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GEOLOGY AND GROUND-WATER RESOURCES OF KIOWA COUNTY, KANSAS

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with anlyses by
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Prepared by the State Geological Survey of Kansas and the United States Geological Survey, with the coöperation of the Division of Sanitation of the Kansas State Board of Health and the Division of Water Resources of the Kansas State Board of Agriculture

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CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY AND GROUND-WATER RESOURCES OF KIOWA COUNTY, KANSAS

By Bruce F. Latta

ABSTRACT

This report describes the geography, geology, and ground-water resources of Kiowa County in south-central Kansas. Kiowa County has a total area of about 720 square miles, and in 1940 had a population of 5,112. The area is in the Plains Border section of the Great Plains physiographic province. Approximately the northern one-third of the county is covered by sand hills and is characterized by typical sand-dune topography. Bordering the sand hills on the south are upland plains which comprise an east-west belt that is about 2 to 8 miles wide and extends across the central part of the county. This belt is characterized by gentle to moderate slopes and in places the surface is nearly flat. The southern part of the county has been deeply dissected by stream erosion resulting in a rugged topography having a local relief of about 300 feet. Approximately the northern half of Kiowa County is in the upper Arkansas drainage basin and is drained by Rattlesnake Creek and its tributaries. The southeastern and south-central parts of the county are in the lower Arkansas drainage basin and are drained by Medicine Lodge River and Mule Creek; the southwestern part is in the Cimarron drainage basin and is drained by tributaries of Sand Creek. The climate is of the subhumid to semiarid type, the mean annual precipitation being about 23 inches and the mean annual temperature about 56° F. Farming and stock raising are the principal occupations. Most of the cultivation is by dry-farming methods. In 1939 only 278 acres of land in the county were irrigated.

The exposed rocks are sedimentary and range in age from late Permian to Recent. A map showing the areas where the different rock formations crop out is included with the report. Most of the county is underlain by Quaternary deposits of silt (Kingsdown silt) or dune sand. Water-bearing silts, sands, and gravels of the Meade formation (Pleistocene) and the Ogallala formation (Tertiary) underlie the Kingsdown silt and the dune sand and crop out in the southern part of the county. Medicine Lodge River in the southeastern part of the county and Wiggins and East Kiowa Creeks in the southwestern part have cut below the Quaternary and Tertiary sediments and exposed Cretaceous and Permian shales, sandstones, and gypsum. The Cretaceous rocks exposed in the area include the Dakota formation, Kiowa shale, and Cheyenne sandstone; the Permian rocks include the Whitehorse sandstone, Dog Creek shale, and the Medicine Lodge gypsum member of the Blaine formation.

The report contains a map showing the depth of the water table in the county. This depth ranges from less than 10 feet in parts of the sand hills area to about 185 feet on the uplands south of Mullinville. Also included in

the report is a water-table contour map that shows the shape and slope of the water table. Ground water moves through the northern part of Kiowa County in a general easterly direction. A prominent ground-water divide in the northwestern part of the dissected area causes the ground water entering the southern part of the county from the west to move in three directions: part northeastward, part eastward, and part southward. The gradient of the water table beneath the sand hills and upland plains averages about 10 feet to the mile and ranges from about 5 to 15 feet to the mile. In the dissected area the gradient of the water table averages about 20 feet to the mile and the maximum slope exceeds 40 feet to the mile.

The ground-water reservoir is recharged principally by precipitation within the area, by the addition of water from many of the ephemeral streams, and by ground water moving in from adjacent areas. Ground water is discharged from the ground-water reservoir by subsurface movement eastward into adjacent areas, by evaporation and transpiration in areas of shallow water table, by wells, and by springs and seepage areas. The springs in Kiowa County are classified as seepage or contact springs, and all occur in the dissected southern part of the county, where many of the valleys have been cut below the water table. Measurements of the flow of streams fed by springs and seepage areas in the county indicate that more than 19 million gallons of water a day is being discharged through springs and seepage areas. Water from many of the springs is utilized for domestic and stock use.

