THE SUBSURFACE STRUCTURE AND STRATIGRAPHY AS RELATED TO PETROLEUM ACCUMULATION IN COWLEY COUNTY, KANSAS

by

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INTRODUCTION

Purpose

The purpose of this investigation is to determine the geologic history, subsurface structure, and stratigraphy of Cowley County, Kansas, and to analyze the relationship of these geological factors to the accumulation of petroleum. It is believed that the analysis of the geological factors associated with the accumulation of petroleum in Cowley County will provide a valuable and working knowledge of the geology of the area and may provide a basis for the recovery of new petroleum reserves.

Location

Cowley County is adjacent to the Kansas-Oklahoma border in the southeast part of Kansas. It is the fifth county west from the Kansas-Missouri border and is bounded on the west by Sumner County, on the north by Butler County, and on the east by both Elk and Chautauqua Counties (Fig. 1).

Size and Shape

Cowley is one of the largest counties in the state of Kansas and is nearly square in shape, having a north-south dimension of 33 miles and an east-west dimension of 34.5 miles. The total area covered by the county is approximately 1,140 square miles.

Physiography

The surface features of Cowley County are almost entirely attributable to the variation in the underlying rocks. The eastern part of the county is marked by the rugged topography of the Flint Hills; the westermost one-sixth includes the eastern portion of the central Kansas plains; and the central part is a transitional low step-like surface (Bass, 1929).

The approximate eastern border of Cowley County is marked by a series of steep, east-facing escarpments produced by resistant chert-bearing limestones. These cherty limestones form the cap rock of the Flint Hills and are a source of chert or "flint". As the surface rocks dip gently westward, these highly resistant limestone beds dip underground, and the surface outcrops are confined to the younger overlying formations. The low, step-like surface produced by these younger overlying formations is much less pronounced than that found in the Flint Hills area. In the western one-sixth of the county the soft clay shale of the Wellington formation is exposed at the surface. This shale is easily disentegrated by weathering and consequently produces the near-level surface which characterizes this portion of the county.

The surface elevations rise above sea level in Cowley County from a low of 900 feet in the southeast corner to a high of slightly over 1,500 feet in the northeast portion of the county (Bass, 1929). Much of the county has an elevation ranging from 1,150 to 1,350 feet above sea level, but abrupt differences occur in the Flint Hills area where relief is commonly 300 to 350 feet within a mile (Bass, 1929).

The two major streams draining the area are the Arkansas and Walnut rivers, in the western one-third of the county. The Arkansas river flows southeastward across the southwest corner of the county, and the Walnut river flows southward and joins the Arkansas river near Arkansas City, Kansas. Timber creek, the major tributary of the Walnut river, drains most of the north-central part of the county. Grouse creek and its principal tributaries, Silver and Cedar creeks, drain the eastern and south-central portion of the county and discharge into the Arkansas river near the state line. The extreme eastern part of the county is drained by the east-flowing tributaries of the Caney river of neighboring Elk and Chautauqua Counties.

Procedure

The stratigraphy and lithology of the sedimentary rock units were obtained by reviewing the literature and by an examination of the Kansas Sample Log Service strip logs at Kansas University.

Structural contour maps were prepared which delineate the top of the Kansas City limestone (Fig. 5) and the Mississippian limestone (Fig. 6). Both maps were contoured by means of a contour interval of 25 feet. The two units chosen to be mapped were selected, not only because of their structural and economic importance, but also due to the fact that the surface of these two units is most commonly logged throughout the area. Sea level datum of formations tops was taken from Herndon Maps where available. In other areas and in places where an elevation was in question, top cards from the Geological Survey of Kansas were used.

Erosion of the Mississippian limestone has reduced the structural relief that originally existed after the folding of the Mississippian and older rocks; however, it is believed that the structure map does depict the major structural features of the Mississippian and older rocks. Some difficulty was encountered in preparing the structure map of the surface of the Kansas City limestone. This is due to the fact that many of the oil operators log the top of the Dennis limestone as the Kansas City limestone; whereas others log the top of the Iola limestone as the top of the Kansas City group, and do not differentiate the two units. This discrepancy is usually obvious, however, and it is believed that the structure map does portray the major structural features which affect the Kansas City limestone. Two maps of Cowley County (Figs. 5A and 6A) were prepared which show the distribution of control points used in contouring Figs. 5 and 6.

Previous Literature

One of the first published geological reports to include Cowley County was written by N. W. Bass in 1929. This literature was published as Bulletin 12 of the State Geological Survey of Kansas and appears under the title, "The Geology of Cowley County, Kansas".

From that time on, numerous reports have been written which describe geological conditions in nearby areas or small portions of the county itself. The important geological structures present in the county were described by Jewett (1951). A short review of the geologic history was given by Lee and Merriam (1954) in an article describing the geology and oil production in eastern Kansas.

An evaluation of the Precambrian rocks of Kansas was made by Farquhar (1957). The areal distribution and stratigraphy of the Upper Cambrian and Lower Ordovician rocks in Kansas was presented by Keroher and Kirby (1948) in a report which includes Cowley County. Lee (1948) discussed the subsurface Mississippian rocks of Kansas. The divisions of the Pennsylvanian System in Kansas were presented by Moore (1949). A correlation study of the Pennsylvanian sandstones in southeastern Kansas was discussed in an article by Cruce (1954).

STRATIGRAPHY

Precambrian

The Precambrian basement rocks of Kansas consist of granite, schist, slate, gneiss, marble, and quartzite (Farquhar, 1957). For purposes of this report the Precambrian rocks are not differentiated and will be referred to as the Precambrian basement complex.

Upper Cambrian and Lower Ordovician

Lamotte Sandstone. The Lamotte (Reagan) sandstone is the lowermost sedimentary rock present in eastern Kansas. This unit appears to be either absent or of such irregular distribution that it has not been reported in Cowley County.

Arbuckle Group. A thick unit of strata, believed to be Cambro-Ordvician in age, non-conformably overlies the Precambrian basement complex in Cowley County. This group of rocks is known as the Arbuckle group and consists of interbedded dolomitic limestones, sandy limestones, sandstones, minor amounts of shale, and is characterized by a high percentage of chert. Well records indicate that the maximum thickness of Arbuckle rocks in the county is about 950 feet. The Arbuckle group is commonly referred to by oil operators and drillers in this region as the "siliceous lime".

Five distinct lithologic units of the Arbuckle group are recognized in eastern Kansas (Keroher and Kirby, 1948). In ascending order they are: (1) Bonneterre dolomite, (2) Eminence dolomite, (3) undifferentiated Van Buren formation and Gasconade dolomite, (4) Roubidoux formation, and (5) undifferentiated Jefferson City and Cotter dolomites. The lower two units are believed to be Upper Cambrian in age, and the upper three units are dated as Lower Ordovician in age.

The Bonneterre dolomite is characteristically a dark-colored, cherty dolomite and grades upward into a fine sandy shale. Keroher and Kirby (1948) report that insoluble residues of fine, angular, glauconitic sand grains, which usually occur in this zone, are absent in the area of Cowley County. The Bonneterre dolomite is present in only the southeastern one-third of the county and has a maximum thickness of about 50 feet.

The Eminence dolomite, which is usually distinguished from the underlying Bonneterre dolomite by its lighter color and abundance of quartzose chert, appears to be absent in Cowley County (Keroher and Kirby, 1948). The absence of this unit may be the result of non-deposition over an uplifted area or of removal by post-Eminence erosion.

Unconformably overlying the Bonneterre dolomite is the undifferentiated Van Buren formation and Gasconade dolomite. The dolomite of this unit is white to light grey and is coarsely crystalline. Much insoluble material is usually present and consists mainly of blue to tan, translucent, vitreous chert or a white, dense chert (Keroher and Kerby, 1948). This unit overlaps older rocks and rests non-conformably upon the Precambrian basement complex in the northwest portion of the county where the Bonneterre dolomite is absent. The thickness ranges from 100 feet to more than 200 feet and increases to the southwest.

Resting unconformably upon the undifferentiated Van Buren formation and Gasconade dolomite is the Roubidoux dolomite. The Roubidox dolomite is a white, coarsely crystalline, sandy dolomite which is difficult to distinguish from the underlying formation without the use of insoluble residues (Keroher and Kirby, 1948). Analysis by Keroher and Kirby (1948) indicate that the insoluble material from the Roubidoux formation is predominately sand-sized particles while the underlying formation contains an abundance of larger chert fragments. The Roubidoux dolomite ranges in thickness from 100 to 150 feet in this area and thickens to the southwest.

The dolomites of the Jefferson City-Cotter formation are variable in both color and texture. Usually they occur as a white to grey, dense, slightly argillaceous, soft dolomite. The dolomite of this formation contains a considerable amount of insoluble material which is largely chert (Keroher and Kirby, 1948). The maximum known thickness of this formation in Kansas is reported in Cowley County where it attains a thickness of 667 feet.

Although less than 10 per cent of the oil wells in Cowley County penetrate the Arbuckle rocks, they contain one of the best petroleum reservoirs in the area. All production of oil from the Arbuckle group is derived from a porous zone near the top of the Jefferson City-Cotter formation. Wells producing from this zone usually have a large initial daily production and a long life.

Middle Ordovician

Simpson Group. A thin layer of strata, resting unconformably upon the Arbuckle rocks, is believed to constitute the lower part of the Simpson group. The lowermost unit of the Simpson group present in Cowley County is usually referred to as the lower Simpson sandy shale. This is characteristically a dark-green or grey-green sandy shale.

Overlying the lower Simpson sandy shale is the St. Peter sandstone.

The St. Peter sandstone is composed of nearly pure white sandstone consisting largely of angular to sub-round, frosted sand grains. A shaly zone is often present near the middle of the unit. The St. Peter sandstone and underlying lower Simpson sandy shale are present only in an area of six townships in the southwest corner of the county and in a smaller area of about one and one-half townships in the northwest corner.

According to Bass (1929) these two units of the Simpson group may be correlated in ascending order with the lower Simpson sandy shale, Burgen sandstone, Tyner formation, and Wilcox sandstone of northeastern Oklahoma. Most oil operators in the area log the upper unit as the Burgen or Wilcox sandstone and the lower unit as the Simpson shale or sandstone.

The thickness of the Simpson group in Cowley County ranges irregularly from 0 to 100 feet. Although some oil production is derived from the Simpson group, it is relatively unimportant as a petroleum reservoir due to its limited distribution and irregular thickness.

Devonian or Mississippian

Chattanooga Shale. The Chattanooga shale consists of a brownish to black, carbonaceous shale ranging in thickness from 0 to 200 feet in this county. This shale unit is dated as Devonian in age by the United States Geological Survey but is believed to be Mississippian in age by most mid-continent geologists. For purposes of this report it is considered as Devonian or Mississippian in age.

The Chattanooga shale, where present, lies with angular unconformity upon all older rocks. In a small area, approximately two miles wide and paralleling the entire southern border of the county, the Chattanooga shale become extremely thin or is absent. It is also absent in an area in the east-central portion of the county. This area is in the form of a narrow band, trending northwest, and having the configuration of a stream valley. This absence is seemingly the result of removal by erosion prior to the deposition of the Cowley formation of Mississippian age.

In Cowley County, the Chattanooga shale is a brownish-black, blocky, spore-bearing shale. Wherever present, the Chattanooga shale is one of the best "marker beds" in the area as it is easily recognized by its position beneath the Mississippian limestone and by its softness and brownish-black color.

A thin veneer of sandstone of irregular thickness and distribution is present at the base of the Chattanooga shale in a few places throughout the area. This sandstone is known as the Misener sandstone and has been correlated by Bass (1929 with the Sylamore sandstone member of the Chattanooga shale in Oklahoma.

Mississippian

Mississippian Limestone. Rocks of Mississippian age, composed predominately of cherty limestone, rest unconformably upon the Chattanooga shale and older rocks in Cowley County. In areas where the Chattanooga shale is absent, these rocks rest directly upon older rocks of Simpson or Arbuckle age. This system of limestone beds constitutes the Mississippian limestone and is designated by oil operators and drillers as the "Mississippi lime".

In the area covered by this report, these rocks range in thickness from 225 to about 450 feet and are usually all logged as "Mississippi lime". In general the Mississippian limestone consists of grey to brown, dense limestone and dolomitic limestone with varying amounts of chert. Interbedded sandstones and shales are also common near the upper and lower part of the Mississippian limestone.

