence flint, which thickens northward.

The following section of the Matfield shale was measured about 2 miles south of Silverdale, near the north quarter corner of sec. 17, T. 35 S., R. 5 E.:

Florence flint.
Matfield shale:

	Ft.	In.
Very limy shale, fossiliferous	3	4
Limestone, grayish tan	2	..
Clay shale, gray to drab; small part covered	9	..
Maroon clay	12	..

29. Prosser, C. S.: U. S. Geol. Survey Geol. Atlas, Cottonwood Falls folio (No. 109), p. 4; 1904.

Matfield shale—*Concluded:*	Ft.	In.
In part covered; part is limy shale	6	8
Hard gray limestone; small fossils and fossil fragments abundant. Makes prominent ledge. (In near-by exposure is 11 feet thick),	4	6
Gray limy shale, particularly limy in upper part	8	..
Gray hard limestone; large fossils abundant	6	..
Gray limy clay	2	10
Maroon clay; base concealed	6	..
Covered	1	6
Total Matfield shale	65	..

Wreford limestone.

Another section measured about 1½ miles east of Burden, near the north quarter corner of sec. 36, T. 31 S., R. 6 E., follows:

Florence flint.

Matfield shale:	Ft.	In.
Buff limy shale, with a few thin beds of fossiliferous limestone, two near the middle fairly prominent	5	6
Light-buff limestone, upper part massive, lower part thin bedded. Lowermost 10 inches abundantly fossiliferous. A conspicuous bed throughout the northern part of Cowley county	3	..
Grayish-tan shale, upper part abundantly fossiliferous	3	..
Covered	11	..
Dull-buff limestone; soft and fossiliferous in upper 1 to 1½ feet. Lower part more massive. Rarely makes a showing in weathered slopes	3	..
Greenish-tan to gray clay shale	7	6
Gray limestone	..	4
Covered	10	..
Light-buff limestone. Uppermost 10 inches thin bedded; next lower 1 foot 6 inches is massive bed; and lower 3 feet 3 inches is massive bed. Forms a prominent ledge of thick blocks in this vicinity. Lowermost 6 to 8 inches is abundantly fossiliferous	5	6
Buff limy shale, in part fossiliferous. A 3-inch bed of limestone occurs 3 inches above base	1	9
Buff limestone with abundant fossils	..	9
Light-buff clay; lowermost few inches is in part of chocolate color,	7	2
Total Matfield shale	58	6

Wreford limestone.

The Matfield shale occupies a relatively narrow band of the surface of Cowley county, in most places forming a fairly steep, grassed slope capped by the lowermost limestone beds of the Florence flint and terminated below by the Wreford limestone ledges. Its most extensive exposures in the county are along Grouse, Silver and Timber creeks.

The Matfield shale was named by Prosser[30] from exposures in Matfield township, Chase county, Kansas, in which the town Mat-

30. Prosser, C. S.; Revised classification of the upper Paleozoic formations of Kansas: Jour. Geology, vol. 10, p. 704 (diagram), 714; 1902.

field Green is situated. Prosser[31] described the beds that make up the formation in 1895 in terms that aptly apply to its general characteristics in Cowley county. His section compiled from observations taken at a number of exposures in Chase county and the near-by region is quoted below:

Florence flint.	
Matfield shale:	Feet.
Yellowish, chocolate-colored, and greenish shales	31
Light-gray limestone, containing an abundance of small Lamellibranchia	2±
Shales, not well exposed	12±
Shaly, buff limestones, containing large brachiopods, sometimes a massive limestone	10±
Shale, not well exposed	15±

The following fossils collected in Cowley county were identified by G. H. Girty:

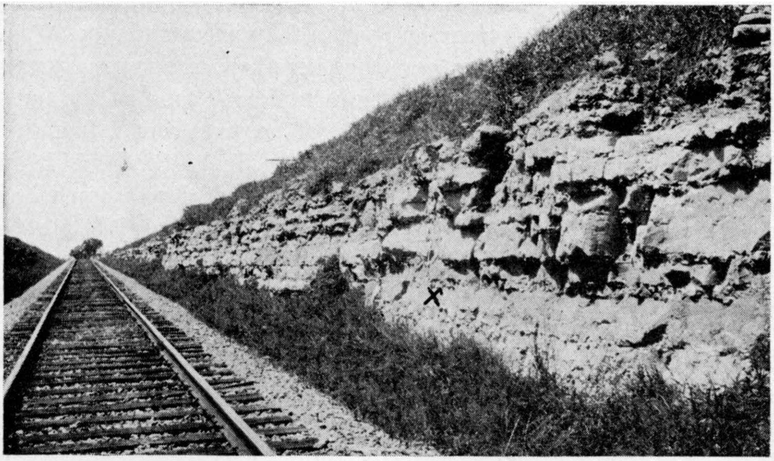
U. S. G. S. No. 6165. Collected 1 mile southeast of Silverdale, in the S. E. ¼, sec. 5, T. 35 S., R. 5 E.:

Derbya multistriata.
Pustula nebraskensis.
Composita subtilita.

FLORENCE FLINT.

Thick-bedded limestone interbedded with chert, ranging in total thickness between 11 feet at the state line to 35 feet in the northern part of the county, constitutes the Florence flint of the Chase group in Cowley county. The limestone beds are relatively soft, massive, rather coarse grained, light buff on freshly broken surfaces, and light gray to white on weathered surfaces; they are very fossiliferous, some of the beds, particularly in the lower part of the formation, being composed almost entirely of fossils, and are for the most part within themselves indistinguishable from the limestone beds of the Fort Riley limestone, the next overlying formation, although in most localities they lack the minute spotting so common in the lower part of the Fort Riley beds. The chert of the Florence flint, which constitutes its most striking characteristic, occurs in abundance throughout the formation interbedded with the limestone except in the lowermost 5 to 6 feet, which is largely limestone. (See Pl. IV.) The relation of the chert and limestone beds is shown in Plate VI. The chert is distinctly nodular, although in some layers the nodules are commonly joined, so that the layer of chert is continuous. In other layers, representing the more common occurrence, the chert

31. Prosser, C. S.: Jour. Geology, vol. 3, p. 773; 1895.



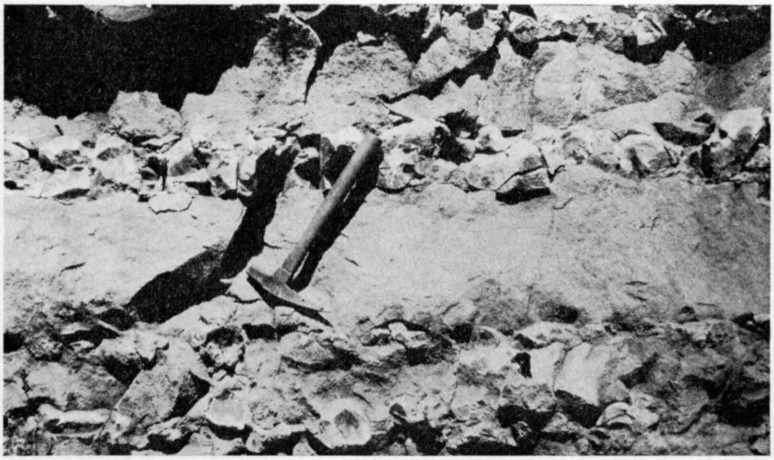


PLATE VI.—*Upper:* A part of the Florence flint in a cut about a mile east of Burden. *Lower:* Close-up view taken at point marked X in upper, to show nature of chert nodules in the limestone.

nodules are separated, and the intervening spaces are filled with limestone. The characteristic mode of occurrence of the chert is in layers interstratified with the limestone, the nodules ranging in thickness from 1 inch to 5 inches, but in some localities relatively small nodules of chert are irregularly distributed within the beds of limestone. The broken faces of a chert nodule are steel-gray and blue; the slightly weathered outer surface is tan and on further weathering becomes dark tan and rusty brown. As a general rule the chert is unfossiliferous. The chert beds are relatively more numerous in the middle part of the formation, where they occur in layers 4 to 10 inches apart. In the lower part the chert beds are typically separated by beds of limestone 6 to 18 inches thick, and in the uppermost part the intervening beds of limestone are about 1 foot thick. Near the south quarter corner of sec. 26, T. 33 S., R. 5 E., the Florence flint is exposed beneath a massive bed of weathered light-gray limestone 2½ feet thick, which forms the basal bed of the Fort Riley limestone. The uppermost 4 feet of the Florence flint is composed here of light-gray limestone containing a layer of chert nodules, separated by spaces averaging about a foot each; the next lower 7 feet contains chert bands about 6 inches apart and parallel with the bedding; below this are beds of light-gray to white weathered limestone 1 to 2 feet thick interbedded with a small amount of chert; and the lowermost foot of the formation is composed of somewhat shaly limestone and chert. The Florence flint has a total thickness of 18 feet at this locality.

The formation thins southward in Cowley county at a comparatively rapid rate; it is 35 feet thick a mile and a half northeast of Floral, near the northwest corner, in sec. 16, T. 31 S., R. 5 E.; 33 feet thick half a mile south of Floral; 18 feet thick near the south quarter corner of sec. 26, T. 33 S., R. 5 E.; and 11 feet thick on the Kansas-Oklahoma line in sec. 18, T. 35 S., R. 5 E. Fath[32] give its maximum thickness in the El Dorado district, 20 miles north of Cowley county, as 35 feet, and the total thickness exposed in the quarry face at Florence, Marion county, as 27 feet. The percentage of chert also appears to decrease southward, there being relatively little chert in the exposure in sec. 18, T. 35 S., R. 5 E., and almost none in a railroad cut on the state line in sec. 18, T. 35 S., R. 6 E., 6 miles farther east.

The upper part of the formation, including all but the lowermost 4 to 6 feet, breaks down more readily than the remainder and forms gentle slopes strewn with weathered sharp-edged fragments of chert averaging about 2 inches in diameter. The beds in the lowermost 4 to 6 feet weather to a white, somewhat rough surface and commonly form a low ledge like that shown in Plate IV, or crop out as two or three steps or rock terraces capping relatively steep slopes of the underlying Matfield shale. These lower beds form more continuous outcrops than any other part of the formation and are so widely exposed that they can be traversed almost continuously across Cowley county.

32 Fath, A. E., op. cit., p. 47.

The contact of the Florence flint with the Fort Riley limestone is drawn at the top of the uppermost chert-bearing bed. The base is drawn at the base of the chert-bearing limestone, which coincides in general with a lithologic change from limestone containing only a minor amount of shale to shaly limestone and shale. Weathered outcrops of the Florence flint resemble somewhat those of the Wreford and Foraker limestones, but it has several features that distinguish it from these other formations. In general its chert nodules are smaller than those in the Wreford, although this characteristic cannot be relied upon, as each formation varies widely in this respect; the Florence flint does not contain beds of limestone that weather in such distinctive vertically pitted white surfaces as are present in the Wreford; its chert nodules lack the fossil *Fusulina* so abundant and omnipresent in the Foraker chert; and except in the southernmost part of the county chert is much more abundant in the Florence flint than in the Foraker. On the whole the limestone beds of these two formations are quite similar in general appearance. Viewed in its relation to an extensive stratigraphic section the Florence flint is readily distinguished by its position, for it is the highest formation, stratigraphically, that contains chert in abundance, although some chert is present in the Herington limestone, and farther north in Kansas chert occurs near the top of the Doyle shale and in the Winfield limestone.[33]

The formation is reported in many well logs as sandstone or sandy limestone and in others as limestone not separated from the overlying Fort Riley beds. The Florence commonly produces water in wells, and springs are numerous along its outcrops.

The Florence flint exerts a marked influence on the surface features in Cowley county, as well as farther north in Kansas. It forms a broad upland surfaced by weathered chert and inclined westward at a low angle conforming to the regional dip of the strata. This upland surface is particularly well developed in northern Cowley county in Tps. 30 and 31 S., and Rs. 6 and 7 E., and thence northward across Butler county. It can be seen along the highway east from Rosalia, Butler county, to the rim of the Flint Hills west of Sallyards, and again for miles northeast of El Dorado on the Cassoday and Matfield Green highway.

Exposures of the lowermost 5 to 8 feet of the formation are comparatively common in Cowley county, but complete exposures of the formation are rare. The lower beds are extensively exposed

33. Prosser, C. S.; Jour. Geology, vol. 3, pp. 772-773, 1895; vol. 10, pp. 715-716, 1902.

along Timber creek in the northern part of the county, bordering Grouse creek on the west nearly the north-to-south length of the county, and on both sides of Silver creek throughout most of its course. About half of the total thickness of the formation is well exposed in a railroad cut about a mile east of Burden. The entire formation and its contact with the Fort Riley limestone above and with the Matfield shale below can be seen in a series of partial exposures along a gulch near the south quarter corner of sec. 26, T. 33 S., R. 5 E., just north of the road.

The Florence flint was named by Prosser[34] from its excellent exposures in the quarries about a mile northeast of Florence, Marion county, Kansas, on the McPherson branch of the Atchison, Topeka & Santa Fe Railway. Prosser describes it as being 20 to 22 feet thick, but Fath[35] states that it is 27 feet thick in the quarry face half a mile northeast of Florence.

FORT RILEY LIMESTONE.

The Fort Riley limestone is well known throughout Kansas and northern Oklahoma because of its extensive use as building stone. The typical rock of the formation is a very light buff limestone of granular texture, relatively soft and occurring in beds as much as 3 feet or even more in thickness. In Cowley county the formation has a total thickness of 45 to 55 feet, but the thick-bedded character of its individual strata does not continue throughout this thickness; in general the lowermost 15 to 20 feet is made up of thick beds, and the remaining upper part is composed of thin-bedded and somewhat shaly limestone alternating with thicker beds which in many localities form a series of low ledges or steps in the slopes. The granular appearance so characteristic of the thick-bedded part of the formation is produced by the occurrence of small white globular masses that are so abundant as to constitute nearly the whole of the rock. Numerous zones within the shaly parts of the formation, as well as a few zones within the thick-bedded portion, are abundantly fossiliferous. The lithologic change between the uppermost beds of the Fort Riley and the lower part of the overlying Doyle shale is not abrupt, but an upward gradation from limestone through a zone of shaly limestone to shale; consequently, the boundary between the two formations cannot be drawn with precision throughout much of the county. In the north half of the county a bed of limestone 2 to 3

34. Prosser, C. S.: Jour. Geology, vol. 3, p. 773, 1895; vol. 10, p. 714, 1902.
35. Fath, A. E., op. cit., p. 47.

feet thick that weathers very white and vesicular and characteristically forms shallow sink holes, like that shown in Plate III, constitutes the uppermost bed of the formation and forms a sharply defined upper boundary. This bed is particularly well exposed in the northern part of T. 30 S., R. 5 E., where there are numerous sink holes in the west half of section 6, north of the center of section 5, and west of the center of section 12.

This porous limestone bed does not persist in typical phase throughout Cowley county, however, but does extend far northward into Butler county. In central and southern Cowley county the upper boundary of the Fort Riley formation is drawn at the uppermost blocky bed of limestone of the interbedded limestone and limy shale zone. A section of the formation measured in T. 30 S., R. 6 E., in the northern part of the county, by Mr. Hudson, of the Empire Gas and Fuel Company, shows a total thickness of 45 feet. Matching this section, drawn up in graphic form, with others obtained in the southern part of the county, suggests that the bed of white porous limestone forming the top of the formation in northern Cowley county may be the limestone bed that occurs about 10 feet below the top (Nos. 7 and 8 of detailed section measured in sec. 6, T. 35 S., R. 5 E., given below) in the southern part of the county, the limy character of the uppermost 10 feet of the formation decreasing northward and merging into lithology typical of the Doyle shale. The meager information available from the reconnaissance study of the area merely suggests this correlation, and more detailed work such as the tracing of beds and the measuring of numerous stratigraphic sections distributed through the county would be necessary to establish the true relation of the individual beds in the zone adjacent to the Doyle-Fort Riley contact. The base of the Fort Riley limestone is more sharply defined; it is drawn above the uppermost limestone bed that contains chert in the Florence flint. The limestone of the Fort Riley is strikingly similar to that of the Florence flint, the absence of chert in appreciable quantity being the only distinguishing feature. The contact between the two formations is not clearly exposed in many localities, but its approximate position is determined by the upper limit of the residual chert fragments from the Florence flint that remain on weathered slopes.

Inasmuch as the upper part of the Fort Riley is composed in part of relatively soft rock that breaks down readily, the formation is rarely exposed in its entirety at any locality. Probably the best exposure seen is that near the old quarry in the SW¼, sec. 6, T. 35

S., R. 5 E., in the bluff formed by Arkansas river, where the following section was measured:

	Ft.	In.
Doyle shale.		
Fort Riley limestone:		
10. Relatively thin-bedded gray-white limestone. Caps the slope and floors the bench above. The uppermost 1½ feet of this bed weathers in a blocky ledge in many exposures	3	..
9. Covered slope	7	6
8. Gray-white limestone; weathers in white nodules	1	..
7. Light-buff to gray limestone; weathers to a soil-covered slope below No. 8	2	6
6. In part covered. Uppermost foot is thin-bedded limestone, and lowermost foot is limy shale	3	..
5. Thick-bedded buff granular limestone. Lower 3 feet soft and in most exposures forms covered slope. Upper 3 feet forms ledge	6	..
4. Covered slope	7	6
3. Massive buff, granular limestone	5	..
2. Shaly limestone; breaks down readily	3	..
1. Buff granular limestone in massive beds 3 to 6 feet thick	17	6
Total Fort Riley limestone	56	..
Florence flint.		

The Fort Riley limestone together with the Florence flint (not differentiated on the geologic map, Plate I) occupy a greater part of the surface of Cowley county than any other formation, being present throughout a broad band that extends from north to south through the central part of the county, containing most of Rs. 4, 5 and 6 E. and the northern part of R. 7 E. The Fort Riley is particularly well exposed in the bluffs immediately east of Arkansas river in T. 35 S., R. 5 E., in bluffs on the east side of Walnut river and on both sides of Silver creek in Ts. 33 and 34 S., R. 5 E.; in bluffs on the east side of Walnut river in T. 33 S., R. 4 E.; and on the south side of Timber creek in T. 31 S., Rs. 5 and 6 E. It is extensively exposed far beyond the limits of Cowley county northward across Kansas and southward 70 miles into Oklahoma.[36]

The type locality of the Fort Riley limestone is Fort Riley, Geary county, Kansas. The name was first applied by Swallow[37] to a series of thick beds of limestone constituting a thickness of 8 to 10 feet that form a prominent ledge in the vicinity of Fort Riley and Junction City. These strata were later correlated by Prosser[38] with those exposed on Cottonwood river near Florence, and the term Fort

36. Miser, H. D.; Geologic map of Oklahoma: U. S. Geol. Survey; 1926.

37. Swallow, G. C.: Preliminary report of the Geological survey of Kansas, p. 14; 1866.

38. Prosser, C. S.; Revised classification of the upper Paleozoic formations of Kansas: Jour. Geology, vol. 10, pp. 714-715; 1902.

Riley limestone was expanded to include not only the thick-bedded limestone that occurs a few feet above the Florence flint, but also the beds of shaly limestone that immediately overlie and underlie the thick beds, making a total thickness there of a little more than 40 feet. Prosser[39] had previously designated the thick-bedded portion as the Florence limestone in the following section taken from exposures near Florence and Fort Riley:

	Ft.	In.
Buff shaly limestone	22	..
Massive buff limestone. Florence limestone	5+	..
Buff shaly limestone	15	..

A comparison of the Cowley county section with Prosser's description of these strata on Cottonwood and Kansas rivers farther north in Kansas indicates that the principal features of the formation persist southward to Cowley county. Prosser[40] describes the Fort Riley limestone as "a series of massive buff limestone, changing to thin-bedded and shaly strata in the upper part of the formation, which have a total thickness of 40 feet or more." Fath[41] describes the formation in Butler county, adjacent to Cowley county on the north, as having a threefold character, being composed of thick-bedded limestone in the lower and upper thirds and thin-bedded limestone in the middle third.

The following fossils collected from the Fort Riley limestone, in sec. 1, T. 35 S., R. 5 E., were identified by G. H. Girty, of the United States Geological Survey:

U. S. G. S. No. 6154*a*:

Fusulina sp.
Echinocrinus sp.
Derbya multistriata?
Meekella striaticostata.
Productus semireticulatus.
Composita subtilita.
Deltopecten occidentalis.
Deltopecten mccoyi.

DOYLE SHALE.

The steep slopes so persistently present below the Winfield limestone and the gently rolling bench land into which they merge below are formed by a relatively thick body of soft rocks known as the Doyle shale. This formation is composed of green, maroon, varicolored, greenish-gray, and tan clay shale, a minor part being limy, and a few thin beds of limestone. In general the limy part

39. Prosser, C. S.; The classification of the upper Paleozoic rocks of central Kansas: Jour. Geology, vol. 3, p. 773; 1895.
40. Prosser, C. S.: Jour. Geology, vol. 10, p. 714; 1902.
41. Fath, A. E.; The El Dorado oil and gas field: Kansas Geol. Survey Bull. 7, pp. 48-49; 1921.

of the formation is confined to the lowermost 25 to 30 feet and the uppermost 10 feet; the remaining middle part is composed mostly of clay shale. The most conspicuous limestone unit occurs in the lower part of the formation, from 25 to 30 feet above the base, and is prominently developed only in the southern part of the county, some of the best exposures being near Silverdale, specifically in the W½, sec. 6, T. 35 S., R. 5 E. Throughout the county, however, a limy zone occurs in the approximate stratigraphic position of this limestone unit, 20 to 35 feet above the base of the formation. This zone is slightly harder than the overlying and underlying beds, so that it forms a slight shoulder in the slope. Prosser[42] mentions the presence of a thin grayish limestone about 20 feet above the base of the Doyle shale in central Kansas, and Fath[43] describes a limestone which he called the Towanda limestone bed as being 35 feet above the base of the Doyle in the El Dorado district in Butler county. In Cowley county the lowermost 20 to 35 feet of the Doyle shale is composed of tan clay shales, in part limy, and thinly laminated shaly limestone.

The uppermost few feet of the formation consists of argillaceous limestone and limy shale containing abundant small concretions ranging between one-eighth and one-half inch in diameter. These concretions are present at every locality where this part of the formation was seen exposed and constitutes a diagnostic feature of this part of the section. The upper part of the Doyle formation is extremely limy in the northwestern part of the county, a few exposures showing beds of limestone 2 to 4 feet thick interbedded with shale in the uppermost 20 feet. Elsewhere in the county, however, this division of the formation is composed largely of shale containing a few thin beds of limestone. A detailed section of the upper part of the Doyle shale measured near the southwest corner of sec. 35, T. 33 S., R. 4 E., follows. The uppermost part of this section is shown in Plate VII:

	Ft.	In.
Winfield limestone.		
Doyle shale:		
Shaly limestone, containing concretions one-eighth to one-half inch in diameter and small fossils; weathered light tan	1	4
Limy shale, containing an abundance of small concretions, weathered light tan	1	4
Thin-bedded shaly limestone and limy shale. The uppermost 8 inches contains abundant small lime concretions	4	..

42. Prosser, C. S., op. cit. (1902), p. 715.
43. Fath, A. E., op. cit., p. 54.

Doyle shale—*Concluded:*	Ft.	In.
Limy shale with a few thin layers of shaly limestone, weathered light tan	3	..
Green clay grading upward into gray and light-tan shale	6	6
Maroon clay containing a thin bed of green clay 3½ feet beneath the top	7	6
Base concealed.		

The following section of the entire Doyle formation was measured with a hand level near the east quarter corner of sec. 1, T. 35 S., R. 4 E.:

Winfield limestone.		
Doyle shale:	Ft.	In.
Grayish-tan limy weathered shale, greenish in lower part, and thin-bedded shaly limestone; increases in lime content upward. Contains fossils and abundant lime concretions one-eighth to one-half inch in diameter in uppermost 4 feet	11	..
Maroon clay, mottled with green in lowermost part	27	..
Green clay, largely noncalcareous. A bed of dark limestone 1 inch thick, made up almost entirely of shells, occurs 4 feet above base	19	..
Covered gentle slope, probably mostly shale	10	..
Light-buff to light-gray cherty limestone. Contains abundant fossils that appear to be of one species. Locally forms a ledge; weathers to a fairly rough surface	2	..
Sod-covered slope	23	..
Total Doyle shale	92	..
Fort Riley limestone.		

The total thickness of the Doyle shale shown here is slightly greater than that measured elsewhere in the county. A section measured by hand level in the NW¼ NE¼, sec. 30, T. 33 S., R. 5 E., shows a thickness of 83 feet; another measured near the south quarter corner of sec. 26, T. 33 S., R. 4 E., shows 83 feet, and still another measured in the NE¼, sec. 23, T. 33 S., R. 4 E., shows it to be 78 feet thick. Considerable variation in thickness at relatively closely spaced localities within Cowley county has been noted also by geologists of the Roxana Petroleum Corporation.[44] The thickness of the formation was not measured in northern Cowley county, but Fath[45] gives a total thickness ranging between 90 and 105 feet in the El Dorado district, 20 to 25 miles north of the northern boundary of Cowley county. Prosser[46] shows this formation as being 62 feet thick in Chase county, but if we add the 17 feet of beds that he

44. Jones, E. L.; personal communication.

45. Fath, A. E.; Geology of the El Dorado oil and gas field: Kansas Geol. Survey Bull. 7, pp. 54-56; 1921.

46. Prosser, C. S.; The classification of the upper Paleozoic rocks of central Kansas: Jour. Geology, vol. 3, pp. 772, 773; 1895.

included in the Winfield below the thick-bedded upper limestone believed to be alone the correlative of the Winfield limestone of Cowley county, the total thickness of the Doyle shale in Chase county is 79 feet.

Clean exposures of the entire formation at one locality were not seen, and in general exposures are poor except for the uppermost 10 to 15 feet, which is extensively exposed because of its position immediately beneath the ledge forming Winfield limestone. The middle part of the formation is rarely exposed, probably the best exposure seen being that lying below a southward-projecting prong capped by the Winfield limestone near the east quarter corner of sec. 1, T. 35 S., R. 4 E. The limestone unit 25 to 30 feet above the base of the formation is exposed rather widely in the southernmost part of the county, but elsewhere forms only a slight shoulder in the grassed slope. The only exposure of the lowermost beds of the formation seen in the county is near the south quarter corner of sec. 26, T. 33 S., R. 4 E., back of the buildings on the George Howard farm.

Prosser[47] described the strata composing the Doyle shale as "yellowish, chocolate, and greenish shales with occasional layers of thin limestone" and designated the unit as "No. 17" of the stratigraphic section given in his early report, but later applied to it the name Doyle shale, from exposures "at various places in the Doyle creek valley to the southwest of Florence," in southern Marion county.[48]

The following fossils, collected from the Doyle shale in Cowley county, were identified by G. H. Girty:

U. S. G. S. No. 6145*b*. Collected near the east quarter corner of sec. 1, T. 35 S., R. 4 E., from the limestone bed 28 feet above the base of the formation:

Pleurophorus subcostatus?

U. S. G. S. No. 6154. Same locality as above. Collected 53 feet below the top of the formation: *Myalina perattenuata?*

U. S. G. S. No. 6150. Collected in railway cut in SE ¼, sec. 19, T. 32 S., R. 4 E., from uppermost few inches of formation:

Spirorbis sp.
Derbya multistriata.
Allerisma terminale.
Schizodus sp.
Deltopecten occidentalis.
Pleurophorus sp.

U. S. G. S. No. 6151. Collected in road cut a little way south of the north quarter corner of sec. 32, T. 31 S., R. 4 E., from a thin limestone bed 2 feet beneath top of formation:

Derbya multistriata.
Composita subtilita.

47. Prosser, C. S.: Jour. Geology, vol. 3, pp. 772-773; 1895.
48. Prosser, C. S.: Jour. Geology, vol. 10, p. 715; 1902.

WINFIELD LIMESTONE.

The uppermost formation of the Chase group, the Winfield limestone, forms probably the most conspicuous outcrop of all the limestone units exposed in Cowley county. It consists of 10 to 11 feet of massive limestone, generally occurring in two beds, that is light buff on freshly broken surfaces and light to dirty gray on weathered surfaces. The unweathered rock is coarse and has a granular texture, constituting a distinctive characteristic in core-drilled specimens. It characteristically weathers to a somewhat siliceous, sharply rough pitted surface. The roughened surface is covered by an abundance of silicified fragments of fossils that have been etched into relief by the weathering away of the surrounding limestone substance. A myriad of fine rod-shaped fragments and small spines, fragments of lacelike Bryozoa, and a few spiny-backed bivalve shells about 1½ inches in diameter occur on the surface of weathered exposures of the rock. In most exposures showing the entire thickness of the formation the pitted character of the rock has its greatest development about 3 or 4 feet below the top of the formation. In this zone, which ranges from 1 inch to 1½ feet in thickness, the greater part of the rock is dissolved and removed, leaving only a course honeycomb or network to support the upper bed; and in a cliff where the rock has been somewhat weathered this porous zone everywhere makes a deep indentation in the cliff face. The formation is thus split into two beds, which in many places crop out as two ledges; in much of the area of its outcrop, however, the upper bed is not exposed, the outcropping ledge of the Winfield being formed by the lower bed alone.

According to Prosser[49] the Winfield limestone is characterized in east-central Kansas by large irregular brown-weathering concretions, and Fath[50] described the concretionary character of the Winfield as being locally developed in the vicinity of El Dorado, in Butler county. The only locality in Cowley county where concretions were seen in the Winfield is 4 miles due north of Winfield, in the SW¼ SE¼, sec. 33, T. 31 S., R. 4 E., which is probably the locality referred to by Prosser[51] as containing concretions typical of those in the Winfield limestone of east-central Kansas. At the locality 4 miles north of Winfield the concretions are of flattish, irregular shapes, commonly 3 to 5 inches thick and 6 to 18 inches wide, com-

49. Prosser, C. S.: Jour. Geology, vol. 3, p. 772; 1895.

50. Fath, A. E.; Geology of the El Dorado oil and gas field: State Geological Survey of Kansas, Bull. 7, p. 59; 1921.

51. Prosser, C. S.; The upper Permian: Kansas Univ. Geol. Survey, vol. 2, p. 64; 1897.

posed of limestone made up almost entirely of fossil fragments. The concretions are embedded in the massive limestone of only the upper bed of the Winfield and weather a deep rusty-brown color, in sharp contrast with the gray of the surrounding rock. They are more resistant than the surrounding limestone and so remain scattered upon the soil-covered slopes that recede from the ledge formed by the lower bed of the Winfield. An abundance of dull-brown weathered slabs 2 to 4 inches thick and 6 to 10 inches wide lie scattered upon the sloping surface below the Winfield limestone outcrop in the northern part of T. 32 S., R. 5 E.; these slabs are probably weathered out of the Winfield, but none were seen in place. Throughout most of Cowley county, however, the Winfield limestone is typically lacking in concretions, and the examples described above are of only local occurrence and constitute exceptions to the usual characteristics of the formation in this region.

The Winfield limestone is clearly exposed in the road cut and quarry immediately west of the Walnut river bridge on West Ninth street west of Winfield, where the following section was measured:

	Ft.	In.
Luta limestone (lower part):		
White or very light gray, somewhat argillaceous limestone, in beds ½ inch to 3 inches thick	8	..
Winfield limestone:		
Massive, dull-gray limestone; surface made rasplike by abundant silicified fossil fragments, fine rods, spines, and an occasional spiny-backed shell. A few small weathered pits are present in an irregular horizontal band near middle	3	..
Honeycombed siliceous limestone with abundant deep pits partly filled with residual red-brown clay; forms a deep notch in cliff face	1	6
Massive limestone, dull gray; surface has a rasplike roughness as a result of a mosiac of silicified fossil fragments of slender rods and spines and an occasional spiny-backed bivalve shell that have been weathered out in relief. The uppermost 2 feet contains relatively abundant weathered pits from ½ inch to 1½ inches in diameter and depth. There are likewise a few pits in the surface of the lower part of the bed, but they are shallower and do not produce so roughened a surface. Forms ledge,	5	6
Total Winfield limestone	10	..
Doyle shale.		

This formation is well exposed also about half a mile northwest of the above-described locality, in the face of an old quarry and in a cut made by the Atchison, Topeka & Santa Fe Railway Company a few hundred yards west of Winfield Junction, in the SW¼, sec. 20, T. 32 S., R. 4 E. The section measured there is similar to that described for the Ninth street locality, except that the contact of the Winfield and Doyle and the uppermost few feet of the Doyle shale is clearly exposed. Argillaceous limestone containing abundant small concretions half an inch in maximum diameter, those measuring about a quarter of an inch being the most numerous, forms the uppermost 2 feet of the Doyle shale and constitutes transition beds between a clay shale below and the massive Winfield limestone above. In recently cut exposures the upper half of the concretionary bed appears as a well-consolidated limestone not greatly dissimilar to the overlying beds. Such an exposure naturally raises the question as to the proper position for the Winfield-Doyle contact. In records of churn-drilled wells the Luta (?) limestone, about 25 feet thick, the 10 to 11 feet of massive limestone (Winfield), and the argillaceous limy beds below are all logged as one unit of limestone. In exposures where the 10-foot bed of massive limestone (Winfield) and the underlying argillaceous limestone (Doyle) have been subjected to a considerable amount of weathering the division between the two is sharply defined. The argillaceous limestone breaks down and weathers more readily than the overlying massive bed, which thus forms an overhanging ledge. The concretionary character of the lower rocks is also accentuated by weathering, because the concretions are more resistant than the matrix that contains them and so weather out upon the surface in abundance. Because of this marked lithologic difference manifest by weathering the Winfield limestone is here identified as the massive cliff-forming limestone, and the underlying concretionary argillaceous limestone and limy shale are allocated to the Doyle shale.

The contact of the Winfield limestone and Doyle shale is exposed at many places in the western part of Cowley county, but only a few of them will be mentioned—namely, near the center of sec. 29, T. 31 S., R. 4 E., on the Winfield-Augusta highway; and on the boundary between secs. 4 and 5, T. 30 S., R. 4 E., on the same highway north of Rock. In the southern part of the county it is exposed in a comparatively recent road cut (and the rocks are consequently not so greatly weathered) in the Big Hill about 5 miles east of Arkansas City on the Arkansas City-Joplin highway—specifically near the west quarter corner of sec. 36, T. 34 S., R. 4 E. A view taken at this locality is shown in Plate VII, the lower picture showing the contact as it is exposed in the road cut in the SW¼, sec. 35, T. 33 S., R. 4 E., where the rocks have been subjected to weathering for a long time. The head of the hammer shown in both views marks the contact of the two formations. In the latter locality weathering has accentuated the lithologic differences between the massive thick beds and

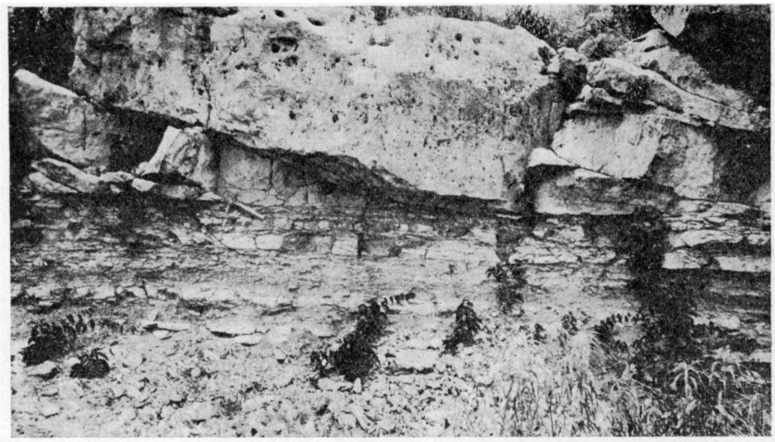


PLATE VII. *Upper:* Wreford limestone and uppermost part of Doyle shale. Hammer head marks the contact of the two formations. View taken at the big hill 5 miles east of Arkansas City on the Joplin highway. *Lower:* Lower part of the Winfield limestone and uppermost part of Doyle shale in SW¼, sec. 35, T. 33 S., R. 4 E. Hammer head marks the contact of the two formations.

the underlying more argillaceous beds. The view is typical of the contrast between the two formations in weathered exposures.

Although the contact of the Winfield and Luta limestones is rarely well exposed, it is sharply defined by an abrupt change from the massive granular dull-gray rock of the Winfield to a thin-bedded fine-grained white to bluish-white, somewhat argillaceous limestone of the Luta.

The Winfield limestone is well exposed throughout most of its outcrop in the western part of Cowley county, as shown on Plate I. Because of its excellent exposures it has been extensively used as a key bed in the structural mapping done by the operating oil companies, so that detailed maps of most of its outcrop were available and were used, supplemented by rather thorough review in the field, in compiling the geologic map (Pl. I); the boundaries of this formation as shown are consequently believed to be fairly accurately drawn. The formation owes its excellent exposures to its stratigraphic situation between two relatively thick, soft shale units—the Enterprise shale above and the Doyle shale below; it is resistant compared with the shales and as a result forms a prominent ledge capping the steep slopes formed by the Doyle shale. Its outcropping edges have been intricately dissected, so that its outcrop line presents a very irregular pattern characterized by numerous isolated patches, which represent flat-topped buttes, rising 75 feet or more above the surrounding region; these buttes are particularly abundant in the vicinity of Winfield, both northeast and southeast of the town, and in the eastern part of the town proper; the old reservoir, Richardson Hall of Southwestern College, and the State Hospital for the Feeble-Minded are built on buttes capped by the Winfield. The formation makes a prominent escarpment skirting the Walnut river bottoms on the west throughout the river's course across Cowley county; it is prominently exposed east of the Winfield-Augusta highway that trends north from Winfield from a point 2 miles north of Winfield northward nearly to Rock and again north of Rock. It the southern part of the county its outcrops are particularly conspicuous throughout much of T. 34 S., R. 4 E., and the western part of R. 5 E. Typical outcrops occur north of the Arkansas City-Joplin highway 2 to 7 miles east of Arkansas City. One outcrop of the Winfield in the northwestern part of the county and another a short distance west of the county boundary are of interest because of their structural significance. In the E½, sec. 14, T. 30 S., R. 3 E., the formation dips westward at a low angle beneath the overlying beds, but it reappears in the N½, sec. 10, where it has been elevated by a small dome-shaped fold. The other outcrop is on the Churchill anticline, about in sec. 26, T. 31 S., R. 2 E., just west of Arkansas river and the Churchill pool, where the Winfield limestone lies several feet above the river bed and crops out in the bluff west of the railroad track. This exposure is about 5 miles west of the westernmost outcrop of the formation in Cowley county.