Most of the water supplies are obtained from wells. In 1941, there were 5 irrigation, 6 public-supply, 4 industrial, 1 railroad, and a large but unknown number of domestic and stock wells in the county. The five wells used for irrigation are all in the sand hills in the northern half of the county and derive water from sand and gravel of the Meade formation. Large supplies of water for irrigation or industrial use can be obtained from wells in the northern and east-central parts of the county. Much of the land in these areas is unsuited for irrigation, however, because the soils are too sandy and the surface is too irregular.

Sand and gravel beds of the Meade and Ogallala formations are the principal source of ground water in the county. They supply water to most of the domestic, stock, and industrial wells and to all of the irrigation and public supply wells. The Meade and Ogallala formations attain a maximum thickness of about 300 feet. The waters from these formations, although hard, are satisfactory for most purposes. Alluvium yields moderate amounts of very hard water to wells in the larger stream valleys. A few domestic and stock wells in the south-central and southeastern parts of the county derive their supplies from the Cheyenne sandstone. The Cheyenne is from 20 to 94 feet thick in this area and consists of fine- to coarse-grained friable sandstone and lenses of gray to black sandy shale. Water in the Cheyenne is highly mineralized and in some localities is unfit for ordinary purposes. The Whitehorse sandstone, which is about 60 feet thick and is composed chiefly of fine-grained friable sandstone and siltstone, supplies small quantities of very hard water to a few wells in southeastern Kiowa County. The Flowerpot shale supplies highly mineralized water to only one of the recorded wells in this area.

The field data upon which most of this report is based are given in tables.

They include records of 101 wells and 21 springs and chemical analyses of the water from 32 representative wells and springs. Logs of 26 test holes, water wells, and oil test wells in the area are given, including 19 test holes put down by the State and Federal Geological Surveys. Also given are 18 measured sections that show the character of the various geologic formations at the surface.

INTRODUCTION

Purpose and scope of the investigation.—The investigation on which this report is based is part of an extensive program of ground-water investigations in the state started in July 1937 by the Geological Survey, United States Department of the Interior, and the State Geological Survey of Kansas, with the coöperation of the Division of Sanitation of the Kansas State Board of Health and the Division of Water Resources of the Kansas State Board of Agriculture. This report presents the results of a study made during the summer of 1941 to determine the availability and quality of ground water and to study and map the various rock formations in Kiowa County.

The principal purpose of the investigation has been to provide basic information necessary to the satisfactory and economical development of domestic, stock, irrigation, industrial, and municipal ground-water supplies. Specific problems in regard to the quantity and quality of ground water that will require more detailed studies in particular areas may arise in the future.

The investigation was made under the general administration of R. C. Moore and K. K. Landes, state geologists, and O. E. Meinzer, geologist in charge of the Division of Ground Water of the Federal Geological Survey, and under the immediate supervision of S. W. Lohman, Federal geologist in charge of ground-water investigations in Kansas.

Location and size of the area.—Kiowa County lies in south-central Kansas and embraces a total of 20 townships, or 720 square miles. Its location with respect to adjoining counties is shown by Figure 1.

Previous geologic and hydrologic work.—The geology of Kiowa County, particularly the Cretaceous rocks in the southeastern part of the county, has attracted the attention of geologists for many years. During the last quarter of the last century more than 30 reports that pertained wholly or in part to the geology of Kiowa County were published. Most of these reports deal only with the Cretaceous rocks in the county. Mudge (1878), St. John (1883, 1887), Cragin (1885, 1886, 1889, 1889a, 1890, 1891, 1891a, 1894,