A study made by Lee (1940) of the subsurface Mississippian rocks in Kansas subdivides the Mississippian limestone into various formations. According to this investigation, only those rocks belonging to the Osagian and Meramecian series are present in Cowley County.

Osagian Series. Rocks of Osage age are divided into four formations by Lee (1940). In ascending order they are: (1) St. Joe limestone, (2) Reeds Spring limestone, (3) Burlington limestone, and (4) Keokuk limestone.

The St. Joe limestone ranges from a white, non-cherty, crystalline to a fine-textured limestone. The lower part of the St. Joe limestone contains dark-greenish, argillaceous shale. In areas where the formation is relatively thick, the upper part is composed of a crinoidal limestone. Red shale and pink limestone are interstratified with this crinoidal limestone in Cowley County (Lee, 1940). The St. Joe limestone ranges in thickness from 0 to 65 feet.

The Reeds Spring limestone rests conformably upon the St. Joe limestone and is composed predominately of grey to brown limestone and dolomitic limestone containing large amounts of dark and pale blue chert. In Cowley County the Reeds Spring limestone is less dolomitic than in most other areas and contains chert only in certain zones (Lee, 1940). The thickness of this limestone ranges from 0 to 50 feet.

The St. Joe and Reeds Spring limestones are often referred to as rocks of Fern Glen age. In areas where a thick crinoidal limestone of St. Joe age is present, a possibility exists for the development of bioherms. If these areas represent bioherms, it seems likely that they have continued their growth during Reeds Spring time and are of Fern Glen age (Lee, 1940).

The Burlington limestone consists of grey limestones and dolomitic limestones containing white opaque chert and rests disconformably upon rocks of Fern Glen age. This limestone is present only in the northern one-third of the county and ranges in thickness from 0 to 25 feet. In areas where it has been removed by pre-Keokuk erosion, it is overlapped to the south by the Keokuk limestone.

A white dolomitic limestone, containing small amounts of white chert, is identified as the Keokuk limestone. An oolitic limestone occurs near the top of the Keokuk limestone in many places (Lee, 1940). The Keokuk limestone ranges in thickness from 0 to 60 feet and wedges out to the south where it has been removed by pre-Cowley erosion.

Meramecian Series. Rocks of Meramec age unconformably overlie the rocks of Osage age. In areas where the Osage rocks are absent, they rest directly upon the Chattanooga shale and older rocks in Cowley County. The Cowley formation and the Warsaw limestone of Meramec age are present in this area.

Following the deposition of Keokuk limestone, erosion accompanied by a slight southerly tilting of the region produced the Cowley Basin in southern Kansas and northern Oklahoma. According to Lee (1940) this basin had a relief exceeding 350 feet and in some places in Cowley and Chautauqua Counties, erosion cut through the Chattanooga shale into older rocks. The Cowley formation was deposited upon this erosional surface.

The Cowley formation consists of grey to brown limestone, grey to black dolomitic limestone, or brown dolomitic limestone and contains abundant chert throughout. A zone of abundant glauconite marks the base of the Cowley formation (Lee, 1940). The Cowley formation is named for Cowley County, Kansas, where it is most typically developed. In this area the Cowley formation constitutes the larger part of the Mississippian System and ranges in thickness from 50 to nearly 300 feet.

Lying conformably above the Cowley formation is the Warsaw limestone. The Warsaw limestone consists of white limestone and dolomitic limestone containing a small amount of grey chert. The Cowley formation appears to grade upward into the Warsaw limestone, and the two can be differentiated only by the lighter color of the Warsaw limestone. In this area the Warsaw limestone ranges in thickness from 30 to 60 feet.

Younger rocks of Mississippian age are absent in Cowley County. If ever present, they were removed by post-Mississippian erosion which preceded the deposition of Pennsylvanian sediments.

Rocks of Mississippian age provide important reservoir rocks for petroleum accumulation in Cowley County. A thinning of Mississippian rocks over structural "highs" has been observed and seems to be closely associated with the occurrence of oil and gas (Lee, 1939). Oil and gas are found in porous zones within the Mississippian rocks, most of which occur within the upper 100 feet.

Pennsylvanian

Rocks of Pennsylvanian age rest with angular unconformity upon the older Mississippian rocks. The Pennsylvanian rocks consist primarily of interbedded limestone and shale with minor amounts of sandstone and have an aggregate thickness ranging from 2,250 to 2,850 feet. A general trend of thickening of Pennsylvanian sediments to the southeast is present in the area.

Cherokee Shale. Overlying the erosional surface of the Mississippian limestone is a thick unit of strata composed almost entirely of fine clastic material and known as the Cherokee shale. Grey, clayey and silty, micaceous shale are the most common constituents, but lenticular sandstone bodies, beds of sandy shale, coal beds, and a few thin beds of limestone are also present. In some areas in Cowley County thin beds of red siltstone are present in the lower part of the Cherokee shale (Bass, 1929).

The Cherokee shale includes all strata from the top of the Mississippian limestone up to the base of the Fort Scott (Oswego) limestone. The thickness ranges from 300 feet in the southeast corner of the county to 125 feet in the northwest corner.

Many of the lenticular sandstone bodies which occur locally within the Cherokee shale are economically important as they are reservoir rocks for petroleum accumulation. The "chat" or "Burgess" sandstone is present in some areas a few feet above the Mississippian limestone and yields oil and gas in some localities (Table 1). The "Bartlesville" sandstone is the name most commonly applied to a sandstone which occurs near the middle and lower part of the Cherokee shale. This sandstone is one of the best petroleum reservoirs present in the county (Table 1). Lying above the "Bartlesville" sandstone and near the middle of the Cherokee shale is the "Burbank" sandstone (Cruce, 1954). Although no oil production is reported from this zone, it is probable that it is commonly mistaken for the "Bartlesville" sandstone due to their similar stratigraphic position. Above the "Burbank" and "Bartlesville" sandstones is the "Cattleman" sandstone. To date only one field is reported to derive oil from this zone (Table 1).

<u>Marmaton Group</u>. Conformably overlying the Cherokee shale is the upper and more calcarious part of the stratigraphic section assigned to the Desmoinesian series. This group of rocks is known as the Marmation group and consists predominately of interbedded limestone and shale. Sandstone and small amounts of coal are also present.

The Marmation group consists of strata upward from the base of the Fort Scott (Oswego) limestone to the unconformity which marks the upper limit of the Desmoinesian series. The Marmaton group is divisible into eight formations in areas where a complete stratigraphic section is present. In ascending order they are: (1) Fort Scott (Oswego) limestone, (2) Labette shale, (3) Pawnee limestone, (4) Bandera shale, (5) Altamont limestone, (6) Nowata shale, (7) Lenapah limestone, and (8) Memorial shale. Of these, only the Fort Scott (Oswego) limestone and Pawnee limestones are identifiable in Cowley County.

The Fort Scott (Oswego) limestone is an important "marker bed" and has an average thickness of about 50 feet. It consists of two grey to brown, dense, fine crystalline limestones separated by a thin black shale and may contain chert in some localities. The Pawnee limestone is a light-grey to pink, fine crystalline, slightly cherty limestone and ranges in thickness from 20 to 30 feet.

The Labette shale, which lies between the Fort Scott (Oswego) and Pawnee limestones, contains the "Peru" sandstone which is locally a reservoir for oil in the area (Table 1). The Labette shale is usually a grey or red and grey, slightly sandy shale which can be identified only by its position between the Fort Scott (Oswego) and Pawnee limestones.

The Marmaton group ranges in thickness from 100 feet to about 200 feet and thickens to the southeast. This variation in thickness is due, in part, to the unconformity which occurs at the upper surface of the Marmaton group. In some areas in the northern part of the county, the "Cleveland" sandstone of the overlying Pleasanton group occurs only a few feet above the Pawnee limestone.

Pleasanton Group. The Pleasanton group marks the lowermost deposits of the Missourian series and consists predominately of clastic sediments. The Pleasanton group extends upward from the top of the Marmaton group to the base of the Hertha limestone and has a thickness of 50 to 100 feet.

In the area covered by this report, the Pleasanton rocks are primarily varicolored sandy shales, grey sandy shales, and grey fine-grained, subangular sandstone. In areas where a thick section of the Pleasanton group is present, a thin limestone usually occurs. This is believed to be the Checkerboard limestone of Oklahoma or its equivalent.

A sandstone near the base of the Pleasanton group yields oil at various localities in the county and is known locally as the "Cleveland" sandstone (Table 1). This is probably correlative with the Hepler sandstone, which is present where the Pleasanton group crops out. This sandstone is sometimes used to mark the base of the Pleasanton group as good "marker beds" are absent from this unit.

Kansas City Group. In Cowley County the Kansas City group consists of varying amounts of cherty limestone, sandy limestone, shale, sandy shale, and sandstone. The Kansas City group includes all rocks from the base of the Hertha limestone upward to the base of the Plattsburg limestone. This group ranges in thickness from 200 to 400 feet and thickens to the south.

The Kansas City group is divisible into three subgroups (Moore, 1949). In ascending order they are referred to as the Bronson, Linn, and Zarah subgroups. In Cowley County only the lowermost two of these subgroups are recognized.

The Bronson subgroup, sometimes referred to as the old "triple" limestone, extends from the base of the Hertha limestone to the top of the Dennis limestone; in ascending order it includes the Hertha limestone, Ladore shale, Swope limestone, Galesburg shale, and Dennis limestone. In the northern part of the county this group of rocks is predominately limestone containing thin intervening shale breaks and consequently is logged as the Kansas City "lime". Toward the south, the base of the group grades into a sandy shale facies, and it is difficult to identify the base of the Kansas City group. For this reason it is sometimes logged as the Kansas City "sand". The thickness of the Bronson subgroup averages slightly less than 200 feet.

The Dennis limestone, which marks the upper boundary of this subgroup, is characteristically a grey to buff, dense, fine crystalline, fossiliferous limestone. In many areas throughout the county it contains a zone of dark-grey to black chert. This limestone becomes increasingly thin toward the south part of the county but is usually recognizable and is logged in most wells. For this reason it was selected as the datum for one of the structural contour maps (Fig. 5) which accompanies this report. Oil and gas production is derived from the upper part of this subgroup in several areas throughout the county (Table 1).

The Linn subgroup rests conformably upon the Bronson subgroup and includes all rocks from the top of the Dennis limestone to the top of the Iola limestone. This subgroup consists mainly of sandy shale, sandstone, and minor amounts of limestone and in ascending order includes the Cherryvale shale, Drum limestone, Chanute shale, and Iola limestone. The Linn subgroup ranges in thickness from 0 to 200 feet and thins to the north, where it is locally absent in some areas.

The "Layton" sandstone member of the Chanute shale is the most widely recognized unit of this subgroup. An unconformity occurs at the base of the Chanute shale, and the "Layton" sandstone lies directly upon the Dennis limestone in the north part of the county where the Cherryvale shale and Drum limestone have been removed by pre-Chanute erosion. Toward the south the interval between the "Layton" sandstone and Dennis limestone increases, and the Cherryvale shale and Drum limestone are present.
A thin, brown, finely crystalline limestone, which is present a few feet above the "Layton" sandstone, is believed to be the Iola limestone and marks the top of the Linn subgroup. In areas where the base of the Lansing group consists of shale, the Iola limestone also marks the boundary between the Lansing and the Kansas City groups.

The "Layton" sandstone yields oil and gas in many areas throughout the county and constitutes one of the most important reservoir rocks in the county (Table 1). The "Layton" sandstone is a grey, fine-grained, sub-angular, micaceous sandstone and is usually correlated with the Cottage Grove sandstone member of the Chanute shale. It is believed, however, that the lowermost sandstone which is logged as "Layton" sandstone, is the Noxie sandstone member of the Chanute shale. In areas where more than one sandstone is logged in this same stratigraphic position, the upper sandstone may be the equivalent of the Cottage Grove sandstone.

Lansing Group. In Cowley County the Lansing group consists of varying amounts of shale, sandy shale, sandstone, and limestone, the amount of shale predominating. This group of rocks rests disconformably upon the Kansas City group and averages about 300 feet in thickness. The Lansing group appears to thin to the northeast. In this report the Lansing group includes all beds from the top of the Kansas City group to the top of the Stanton limestone.