On a much-weathered surface where the outcrop of the formation is represented by limestone fragments projecting out of the soil the Winfield resembles the Foraker limestone of the Wabaunsee group and certain beds of the Fort Riley limestone. The beds of each of these formations weather to very light gray, irregularly shaped, more or less flat nodular forms containing pit holes through the rock. Such outcrops of the Winfield can be distinguished from the Foraker by the absence of small sharp-edged fragments of tan-colored chert strewn upon the surface and containing large *Fusulina* in abundance, which are always present upon a weathered surface of the Foraker; the Winfield has a little grayer color, which distinguishes it from the white weathered surface of the Fort Riley; and its etched fossil fragments of slender rods and spines are most distinctive. The abundant small concretions that occur in the uppermost part of the Doyle shale, immediately beneath the Winfield limestone, constitute the most certain criterion for its identification, because they are present at all exposures seen throughout the county and were not found elsewhere in the section.

Prosser[52] described and named the Winfield limestone in 1897 from its exposures in the bluffs of Walnut river west of Winfield and definitely correlated it with a limestone which he had previously described and called "Marion concretionary limestone,"[53] from its exposures near Marion, Marion county, Kansas. In 1910 Prosser[54] again described this limestone and definitely substituted the name Winfield formation for "Marion flint and concretionary limestone," stating that the formation consisted of "a cherty limestone at the base with a massive concretionary one at the top, the two separated by yellowish shales," with a total "thickness of about 25 feet." It appears probable from a correlation of Prosser's central Kansas section of the Chase group and a section of the same group as exposed in Cowley county that the Winfield limestone as described herein

52. Prosser, C. S.; The upper Permian: Kansas Univ. Geol. Survey, vol. 2, p. 64; 1897.

53. Prosser, C. S.; The classification of the upper Paleozoic rocks of central Kansas: Jour. Geology, vol. 3, p. 772; 1895.

54. Prosser, C. S.; Revised classification of the upper Paleozoic formations of Kansas: Jour. Geology, vol. 10, pp. 715, 716; 1910.

corresponds to the "massive concretionary" limestone that Prosser described as being about 10 feet thick and occurring at the top of his Winfield formation. The lower part of his Winfield formation may then correspond to the uppermost part of the Doyle shale as described herein, the lower cherty limestone being absent in southern Kansas.

The following fossils collected from Reservoir Hill, in the eastern part of the town of Winfield, were identified by G. H. Girty:

U. S. G. S. No. 6149:

Echinocrinus aff. *E. cratis.*
Spirorbis sp.
Stenopora sp.
Rhombopora lepidodendroides.
Derbya multistriata?
Composita subtilita.

SUMNER GROUP.

All strata lying between the top of the Winfield limestone and the "Red Beds" are here included in the Sumner group. This group includes, from the base upward, the Luta limestone, the Enterprise shale, the Herington limestone, and the Wellington formation. As thus defined the terms "Marion formation," "Pearl shale," and Abilene conglomerate of former Kansas Geological Survey reports[55] are not used. Only the lower part of the Sumner group—the beds up to and including a little less than 100 feet of the Wellington—is exposed in Cowley county, but the entire unit underlies the region several miles west of the county. The group is characterized by a large percentage of soft shale, with minor amounts of limestone, decreasing in abundance upward; beds of gypsum are abundant in parts of the group, and in central Kansas it includes thick beds of salt.

LUTA LIMESTONE.

Overlying the Winfield limestone and composing the basal formation of the Sumner group is 20 to 25 feet of thin-bedded light-blue limestone that weathers chalky white and occupies the stratigraphic position of the Luta limestone, described by Beede[56] as intervening between the Enterprise and Winfield formations in the vicinity of Marion, Marion county, Kansas, about 50 miles north of Cowley county. Inasmuch as this limestone is exposed in only a few localities in Cowley county and does not constitute a mappable unit it is not separated from the overlying Enterprise shale on the geologic map (Pl. I), where it is for convenience treated as a member of the

55. Moore, R. C., and Haynes, W. P.; Kansas Geol. Survey Bull. 3; 1917. Moore, R. C.; Kansas Geol. Survey Bull. 6, pt. 2; 1920.

56. Beede, J. W.; Formations of the Marion stage of the Kansas Permian: Kansas Acad. Sci. Trans., vol. 22, pp. 248-256; 1908.

Enterprise shale. It is in part abundantly fossiliferous, particularly about 3 and 5 feet above the base; the uppermost 5 feet is shaly and becomes less limy upward, grading into greenish shale above. A short distance west of the west boundary of Cowley county, just west of Arkansas river and the Churchill oil pool, about in sec. 26, T. 31 S., R. 2 E., the Winfield limestone, Enterprise shale, and Herington limestone are exposed; there the thin-bedded Luta limestone is 25 feet thick, although in the uppermost 10 feet limestone is alternately bedded with shale, and the limestone beds are increasingly shaly upward. The entire thickness of the formation is rarely exposed, but exposures of the beds occupying the lowermost few feet were seen in road-drainage ditches and excavations at a number of localities in the county.

The following fossils collected from the Luta limestone were identified by G. H. Girty:

Fucoid.
Delocrinus. sp.
Fenestella sp.
Rhombopora lepidodendroides?
Derbya multistriata.
Echinocrinus aff. *E. cratis.*
Septopora sp.
Productus semirecticulatus.
Composita subtilita.
Parallelodon tenuistriatus?
Myalina sp.
Pseudomonotis sp.
Pleurophorus? sp.
Bellerophon? sp.

ENTERPRISE SHALE.

The Enterprise shale is composed largely of greenish and blue shale beds occurring between the Luta and Herington limestones. Two thin but persistent beds of limestone separated by 3 to 4 feet of shale occur in the upper part of the Enterprise throughout its outcrop in the southern part of Cowley county. The upper one, which weathers light tan, is 8 to 10 inches thick and lies between 6 and 9 feet beneath the top of the formation. The lower part of this limestone bed and the shale immediately below it are crowded with fossil brachiopods. The lower limestone bed is 1 to 2 feet thick and weathers into a chippy ledge containing abundant specimens of a flattish circular form about the size of a half dollar. These specimens are probably masses of fossil calcareous algæ covering shells. The fossil forms associated with these limestone beds, particularly those of the lower bed, serve excellently to identify them in several partial exposures in the southern part of the county.

Because of the relative abundance of soft, easily decomposed rocks the Enterprise shale forms long, gently graded slopes, making the determination of its total thickness difficult to obtain. The few sections measured indicate that it varies considerably in thickness within the county; two measured sections in the southwestern part of the county, one about a mile southeast of Arkansas City, in the SW¼, sec. 5, T. 35 S., R. 4 E., and the other about a mile northeast of Arkansas City, near the center of sec. 18, T. 34 S., R. 4 E., show a thickness of about 52 feet, but a core-drill record of the Roxana Petroleum Corporation shows a thickness of 36½ feet in the north-central part of T. 34 S., R. 3 E. A hand-level section measured in the northwestern part of the county, in sec. 3, T. 30 S., R. 3 E., shows a total thickness of 60 feet for the Enterprise shale and Luta limestone. A variation in thickness of the part of the formation above the thin limestone beds in the upper part and the appearance of a number of cores from borings made in this region by the Roxana Petroleum Corporation[57] suggest the presence of an unconformity, probably of slight relief and perhaps local extent, between the Enterprise shale and the Herington limestone.

The base of the Enterprise shale in Cowley county is indefinitely marked by a gradational change downward from shale beds through limy shale to the soft, thin-bedded limestone of the Luta. At the top the change from the soft shale beds of the uppermost part of the Enterprise to the thick-bedded limestone of the Herington is a rather definite boundary.

Throughout most of the area of their outcrop in Cowley county the Enterprise shale and Luta limestone occupy a gently graded soil-covered slope between the ledge below formed by the Winfield limestone and one above formed by the Herington limestone. The ledge-forming ability of the Herington is not so pronounced as that of the Winfield, and in parts of the county the Herington forms not the slightest interruption in the general lay of the surface. The outcrop of the Enterprise and Luta forms a relatively narrow band in the eastward-facing slope on the west side of Walnut river from the northern boundary of the county southward to Arkansas City and continues south of Arkansas river, occupying an even narrower strip of the surface. In sec. 10, T. 30 S., R. 3 E., and near Arkansas City, both north and south of Arkansas river, the slopes are exceptionally steep, and parts of the Enterprise are clearly exposed, although throughout most of the area occupied at the surface by this formation the beds are entirely concealed beneath a mantle of soil. Parts of the formation are exposed southwest of Winfield, in the northwestern part of the Country Club's grounds. The most complete exposure seen is that in the steep slope below the east end of the mu-

57. Jones, E. L.; personal communication.

nicipal golf course north of Arkansas City, near the center of sec. 18, T. 34 S., R. 4 E., where the following section was measured by hand level:

	Ft.	In.
Herington limestone, capping the slope.		
Enterprise shale:		
Buff limy shale; a very shaly limestone 4 inches thick about 3 feet above the base	5–9	..
Compact limestone; weathers buff. Abundant brachiopods (*Composita subtilita*) in its lower part	..	10
Buff weathered shale, limy; abundant brachiopods in uppermost few inches	3	..
Limestone; weathers to very light buff and breaks down into small chips, with numerous forms that are flattish circular and about the size of a half dollar, covered with fossil algæ, and constituting its most striking characteristic	1	..
Light-tan weathered shale	1	4
Greenish-gray shale	7	..
Purplish-gray shale	2	..
Greenish-gray shale	8	..
Bluish-gray shale	3	..
Limy shale; weathers into white chips	1	..
Greenish and bluish-gray shale grading into weathered buff shale in lower part	16	6
Total Enterprise shale	52	8
Luta limestone:		
Covered slope	7	6
Thin-bedded chalky-white weathered limestone	1	..
Covered but known from near-by exposures to be thin-bedded bluish-gray limestone, in part very fossiliferous	9	..
Winfield limestone, 10 feet thick, exposed in the railroad cut at the base of the slope.		

The Roxana Petroleum Corporation, through E. L. Jones, courteously furnished the following record of a core-drill hole bored in the northern part of T. 34 S., R. 3 E.:

	Ft.	In.
Herington limestone:		
16. Limestone, porous in upper part and fossiliferous below	10	..
Enterprise shale:		
15. Blue shale	1	..
14. Green shale	8	..
13. Blue shale	3	..
12. Limy shale	3	..
11. Limestone	2	..
10. Blue shale	2	..
9. Limy shale and limestone	2	..
8. Blue shale	6	6
7. Limestone	2	..
6. Green shale	7	..
Total Enterprise shale	36	6

	Ft.	In.
Luta limestone:		
5. Banded limy shale	5	6
4. Limy shale and limestone	3	..
3. Limestone with some shale	8	..
Winfield limestone:		
2. Granular limestone	9	6
Doyle shale:		
1. Limestone containing abundant small concretions; referred to as "birdseye maple" limestone	5	..

The Enterprise shale was named by Beede[58] from exposures near Enterprise, Dickinson county, Kansas.

The following fossils collected from the Enterprise (Nos. 11 and 13 of section quoted above) were identified by G. H. Girty:

U. S. G. S. Nos. 6152 and 6152*b*. Collected in the N.W. ¼, sec. 32, T. 31 S., R. 4 E.:

Spirorbis sp.
Septopora biserialis.
Derbya multistriata.
Composita subtilita.
Deltopecten occidentalis.
Calcareous algæ (?) embedding various fossils.

HERINGTON LIMESTONE.

Above the Enterprise shale is a unit of light-buff limestone and dolomite about 30 feet thick known as the Herington limestone. Only the lowermost 3 to 6 feet, composed of fossiliferous limestone, crops out in most localities, commonly forming a ledge in the slope. The upper two-thirds of the formation has the appearance of fine-grained tan sandstone that is rarely exposed; in one locality seen it is cross-bedded, the laminæ being very thin and deviating at a low angle from the true bedding planes; tests of outcrop samples and a core sample from a drill hole showed that this upper part of the formation is dolomite. Observations at a few exposures indicate that the separation of the limestone and dolomite is not a sharply defined boundary but a zone of gradation from limestone below to dolomite above. The dolomite is relatively soft and is rarely exposed, but the limestone constitutes the ledge-forming part of the formation. Numerous geodes of calcite 1 to 6 inches in diameter, the larger ones ellipsoidal and the smaller ones spherical, are distributed through beds of dolomite, where they are exposed beside the road on the line between the SW¼, sec. 26, and the NW¼, sec. 35, T. 34 S., R. 3 E. The geodes have walls only one-fourth to one-half inch thick composed of calcite crystals, and are embedded

58. Beede, J. W., op. cit., p. 253.

in sugary-textured, relatively soft dolomite that gives no visible reaction with cold hydrochloric acid. The exposure here reveals a total thickness of 20 feet of dolomite beds; the lower 12 feet is thin bedded and contains most of the geodes; the upper 8 feet is thick bedded. Spherical and irregularly shaped small nodules of white, drusy chert characterize weathered exposures of the Herington; the chert nodules are commonly 2 to 3 inches in diameter and have crenulated outer surfaces closely resembling heads of cauliflower. Nodules were not seen in place within the formation, but they lie everywhere strewn upon the surface formed by the upper part of the Herington. The similarity of shape and size between the calcite geodes seen in the dolomite beds and the chert nodules suggests that the chert may represent replacement of the calcite. Inasmuch as no chert nodules of similar shape and appearance occur in this region in other strata of the exposed stratigraphic succession, these nodules served excellently to identify the Herington in areas of poor exposures.

The Herington limestone constitutes one of the most important stratigraphic units in this part of Kansas, because it is the "key bed" through which hundreds of cored holes have been drilled to obtain information concerning the attitude of the strata throughout an extensive region west of the outcrop of the formation. Common practice is to drill down within a few feet of the Herington with a fishtail bit, which does not preserve a core, and then drill through the Herington with a bit equipped for coring.

The Herington limestone was named by Beede[59] from exposures in and near Herington, Dickinson county, and correlated with exposures near Winfield and Arkansas City, Cowley county, and other exposures in Noble county, Oklahoma. Beede describes the formation as being composed of a lower resistant fossiliferous limestone, with softer flaggy beds containing geodes above.

The following fossils collected near the center of sec. 18, T. 34 S., R. 4 E., from the ledge-forming limestone beds were identified by G. H. Girty:

U. S. G. S. Nos. 6148 and 6148*b*:

Septopora biserialis.	*Pleurophorus calhouni.*
Crania modesta.	*Pleurotomaria* sp.
Composita subtilita.	*Myalina wyomingensis?*
Deltopecten occidentalis?	*Pseudomonotis equistriata.*

59. Beede, J. W.; Formations of the Marion stage of the Kansas Permian: Kansas Acad. Sci. Trans., vol. 22, p. 253, 254; 1908.

WELLINGTON FORMATION (REDEFINED).

Strata with an aggregate exposed thickness of about 80 feet occur above the Herington limestone in the western part of Cowley county; almost this total thickness is occupied by soft clay shale. Although the unit contains a few beds of limestone there is no individual bed or group of beds that can be readily distinguished at the surface throughout any but exceedingly local areas. In short, this group of beds does not lend itself to separation into smaller units in Cowley county. Consequently the name "Pearl shale," which was applied by Beede[60] in Dickinson county to the 70 feet of beds succeeding the Herington limestone, is not used in Cowley county, but the Wellington formation is redefined so as to include the rocks above the Herington limestone.

Because of their softness these beds are rarely exposed. The few partial exposures seen, one of the best a short distance east of Geuda Springs along the river highway and another in the NE¼, sec. 21, T. 34 S., R. 3 E., indicate that they are composed of varicolored banded beds of clay shale, in minor parts limy. Coarsely honeycombed beds of gypsiferous limestone occur about 50 feet above the base of the formation and locally form conspicuous outcrops. A bed of limestone about 3 feet thick, that weathers similarly to these, crops out in a prominent ledge across secs. 7, 17 and 20, T. 33 S., R. 3 E., in the Rainbow Bend oil field. The exact stratigraphic position of this bed was not determined, but it is probably the bed mentioned in many core-drill records of this region as a bed of limestone and gypsum 4 to 8 feet thick about 50 feet above the base of the Wellington formation.

It is apparent that because of lack of good exposures, which in turn is the result of the composition of the strata, little detail as to the nature of the rocks in the Wellington formation can be gained from a surface examination. Because of this dearth of exposures of mappable surface beds throughout the extensive area occupied by the Wellington formation several of the oil companies operating in the region have resorted to drilling a large number of shallow holes, extracting cores from parts of the rocks drilled through, in order to obtain definite altitudes on some recognizable key bed for the determination of the attitude of the rocks. Throughout a broad area west of the outcrop of the Herington limestone the holes are drilled to the base of the Herington, as it serves admirably as a key bed. As a byproduct of such procedure the operators have gained an extensive

60. Beede, J. W., op. cit., p. 225; named from Pearl, Dickinson county.

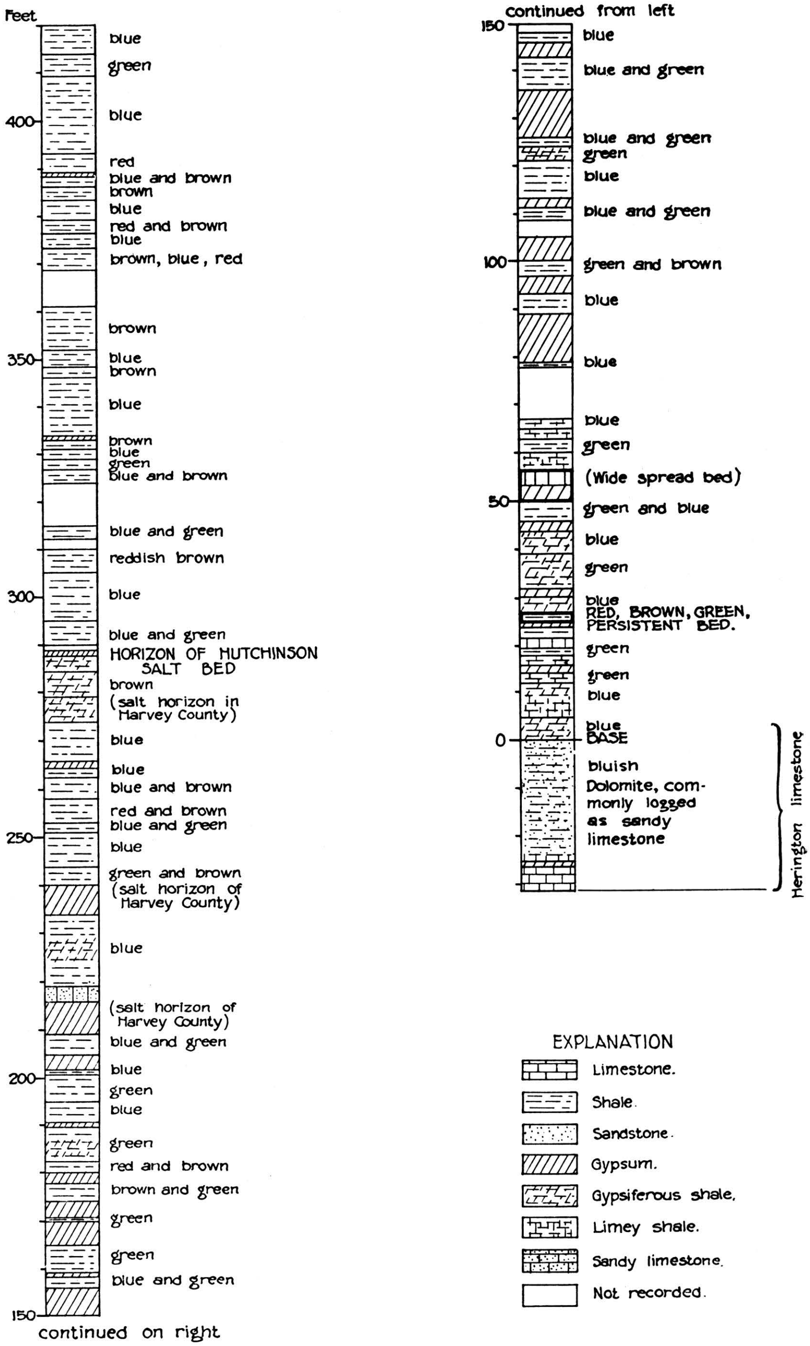


FIG. 6.—Section of lower part of Wellington formation as recorded in core-drill hole in southeastern Sumner county.
(Figures represent interval in feet from base of Wellington formation.)

and detailed knowledge of the strata that make up the Wellington shale. E. L. Jones, of the Roxana Petroleum Corporation, kindly supplied a few logs typical of the region and called attention to those beds that are particularly persistent throughout etxensive areas and to the fact that beds of salt, so characteristic of the Wellington formation in the vicinity of Hutchinson and elsewhere in central Kansas, change laterally southward and eastward to interbedded salt and gypsum and finally to beds of gypsum. The log of a core-drilled hole that penetrated the lowermost 400 feet of the Wellington formation in southeastern Sumner county, adjacent to Cowley county on the west, is reproduced in Figure 6, but only the lowermost 80 feet or less of the beds shown in the Wellington are present in Cowley county. The lowermost 25 feet of the Wellington is recorded as interbedded blue and green shale, in part limy and gypsiferous and containing several thin beds of limestone and gypsum. About 25 feet above the base of the formation is a bed of shale only 2 to 4 feet thick that is in part green but contains some red and brown shale which according to Jones[61] is persistent from central Harvey county, Kansas, southward across Sedgwick county, eastern Sumner county and western Cowley county into Oklahoma. In many localities this varicolored shale bed is underlain by a thin bed of gypsum. Above it is 20 to 25 feet of alternately bedded green and blue clay shale containing several thin beds of gypsum. Succeeding these beds, about 50 feet above the base of the formation, is a bed of limestone and gypsum 4 to 8 feet thick that is recorded in nearly all core-drill logs throughout this part of the state. This may be the bed that crops out and forms a porous ledge in the western part of the Rainbow Bend oil field. Overlying this limestone-gypsum bed is a little more than 20 feet of green and blue clay shale succeeded by a series of interbedded gypsum and green and blue clay shale with two or three thin reddish layers that occupies the interval from about 80 to 290 feet above the base of the formation. The lowermost part of this unit is commonly occupied by a bed of gypsum about 10 feet thick, and 35 feet above it is another of similar thickness; both beds are widespread in their occurrence and recognizable in shallow drill holes. Logs of core-drill holes farther north in the state indicate that the uppermost part of this unit, which is occupied by gypsum and gypsiferous shale in Sumner county, contains the thick salt bed mined at Hutchinson and Lyons.[62] Two units, one about 50 feet and the other about 70 feet

61. Jones, E. L.; personal communication.
62. Jones, E. L.; personal communication.

beneath the main Hutchinson salt bed, shown by core drilling to contain salt beds throughout an extensive region north-northwest of Sumner county, are occupied by beds of gypsum, each 5 to 8 feet thick, in southern Sumner county. The 130 feet of beds next above the Hutchinson salt horizon recorded in Figure 6 consist of blue clay shale with less green and an increasing number of red beds.

The section recorded in Figure 6 includes only the lowermost 420 feet of the Wellington formation, although it attains a thickness greater than 800 feet a little farther west in Kansas. As reported in well logs that penetrate the entire formation it may in general be divided into three units—an upper one of blue clay shale 200 to 450 feet thick, a middle one containing thick beds of salt and thin beds of blue clay shale with a maximum thickness of about 400 feet, and a lower one of interbedded shale and gypsum. The lower boundary of the formation is difficult to determine in well logs, because the gypsum beds beneath the main salt are commonly recorded as limestone, and consequently the log shows no lithologic difference between the rocks of the lower part of the Wellington formation and those of the formation below it. There is but little doubt involved in determining the position of the upper boundary of the formation in well logs; it is placed at the horizon of change from the great thickness of red beds of the upper part of the Permian series to the blue clay shale of the upper division of the Wellington formation, a horizon that is rarely missed by the drillers. The location of the outcrop of the top of the Wellington formation is quite another matter, however. Because of the softness of the strata that make up the Wellington formation and the overlying "Red Beds," the contact between the two, which lies many miles west of Cowley county, is thickly mantled by soil and cannot be traced from surface observations, except in a very general way. The Herington limestone, although concealed in places along its eastern margin, is sufficiently well exposed throughout much of its outcrop to permit the mapping of the lower boundary of the Wellington formation with a fair degree of accuracy. It is fairly well exposed in Cowley county except throughout the region west of Hackney.

The Wellington formation occupies the westernmost tier of townships in Cowley county, much of the surface of Sumner, Sedgwick, and Harvey counties, and the western part of Butler county and thence narrows northward into northern Dickinson county. The area underlain by it is characterized by broad plains practically devoid of outcropping rocks, forming a strikingly featureless surface when contrasted with the surface of the remainder of the state lying to the east and formed by the alternately bedded resistant limestone and shale in the lower part of the Permian and the upper part of the Pennsylvanian series.

The Wellington formation was named by Cragin[63] from exposures and the record of a boring near Wellington, Sumner county, Kansas. Cragin applied the name to only those beds that lie above the principal salt beds and below the "Red Beds" and described them as constituting a body of clay shale of blue-gray, drab, slate, buff, and various shades of blue and brownish-red colors 250 to 450 feet thick. Some beds of shaly limestone, calcareous shale, gypsiferous shale, gypsum, and dolomite are present in the upper half of the formation where it crops out in the type locality, according to Cragin; he described the lower half as greenish and blue with some reddish clay shale as recorded in a well drilled at Wellington. Moore and Haynes[64] extended the lower boundary of the Wellington formation to include the salt beds and all beds above the Abilene conglomerate,[65] which was described as being about 70 feet above the Herington limestone. The Abilene conglomerate was later described by Moore[66] as being of Tertiary age and therefore excluded from the Permian series. Inasmuch as the rocks that occupy the entire interval between the Herington limestone and the horizon of the principal salt beds are essentially similar to the beds that are interbedded with the salt and occupy the interval above the salt and beneath the "Red Beds," the whole is herein included in the Wellington formation; that is, the entire interval between the Herington limestone below and the "Red Beds" above. It is true that the bed of gypsiferous limestone that occurs about 50 feet above the Herington limestone, the salt beds, and some beds of gypsum are widespread in this part of the state as recorded in well logs and on the basis of well records might serve to separate the formation into several divisions. The surface expression of these beds is so weak, however, that the positions of their outcrops are not mappable except in areas of local extent, and on the basis of the present information it is not deemed expedient to subdivide the Wellington.

63. Cragin, F. W.; The Permian system in Kansas: Colorado College Studies, vol. 6, p. 17; 1896.

64. Moore, R. C., and Haynes, W. P.; Oil and gas resources of Kansas: Kansas Geol. Survey, Bull. 3, pp. 115, 116; 1917.

65. Prosser, C. S.: Jour. Geology, vol. 3, p. 786; 1895. Named from Abilene, Dickinson county, Kansas.

66. Moore, R. C.; Oil and gas resources of Kansas: Kansas Geol. Survey, Bull. 6, p. 63, footnote; 1920.

Tertiary (?) System.

Pliocene (?) Series.

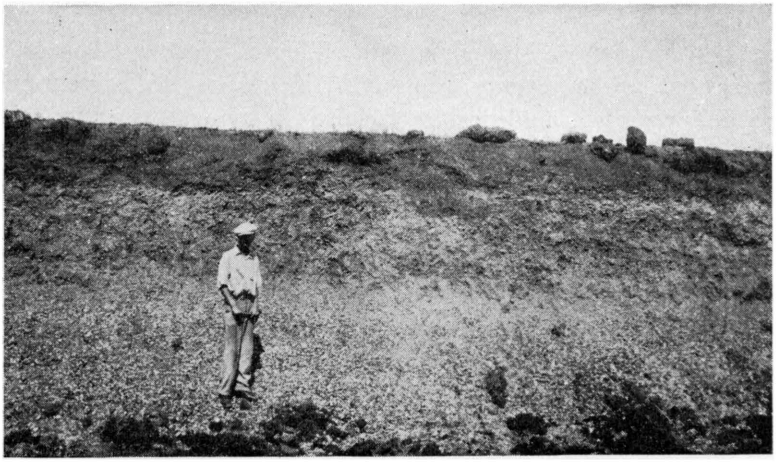
GRAVEL.

Deposits of gravel composed largely of chert, as much as 19 feet and possibly more in thickness, are present at the surface in parts of Cowley county, at altitudes above the stream beds ranging between 150 and a little more than 200 feet. No particular study was made of the gravel deposits, and they were not mapped, but were noted wherever seen in the course of other field work. Accordingly there are, no doubt, many localities containing gravel deposits that were not seen. A deposit forming the upland northeast from Floral has the highest altitude of the deposits noted, being a little more than 1,300 feet above sea level.[67] The thickest deposit seen has a maximum thickness of 19 feet. It is exposed in a working gravel pit northeast of Silverdale, in the NW¼, sec. 21, T. 34 S., R. 5 E. The extent of this deposit was not determined, but it is known to occupy much of the S½, sec. 16, the SE¼, sec. 17, the NE¼ and a small part of the SE¼, sec. 20, most of the W½, sec. 21, a small part of the NW¼, sec. 28, and the NE¼, sec. 29. It is estimated that 95 per cent of the gravel is made up of fragments of chert and the remaining 5 per cent is limestone. Fine materials—sand, silt, and clay—fill the spaces between the gravel particles and bind the gravel together so firmly that it will stand in vertical walls on the pit face. (See Pl. VIII.) Most of the gravel particles are less than 1½ inches in diameter, although a small percentage are as much as 5 inches; the prevailing size appeared to be about 1 inch. Most of the particles are subangular; the original shapes are in large part retained, but the corners and edges are rounded; a small percentage of the particles are well rounded. Some fragments contain well-preserved fossils. The pebbles have a glazed surface of tan to reddish-brown color. This gravel deposit is estimated from the topographic map to lie at its highest point a little more than 200 feet above the present stream bed of Grouse creek. It was being actively worked at the time of the examination.

A gravel deposit similar in character to that described above surrounds the center of sec. 32, T. 34 S., R. 5 E., immediately north of Silverdale. It appears to be much thinner and occurs at an altitude about 50 feet lower than the other deposit. A steam shovel,

67. Altitudes based on the Burden topographic map of the U. S. Geological Survey.

cars, washer, and tipple at the locality had stood idle for a year or more at the time of the field examination of the area, but it is reported that this gravel deposit was being worked in 1927.



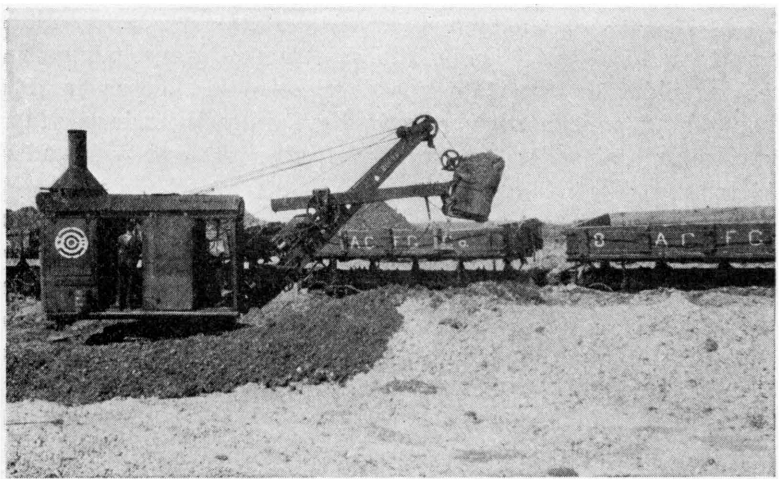


PLATE VIII. *Upper:* Gravel pit 3 miles northeast of Silverdale. *Lower:* Loading gravel from pit 3 miles northeast of Silverdale.

Gravel occurs along Walnut river at heights ranging from less than 50 feet to more than 100 feet above the river and is believed to represent deposits laid down much later than the deposits at Silverdale. However, gravel was seen at higher altitudes in a few localities bordering Walnut river, and it is believed that many other similar deposits are probably present. One of those seen occurs at an altitude of a little above 1,200 feet in the SE¼, sec. 8 and the SW¼, sec. 19, T. 33 S., R. 4 E., 3 miles south of Winfield, and another surrounds the corner common to secs. 25, 26, 35 and 36, T. 30 S., R. 3 E., lying a little above 1,250 feet. Several deposits of gravel were seen on the north side of Dutch creek in the north-central part of the county, some lying high above the stream and probably representing deposits equivalent in time of deposition with those at Silverdale and others occurring at lower altitudes and deposited at a much later date. Gravel occupies the surface of an area of considerable extent northeast of Floral at an altitude of a little more than 1,300 feet; gravel was seen at an altitude of 1,250 feet about 1½ miles southwest of Floral, in the northern part of sec. 24, T. 31 S., R. 4 E., and at a somewhat lower altitude a mile farther southwest, in section 26.

What has been commercially one of the most important gravel deposits in southern Kansas occurs largely in Butler county, but extends into Cowley county, bordering the Winfield-Augusta highway in the NW¼, sec. 4, and the NE¼, sec. 5, T. 30 S., R. 4 E. The gravel caps the upland and lies at an altitude of 1,200 to a little more than 1,250 feet. One of the most active gravel mining and washing plants in the state was developing this deposit in 1926, about half a mile north of the Cowley county boundary. More gravel occurs at a little above 1,250 feet on the county boundary 1½ miles east of this deposit.

Outside of Cowley county extensive gravel deposits border the bottoms of Walnut river and its tributaries in southern Butler county, particularly at Leon and on both sides of Little Walnut creek from 2 to 6 miles south of Haverhill. Other deposits were seen north of El Dorado, in central Butler county; in the vicinity of Cottonwood Falls, Chase county, bordering South Fork and Cottonwood river; and in Lyon county near Emporia and Americus, on the divide between Neosho and Cottonwood rivers. There are also extensive deposits on the uplands in Anderson, Osage and other counties in east-central Kansas. In fact, deposits of chert gravel, in general similar to those described as occurring in Cowley county, are extensively distributed along the streams but far above their present flood plains throughout much of eastern Kansas.

Origin. The nature of the material and the location of the deposits demonstrate that these gravel deposits were laid down by streams flowing at higher positions than those of the present day. The fact that the individual pebbles have retained in the main their original shapes, modified only by rounded edges and corners, indicates that they have been transported only moderate distances. Fossils occurring in individual particles common to the rocks in the lower part of the Permian series have been identified in many localities, the following species being abundant, according to Wooster:[68]

Productus semireticulatus.
Athyris (Composita) subtilita.
Fusulina cylindrica.
Various species of cup corals, crinoids and lace corals.

These fossils and the type of material that makes up the gravel deposits appear to prove that they were derived largely from the chert-bearing Florence flint and Wreford limestone. Most of the streams carrying the material flowed eastward, but those in Cowley county flowed southward and southwest ward in general as they do to-day, except that they flowed at relatively higher altitudes.

Age. Very little information concerning the age of the gravel deposits was obtained in Cowley county, but fortunately similar deposits that occur in the northeastern third of the state have been studied in some detail with reference to age of deposition by Todd.[69] This author recognizes three main types of stream deposits in the region of Kansas river—higher-level chert gravel, lower-level chert gravel, and dirft-filled channels. It appears probable that Todd's higher-level chert gravel may be correlated with the higher gravel of Cowley county and other localities in eastern Kansas. He describes deposits as forming terraces and capping upland surfaces bordering Kansas river, Mill Creek, and other eastward-flowing streams and occurring 125 to 150 feet higher than the present stream levels. He states that these higher gravel deposits are composed largely of chert fragments that are easily traced to their source in the chert-bearing limestone formations in the lower part of the Permian series. They contain no northern erratics, although such rock types were seen lying upon the gravel beds at a number of localities. Inasmuch as it is well established that the material containing the northern erratics common to northeastern Kansas was brought there by the continental ice sheets that moved southward into this region during the Kansan stage of the Pleistocene epoch, the finding of

68. Wooster, L. C.; Chert gravels of eastern Kansas: Kansas Acad. Sci. Trans., vol. 27, pp. 58-62; 1914.
69. Todd, J. E.; Kansas during the ice age: Kansas Acad. Sci. Trans., vol. 28, pp 33-48; 1918. History of Kaw Lake: *Id.*, pp. 187-199.

none of this material in the gravel and its occurrence in the deposits overlying the gravel beds indicate a Pre-Kansan age for the gravel, and Todd believes that they are Pre-Pleistocene, having been deposited in very late Pliocene time. On this basis it may be tentatively assumed that the gravel deposits that occur at altitudes between about 1,200 and 1,300 feet in Cowley county, such as those near Silverdale and Floral and north of Rock, were deposited in late Pliocene time by streams such as Walnut river, Grouse creek, and others flowing 175 to 225 feet above their present levels but in general following the same courses as they occupy at present. This means that about 1,000,000 years has elapsed since the higher gravel deposits were laid down in Cowley county.

Quaternary System.

Gravel.

Gravel deposits composed largely of chert particles occur at various levels, and apparently in no systematic levels between the position of the high gravel and the present streams. They were probably derived from the higher Pliocene (?) gravels, reworked and redeposited as the streams haltingly cut downward during Pleistocene time, though some of the higher deposits may be of Pre-Pleistocene age. The deposits here described differ little from the Pliocene (?) gravel except that they appear to contain a larger percentage of smaller particles, and the particles are somewhat less angular. Gravel of this nature has been mined for local road surfacing in the NE¼, sec. 4, T. 33 S., R. 4 E., a little more than a mile south of Winfield. This deposit lies at an altitude of about 1,125 feet, a little more than 50 feet above Walnut river, and is composed of somewhat finer, more rounded chert particles than the deposits at Silverdale.

Occurring at approximately the same altitude and having the same general character as the gravel in sec. 4, T. 33 S., R. 4 E., gravel deposits were seen at a number of localities on the upland immediately west of the Walnut river bottoms, from a point west of Winfield north for 10 miles. It is probable that gravel is rather widespread in this vicinity and on northward to and beyond the northern boundary of the county. The lower gravel deposits on Dutch creek, about 3 miles southwest of Floral, also belong in this class.

LOESS.

Distribution. Relatively thick deposits of loess, diminishing in thickness northeastward, occur in the southwestern part of Cowley county, at all levels between the slopes a few feet above the alluvium of the bottom lands and the highest divides. The loess ranges in thickness from a few inches to more than 25 feet; it has a reddish-brown color, stands in vertical walls 15 to 20 feet high in road cuts and stream channels, and exhibits a crude columnar structure in many exposures. Plate IX shows the loess standing in vertical embankments on each side of the road in the southern part of the county in T. 35 S., R. 4 E. Deposits of loess are exposed at a number of localities east, south and west of Arkansas City; and loess borders the Arkansas City-Joplin highway a little less than half a mile east of Walnut river and stands in vertical bluffs bordering the road at several localities a short distance farther east. It is well exposed about a mile west of Arkansas City only a few feet above the level of the Arkansas river bottom land, and it occupies much of the surface for miles southwest of the town, exposures being abundant on all roads. Thin local deposits extend northward nearly to Winfield.

Origin. Inasmuch as the loess in Cowley county is composed of very fine homogeneous material occurring at all altitudes mantling the surface, and stands in vertical walls exhibiting a columnar structure, a characteristic feature of many deposits of loess elsewhere, it is thought to have been very largely deposited by wind and to be a true loess. Its reddish-brown color, its diminishing thickness northeastward in Cowley county, and the fact that the prevailing winds of this region are northerly, indicate that the "Red Beds" of Oklahoma constitute its chief source, although other strata, particularly Permian beds beneath the "Red Beds," probably have furnished a part of the material.