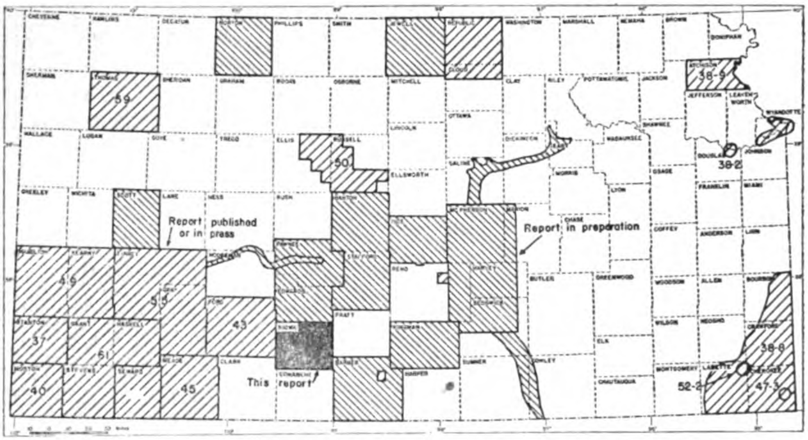

Fig. 1. Area covered by this report and other areas in Kansas for which coöperative ground-water reports have been published or are in preparation.

1894a, 1895), Hay (1887, 1890, 1893), Williston (1892), Knowlton (1895), Hill (1895), Prosser (1897), Vaughan (1897), Gould (1898, 1899, 1900), and Haworth (1897) are the geologists who made the more important of these field studies.

A report by Johnson (1901) on the "Utilization of the High Plains" deals with the physiography, underground waters, and the land economy of the High Plains, including Kiowa County. A second paper by Johnson (1902) contains conclusions and a summary of the first paper. Gould (1901) contributed an important paper entitled "The Dakota Cretaceous of Kansas and Nebraska," which includes specific data on the Cretaceous rocks of this area. A preliminary report on the geology and ground-water resources of the central Great Plains by Darton (1905) contains a brief reference to Kiowa County. A very brief description of the availability of ground water in Kiowa County, including analyses of some typical well waters collected at Greensburg and Wellsford, was given by Parker in 1911 (pp. 121-122). Two years later, Haworth (1913) gave a general description of the well waters in Kansas.

In 1920 Twenhofel published a short report on the "Comanchean and Dakota strata" of Kansas which includes many references to Kiowa County. A few years later he (Twenhofel, 1924) prepared a more detailed report on the same subject, and Twenhofel and Stryker (1925) outlined the subsurface distribution of the Comanchean rocks in western Kansas. A description of the flora of the Cheyenne sandstone of Kansas was published by Berry in 1922. All of the fossil plants described in Berry's paper were collected from the Cheyenne sandstone in Kiowa County. Bullard (1928) discussed the distribution, origin, and correlation of the Lower Cretaceous rocks of western Oklahoma and adjacent states. The following year Gould (1929) contributed a short paper on Comanchean reptiles from Kansas. An unpublished report on the geology of Barber County (Knight, 1929), which adjoins Kiowa County on the southeast, discusses chiefly the Permian formations of Barber County but also includes brief descriptions of the Comanchean and younger rocks. Of popular interest is the description of the excavation of a meteorite crater near Haviland, Kiowa County, by Nininger and Figgins (1933).

The physiography and geology of south-central Kansas, including most of Kiowa County, is described in an unpublished doctorate thesis by Courtier (1934). In 1937 Smith contributed a report on Pleistocene gravels in southwestern Kansas in which he lists fossils collected from a gravel pit south of Brenham, Kiowa County. A later report by Smith (1940) includes a few brief references to the geology of Kiowa County. In 1940 Moore prepared a generalized report on the ground-water resources of Kansas including Kiowa County.