In the northeast portion of the county, the upper part of the Lansing group consists predominately of limestone, the amount of shale increasing toward the base. Toward the southwest the base becomes increasingly shaly, and a few thin sandstone beds occur. The upper limestone also thins rapidly to the southwest and grades into a sandy shale facies.

The Stanton limestone, which marks the upper boundary of the Lansing group, is a grey to brown, dense, fine crystalline, fossiliferous limestone. The underlying sandstone is predominately a grey, fine-grained, sub-angular, micaceous sandstone. The shale portion of the Lansing group consists of grey shales which grade into varicolored shales toward the south part of the county.

Some oil and gas production is reported from the "Lansing-Kansas City" group throughout the county (Table 1). It is probable that this production is derived mainly from the Kansas City "lime" in the north part of the county and from a sandstone member of the Lansing group in areas to the south.

Pedee Group. The uppermost group of rocks of Missouri age are referred to as the Pedee group (Moore, 1949). In Cowley County the Pedee group consists of all beds above the Lansing group to the base of the "Stalnaker" (Tonganoxie) sandstone and ranges in thickness from 0 to nearly 150 feet. The group thins to the northwest where it wedges out and the "Stalnaker" (Tonganoxie) sandstone rests directly upon the underlying Lansing group. This pinch-out is a result of post-Missourian--pre-Virgilian erosion.

In this area the Pedee group consists largely of red and grey sandy shale. In the southeast portion of the county a grey to white, dense, fine-grained limestone overlies the aforementioned shale. This is the Iatan limestone and marks the upper limit of the Pedee group. In areas where the Iatan limestone is absent, the Pedee group does not contain a good "marker bed".

Douglas Group. The Douglas group marks the lowermost rocks of Virgil age and rests unconformably upon the underlying rocks of Missouri age (Moore, 1949). This group consists of all beds from the base of the "Stalnaker" (Tonganoxie) sandstone upward to the base of the Oread limestone and averages slightly less than 350 feet in thickness.

The "Stalnaker" (Tonganoxie) sandstone is the lowermost recognizable unit of the Douglas group. This sandstone is predominately a grey, fine-grained, sub-angular, micaceous sandstone containing interbedded red and grey shales and ranges in thickness from only a few feet to slightly over 100 feet. This sandstone is an excellent water reservoir and in a few localities throughout the county contains oil and gas. (Table 1).

Two thin limestones, the Westphalia and Haskell limestones, are easily recognized by their stratigraphic position above the "Stalnaker" (Tonganoxie) sandstone. The Westphalia limestone is a cream to grey, dense, fine crystalline limestone and contains fusulinids. It is approximately 10 feet thick in the area covered by this report. The Haskell limestone is present about 15 feet above the Westphalia limestone and is a grey to brown, dense, fine crystalline limestone. The Haskell limestone is about 20 feet thick in this area. A grey shale which is present between the Haskell and Westphalia limestones is recognized as the Vinland shale.

The overlying Robbins shale member of the Stranger formation and the Lawrence formation are not differentiated for purposes of this report. They consist of varicolored, sandy, micaceous shales. A fine-grained, sub-angular, micaceous sandstone which is present is believed to represent the Ireland sandstone member of the Lawrence formation.

Shawnee Group. The Shawnee group is represented by a series of thick-bedded limestones containing interbedded shales and sandstones in Cowley County. This group consists of all beds from the base of the Oread limestone upward to the top of the Topeka limestone and maintains a rather constant thickness of about 650 feet throughout the county.

The Oread limestone is easily recognized by its thickness and by the thin, black, fissile shale (Heebner shale) which occurs near the middle of the formation. The Topeka limestone, which marks the top of the Shawnee group, is also sometimes logged in the area, especially in the west one-half of the county where oil production is derived from sandstone beds near the middle and top of the Shawnee group.

Oil production is derived from sandstone beds within the Shawnee group. A sandstone known locally as the "Peacock" sandstone is described by Bass (1929) as occurring about 150 feet above the Oread limestone. This sandstone is probably a sandstone member of Tecumseh shale and is named for the Peacock oil field which was opened in 1916 and since then has been combined with the Winfield oil field. Oil production from the "Hoover" ("Elgin") sandstone is believed to be from a sandstone member of the Kanwaka shale. Other production which is reported from the "Shawnee" may also come from these two sandstones or may be from a porous zone in one of the limestones of the Shawnee group (Table 1).

Wabaunsee Group. The Wabaunsee group marks the uppermost rocks of Pennsylvanian age present in Kansas (Moore, 1949). This group includes all beds from the top of the Topeka limestone to the unconformity which separates the Pennsylvanian and Permian Systems. In Cowley County the Wabaunsee group has an average thickness of about 400 feet and consists largely of alternating shales and shaly limestones. This group of rocks is usually not differentiated in well logs as it does not contain any oil producing horizons, and the underlying Topeka limestone constitutes a better "marker bed" than any present in the group.

Beds constituting the upper one-half of the Wabaunsee group are exposed in the southeast corner of the county and form the lowermost steep slopes of the Flint Hills. The Burlingame limestone member of the Bern limestone is the lowermost exposed bed and also constitutes the most easily recognized "marker bed" of the group.

Permian

Rocks of Permian age present in Cowley County are those belonging to both the Wolfcampian and Leonardian series. These rocks are exposed by surface outcrops and the oldest rocks are found in the southeast corner of the county. As the surface rocks dip gently westward, the older rocks dip underground and are overlain by successively younger rocks.

The Wolfcampain series is divided into three main groups in this ascending order: (1) Admire group, (2) Council Grove group, and (3) Chase group. The Sumner group of the Leonardian series is the uppermost group of rocks of Permian age present in the county.

Admire Group. The Admire group consists of rocks from the disconformity at the base of the Permian System upward to the Foraker limestone.

A sandstone bed which occurs locally near the base of the group is believed to be the Indian Cave sandstone member of the Towle shale. Gas production was reported from this sandstone in the western part of the county, and shows of oil were reported also from this same sandstone. This sandstone is the only identifiable bed in the group as the upper beds consist mainly of grey shale containing a few thin beds of sandstone and limestone. The Admire group has an average thickness of about 50 feet in this area.

Council Grove Group. The Council Grove group includes all beds upward from the base of the Foraker limestone to the base of the Wreford limestone. This group has an average thickness of about 150 feet and is exposed only in the eastern one-third of the county. Beds which form prominent outcrops and are easily identified are the Americus limestone, the Neva limestone, the Bader limestone, and the Crouse limestone.

Chase Group. The rocks of the Chase group average about 375 feet in thickness and occupy about one-half of the surface area of the county. This group comprises rock strata from the base of the Wreford limestone upward to the top of the Nolans limestone. The Wreford limestones, the Barneston limestones and the Herrington limestone member of the Nolans limestone are all conspicuosly thick limestone beds and constitute excellent "marker beds".

Sumner Group. In Cowley County the Sumner group is represented by 80 feet of argillaceous shale belonging to the Wellington formation. This formation is present in only the western one-sixth of the county and produces a plains type topography.

Tertiary (?)

<u>Pliocene</u>. Deposits which are described by Bass (1929) as probably Tertiary in age consist of upland chert gravels which are present 150 to 225 feet above streams. These gravel deposits are quarried for road material in some areas throughout the county.

Quaternary

<u>Pleistocene</u>. Deposits of chert gravel bordering the larger streams and present 10 to 100 feet above the stream beds are considered by Bass (1929) to be Pleistocene in age. Loess deposits which are present in the southwestern part of the county are also believed to be Pleistocene in age (Bass, 1929).

GEOLOGIC HISTORY

Precambrian Era

The Precambrian rocks of Kansas have been described as a basement complex consisting of a metamorphosed sequence cut by igneous intrusions (Farquhar, 1957). Many geologists believe that the basement complex of Kansas is so arranged that granite and quartzite are present in the nucleus of uplifts and that schist, gneiss, slate, or marble occur upon the flanks of the upwarped areas. The Precambrian history of these rocks, however, is unknown as they lie buried beneath thick accumulations of younger strata.

The Precambrian surface was eroded to the extent that only a few isolated hills or monadnocks were present upon an otherwise peneplained surface. Upon this eroded surface, younger sedimentary rocks were deposited. Records of drilling depths in Cowley County show that a thick stratigraphic sequence of Paleozoic rocks rests upon the Precambrian surface. The Precambrian surface is present at depths ranging from approximately 3,100 to 4,500 feet in the Cowley County area.

Paleozoic Era

The first major Paleozoic diastrophism occurred during late Cambrian time, when the area which now includes Cowley County was slowly subsiding and receiving thick accumulations of carbonates and fine clastics. This area was on the west flank of a basin which centered about the present location of the Ozark Uplift. It was during this period of submergence that rocks constituting the Arbuckle group were deposited. Keroher and Kirby (1948) suggested that three unconformities mark minor periods of crustal unrest during the deposition of Arbuckle rocks.

Following the deposition of Arbuckle rocks, a period of uplift and erosion occurred. After the upper surface of the Arbuckle rocks had been considerably dissected, the region was submerged and tilted northward into the North Kansas Basin (Fig. 2) as the Chautauqua Arch (Fig. 2) slowly began to rise (Lee and Merriam, 1954). During the following period of submergence, rocks of Simpson age were deposited. After the deposition of Simpson rocks, the seas once again retreated, and the area was subjected to weathering and erosion.

Strata representing the Viola (Kimmswick) limestone, Maquoketa (Sylvan) shale, and "Hunton" limestone are absent in this area. According to Lee (1943), these sediments were once present in the area but were removed by pre-Chattanooga erosion as movements of the Chautauqua Arch were accelerated near the end of Devonian time. Paleogeologic maps of southeastern Kansas show that the Chautauqua Arch was a broad, west-trending nose around which the sediments were exposed in parallel bands as the surface was beveled to a near-level plain by erosion (Lee and Merriam, 1954). During this period of erosion, rocks of Simpson and Arbuckle age were exposed in all of Cowley County. Upon this erosion surface, the Chattanooga shale was deposited and rests in angular unconformity upon all older rocks. A period of uplift and erosion marked the end of Chattanooga time.

Lowermost Mississippian rocks present in the area are those of Osage age. Rocks of Kinderhook age, if ever present in the area, were removed by pre-Osage erosion. A slight southerly tilting of the region, accompanied by erosion, marked the end of Osage time and produced the Cowley Basin (Lee, 1940). The rocks of Meramec age were deposited in the Cowley Basin and rest in angular unconformity upon rocks as old as the Arbuckle group.

Near the end of Mississippian time, a marked uplift occurred as the Nemaha Ridge arched its way across Kansas (Fig. 3). At this time, rocks of Mississippian age were subjected to weathering and erosion and were worn down to their present attitude such that they thinned over structural "highs" and thickened in the "lows". Many of the small local structures of Cowley County are believed to have originated during this period of deformation, due to their near-parallel alignment with the Nemaha Ridge and also because of the thinning of Mississippian rocks over their crests.

Following this period of erosion, which lasted through the Morrowan and Atokan stages of early Pennsylvanian time, southeastern Kansas slowly began subsiding. Accompanying this subsidence was the encroachment of the Cherokee Sea from the McAlester Basin in eastern Oklahoma. It was during this period of submergence that the Cherokee Basin (Fig. 3) of southeastern Kansas originated. The Nemaha Ridge on the west and the Bourbon Arch (Fig. 3) on the north marked the boundary of the Cherokee Basin in Kansas. The Bourbon Arch, believed to be approximately the same age as the Nemaha Ridge, was a low structural divide which separated the Cherokee Basin from the Forest City Basin to the north.

Weirich (1953) states that southeastern Kansas was a part of the shelf area of the Cherokee Basin, the hinge line lying to the south in Oklahoma. The abundance of coal deposits, minor unconformities, and a thinning of Cherokee sediments to the northwest supports this statement and indicates that the area of Cowley County was near the shore line of the Cherokee Sea. The well known "shoestring sands" ("Bartlesville" sandstone) are believed to have been shoreline deposits of the Cherokee Sea (Bass, 1936).