Age. As shown by the discussion of the chert gravel deposits, it appears probable that the streams of Cowley county were flowing at levels about 200 feet above their present positions at the beginning of Pleistocene time, and that the process of lowering their channel beds to the present levels occupied all of Pleistocene time and part of Recent time. The alluvium forming the bottom lands is regarded as having accumulated in Recent time. The fact that the loess occurs well down in the valley trenches, thickly covering the slopes to levels within a few feet of the bottom lands, indicates that much of it accumulated not long prior to Recent time, probably late in the Pleistocene, after much of the down-cutting of the stream courses had been accomplished. Very likely the deposition was relatively slow and extended throughout a long period, and probably is still continuing but with diminished intensity.

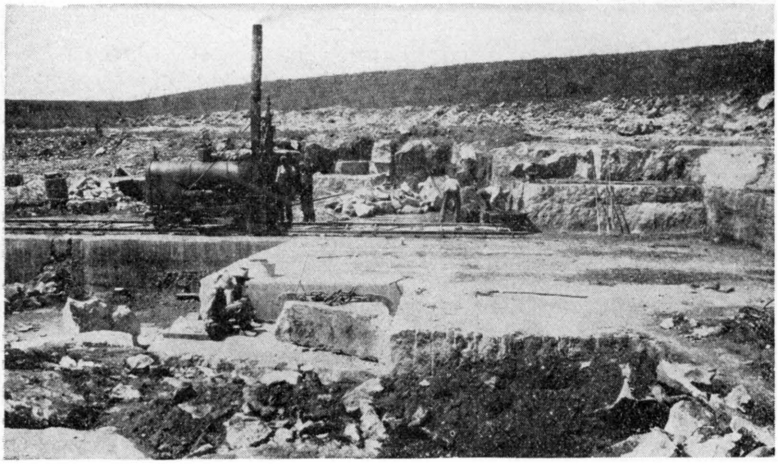


PLATE IX. *Upper:* Silverdale quarry of the Arkansas City Sand and Gravel Company, 1½ miles northeast of Silverdale. *Lower:* Road cut in loess in T. 35 S., R. 4 E., in southern part of Cowley county.

ALLUVIUM.

Alluvium having a known maximum thickness of 55 feet occupies the lower parts of the valleys of all the principal streams of Cowley county. The material consists of clay, silt, sand and gravel deposited during flood periods of the streams, in Recent geologic time, since the streams have reached their present levels and have been engaged in widening their valley bottoms. The alluvial plain of the Arkansas has a maximum width of 3 miles, and that of Walnut river 2 miles. Grouse, Silver, Dutch, Timber, and Rock creeks have also developed fairly extensive bottom lands, but their widths exceed half a mile in only a few localities. The extent of the alluvium bordering the principal streams of the county is shown on the geologic map (Pl. I). Surface exposures and drilled wells indicate that the alluvium along Arkansas river is composed largely of quartz sand, but that the alluvium bordering other streams contains a large proportion of clay and silt with very little quartz sand. Logs of wells drilled for oil in the Arkansas river bottom in the extreme western part of the county record the alluvium as being about 55 feet thick and composed largely of quartz sand with some gravel, all except the uppermost few feet being water bearing. According to the city water superintendent the water wells at Arkansas City, in the alluvium of Arkansas river, penetrated 10 feet of loose sand, below which is 15 feet of sharp water-bearing sand, and next below is 20 feet of water-bearing sand and gravel, the individual particles ranging between fine sand and grains the size of peas. Core-drilled holes recently driven into the alluvium of Walnut valley a few miles southwest of Rock are reported[70] to have penetrated about 35 feet of alluvium lying above the bedrock. The uppermost 25 to 30 feet was composed almost entirely of black clay and silt, and the lowermost 7 to 8 feet of gravel with pebbles ranging between one-fourth and one-half inch in diameter. The alluvium bordering most of the lesser streams of Cowley county is similar to that of Walnut river.

This difference in the nature of the material in the alluvium of the Arkansas and Walnut valleys is readily accounted for by comparing the surface materials of their drainage basins. The area drained by Walnut river and the smaller streams of Cowley county is underlain at the surface by beds of limestone and shale containing only a very small amount of sandstone. The material eroded from these rocks and transported to the river bottoms consists of fine clay and silt particles with minor amounts of coarser material. Arkansas river, however, flows through an extensive region several miles west of Cowley county that is covered with wind-blown sand and underlain by rocks composed largely of sand (the Dakota sandstone), and the alluvium that occupies its valley reflects the char-

70. Bailey, Joe (The Trees Oil Co.); personal communication.

acter of these rocks, which have furnished much of the material of which it is composed. The lack of coarse material in the alluvium of the Walnut valley is of no little economic importance, because the compact material yields only a small amount of water, insufficient to supply towns the size of Winfield. In contrast, the quartz sand of the alluvium of the Arkansas valley is very porous and readily yields abundant flows of water.

Dune Sand.

Patches of wind-blown quartz sand occur on the upland between Arkansas and Walnut rivers a few miles east of Arkansas City and thicker and more extensive deposits are present west and northwest of Arkansas City on the uplands near the Arkansas. Although these sand deposits were not examined in detail, the abundance of sand in the Arkansas valley and the northerly direction of the prevailing winds suggest that the sand is at least in part derived from the river bottom lands.

Oil-and-gas-producing Rocks.

There are nearly 30 localities in Cowley county where oil or gas or both have been found, and the beds that contain these substances are widely distributed vertically through the stratigraphic succession. So far as number of producing localities is concerned, the most important strata are probably the numerous sandstone beds in the Admire shale, sandstone and sandy limestone beds in the upper part of the Kansas City group, and sandstone beds in the lower part of the Cherokee shale. The last-named beds, known as the Bartlesville sand, have produced by far the greatest amount of oil in Cowley county. The lowest rocks that produce oil or gas in the county are reported as sands and porous limestones in the uppermost part of the Ordovician rocks. The producing beds of the Ordovician probably do not represent the same horizon in all localities, but no attempt has been made in connection with this work to correlate these deeper-lying rocks, nor is it positively known in what part of the Ordovician system they occur.

Rocks of probable Ordovician age produce oil in the State School, Slick-Carson, and Graham pools.* The upper part of the "Mississippi lime" contains porous beds that produce relatively small amounts of oil in the Dexter, Otto, Countryman, and Mahannah fields. Fragmental material composed largely of chert pebbles and

* Refer to Plate XI for field location.

sand grains is distributed in discontinuous patches on the surface of the "Mississippi lime." The material is locally called "chat." It produces oil in a well drilled in sec. 5, T. 34 S., R. 3 E. Beds of sandstone in the lower part of the Cherokee shale (the Bartlesville sand) are abundant producers of oil and gas. The producing sand of the Rainbow Bend field belongs in this zone. It lies immediately above the "chat" in parts of the field and in contact with the "Mississippi lime" where the "chat" is not present. In other localities the Bartlesville sand is separated from the Mississippian limestone by 50 to 100 feet of shale and commonly produces both oil and gas. In Cowley county this sand is productive in the Eastman, Rock, Winfield, and Clarke fields; in one well in the Slick-Carson field; in a small part of sec. 30, T. 30 S., R. 4 E., 2 miles southwest of Rock; in a small part of sec. 6, T. 30 S., R. 6 E.; and in parts of secs. 16, 17, 20, and 21, T. 34 S., R. 3 E. A bed of sandstone near the middle of the Cherokee shale yields oil in the Empire-McCormick pool. Oil is produced from a bed near the middle of the Marmaton group in the Olsen pool; and sandstone in the upper part of the Marmaton or near the contact of the Marmaton and Kansas City groups contains oil in wells in the Biddle pool and in one well in the Peacock pool. The sand near the contact of the Marmaton and Kansas City groups produces oil and gas in the State School pool. The Kansas City group yields gas and oil abundantly in several localities. Production from the uppermost part of the group is the more widespread, although other parts of the group are productive in several localities. Oil is found in the upper part of the Kansas City group in the Biddle, Elrod, Slick-Carson, Countryman, and Graham pools and in sec. 28, T. 31 S., R. 4 E.; oil and gas in the Winfield and State School pools; and only gas in the Grand Summit and Empire-McCormick pools. A sandy zone about 100 feet below the top of the group produces a little oil in the Slick-Carson pool and has yielded gas in the Falls City pool. A similar zone about 200 feet beneath the top of the group yields oil in the Rockwell pool, oil and gas at Grand Summit, and gas in the Empire-McCormick field. Sandstone in the lower part of the Lansing group has produced gas in the Falls City field; a similar bed near the middle of the Lansing group has produced gas in the Olsen pool; and a thick sandstone in the uppermost part of the group that is widespread and contains water in most localities yields oil in the Udall pool, gas in the Falls City field, gas in one well in sec. 14, T. 34 S., R. 4 E., and gas in sec. 4, T. 35 S., R. 4 E. It is this upper sand that has produced the abundant flow of oil in the Churchill pool, adjacent to Cowley county on the west.

Oil occurs in the Udall pool in sand in the upper part of the Douglas group, a short distance beneath the Oread limestone, and sandstone at this stratigraphic position contained gas in the Floral field. Sandstone occurring about 150 feet above the Oread limestone in the lower part of the Shawnee group and known as the "1400 foot" sand produces oil in the Peacock and Winfield pools; sand at the same horizon contained gas in the Dexter and Otto fields. The upper part of the Shawnee group produced gas in sec. 16, T. 34 S., R. 3 E. Gas-producing sand lenses occur in the Admire shale; they have yielded gas abundantly throughout extensive areas in the Winfield district, in several localities in the Arkansas City district, in the Dexter, Otto, and Countryman fields, and in one well in sec. 33, T. 33 S., R. 3 E.

One prevailing characteristic of the oil- and gas-producing beds is their lenticularity. The numerous beds of gas-producing sandstone in the Admire shale appear not to be clearly defined beds continuous over a large area, but rather to form a sandy zone in the shale formation, composed of interfingering lens-shaped beds of sandy shale and sandstone, each 5 to 20 feet thick. A single bed may continue throughout several square miles, and its outline in plan may commonly be more or less equidimensional—that is, it does not present a narrow, elongated pattern such as that of many of the producing sands in the Cherokee shale, which are typically developed in Greenwood county.

The sandstone in the uppermost part of the Lansing group is the thickest and most widespread sandstone unit in the stratigraphic section. It is not uncommonly more than 100 feet thick and is reported in the logs of wells in all the principal fields in the county. In most localities it produces a "hole full of water." Contrasted with this sand are the sands at the "Bartlesville horizon" in the lower part of the Cherokee shale, either at its base and lying directly upon "Mississippi lime" or slightly higher and separated from the "Mississippi lime" by 50 feet or less of "chat" or by 25 to 100 feet of shale or "chat" and shale. Sand bodies at this general horizon range between 20 and 75 feet in thickness and are continuous for several miles, but terminate comparatively abruptly in directions at approximate right angles to the direction of elongation. The characteristic pattern formed by the distribution of these sand deposits consists of somewhat irregularly trending bodies several

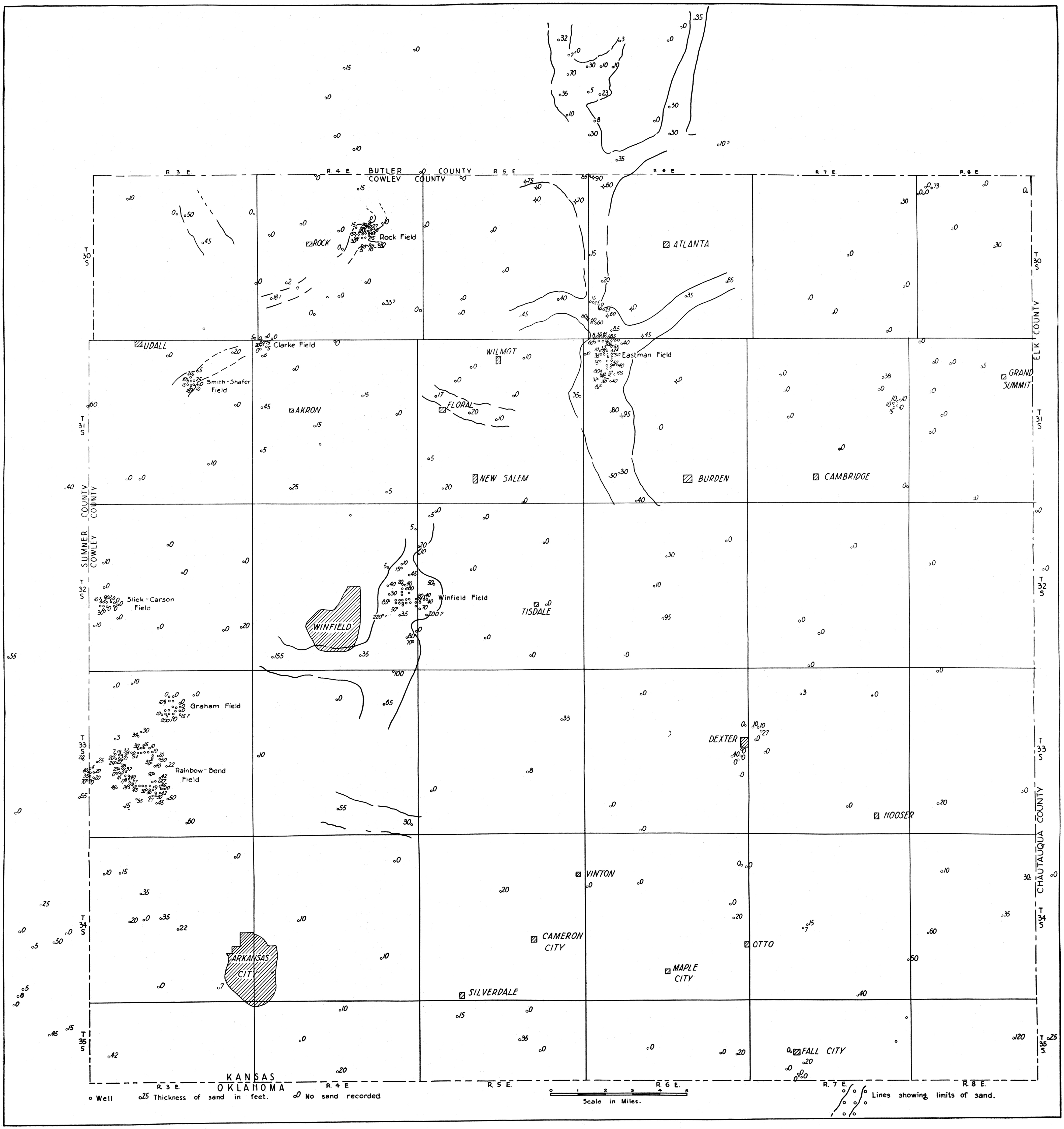


Plate X.—Sketch map showing distribution and thickness of sand at "the Bartlesville horizon" in Cowley county.

times longer than their widths. The producing sands in the Eastman and Rock pools are typical examples of these deposits. The areal shape of the sand body in the Rainbow Bend pool is more nearly circular, with a lobe trending southeastward. Plate X is a sketch map of the county showing the distribution of sand at this horizon and the thicknesses of the sand as reported in logs of drilled wells that penetrated the stratigraphic horizon of the sandstone but encountered no sand.

Little detailed information concerning the character of the material composing the sand bodies is available. Chunk samples from the Smith-Shafer, Winfield, and Rainbow Bend fields show the sand to be composed largely of subangular quartz grains containing a considerable percentage of clay. Some samples are slightly calcareous, and others are not. In general the sand is not extremely well sorted. A mechanical analysis of one chunk sample from the Smith-Shafer field shows a relatively wide range in the size of the material. Coal is reported to occur in the upper part of the sandstone in the Wright No. 2 well, in the NE¼, sec. 28, T. 33 S., R. 3 E., in the eastern part of the Rainbow Bend field. Coal is said to have been found in the sand in the Smith-Shafer pool, and it is reported at this horizon in the Carlton well, near the center of sec. 10, T. 30 S., R. 3 E.

The information at hand is insufficient to indicate definitely the origin of these sand bodies. Sand bodies at this horizon in Greenwood county and southeastern Butler county have been interpreted by Cadman[71] as being continental deposits laid down by streams. Characteristics that would be found in a continental deposit, perhaps filled stream channels such as Cadman has described for the region immediately northeast of this county, are exhibited by the Bartlesville sand in the vicinity of the Eastman and Rock fields and to a certain extent in the Winfield field. The occurrence of coal in the sand at a few places, the presence of "red rock" at the horizon of the sand in many wells, the relatively large percentage of clay in the sand, and the angular shape of the sand grains are in harmony with this mode of origin. But in Cowley county these characteristics are not sharply enough defined to eliminate other possible modes of origin. The northeast-southwest alinement of the principal localities of thickest sand development in Cowley county is in general strike with the Mississippian surface in early Pennsylvanian time (indicated by a map representing the range in thick-

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71. Cadman, W. K.; The golden lanes of Greenwood county, Kansas: Am. Assoc Petroleum Geologists Bull., vol. 11, p. 1151-1172; 1927.

ness of the Cherokee shale; map not reproduced here), a fact which suggests a parallelism with the shore line of the early Pennsylvanian sea and a marine origin of the sand bodies. The occurrence of coal could be accounted for by assuming it to have accumulated in near-shore swamps during times of slight regressions of the sea. The other features shown by the chunk samples are not so sharply defined but that they may represent either marine or continental deposits. In view of the nature of the occurrence of sand bodies at the Bartlesville horizon in near-by districts, the distribution of the deposits, and the other very meager data that are not definitely opposed, the present information appears to indicate a continental origin—as buried stream-channel deposits—for the sand lenses in the Eastman, Rock, and Smith-Shafer fields, the sand in sec. 30, T. 30 S., R. 4 E., and probably the sand of the Winfield pool. The data are insufficient to venture an opinion as to the origin of the sand in the Rainbow Bend field and other localities.

Sand such as that in the Lansing group would appear to be of different origin. Its widespread, sheetlike distribution and the nature of adjacent beds suggest that it was deposited in a marine body of water.

STRUCTURE.

Regional Structure.

Cowley county is situated on the Prairie Plains monocline, which constitutes the western flank of the Ozark uplift and involves an extensive region in western Missouri, eastern Kansas, and northeastern Oklahoma in which the strata dip at a low angle westward. In the northeastern part of this general region the direction of dip swings to the northwest, and in the southeastern part it is toward the southwest. The rate of dip is usually reported to average about 30 feet to the mile in eastern Kansas. Ley[72] states that the rate of dip rarely exceeds 40 feet to the mile. The Fort Scott limestone has a total fall of a little more than 2,700 feet from its outcrop near Oswego, Labette county, due westward 110 miles to the Rainbow Bend oil field in Cowley county. This is an average component dip of about 25 feet to the mile. It is largely this regional westward tilt of the beds that causes the formations to crop out in parallel bands in eastern Kansas, each successive band toward the east exposing stratigraphically lower and older strata.

In Cowley county, as well as elsewhere on the Prairie Plains monocline, the prevailing attitude of the strata is modified locally by departures from the westward tilt. The deviations range from a steepening of the westward dip through horizontality to eastward or reverse dips. It is on the structural features formed by these local variations upon the Prairie Plains monocline that many of the important oil fields have been developed.

Several writers[73] have recently given summaries of the characteristics of the structural features of the Prairie Plains monocline in northeastern Oklahoma and southeastern Kansas, from which the following statements are largely taken. The characteristic folds are anticlinal noses, domes, terraces, synclines, and basins, of small lateral extent, each commonly within an area 2 miles square. Some anticlines and synclines reach a length of 2 to 3 miles, but larger

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72. Ley, H. A.; Subsurface observations in southeast Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 8, p. 449; 1924.

73. Powers, Sidney; Structural geology of the midcontinent region—a field for research: Geol. Soc. America Bull., vol. 36, pp. 379-392; 1925. Ley, H. A.; Subsurface observations in southeast Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 8, p. 449; 1924. Rubey, W. W.; Progress report on a subsurface study of the Pershing oil and gas field, Osage county, Oklahoma: U. S. Geol. Survey Bull. 751, pp. 23-70; 1923. Rubey, W. W., and Bass, N. W.; The geology of Russell county, Kansas: Kansas Geol. Survey Bull. 10, pp. 72-75; 1925.

ones consist of groups of smaller features. In many folds the amount of closure increases with depth—that is, the beds at depth are more steeply folded; others, designated by Powers as surficial folds, disappear gradually downward, usually within the Pennsylvanian series. Commonly the axes of folds are inclined—that is, the crest of an anticline, for instance, as defined in the surface beds, does not directly overlie the crest as defined in some deeper bed. Most of the folds are irregularly arranged, but some are alined in more or less systematic plan. Most of the major-trend lines in eastern and central as well as western Kansas and northern Oklahoma have a northeast-southwest alinement.

History.

Inasmuch as all strata in this region upward through the Permian series maintain the westward dip, as shown in the surface exposures, the tilting that gave the beds their present attitude is known to have occurred after the time of deposition of the Permian strata. Evidence less readily recognized in this part of Kansas, but disclosed by other workers from studies of subsurface data derived from well records and from surface studies carried on elsewhere in the general region, indicates that other important structural movements that affected the rocks in the region containing Cowley county occurred at earlier dates. Subsequent to the deposition of strata hundreds of feet thick, during Cambrian time and part of Ordovician time, which were laid down on an irregular surface of Pre-Cambrian igneous and metamorphic rocks, a pronounced uplift that centered in the locality of the present Ozark mountains affected an extensive region including northeastern Oklahoma and eastern Kansas.[74] Later in Ordovician time more sediments were deposited. Another uplift ended Ordovician sedimentation. The strata were then folded, uplifted, and subjected to erosion throughout a long period. The land was again submerged, and Silurian and Devonian sediments, interrupted by at least one period of uplift and erosion,[75] were deposited over parts of the region but failed to cover several anticlinal areas[76] that stood as hills on the old surface and so formed islands in the sea. Slight uplift with some erosion followed, and then the region was submerged and received the deposits now known as the

74. White, L. H.; Subsurface distribution and correlation of the pre-Chattanooga series of northeastern Oklahoma: Oklahoma Geol. Survey Bull. 40-B, pl. 1; 1926. Edson, F. C.; Ordovician correlation in Oklahoma: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 968; 1927.

75. Edson, F. C., op. cit., p. 968.

76. Powers, Sidney, op. cit., p. 383.

"Mississippi lime." After the deposition of the Mississippian beds there was a marked uplift. Gently inclined anticlines, domes, and synclines were formed, and some faulting occurred. Evidence of these phenomena, except the faulting, is present in Cowley county, and faulted Mississippian beds overlain by unbroken Pennsylvanian and Permian strata are reported[77] in the Tonkawa and Thomas oil fields in Oklahoma, a short distance southwest of Cowley county. Deposition of the thick Pennsylvanian and Permian series followed, and other important events occurred later in Mesozoic time. It is evident, then, that many structural features that were formed in the deeply buried older rocks prior to the deposition and emergence of the surface beds will not be manifest in the strata now at the surface. For instance, the Cambrian and Ordovician beds, and perhaps others, probably dip westward in Cowley county[78] at a steeper angle than the Mississippian and overlying beds and no doubt contain many structural features of local extent that remain unknown. However, many of the Ordovician folds are defined in the Mississippian and higher beds, with angles of inclination diminishing upward.

Local Structure of Surface Beds in Cowley County.

Although the beds at the surface in Cowley county conform in general attitude with the Prairie Plains monocline, the local departures from the regional westward dip are so numerous as almost to obscure the broader relations when only a small area is considered. The deviations from the regional attitude consist of anticlinal noses, terraces, anticlines, synclines, domes, and basins. Most of the area of Cowley county has been mapped in detail with reference to the attitude of the surface beds by oil-company geologists, but little information of this nature was available for study in connection with this report, and no work of this type was done by the writer in the field. It is known, however, that all the folds have only very low dips, rarely exceeding 1°, and that some of the small and all of the major folds have a northeast-southwest alinement, in harmony with the pattern made by the chief trend lines of folding in the general region.

Of all the structural features in the county the Dexter anticline, shown in part in figure 18, has the most pronounced expression in the surface beds. It is an asymmetric fold with its steeper flank on

77. Clark, G. C., and Cooper, C. L.; Oil and gas geology of Kay, Grant, Garfield, and Noble counties: Oklahoma Geol. Survey Bull. 40-H; 1927.

78. White, L. H., op. cit., pl. 1.

the east, trending nearly due north for several miles near Otto, thence swinging to the northeast near Dexter. According to Clark and Cooper[79] the trend of the fold continues southwestward through the Mervine and Ponca anticlines in Oklahoma. In the vicinity of Dexter the beds dip eastward as much as 100 feet in half a mile and westward about the same amount in a mile. Numerous structural sags or saddles cross the anticline, thus forming a series of local "highs." A fold of similar type that is believed to overlie the "granite ridge" lies in the northwestern part of Cowley county, crossing the western boundary of the county about the middle of the west line of T. 31 S., R. 3 E., trending northeastward, passing about half a mile west of Udall, thence northeastward crossing the north boundary of the county on the north line of the NE¼, sec. 3, T. 30 S., R. 3 E. This is a part of a series of folds that trend northeastward across Kansas, including the Augusta, El Dorado, and Burns anticlines, and southwestward far into Oklahoma,[80] through the Blackwell, Retta, Thomas, and Garber fields. As on the Dexter anticline, local "highs" of pronounced structural relief are present on this fold. There is one that centers about the town of Oxford, and another a short distance northeast of Oxford on which are located the Oxford and Churchill (South Udall) oil pools, both largely outside of Cowley county. Another local dome that produces oil lies about 2 miles north of Udall, and another on which two dry holes have been drilled is in sec. 10, T. 30 S., R. 3 E. As in the Dexter fold, the east limb of the "granite ridge" anticline in Kansas is steeper than the west limb, but the angle of inclination of the beds is probably greater than in the Dexter fold. Unlike that of the Dexter fold, however, the attitude of the beds throughout much of this region is not determinable from surface observation, because the surface is immediately underlain by a thick body of soft shale beds that contain no readily traceable hard layers that might serve as datum planes for mapping. The attitude of the beds has been determined by core drilling at regular intervals throughout the region. The procedure followed in drilling an area to obtain structural data is usually as follows: A core of the rocks penetrated is taken in the first few wells drilled in the region to locate the approximate depth of some bed suitable to serve as a "key" bed; subsequently, wells are drilled with a fishtail bit to a depth a short distance above the "key" bed and a core is taken of only the lower part of the hole—

79. Clark, G. C., and Cooper, C. L.; Oil and gas geology of Kay, Grant, Garfield and Noble counties: Oklahoma Geol. Survey Bull. 40-H, p. 24; 1927.

80. Clark, G. C., and Cooper, C. L., op. cit., p. 26.

that is, through a relatively small series containing the "key" bed. In the western part of Cowley county wells are cored through the Herington limestone, which there lies at a shallow depth.

The Winfield anticline, which is about midway between the Dexter and "granite ridge" folds, trends approximately parallel to them and is discernible in the surface beds, the Winfield limestone and other traceable rock layers being widely exposed in the vicinity. The degree of dip of the surface beds is much less than in either of the other two folds, but like them this fold has the steeper dips on the east flank, and local constrictions divide it into a number of "highs" separated by low structural saddles. These three anticlinal folds, the Dexter-Otto, Winfield, and "granite ridge," are the three most extensive structural units evident in the surface beds in the county, and their general features are duplicated in many other lesser folds. Structural terraces, noses, domes, synclines and basins are numerous. Although features such as the Dexter anticline are striking because of their size, it is the noses, small domes and anticlines, and shallow basins that are most abundant in the county and so constitute the typical structural features. Many of these, although by no means all, have an alinement similar to that of the larger features. The deviations in attitude from horizontality are generally so slight as to be impossible of detection with the eye, and it is only by detailed plane-table mapping, carrying accurate altitudes, that the true attitude of the beds can be determined.

Attitude of the Mississippian Surface.

The Mississippian strata were deposited on the bottom of a marine sea, were later elevated above the sea and flexed into gently arched folds, and were finally subjected to a long period of erosion. Because the strata were hard and resistant erosion was more effective on the higher lands, which were also structural "highs"; consequently the result was similar to that obtainable by running a plane over a folded layer of wax or putty; the tops of the folds would be planed off, leaving the layer thinner at those localities. So it was with the Mississippian beds: the rocks at the tops of the folds were eroded away more rapidly than those on the flanks and in the downfolds, reducing the thickness over the crests of the structural "highs."

The upper surface of the Mississippian series is shown on Plate XI by contour lines representing levels at intervals of 50 feet. Accordingly it is a topographic map of the buried Mississippian surface, but because the topographic features of this surface appear to conform in large part with the structural features of the Mississippian beds the map represents also a modified picture of the attitude of these strata. This conformity of structure and buried topography was produced during the long period subsequent to folding of the strata, when erosion prevailed and this old surface was formed. The present strike of the Mississippian surface in Cowley county is approximately N. 35° W., and it slopes southwestward at an average rate of about 22 feet to the mile. It is highest near the northeast corner of the county, where it is 1,300 feet below sea level, and lowest near the southwest corner, where it is 2,300 feet below sea level.

The Mississippian beds are shown as being deformed in a series of elongate folds trending northeast, approximately parallel with the trend of the "granite ridge." Inasmuch as the data that served as a basis for the contouring were obtained solely from records of drilled wells, there are necessarily large areas for which information was lacking and the projection of the contours across these areas, which constitute a large percentage of the total, is purely hypothetical. The actual conditions are, without doubt, much more complicated than those illustrated in Plate XI, but the information available from well records unsupplemented by surface maps indicates the generalized structural pattern shown.

The largest structural features shown are the same folds that are most prominent in the surface folds—the Dexter, Winfield, and "granite ridge" anticlines—on each of which there are local domes. A fourth prominent feature is an extensive "high" that extends practically across the county about midway between the Dexter and Winfield folds. Only a few wells have been drilled in this region, and so the contouring is necessarily very much generalized and subject to radical changes. This anticline appears to be alined with and probably constitutes the southwestward continuation of the Beaumont arch, which extends northeastward across the southeast corner of Butler county to and probably beyond Eureka.[81]

Thinning of Mississippian Beds Over Structural Features.

Because the thinning of the Mississippian series over the crests of the folds was accomplished by a removal of more of the upper part of the series there than in the troughs of the folds, a representation of the attitude of these strata must make due allowance for the variations in thickness. If such adjustments are made and a uniform thickness is assumed for the series, the structural features are

81. Ley, H. A., op. cit., p. 117.

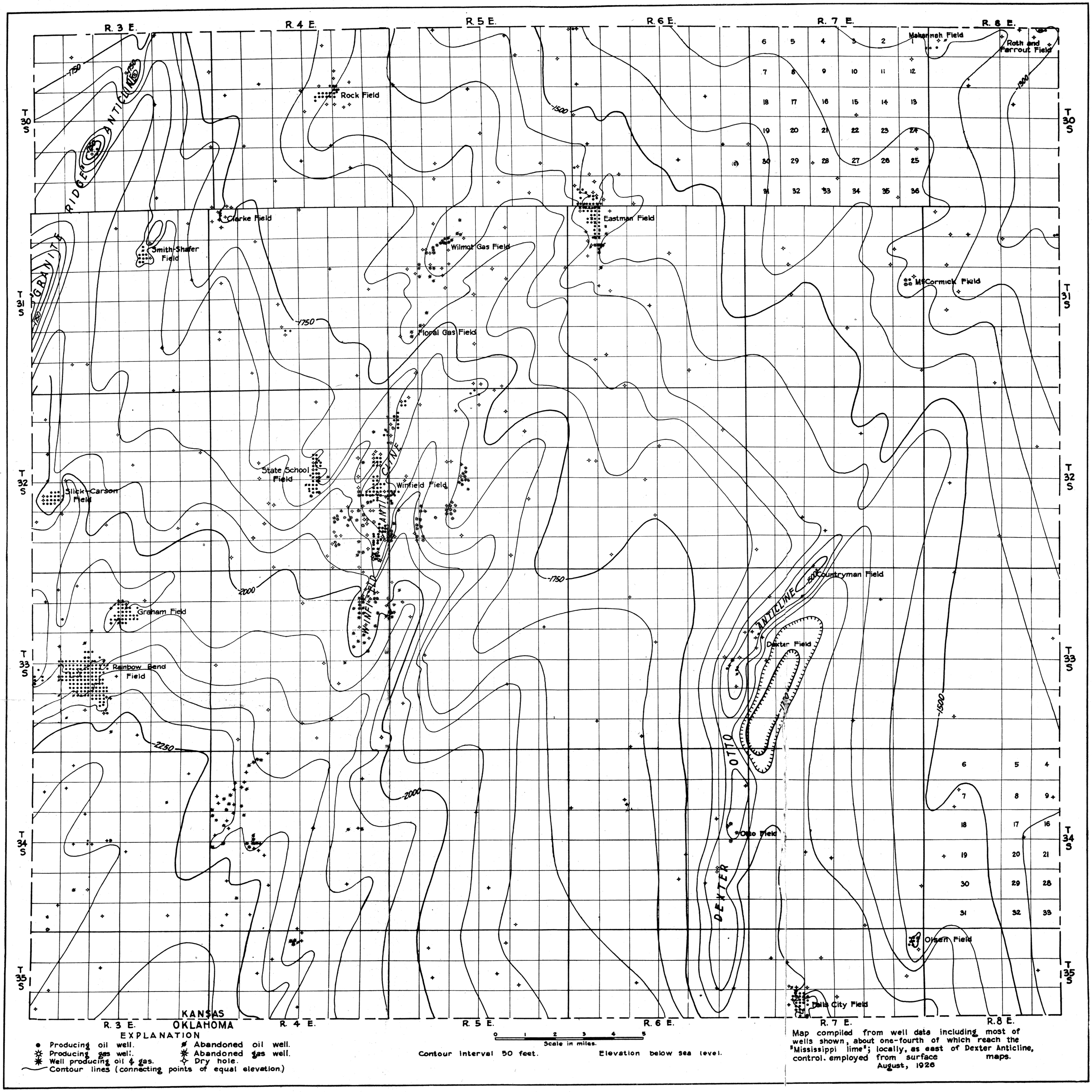

Plate XI.—Contour map of the upper surface of the "Mississippi lime" in Cowley county.

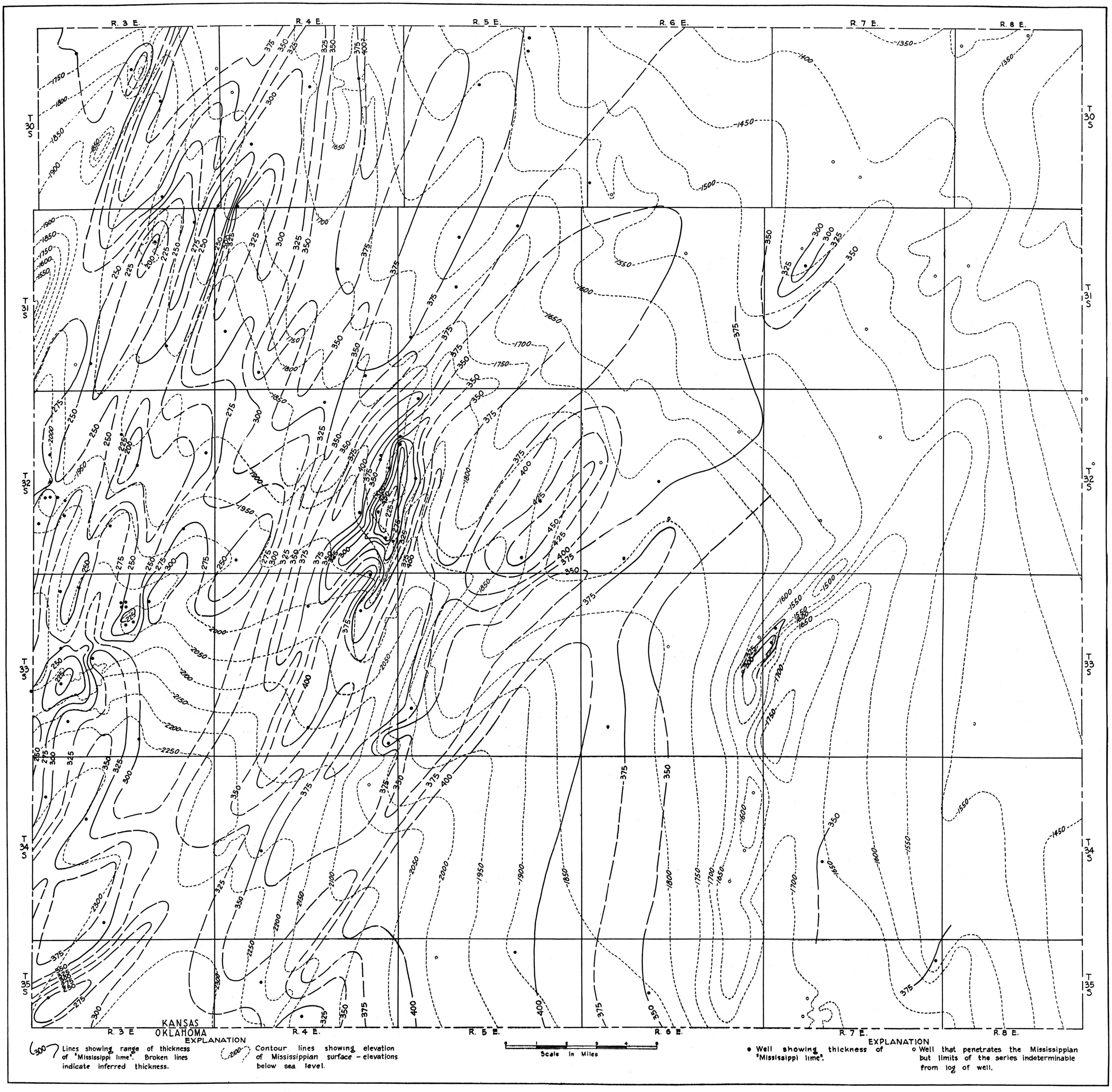

PLATE XII.—Sketch map showing thickness of the "Mississippi lime" and its relation to the attitude of the Mississippian surface in Cowley county.

greatly accentuated from the attitude shown on Plate XI. For example, from the crest of the Winfield anticline, in sec. 25, T. 32 S., R. 4 E., to the trough of the syncline three-quarters of a mile to the southeast the slope of the upper surface of the Mississippian amounts to about 110 feet. Data revealed by well logs indicate that the series is about 150 feet thicker in the synclinal trough than over the anticlinal crest. If the thickness was originally constant between the two points, the actual amount of eastward dip of the beds must then be the sum of these two amounts, which is 260 feet. A generalized picture of the thickness of the Mississippian series throughout much of Cowley county is presented on Plate XII by lines joining points of equal thickness (isopachous lines), and the attitude of the Mississippian surface is shown by dotted contour lines in order to show the relation between the two. The chief fact shown is that the Mississippian beds are much thinner over the crests of the folds than in the adjacent synclines. The actual relation is no doubt less simple and less systematic than that shown, but the data supplied by well logs furnish a general picture about as indicated.