A report published in 1942 on the availability of ground-water supplies for national defense industries in Kansas includes a description of the availability of ground-water supplies in eastern Kiowa County (Lohman and others, 1942, pp. 36-37). A general report describing the mineral resources of Kansas for wartime industries was also published in 1942 (Jewett and Schoewe). In the same year, Plummer and Romary described the stratigraphy of the pre-Greenhorn Cretaceous beds of Kansas. Although their report deals chiefly with central and north-central Kansas, it also includes important references to the Cretaceous geology of Kiowa County. In 1938 and 1939 Waite (1942) made a detailed study of the geology and ground-water resources of Ford County, which borders Kiowa County on the west. A similar study was made by Frank Byrne in Barber County in 1941, but as yet no report has been issued on this work. A report on water levels and artesian pressure in observation wells in the United States in 1940 includes a chapter on the observation-well program in Kiowa County (Meinzer and Wenzel, 1942, pp. 136-137). Similar reports for the years 1941 and 1942 were published in 1943 and 1944 (Meinzer and Wenzel, 1943, pp. 119-120; 1944, pp. 135-136) and additional reports of this series will be published annually. Reference is made to the geology of Kiowa County in a recent report by Hibbard (1944) on the Pleistocene deposits of southwestern Kansas.

Methods of investigation.—The field work upon which this report is based occupied three months in the summer of 1941 and about two weeks in the summer of 1942. Approximately 100 wells and 27 springs were visited during this time. The total depth and the depth to water level were measured in about 72 of the wells. All measurements were made with a steel tape from a fixed measuring point at the top of each well. Information concerning the nature and thickness of the water-bearing material, yield of the wells and springs, and the use and general character of the water was obtained from many farmers and drillers in the county. Samples of water were collected from 30 wells and springs, and chemical analyses of these samples were made by H. A. Stoltenberg, chemist, in the Water and Sewage Laboratory of the Kansas State Board of Health at Lawrence.

During the summer and fall of 1941 eighteen test holes (Fig. 10) were drilled by Ellis D. Gordon, Perry McNally, and Laurence Buck, using a portable hydraulic-rotary drilling rig owned by the State and Federal Geological Surveys. Samples from the test holes were collected and studied in the field by McNally and were again studied in the office by me. Landowners and well drillers provided additional logs of wells in the county. The altitudes of the land surface at the sites of the test holes and the altitudes of the measuring points of the wells were determined by John B. LaDuex and Fay Mann, assisted by Milton Sears and Willis Ray. The water-table contours shown on Plate 1 are based upon these altitudes and the measured depths to water level in wells.

In 1941, Melvin Scanlan of the Division of Water Resources, Kansas State Board of Agriculture, and Woodrow Wilson of the Federal Geological Survey measured the flow of many of the spring-fed streams in the county. These measurements are given in Table 3.

The areal geology shown on Plate 1 was compiled from field studies supplemented by use of aerial photographs. Many geologic sections were measured (see pp. 117-126).

Field data were compiled on topographic maps of the U. S. Geological Survey and on a county highway map prepared by the State Highway Department. The county highway map was also used as a base map in preparing Plates 1 and 2. The drainage pattern was taken from aerial photographs obtained from the United States Department of Agriculture, Agricultural Adjustment Administration.

The locations of all wells and springs visited during the course of the investigation are shown on Plate 2, and the springs are also shown and numbered in Figure 6. The well and spring numbers on the maps correspond to the well and spring numbers used throughout the tables and text of this report.

Acknowledgments.—I am indebted to numerous farmers, ranchers, well drillers, and city officials who willingly supplied information concerning the hydrology and geology of the county; without their aid it would not have been possible to write this report. I also wish to thank John C. Frye, executive director of the State Geological Survey, and Claude W. Hibbard, curator of vertebrate paleontology of the Dyche Musueum of Natural History, University of Kansas, who spent several days in the field with me studying the rocks of Kiowa County and adjacent areas. I am grateful to Hibbard and A. B. Leonard, assistant professor of zoölogy, University of Kansas, for their helpful identification of fossil material collected during this investigation.

The manuscript for this report has been critically reviewed by O. E. Meinzer and S. W. Lohman of the Federal Geological Survey; R. C. Moore, State Geologist, State Geological Survey of Kansas; George S. Knapp, chief engineer, Division of Water Resources, Kansas State Board of Agriculture; and Paul D. Haney, director, and Ogden S. Jones, geologist, Division of Sanitation, Kansas State Board of Health. The manuscript was edited by Johanna Kollmorgen and Betty Hagerman and the illustrations were drafted in final form by Robert White, Robyn Ashby, and Murl Rush.