The lowermost rocks of Pennsylvanian age present in the area are those belonging to the Cherokee group. Rocks of the Cherokee group were deposited in the Cherokee Basin and rest in angular unconformity upon older rocks of Mississippian age. According to Lee (1943), the Cherokee and Forest City Basins were incorporated into one large basin at the end of Cherokee time as the Bourbon Arch was buried by Cherokee sediments.

Above the Cherokee group is a thick stratigraphic unit of rocks constituting the remainder of the Pennsylvanian System. The thickness of this stratigraphic section of rocks suggests that the area remained submerged throughout most of the Pennsylvanian time. The presence of many local unconformities and clastic nature of many of the rock units indicate that the rate of subsidence and deposition were nearly contemporaneious, and that deposition took place in a relatively shallow sea. A general trend of thinning of the Pennsylvanian strata to the north seems to indicate that the area was tilted to the south throughout most of Pennsylvanian time.

The uppermost sedimentary rocks of Paleozoic age present in the area are those representing Permian deposition. The lowermost rocks of Permian age are separated from the underlying rocks of Pennsylvanian age by an obscure disconformity at the base of the Admire group. This disconformity is not as evident as many of the disconformities within the Pennsylvanian stratigraphic section and suggests that deposition was nearly continuous from Pennsylvanian into Permian time. Several hundred feet of younger Permian rocks, and possibly Cretaceous rocks, at one time covered the area, but have since been removed by post-Permian and post-Cretaceous erosion.

Mesozoic and Cenozoic Eras

In summary it can be said that Cowley County has remained emergent and subject to erosion since near the end of Permian time, the possible exception being late Cretaceous time. Later structural movements, that can be definitely dated no closer than post-Permian in age, have given the rocks their present low dip to the southwest. These later movements have also possibly altered or rejuvenated some of the older structures of the area.

STRUCTURE

Regional

Chautauqua Arch. Cowley County is situated on the west flank of the Ozark Uplift on a structure which is commonly known as the Chautauqua Arch (Fig. 2). The Chautauqua Arch appears to be the most important pre-Mississippian structural element of the area and perhaps most directly controls the regional dip of the rocks in Cowley County. Movement of the Chautauqua Arch began as early as Simpson time but was not climaxed until late Devonian time.

Cherokee Basin. The county is also situated on the west flank of the Cherokee Basin (Fig. 3), a northward extension of the McAlester Basin from Oklahoma into southeastern Kansas. This basin is seemingly the most important post-Mississippian structure of the area as it controlled the deposition of the Pennsylvanian sediments which are important reservoir rocks for petroleum accumulation. The boundary of the Cherokee Basin in Kansas is marked on the north by the Bourbon Arch (Fig. 3), and on the west by the Nemaha Ridge (Fig. 3).

Nemaha Ridge. The Nemaha Ridge, known locally as the "granite ridge", crosses the extreme northwestern part of the county and trends northeast-southwest. Although the Nemaha Ridge was a prominent structural feature during early Pennsylvanian time, as it separated the Cherokee Basin from the Sedgwick Basin, it appears to have little effect upon the surface rocks and produces only a local reversal in the regional dip. The Nemaha Ridge is dated as late Mississippian or early Pennsylvanian in age.

Bourbon Arch. The Bourbon Arch, situated to the northeast of Cowley

County, is a post-Mississippian structure believed to be approximately the same age as the Nemaha Ridge. This feature consists of a low structural divide which separated the Cherokee and Forest City Basins during Cherokee time. According to Lee (1943), the Bourbon Arch was buried by Cherokee sediments at the end of Cherokee time, and the Forest City Basin became a northward extension of the Cherokee Basin. Post-Permian uplift of this structure may be in part responsible for the southward component of the regional dip of the rocks in the area.

Regional Dip. The regional dip of the surface rocks in Cowley County is predominately to the west but inclined slightly to the south. The average rate of dip is about 25 feet per mile and rarely exceeds 40 feet per mile (Bass, 1929). Departures from the regional dip range from steepening of the general southwestward dip to northeastward or reverse dips (Bass, 1929). These variations consist of anticlinal noses, domes, terraces, plunging synclines, and small basins.

The direction and rate of the dip of the subsurface rocks changes with depth. Regional dip on the upper surface of the Kansas City limestone is about 33 feet per mile to the southwest (Fig. 5). The rate of dip again changes and is only 27 feet per mile on the surface of the Mississippian limestone (Fig. 6). This decrease in the rate of dip is probably a result of pre-Pennsylvanian erosion of the Mississippian limestone.

Local

Variations in the regional dip are numerous throughout the county. Most of the folds have only very low dips, seldom exceeding one degree, and the amount of closure of anticlinal folds usually increases with depth. A few surficial folds are present, however, which die out with depth, usually within the Pennsylvanian series (Bass, 1929). Fold axes are commonly inclined so that the crests of folds migrate with depth. The direction of migration appears to be to the northwest in most cases. Many of the small and all of the major folds have a northeast-southwest alignment which is approximately parallel to the axis of the Nemaha Ridge.

Dexter Anticline. Of the structural features in the county, the Dexter Anticline is the most pronounced in surface expression (Bass, 1929). It is commonly referred to as the Dexter-Otto or Otto-Beaumont Anticline. This is an anticlinal trend which extends from southeastern Cowley County near Otto to the vicinity of Beaumont in southeastern Butler County (Jewett, 1951). Overall, this trend is 50 miles or more in length and is made up of several dome-like portions, the most pronounced being near Otto, Dexter, and Beaumont (Jewett, 1951).

Winfield Anticline. The Winfield Anticline is the name applied to the anticlinal trend which is present in the central part of the county. This structure is discernable in the surface rocks approximately two miles east of Winfield, and therefore has been termed the Winfield Anticline. The trend of this anticline is distinguishable in the subsurface rocks across the entire county but is most pronounced in an area approximately 12 miles long to the north and south of Winfield. The Winfield Anticline lies approximately midway between the Dexter Anticline and the Nemaha Ridge. Many of the county's most productive oil fields appear to be associated with this structure.

Rainbow Anticline. A trend of folding which lies between the Winfield Anticline and the Nemaha Ridge is usually referred to as the Rainbow Anticline. This structure is named for the Rainbow Bend oil field, but may also be referred to as the Graham Anticline for the Graham oil field which is also located upon the same structure. This anticlinal trend can be traced across the northern two-thirds of the westernmost tier of townships present in the county.

Many other small structures, which have not been named and are too numerous to mention, are present throughout the county. Most of these smaller structures are extensions of the major structures within the county which have been described.

RELATIONSHIP OF STRUCTURE AND STRATIGRAPHY TO PETROLEUM ACCUMULATION

As shown by a comparison of Fig. 4 to Figs. 5 and 6, much of the oil accumulation in Cowley County is a result of structural conditions. Many of the county's oil fields occur upon anticlinal folds which appear as only a nose on surface structural contour maps using a contour interval of ten feet (Bass, 1929). Exceptions are present, however, in places where some of the most pronounced folds are nearly barren of oil production. An example of this is the Dexter Anticline in the eastern one-third of the county. To date, only four small oil fields have been discovered along this large anticlinal trend. Several oil fields throughout the county also appear to be independent of structural conditions, and oil accumulation is controlled by stratigraphic conditions. An example of this is the Shannon oil field in the southeast one-fourth of township 31 south, range 5 east (Fig. 4).

Arbuckle Group

Production of oil from the Arbuckle group is concentrated in the western one-third of the county. At the present time, 15 oil fields derive oil from a porous zone near the upper surface of the Arbuckle group. This accumulation is seemingly the result of structural conditions which are largely reflected in the surface of the Mississippian limestone as shown by Fig. 6. Although all oil production derived from the Arbuckle group at the present time appears to be controlled by structural conditions, it seems likely that stratigraphic conditions exist within the Arbuckle rocks which should be favorable for the formation of stratigraphic traps. These stratigraphic conditions are a result of onlap relations between the various formations of the Arbuckle group. As only a few wells throughout the county penetrate the entire Arbuckle group, it is possible that virtually untested petroleum reservoirs are present within the group.

Simpson Group

The areal extent of the Simpson group restricts oil production from this zone to the western part of the county. At the present time only three fields are reported to derive production from this zone in Cowley County. Onlap relations between the Simpson group and the Chattanooga shale offer geological conditions favorable for stratigraphic entrapment of oil. All oil production from this zone appears to be the result of these stratigraphic conditions but is also associated with structural conditions.

Mississippian Limestone

The Mississippian limestone constitutes one of the most important reservoir rocks for petroleum accumulation in the county. Most of the oil accumulation from this zone appears to be associated with structural features which are shown on Fig. 6. A few oil fields which report production from this zone, but do not appear as structural "highs" on Fig. 6, are most likely also controlled by structural conditions. A thinning of Mississippian rocks over structural "highs" and a thickening in the "lows" has reduced the relief on the surface of the Mississippian limestone to the extent that some of the smaller structures do not appear on Fig. 6.

According to Lee (1939), a thinning of Mississippian rocks over structural "highs" is closely associated to the occurrence of oil and gas. Most oil and gas production is derived from a porous zone in the upper 100 feet of the Mississippian limestone, but Smith (1955) reports that "chat" zones appear locally throughout the middle and upper parts of the Mississippian section and are oil-bearing in areas to the south in Kay County, Oklahoma.

Pennsylvanian Sandstones

Oil accumulation in the Pennsylvanian sandstones appears to be controlled by a combination of both stratigraphic and structural conditions. A comparison of Fig. 4 to Figs. 5 and 6 shows that most of the oil production from the Pennsylvanian sandstones is associated with a structural "high of some type. Stratigraphic conditions which restrict oil accumulation in these sandstones include areal extent of the reservoir rock, thickness of the reservoir, and reservoir porosity.

Pennsylvanian sandstones which yield oil and gas in Cowley County include in ascending order: "Burgess", "Bartlesville", and "Cattleman" sandstones of the Cherokee group; "Peru" sandstone of the Marmaton group; "Cleveland" sandstone of the Pleasanton group; "Layton" sandstone of the

Kansas City group; "Stalnaker" sandstone of the Douglas group; and "Peacock" and "Hoover" sandstones of the Shawnee group. Except for the "Stalnaker" and "Layton" sandstones, all of these occur as lenticular sandstone deposits or erosional outliers of only local extent. The "Layton" sandstone is present in all of the county except the northern one-third, and the "Stalnaker" sandstone is absent only in a small area of approximately two townships in the northeast corner of the county (Winchell, 1957).

Oil accumulation in the aforementioned sandstone deposits of local extent is controlled most directly by the areal extent of the reservoir rock, but structural conditions also appear to be an important factor. Oil accumulation in the "Layton" sandstone does not appear to be the result of any single factor. In some areas, oil production from this zone appears to be independent of structural conditions and is probably controlled by reservoir porosity. Oil accumulation in the "Stalnaker" sandstone appears to be the result of structural conditions, but in only a few cases is oil present in this zone. In most areas the "Stalnaker" sandstone yields only water.

Oil production which is reported from the Kansas City (Table 1) appears to be concentrated in the northern part of the county. In most cases this production probably is derived from a porous zone near the top of the Kansas City limestone. Porosity of the reservoir rock may be the result of post-Kansas City—pre-Lansing erosion which developed solution channels in the Kansas City limestone. The Kansas City limestone is conformably overlain by younger sedimentary rocks in the southern part of the county and not subjected to erosion in that area. This may in part explain why most of the oil production from the Kansas City limestone is concentrated in the northern part of the county. Some of the oil production which is reported from the Lansing-Kansas City (Table 1) may be from a sandstone near the base of the Lansing group.

Admire Group

Gas production reported from the Admire group probably is derived from the Indian Cave sandstone which is present in a few localities. Accumulation of petroleum in this zone is seemingly controlled by the areal extent of the reservoir rock and also by structural conditions.

HISTORY OF THE PETROLEUM INDUSTRY IN COWLEY COUNTY

The petroleum industry has been important in Cowley County for many years. Shallow gas production was discovered near Winfield as early as 1902 (Bass, 1929). The discovery of gas near Dexter in 1903 attracted wide interest due to a high content of helium. A plant for the extraction of helium was built near Dexter in 1927 (Bass, 1929). Although this plant is no longer in operation, it was the second such plant built in the United States and the first in the world devoted to the commercial production of helium (Bass, 1929).