Mississippian Surface at Time of Burial.

The upper surface of the Mississippian beds was a land surface that had been subjected to erosion for a long period prior to its burial by the Cherokee shale. During the time when sediments were accumulating upon this irregular surface deposits collected first in the low places and gradually encroached upon the higher parts, finally burying the entire surface of the Mississippian beds, including the highest hills. The surface of deposition was then essentially a horizontal plane. If the intervals between the surface of deposition and the buried erosion surface were known, the configuration of the buried surface could be indicated by a contour map similar to the representation of a sea or lake bottom based on measurements of the depths beneath the water surface. Any widespread layer such as a bed of limestone should represent the depositional surface at the time of its formation, and intervals between this limestone bed and the buried erosion surface could be calculated from records of drilled wells. There is no such marker bed close above the Mississippian surface that is readily recognizable in well logs, but the Fort Scott limestone, next above the Cherokee shale, provides such a datum plane. The position of the Fort Scott ranges from 125 feet to a little more than 300 feet above the Mississippian surface. On a map of the county (not shown here) contour lines were drawn representing the intervals between the base of the Fort Scott limestone and the upper surface of the Mississippian beds. If the Fort Scott limestone was deposited on a horizontal plane, and it probably did not depart much from horizontality, this map should show the attitude and conformation of the Mississippian surface at the beginning of Fort Scott time. The map indicates that the Mississippian surface sloped gently southeastward and was characterized by very low hills over the anticlines and domes, with intervening shallow valleys. The surface was nearly a peneplain. The topographic relief in the area of the Slick-Carson dome was only 10 to 15 feet, in the area of the Winfield anticline even less, and in the area of the Dexter-Otto anticline there was a maximum relief of 35 feet.

Structural Details of the Slick-Carson Dome.

Only a few data relative to the structural features of the Ordovician beds are available in Cowley county, but it is known from well records obtained in the general region that these beds are commonly more steeply inclined over domes and anticlines than the upper surface of the Mississippian beds. Numerous wells in the Slick-Carson field of Cowley county have penetrated the Pre-Chattanooga beds, and the data revealed by them are in accord with those found elsewhere. Figure 7 shows the attitude of the upper surface of the Pre-Chattanooga beds (Ordovician?), the Mississippian surface, and the base of the Fort Scott limestone, also the attitude of the Mississippian beds after restoration to a uniform thickness of 300 feet. The structure of the restored Mississippian surface, which should represent more nearly the true attitude of the beds, is not materially different from that of the Pre-Chattanooga surface, but the base of the Fort Scott limestone is much less steeply folded. Contouring on beds at higher horizons shows a progressive flattening upward, as is illustrated by the cross sections in Figure 7-E.

The flattening of the arch formed by the strata means a thicker prism of sediments on the flanks of the fold than on the crest. In the Slick-Carson field this thinning over the crest is slightly greater in the shale units than in the units occupied largely by limestone. This radial convergence in the shale toward the crests of the domes is a common phenomenon in dome-shaped folds in the Midcontinent region and is cited by Blackwelder[82] in his discussion of the Midcontinent structural features as one of several criteria that suggest condensation of sediments over a buried irregular surface.

82. Blackwelder, Eliot; The origin of the central Kansas oil domes: Am. Assoc. Petroleum Geologists Bull., vol. 4, p. 94; 1920.

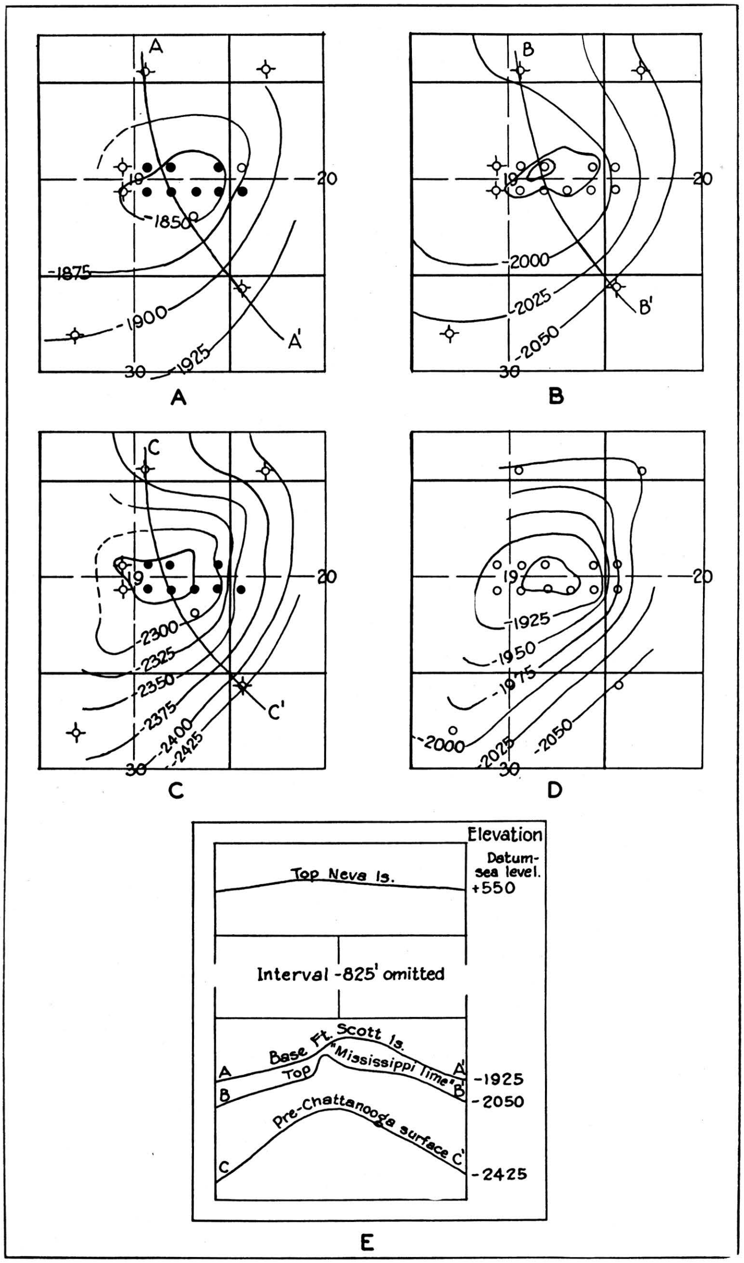

FIG. 7.—Structure contour maps of Slick-Carson field, T. 32 S., R. 3 E., Cowley county. A—Contours drawn on base of Fort Scott limestone. B—Contours drawn on surface of Mississippian rocks. C—Contours drawn on beds of Pre-Chattanooga age. D—Contours drawn on hypothetical restored top of Mississippian limestone, the series assumed to be 300 feet thick. E—Cross sections of figures A to D. (Neva limestone, represented, lies 600 feet beneath the present surface, 2,375 feet above the Fort Scott; contour map not shown.)

Origin of the Structural Features.

Inasmuch as no conclusive data to show the origin of the structural features of this region were obtained from the study of Cowley county, nothing more than a brief summary of a part of the recent writings[83] on this phase of the geology of the Midcontinent region will be given here. Numerous writers, including Blackwelder, Mehl, Powers, Rubey, and others, have sought to show that many of the structural features of this region are formed by the compaction of the sediments over buried uneven surfaces, the irregularities on the Pre-Cambrian, Ordovician and Mississippian surfaces being chiefly effective. The theory advanced may be briefly summarized as follows: If a surface of varying relief is buried by a sedimentary deposit or series of deposits the column of sediments over a hill or mountain will be shorter than one over a near-by valley. As layer upon layer is deposited pressure due to the accumulating load causes settling and compaction of the sediments, and the longer column over the valley, because of its length, should shrink more than the shorter one over the hill, provided the hill and other portions of the buried terrane are composed of rock in which there would be no appreciable amount of shrinkage. This greater compaction over the valleys would cause the rock layers to be bent downward there and to conform in general attitude with the configuration of the underlying surface. Characteristics that it is claimed should be pro-

83. Blackwelder, Eliot; The origin of the central Kansas oil domes: Am. Assoc. Petroleum Geologists Bull., vol. 4, pp. 89-94; 1920.
Mehl, M. G.; The influence of the differential compression of sediments on the attitude of bedded rocks: Science, new ser., vol. 51, p. 520; 1920 (abstract).
Powers, Sidney; Reflected buried hills and their importance in petroleum geology: Econ. Geology, vol. 17, pp. 233-259; 1922.
Gardescu, I. I., and Johnson, R. H.; The effect of stratigraphic variation on folding: Am. Assoc. Petroleum Geologists Bull., vol. 5, pp. 481-483; 1921.
Monnett, V. E.; Possible origin of some of the structures of the Midcontinent oil field: Econ. Geology, vol. 17, pp. 194-200; 1922.
Fath, A. E.; The origin of the faults, anticlines, and buried "granite ridge" of the northern part of the Midcontinent oil and gas field: U. S. Geol. Survey Prof. Paper 128, pp. 75-84; 1921.
Bloesch, Edward; Unconformities in Oklahoma and their importance in petroleum geology: Am. Assoc. Petroleum Geologists Bull., vol. 3, pp. 263-285; 1919.
Gardner, J. H.; The Midcontinent oil fields: Geol. Soc. America Bull., vol. 28, pp. 685-720; 1917.
McCoy, A. W.; A short sketch of the paleogeography and historical geology of the Midcontinent oil district and its importance to petroleum geology: Am. Assoc. Petroleum Geologists Bull., vol. 5, pp. 541-584; 1921.
Parks, E. M.; Migration of oil and water—a further discussion: Am. Assoc. Petroleum Geologists Bull., vol. 8, p. 704; 1924.
Rubey, W. W.; Progress report on a subsurface study of the Pershing oil and gas field, Osage county, Oklahoma: U. S. Geol. Survey Bull. 751, pp. 23-70; 1924.
Rubey, W. W., and Bass, N. W.; The geology of Russell county, Kansas: Kansas Geol. Survey Bull. 10, pp. 72-86; 1925.
Heald, K. C.; Discussion of Mr. Power's statement: Geol. Soc. America Bull., vol. 36, p. 388; 1925.
Hedburg, H. D.; The effect of gravitational compaction on the structure of sedimentary rocks: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 1035-1072; 1926.
Rubey, W. W.; Discussion of Hedburg's paper: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 621-632; 1927.
Charles, H. H.; Oil and gas resources of Kansas, Part VII, Anderson county, pp. 28-35; 1927.

duced by such a process and are actually found in many folds in the region were summarized by Blackwelder[84] as gently inclined beds that are underlain by more steeply inclined beds, thinning of shale units toward crests of anticlines, lack of systematic arrangement of folds, and the presence of hills of hard rock beneath the anticlines in the Pennsylvanian and Permian beds. Powers[85] has discussed this hypothesis, compared it with others, and suggested its operation coupled with slight movements resulting from tangential compression.

The Mississippian structure map of Cowley county (Pl. XI) indicates a definite alinement of the buried folds, suggesting folding by tangential compression rather than compaction over buried topography, but it is frankly admitted that throughout extensive areas where data are lacking the actual attitude of the Mississippian surface may differ widely from that shown. A map showing the range in the thickness of the Cherokee shale (drawn for purposes of study but not reproduced in this report) indicates that the features of the Mississippian surface were probably not sufficiently prominent to be reflected in the present surface beds by compaction of the overlying sediments. Deeper-lying irregularities, perhaps those on the Pre-Cambrian surface, would have to be called upon to supply the base over which compaction has taken place. The finding of "granite" at relatively shallow depth beneath a pronounced fold near Oxford, a short distance west of Cowley county, the reported occurrence of similar rock at moderate depth beneath the Dexter anticline, and the radial convergence of the shale units over the anticlines in the county (see Fig. 9) may lend support to the compaction theory. However, the last-named item is capable of other explanations. It may indicate progressive uplift.[86]

Many characteristics of the folds of the region are more in accord with the theory of tangential compression. Some of the features present that are explained more plausibly by assuming the rocks to have been subjected to tangential compressive forces are the regional alinement of most of the major trends of folding, the systematic arrangement of fault zones in parts of the region, the elongated buried folds from which great thicknesses of sediments were removed in post-Mississippian, Pre-Pennsylvanian time, the faulting of the Mississippian and older beds, and the tilting of axes

84. Blackwelder, Eliot: Am. Assoc. Petroleum Geologists Bull., vol. 4, pp. 93, 94; 1920.

85. Powers, Sidney; Reflected buried hills and their importance in petroleum geology: Econ. Geology, vol. 17, pp. 252-258; 1922.

86. Fath, A. E.: Kansas Geol. Survey Bull. 7, p. 165; 1921.

of the folds. Changes in the lithologic character of the sediments over anticlinal folds, although not known to be manifest in Cowley county, are said by Ley[87] to be present in the Pennsylvanian beds over the Longton ridge, in Elk county, adjacent to Cowley county on the east, indicating progressive folding in Pennsylvanian time. The chief objection to this theory appears to be that much of the region considered is so far removed from any source of tangential pressure (the assumption commonly being made that the source must have been in the region of the Ozark mountains or the ranges of southern Oklahoma), that the stratigraphic section as well as the basement upon which it rests would not transmit the pressures required to produce the folds.

Gardner[88] believes that the characteristics of the Midcontinent folds are not out of harmony with the theory of origin by tangential pressure. It is his belief[89] that local folds are "not the result of tangential pressures moving outward from an area of maximum lift, such as the Ozark and Arbuckle areas, but that these smaller folds are the result of the same pressure that produced the large lift; that they are smaller expressions of the same thing and not secondary results; that they were probably coincident and represent areas of failure to withstand deforming forces, the components of which were essentially vertical." It is Gardner's opinion that the disturbing forces culminated in the Arbuckle, Ouachita, and Ozark uplifts, thus relieving the pressure elsewhere and stopping the formation of the small folds rather than causing them. He accounts for the reduced section above anticlines and domes on the assumptions that the disturbing forces were deep-seated, that the most intense folding occurred at great depth, and that the forces acting at shallow depth were resultants that were in large part vertical. Gardner aptly illustrates the effect that a vertical force from below would have upon alternate layers of hard and soft rocks by likening the process to the raising of a tent from a center mast pole; "An extra pressure is necessary at the point of application due to the weight of the material on the flanks and to the resistance against folding; . . . strata above the point of lift must transmit pressure to higher strata and consequently are subjected to greatly increased compression, resulting in distortion and lessening the thickness of compressible beds above the area where pressure is applied."

87. Ley, H. A.; Subsurface observations in southeast Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 8, p. 450; 1926.

88. Gardner, J. H.; Rock distortion on local structures in the oil fields of Oklahoma: Am. Assoc. Petroleum Geologists Bull., vol. 6, pp. 228-239; 1922. The vertical component in local folding: Southwestern Assoc. Petroleum Geologists Bull., vol. 1, pp. 107-110; 1917.

89. Gardner, J. H., op. cit. (1922), pp. 236-237.

Relation of the Attitude of the Beds to the Occurrence of Oil and Gas.

Most of the oil and gas in Cowley county occurs on structural "highs" of some type, although some of the most pronounced folds produce little or none and some very productive pools appear to be largely independent of structural conditions and to be controlled by the porosity and extent of the reservoir bodies. Even a slight deviation from the regional monoclinal dip in the surface beds is worthy of a test well. Many successful oil and gas wells have been drilled where structure-contour maps of the surface rocks using a contour interval of 10 feet show only a nose—that is, not even a closure of 10 feet. Surface structure of this type is illustrated in Figure 15, showing the attitude of the surface beds in the Clarke field; Figure 21, showing a structural nosing of the surface beds about 1½ miles southeast of Akron; and Figure 10, a structure-contour map of the State School field. The Dexter-Otto anticline, shown in Figure 18, is an example of a pronounced fold evident in the surface beds but containing a relatively small amount of oil and gas so far as has yet been found. Fields such as the Eastman, Rock, and Rainbow Bend appear to be, in the main, defined by the porosity and lensing out of the reservoir sand bodies, although the accumulation of oil and gas in these localities may be dependent in a broad way upon the attitude of the beds.

OIL AND GAS.

The discovery of oil and gas in Cowley county antedates the advent of Kansas among the leading oil and gas producing states. Kansas has produced oil since shortly after the Civil War, and yet its annual production had never exceeded 5,000,000 barrels until 1916. In that year and the next two, owing to the flush production of the El Dorado, Towanda, and Augusta pools, of Butler county, the output increased with rapid strides. The total in 1918 exceeded 45,000,000 barrels, which constitutes the peak of production to date. Although Cowley county contributed but little to this rapid rise, interest, and activity in the search for oil in the county were coincident with it. A little gas had been found near Winfield as early as 1902, and gas had been discovered at Dexter in 1905. The Dexter gas had attracted wide attention, because it was the first natural gas in which helium had been discovered. A little oil was found near Dexter in 1914; the Peacock oil field, near Winfield, was opened in 1916, and the Clarke pool in 1917. The Winfield district became a large oil producer in 1922, after having been a productive gas field for several years. The Eastman, Rainbow Bend, and Rock Fields, opened in 1923, swelled the county's production in 1924 and really marked the entrance of Cowley county into the group of leading oil-producing counties of the state. Rainbow Bend reached its peak in the summer of 1925, when it produced a daily average of 22,000 barrels for a short time and completed the year with a production of nearly 4,000,000 barrels. The Slick-Carson and Graham fields were opened in 1924 and added nearly 1,500,000 barrels of oil to the county's production in 1925 and nearly 1,000,000 barrels in 1926. The Winfield district had maintained an annual output of about 750,000 barrels for several years prior to the discovery of the State School pool, which added materially to the district's production in 1926 and 1927, bringing the total to nearly 1,250,000 barrels in 1927.

The annual oil production, in barrels of 42 gallons, of Cowley county compared with the total production of the entire state for the years 1924 to 1927 is given in the following table.[90] The pro-

90. Data from *Oil and Gas Journal.*

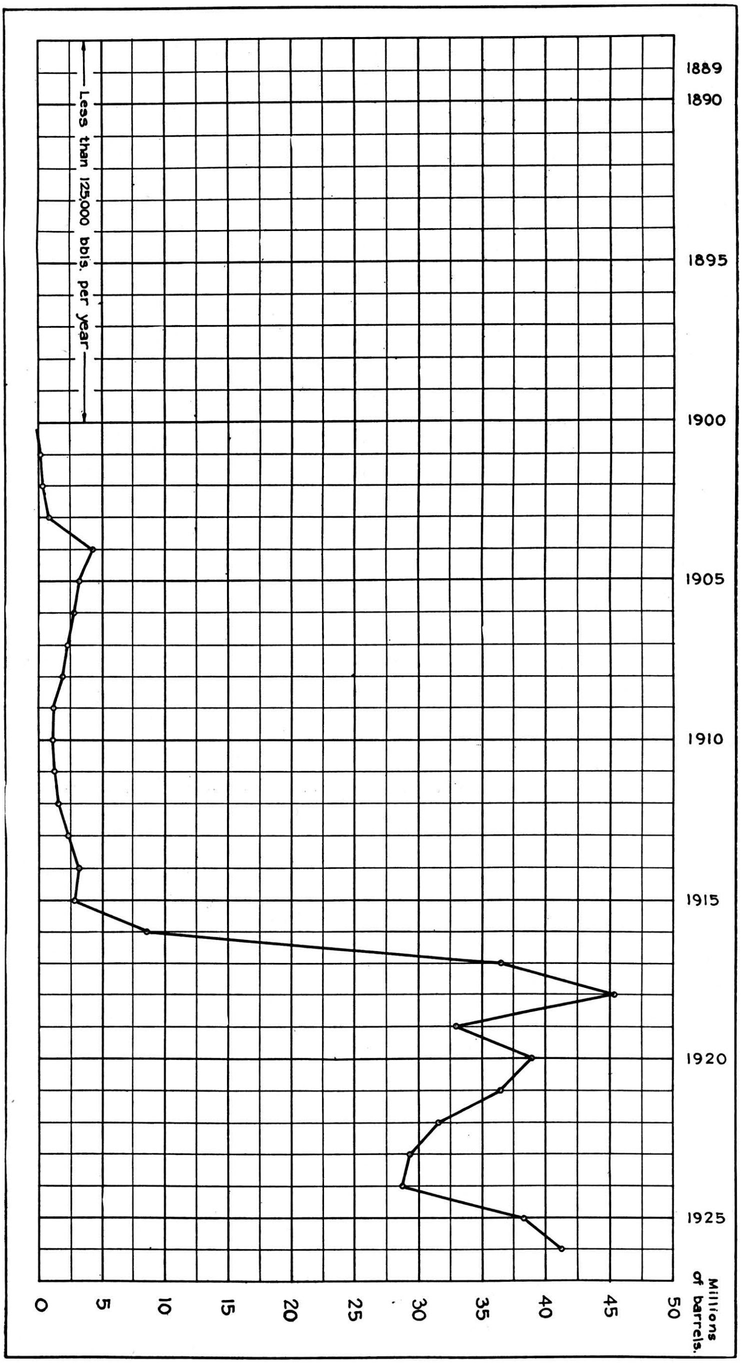

FIG. 8. Annual oil production in Kansas, 1889 to 1927.

duction of gas has been important for 10 years, but no data are available as to the amounts produced.

Year.	Cowley county.	Kansas.
1924	2,266,340	29,671,551
1925	7,038,874	38,151,622
1926	3,943,061	41,346,511
1927	3,303,691	41,943,577

The place that Cowley county has in the state's oil industry is shown by the drilling activity in the county in the last several years. Largely owing to the impetus furnished by the Rainbow Bend pool, the county was surpassed only by Greenwood county in the number of wells completed and was the leading county in the state in new oil production in 1925; in 1926 Cowley county stood fourth in number of wells completed and fifth in new production; in 1927 Cowley county was third in number of wells completed and fourth in amount of new production.[91]

The oil from different parts of the county and different horizons in any one field varies somewhat in quality, but the bulk of the oil produced is of good grade, ranging in gravity between 37° and 42° Baumé.

A part of Cowley county's oil is refined within her own borders, at refineries in Arkansas City. Refineries at Wichita and Ponca City, Okla., receive a part of the oil. Gasoline is extracted from the gas produced in the Rainbow Bend and Winfield fields. The gas produced in the county is used in part for domestic purposes within the county, but most of it enters the trunk pipe lines. Winfield has recently installed a municipal gas plant in place of one operated for years by the Cities Service Company and is getting its gas supply from wells east of the town.

Oil and Gas Fields.

Winfield District.

Location. The oil and gas fields here included in the Winfield district are near the town of Winfield, in the west-central part of Cowley county. The district embraces Tps. 32 and 33 S., Rs. 4 and 5 E., and includes the Winfield field proper, the State School, Peacock, Biddle, and Elrod pools, and a number of gas-producing areas east and south of these.

History. Gas was discovered about a quarter of a mile east of Winfield, in the southwest corner of the NW¼, sec. 26, T. 32 S., R. 4

91. Data from *Oil and Gas Journal.*

E., as early as 1902[92] at a depth of 460 feet, constituting the first discovery of gas west of the Flint Hills. The cost of the drilling was assumed by the city of Winfield through a bond issue of $15,000 voted for this purpose. The well was reported to yield 125,000 cubic feet of gas. It was not regarded as a commercial producer, and after being drilled to a depth of 1,400 feet it was abandoned. Two other wells, also yielding encouraging shows of gas, were drilled by the city near by.[93]

Little information concerning subsequent drilling is available. Meager items, such as dates on log records, indicate that many of the gas wells in the northeastern part of T. 33 S., R. 4 E., were drilled in 1915 and 1916; those in the southeastern part of T. 32 S., R. 4 E., in 1916 and 1917; and those between Tisdale and Winfield several years later. The first commercial oil well was drilled on the George Lierman farm, in the NE¼ NW¼ NE¼, sec. 25, T. 32 S., R. 4 E., where oil was found at a depth of 2,300 feet. The Minnehoma Oil and Gas Company then drilled the McFadden No. 1 well, in the NE¼ NE¼ SE¼, sec. 25, T. 32 S., R. 4 E., but found no oil in the 2,300-foot sand. It was drilled deeper and found oil in the uppermost few feet of the "Mississippi lime."[94] The exact date of this drilling was not learned, but it was probably about 1915. In 1916 the Peacock field was opened in section 36, with oil at a depth of 1,400 feet.[94] Dates of later development are mostly unavailable. Some time later the Emerald Oil Company deepened its Kukuk No. 7 well and found oil in the Bartlesville sand, near the base of the Pennsylvanian series.[94] Still later wells drilled a mile or more to the north found oil at depths of about 2,600 feet in the lower part of the Kansas City group. Oil was being produced in the Biddle pool early in 1922 and in the Elrod pool in 1923. Some of the wells near the center of sec. 6, T. 32 S., R. 5 E., were drilled in 1923, and the State School pool was opened in 1926. Development of parts of the Winfield district is still in progress.

Most of the wells drilled in the Winfield district and their approximate depth are shown by symbols on Figure 9. Although not so indicated on the map, many of the shallow gas wells are now abandoned. Recently a number of additional shallow wells (not shown in Fig. 9) have been drilled to furnish an additional supply to the municipal gas plant. In the heart of the Winfield pool proper from two to four wells are drilled on each location, each well tapping

92. Haworth, Erasmus; Mineral resources of Kansas, 1902, pp. 37-38; 1903.
93. Information supplied largely by John H. O'Connor, postmaster of Winfield.
94. These data furnished by Everett Carpenter, of Bartlesville, Okla.

a separate producing sand, but the scale of the map would not permit showing them. Therefore, this part of the map shows many less wells than are actually on the ground.

Stratigraphy. Stratified rocks consisting of interbedded red and gray shale and light-gray limestone of Permian age occupy the surface of the district. Only the limestone beds form conspicuous exposures throughout most of the district; the shale beds, because of their softness, readily weather into soil-covered slopes. The Permian rocks extend beneath the surface for 350 to 450 feet. Interbedded shale and limestone with minor amounts of sandstone of Pennsylvanian age underlie the Permian rocks and constitute a total thickness of about 2,750 feet, although they are thinned somewhat over the crest of the Winfield anticline. The Mississippian limestone ranges in thickness from 225 to 400 feet, and this formation also is thinnest over the crest of the Winfield anticline. Except for a few thin lenses of sandstone and limy shale, it consists entirely of limestone. Beneath the Mississippian limestone is 60 to 70 feet of black Chattanooga shale, underlain by a thick series of Ordovician strata composed of thick beds of siliceous limestone and some shale. One well in this district drilled on the county poor farm in the northeast corner of SE¼, sec. 34, T. 32 S., R. 4 E., has penetrated the uppermost 700 feet of the Ordovician strata, reaching a total depth of 4,140 feet. Throughout this thickness the strata consist of alternating thick beds of limestone, sandy limestone, and sandstone.

Structure. The accumulation of oil and gas in the Winfield district is in the main controlled by the structural attitude of the stratified rocks, shown in a general way by the contour map (Pl. XI), although the lensing out of the producing sand bodies is in parts of the district equally effective. The oil and gas deposits have accumulated in the higher parts of the anticlinal folds, in porous beds that are extremely lenticular in their occurrence. The most prominent structural feature in the district is the Winfield anticline, which trends slightly east of north through the northeastern part of T. 33 S., R. 4 E., and the southeastern part of T. 32 S., R. 4 E., and thence swings more strongly to the northeast and extends across the northwestern part of T. 32 S., R. 5 E. The Peacock, Winfield, Biddle, and Elrod pools, in T. 32 S., Rs. 4 and 5 E., and the gas pool in the northeastern part of T. 33 S., R. 4 E., are on this fold. A rather pronounced syncline in which there are no oil or gas wells parallels this anticline on the east, and a less pronounced one,

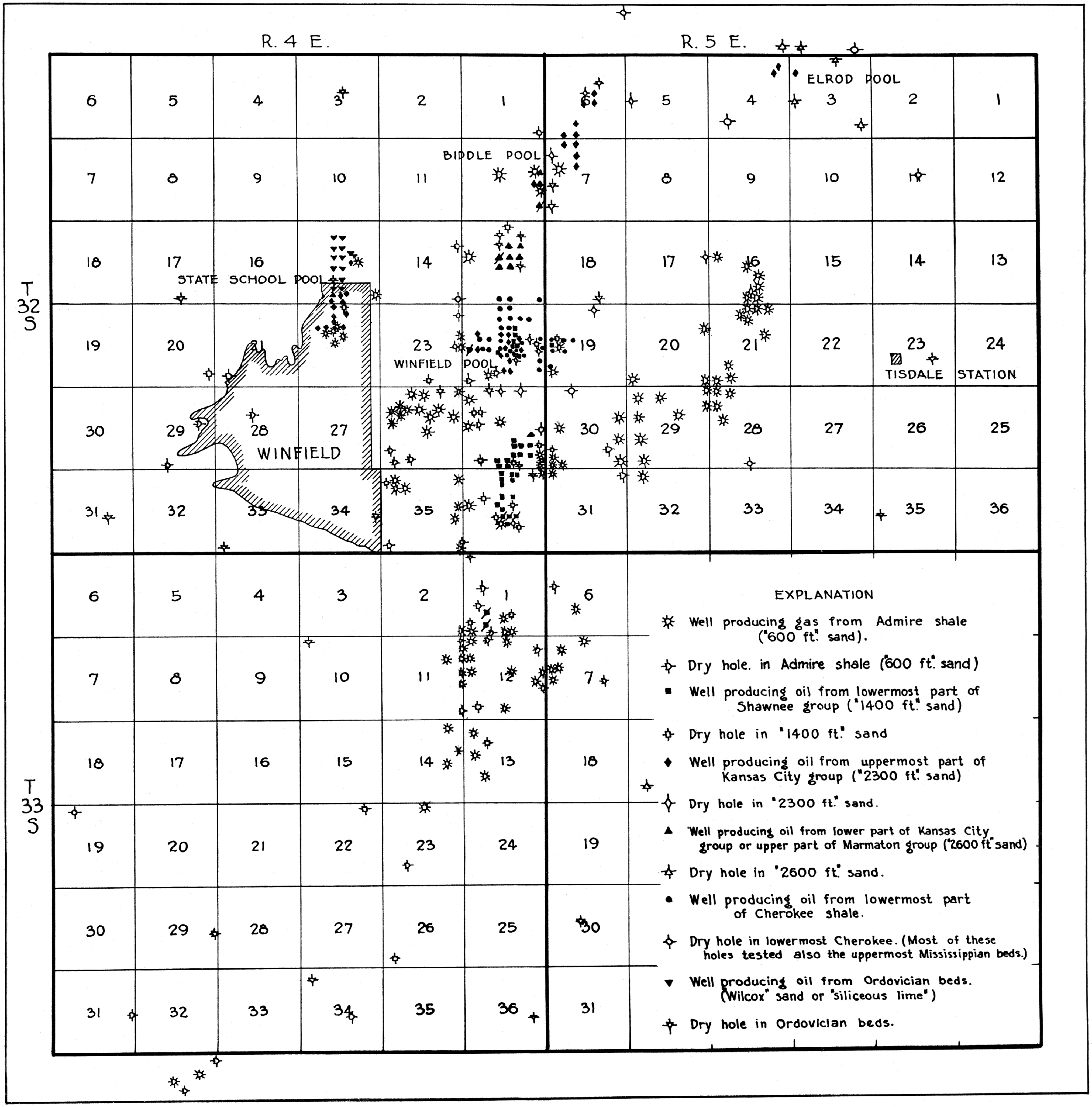

Fig. 9.—Oil and gas wells in the Winfield district.

separating the Winfield and State School pools, parallels it on the west. The State School pool lies on a gently dipping anticlinal nose in the surface rocks that trends approximately parallel with the Winfield fold. Eastward from the trough of the syncline that borders the Winfield anticline on the east the rocks rise at a fairly uniform rate for several miles to the central part of T. 32 S., R. 5 E., in the area of the gas pools in secs. 16, 21, and 28, where this uniform attitude is slightly interrupted by a gently dipping fold trending southwestward. No doubt many more structural irregularities in this district would be shown by detailed maps of the rock layers that crop out at the surface, but such data are not available for publication at this time.

Peacock pool. Oil and gas have been produced since 1916 in sec. 36, T. 32 S., R. 4 E., 1½ miles southeast of Winfield, in the area known as the Peacock field. This area is largely depleted, however, as only two or three wells are still producing. Production has been extended northward into the S½, mainly the SE¼, of sec. 25. Oil is produced chiefly from the "1,400-foot" or Peacock sand, which is a zone in the lower part of the Shawnee group, about 150 feet above the Oread limestone, that contains several relatively thin beds of sandstone with interbedded shale and limestone. Gas was found in no fewer than three sands in the Admire shale at depths ranging between 450 and 700 feet, and wells producing as much as 3,000,000 cubic feet of gas daily were drilled to these shallow sands. Beneath these is a thick water-bearing sand near the base of the Admire. A sandy zone near the middle of the Shawnee group, above the Peacock sand, also yields water. Several sandstone zones beneath the Peacock sand have been penetrated by deep holes at the edge of the producing area. Shows of oil have been found in sands in the Douglas, Lansing, and Kansas City groups. Oil is produced in the northwest corner of the NE¼ SE¼, sec. 25, from sand near the Kansas City-Marmaton contact, probably in the uppermost part of the Marmaton, struck at a depth of 2,675 feet. A number of deep wells drilled in the edge of the field report thick beds of sandy shale in the Cherokee shale with no indication of oil production from them. One well had a good show of oil from the uppermost part of the Mississippian limestone. The Ordovician rocks yielded water in these deep wells, but as none of them were drilled on the highest part of the fold they do not prove conclusively that the Ordovician beds contain no oil here.

An analysis of oil from the Peacock sand of this field by the United States Bureau of Mines is given below:

Sample No. 584, Peacock field, Cowley county, Kansas.

Specific gravity, 0.853; Baumé gravity, 34.1°; sulphur, 0.23 per cent; water, 0.1 per cent; Saybolt Universal viscosity at 70° F., 65.0; at 100° F., 49.2; pour test, 14° F.

DISTILLATION, BUREAU OF MINES HEMPEL METHOD.

Air distillation; barometer, 738 millimeters. [First drop at 85° C. (185° F.).]

Temperature.		Cut, per cent.	Sum, per cent.	Gravity.		Viscosity.	Cloud test, deg. F.
Deg. C.	Deg. F.			Specific.	Deg. B.		
75–100	167–212	1.0	1.0	0.737	60.0	....	....
100–125	212–257	5.7	6.7				
125–150	257–302	6.0	12.7	.753	55.9	....	....
150–175	302–347	6.7	10.4	.773	51.1	....	....
175–200	347–392	6.5	25.9	.790	47.2	....	....
200–225	392–437	6.7	32.6	.808	43.3	....	....
225–250	437–482	6.4	39.0	.820	40.7	....	....
250–275	482–527	7.1	46.1	.834	37.9	....	....
Vacuum distillation at 40 millimeters.							
Up to 200	Up to 392	5.1	5.1	.855	33.7	41	9
200–225	392–437	6.1	11.2	.865	31.9	48	32
225–250	437–482	6.6	17.8	.874	30.2	64	52
250–275	482–527	5.1	22.9	.883	28.6	94	68
275–300	527–572	6.3	29.2	.896	26.3	154	86

Carbon residue of residuum, 8.68 per cent.

Approximate summary.

	Per cent.	Gravity.	
		Specific.	Deg. B.
Gasoline and naphtha	25.9	0.763	53.5
Kerosene	20.2	.821	40.5
Gas oil	11.2	.860	32.8
Light lubricating distillate	11.7	.878	29.5
Medium lubricating distillate	6.3	.896	26.3

Winfield pool. In the Winfield pool proper, centering in the central part of sec. 24, T. 32 S., R. 4 E., gas has been produced from the "600-foot" sand, in the Admire shale; oil and gas from the Peacock or "1,400-foot" sand, in the lower part of the Shawnee group, at depths ranging between 1,400 and 1,500 feet; oil with gas from the "2,300-foot" or Layton sand, in the uppermost part of the Kansas City group, at depths of about 2,300 feet; and much oil with gas from a thick sand in the lowermost part of the Cherokee shale, correlated with the Bartlesville sand of Oklahoma. Ordovician beds have not been tested on the highest part of the fold containing the Winfield pool, but a number of wells drilled in the near vicinity, on the flank of the main anticlinal fold, have found water in the uppermost beds of the Ordovician.

The largest initial production of oil per well was found in the Bartlesville sand, a few wells producing more than 750 barrels a day, and most of them about 200 barrels a day. Initial oil production per well from the "2,300-foot" sand was comparatively small, and that from the "1,400-foot" sand was around 200 to 300 barrels a day. The initial daily production in the shallow gas wells was relatively small, rarely exceeding 2,000,000 cubic feet.

Sands other than those described above as producing bodies have yielded shows of oil or gas in the Winfield pool. In some wells as many as three sands in the Admire shale have yielded gas flows. A thin sand that is present in only a few wells about 150 feet above the horizon of the "1,400-foot" oil sand has produced shows of gas, and a lower sand in about the middle of Douglas group has yielded shows of oil in a few wells. A thick sand that occurs in the uppermost part of the Lansing group as here correlated is widespread in Cowley county and yielded shows of oil in a few wells drilled in the Winfield pool.

There is a gasoline absorption plant in this field. Gasoline is extracted from gas produced with the oil from three sands—the "1,400-foot," the "2,300-foot," and the Bartlesville sand. About one-third to one-half gallon of gasoline is recovered per 1,000 cubic feet of gas handled, and the plant has an average daily run of about 4,000 gallons.

Rockwell pool. Several wells near the center of sec. 13, T. 32 S., R. 4 E., have produced oil from a relatively thin sandstone that occurs a little more than 200 feet beneath the top of the Kansas City group. Throughout most of the productive area, which is small, the producing sand is only about 5 feet thick; nevertheless, the wells have yielded initially a fair amount of oil. The producing wells are listed below:

Farm.	Well No.	Operating company.	Location in sec. 13, T. 32 S., R. 4 E.	Initial daily production (bbls.).
Rockwell	4	Marland Oil Co.	Northeast corner SW¼ NE¼	595
do	3	Marland & Neely	Northwest corner SW¼ NE¼	150
do	1	W. M. Neely Oil Co.	Southwest corner SW¼ NE¼	225
do	2	Marland & Neely	Southeast corner SW¼ NE¼	130
Spengler	1	Sinclair Oil & Gas Co.	Southwest corner SE¼ NW¼	625
Newman	1	J. A. Hull Co.	Northeast corner NE¼ SW¼	260
Cook	1	Gypsy Oil Co.	Northwest corner NW¼ SE¼	200
Total				2.185

Dry holes have been drilled north, northwest, and southeast of the producers. Most of these dry holes penetrated a thin sand at the horizon of the producing sand, but it failed to yield oil.

Only three of the wells drilled around the center of section 13 produced shows of gas in the Admire shale, although sand bodies in this formation ("600-foot" sand) yield gas abundantly throughout an extensive area in this general region. Very little sand capable of serving as a gas reservoir is recorded in the formation in section 13, which is probably the reason for the absence of gas accumulation. A dry hole near the east edge of section 14, half a mile west of the oil pool and far down the west flank of the fold, shows two thick beds of sand carrying water in the lower part of the Admire shale, and a well near the west quarter corner of section 13 is reported to have yielded a small amount of gas from one of these sands.