GEOGRAPHY

Topography and Drainage

Kiowa County is in the Plains Border section of the Great Plains physiographic province (Fenneman, 1931, Pl. 1). The highest point is the divide between Turkey Creek and the West Fork of Rattlesnake Creek at the western county line, where the altitude reaches about 2,440 feet. The lowest point—where Medicine Lodge River leaves the county—has an altitude of about 1,740 feet. The total relief in the county is therefore about 700 feet, although locally the relief does not exceed 300 feet.

Kiowa County may be divided into three physiographic divisions which exhibit differences in topography, drainage, and origin (Fig. 2): the sand hills, the upland plains, and the dissected area.

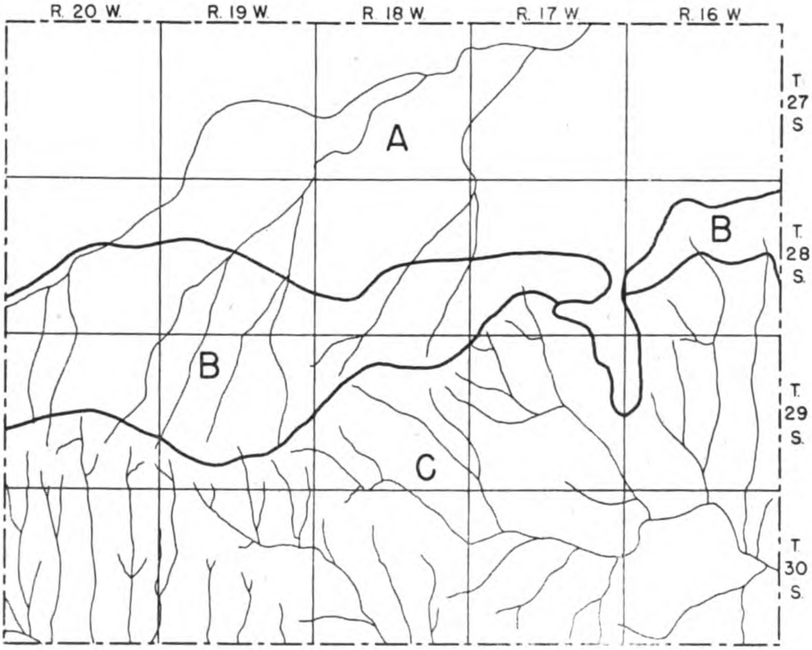

FIG. 2. Physiographic divisions of Kiowa County: (A) sand hills; (B) upland plains; and (C) dissected area.

Sand hills.—Approximately the northern third of Kiowa County is part of the large dune-covered area that lies south of the great bend in the Arkansas River and extends westward as a narrow belt bordering the south side of Arkansas Valley. The sand hills in Kiowa County are characterized by typical sand dune topography, having moderate slopes and hills separated by small basins. The maximum local relief of the sand hills is about 60 feet, and the average is only about 30 feet.

Most of the sand hill area is covered by vegetation and is thus protected from wind erosion, but in a few places there are small areas of bare sand that are subject to wind attacks (Pl. 3A.) Some parts of the sand hills are suited to cultivation but others are not, and much of the northwestern part of the area is used for raising cattle.

The central and western parts of the sand hills are partly drained by Rattlesnake Creek and its tributaries (Pl. 1), but the greater