Oil was discovered near Dexter in 1914, but the first important commercially producing oil field in the county, the Peacock oil field near Winfield, was not discovered until 1916 (Bass, 1929). This field attracted much attention, and extensive developments took place near Winfield in the 1920's (Jewett, 1954). Peak production for Cowley County was reached in 1925 as production totals for that year amounted to 7,038,874 barrels of oil (Jewett, 1954). Of this 1925 total, nearly 4,000,000 barrels came from the Rainbow Bend oil field alone. In 1926, production had declined to 3,943,061 barrels of oil (Jewett, 1954). From then to the present time, production has fluctuated from slightly less than 2,000,000 to more than 3,000,000 barrels of oil annually (Jewett, 1954).

In 1959, Cowley County reported 102 producing oil and gas fields (Table 1) and a total annual production of 3,858,450 barrels of oil. Of the 1959 total, 1,244,645 barrels were produced by secondary recovery methods. A total of 65 secondary recovery projects were reported operating in the county during 1959, as Cowley County ranked third in the state in production by secondary recovery methods. Gas production in 1959 amounted to 1,320,315 thousand cubic feet. In terms of total cumulative oil production, Cowley County ranked ninth in the state at the end of 1959, having a cumulative total of 100,348,582 barrels of oil. The county ranked tenth in the state in annual production during 1959. (Goebel and others, 1960.)

FUTURE POSSIBILITIES

The oil outlook for the future in this area is by no means dim. Most of the oil production in the county is rather small, and operating costs are marginal; but, as most of the reservoir rocks are relatively shallow in depth, the payout time of the initial investment is short.

Although much of the county has been explored and partially developed, good possibilities for finding small oil pools in numerous areas still exist. Deeper drilling, particularly in the eastern part of the county along the trend of folding of the Dexter Anticline, may lead to the discovery of many new wells. Deepening of many old wells may result in the revival of fields where production appears to be depleted. Also, secondary recovery projects should result in continued life for many of the old fields.

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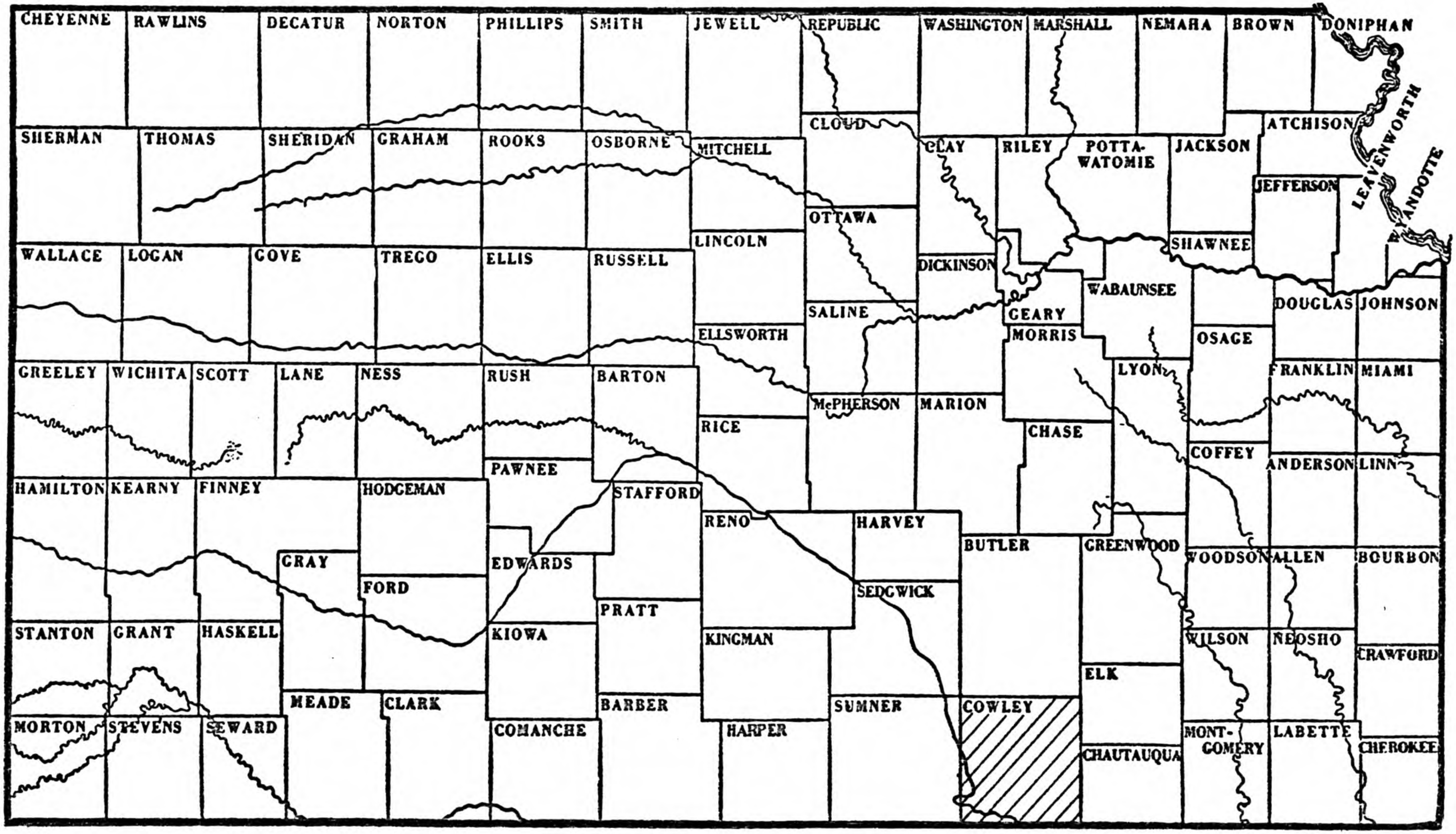
APPENDIX



Area covered by this report

Fig. I. Index map of Kansas showing location of Cowley county.

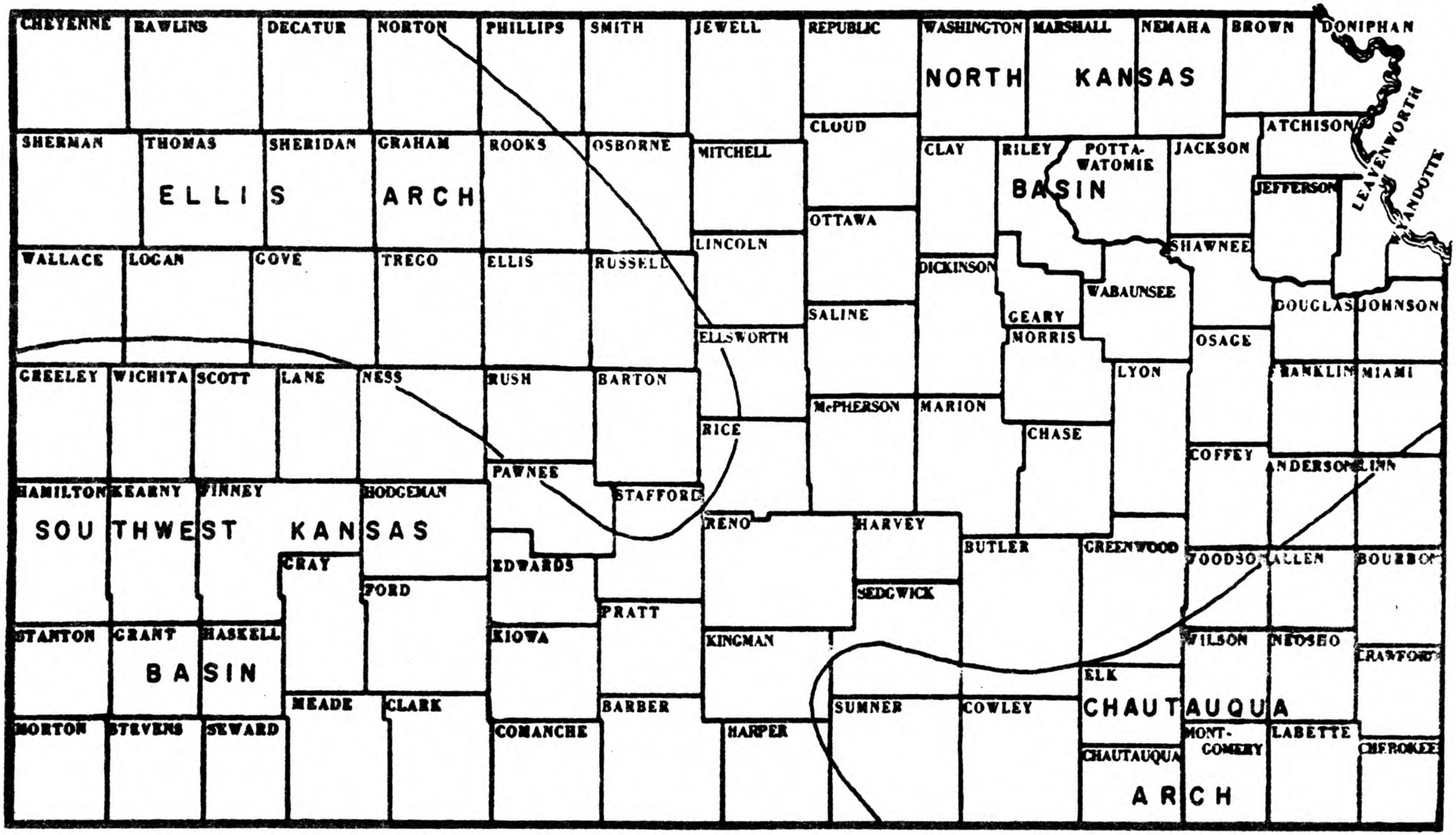


Fig. 2. Map of Kansas showing major pre-Mississippian structural features.