Beds of sandstone about 150 feet above the base of the Shawnee group are present throughout the field but yield water; a show of oil is reported from one well. A sandstone bed that ranges between 50 and 160 feet in thickness in the uppermost part of the Lansing group, and throughout the area occurs at a depth of about 1,900 feet, produced a show of oil in three wells and an abundance of water in all wells. The uppermost beds of the Kansas City group, struck at about 2,300 feet, are sandy throughout much of the field and consist of limestone in other parts; several wells reported shows of oil from this horizon but none sufficient for commercial production. These beds produce oil, however, in the central part of section 24, a mile south of this field. The chief producing sand of the field lies a little more than 200 feet beneath the top of the Kansas City group. Four wells in the field have been drilled through the lower beds of the Pennsylvanian and through the Mississippian limestone and Chattanooga shale into the uppermost few feet of the Ordovician rocks. The logs of these wells show, aside from the porous layers described above, a thick bed of water-bearing sandstone near the contact of the Kansas City and Marmaton groups, probably in the upper part of the Marmaton, and sandstone in the lower part of the Cherokee shale; a show of oil from this lower sand was reported in only one well, although oil is obtained from sands at this horizon in the north end of the Winfield pool, less than half a mile south of this field. Porous lenses containing water were reported in the Mississippian limestone. The uppermost few feet of the Ordovician beds, which were encountered at a little less than

3,500 feet beneath the surface, are reported as water-bearing sandstone.

Biddle pool and northeast extension. Somewhat spotted and scattered oil production has been obtained from parts of secs. 6 and 7, T. 32 S., R. 5 E. and the eastern part of sec. 12, T. 32 S., R. 4 E. Several wells have produced a small amount of gas from sands in the Admire shale, struck at depths of about 600 feet. The "2,300-foot" sand, which is a sandy zone near the top of the Kansas City group, yields small amounts of oil in several wells in secs. 6 and 7, T. 32 S., R. 5 E. The "2,600-foot" sand, which occurs near the Kansas City-Marmaton contact, supplies the oil for a few wells of small yield in the eastern part of sec. 12, T. 32 S., R. 4 E. According to the log, one well, in the southwest corner of the NE¼ NW¼, sec. 7, produces oil from sand struck at a depth of 1,900 feet. Three wells just outside the producing area have been drilled entirely through the Pennsylvanian, Mississippian, and Chattanooga beds into the uppermost Ordovician rocks. According to the logs of these deep wells the lower part of the Cherokee shale contains a large amount of "red rock" in this locality at the general horizon of thick oil-bearing sands of the Winfield pool, 2 miles to the south. The Mississippian and Ordovician rocks that have been penetrated yielded only water in two of these wells, but gave good shows of oil in the Arkansas Fuel Oil Company's Crotsley No. 3 well, in the northwest corner of SW¼, sec. 7, T. 32 S., R 5 E. The wells drilled in this field are shown on Figure 9.

Elrod pool. A few wells in the northern parts of secs. 3 and 4, T. 32 S., R 5. E., have produced a small amount of oil from the uppermost beds of the Kansas City group. The producing beds are correlated with the "2,300-foot" sand of the Winfield pool but are encountered here at a depth of nearly 2,400 feet. The producing area is small. Several dry holes have been drilled through the "2,300-foot" sand and a little more than 300 feet of beds that lie beneath it. Two dry holes were drilled about a quarter of a mile north of the producers, one half a mile south, one half a mile east, and one a mile southeast. One hole, in the northeast corner of the SW¼ SW¼, sec. 4, was drilled into the uppermost beds of the Mississippian limestone, which yielded a show of oil. The lower part of the Cherokee shale, which contains oil-bearing sandstone beds in the Winfield pool, consists largely of "red rock" here, according to the log of this well. Another hole was drilled into the uppermost Mississippian rocks in the SE¼, sec. 34, T. 31 S., R. 5 E., about three-quarters of a mile northeast of the producing wells. The log records a show of oil about the middle of the Kansas City group, no sand in the Cherokee shale, and no shows of oil or gas in the Mississippian limestone.

A sample of the oil from the Elrod pool has been analyzed by the United States Bureau of Mines, with the results shown below.

Sample No. 585, Elrod field, Cowley county, Kansas.

Specific gravity, 0.853; Baumé gravity, 34.1°; sulphur, 0.20 per cent; water, none; Saybolt Universal viscosity at 70° F., 65.6; at 100° F., 49.8; pour test, 5° F.

DISTILLATION, BUREAU OF MINES HEMPEL METHOD.

Air distillation; barometer, 737 mm. [First drop, 54° C. (129° F.).]

Temperature.		Cut, per cent.	Sum, per cent.	Gravity.		Viscosity.	Cloud test, deg. F.
Deg. C.	Deg. F.			Specific.	Deg. B.		
75–100	167–212	4.1	4.1	0.701	69.7	....	....
100–125	212–257	5.5	9.6	.734	60.7	....	....
125–150	257–302	5.2	14.8	.754	55.7	....	....
150–175	302–347	5.8	20.6	.773	51.1	....	....
175–200	347–392	5.3	25.9	.790	47.2	....	....
200–225	392–437	5.9	31.8	.806	43.7	....	....
225–250	437–482	6.2	38.0	.820	40.7	....	....
250–275	482–527	6.5	44.5	.834	37.9	....	....

Vacuum distillation at 40 mm.

Up to 200	Up to 392	5.3	5.3	0.855	33.7	40	16
200–225	392–437	5.9	11.2	.861	32.6	47	30
225–250	437–482	5.7	16.9	.873	30.4	62	48
250–275	482–527	5.2	22.1	.884	28.4	93	61
275–300	527–572	6.7	28.8	.897	26.1	160	79

Carbon residue of residuum, 7.4 per cent.

Approximate summary.

	Per cent.	Gravity.	
		Specific.	Deg. B.
Gasoline and naphtha	25.9	0.753	55.9
Kerosene distillate	18.6	.820	40.7
Gas oil	11.2	.858	33.2
Light lubricating distillate	10.9	.878	29.5
Medium lubricating distillate	6.7	.897	26.1

Shallow gas fields. Relatively thin lenticular sands in the Admire shale of the Wabaunsee group yield gas throughout an extensive area in the Winfield district. Because these sand lenses occur about 600 feet beneath the surface throughout much of the district this gas-producing zone is known as the "600-foot" sand. Parts of the area were drilled as early as 1906, and the gas from this horizon supplied much of the gas used for domestic purposes in this region for many years. Much of the gas of the drilled area is now depleted, but other parts are still producing, and additional wells are being drilled.

The wells in the south-central part of section 16 and north-central part of sec. 21, T. 32 S., R. 5 E., about 2 miles northwest of Tisdale, yielded initial gas flows ranging from 1,000,000 to 3,250,000 cubic feet a day, with rock pressures of 170 to 250 pounds to the square inch. The initial daily production of the wells surrounding the corner common to secs. 20, 21, 28, and 29, T. 32 S., R. 5 E., ranged from a little less than 1,000,000 to 3,000,000 cubic feet, with rock pressures of 250 to 280 pounds to the square inch. The wells in the western part of section 29 and eastern part of sec. 30, T. 32 S., R. 5 E., yielded from 250,000 to 2,000,000 cubic feet of gas each, under a rock pressure of about 260 pounds to the square inch. The wells in the southwestern part of section 30 yielded as much as 3,250,000 cubic feet a day. Little information is available concerning the gas wells immediately east of Winfield. The meager data at hand indicate that several wells had an initial daily gas production of about 2,250,000 cubic feet. Many of the wells drilled in the area surrounding the corner common to secs. 1, 2, 11, and 12, T. 33 S., R. 4 E., yielded less than 1,000,000 cubic feet of gas daily, but a few wells are reported to have exceeded this amount. Initial production of less than 500,000 cubic feet each was obtained from the wells in secs. 13 and 14, T. 33 S., R. 4 E. The rock pressures reached 265 pounds to the square inch. The wells in the eastern part of section 12 yielded less than 1,000,000 cubic feet each. Other localities in this region, a few of which are the Winfield pool, the Biddle pool, and sec. 5, T. 34 S., R. 4 E., have furnished gas from the "600-foot" sand in amounts comparable to those from the wells above mentioned.

The gas from the Winfield district contains helium in greater amount than the average content of natural gas. An analysis[95] of a pipe-line sample taken in 1918 showed a helium content of 0.38 per cent, gas from a well 5 miles northeast of Winfield contained 0.813 per cent, and gas from a well 3 miles east of Winfield contained 0.34 per cent, according to analyses made by Dr. H. P. Cady, of the State University.

In a general way the gas accumulation of this district is controlled by the structural attitude of the strata. The largest yields are found in the highest parts of the folds; some gas in sands found at shallow depths extends far out on the flanks—in fact, much farther

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95. Rogers, G. S.; Helium-bearing natural gas: U. S. Geol. Survey Prof. Paper 121, pp. 100, 101; 1921.

than the oil and gas of the deeper-lying producing sands; no gas is found in the lowest parts of the broad synclines that lie between the anticlinal folds. The gas wells in secs. 16, 21, 28 and 29, T. 32 S., R. 5 E., are on a broad, gently flexed fold that trends southwestward. The gas and oil fields that lie near the line between R. 4 E. and R. 5 E. are on an extensive fold that trends slightly east of north throughout much of the region and swings northeastward across the northwestern part of T. 32 S., R. 5 E. This anticlinal fold broadens out in sec. 26, T. 32 S., R. 4 E., a fact which may account for the extreme width of the gas-producing area there. If the axial line of the southwestward-trending fold that extends through the central part of T. 32 S., R. 5 E., and contains the gas pools of secs. 16, 21, 28 and 29 is projected it will intersect the fold containing the Winfield pool at the locality of the gas wells in the northeastern part of T. 33 S., R. 4 E. It may be that the coalescing of these two gently dipping folds has formed a broad dome-shaped flexure in this locality, thus accounting for the wide distribution of the gas production there.

State School pool. The most recently opened pool in the vicinity of Winfield is the State School pool, in part within and in part just north of the northeastern part of the town. Most of the oil is produced from the uppermost Ordovician beds, from wells surrounding the center of sec. 15, T. 32 S., R. 4 E. The discovery well, on state land in the northwest corner of the SE¼, sec. 15, located by the State Geological Survey of Kansas and drilled by the J. A. Hull Oil Company, had an initial production from this horizon of nearly 12,000 barrels of oil a day. Most of the wells producing oil from this horizon quickly settle from an early flush production to a relatively small daily yield of oil and considerable water. The settled production of the west offset to the discovery well was 160 barrels a day; that of the north offset about 400 barrels; and the east offset, although having a initial production of 600 barrels, soon settled to a production of 30 barrels of oil and 60 barrels of water. Wells farther north of the discovery well have maintained a higher settled yield, however. The wells are pumped by means of gas forced into the oil sand under pressure, the gas being obtained in the field from shallower sands. Production from the Ordovician beds has not extended far south of the discovery well, but sands found at shallower depth have proved productive there. The chief production from shallow beds is obtained from a sandstone in the uppermost part of the Kansas City group, struck at a depth of about 2,300 feet. It

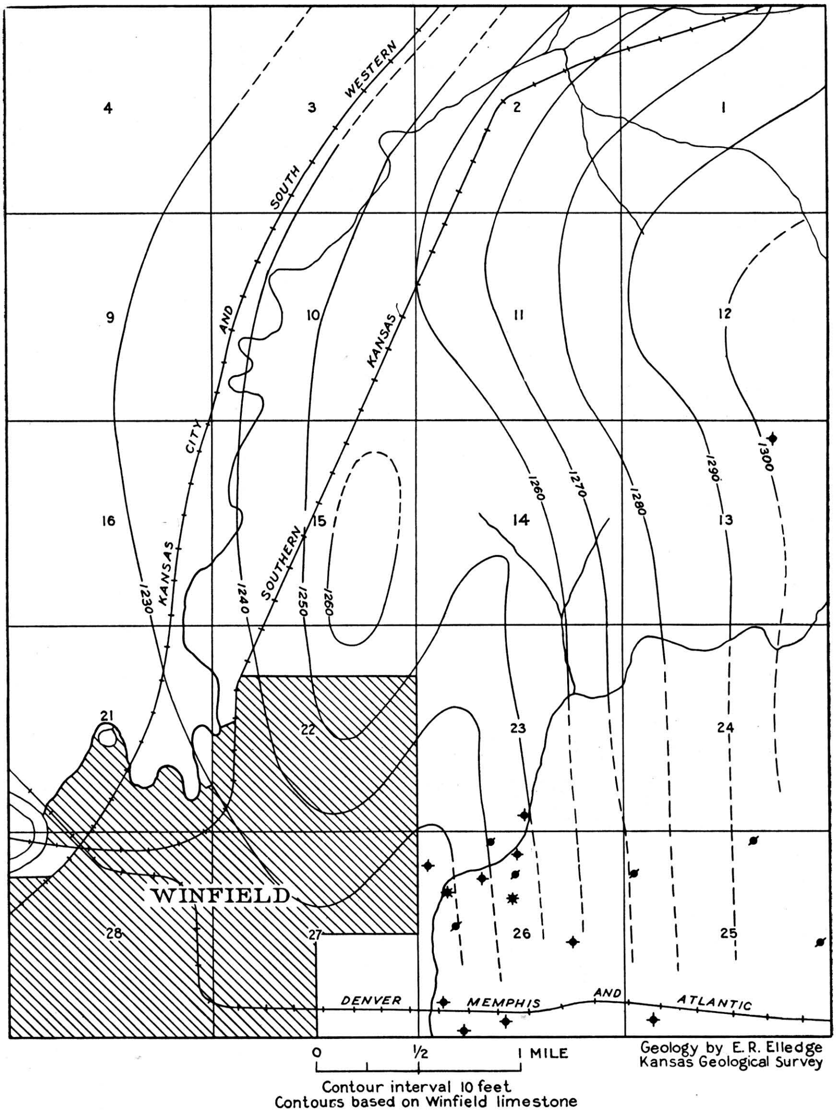

Fig. 10.—Structure contour map of the surface beds in the State School field, mapped by E. R. Elledge in August, 1920.

yields gas and oil. It is production from this sand that has extended the field southward within the city limits of Winfield. A few wells obtain oil and gas at a depth of about 2,500 to 2,600 feet from a sandy zone that is near the contact of the Kansas City and Marmaton groups.

The attitude of the surface rocks in the State School field is shown in Figure 10, made by E. R. Elledge for the Kansas Geological Survey. Structure contours were drawn on a single layer or bed of rock, the Winfield limestone, on the basis of a detailed plane-table survey of the area. The rocks have a regional dip to the west, with a local southwestward nosing.

Rainbow Bend Field.

Location. The Rainbow Bend field is in the extreme western part of Cowley county, in the western part of T. 33 S. R. 3 E., and the western extension of the field extends across the county boundary into Sumner county. The main part of the field lies within a great bend of Arkansas river, from which the name of the field is derived.

History of development and production. On November 28, 1923, a well being drilled in the northwest corner of the SE¼, sec. 20, T. 33 S., R. 3 E., on the Johnson farm, came in as a flowing oil well with an initial daily production of 337 barrels from sand struck at a depth of 3,198 feet. It is of interest that the original contract for drilling this well specified a total depth of 3,000 feet; an additional 198 feet discovered Cowley county's richest oil pool. The acreage block for the test had been assembled and a favorable report based on a geologic survey of the surface had been made by M. W. Baden, of Winfield, prior to the drilling of the well.

This field has been systematically developed because it is owned jointly by only three operating oil companies. The Independent Oil and Gas Company and the Waite-Phillips Company originally owned the entire field. Later the Marland Oil Company purchased one-half of the Independent's half interest and the Waite-Phillips Company was purchased by the Barnsdall Oil Company. At present the field is owned by the Barnsdall Oil Company, one-half interest; the Independent Oil and Gas Company, one-fourth; and the Marland Oil Company, one-fourth. The discovery well came in late in 1923; 18 wells were drilled in 1924, about 100 in 1925, and 10 in 1926.

The wells drilled in 1924 had an average initial production of 995 barrels of oil a day; those drilled in 1925 averaged 700 barrels, and those in 1926 less than 100 barrels. Practically all the wells drilled in 1926 were near the edge of the pool, as were also many of those drilled in 1925, although in 1925 the bringing in of a number of wells with initial yields greater than 2,000 barrels a day largely offset the adverse effect of small edge wells on the average. The initial daily production of the wells has been as high as 3,624 barrels, this amount being obtained by the T. Snyder No. 2 well, in the northwest corner of the SW¼ SW¼, sec. 21. Although the discovery well is near the center of the producing area, each offset to it had a much greater initial production than it, the amounts ranging from 637 barrels, made by the Charles Glasgow No. 1, the west offset, to 3,000 barrels, made by the L. Johnson No. 3, the south offset. The north offset made 1,906 barrels, and the east offset 900 barrels. The peak production of the field was reached in the summer of 1925, a year and a half after the bringing in of the discovery well, when a little more than 20,000 barrels of oil a day was produced. In June, 1927, the field was making a little less than 2,000 barrels of oil a day from 125 producing wells. It was also producing 4,000,000 cubic feet of gas a day, from which 8,500 gallons of casing-head gasoline was extracted. None of the gas was being returned to the oil sand, and it was stated by representatives of the operating companies that they felt confident the oil production could be more than doubled by returning gas to the sand, thus restoring in part the original rock pressure. The field has produced to date (June, 1927) a total of more than 8,500,000 barrels of 41° oil. The total production of gas and casing-head gasoline was not learned.

The peak of gas production was reached in June or July, 1925, when a daily production of 112,000,000 cubic feet was maintained. The gasoline content at that time was 1.5 to 1.6 gallons per 1,000 cubic feet of gas.[96]

Surface rocks. As shown on the county geologic map (Pl. I), most of the surface of the Rainbow Bend field is occupied by alluvium of the Arkansas river valley. The remainder of the field and an extensive surrounding region is underlain at the surface by the lower part of the Wellington formation, which is composed of soft shale and contains, except in small areas, scarcely any hard beds that crop out in sufficient prominence to serve as key beds for structural mapping. Throughout most of the area of outcrop of the Wellington formation the surface is a gently undulating soil-covered plain containing few bedrock outcrops. A bed of cavernous limestone about 3 feet thick crops out in secs. 7, 17 and 20, T. 33 S., R. 3. E. The exact stratigraphic position of this bed is not known, but it may be a bed of limestone and gypsum that is recorded in numerous core-drill logs in the vicinity, occurring about 50 feet above the base of the Wellington. On the basis of well-log correla-

96. Production figures supplied by R. B. Rutledge, of Barnsdall Oil Company.

tions it appears probable that the Herington limestone and perhaps even the uppermost part of the Enterprise shale have been removed by erosion from the structurally highest areas in parts of section 17.

Buried rocks. Most of the formations that crop out in Cowley county eastward from the Rainbow Bend field can be recognized in the logs of wells drilled in the field. The log of the Waite Phillips-H. Thurlow No. 7 well, in the SE¼, sec. 17, T. 33 S., R. 3 E., records the following formations, which crop out within Cowley county: The alluvium of Arkansas river valley is reported as being 53 feet thick, which is a representative thickness for much of the bottom land bordering the river. The Winfield limestone is believed to have been encountered at a depth of 100 feet, the Fort Riley limestone at 200 feet, the Wreford limestone at 245 feet, the Crouse limestone at 345 feet, the Cottonwood limestone at 515 feet, the Neva limestone at 565 feet, the Red Eagle limestone at 618 feet, the Foraker limestone at 655 to 705 feet. The Admire shale, Emporia (?) limestone, and Willard (?) shale extend to a depth of 1,015 feet, where two thin beds of limestone that may be the Burlingame limestone were struck. The sandstone between depths of 980 and 1,000 feet appears to be at the horizon of the sandstone in the Willard shale that is so well exposed in the town of Cedarvale, a few miles east of Cowley county.

Several thin beds of sandstone were encountered in the wells of the Rainbow Bend field above a depth of 2,000 feet, but none produced even shows of oil or gas. The sand in the uppermost part of the Lansing group, which is so productive a few miles north of the field, in the Churchill pool of Sumner county, and in and directly south of the town of Oxford, was encountered at depths of about 2,200 feet in the Rainbow Bend field, but produced only water. The uppermost part of the Kansas City group lies about 2,600 feet beneath the surface in the Rainbow Bend field and gave very good shows of oil—as much as 25 barrels. No commercial production is obtained from this sand, however, in the Rainbow Bend pool, although it produces about a mile to the northeast, in the Graham pool, and elsewhere in Cowley county. Snow and Dean[97] have correlated this sand with the Layton sand of Oklahoma and the Stokes sand of the El Dorado field. The only sand that produces oil or gas in the Rainbow Bend field is found near the base of the Pennsylvanian series lying directly upon the Mississippian limestone or separated from it by a relatively thin veneer of chert derived from the

97. Snow, D. R., and Dean, David; Rainbow Bend field, Cowley county, Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 9, pp. 974-982; 1925.

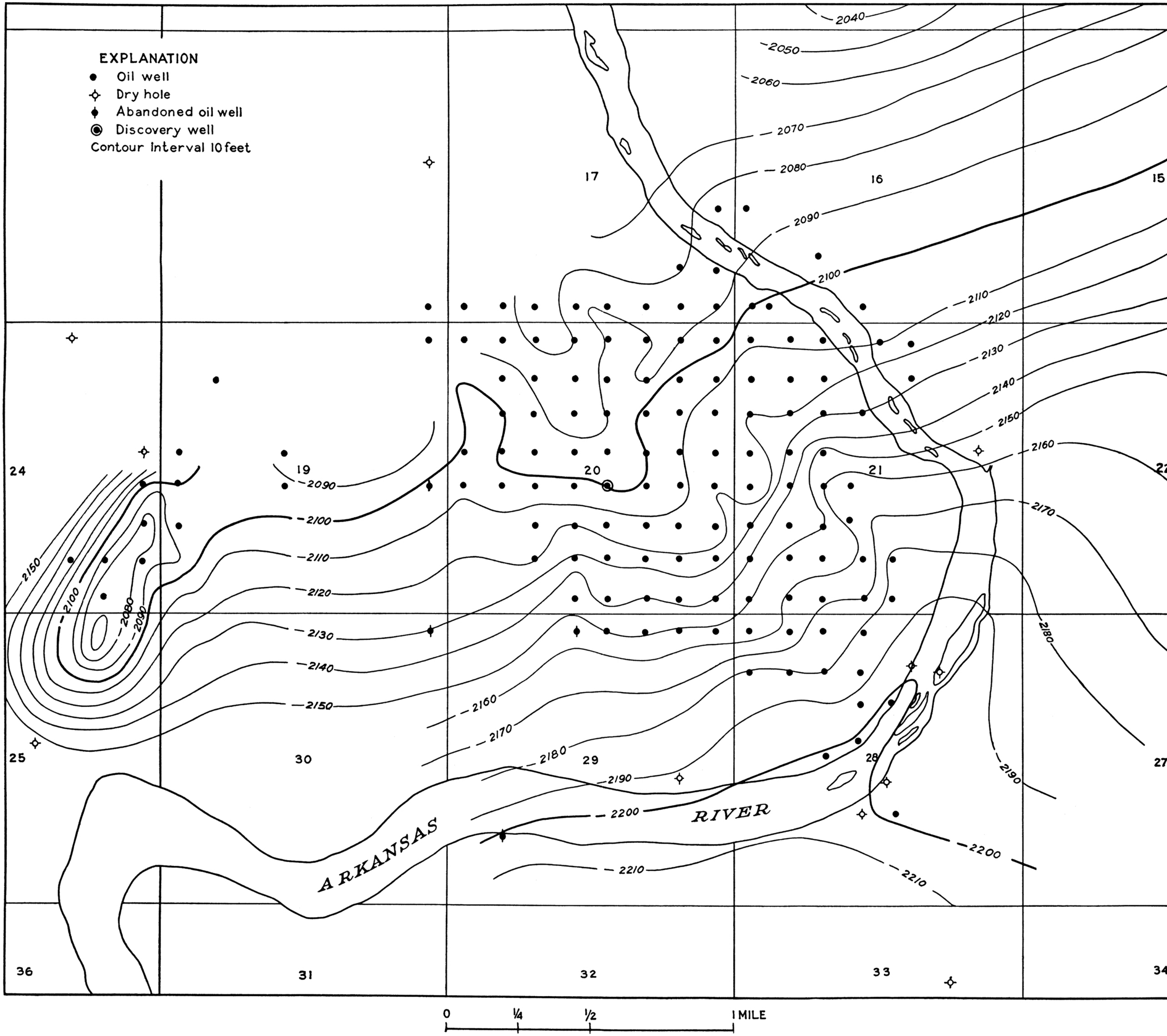

FIG. 11.—Contour map showing attitude of the top of the "Mississippi lime" in the Rainbow Bend field, T. 33 S., R. 3 E.

limestone by erosion in early Pennsylvanian time. This sandstone appears to be a sand lens of more or less circular shape, thinning and disappearing toward the west, north and east and having a lobelike projection toward the southeast. The sand has been called the Rainbow Bend sand and has been correlated by Snow and Dean[98] with the Burbank sand of the Burbank field of Oklahoma. These authors state that a cross section from Burbank to Rainbow Bend shows that this sand in the Oklahoma field is separated from the Mississippian limestone by an appreciable thickness of shale. The shale body thins northward to entire disappearance, and so in Kansas the sand lies directly upon the Mississippi limestone. According to Rutledge[99] both the Rainbow Bend sand and the Burbank sand are now commonly assigned by geologists of this region to "the Bartlesville sand horizon." It is recognized that the name Bartlesville as applied here and in numerous other localities in Kansas does not imply that the sand is continuous or necessarily contemporaneous in deposition with the Bartlesville sand at the type locality, Bartlesville, Okla. The name is applied to a zone in the lower part of the Chorekee shale that contains lenticular sand bodies in many localities throughout eastern Kansas and northern Oklahoma. In many places the sands are separated from the "Mississippi lime" by a shale unit that reaches a thickness of 200 feet but is commonly less than 100 feet thick. In several localities, however, the sand lies directly upon the Mississippian surface, as it does in the Rainbow Bend field. The sand body in the Rainbow Bend field is composed largely of angular to subrounded quartz grains, in general rather poorly sorted, and contains, at least in parts of the field, a considerable percentage of clay. The sand grains are held together by clay and calcareous cement and in part by siliceous cement. The log of the Phillips well, on the east bank of Arkansas river in the NE¼, sec. 28, reports coal in the upper half of the sand body. Throughout the entire field, except in the extreme southeastern part, the sand body is devoid of any appreciable amount of water. Wells are usually drilled entirely through the sand and a few feet into the underlying "chat," or into the Mississippian limestone if "chat" is not present. Water is encountered only a few feet beneath the upper surface of the limestone.

Structure. The contour map (Fig. 11) shows the attitude of the upper surface of the "Mississippi lime" in the Rainbow Bend field. The producing wells are on the southeast flank of a "high" whose

98. Snow, D. R., and Dean, David; op. cit., p. 980.
99. Rutledge, R. B.; personal communication.

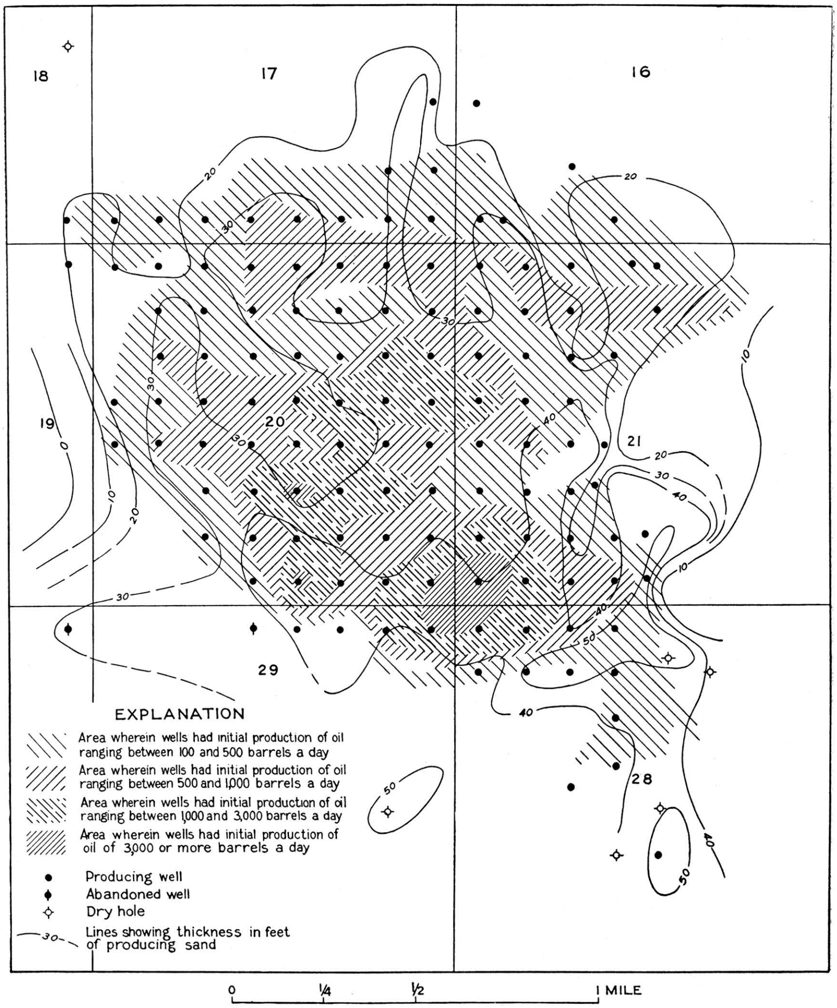

FIG. 12.—Relation between initial production and thickness of producing sand in the Rainbow Bend field, T. 33 S., R. 3 E.

crest must lie at some point northwest of the pool. The producing sand body thins northwestward and is probably absent in the higher parts of the fold. Recently oil has been found in Pre-Mississippian beds that lie structurally high near the east quarter corner of section 7, about 1½ miles northwest of the Rainbow Bend field, but the detailed structural relationship between the two areas is not yet known.

Occurrence of the oil and gas. The largest yields are obtained well down on the southeast flank of the dome, some in an area surrounding the corner common to sections 20, 21, 28 and 29 and others in the south-central part of section 20. Figure 12 was prepared in an effort to determine if there is a definite relation between amounts of oil production and the total thickness of the sand body. It appears from this study that the total thickness of the sand does not absolutely control the initial production of the wells. The thickest part of the sand body occurs in the north-central part of section 28 and extends into section 21, where it is a little more than 50 feet thick, but the initial production of the wells in this area ranged from less than 100 barrels to 500 barrels, whereas the producing sand body of a 3,000-barrel well in NW¼ SE¼, sec. 20, is only 23 feet thick. The wells near the corner common to sections 20, 21, 28 and 29 had initial production above 3,000 barrels, but sand thicknesses averaging about 43 feet. However, the total thickness of the sand cannot be said to have no effect upon the initial production of the wells, because none of the very large producers occur where the sand is excessively thin, but all occur where the sand body has an appreciable thickness, and some small wells occur where the sand is comparatively thick. Rutledge and Snow,[100] who have followed closely the development in this field, state that the controlling factors in amount of production are the porosity and thickness of the producing part of the sand. They state that wells such as those in the NE¼ of section 29, which show a large total thickness of the sand body but had a very small initial production, were drilled into a very hard sand that is extremely "tight"—that is, very closely cemented. According to these geologists it is only in the southeastern part of the field that edge water controls production; elsewhere toward the edge of the pool either the thinning of the sand practically to disappearance or increased cementation of the sand bringing about a low porosity, determine the limits of the producing area.

Graham Field.

Location. The Graham field is in the western part of Cowley county about a mile northeast of the Rainbow Bend field, in secs. 3, 9 and 10, T. 33 S., R. 3 E.

History of development and production. The Graham pool was discovered by the Marland Oil Company on August 1, 1924, when that company drilled W. Graham well No. 1, in the northeast corner of section 9, into Ordovician (?) beds, which were struck at a

100. Rutledge, R. B., and Snow, D. R.; personal communication.

depth of 3,518 feet. The well had an initial daily production of 1,000 barrels. The location was staked on the basis of the presence of a dome-shaped uplift in the near-surface rocks disclosed by core drilling. The largest well in this field was the Marland Oil Company's J. A. Bower No. 4, on the crest of the dome, which had an initial production of 3,600 barrels of oil a day from depths of 3,484 to 3,492 feet. Only oil is produced in the field, although good shows of gas were encountered in many wells. Thirty-eight wells have been drilled in the field. Three were drilled in 1924, and the remainder in 1925. Four of them are twin wells drilled only to the shallow sand and located directly beside wells to the deep "pay." In all, 21 wells were completed as producers from Ordovician (?) beds and 12 were completed as producers from the shallower Layton sand. Four wells were completed as dry holes after testing the shallow and deep horizons. One well, the G. T. Wright No. 4, near the center of the pool, was completed as a dry hole after testing only the shallow horizon.

The field was defined and drilled by the end of 1925. There are at present 32 producing wells in the field. The greatest amount of oil has come from the Ordovician (?) beds, the production from the Layton sand amounting to only a small percentage of the total. The oil has a gravity of 42° Baumé. The total production of the pool to June 1, 1927, was about 1,500,000 barrels of oil,[101] and the daily production at that time about 600 barrels.[101]

Stratigraphy. The surface of the Graham field is occupied by wind-blown sand and soil concealing the lowermost beds of the Wellington formation. The correlation of well logs leads to the belief that the Herington limestone is but a few feet beneath the surface over the crest of the dome, near the center of the field. Wells drilled in this field accordingly start near the top of the vertical section of rocks given on Plate I and penetrate the entire series in the first 1,000 feet of depth. These rocks, which crop out farther east in Cowley county, are for the most part readily recognizable in the logs of the wells drilled in the Graham pool. For example, in the log of the J. A. Bower No. 4 well, in the NW. ¼, sec. 10, on the crest of the dome, the "sandstone" reported at depths of 35 to 40 feet is believed to be the Herington limestone; the Winfield limestone is thought to have been struck at 95 feet, the Fort Riley limestone at 200 feet, the Wreford limestone, reported as sandstone, at 365 feet, the Cottonwood limestone at 500 feet, the Foraker lime-

101. Estimated from known total for 20 wells.

stone at 640 to 695 feet, and the Burlingame limestone at a little beneath 1,000 feet. Wells near the crest of the dome penetrated the lowermost 500 feet of the Permian rocks, 2,700 feet of Pennsylvanian beds, about 240 feet of "Mississippi lime," about 80 feet of Chattanooga shale, and from 2 to 10 feet of limestone of Ordovician (?) age. A regional correlation of these rocks is shown in the correlation table (Pl. II).

Oil-producing rocks. Beds at two widely separated horizons yield oil in the Graham field, the more productive zone being the uppermost few feet of limestone of Ordovician (?) age, encountered at depths averaging about 3,500 feet. Some oil is produced also from a sandy zone in the uppermost part of the Kansas City group, of Pennsylvanian age, encountered at depths averaging about 2,550 feet. This upper zone has been correlated by Snow and Dean with the Layton sand of Oklahoma and the Stokes sand of the El Dorado field.[102] The production from the shallow sand has been relatively slight, although 13 wells are producing oil from this sand. According to the logs, the Rainbow Bend sand, which lies at the base of the Pennsylvanian series and is so productive of oil a mile to the southwest, in the Rainbow Bend field, is present with a wide range in thickness and irregular distribution in the Graham field. A number of wells in the SE¼ and the N½ NE¼, sec. 9, and the N½ SW¼ and the N½ NW¼, sec. 10, record sand at this horizon, but logs of wells near the center of sec. 10 and some of the wells in the NW¼, sec. 10, and the NE¼, sec. 9, show no sand.[103] Most wells found good shows of gas at this horizon, one well reporting 5,000,000 cubic feet; others had a show of oil,[104] but no commercial production of either oil or gas is obtained. A show of gas was found in a thin sand near the middle of the Shawnee group in one well, the Bower No. 3 of the Marland Oil Company, in the southeast corner of the SE¼ NW¼, sec. 10. A sand body of irregular thickness, the maximum being 150 feet, occurring in the lower part of the Shawnee group, produced a "hole full of water" in most wells. Sand in the upper part of the Lansing group is also as much as 150 feet thick in the Graham field and yielded similar results.

Structure. The attitude of the rocks in the Graham field and the surrounding area cannot be determined from observation of the

102. Snow, D. R., and Dean, David; op. cit., p. 978.

103. Rutledge, R. B.; personal communication.

104. According to Rutledge, the material reported as sand is in most places "chat" lying on the "Mississippi lime" and does not represent the Rainbow Bend sand.

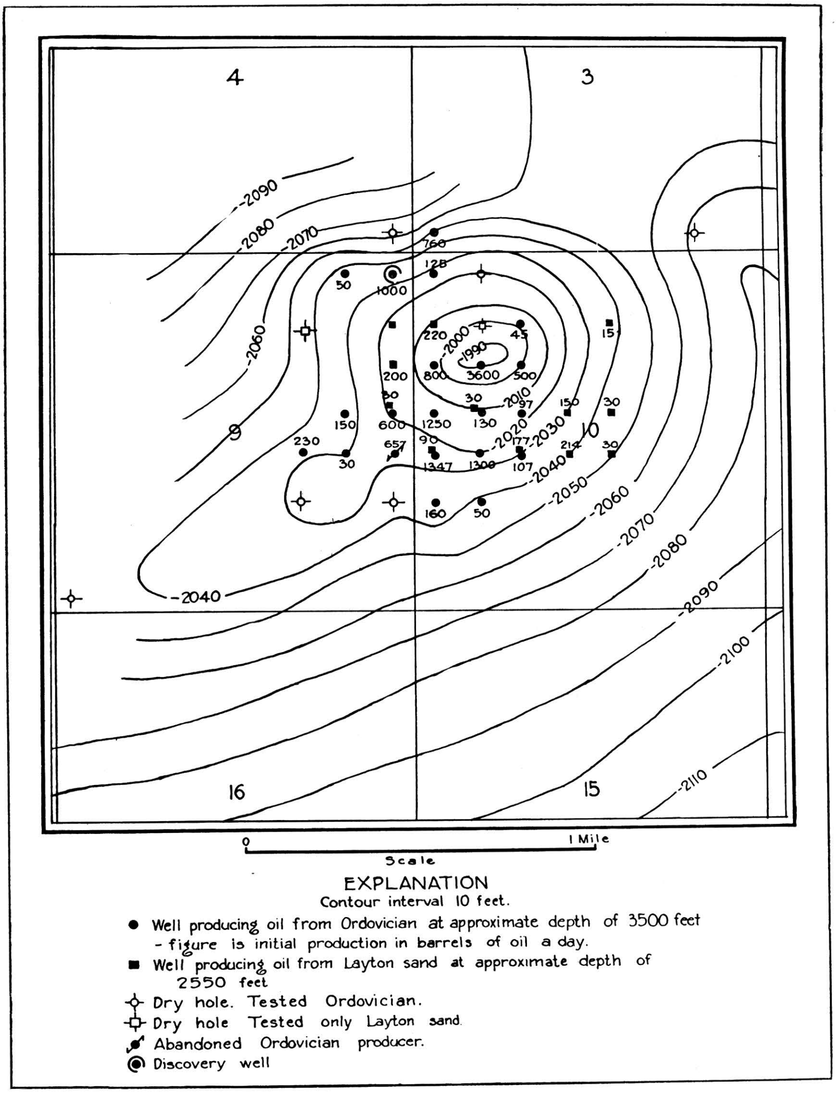

FIG. 13.—Contour map of the top of the "Mississippi lime" in the Graham field, T. 33 S., R. 3 E.

surface beds, because of the absence of outcrops of beds that can be traced throughout any appreciable area. The bedrock is concealed beneath a mantle of wind-blown sand and soil. The domed attitude of the beds was discovered by the sinking of systematically spaced core-drill holes to a sufficient depth to penetrate a recognizable layer of rock, usually referred to as a key bed, which in this region is the Herington limestone. On the basis of data thus procured a definite domed structure was outlined on the Herington limestone, although the amount of dip away from the crest of the dome as reflected by this formation is less than that of deeper strata determined by later deep drilling when the field was developed for oil. The upper surface of the Mississippian limestone is shown in Figure 13 by contour lines, drawn by geologists of the Marland Oil Company on the basis of data obtained from wells drilled in the field. This map does not represent the true attitude of the Mississippian beds, however, because a considerable thickness of its uppermost part was eroded prior to its burial by the present overlying beds. The contour lines of Figure 13 then actually represent the present configuration of this old erosion surface in the Mississippian limestone.