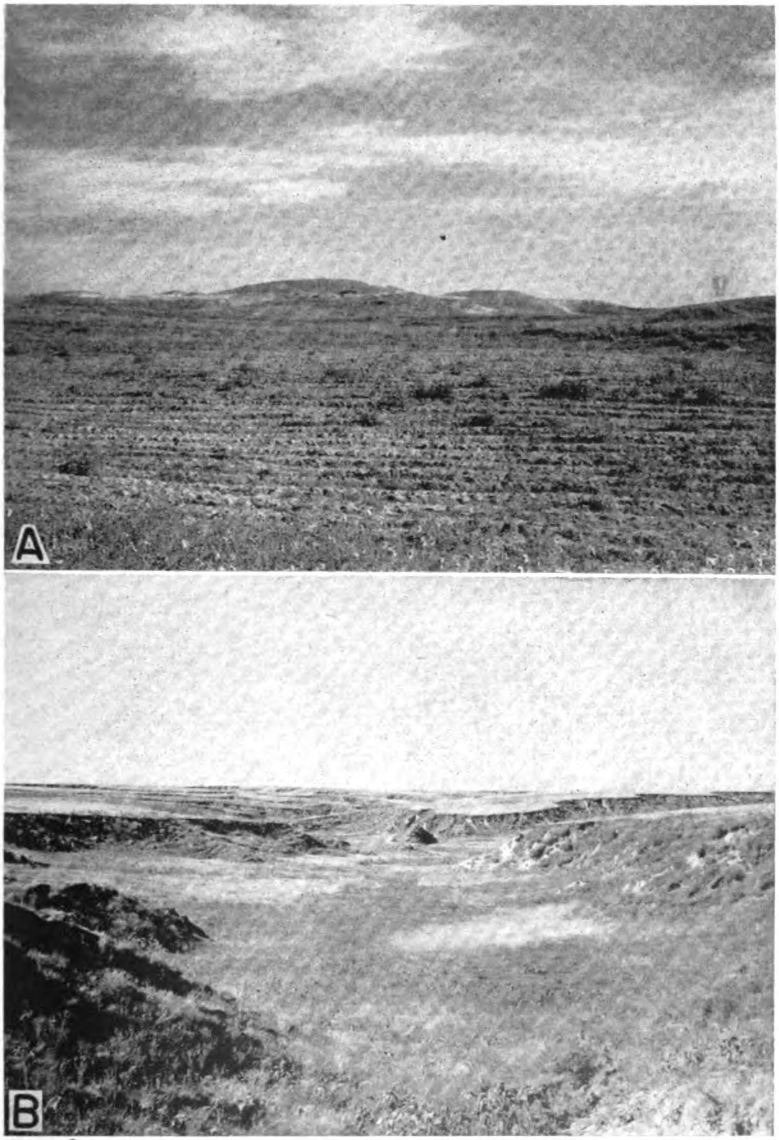

PLATE 3. *A,* Sand hills south of Haviland, Kansas, looking north from the SW¼ sec. 36, T. 28 S., R. 17 W.; *B,* characteristic erosion of the Kingsdown silt, looking southward from the head of East Kiowa Creek in the NW¼ sec. 30, T. 29 S., R. 19 W.

part of this area has no surface drainage. Instead of running off the rainfall collects in the numerous basins and hollows where most of it seeps into the ground and the rest is evaporated. The relationship of the sand hills to ground-water recharge is discussed on page 39.

Upland plains.—The upland plains division comprises an east-west belt about 2 to 8 miles wide across the central part of the county (Fig. 2). It is bounded on the north by the sand hills and on the south by the dissected area. The boundary between the upland plains and the dissected area is rather indistinct.

The upland plains are the remnants of a once extensive plain that extended over all or nearly all of Kiowa County. The plains are characterized by gentle to moderate slopes in the west and by a nearly flat to gently rolling surface in the east. Although erosion of the soft Kingsdown silt by streams (Pl. 3B) has modified much of the area, some remnants of the original plain are still preserved.

Dissected area.—The dissected area comprises all of Kiowa County south of the upland plains (Fig. 2). The surface of this area was at one time continuous with that of the upland plains but has been deeply dissected by stream erosion. Erosion in the east has cut below the Quaternary and Tertiary silts, sands, and gravels and has exposed a large area of shales and sandstones of Cretaceous and Permian age (Pl. 1). These rocks have also been exposed in two small areas in the southwestern part of the area. Dissection has resulted in a rugged topography having a local relief of approximately 300 feet. In the north where the streams have not yet cut into the more resistant rocks, the slopes are gentle to moderate (Pl. 4A), but in the south where erosion has exposed "mortar beds" or sandstone the slopes are moderate to very steep (Pl. 4B). The Kiowa shale generally forms moderate slopes except where it is capped by "mortar beds" or sandstone.