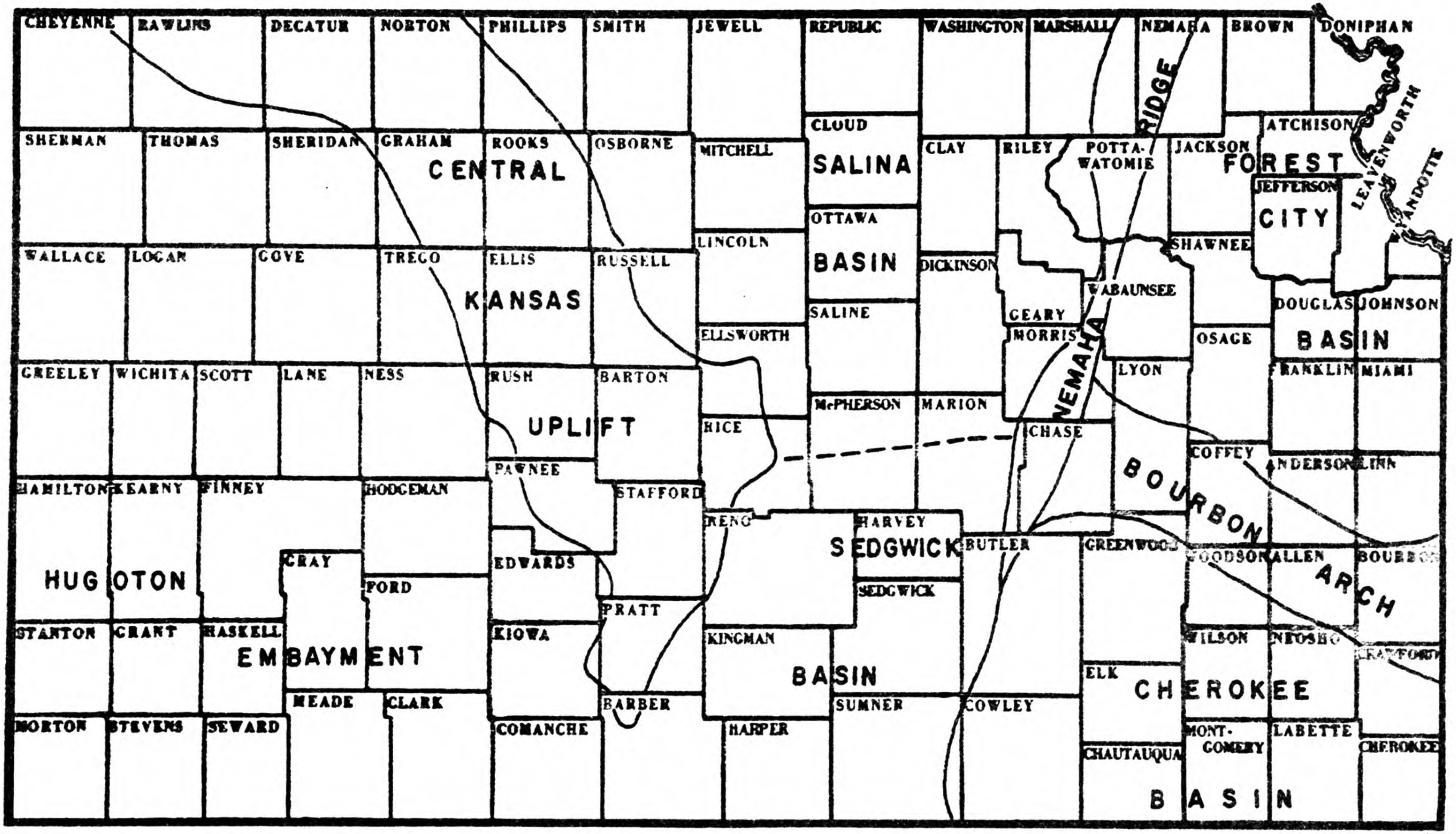
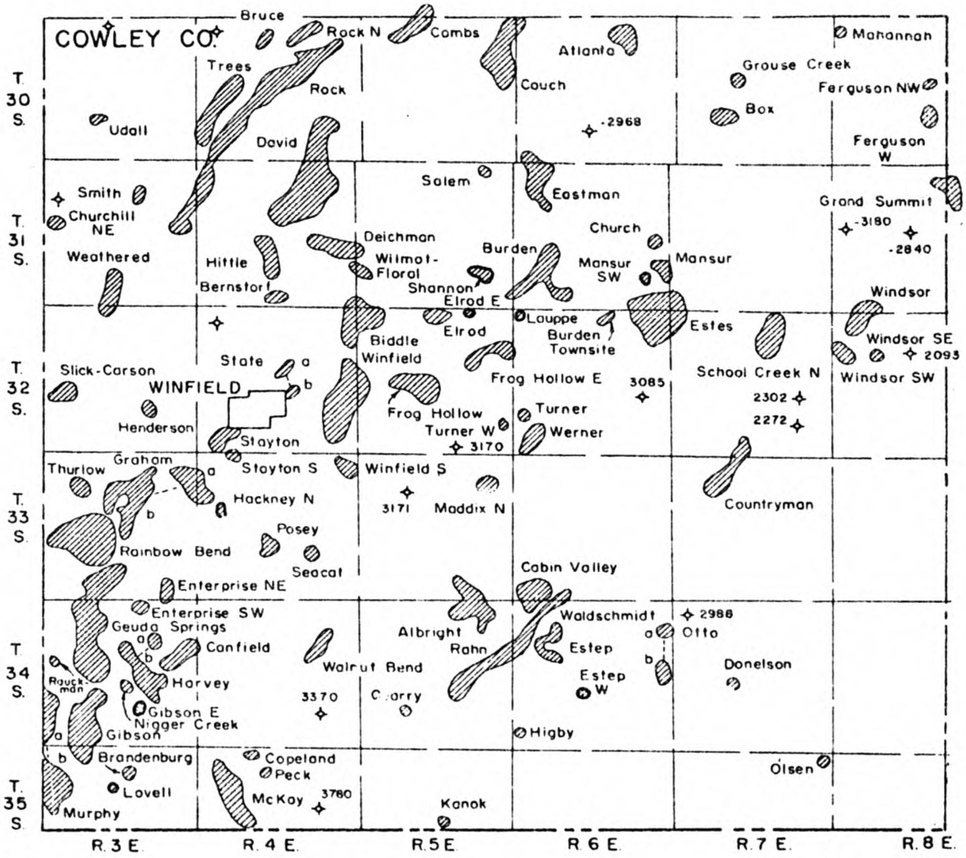


Fig. 3. Map of Kansas showing major post-Mississippian structural features.



Scale: 1 inch = 8 miles

EXPLANATION

- Oil field
- Oil field discovered in 1959
- Gas field discovered in 1959
- Dry wildcats and total depth 1959
- 3576 Well penetrated Precambrian

Fig. 4. Map of Cowley county showing oil and gas fields.

(Taken from Goebel, Hilpman, Beene, and Noever, 1960)

Table 1. Producing Oil Fields in Cowley County During 1959

Field name and year of discovery	Discovery well location	Area, acres	Oil Production, bbl during 1959	Oil Production, bbl to end 1959	Producing wells	Wells abd., 1959	Producing zone: Name	Depth ft.	Thickness, ft.	Aver. grav.
Albright ('56)	3-34-5E	1,320	104,552	421,725	35		Mississippian	3,126	10	
Atlanta ('58)	11-30-6E	540	89,602	131,177	18		Shawnee	1,631	7	
							"Stalnaker"	1,816	4	
							Kansas City	2,174	6	
							Mississippian	2,869	28	
							Arbuckle	3,274		
Bernstorf ('58)	33-31-4E	80	14,043	19,605	2		"Bartlesville"	3,043	18	
Biddle ('22)	7-32-5E	960	110,484		41		Kansas City	2,000	20	
							"Layton"	2,300		
							"Bartlesville"	2,878	14	
Box ('48)	28-30-7E	320	15,229	260,650	13		Mississippian	2,840	15	
Brandenburg ('55)	3-35-3E	40	1,893	17,231	1		Simpson	3,664	7	
Bruce ('50)	9-30-4E	200	19,566	68,316	4		Arbuckle	3,306		25
Burden ('26)	31-31-6E	1,280	32,993		51		"Layton"			
							"Peru"			40
							"Bartlesville	2,900	35	39
Burden Townsite ('58)	3-32-6E	40	151	3,099	1		"Layton"	2,205		
Cabin Valley ('52)	31-33-6E	640	150,362	1,230,250	39	1	"Layton"	2,188	9	40
Canfield ('52)	13-34-3E	900	22,471	265,851	17	3	"Layton"	2,651	4	42
							Lans.-K.C.	2,839		
							"Bartlesville"	3,375		
Cedarvale ('53)	9-34-8E	no report		2,168			"Mississippian	2,365	10	
Centennial North ('53)	1-33-3E	Included with Graham					"Bartlesville"	3,256	4	
Church ('54)	13-31-6E	40	1,683	18,006	1		Mississippian	2,935	12	34
Churchill Northeast ('55)	18-31-3E	40	1,878	12,465	1		Kansas City	2,420		
Clark ('14)	6-31-4E	Combined with Rock					"Bartlesville"	2,840	20	39
Combs ('47)	5-30-5E	500	39,025	664,054	17		"Bartlesville"	2,823	20	40
							Mississippian	2,850		
Copeland ('52)	5-35-4E	40	1,020	2,008	2		Mississippian	3,211	13	

Table 1. (Continued)

Field name and year of discovery	Discovery well location	Area acres	Oil production, bbl. during 1959	Oil production, bbl. to end 1959	Pro ducing wells	Wells abd., 1959	Producing zone Name	Depth ft.	Thickness, ft.	Aver. grav.
Couch ('37)	13-30-5E	1,140	68,157	2,496,713	51		"Bartlesville"	2,800	15	41
Countryman ('25)	4-33-7E	800	37,287		17		"Layton"	1,950	12	34
							Mississippian	2,870		
Crane ('57)	7-33-4E	Combined with Graham					Mississippian	3,252	10	
David ('35)	35-30-4E	2,460	72,278	3,767,995	155	1	"Bartlesville"	2,900	40	
							Arbuckle	3,463		
Deichman ('41)	24-31-4E	540	164,447	377,344	19		"Bartlesville"	2,900	35	
							Mississippian	3,000		
Denton			no report	746						
Dexter ('14)	33-6E		no report			2	Mississippian	2,750		
Donelson	21-34-7E	40	1,128	1,128	1					
Dunbar	30-5E		No report	8,923		1	Lans.-K.C.			
Eastman ('24)	5-31-6E	820	31,568		30	1	"Bartlesville"	2,890	20	36
Elrod	4-32-5E	100	7,012		3		"Layton"	2,411		
Elrod East ('59)	3-32-5E	20	968	968	1		"Layton"	2,340	3	
Enterprise Northeast ('52)	35-33-3E	160	469	45,072	3	2	"Bartlesville"	3,335	12	
							Mississippian	3,321	12	
Enterprise Southwest ('53)	3-34-3E	20	470	7,258	1		"Bartlesville"	3,360	10	39
Estep ('58)	21-34-6E	40	9,607	10,482	1		"Stalnaker"	1,803	4	
Estep West ('59)	29-34-6E	40	417	417	1		Mississippian	3,130	8	38
Estes ('54)	12-32-6E	1,280	78,922	560,045	43	5	"Layton"	2,190	13	36
Ferguson Northwest ('50)	16-30-8E	140	712	41,710	4	3	Kansas City	2,200		
Ferguson West ('34)	21-30-8E	120	213		3	1	Kansas City	2,180		
Frog Hollow ('37)	20-32-5E	720	108,615	5,033,138	39		"Bartlesville"	3,000	20	
Frog Hollow East ('41)	15-32-5E	640	22,358	383,065	9	1	"Bartlesville"	3,000	8	
							Mississippian	3,077	20	
Geuda Springs	5-34-3E	2,560	145,300	1,718,755	63	1	"Cleveland"	2,984	2	
							"Bartlesville"	3,300	14	
							"Chat"	3,345	25	
Gibson ('41)	29-34-3E	1,380	132,577	2,948,578	91		"Bartlesville"	3,350		35
							Mississippian	3,400	12	
							Simpson	3,774	6	
							Arbuckle	3,780	11	

Table 1. (Continued)

Field name and year of discovery	Discovery well location	Area, acres	Oil production, bbl During 1959	Oil production, bbl To end 1959	Producing wells	Wells abd., 1969	Producing zone Name	Depth ft.	Thickness ft.	Aver. grav.
Graham ('28)	3-33-3E			3,553,832	71	1	"Layton"	2,550	15	39
a		640	104,776				"Bartlesville"	3,213	50	
b		1,280	200,940				Mississippian	3,284	16	
							Arbuckle	3,518	5	
Grand Summit ('26)	4-31-8E	20	476		1		Kansas City	2,000	19	
Grouse Creek ('51)	16-30-7E	160	3,866	37,116	4		Mississippian	2,890		37
Hackney (56)	19-33-4E		no report	2,454			Mississippian	3,246	12	
Hackney North ('59)	18-33-4E		no report				Mississippian	3,236	6	34
Harvey ('52)	23-34-3E			1,269,092	41	1	"Layton"	2,574	18	33-40
a		120	6,103				"Bartlesville"	3,278		
b		1,100	59,176							
Henderson ('42)	26-32-3E	80	593	136,258	2		Kansas City	2,690	9	
							Arbuckle	3,419		
Higby ('57)	31-34-6E	40	4,386	6,136	1		Mississippian	3,180	10	
Hittle ('26)	28-31-4E	540	61,282	9,752.651	27		Kansas City	2,400	20	
							Arbuckle	3,280		
Kanok ('56)	15-35-5E	120	10,952	55,345	3		Mississippian	3,172	4	
Kanok North ('57)	3-35-5E		no report	140			Mississippian	3,136	4	
Lauppe ('59)	6-32-6E	80	251	251	1		"Burgess"	3,079	8	
Lovell ('59)	9-35-3E	80	1,867	1,867	1		"Bartlesville"	3,458	8	40
McKay ('51)	17-35-4E	1,180	25,036	520,511	32		"Bartlesville"	3,314		
Maddix North ('57)	12-33-5E	240	48,526	84,392	6		Mississippian	3,014	13	
Mahannah ('59)	6-30-8E	120	22,776	22,775	3					
Mansur ('49)	25-31-6E	300	4,890	114,873	9		"Layton"	2,170	16	
Mansur Southwest ('59)	26-31-5E		no report				"Layton"	2,206	3	36
Maple ('58)	2-30-3E		no report	1,354		1	"Bartlesville"	3,067	6	
Murphy ('33)	7-35-3E				45	4	"Bartlesville"	3,450	10	
a		320	4,403				"Chat"	3,500		
b		900	34,638							
Nigger Creek ('51)	22-34-3E	20	1,023	10,772	1		"Bartlesville"	3,281		
Olsen	1-35-7E	140	31,676	79,953	7					