The limestone unit is thinner over the crest of the fold than low on the flank, varying in thickness as much as 90 feet in three-quarters of a mile. If a uniform thickness were assumed for the Mississippian limestone the structure would accordingly show steeper dips than those shown in Figure 13. A structure map similar to Figure 13 but drawn on the top of the Ordovician strata, which lie about 350 feet below the top of the Mississippian limestone, shows very much steeper dips in these beds on the north and northwest flanks of the dome but conforms closely to the attitude of the Mississippian surface on the south flank.

Slick-Carson Field.

Location. The Slick-Carson field is near the center of the west side of Cowley county, about 3 miles southeast of Oxford, in secs. 19 and 20, T. 32 S., R. 3 E. The field is small, occupying only a small part of section 19 and a few acres in section 20.

History and production. Oil was discovered in sec. 19, T. 32 S., R. 3 E., in the Carson No. 1 well, drilled by T. B. Slick, in October, 1924. Most of the other wells of the field were drilled in 1925 and 1926. The oil is produced chiefly from beds at two horizons separated by 800 feet of strata, and so twin wells have been drilled throughout the main part of the pool, one set of wells being drilled to depths of 2,600 to 2,700 feet and the other to about 3,450 feet. Eight producers and seven dry holes have been drilled to the deeper sand in and near the field, and ten producers have been drilled to the shallow sand. According to information obtained from well logs, the initial daily production of wells producing from the deeper sand has been as much as 1,300 barrels of oil, but averaged about 400 barrels; that of wells producing from the shallow sand has been as much as 1,000 barrels and averaged about 275 barrels. One well produced oil from sand in the lowermost part of the Cherokee

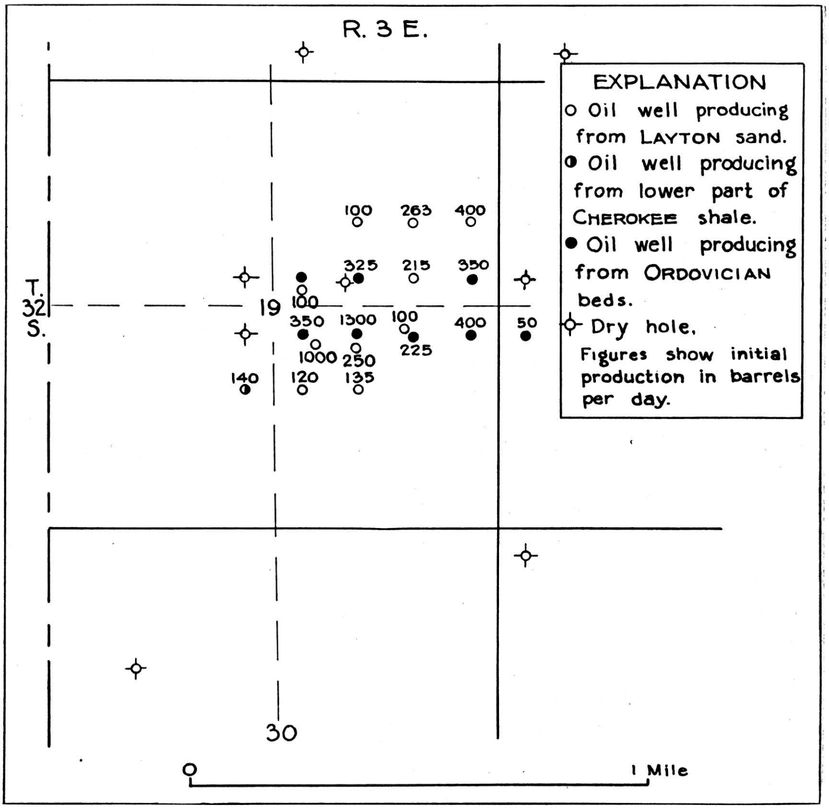

FIG. 14.—Map of Slick-Carson field, T. 32 S., R. 3 E.

shale, about midway in depth between the deep and shallow sands. Its initial production was 140 barrels of oil a day. The wells of the field are shown in Figure 14.

Surface rocks. The surface of the Slick-Carson field is occupied by Recent alluvium of the Arkansas river valley, which completely mantles the bedded Permian rocks that lie 40 feet, more or less, beneath the surface. It is impossible to determine the attitude of the bedded rocks that are involved in the folding of the region from a study of the surface, because the alluvium is of Recent age and was spread over the area long after the Permian and deeper-lying rocks were folded. In such an area the attitude of the buried rocks is determined by core drilling through the alluvium to a definitely recognizable key bed in the underlying rocks.

Buried rocks. Few of the individual limestone beds and formations seen at their outcrops farther east in Cowley county can be recognized in the logs of wells drilled in this field, but the several groups of strata can be fairly satisfactorily determined by well-log correlation. The lowermost part of the Wellington formation immediately underlies the alluvium, which is 30 to 40 feet thick in this area. The Herington limestone is believed to be a little less than 100 feet beneath the surface. The red bed encountered at depths of about 100 to 110 feet is believed to be in the upper part of the Doyle shale, and the limestone above it to be the Winfield limestone and the Luta limestone. The red beds reported at depths of about 350 feet are thought to be in the Matfield shale, and the limestone beds above them to be the uppermost part of the Matfield, the Florence flint, and the Fort Riley limestone. The persistent red bed struck at 400 to 420 feet is probably in the uppermost part of the Garrison shale, and the limestone above it is the Wreford limestone. The Neva limestone is encountered beneath a red shale at a depth of about 600 feet. The upper half of the Wabaunsee group is reported in most logs as chiefly limestone with thin beds of shale. The lower half is largely shale. Thin sandstone lenses occur in the lower part of the group, and limestone beds are reported near what is assumed to be the base, at a depth of about 1,000 feet. The Shawnee group extends from this depth to about 1,800 feet and consists of alternately bedded limestone and shale. Water-bearing sandy zones occur near the top and near the base. The Douglas and Lansing groups combined extend to a depth of a little greater than 2,500 feet and are made up chiefly of shale; thin beds of limestone are prevalent in the uppermost part, and a thick water-bearing sandstone occurs near the middle, probably near the contact of the two groups. The Kansas City and Marmaton groups, composed largely of limestone, occupy the underlying interval to a depth of about 3,000 feet. The upper part of the Kansas City group contains thick beds of sandstone that constitute one of the two chief oil-producing zones of the field. The Cherokee shale, with a thickness of 115 to 120 feet, underlies the Marmaton group and is composed almost entirely of shale. A thin bed of sandstone occurs near the base of the Cherokee in wells surrounding the center of section 19. The Mississippian limestone is logged in most wells as a solid unit of limestone averaging about 230 feet in thickness; it is thinnest in the central part of the field. Beneath it is 75 feet, more or less, of black shale called the Chattanooga shale. A thin sandstone is present in most wells beneath the Chattanooga shale. Where this sandstone is absent the drill goes directly into limestone, at a depth of a little more than 3,400 feet. One well was drilled 400 feet below the base of the Chattanooga shale, penetrating alternately bedded sandy limestone and limestone beds with two beds of sandstone in the uppermost 100 feet.

Possible oil-producing rocks. Thin sandstone beds in the lower half of the Wabaunsee group have yielded gas in parts of Cowley county. These beds were reported in about half of the wells in this field, but only one well yielded a show of gas. Water was reported in the remaining wells. Nearly all wells reported sandstone in the upper part of the Shawnee group and another sandy zone in the lower part. The upper zone yielded a show of oil in one well, a show of gas in two wells, and water in almost all others—many of them a "hole full of water." The lower zone produced only water. A thick sandstone unit that occurs near the Douglas-Lansing contact, herein correlated with the uppermost part of the Lansing group, yielded an abundance of water in practically all wells except one, which had a show of oil with water at this horizon.

A zone a few feet below the top of the Kansas City group, about 2,600 feet beneath the surface, is recorded in most well logs as sandstone, in others as limestone and sandstone or sandy shale, and in a few as sandy limestone. It carries oil throughout most of the field and is the chief shallow producer. In part of the area a sandy zone is present about 75 feet beneath this one. It produced oil in one well, gave shows of oil and gas in others, and yielded water in most wells. No sands occur in the Marmaton group, and no shows of oil or gas were reported from it. Shows of oil were reported from sand near the base of the Cherokee shale in three wells near the center of section 19, and oil is produced from this sand in one of these wells—in the southeast corner of NE¼ SW¼. Southwest of the field, just west of the county boundary, in the northeast corner of the SE¼ SE¼, sec. 24, T. 32 S., R. 2 E., Sumner county, a small oil production is obtained from this sand. No sands or shows of oil or gas were reported from the Mississippian limestone. One well reported a thin layer of "chat" on top of the limestone, which yielded a small show of oil. A thin sand lying immediately beneath the Chattanooga shale produces oil throughout most of the field; some wells produce oil from porous limestone found at this horizon where the sand is absent. It is not known whether the sand is the Misener, the "Wilcox," or some other part of the Ordovician, or whether the porous limestone is part of the Simpson or the Arbuckle limestone.

Structure. In the Slick-Carson field the bedded rocks that lie beneath the alluvium of the Arkansas river valley have a domed attitude. A study of well records indicates that the departure from horizontality is only slight, however, in the near-surface beds but becomes greater with depth. The oil production is confined to the higher parts of the dome. Structure-contour maps of several horizons in the field are shown in Figure 7.

SMITH-SHAFER POOL.

Location. The Smith-Shafer pool is about 2 miles southeast of Udall, in the northwestern part of the county. The producing wells are confined to the E½, sec. 10, T. 31 S., R. 3 E.; two dry holes immediately east of the producers have been drilled in section 11.

History and production. Oil was discovered in this field in 1917. Thirteen wells have been drilled; all but three were completed as oil producers, one of which has since been abandoned. The oil is produced from the Bartlesville sand, which lies at a depth of about 3,050 feet. No appreciable amount of gas was found, and the daily oil production is relatively small, but the wells are comparatively long-lived. In June, 1927, the field was making about 200 barrels of oil a day from nine wells.

Surface and buried rocks. The greater part of the surface of the Smith-Shafer field is occupied by the lower part of the Wellington formation; the Herington limestone and Enterprise shale occupy the northeastern part of the field. The rocks of Permian age extend to a depth a little greater than 400 feet; next below are the Pennsylvanian beds, with an aggregate thickness of about 2,660 feet, consisting of alternate layers of limestone and shale with a relatively few beds of sandstone. Unlike the strata of the gas-producing region near Winfield, these beds contain no sandstone in the uppermost few hundred feet; the Admire shale, which contains numerous gas-producing sandstone beds near Winfield, Arkansas City and Dexter, is composed here of alternately bedded shale and limestone. A thin bed of sandstone containing water is present in part of the field at a depth of about 1,700 feet, in the lower part of the Shawnee group. A thick water-bearing sandstone that occurs in the uppermost part of the Lansing group and is widespread in the county is present here at depths of about 2,100 to 2,200 feet. The uppermost part of the Kansas City group, which is sandy and productive of oil in several pools in the county, is here composed of light-gray limestone. The middle part of this group is sandy, but yields only water in this field. The producing sand, struck at depths of about 3,050 feet, is in the lower part of the Cherokee shale and ranges in thickness from less than a foot to 23 feet. It is thickest near the crest of the structural nose that lies near the center of the producing area and thins in all directions away from it. The well drilled in the northwest corner of the SW¼, sec. 11, had no sand at this horizon, and the one drilled in the northwest corner of the NW¼, sec. 11, had only 5 feet of sand. The three wells drilled in the SE¼ NE¼, sec. 10, had sand from 20 to 23 feet thick, but the north offset, in the southwest corner of the NE¼ NE¼, sec. 10, had only 5 feet of sand, and the west offset, in the southeast corner of the SW¼ NE¼, sec. 10, only 10 feet. The sand body diminishes in thickness southwestward, also, but not so abruptly, being 14 to 16 feet thick in the southernmost wells drilled.

The Mississippian limestone underlies the Pennsylvanian beds with a varying thickness, ranging from 200 to 260 feet. It has been penetrated by only three wells in the field and is reported as being composed entirely of limestone. The great variation in thickness of the Mississippian limestone is due to the fact that its upper part was removed by erosion prior to the deposition of the overlying Pennsylvanian and Permian beds. The three deep wells also penetrated the Chattanooga shale, of early Mississippian age, and the uppermost 200 feet of Ordovician (?) rocks. The Chattanooga shale is composed of black shale about 80 feet thick. The Ordovician (?) rocks are reported in the well records as siliceous limestone and sandstone carrying water.

Structure. The oil of this field occurs in a lenticular sand body which, along with other beds, has been folded into a southwestward-trending nose. As shown on Figure 15, kindly supplied by the Trees Oil Company, the dips in the surface rocks are very slight. However, no hard beds that can be mapped throughout any appreciable area crop out in the producing part of the field, and the surface nosing is projected from the data concerning the attitude of the Herington limestone obtained in sections 11, 2 and 3. Well records indicate that the buried rocks are more steeply folded. Structure contours (with 10-foot interval) drawn on the top of the Kansas City group show a pronounced nose trending southwestward, with perhaps a slight doming centering in the southwestern part of the SE¼ NE¼, sec. 10. Several horizons were contoured, and at each

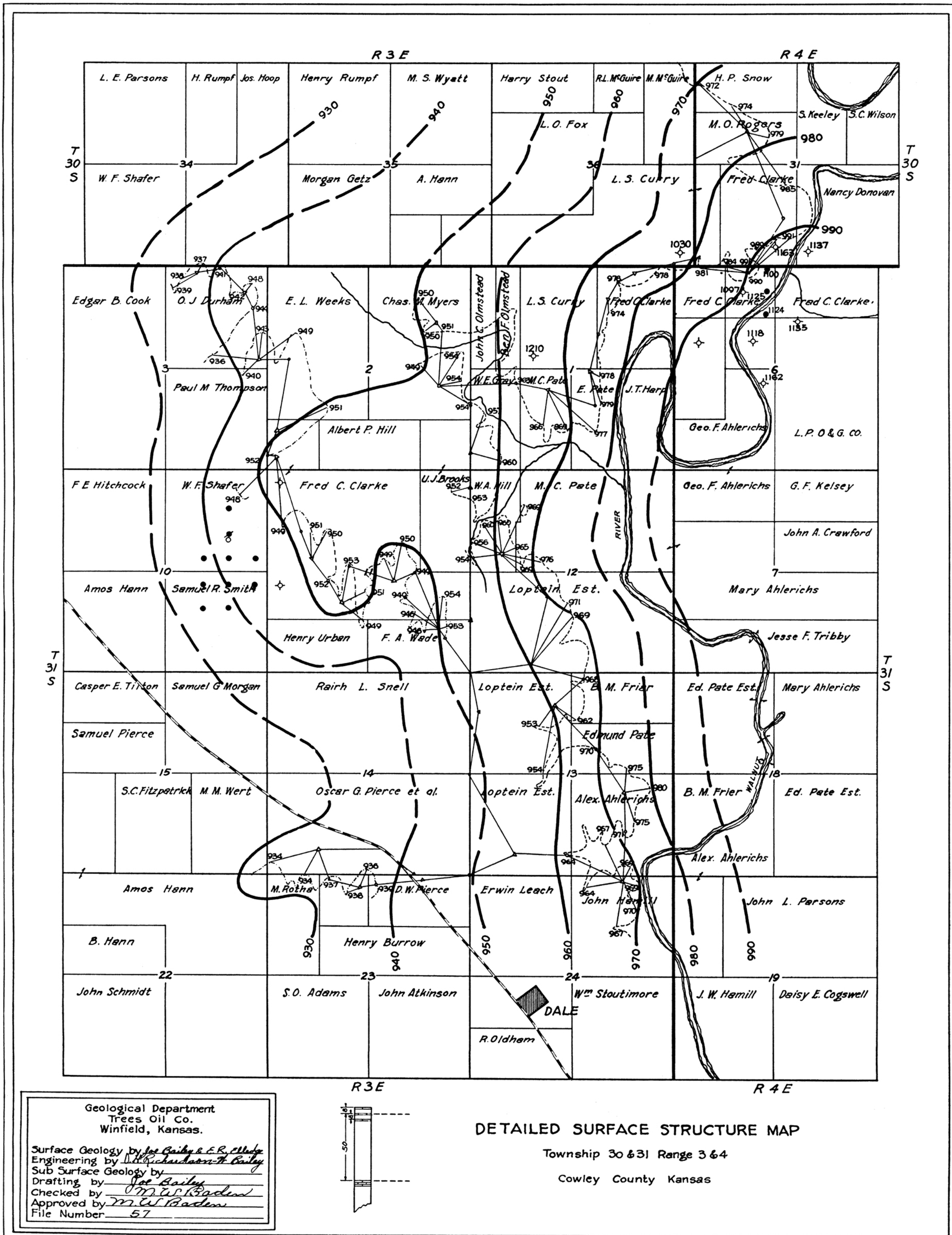

FIG. 15.—Detailed surface structure map of Tps. 30 and 31 S., Rs. 3 and 4 E.

the beds logged in the well drilled in the northwest corner of section 11 are higher than corresponding beds in the producing part of the field. The top of the Ordovician beds in the northwest corner of section 11 is 85 feet higher than in the northwest corner of the SE¼ NE¼, sec. 10, and 107 feet higher than in the northwest corner of the SW¼, sec. 11. The Mississippian limestone is thinnest in the well drilled in the northwest corner of section 11. If it is assumed that the "Mississippi lime" had originally an equal thickness throughout the locality of all three wells, the dips in its upper surface thus restored closely parallels that of the Ordovician beds.

The accumulation of oil on what is structurally not the highest part of the fold may be accounted for by the pinching out of the producing sand body in the direction of the well in the northwest corner of section 11. Also, the pitch of the fold appears to flatten, and there may be in reality a structural depression, or saddle, between the northwest corner of section 11 and the producing wells in section 10.

Future drilling. The subsurface data show that the highest part of this fold lies northeast of the producing wells, as all beds have a higher altitude in the well drilled in the northwest corner of section 11 than in the wells drilled in section 10, and they may be still higher to the northeast, in the southern part of section 2. The surface structure map made by the Trees Oil Company (Fig. 15) shows a pronounced nose centering about the center of the south line of the SE¼ SW¼, sec. 2. On the basis of these data it would appear that the well in the northwest corner of section 11 that obtained water in the Ordovician beds did not test the highest part of the fold, and that a well located about the middle of the south line or the center of the SE¼ SW¼, sec. 2, might yield oil. The possibility that productive sand lenses in the Cherokee shale and higher beds may occur here is also not to be denied, but any well drilled should be continued 200 feet or more into the Ordovician beds. If shallow holes were core drilled in the S½, sec. 2, and N½, sec. 11, the information thus obtained should disclose the highest part of the fold more closely than can be done from present knowledge.

Rock Field.

Location. The Rock pool is in the northwestern part of the county, about 1½ miles northeast of the town of Rock, in secs. 10, 11, 14 and 15, T. 30 S., R. 4 E. All but three of the producing oil wells are in the NW. ¼, sec. 14, and the NE. ¼, sec. 15.

History of development and production.[105] Oil has been produced in the Rock pool for the last five years, the discovery well, in the northeast corner of section 15, on the Newton farm, having been brought in on January 13, 1923, with an initial production of 125 barrels of oil a day. The peak production of the field was reached in October, 1923, when an average daily production of 763 barrels was made; the greatest yearly yield was made in 1924, when 226,000 barrels of oil[106] was produced; and the greatest initial production for a single well was 150 barrels a day. In October, 1927, the entire pool was producing 240 barrels of oil a day from 19 wells, and the total production of the field to that date was about 800,000 barrels.[106] Only a very little gas, occurring with the oil, has been produced.

The following table, supplied by the White Eagle Oil and Refining Company, shows the average daily production of oil by months, in barrels, from the time of opening of the field through October, 1927.

	1923	*1924*	*1925*	*1926*	*1927*
January	67	542	548	422	298
February	118	592	486	368	285
March	110	588	485	358	281
April	234	665	436	373	278
May	650	657	511	351	272
June	661	673	512	333	271
July	579	696	482	363	254
August	592	700	517	361	260
September	726	606	482	324	239
October	763	586	480	335	241
November	657	628	443	314	...
December	559	573	421	318	...

The total yearly production calculated from this table is as follows:

	Barrels.
1923	173,610
1924	225,930
1925	176,487
1926	128,394
1927 (first 10 months only)	81,912
	786,333

The royalty fees derived from 11 of the 19 producing wells of the pool (those on the Newton farms) are received by the city of Winfield and applied toward the operation of a city hospital.

Properties of the oil. The following summarized analysis of the oil produced in the Rock pool was kindly supplied by the White Eagle Oil and Refining Company:

	Per cent.	*Gravity, deg. B.*	*Remarks.*
Gasoline	35.87	....	120° initial, 431° end point.
Kerosene	9.37	42.0	140° flash point, (Foster cup).
Fuel oil	59.43	24.9	240° flash point, 260° fire (Cleveland cup).
Loss	.33	....	

Color of oil, black. Gravity, 38.4° Baumé.

105. These data were supplied by T. R. Ermey, of the White Eagle Oil and Refining Company.

106. Figures obtained by calculations made from table of average daily production.

Surface and buried rocks. Most of the area of the Rock pool is underlain at the surface by the lower part of the Doyle shale, which is composed largely of thick beds of gray shale but contains a few thin beds of limestone that crop out and are mappable

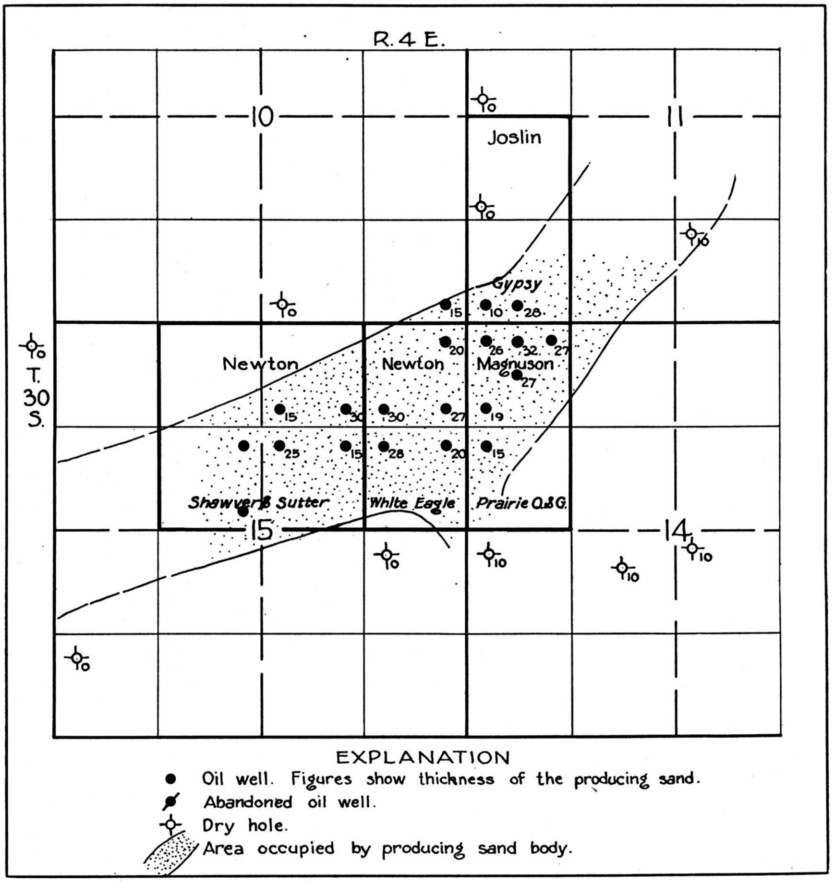

Fig. 16.—Map of the Rock pool, T. 30 S., R. 4 E., Cowley county.

throughout part of the field. Beds of limestone in the upper part of the Fort Riley limestone crop out on the north, west and south sides of the field. Permian strata extend beneath the surface to a depth of about 300 feet, and the Pennsylvanian beds extend thence to a depth of about 2,850 feet. These series maintain in general the characteristics exhibited throughout the county, described under "Stratigraphy"; total thickness here is notably less than in the southern part of the county, however, and certain parts of the series, such as the Kansas City group, contain a much greater percentage of limestone than farther south. The Mississippian limestone is about 350 feet thick and is reported in the logs of the one well in the field and others near by to consist of white and brown limestone—probably chert, inasmuch as one log reports it as sandy limestone—with "breaks" of shale in the lower part. The few wells in the vicinity of the Rock pool that have penetrated the Chattanooga shale beneath the Mississippian limestone report it as being about 40 feet thick; the next underlying strata have been penetrated for 100 feet and were reported to consist of shale, sandy shale, and thin beds of limestone that may belong to the Simpson formation or to other parts of the Ordovician system.

The producing sand lies at a depth of about 2,750 feet, in the lower part of the Cherokee shale and is separated from the "Mississippi lime" by about 50 feet of shale. Like sand bodies at this approximate stratigraphic position in other fields of this region, it is commonly known as the Bartlesville sand. As indicated in Figure 16, the sand is an elongate body, being about a half mile wide and more than a mile long; its longer dimension extends northeast. In the logs of all the dry holes north of the producers and the two in section 15, south of them, no sand was reported at the horizon of the producing bed, although a few logs reported sandy shale; those drilled in the south one-half of section 14 found a thin sand carrying water. The sand body appears to be of the type which is so common in Greenwood county, northeast of this region, and which, because of the elongated shape, is frequently referred to as a "shoestring" sand.[107]

Locality.	*Farm name.*	*Operating company.*
W½ SW¼, sec 11	Joslin	Gypsy Oil Co.
W½ NW¼, sec. 14	Magnuson	Prairie Oil and Gas Co.
E½ NE¼, sec. 15	Newton	White Eagle Oil and Refining Co.
W½ NE¼, sec. 15	Newton	Shawver & Sutter.
E½ NW¼, sec. 15	Newton	Shawver & Sutter.

It is not known whether there is a definite relation between the attitude of the strata and the accumulation of oil here, as no detailed maps showing the structure of the surface beds in the Rock pool are available, but data supplied by the drilled wells indicate that the occurrence of oil is controlled in the main by the lensing out of the reservoir bed rather than by the structure. Altitudes on the top of a limestone unit in the lower half of the Shawnee group, which was encountered at depths of about 1,150 feet, show the beds to

107. Cadman, W. K.; The golden lanes of Greenwood county, Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 11, pp. 1151-1172; 1927.

dip northwestward across the field at a comparatively uniform rate of about 50 feet to the mile. Data from the two wells near the center of section 15, southeast of the pool, indicate a slight reversal of dip toward the southeast, suggesting that the failure of these wells to produce oil may be attributed to their structural location. The map showing the regional attitude of the Mississippian limestone (Pl. XI) indicates that the producing sand body trends diagonally across the northwest flank of a broad southwestward-trending nose. The presence of this structural nose suggests that the attitude of the strata may have played a part in the accumulation of oil at this locality, although the lensing out of the reservoir bed is probably the more potent factor. However, Cadman[108] states that the presence of oil in the "shoestring" sands in Greenwood county in general bears no relation to the attitude of the beds in the underlying Mississippian limestone nor to the local flexures in the overlying rocks.

It appears probable that the productive area will be extended southwestward in the W½, sec. 15, and northeastward in the SW¼, sec. 11.

Eastman Field.

Location. The Eastman pool is 4 miles east of Wilmot, in the northern part of Cowley county, in the extreme southwestern part of T. 30 S., R. 6 E., and northwestern part of T. 31 S., R. 6 E. It has a north-south elongation, and the length is several times the width.

History and production. The field was opened early in 1924 and by the end of that year had produced a little more than 200,000 barrels of oil. It produced 440,000 barrels of oil in 1925 and 315,000 barrels in 1926. In the spring of 1927, 37 wells were producing a total of about 800 barrels a month. Nineteen wells have produced large amounts of gas with the oil, but no data as to the total amount of gas produced are available. The aggregate initial daily production of the gas is 250,000,000 cubic feet. One well had an initial gas production of 35,000,000 cubic feet, five wells produced initially about 20,000,000 cubic feet each, and four wells averaged a little less than 15,000,000 cubic feet. The other gassers ranged from 3,000,000 to 10,000,000 cubic feet each. Oil was produced by 50 wells, of which 19 produced gas also. The oil producers had an average initial daily production of 180 barrels, and the gas wells averaged 13,000,000 cubic feet. There were no exceptionally large producing oil wells in the field. Three wells had an initial daily

108. Cadman, W. K.; op. cit., p. 1170.

production of a little more than 700 barrels, 27 had less than 100 barrels, and the others ranged between these limits. The wells in the Eastman pool are shown on Plates X and XI.

Quality of the oil. The crude oil from this pool is a paraffin-base oil with a greenish-brown color ranging in gravity from 34° to a little more than 36° Baumé. Two analyses typical of the oil from the Eastman pool, furnished by the Empire Gas and Fuel Company, are given below.

Eastmen No. 1, sec. 7, T. 31 S., R. 6 E.

Empire laboratory No. A 564. Sample taken from flow while tools were in hole, December 13, 1921. Bartlesville sand; gravity, 34.1° Baumé; viscosity, thin liquid; color, reddish brown; water, 0.1 per cent; B. S., 0.9 per cent. Overpoint, 164° F. Time, 12 minutes.

Distillation: Engler method—1,000 cubic centimeters.

Per cent by volume.	*Temperature, deg. F.*	*Gravity, deg. B.*	*Per cent by volume.*	*Temperature, deg. F.*	*Gravity, deg. B.*
5	242	62.7	45	542	37.1
10	300	55.2	50	560	35.7
15	332	52.2	55	586	34.2
20	390	48.6	60	610	33.6
25	426	46.3	65	630	32.4
30	460	43.0	70	648	31.3
35	488	40.7	75	666	30.6
40	520	38.9			

Approximate summary.

	Per cent.	*Gravity, deg. B.*	*Initial point, deg. F.*	*End point, deg. F.*
Gasoline	9.0	58.6	...	...
Naphtha	11.5	50.5	188	480
Kerosene	17.5	42.6	292	600
Gas oil	36.1	33.6	...	...
Residuum	24.6	18.9	...	...
Water	.6	....	...	...
Loss	.7	....	...	...

Martin & Wilson's Eastman No. 1, southwest corner sec. 5, T. 31 S., R. 6 E.

Empire laboratory No. 2090. Production, 290 barrels of oil, 8,500,000 cubic feet of gas with the oil. Sampled February 8, 1924. Bartlesville sand, depth 2,850 feet. Viscosity, medium thin liquid; gravity, 36.3° Baumé; color, greenish brown; water, none; sulphur, 0.17 per cent; B. S., trace. Overpoint, 116° F. Time, 16 minutes.

Distillation: Engler method—1,000 cubic centimeters.

Per cent by volume.	*Temperature, deg. F.*	*Gravity, deg. B.*	*Per cent by volume.*	*Temperature, deg. F.*	*Gravity, deg. B.*
5	269	65.7	40	504	41.2
10	302	58.7	45	547	38.9
15	329	55.7	50	584	36.8
20	364	52.3	55	620	35.4
25	391	49.3	60	659	33.7
30	426	46.6	65	694	32.1
35	468	43.8	70	712	31.9

Approximate summary.

	Per cent.	*deg. B. Gravity,*	*deg. F. Initial point,*	*deg. F. End point,*
Gasoline	18.6	58.5	152	425
Naphtha	3.2	50.5	...	...
Kerosene	26.4	42.5	327	620
Gas oil	21.2	31.1	...	...
Residuum	20.0	22.5	...	...
Water	.0	....	...	...
Loss	.6	....	...	...

Surface and buried rocks. The surface in the Eastman field is occupied by rocks that belong to the Chase group, of Permian age. The rocks consist of alternately bedded shale and limestone, and the limestone contains an abundance of chert in the Florence flint, a formation of the Chase group. Outcropping ledges of limestone are fairly well exposed throughout much of the field and the surrounding area. Most of the wells start in the Fort Riley limestone and penetrate underlying Pennsylvanian rocks to a depth of about 2,850 feet, where the producing sand body lies. Well-log correlation indicates that in the Eastman field the Permian rocks, including the Chase and Council Grove groups, extend to a depth of about 300 feet; the Wabaunsee group of Pennsylvanian rocks from that depth to a little more than 800 feet; the Shawnee group to a depth of about 1,550 feet, where the Oread limestone is struck; the Douglas and Lansing groups, consisting largely of shale, with some sandstone and limestone, from 1,550 to about 2,250 feet; the Kansas City and Marmaton groups, composed largely of limestone, with considerable shale in the Marmaton, from 2,250 to 2,700 feet; the Cherokee shale, consisting of shale and sandstone, to a little below 2,900 feet; the Mississippian limestone, consisting almost entirely of limestone, to about 3,300 feet, and beneath it less than 100 feet of black shale believed to be the Chattanooga shale underlain by the Ordovician strata. A thin sandstone underlain by limestone is recorded in the uppermost Ordovician beds.

The producing sand is correlated with the Bartlesville sand and lies in the lower part of the Cherokee shale. Drilling has shown it to be a lenticular sand body elongated in a north-south direction and being probably less than 2 miles wide from east to west. It ranges from a featheredge to 100 feet in thickness. Two thick sands were penetrated at shallower depths but yielded water—one in the lower part of the Shawnee, about 60 feet above the Oread limestone, struck at a depth of about 1,500 feet, and the other consisting of a series of sand in the lower part of the Douglas group and upper part of the Lansing group. More than 15 wells were drilled through the Bartlesville sands into the uppermost part of the Mississippian limestone; two wells were driven through the Mississippian into the Ordovician rocks, but these lower rocks yielded no oil or gas. One of these deep wells is the Crouch No. 4, in the southwest corner of the NE¼ SE¼, sec. 31, T. 30 S., R. 6 E., drilled by C. W. Titus to a depth of 3,399 feet, and the other is the L. H. Spahr No. 1, in the southwest corner of the SE¼ SW¼, sec. 5, T. 31 S., R. 6 E., drilled by the Southwestern Petroleum Company to a depth of 3,291 feet. The top of the Ordovician lies about 40 feet higher in the Spahr well than in the Crouch No. 4.

Structure. But little information concerning the attitude of the beds in the Eastman field was made available. The generalized structure map of this area is shown on the county map (Pl. XI), based on altitudes and logs of a part of the drilled wells. As shown on this map, the field appears to lie in an area that is slightly higher structurally than the region immediately surrounding it, but all wells drilled on this "high" do not produce oil or gas, and others situated off the highest part are producers. The data at hand do not furnish a satisfactory explanation as to the causes for production in some wells and the lack of it in others. Near the central part of section 6 production appears to be limited westward by the thinning of the producing sand body in that direction. However, a well drilled by the Lewis Oil Company in the southeast corner of the NW¼ NE¼, sec. 31, T. 30 S., R. 6 E., appears to be located on the higher part of the structural flexure and to contain a thick body of sand at the Bartlesville sand horizon, but failed to produce. A similar situation exists for wells in the E½, sec. 7, T. 31 S., R. 6 E. No information as to the porosity of the sand body is available, but the lack of production under these conditions suggests that the sand may be not sufficiently porous here to serve as a reservoir for oil. East and west of the field wells have encountered no sand at the Bartlesville horizon. It can be said that in a broad way the lensing out of the sand body limits the productive area, but other factors must locally control the occurrence of oil and gas.

Dexter-Otto District.

Location. The most pronounced structural feature in Cowley county is an extensive anticlinal fold that passes northward near Otto and Dexter, in the southeastern part of the county, and thence trends northeastward, passing near Grand Summit. (See Pl. XI and Fig. 18.) Small amounts of oil and gas have been produced on parts of this fold, the principal areas being a relatively small tract about a mile northwest of Otto, a larger area near Dexter, and a third about 3 miles northeast of Dexter. These three areas are designated herein respectively the Otto, Dexter, and Countryman fields.

History and production. The Dexter field proper was one of the early gas pools of this part of the state and one which attracted wide interest because of the discovery by Cady and McFarland[109] of

109. Cady, H. P., and McFarland, D. F.; The composition of natural gas with special study of the constituents of Kansas gases: Kansas Univ. Geol. Survey, vol. 9, pp. 228-302; 1908.

helium in the gas from the discovery well, this being the first helium found in natural gas. Gas was discovered at Dexter early in 1903[110] at a depth of 325 feet, and by the end of 1908, 22 producing wells had been drilled.[111] Later drilling discovered more gas at depths near 1,000 feet, and oil was found at about 2,750 feet. Subsequent to the discovery of gas at Dexter wells were drilled a short

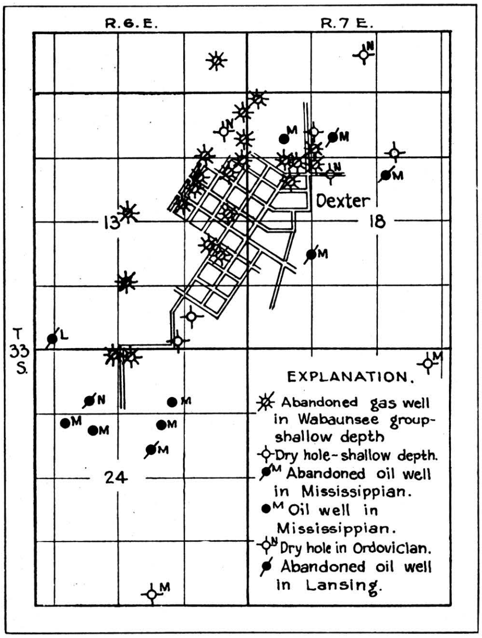

FIG. 17. Sketch showing wells in Dexter field.

distance northwest of Otto. Gas was found in fair abundance at a depth of about 1,100 feet and small amounts of oil near a depth of 3,000 feet. In recent years oil has been produced about 3 miles northeast of Dexter, in the Countryman field.