Drainage basins.—Kiowa County is in three drainage basins: upper Arkansas, lower Arkansas, and Cimarron. Approximately the northern half of the county is in the upper Arkansas drainage basin and is drained by Rattlesnake Creek and its tributaries (Pl. 1). After leaving Kiowa County, Rattlesnake Creek flows in a general northeasterly direction and empties into Arkansas River in southwestern Rice County. Throughout its course in Kiowa County, Rattlesnake Creek is an ephemeral stream—that is, it flows only in response to local rains. The southeastern and south-central

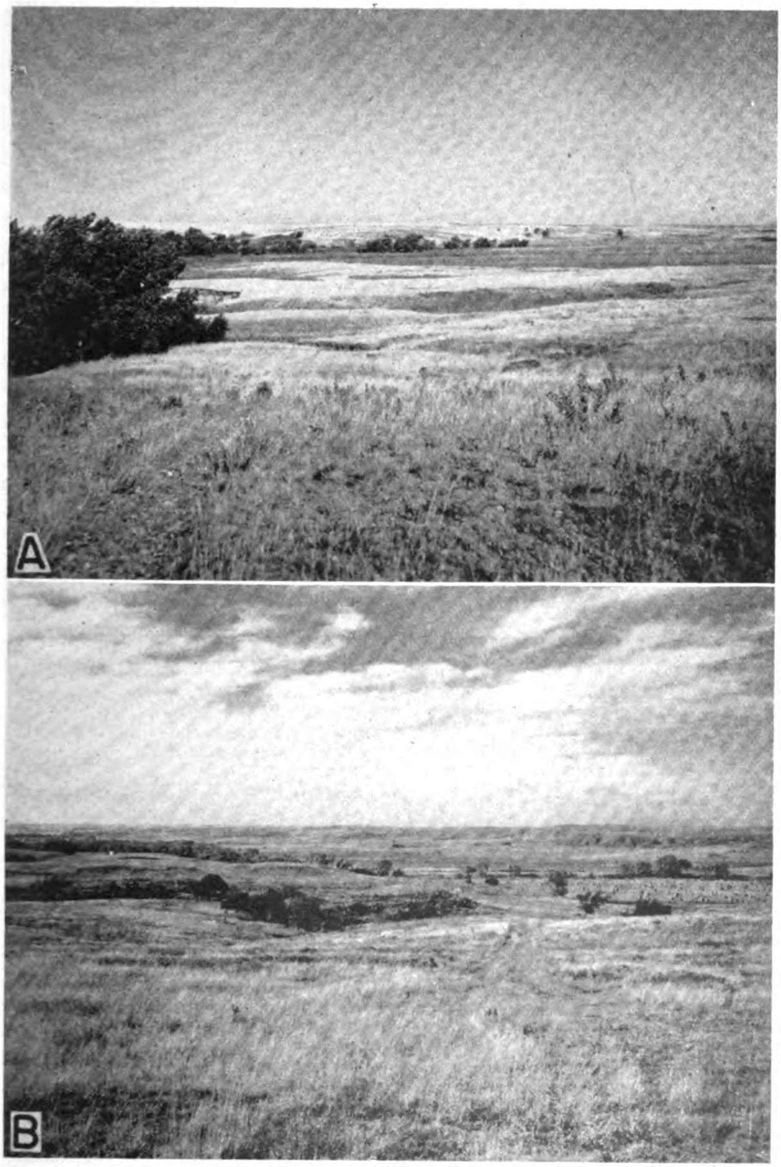

PLATE 4. Thompson Creek Valley. *A,* Spring area near the head of Thompson Creek in the NW¼ sec. 10, T. 29 S., R. 17 W. The flat land in the distance is part of the upland plains. *B,* View looking southwest across Thompson Creek Valley from the middle of sec. 6, T. 30 S., R. 16 W. The bluffs are formed by Kiowa shale.