Table 1. (Continued

Field name and year of discovery	Discovery well location	Area, acres	Oil production, bbl. during 1959	Oil production, bbl. to end 1959	Producing wells	Wells abd., 1959	Producing zone: Name	Depth ft.	Thickness, ft.	Aver. grav.
Otto ('27)	25-34-6E				5		"Stalnaker"	1,845	6	
a		80	1,172				"Chat"	3,017	50	
b		100	1,241							
Peck	9-35-4E	60	174	935	1	1				
Posey ('56)	21-33-4E	160	54,449	159,318	11		"Layton"	2,464	6	
							Cleveland	2,751	10	
							"Peru	2,953	4	
							Mississippian	3,164	14	
"Priest"	7-33-6E		no report	98						
Pudden	16-35-4E		no report				Lans.-K.C.	2,332		
Quarry ('54)	28-34-5E	60	1,245	30,045	1	1	"Cleveland	2,684	18	38
Rahn ('39)	13-34-5E	1,600	125,704		32		"Bartlesville"	2,900	30	
Rahn Northeast ('49)	27-33-6E		no report	71,193			"Bartlesville"	2,902		
Rainbow Bend ('23)	20-33-3E	1,920	266,785	17,581,039	77		"Burgess"	3,200	50	
							Arbuckle	3,550		
Rainbow Bend Southwest ('54)	33-33-3E		no report	7,881		1	Mississippian	3,356	18	
Rauckman ('56)	18-34-3E	160	5,790	40,205	4		"Bartlesville"	3,358	6	
Rock ('23)	15-30-4E	2,560	528,213	5,872,858	105		"Bartlesville"	2,800	30	
Rock North ('37)	3-30-4E	320	118,667	392,563	12		"Bartlesville"	2,800		
Salem ('57)	2-31-5E	40	3,904	11,825	1		Mississippian	3,050	2	
School Creek North ('53)	10-32-7E	960	146,346	1,275,499	54		"Layton"	2,114	6	34
							"Bartlesville"	2,826	9	
Seacat ('44)	26-33-4E=	300	19,065	120,881	9		"Layton"	2,385		
							Mississippian	3,100		43
Shannon ('59)	26-31-5E	200	3,166	3,166	6		"Layton"	2,314	3	
Slick-Carson ('24)	19-32-3E	280	17,343	7,748,077	6	12	"Layton"	2,600		
							"Bartlesville"	3,150		
							Arbuckle	3,450		
Smith ('17)	31-3E	160	5,278		3		"Bartlesville"	3,050		
State ('26)	15-32-4E				11		"Layton"	2,400	12	
a		120	2,577				Arbuckle	3,300		
b		40	8,994							

Table 1. (Continued)

Field name and year of discovery	Discovery well location	Area acres	Oil production, bbl. during 1959	Oil production, bbl. to end 1959	Producing wells	Wells abd., 1959	Name	Depth ft.	Thickness, ft.	Aver. grav.
Stayton South ('53)	5-33-4E	100	3,421	59,058	5		"Bartlesville"	3,165	23	40
Stayton ('49)	32-32-4E	480	2,936	146,943	7		"Bartlesville"	3,100	8	33
Thurlow ('27)	8-33-3E	220	1,851		2		Simpson	3,500	5	
Trees ('35)	19-30-4E	720	15,928		24		"Bartlesville"	2,875	25	
Turner ('37)	30-32-6E	80	4,189	301,690	3		"Layton"	2,232	15	
Turner West ('52)	25-32-5E	20	846	11,149	1		Mississippian	3,054		38
Udall ('26)	28-30-3E	100	5,434		3	1	Shawnee			38
							Arbuckle	2,850		
Waldschmidt ('57	8-34-6E	640	41,519	95,040	11		"Stalnaker"	1,821	2	
							Mississippian	3,080	12	
Walnut Bend	11-34-4E	120	17,080		4					
Walnut Bend North ('56)	36-33-4E	no report		187		1	Mississippian	3,188	8	
Weathered ('35)	28-31-3E	640	42,937	2,986,727	20	6	"Stalnaker"	2,080	15	
							Lans-K.C.	2,480	12	
							"Bartlesville"	3,018	6	
							Mississippian	3,020	8	
							Arbuckle	3,250	5	
Werner ('56)	31-32-6E	540	38,283	85,118	8	2	"Layton"	2,460	13	
							Mississippian	3,074	8	
Wilmot-Floral	31-5E	280	29,043		6		"Cattleman"	2,880		
							"Bartlesville"	2,910		
Windsor ('57)	6-32-8E	740	31,456	117,215	14		"Layton"	1,935	10	
Windsor Southeast ('58)	7-32-8E	40	6,281	6,410	2	1	"Layton"	1,858	18	
Windsor Southwest ('58)	7-32-8E	540	46,505	89,441	13		"Layton"	1,894	10	
Winfield ('14)	32-5E	1,980	102,929		86	3	Admire	600		38
							"Peacock"	1,400	15	
							"Layton	2,300	20	
							"Bartlesville"	3,050	12	
							Arbuckle	3,300	5	
Winfield South ('45)	1-33-4E	260	8,491	105,123	6		"Hoover"	1,400		38
Miscellaneous		200	34,115		5-					
Total Cowley County		44,260	3,858,460	100,346,582	1,591	58				

Taken from Goebel, Hilpman, Beene, and Noever, (1960)

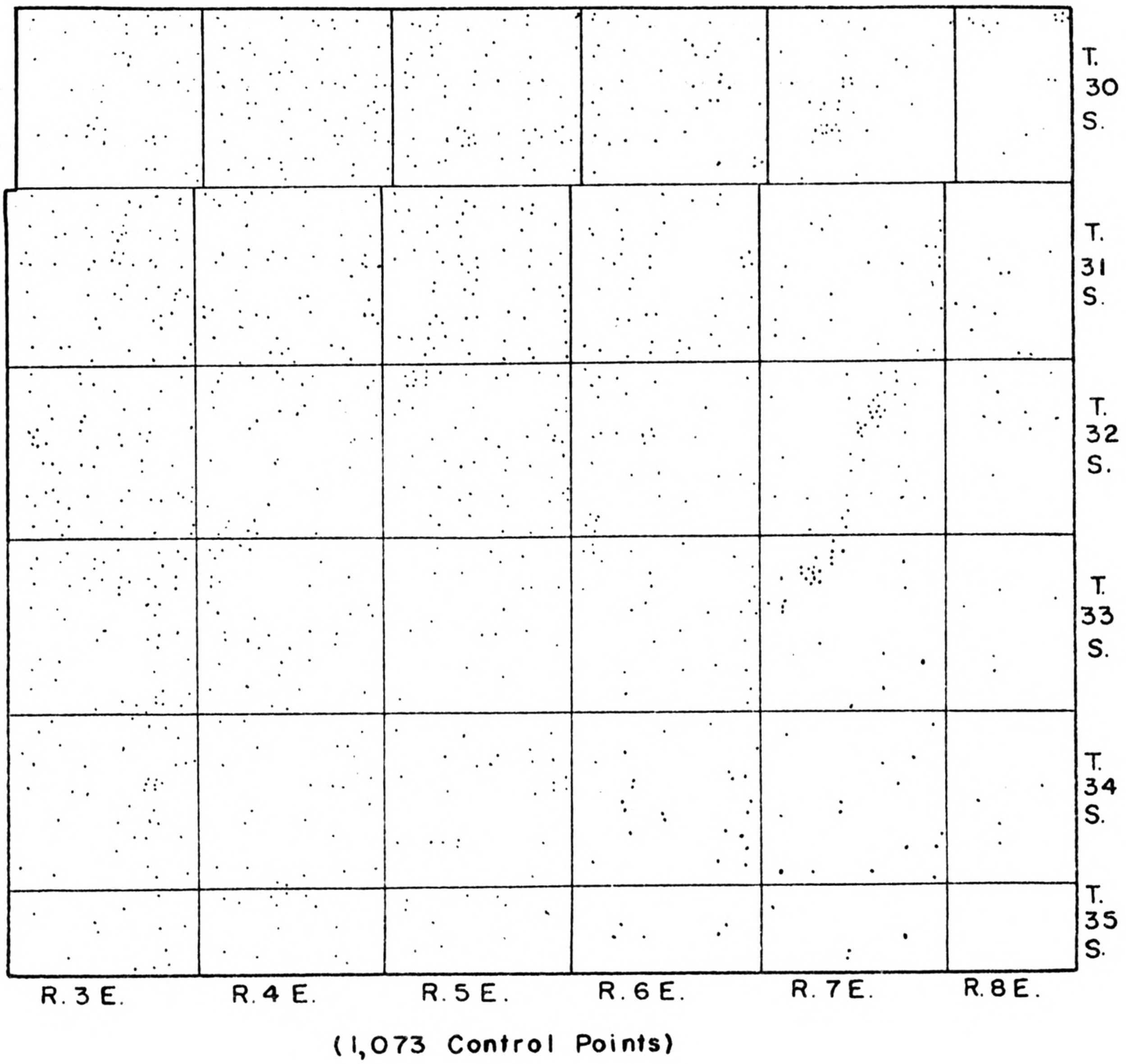


Fig. 5A. Map of Cowley county showing distribution of control points used for contouring FIG. 5.