The shallow wells near Dexter had an average open-flow capacity of about 3,000,000 cubic feet of gas with an initial rock pressure of 110 pounds to the square inch.[112] The discovery well had an initial open flow of 6,000,000 cubic feet of gas, and a few other wells had an open-flow capacity of 5,000,000 cubic feet. The wells near Otto that found gas at depths averaging about 1,100 feet had an initial

110. Haworth, Erasmus, and McFarland, D. F.; The Dexter, Kansas, nitrogen gas well: Science, new ser., vol. 21, p. 191; 1904.

111. Rogers, G. S.; Helium-bearing natural gas: U. S. Geol. Survey Prof. Paper 121, pp. 76-77; 1918.

112. Rogers, G. S.; loc. cit., p. 76.

production of less than 2,000,000 cubic feet each, with rock pressures of about 250 pounds to the square inch. The original wells near Dexter were abandoned years ago, but recently additional wells have been drilled to furnish gas to a plant erected to extract helium. The deep wells drilled for oil near Dexter and Otto have met with only slight success. The daily yield is extremely small, and several wells have been abandoned because the small production did not pay for the cost of operation. It is reported that the wells 3 miles northeast of Dexter, in the Countryman field, yield paying quantities of oil.

Helium content of gas. The gas of this district is noteworthy for its high content of helium. Commonly natural gas contains less than 0.3 per cent of helium, but the helium content of the gas from the Dexter-Otto district ranges from 1 to 2.1 per cent. Recently interest has been revived in the Dexter gas as a source of helium as a commercial product, and a number of samples of the gas have been analyzed by Dr. H. P. Cady at the State University. The following data are quoted from Rogers' report on the investigation of helium-bearing natural gas,[113] carried on during the war in search for a supply of helium for inflating dirigibles:

Helium content.

Rogers' report.

FIELD.	Name of well.	Locality.			Depth, feet.	Helium, per cent.
		Sec.	T. S.	R. E.		
Dexter	Discovery	18	33	7	310	1.84
do	Greenwell	18	33	7	310	1.64
do	(?)	18	33	7	700	.955
do	Hale	13	33	7	350	1.83
do	Bolton	13	33	7	350	1.68
Otto	Day No. 1	24	34	6	1,145	1.90
do	Melick	13	34	6	1.150	0.50
Results of analyses by Prof. H. P. Cady.						
Dexter	Olsen No. 1	1	33	7	....	0.78
5 mi. southwest of Dexter	Esch No. 1	33	33	6	540	2.11

Surface rocks. Aside from the alluvium that occupies the bottoms along Grouse creek, rocks belonging to the Wabaunsee, Council Grove, and Chase groups crop out in the Dexter-Otto district. Near Dexter the valley of Grouse creek parallels in general the crest of the anticlinal fold and has been cut into the soft Eskridge shale, producing a broad valley with steep walls formed by the resistant limestone beds of the Cottonwood limestone, Garrison shale, and

113. Rogers, G. S.; op. cit., pp. 100, 101.

Wreford limestone. Throughout the rugged part of the district the Wreford limestone is the dominant rock at the surface and because of its superior hardness controls to a large extent the surface features of the district. The Eskridge shale occupies a part of the flat region immediately south of Dexter and because it consists of soft material is rarely exposed. The Cottonwood limestone exhibits its usual characteristics in a few exposures about a mile south of Dexter, in a road cut on the highway 4½ miles south of Dexter, and capping the creek bank south of the producing oil wells 3 miles northeast of Dexter. The Garrison shale consists of gray, maroon, and green shale with several beds of hard gray limestone that form ledges in the slopes beneath the capping ledge made by the Wreford limestone. The Wreford limestone consists of beds of gray limestone and chert, exposed almost continuously on both sides of Grouse creek. The Matfield shale is not exposed, but its lowermost part is believed to form the rolling upland plains that slope gently downward to the rim rock or ledge formed by the Wreford limestone.

Buried rocks. Wells drilled in this district have penetrated the strata to a maximum depth of 4,010 feet, and a well about 5 miles southwest of Otto, a short distance west of the district, was drilled to a depth of 4,545 feet. Inasmuch as these deep wells were reported by the drillers to have struck granite, their logs furnish a complete section of the sedimentary rocks of the district. The Permian and Pennsylvanian rocks in this district consist of a series of interbedded limestone, shale, and sandstone similar to that found in other fields in this part of the state. The Pennsylvanian beds have a total thickness of a little less than 2,900 feet and exhibit in general the characteristics common to the remainder of the county. A few exceptions may be noted: The Cherokee shale is notably lacking in beds of sandstone except in one or two wells near Otto, a character that is fairly typical of the eastern part of the county. The Mississippian limestone as reported in well records in the district ranges in thickness from 300 to 390 feet, thinning over the crest of the Dexter-Otto fold. It is composed of limestone, sandy limestone, and thin beds of sandstone, logged as sandstone "breaks." It is from these sandstone "breaks" that most of the producing oil wells of the district derive their oil.

Some logs record about 50 feet of black shale immediately beneath the Mississippian limestone; this is believed to be the Chattanooga shale. Logs of other wells in the vicinity do not show shale at this horizon but report limestone, sandy limestone, or sandstone and limestone, of probable Ordovician age. Three wells on the western flank of the Dexter-Otto anticline record the Chattanooga shale—the Phillips Petroleum Company's Eckhart No. 1, in sec. 9, T. 35 S., R. 6 E., records the Chattanooga as 25 feet thick; the Mississippi Valley Oil Company's Spear No. 1, in sec. 21, T. 33 S., R. 6 E., records 50 feet of Chattanooga shale; and the Plateau Oil Company's Elliott No. 1, in sec. 16, T. 33 S., R. 6 E., records 52 feet. Only one deep well, the Phillips Petroleum Company's Julia McGill No. 1, in the NW¼, sec. 21, T. 34 S., R. 7 E., has been drilled in the syncline that parallels the Dexter-Otto fold on the east; 50 feet of Chattanooga shale was recorded in this well. Four wells, one in sec. 26, one in sec. 24, and one in sec. 12, T. 34 S., R. 6 E., and one in sec. 13, T. 33 S., R. 6 E., drilled near the crest of the fold, record no Chattanooga shale. Two other holes near the crest of the fold, in the vicinity of Dexter, record normal thicknesses of the shale, however—the Doric Oil Company's Smith No. 1, in sec. 18, and the Brown Bros.' Riding No. 1, in sec. 7, T. 33 S., R. 7 E. If the well records cited above truly record the facts, they show that the Chattanooga shale is present low on the east and west flanks of the Dexter-Otto anticlinal fold and that it is present over parts but absent over other parts of the crest of the fold. These data may indicate that some folding took place after the deposition of the Chattanooga shale but before the deposition of the Mississippi limestone, and that the low structural ridge then formed was in part stripped of its covering of Chattanooga shale and later submerged and covered by Mississippian limestone. If it were not for the presence of the Chattanooga shale with normal thickness in the Smith and Riding wells it might be assumed that the Chattanooga shale was never deposited over the crest of the fold and that its absence is due to the overlapping of the Chattanooga sediments upon the flanks of a previously formed anticlinal ridge in the Ordovician rocks, the crest of which was not submerged in the Chattanooga sea. The presence of the shale in these two wells, however, indicates that the deposition of the Chattanooga shale extended across the site of the fold. The absence of Chattanooga shale in some wells and its presence in others might be explained by processes other than sedimentation. Faulting in the buried rocks might have brought the Mississippian beds into juxtaposition with Ordovician beds or other parts of the Mississippian rocks, so that some wells would pass from Mississippian rocks directly into Ordovician, or parts of the Mississippian might be repeated in a vertical hole, thus giving an abnormal thickness. Inasmuch as the rocks of each of these series are reported by the driller to be very similar, it would be impossible to tell by the logs alone whether the deeper rocks penetrated belonged to the Ordovician or Mississippian.

The few wells that have penetrated the rocks beneath the Chattanooga shale report a thick series of hard siliceous limestone interbedded with sandstone and relatively few thin beds of shale, the limestone beds comprising about two-thirds of the total thickness; and it appears probable that the beds reported as sandstone are also siliceous limestone. Little work to determine the age of these rocks has been done, and they are commonly grouped together as being Ordovician and Cambrian. The log of the Eckhart No. 1 well of the Phillips Petroleum Company, in the SW¼, sec. 9, T. 35 S., R. 6 E., reported a total thickness of 1,050 feet of beds referred to the Ordovician and Cambrian, overlying granite encountered at 4,545 feet. The Smith No. 1 well of the Doric Oil Company, in the northwest corner of the SE¼ NW¼, sec. 18, T. 33 S., R. 7 E., penetrated a total thickness of 900 feet of sandy limestone and struck granite at a depth of 4,005 feet.

Rocks productive of oil and gas. The discovery gas well, drilled in 1905, and the wells drilled immediately afterward produced gas from a sandstone in the Admire shale at a depth of about 325 feet. Beds at this general horizon, although probably not the same beds, have produced gas elsewhere in Cowley county, particularly near Winfield and Arkansas City. Fairly strong flows of gas were struck at this horizon in the wells drilled in the Countryman field, 3 miles northeast of Dexter. It was in the gas from this sand that Cady and McFarland discovered helium gas, and so large a percentage of the gas produced from this sand at Dexter is noninflammable that users found it difficult to ignite. A series of sands in the lower part of the Shawnee group, about 150 feet above the Oread limestone, yielded appreciable flows of gas near Dexter and near Otto. These beds lie at a depth of about 1,000 feet near Dexter and a little more than 1,100 feet near Otto. Shows of gas were encountered at this horizon in the wells drilled in the Countryman field. Gas shows were found in sandstone beds in the Douglas group in wells drilled in the Countryman and Dexter fields. Sandy zones in the Lansing group produced shows of gas and oil in several wells near Dexter and in the Countryman field. The sandy upper part of the Kansas City group has produced oil in one well in the Countryman pool and supplied good shows of oil in other wells. Shows have been reported from this horizon in the Dexter pool. Shows of oil and gas have been reported from the lower part of the Marmaton group in the Countryman and Dexter pools, and a small production of oil was obtained from a bed at this horizon in one well near Otto. Another well near Otto had a show of oil in a sandstone in the lowermost part of the Cherokee shale; but no sand occurs at this horizon throughout most of the Dexter-Otto district.

The upper part of the Mississippian limestone is the chief oil-producing zone in the district. Sandy streaks in the limestone yield oil in the Dexter and the Countryman fields, and shows, together with some small production, are obtained from these beds near Otto. The production is so small, however, that it has never been of great importance. A few wells started off with a fair yield but quickly dropped to a very low daily production.

Several wells near the crest of the anticline in the Otto field are believed to have reached the upper part of the Ordovician strata, and three wells near Dexter have penetrated some distance into the Ordovician rocks, but yielded only disappointment. These beds have not been tested in the Countryman pool.

Structure. The Dexter-Otto anticline is the most extensive pronounced fold to be seen expressed in the surface rocks in Cowley county. A structure-contour map of the surface beds in the southern and central parts of the district was kindly supplied by M. W. Baden, of the Trees Oil Company, and is reproduced in Figure 18. The anticline trends nearly due northward from the state line, in sec. 13, T. 35 S., R. 6 E., to a point near Dexter and thence northeastward into secs. 33 and 27, T. 32 S., R. 7 E. Although farther northeast it is less distinctly reflected in the surface rocks, the fold is believed to continue beyond the county boundary, passing a little more than half a mile west of Grand Summit. According to Clark and Cooper[114] the trend of the Dexter-Otto fold continues southwestward in Oklahoma, where the Mervine and Ponca anticlines are on this trend and exhibit many features similar to the Dexter-Otto fold. Dome-shaped folds superposed on the major anticline and constituting only local features of it are shown on the structure map of the surface rocks of the southern part of the district (Fig. 18). The principal domes are one about a mile north of Otto, one near Dexter, and a third, not shown in Figure 18 but shown on Plate XI, about 3 miles northeast of Dexter. It seems probable that similar features may be present farther northeast, but detailed surface maps

114. Clark, G. C., and Cooper, C. L.; Oil and gas geology of Kay, Grant, Garfield, and Noble counties: Oklahoma Geol. Survey Bull. 40-H, p. 24; 1927.

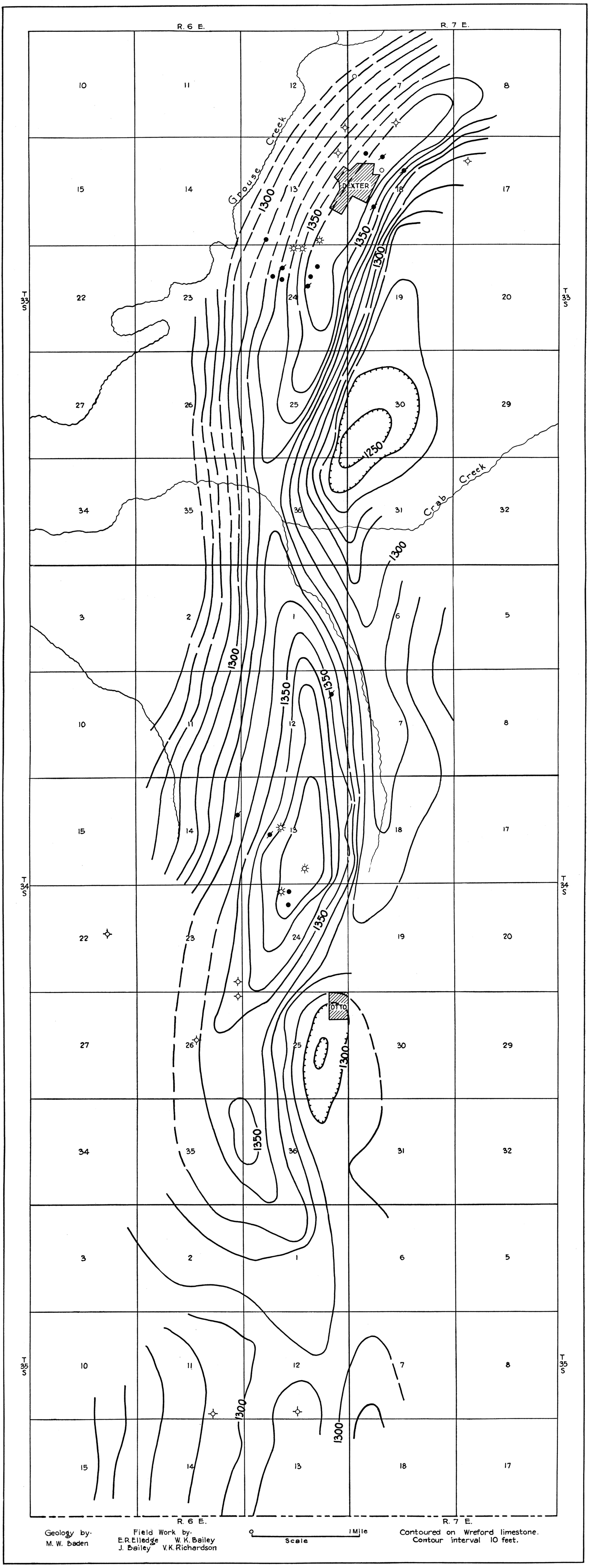

FIG. 18.—Map of the Dexter anticline.

of this region were not available for use in this report, and so it is not known by the writer whether such features are actually present. The anticlinal fold is asymmetric in cross section, dips on the east side being greater than those on the west. According to Baden's map (Fig. 18), the surface rocks have a maximum dip eastward of about 100 feet in half a mile and a maximum dip westward of about 50 feet in half a mile. The average rate of dip is slightly less steep than the maximum, but throughout is steeper on the east side of the fold than on the west side. Wells that penetrate the Mississippian limestone are not so distributed as to afford much information for a comparison of the amount of dip in the surface beds with that of the buried Mississippian rocks, but such information as is disclosed by two wells southeast of Dexter, the Sinclair Oil and Gas Company's J. W. Searle well No. 1, in the SW¼, sec. 18 (see Pl. XI), and the Devonian Oil Co.'s Radcliff well No. 1, in the NE¼, sec. 19, T. 33 S., R. 7 E., show the surface rocks to dip about 80 feet southeastward in two-thirds of a mile and the upper surface of the Mississippian limestone to decilne 155 feet in the same distance. To ascertain the true amount of dip in the Mississippian beds the amount of erosion of the uppermost Mississippian rocks should be known. On the basis of logs of wells drilled in this general region that show the Mississippian limestone thinner over the crest of the Dexter-Otto anticline than it is east and west of the crest, a conservative assumption of thinning by erosion between these two wells would be 25 feet, making the true dip of the Mississippian beds about 180 feet in two-thirds of a mile. Similar study of wells south of Dexter on the west flank of the fold indicates that the slope of the Mississippian surface adheres closely to the dip of the surface beds; but if a thinning of the Mississippian series by erosion is assumed to have taken place toward the crest of the fold the actual dip of the Mississippian rocks is slightly greater than that of the surface beds. Because no deep wells have been drilled far down the west flank, however, few definite data relative to the dip of the Mississippian rocks there are available.

Oil and gas possibilities. Although several wells in the vicinity of Dexter and Otto have been drilled into the Ordovician rocks and found them water bearing, not all the possible oil-bearing beds have been tested in all the structurally favorable areas on this fold. No deep wells have been drilled in the Countryman pool, and none have gone more than a few feet into Ordovician beds near Otto. The productive possibilities of stratigraphically higher beds have been determined in the principal parts of the district.

Falls City Field.

Location. The Falls City field is in the southeastern part of Cowley county, in secs. 8, 9, 16 and 17, T. 35 S., R. 7 E. It extends southward across the state line into Oklahoma, but it is principally the Kansas part that is considered herein.

History, production, and character of gas and oil. The Falls City field was opened in 1916 by the discovery of an initial production of 7,000,000 cubic feet of gas at a depth of 1,480 feet in the Falls City Land and Cattle Company's well No. 1, in the center of the north line of the NE¼, sec. 17, T. 35 S., R. 7 E. Well No. 2, near the center of the NE¼, sec. 17, followed in the same year with an initial production of 6,000,000 cubic feet of gas having a rock pressure of 500 pounds to the square inch,[115] derived from the same sand as that producing in well No. 1. The field was later taken over and developed by the Phillips Petroleum Company. Beds deeper than the gas sand were found to contain oil, one producing bed occurring at a depth of 2,000 feet and a second at a depth of 2,700 feet. A total of 33 wells have been drilled in the Kansas part of the field, 7 of which have been dry holes. Eight producers and 3 dry holes have been drilled in the Oklahoma part of the field. The total oil production of the field to June 1, 1927, was 780,000 barrels; the total gas production to the same date is estimated by the Phillips Petroleum Company as a little more than 15,000,000,000 cubic feet. In June, 1927, the field was producing 10 barrels of oil a day from 21 wells. The oil has a gravity of 41.2° Baumé.[116] A chemical analysis of the oil, made in the laboratories of the Phillips Petroleum Company in January, 1927, is given on next page.

The gas in this field has a high content of helium, according to the analyses of samples of gas from two wells in section 17, producing from a depth of 1,475 feet. The gas from one well contained 1.047 per cent of helium, and that from the other contained 0.94 per cent.[117]

Surface rocks. The rocks exposed at the surface in the Falls City field belong to the upper part of the Wabaunsee group and to the Council Grove group. Named from the base upward, they are the Eskridge shale, Cottonwood limestone, and Garrison shale. The Cottonwood limestone is the most prominent formation cropping out in the region. It forms a sinuous ledge of hard, blue-gray limestone

115. Roundy, P. V.; Unpublished manuscript in U. S. Geological Survey files.
116. Most of these data supplied by Phillips Petroleum Company.
117. Rogers, G. S.; op cit., p. 101.

Analysis of sample from Falls City field.

Gravity, 42.3° A. T. I. @ t. 60° F.; B. S. and water, none; initial boiling point of crude, 77° F.

Air distillation: Straight run, 300 cc. charge.

TEMPERATURE, DEGREE F.	Volume, cubic centimeters.	Per cent.		Gravity, deg. A. P. I.
		Cut.	Total.	
Up to 122	9.6	3.20	3.20	85.7
122-167	7.3	2.43	5.63	80.8
167-212	14.9	4.97	10.60	70.3
212-257	21.6	7.70	17.80	61.9
257-302	16.7	5.57	23.37	56.8
302-347	16.7	5.57	28.94	52.4
347-392	14.3	4.77	33.71	48.1
392-437	15.8	3.27	38.98	46.3
437-482	16.1	5.37	44.35	43.0
482-527	19.7	6.57	50.92	38.6
Vacuum distillation at 40 mm.				
Up to 392	11.8	3.93	3.93	36.4
392-437	18.6	6.20	10.13	35.0
437-482	16.1	5.37	15.50	32.2
482-527	16.3	5.43	20.93	30.0
527-572	11.1	3.70	24.63	28.9

Distillation summary.

	Per cent.	Gravity at temperature 60 deg. F.	Gallons per barrel.
Gasoline and naphtha	33.71	61.9	14.15
Kerosene	17.21	43.4	7.23
Gas oil	10.13	35.6	4.25
Light lubricants	10.80	....	4.53
Medium lubricants	3.70	....	1.55
Viscous lubricants	24.45	....	10.28
Distillation loss	10.00	....	....

on both sides of Beaver creek and is particularly conspicuous on the east side. The limy shale that constitutes the uppermost part of the Eskridge shale is clearly exposed beneath the Cottonwood ledge and contains an abundance of fossils at many places in the vicinity of the field. Two thin beds of limestone that occur in the lowermost 50 feet of the Garrison shale, overlying the Cottonwood, crop out almost continuously throughout the district and with the Cottonwood limestone afford excellent key beds for structural mapping.

Buried rocks. The drill has penetrated the buried sedimentary rocks to a depth of about 3,200 feet. Major units within this interval can be correlated by means of well records with rocks that crop out in the eastern part of the state, but it is impossible to determine definite group boundaries or individual formations within the groups. Well-log correlation indicates that in the E. C. Lemaster well No. 1, in the southwest corner of the SE¼, sec. 8, T. 35 S., R. 7 E., beds of Pennsylvanian age extend from a few feet beneath the surface to a depth of 2,875 feet; the Wabaunsee group occupying the uppermost part and extending downward to a depth of about 550 feet, the Shawnee group from that depth to about 1,240 feet, the Douglas and Lansing groups from 1,240 to 1,980 feet, the Kansas City and Marmaton groups from 1,980 to 2,655 feet, and the Cherokee shale from 2,655 to 2,875 feet. The Mississippian limestone was encountered at a depth of 2,875 feet and extends nearly to the bottom of the hole, 3,212 feet, but this entire interval is reported as sandstone, and it is impossible to determine from the log whether rocks older than the Mississippian were penetrated.

Productive beds. Beds of economic importance because of their yield of oil and gas occur near the top of the Kansas City group, in the upper part of the Cherokee shale, and in the Lansing group. Most of the oil wells obtain their oil from sandstone in the upper part of the Kansas City group, encountered at a depth of about 2,000 feet. Wells Nos. 1, 3, 6, 13, 12, 9, 5, 4, 10 and 14, in the NE¼, sec. 17 (see Fig. 20), Nos. 26, 21 and 24, in the SE¼, sec. 17, and Nos. 16 and 19, in the W½, sec. 16, have produced oil from this horizon; their aggregate initial production was about 1,000 barrels of oil a day. A few wells have produced oil from a lenticular sandstone, which is not present in all wells. This sandstone occurs in the upper part of the Cherokee shale and was encountered at a depth of about 2,700 feet. It has yielded oil in well No. 7, near the center of the E½, sec. 17; a show of oil in well No. 1, in the northeast corner of the SW¼, sec. 17; and gas in wells Nos. 20A and 29A, in the SE¼, sec. 17. Two gassers—well No. 17, near the southwest corner of sec. 16, and well No. 6, in the NE¼, sec. 17—derive their gas from a sandstone in the lower part of the Lansing group lying a little more than 1,800 feet beneath the surface. The sand body is extremely lenticular in habit. No sand is recorded at this horizon in wells Nos. 10 and 12, on the crest of the fold. Other wells encountered a considerable thickness of sand that contained water. Gas is produced from a sandstone that is about 350 feet above the bed just described and is believed to be near the contact of the Lansing and Douglas groups. It was the discovery of gas in this sand that opened the field. The sand body is lenticular. In the NE¼, sec. 17, well No. 1 had an initial production of 7,000,000 cubic feet of gas from this sand, and wells Nos. 2, 4 and 7 each had an initial production of 5,000,000 cubic feet. A number of shows of gas and oil were reported from the uppermost part of the Lawrence shale, a sandy zone close beneath the Oread limestone, in many wells drilled in the NE¼, sec. 17, the SE¼, sec. 8, and at scattered localities elsewhere in the field.

Structure. According to the surface structure map shown in Figure 19, supplied by the Phillips Petroleum Company, the Falls City field is developed on an anticlinal nose trending southwestward through the NE¼, sec. 17.

Production from the principal producting zone (the uppermost

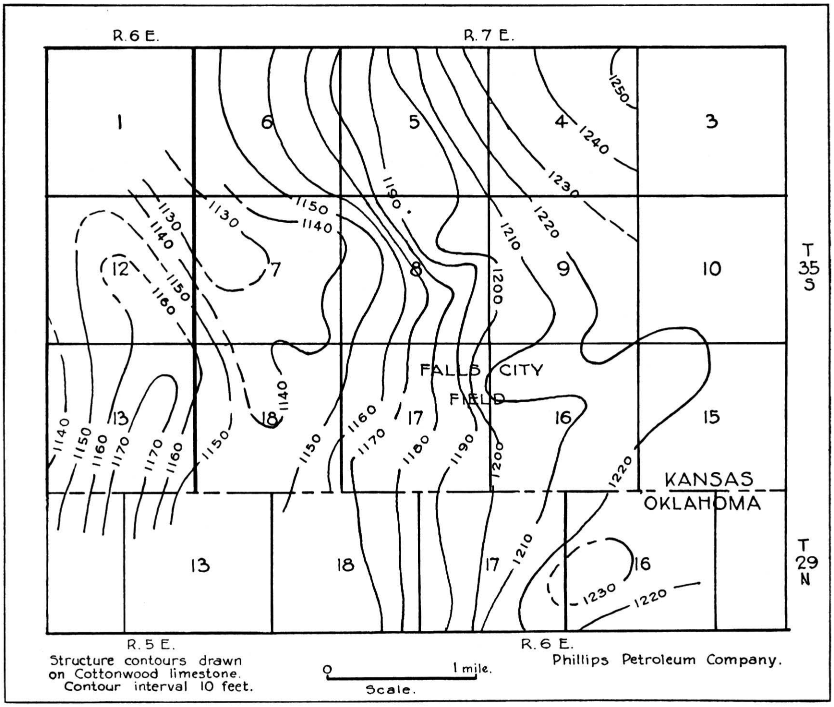

FIG. 19. Map showing attitude of surface beds in Falls City field and vicinity.

part of the Kansas City group) appears to be controlled by the attitude of the rocks, inasmuch as it is confined to the higher parts of the fold. The lenticular shape of the sand bodies, coupled with the structure, appears to be the factor that controls production in the other producing beds. Possible producing zones beneath the upper part of the Cherokee shale have not been tested with the drill on the higher part of the fold. Three holes—the E. C. Lemaster No. 1, in the SW¼ SE¼, sec. 8; the Easly No. 1, in the northeast corner of the SW¼, sec. 17, and the Falls City No. 16, in the SW¼ NW¼, sec. 16, have been drilled into rocks that lie beneath the

Pennsylvania beds. The Lemaster and Easly holes are far down the west flank of the fold and so do not constitute adequate tests of the lowermost Pennsylvanian nor of the Mississippian and Ordovician rocks, all of which produce oil elsewhere in the Midcontinent region. The Falls City No. 16 well is on the east flank of the fold, as shown by the subsurface map, and it was not drilled to a sufficient depth to test the Ordovician rocks, but it did penetrate the lowermost Pennsylvanian and the uppermost 100 feet of the Mississippian beds. In this well a sand body only 5 feet thick was logged at the base of the Cherokee shale, and one 15 feet thick was logged 140 feet above the base. The Cherokee shale was reported to contain no beds of sandstone in the Lemaster and Easly wells mentioned above. Consequently it appears unlikely that reservoir beds are present in the lower part of the Cherokee shale on the highest part of the fold. The "2,700-foot" producing sand, which is a sandstone in the upper part of the Cherokee shale, has been shown to be present and contain oil in a few wells in the northeast one-fourth and southeast one-fourth of section 17 and is probably present on the highest part of the fold. The Mississippian rocks are not known to contain oil in close proximity to this field, but commonly produce at a number of localities in this general region of Kansas and Oklahoma. Beds of Ordovician age yield an abundance of oil in fields not remote from the Falls City field. Should these lower beds be tested with the drill here the test well should be located on the highest part of the dome, which is near the site of well No. 12, in the northeast one-fourth of section 17, according to the subsurface map shown in Figure 20, and drilling should continue through a thickness of at least 150 to 200 feet beneath the base of the Chattanooga shale. A total depth of 3,500 feet should be ample. Production from the lowermost Cherokee or the Mississippian beds appears unlikely, but the possibility of obtaining oil in the Ordovician rocks cannot be positively eliminated until such a test is made. A dome with a small closure on the east is shown in the northeast one-fourth of section 17 by the subsurface structure map, supplied by the same company (Fig. 20).

Other Fields in the County.

Clarke pool. Three producing oil wells surrounded by dry holes have been drilled in sec. 6, T. 31 S., R. 4 E., on Walnut river. Alluvium of the Walnut river valley occupies the surface. The wells produce oil from a lenticular body of sand occurring at a depth of 2,840 feet, in the lowermost part of the Cherokee shale. No sand

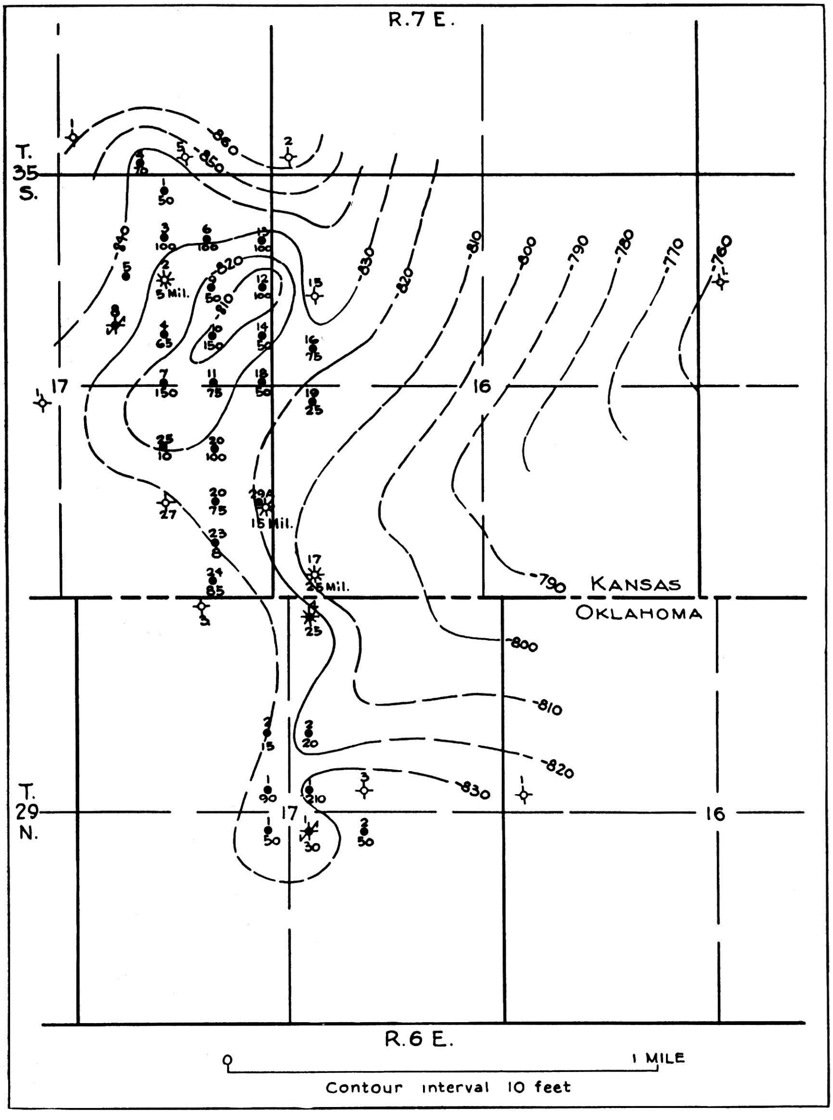

FIG. 20. Subsurface structure-contour map of Falls City field.

occurs at this horizon in most of the wells surrounding the producers. Two wells, one drilled in the northeast corner of the southwest one-fourth of section 6 and the other in the northwest corner of the southwest one-fourth of northeast one-fourth of section 6 penetrated a thin bed of sand, but these wells are far down the flank of the fold on which the field is situated. Inasmuch as the oil of this region commonly occurs in the highest part of the folds, the absence of oil in appreciable amounts in these two wells may be explained on the assumption that they were unfavorably located structurally. One well, the Donovan No. 1 of the Benedum and Trees Company, has been drilled to the Ordovician beds. It showed the Mississippian limestone to be thick and found no oil in the Ordovician rocks. The crude oil from the Clarke No. 1 well has a specific gravity of 0.8271 at a temperature of 15° C., a Baumé gravity of 39.2°, and a viscosity of 1.31 at 20 C.[118]

Udall pool. Oil was discovered 2 miles north of Udall in 1926 on a dome-shaped uplift alined with the axis of the buried "granite ridge" that extends across Kansas into Oklahoma. Oil was found at a depth of 1,850 feet in sands in the upper part of the Douglas group, close beneath the Oread limestone. One well was drilled deeper, and more oil was found at 2,050 feet in a sandstone, called the Stalnaker sand, that occurs about at the contact of the Douglas and Lansing groups, and is herein placed in the uppermost part of the Lansing. (See Pl. II.) This sand produces oil in the Churchill and Oxford pools, a few miles to the southwest, in eastern Sumner county. Some oil was found in sand near the base of the Cherokee shale, and a show of oil was obtained from chert a few feet below it. The drill penetrated about 50 feet into the Mississippian limestone, and the well was plugged back to the Stalnaker sand. Four wells, three of which produce oil from the "1,850-foot" sand and one from the Stalnaker sand, have been drilled about the corner common to sections 20, 21 28 and 29. The field is being extended by wells drilled to the shallower sand. The possibility of production from the Cherokee sand has not been entirely eliminated by the one deep well, and the Ordovician beds remain yet untested.

Redbud dome. Another dome-shaped fold occurs about 3 miles northeast of the Udall pool, in sec. 10, T. 30, R. 3 E., in line with the "granite ridge." The Permian rocks that occupy the surface are well exposed, so that their attitude is readily determined by a surface examination of the area. The Winfield limestone dips westward beneath overlying beds in the east half of section 14 but again rises to the surface in the north-central part of section 10, near the crest of the dome. Two holes have been drilled in the area; one near the crest of the dome was stopped in the upper Mississippian limestone beds, or possibly the Ordovician beds if the "Mississippi

118. Whitaker, W. A., Campbell, F. W., and Estes, Clarence; The physical and chemical properties of Kansas petroleums: Kansas Geol. Survey, vol. 3, p. 181; 1917.

lime" is absent, and the other, far down the west flank of the dome, was drilled into the Ordovician beds. Neither well obtained oil in commercial quantity, although shows of oil were obtained from beds at two horizons in the Shawnee group, from the upper part of the Douglas, from the uppermost part of the Stalnaker sand, from sand in the lower part of the Lansing, and, in the well drilled near the crest of the dome, from sandy shale containing coal in the lowermost part of the Cherokee shale. If the Ordovician beds have not yet been tested on the higher part of the fold they remain as a possible source of oil.

Sec. 30, T. 30 S., R. 4 E. Oil was discovered early in 1927 in sand in the lower part of the Cherokee shale in sec. 30, T. 30 S., R. 4 E., about 2 miles southwest of Rock. The settled production of the well was relatively small. The site for the well was chosen on the basis of structural data disclosed by core drilling. The sand body found here may be the southwestward continuation of the producing sand of the Rock field.

Sec. 28, T. 31 S., R. 4 E. Oil was found in 1926 in a well drilled about 2 miles southeast of Akron, in the northwest corner of the NE¼, sec. 28, T. 31 S., R. 4 E., at a depth of about 2,400 feet, in sandstone and sandy limestone in the upper part of the Kansas City group. Dry holes have been drilled northwest and south of the discovery well, but drilling in 1927 has extended the known productive area eastward to the southeastern part of section 21 and northeastern part of section 28. The wells produced initially between 75 and 125 barrels of oil a day. One hole has been drilled to the top of the Mississippian limestone—the Lewis No. 2 well, in the southwest corner of the NW¼ NE¼, sec. 28. It found no sand in the Cherokee shale. A structure-contour map of the surface beds, supplied by the Trees Oil Company, is shown in Figure 21.

Wilmot gas field. Twenty or more shallow wells have produced gas in a rather wide area between Wilmot and Floral. The gas occurs in thin beds of sandstone in the upper part of the Admire shale, at depths of about 600 feet. Several holes in the general area have been drilled to the Mississippian limestone, and others have tested also the Ordovician beds. A well drilled in the northwest corner of sec. 9, T. 31 S., R. 5 E., found a show of oil in sandstone near the middle of the Shawnee group, another in the upper part of the Douglas group, and another in the Lansing; a thick sandstone near the Lansing-Douglas contact yielded water, the upper part of the Mississippian limestone furnished a show of oil, and the Ordovician beds produced water. No sand was found in the Cherokee shale nor in the upper part of the Kansas City group, though oil is obtained at these two horizons elsewhere in the county. Few altitudes of the drilled wells are available for use in a structural study of the area, and so only a regional structural picture is shown on

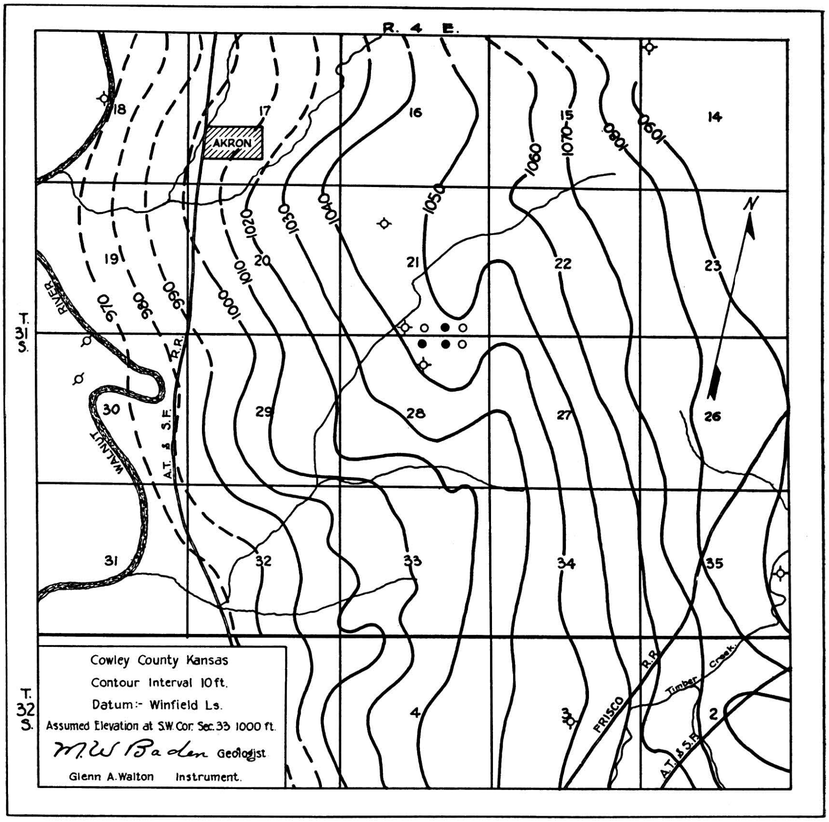

FIG. 21. Map showing attitude of surface beds in parts of Tps. 31 and 32 S., R. 4 E.