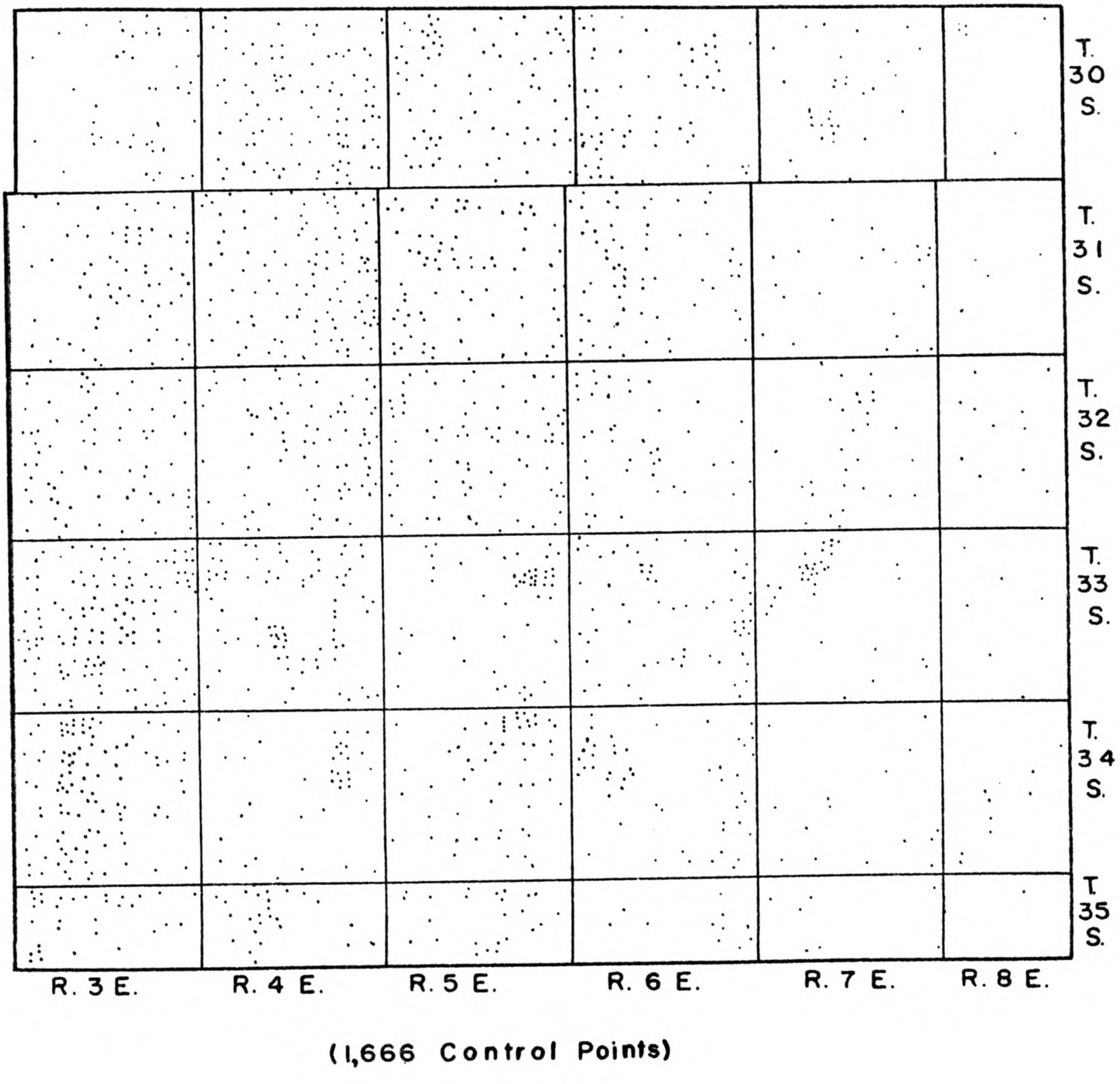
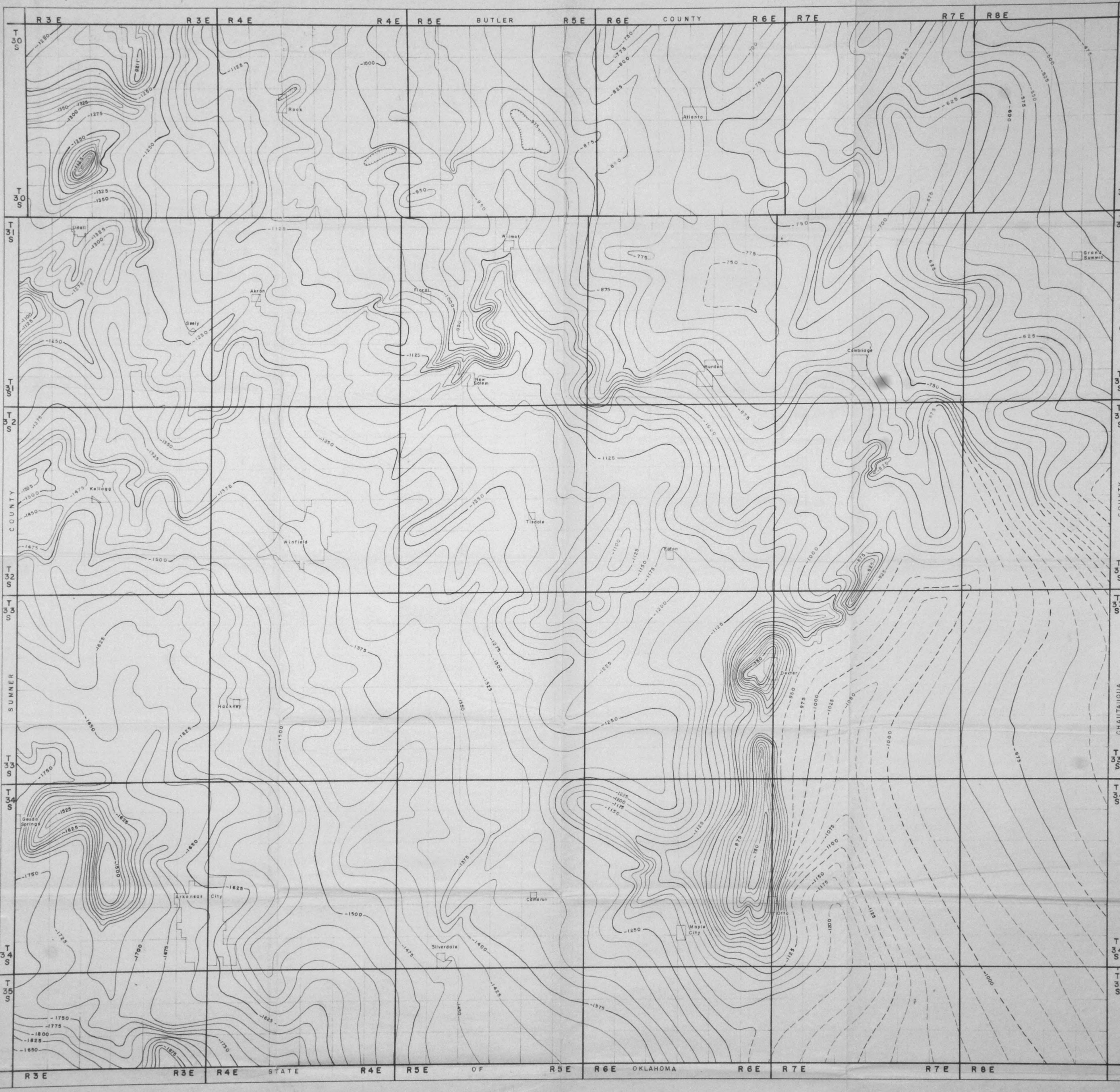


Fig. 6 A. Map of Cowley county showing distribution of control points used for contouring FIG. 6.

Figs. 5 and 6 in accompanying envelopes.

COWLEY COUNTY KANSAS

FIG. 5



Scale: 1 inch = 1 mile

Contour Interval: 25 feet (broken lines indicate inadequate control)

Datum: Sea Level

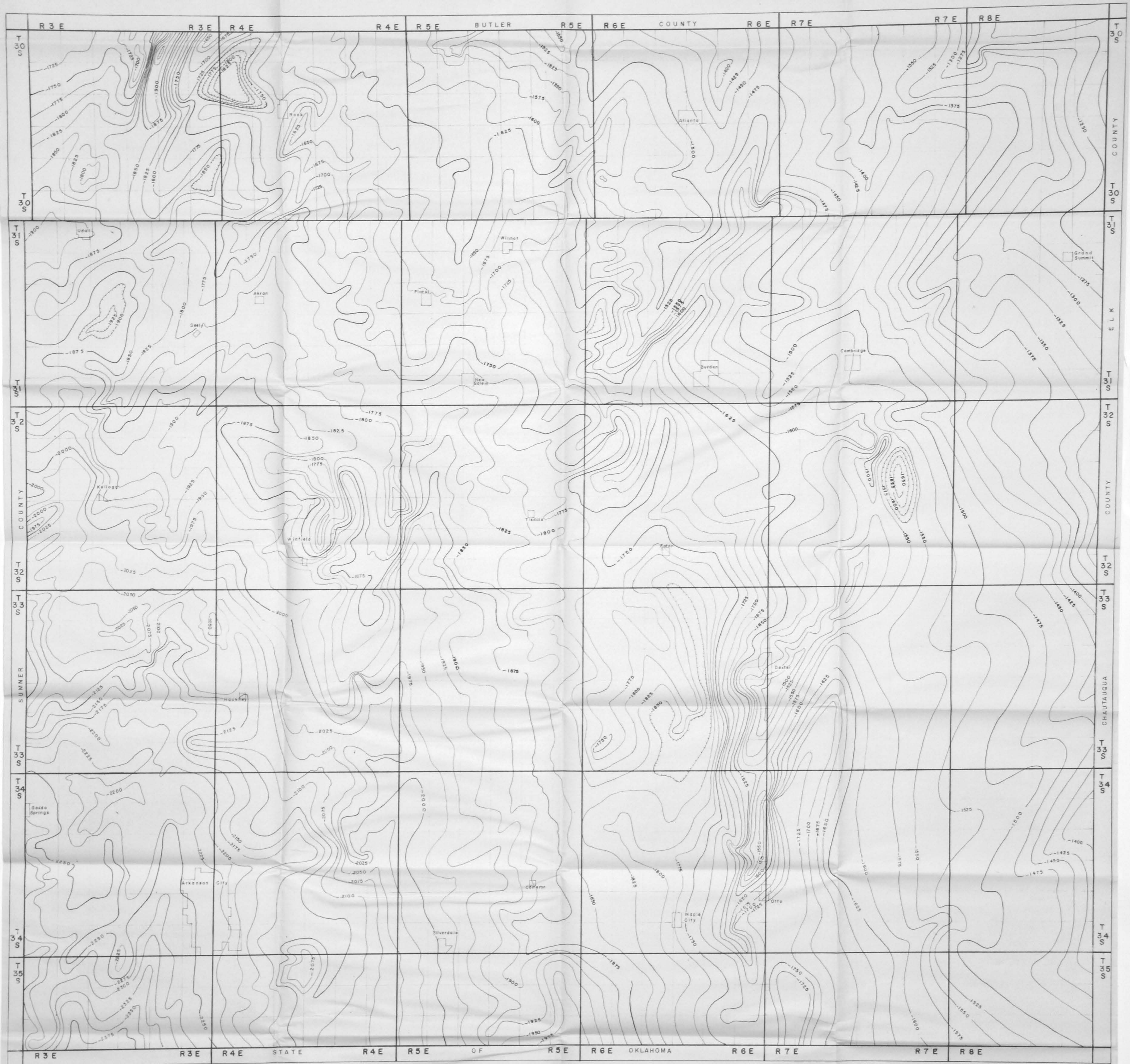
STRUCTURAL CONTOUR MAP ON THE SURFACE OF THE KANSAS CITY LIMESTONE

AUGUST 1961

ARTHUR L. BOOTH

COWLEY COUNTY KANSAS

FIG. 6



Scale: 1 inch = 1 mile   1/2 0 1 2 miles

Datum: Sea Level

Contour Interval: 25 feet

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STRUCTURAL CONTOUR MAP ON THE SURFACE
OF THE
MISSISSIPPIAN LIMESTONE

AUGUST 1961

ARTHUR L. BOOTH

THE SUBSURFACE STRUCTURE AND STRATIGRAPHY AS RELATED TO PETROLEUM ACCUMULATION IN COWLEY COUNTY, KANSAS

by

ARTHUR LEE BOOTH

B.S., Kansas State University, 1960

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

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1962

The purpose of this investigation is to analyze the subsurface structure, stratigraphy, and geologic history and to relate these geological factors to the accumulation of petroleum in Cowley County, Kansas. Information was obtained by reviewing previous literature, by an examination of Kansas Sample Log Service strip logs, and by an analysis of structural contour maps which were prepared to supplement this investigation.

Cowley County, located in southeastern Kansas, lies adjacent to the Kansas-Oklahoma border and is the fifth county west from the Kansas-Missouri border. Cowley County has a total area of approximately 1,140 square miles. The county has been an important producer of oil and gas since 1916, and in 1959 ranked tenth in the state in annual production and ninth in the state in total cumulative production.

In Cowley County the Precambrian basement complex is present at depths ranging from 3,100 to 4,500 feet. Overlying the Precambrian basement complex is a thick stratigraphic section of Paleozoic rocks ranging from Cambrian to Permian in age. Rocks ranging in age from uppermost Pennsylvanian to Permian are exposed at the surface in the area. Upland chert gravel and loess deposits which are present in a few localities are believed to be Pliocene and Pleistocene in age.

The most important pre-Mississippian structural features affecting the area include the North Kansas Basin and the Chautauqua Arch. Important post-Mississippian structural features are the Nemaha Ridge, Bourbon Arch, and Cherokee Basin. Three major trends of folding are present within the county and are usually referred to as the Dexter Anticline, Winfield Anticline, and Rainbow Anticline. These three smaller structural features are believed to be of approximately the same age as the Nemaha

Ridge.

In Cowley County the surface rocks dip to the west and slightly south at an average rate of 25 feet per mile. The direction and rate of dip, however, varies according to depth. Regional dip on the surface of the Kansas City limestone is 33 feet per mile to the southwest. The regional dip on the surface of the Mississippian limestone is 27 feet per mile to the southwest.

Petroleum accumulation in Cowley County appears to be dependent upon several factors. Structural conditions appear to be the most important in controlling petroleum accumulation, but stratigraphic conditions are also important, particularly in lenticular sandstone beds of Pennsylvanian age. Stratigraphic conditions which are important are: areal extent of the reservoir rock, thickness of the reservoir rock, and reservoir porosity.

Oil accumulation in the Arbuckle and Mississippian limestones is seemingly the result of structural conditions. All oil accumulation in the Simpson group appears to be the result or stratigraphic conditions, but occurs on the flanks of structural "highs". Conditions which favor oil accumulation in the lenticular Pennsylvanian sandstone beds appear to be largely stratigraphic, but most oil production from these beds is associated with a structural "high" of some type.