Plate XI. The general attitude of the buried Mississippian beds appears to be that of a gently dipping broad anticlinal nose trending southwestward through the gas field, in approximate alinement with the State School pool, near Winfield.

Floral gas field. Several gas wells that have produced as much as 8,000,000 cubic feet of gas a day have been drilled about a mile south of Floral. The gas occurs in sandstone beds in the upper part of the Douglas group, a short distance beneath the Oread limestone.

Sands at this horizon produce oil in the Udall pool, about 12 miles northwest of this area. The gas wells are on a northeastward-trending fold that may be the continuation of the fold in the Wilmot gas field or may lie *en échelon* with it. The general attitude of the buried rocks is shown on the county map (Pl. XI).

Sec. 6, T. 30 S., R. 6 E. One well produces oil from sand near the base of the Cherokee shale in the northwest corner of sec. 6, T. 30 S., R. 6 E., a short distance south of the Fox-Bush pool, of Butler county. Dry holes have been drilled at the east and west offset locations, and another was drilled about half a mile southeast of the well.

Mahannah pool. Three or four small oil producers have been drilled in the western part of sec. 6, T. 30 S., R. 8 E., in the northeastern part of the county. The oil is derived from a sandy zone near the top of the Mississippian limestone. One well was drilled to a depth of 3,130 feet and found a show of oil in the upper part of the Mississippian limestone and water in the uppermost Ordovician beds.

Roth-Faurot pool. The south end of a small oil pool known as the Roth-Faurot pool extends into the extreme northeastern part of Cowley county, in the north-central part of sec. 4, T. 30 S., R. 8 E. The oil is produced from sandstone in the lower part of the Kansas City group, which was encountered at depths of about 2,150 feet. Some gas and oil were found at several horizons in the Kansas City group above the chief producing bed. Few structural data concerning this area are available. The information disclosed by the few altitudes of wells that are at hand indicates that the oil has accumulated in the higher part of a southwestward-trending anticline or nose.

Grand Summit pool. Three wells, two of which are just west and the third immediately east of the county boundary about 1½ miles northeast of Grand Summit siding, in secs. 3 and 4, T. 31 S., R. 8 E., were drilled in the winter of 1926-'27 by the Minnehoma Oil and Gas Company. From 5,000,000 to 8,000,000 cubic feet of gas was struck in each well at a depth of about 1,800 feet, in sandstone in the uppermost part of the Kansas City group. More gas and sufficient oil for a daily production of about 25 barrels per well was found in porous limestone about 200 feet lower in the Kansas City group.

Sec. 18, T. 32 S., R. 6 E. A well drilled in the southeast corner of the SW¼ NE¼, sec. 18, T. 32 S., R. 6 E., produced a small amount of oil from a sandy zone about 100 feet beneath the top of the Mississippian limestone. Five shows of gas and five shows of oil were encountered in the well, which was drilled to a depth of 3,472 feet.

Empire-McCormick pool. Four wells surrounding the center of sec. 13, T. 31 S., R. 7 E., were drilled in 1922-'23. The area is known as the Empire-McCormick pool. The McCormick No. 1 well, in the northwest corner of the SE¼, sec. 13, produced initially 4½ barrels of oil a day from sand a little way below the middle of the Cherokee shale. It had a good flow of gas from a thick sandstone (Layton sand) in the uppermost part of the Kansas City group, struck at 2,040 feet, more gas at 2,240 feet, 500,000 cubic feet of gas at 2,320 feet, and a show of oil in the Fort Scott limestone at 2,532 feet. The well was abandoned, but the Brown No. 1, drilled as the north offset to it, produced oil from the sand in the Cherokee. The log of the Brown No. 2 well, in the southeast corner of the NW¼, sec. 13, records a bed of "red rock" showing no oil at the horizon of the producing Cherokee sand. This well was drilled into beds near the base of the Mississippian limestone and then plugged back to the gas sand (Layton sand) in the uppermost part of the Kansas City group, which yielded 2,500,000 cubic feet of gas a day under a rock pressure of 325 pounds to the square inch. The Keilhorn No. 1 well, in the northwest corner of the SW¼, sec. 13, showed a very thin bed of dry sand in the Cherokee shale and after testing the uppermost few feet of the Mississippian limestone was plugged back to the Layton sand, from which 5,500,000 cubic feet of gas was produced daily under a rock pressure of 460 pounds to the square inch. Two of these wells produced shows of gas from sandstone in the Admire shale, encountered at a depth of 500 feet, and one well yielded a show of gas from sandstone in the upper part of the Douglas group, immediately beneath the Oread limestone. A thick bed of sandstone capable of serving as a gas and oil reservoir, in the lower part of the Shawnee group, less than 100 feet above the Oread, produced a "hole full of water" in these wells. A well was drilled in 1925 in the northeast corner of the SW¼ NE¼, sec. 13, northeast of the producers, to a depth of 3,345 feet, penetrating all beds to the upper part of the Ordovician rocks. The Chattanooga shale appears to be absent in this part of the county, and so the Mississippian and Ordovician beds, which are both reported as being mostly limestone, cannot be distinguished by the well logs. The lowermost 510 feet penetrated is reported as limestone with a few beds of sandstone; the lowermost 150 feet, more or less, may be of Ordovician age and the remaining upper part of the 510 feet Mississippian. This well passed through 35 feet of sand between beds of "red rock" in the Cherokee shale, but it failed to produce oil. Shows of oil and gas were obtained at several horizons in the Kansas City and Marmaton groups.

Little information concerning the attitude of the strata in the field is available. The regional sturctural study shown on Plate XI indicates that the oil and gas occur on a structurally "high" area, but drilled wells in this part of the county are so widely spaced that no details of the fold could be learned from the well records.

Olsen pool. Oil was found by drilling carried on about 1922-'23 7 miles south of Hooser, on the Olsen farm, in sec. 1, T. 35 S., R. 7 E. Eight or more oil wells and two gas wells have been drilled here. The yield of the wells has been small, commonly ranging between 50 and 75 barrels a day initially for each well, but production is still maintained. The oil is found at a depth of about 2,375 feet, in sandstone that occurs in about the middle of the Marmaton group. Good shows of oil and gas were encountered at several horizons in the Kansas City group, which is here composed chiefly of sandstone and shale. From 11,000,000 to 18,000,000 cubic feet of gas was found in a sandstone in the middle part of the Lansing group, struck at about 1,700 feet. Thick beds of sandstone occur near the contact of the Douglas and Lansing groups and in the lower part of the Shawnee group but contain water. A well in the SE¼, sec. 1, southeast of the pool, was drilled through the Pennsylvanian and Mississippian beds into the Ordovician rocks. It found no sands in the Cherokee shale, and aside from a small show of oil in the uppermost beds of the Mississippian limestone it, gave no encouragement for oil or gas production from the beds beneath the sand that produces oil in the Olsen pool. The well is far down the flank of the fold, however, and does not constitute a conclusive test of the deeper-lying beds of the Olsen field.

The attitude of the surface rocks, which consist of limestone and shale beds in the upper part of the Wabaunsee group, can be readily determined by a detailed surface survey, inasmuch as outcrops of mappable rock layers are comparatively numerous and widely distributed in the vicinity of the field. According to a structural map of the area (Fig. 22), kindly furnished by the Phillips Petroleum Company, the surface rocks dip in general westward at the rate of about 40 feet to the mile, with a nosing that trends westward and passes just north of the center of section 1.

Arkansas City district. A large amount of gas and some oil have been produced near Arkansas City, in southern Cowley county. The principal development took place about 1916, but many of the wells were abandoned a few years later, and even records of their locations and logs of the wells are now difficult to obtain. The principal gas-producing districts, shown in Figure 23, were in an area centering about 2 miles north of Arkansas City, in secs. 18 and 7,

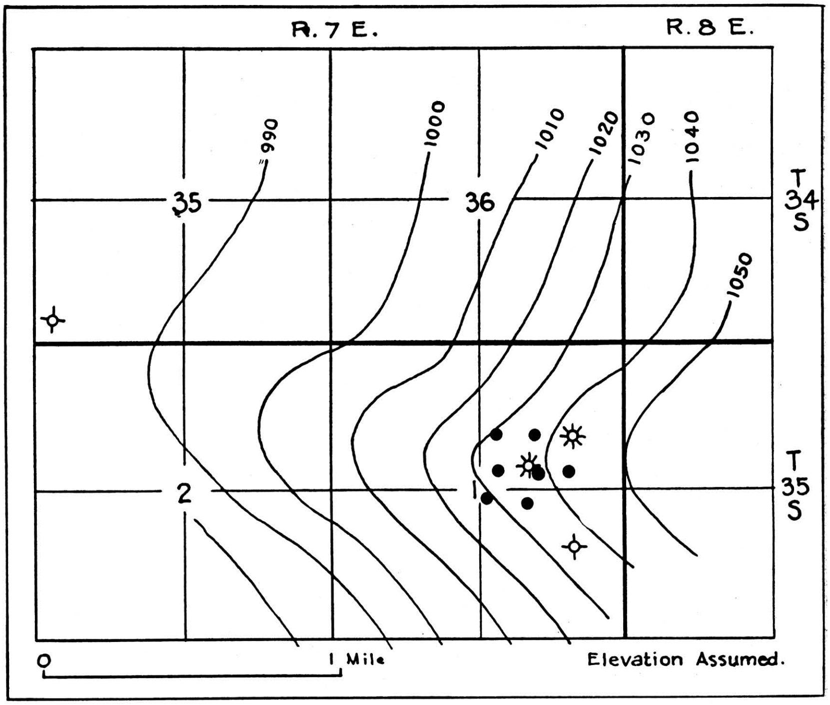

FIG. 22. Map showing attitude of surface beds in Olsen field.

T. 34 S., R. 4 E.; a small area 2 miles farther northeast, in the N½, sec. 5, T. 34 S., R. 4 E.; a small area about 2 miles northeast of Arkansas City, surrounding the south quarter corner of sec. 17, T. 34 S., R. 4 E.; and a small area about 3 miles southeast of Arkansas City, in the NE¼, sec. 4, T. 35 S., R. 4 E.

In the comparatively large area centering in sections 7 and 18 the gas was produced chiefly from a sandstone in the upper part of the Admire shale that appears to be continuous throughout much of the field and was encountered at depths ranging from 650 to 850 feet. Very little information about the yield of the wells is available, but the logs of several wells record yields between 1,000,000 and 2,000,000 cubic feet a day. Several other beds stratigraphically higher than the chief gas-producing sand (up to a level within 200 feet of the surface) yielded shows of gas. One well in the north-

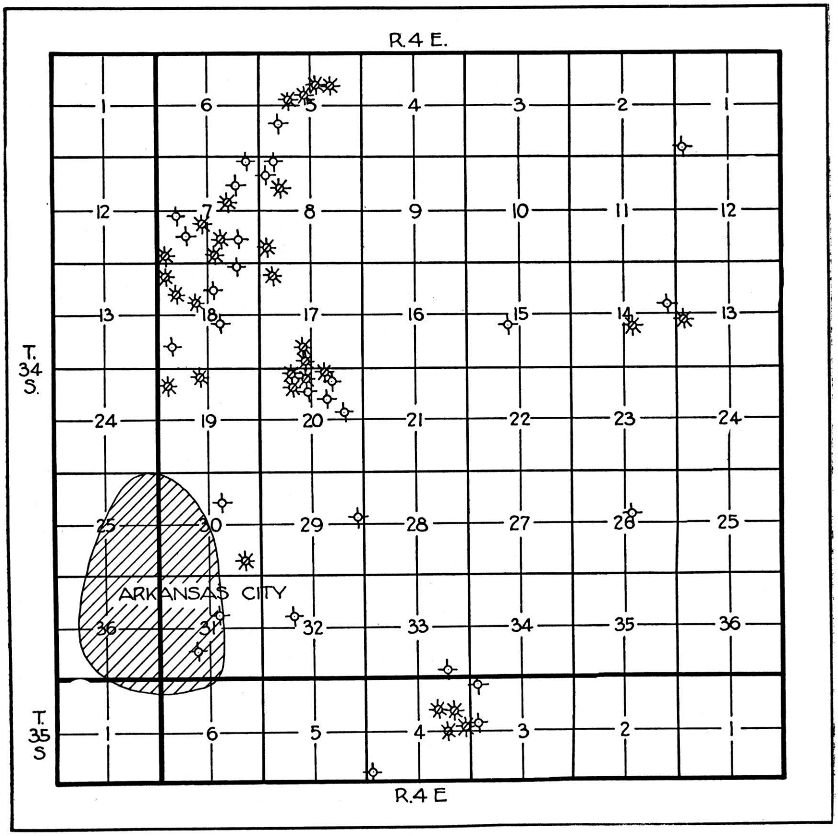

FIG. 23. Plat showing wells in Arkansas City district.

west quarter of section 8 was drilled to a depth of 3,510 feet, but lower beds that yield oil and gas elsewhere in the county failed to produce here. This well, however was drilled in an area that fails to produce even from the shallow gas sand, and so it may not constitute a conclusive test.

A few wells in the N½, sec. 5, T. 34 S., R. 4 E., have produced gas from the sandstone in the upper part of the Admire shale. Yields ranging between 200,000 and 5,000,000 cubic feet a day were reported for the wells. Two wells were drilled to a depth a little greater than 2,500 feet and penetrated a number of water-bearing sands in the Shawnee, Douglas, and Lansing groups, stopping in the lower part of the Lansing.

The wells surrounding the south quarter corner of section 17 yielded as much as 8,000,000 cubic feet of gas each from sands in the upper part of the Admire shale, which was struck at depths between 650 and 750 feet. A well in the northwest corner of the NE¼, sec. 20, near the center of the field, was drilled to a depth of 3,740 feet and thus tested the uppermost Ordovician beds and all beds above them. According to the record of this well thick beds of sandstone capable of serving as reservoir beds for oil and gas are fairly abundant in the lower part of the Shawnee group. Others occur in the Douglas group, and a sandstone unit more than 150 feet thick occurs near the Douglas-Lansing contact. More sand was struck lower in the Lansing, and the upper half of the Kansas City group is sandstone instead of being composed of limestone, as it is farther north in the county. A thin sandstone occurs in the lower part of the Cherokee shale. All these beds, as well as sandstone in the uppermost part of the Ordovician beds, failed to yield oil or gas.

Gas is produced from the upper part of the sand that occurs near the contact of the Douglas and Lansing groups, which were struck at about 1,930 feet in sec. 4, T. 35 S., R. 4 E. Sands in the Shawnee group, which was struck at depths between 1,400 and 1,500 feet, also yielded some gas. One well near the gas well was drilled to a depth of 3,645 feet, testing all beds to the uppermost few feet of the Pre-Chattanooga beds, possibly Ordovician (?). Shows of oil and gas were found in the Marmaton group at 2,850 feet and in sands in the Cherokee shale at 3,100 and 3,250 feet. The uppermost beds in the Mississippian and also the Pre-Chattanooga beds yielded water.

An initial daily production of 8,000,000 cubic feet of gas was found in sandstone in the upper part of the Lansing group, which was struck at a depth of 1,900 feet in a well 4 miles northeast of Arkansas City, in the northwest corner of the SE¼, sec. 14, T. 34 S., R. 4 E. A well half a mile farther east, in section 13, also produced some gas, but it is not known from what depth or at what stratigraphic horizon. These two wells are on the general trend of the Beaumont arch, a long structural fold that extends through Greenwood county and southeastern Butler county and enters Cowley county near its northeast corner, extending thence southwestward nearly across the county, as shown on Plate XI.

T. 34 S., R. 3 E. Several more or less widely separated wells in T. 34 S., R. 3 E., have produced oil or gas and some of them may prove to have been openers of pools. Two wells drilled by the Roxana Petroleum Corporation in section 16, on the Chaplin farm, have produced gas from sands in the upper part of the Shawnee group, which was struck at depths of a little more than 1,400 feet; one well yielded initially 1,500,000 cubic feet and the other 2,500,000 cubic feet of gas a day. This sand produced initially 24,000,000 cubic feet of gas in the Mullet No. 1 well of the Marland Oil Company in the southwest corner of the SE¼, sec. 31, completed in the middle in November, 1926.

Oil has recently been produced from sand in the lower part of the Cherokee shale in wells drilled about the corner common to sections 16, 17, 20 and 21. The well in the southeast corner of section 17 had an initial production of 100 barrels of oil a day; the well in the northeast corner of section 20 yielded 25 barrels a day; the one in the northwest corner of section 21 is a dry hole. These wells are in the area occupied at the surface by the Wellington formation, which is composed chiefly of soft beds of shale. No reliable key beds for structural mapping crop out in much of the area, and the attitude of the strata must be determined by data disclosed by the drilling of shallow holes from which cores of the beds are taken.

A well that produced initially 60 barrels of oil a day was drilled in 1926 by the Gypsy Oil Company in the southeast corner of the NW¼, sec. 5, on the Martin farm. The oil was found in "chat" that lies upon the "Mississippi lime." Gas is reported to have been produced in one well in the S½, sec. 11, but no data are at hand as to the depth of the producing bed or the yield of gas.

Sec. 33, T. 33 S., R. 3 E. Gas is reported to have been produced from sand in the Admire shale at a depth a little greater than 900 feet in a well in the NE¼, sec. 33, T. 33 S., R. 3 E., a short distance southeast of the Rainbow Bend field.

Industries Related to the Exploitation of Oil and Gas.

Refineries.

A part of Cowley county's oil is refined within her borders. The largest refinery is that of the Roxana Petroleum Corporation, at Arkansas City. It has a daily capacity of 20,000 barrels and operates at more than three-fourths capacity much of the time. The Arkansas City Refining Company's plant, with a daily capacity of 8,000 barrels, and the Kanotex Refining Company's plant, with a daily capacity of 10,000 barrels, are also at Arkansas City. Some oil from Cowley county goes to the plants of the Barnsdall Refineries (Inc.), and Derby Oil Company, in Wichita, and a part goes to refineries at Ponca City, Okla.

Gasoline-extraction Plants.

There are in Cowley county several plants that extract gasoline from the gas produced. A large plant of the absorption type in the Rainbow Bend field was extracting about 8,500 gallons of 85-degree gasoline from 4,000,000 cubic feet of gas a day at the time of the field examination. A greater production was made when the field was producing more gas. The peak gas production of the field occurred in the summer of 1925, when 112,000,000 cubic feet of gas a day was produced, averaging in gasoline content between 1.5 and 1.6 gallons per 1,000 cubic feet.[119] The capacity of the plant, however, was not sufficient to permit handling all the gas during the peak-production year. The present gasoline content of the gas produced at Rainbow Bend averages about 2.2 gallons per 1,000 cubic feet.[119]

A plant of similar type in the Winfield field treats gas from three sands—the "1,400-foot," "2,300-foot" and "3,000-foot Bartlesville." The gas from the last-named sand is the richest in gasoline. About 4,000 gallons of 85-degree gasoline was being produced daily at the time of the field examination. The gas treated averages about one-half to one-third gallon of gasoline per 1,000 cubic feet. There is another plant at Arkansas City and another in the Eastman field, but no data as to their production were obtained.

The general process followed in these plants is to pass the gas through a specially prepared oil, which absorbs the gasoline. The saturated oil is then heated under pressure. The gases given off are passed through cooling coils, where they condense to liquid. The product is a gasoline of very high gravity that is used to blend with low-grade gasoline. It is not blended at the plant, however, but is marketed to refiners. Considerable loss occurs in loading the gasoline because of its highly volatile character. To minimize the loss it is common practice to load at night and take other precautions to diminish evaporation.

Compression Plants.

One large gas "booster station" has been built in the county. This is one of numerous plants where the gas of the trunk lines is compressed and returned to the lines under pressure. Gas has

119. Rutledge, R. B.; personal communication.

recently been employed in the county to increase the production of oil wells. Oil wells in the State School pool are made to flow by using gas that is produced in the field. The gas is first compressed and then forced into the well through casing surrounding the tubing; it returns through the tubing and lifts the oil with it.

Helium Plant.

One of the most interesting industries to enter the county is that engaged in the commercial extraction of helium. The discovery of helium in natural gas was made in Cowley county more than 20 years ago, and the county now possesses at Dexter the only plant in the country engaged in extracting helium for commercial use. The story of helium gas at Dexter is told in a most interesting article by J. L. Dwyer, in the *Oil and Gas Journal* for March 1, 1928, quoted in entirety below:

The only plant in the world devoted to the commercial production of helium is owned by the Helium Company, and is located at Dexter, Cowley county, Kansas, in the southeastern part of the state. There is one other plant which makes helium, located at Fort Worth, Tex., and owned by the federal government and operated by the helium division of the United States Bureau of Mines. The combined output of these two plants constitutes the total production of this valuable gas, upon which the future expansion of airship construction and progress so greatly depends. The two plants are strictly competitive because, under a ruling of congress, the government plant may operate and produce helium only when it can do so at a figure which compares favorably with the cost of the product of commercial plants. The federal plant is supported by congressional appropriation.

The Helium Company (which is a subsidiary of the Kentucky Oxygen and Hydrogen Company, of Louisville, Ky.) was attracted by the possibilities of extracting helium from natural gas. Plans and contracts for a supply of suitable natural gas were made, and ground for the plant was broken on May 1, 1927. The plant was in operation, and the first cylinder of helium was shipped on September 1, 1927, and since that time, the plant has been in active operation.

According to the statement of R. R. Bottoms, general manager of the company, the natural gas which is produced in this part of Kansas abounds in traces of helium, but the majority of gases do not contain sufficient quantities to warrant processing. The history of helium discovery in Kansas is interesting and might be related.

In 1906 a wildcat well drilled on the edge of the town of Dexter found natural gas at a depth of 500 feet. This well apparently meant a great deal to the community and created much interest in a spot which had been confined to agriculture. There was unlimited publicity attendant upon this gas well, and the town fathers decided to make a gala day of the occasion. A band was hired, speakers were obtained, and a holiday proclaimed.

EVERYTHING WENT WELL, EXCEPT

The program was to have been an introductory speech by the mayor, who would then touch a torch to the well and allow the gas to shoot many feet into the air. After this spectacular performance the various speakers were to have been introduced, and their chief mission was to dwell upon the boon which the gas would prove to the growth of the town. Industries were assumed to be anxious to locate at Dexter on account of the cheap fuel which would be provided, and all was rosy.

The first part of the program was perfect. Lines were laid from the well to the speakers' stand, and the mayor made his introductory remarks, and then the gas was turned on, and the torch held by the mayor was lighted and applied to the end of the pipe. To the amazement of all, the torch was blown out by the gas. It was concluded that the pressure of the gas was too great, and accordingly, the output was pinched in, and a second torch applied. It suffered a fate similar to the first. The town dads were good and mad by this time, and a decidedly damp blanket was thrown over the celebration, but in an effort to snatch victory from defeat a huge bonfire was built near the end of the pipe, and when it was going good the gas was turned into the bonfire. The bonfire went out like the torches.

The celebration was completely blown up, and the town authorities sent for Dr. H. P. Cady, a professor of Kansas University. After examining the gas, Doctor Cady found that it contained a good percentage of helium. The helium was never put to use until the Dexter plant was started.

OPPOSITE OF REFINERY.

There are innumerable features about a helium plant, and probably the most terse manner of describing it is to state that it is exactly the opposite of an oil refinery. The refinery takes liquids and, after vaporizing them, separates the vapors, various products being derived from these vapors. A helium plant does exactly opposite. It takes natural gas and liquefies the various elements found in it. After liquefaction takes place, the helium, which is the least liquefiable of the elements in the natural gas, is left in gas form and is placed in cylinders similar to oxygen cylinders.

In oil refining the temperatures of the liquids are raised, in order to vaporize the contents, the lighter hydrocarbons being driven off first. In helium extraction the temperatures of the gases are decreased until the liquefaction temperatures are reached, and since helium has a much lower liquefaction temperature than any of the other elements in natural gas, it remains after the methane, butane, nitrogen, and hydrogen are removed. The liquefaction temperature of nitrogen is 195° below zero Centigrade. That of hydrogen is 254° below zero Centigrade, and that of helium is 268° below zero Centigrade. The zero used is the absolute zero. By converting this scale into Fahrenheit, it is found that helium has a liquefaction temperature of 462° below zero.

BETTER GAS FOUND DEEP.

Practical operation in helium production has necessarily taught many lessons and exploded some theories which had previously been held. The most important is that the deeper the sand which contained the gas the poorer helium contents would be found. The first helium gas in this area of Kansas was found at a depth of 500 feet, and the gas contained 1.7 per cent helium. The next sand to be used was found at a depth of 1,050 feet, and this gas contained 1.8 per cent helium. A sand at a depth of 1,100 feet contained 2 per cent helium, and the recent well of the Blaudell Oil Company, near Moline, in Elk county, found gas with a helium content of 3.4 per cent at a depth of 2,000 feet. This well, it is said, contains the highest percentage of helium in any gas which has been found. It is not believed that the area in general will develop wells having a content which shows this yield, as many other wells around the Blaudell well have been tested and their helium content found to be less than 1 per cent.

The work of extracting helium from natural gas is unusually interesting. A novel sidelight is that gasoline, which occurs in the gas, constitutes a very objectionable feature. The extremely low temperatures used cause the gasoline to freeze and impede the process. The gasoline piles up like ice cream, and after the officials of the plant had tried to eliminate this difficulty, a Southwestern Engineering Company portable gasoline plant was built and is used to remove the gasoline from the gas.

At present the plant is taking natural gas from two different fields—one a mile from Dexter and the other 5 miles. At this time a third gas field is being connected to the plant, and it is also 5 miles distant. The gas is taken from the wells and by ordinary gas-booster stations is sent through 4-inch lines to the plant. A pressure of 50 pounds is used for transmission. The gas is received and sent through scrubbers, which remove all traces of carbon dioxide. The carbon dioxide is another unfavorable compound which must be taken out, as it has a tendency to clog the small tubes used in the process. After the carbon dioxide is removed the gas is sent through the gasoline plant, where the gasoline content is eliminated. The gas is then sent into the plant proper, where it is compressed to 350 pounds pressure.

The main equipment in the plant consists of two 185-horsepower Cooper gas engines direct-connected to two-stage compressors, and one small 50-horsepower Cooper unit. The actual processing apparatus consists of a separating column with a large number of small copper tubes of ⅛-inch diameter, and a series of heat exchangers.

METHOD OF OPERATION.

The gas is taken to the compressors and raised to 350 pounds pressure. Before it is sent into the separating column this pressure is increased to 2,000 pounds. By decreasing the pressure from 2,000 pounds to atmospheric there is a gradual change in the temperature of the gases, and the work of the heat exchangers functions to decrease the temperature of the various elements in the gases to the liquefaction point. Any methane, nitrogen, and hydrogen are driven off in liquid form, and the decrease in temperature is continued until only the helium is left. The average helium manufactured at this plant is 96.5 per cent pure.

The gas left after the helium is extracted is allowed to blow into the air. It is not salable gas, for on account of its 98½ per cent nitrogen content, it is noninflammable. The gas at the government plant at Fort Worth contains only 50 per cent nitrogen and is therefore a combustible gas and sold for heating purposes.

Formerly it was thought helium was found only in noncombustible gas, but in the Petrolia and Nocona fields of north Texas helium occurs in combustible gas.

When the helium process is completed, the product is immediately placed in cylinders, which have a normal capacity of 1½ cubic feet. When compressed to 2,000 pounds pressure, these cylinders contain 175 cubic feet of helium, and they are shipped 600 cylinders in a carload. The Dexter plant has an annual capacity of 8,000,000 cubic feet of helium, and the government plant at Fort Worth is said to have an annual capacity of 6,000,000 cubic feet. The combined output of these plants hardly suffices to fill the government's requirements at this time.

The use of helium gas up to the present has been confined to filling the bags of dirigible airships. It replaced hydrogen gas and was far more desirable on account of its noncombustible quality. At the outbreak of the war helium commanded a price of $1,500 per cubic foot, and since an airship requires some 2,000,000 cubic feet to fill the bag, it would have cost $3,000,000,000 to fill the Los Angeles. Through industrial research great reductions in cost were made, and in a plant which was operated during the war helium cost $500 per cubic foot to produce. Progress resulted in the reduction of this cost to $75 per foot, and at the present time helium is sold to the government at $34.70 per 1,000 feet.

HELIUM FOR RADIOS.

Experiments in the use of helium for radio tubes has revealed some startling facts, and it is now believed that radio tubes filled with helium are far more efficient than vacuum tubes. The helium-filled tubes are said to give a clearer sound and have been declared a decided improvement on the older types of tubes. In this use there seems to be a much larger potential output for helium, and owing to the fact that radio tubes require helium which is 100 per cent pure, the cost of processing is greatly increased. According to reports, helium 100 per cent pure sold for radio tubes will command a price of $400 per cubic foot, and this figure will probably permit greater latitude in experimental work in the processing of helium.

Like many other products, we still have new markets to find for helium.

Economic Products Other than Oil and Gas.

Gravel Mining.

The chief gravel deposit near Silverdale was being actively exploited in 1926 by the Arkansas City Sand and Gravel Company, of Arkansas City. The gravel was being recovered with a small steam shovel (shown in Pl. VIII) that was operating at the time of the examination in the NW¼, sec. 21, T. 34 S., R. 5 E. The shovel loads dump cars each holding from 12 to 15 cubic yards of gravel. The cars are hauled by a donkey engine about a mile southwest to a washing plant in the NE¼, sec. 29. The deposit being worked averages about 10 feet thick and has a maximum thickness of 19 feet. The thin covering of soil that occupies the uppermost foot or more is mined with the gravel. (See Pl. VIII.) No shooting is necessary. At the washer the gravel is dumped onto an inclined platform; a stream of water from a hose is played upon it, forcing it forward into two elongated vats, each containing two revolving drums 32 feet long and set with numerous short blades that stir the gravel and force it forward in the vats; the bottoms of the vats are perforated to allow passage of dirty water and mud; streams of water are played on the gravel in the vats in addition to the water coming from the dumping platform. The gravel, after taking about one minute to pass through the vats, discharges from the far end onto a coarse screen plate that allows everything except the large particles to pass through it to an endless apron that transports the material to the tipple, where it is run through revolving screens for sizing and dumped into the appropriate compartments in the storage bins. The separations commonly made are, chat (particles below ¼ inch diameter), gravel of size ¼ to ½ inches, and gravel of size ¼ inch to 2¼ inches. Small streams of water are played upon the gravel as it passes over the screens. The very coarse particles that are separated as the gravel falls from the washer vats are passed through a crusher before being discharged onto the endless apron. The water is pumped from Grouse creek and is used at the rate of 400 gallons a minute. When operating the plant produces about one carload (55 tons) an hour.

The resultant products are marketed largely in three grades, most of the material falling in the grade containing gravel ¼ inch to 1½ inches in diameter. This grade is known in the trade as "Silverdale washed and graded flint gravel ¼ inch to 1½ inches" and is sold at $1.35 a ton f. o. b. plant; another grade measures ¼ inch to 2¼ inches and is sold at $1.25 a ton. About 20 per cent of the washed product is fine material below ¼ inch in diameter and is marketed as "flint chats" at 60 cents a ton. The landowner receives 5 cents a ton royalty for gravel removed from his land. The gravel is used chiefly for road construction. The unwashed material is used for road surfacing where no cement or other binder is added, and the washed gravel is used with a binder. The road-building program in progress in northern Oklahoma and eastern Kansas during the last few years has greatly enlarged the market for these gravel products.

A steam shovel, dump cars, and washer were standing idle at a gravel pit a little less than half a mile northeast of Silverdale at the time of the field examination, but is reported to have resumed operation later. A small plant about 3 miles northwest of Winfield, near the center of the W½, sec. 18, T. 32 S., R. 4 E., was being operated part time in 1926. It consisted of a tractor engine, a large worm screw and water pipe for cleaning the gravel, a bucket chain for hoisting, and a bin for storage. The gravel is mined with slip scrapers. Gravel for surfacing the Winfield-Arkansas City highway a few years ago was mined in the NE¼, sec. 4, T. 33 S., R. 4 E., about a mile south of Winfield.

One of the largest gravel-mining operations in southern Kansas was taking gravel in 1926 from pits a few hundred yards north of the Cowley county line, 3 miles north of Rock. The plant is owned by the Peerless Flint Gravel Company, of Wichita, Kan., and the process used is essentially similar to that used at the Silverdale plant described above. A part of the gravel deposit extends southward from the plant into Cowley county, but thins in that direction.

Sand Mining.

Sand is dredged with a suction dredge from the bed of Arkansas river immediately west of Arkansas City by the Arkansas City Sand and Gravel Company. The product is marketed as "Arkansas river washed and graded sand" at 70 cents a ton f. o. b. plant. The state of Kansas is paid a royalty of 2 cent a ton for all sand extracted.

Stone Quarrying.

The Fort Riley limestone has been quarried for building stone for many years near Silverdale. The product, commonly called "Silverdale stone," is widely known by builders throughout northern Oklahoma and southern Kansas. Large shipments of building stone have been sent as far away as Topeka, Kan. The Silverdale quarry, shown in Plate IX, is near the gravel washer in the NE¼, sec. 29, T. 34 S., R. 5 E., about 1½ miles northeast of Silverdale, and is owned and operated by the Arkansas City Sand and Gravel Company. The product is marketed as (*a*) Silverdale stone, surfaced on two sides, at 40 cents a cubic foot; (*b*) rough blocks, at 40 cents a cubic foot; and (*c*) riprap (broken stone) at $1 a ton.

Quarries at other localities in the county have been operated intermittently in years past. Building stone for several buildings in Winfield has recently been quarried from the Fort Riley limestone about a mile east of Winfield. Considerable stone has been quarried from the same formation in the northeastern part of Winfield. The Fort Riley limestone supplied the stone for the courthouse in Wichita, quarried near the east quarter corner of sec. 1, T. 35 S., R. 4 E., 6 miles southeast of Arkansas City. A partly constructed cement plant has stood near this locality for several years. It was planned to use stone from the Fort Riley formation, but the plant has never been in operation.

WATER SUPPLY.

The municipal water supplies for the two largest towns in the county are derived from relatively shallow wells in the Arkansas river bottoms. The six wells that furnish water for Winfield are in sec. 17, T. 32 S., R. 3 E., about 6 miles northwest of the town; four wells in the southwestern part of the town supply Arkansas City.

The Arkansas City wells have a diameter of 25 inches inside the screen and are drilled to depths of about 50 feet through alluvium composed largely of quartz sand ranging from very fine grains up to those about the size of a pea, with lesser amounts of clay. The wells are equipped with concrete screens that extend from about 15 feet beneath the surface to the bottom. They furnish a minimum of 2,000,000 gallons of water a day and have supplied as much as 5,000,000 gallons. Only one or two wells are pumped at a time, and the city's demand has never approached their capacity.

The Winfield city wells are a little more than 50 feet in depth and are reported to penetrate sand and gravel; the lower 30 feet is water-bearing. The individual well capacities average about 3,000,000 gallons a day. The city's demands range between 1,000,000 and 3,000,000 gallons a day.

The quality of the water used in Winfield and Arkansas City is shown by the analyses quoted below.[120] The water is of about the average hardness for the state and the general surrounding region. The Arkansas City water contains also a high content of chlorine.

Analyses of Water from Public Supplies in Cowley County.

[*Analyzed by Kansas State Board of Health.*]

Parts per million.

	Arkansas City.	Winfield.
Date of collection	July 23, 1927	Mar. 22, 1927
Silica (SiO_2)	12	15
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	2.8	2.0
Calcium (Ca)	96	86
Magnesium (Mg)	21	18
Sodium and potassium (Na+K)	141	43
Bicarbonate radicle (HCO_3)	252	349
Sulphate radicle (SO_4)	83	64
Chloride radicle (Cl)	229	19
Nitrate radicle (NO_3)	18	1.8
Total dissolved solids	795	411
Total hardness as $CaCO_3$ (calculated)	326	289

120. Chemical analyses furnished by J. L. Barron, State Board of Health, Lawrence, Kan.

The alluvium bordering all the principal streams of the county yields water to wells in sufficient quantities to supply small towns and farmsteads, but the potential well-water supply of the Arkansas river bottoms is greater than that of any other stream valley in the county, not only because the water-bearing alluvium occupies a greater area, but because the material that composes it is more porous and therefore more readily yields a large flow of water than the finer, compact material that makes up so large a proportion of the alluvium bordering other streams in the county. The city of Winfield sunk wells into the alluvium bordering Walnut river and failed to obtain sufficient water for the city's needs. Shallow surface exposures of the alluvium of Walnut valley show it to be composed largely of clay, whereas exposures of the same type in the Arkansas bottoms reveal mostly quartz sand. Moreover, core-drill holes near Rock have shown the alluvium of Walnut valley to consist largely of compact clay. The difference in types of alluvial material in the Arkansas valley and in other valleys in the county is due to difference in the types of rocks traversed by the streams farther up their courses.

Farms on the uplands are commonly supplied with water from drilled wells between 50 and 300 feet deep. Salt water is frequently encountered at depths of about 300 feet and in some localities as shallow as 100 feet. A water well drilled on the Elliot farm, 1 mile south and 1½ miles east from Winfield, is reported to have struck salt water at a depth of 100 feet; and a well 7 or 8 miles south of Winfield found salt water at a depth of 135 feet. Numerous wells, however, have found fresh water to depths of 250 to 300 feet. There are many prolific aquifers in the stratigraphic succession, notably the Florence flint and the Wreford limestone, and in most localities where these beds are not more than 250 feet deep they yield abundant supplies of potable water. Many large springs issue from the Florence flint and the Wreford limestone along their outcrops. In the eastern slope of the Flint Hills many stock pastures are abundantly supplied with water from springs that issue from the Garrison shale. Numerous springs issue just above the Crouse limestone member, others from the Foraker limestone, and there are many springs that flow from beds in the Admire shale, notably from a limestone and sandstone zone about 75 feet below the top of the formation.

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