parts of the county are in the lower Arkansas drainage basin and are drained by Medicine Lodge River and Mule Creek. Mule Creek is an ephemeral stream that heads in south-central Kiowa County, flows southeastward, and joins the Salt Fork of Arkansas River in southwestern Barber County. Medicine Lodge River also heads in south-central Kiowa County, flows in an easterly direction through the county, and empties into the Salt Fork of Arkansas river in northern Oklahoma. Medicine Lodge River has three main tributaries in this area—Thompson Creek, Spring Creek, and Soldier Creek, all of which enter from the north. Medicine Lodge River and its major tributaries are perennial streams fed by ground water.

The southwestern part of Kiowa County is in the Cimarron drainage basin and is drained by the following tributaries of Sand Creek: Turkey Creek, Middle Kiowa Creek, Wiggins Creek, and East Kiowa Creek, all of which are ephemeral in their upper courses but perennial in their lower courses in Kiowa County. Sand Creek is a perennial stream that flows across the extreme southwestern corner of Kiowa County and joins Bluff Creek in west-central Comanche County, which in turn flows into Cimarron River in southwestern Comanche County.

Population

The 1940 census gives the population of Kiowa County as 5,112, an average of 7.1 inhabitants per square mile. Greensburg, the county seat and largest city, had a population of 1,417; Haviland, 499; Mullinville, 428; and Wellsford, 64. Population figures are not available for the small communities of Belvidere, Joy, and Brenham.

Transportation

The main line of the Chicago, Rock Island and Pacific Railroad crosses Kiowa County from east to west passing through all towns in the county with the exception of Belvidere. Belvidere is served by a branch line of the Atchison, Topeka and Santa Fe Railway, which crosses the southeastern corner of the county.

Most of the county is covered by a network of modern highways and improved secondary roads. U. S. highway 54 passes from east to west through the central part of the county. U. S. highway 154 comes from the southwest and joins highway 54 a mile east of Mullinville. Kansas highway 1 crosses the county from north to south passing 1 mile west of Greensburg. These highways are all oil-surfaced. Many of the county roads are graveled and are kept in good condition throughout the year. Many of the section roads are graded except in the northwestern, southwestern, and southeastern parts of the county (Pl. 1).

Agriculture

The principal occupations in Kiowa County are farming and stock raising. Much of the land in the southwestern and southeastern parts of the county is covered with native buffalo grass and is used for stock raising. Most of the rest of the county is under cultivation by dry-farming methods. In 1940 there were 735 farms in Kiowa County, averaging 608.5 acres in size (16th U. S. census, 1940). There were 108,515 acres of wheat harvested in the county, 11,803 acres of sorghums, 3,964 acres of barley, 3,720 acres of corn, 3,672 acres of rye, and 380 acres of hay. In 1939 only 278 acres of land in Kiowa County were irrigated.

Climate

The climate of Kiowa County is of the subhumid to semiarid type, involving slight to moderate precipitation, abundant sunshine, moderately high average wind velocity, and rapid evaporation. Although summer days are hot, the heat is alleviated somewhat by good wind movement. The winters are moderate with occasional severe cold periods of short duration. There is relatively little snowfall.

The mean annual temperature at Greensburg is 56° F. The mean monthly temperatures in summer are 73.9° F. for June, 79.4° F. for July, and 78.4° F. for August. The mean monthly temperatures for January and December, generally the coldest months, are 32.4° F. and 33.9° F., respectively. The average growing season—the average interval between the last killing frost in the spring and the first killing frost in the fall—is 183 days, and has ranged from 151 to 224 days.

The mean annual precipitation at Greensburg is 22.15 inches. Deviations from the mean, however, are frequent and extreme. The recorded annual precipitation ranges from a minimum of 10.51 inches in 1939 to a maximum of 31.33 inches in 1915. About 75 percent of the annual precipitation falls during the crop-growing season from April through September (Fig. 3).

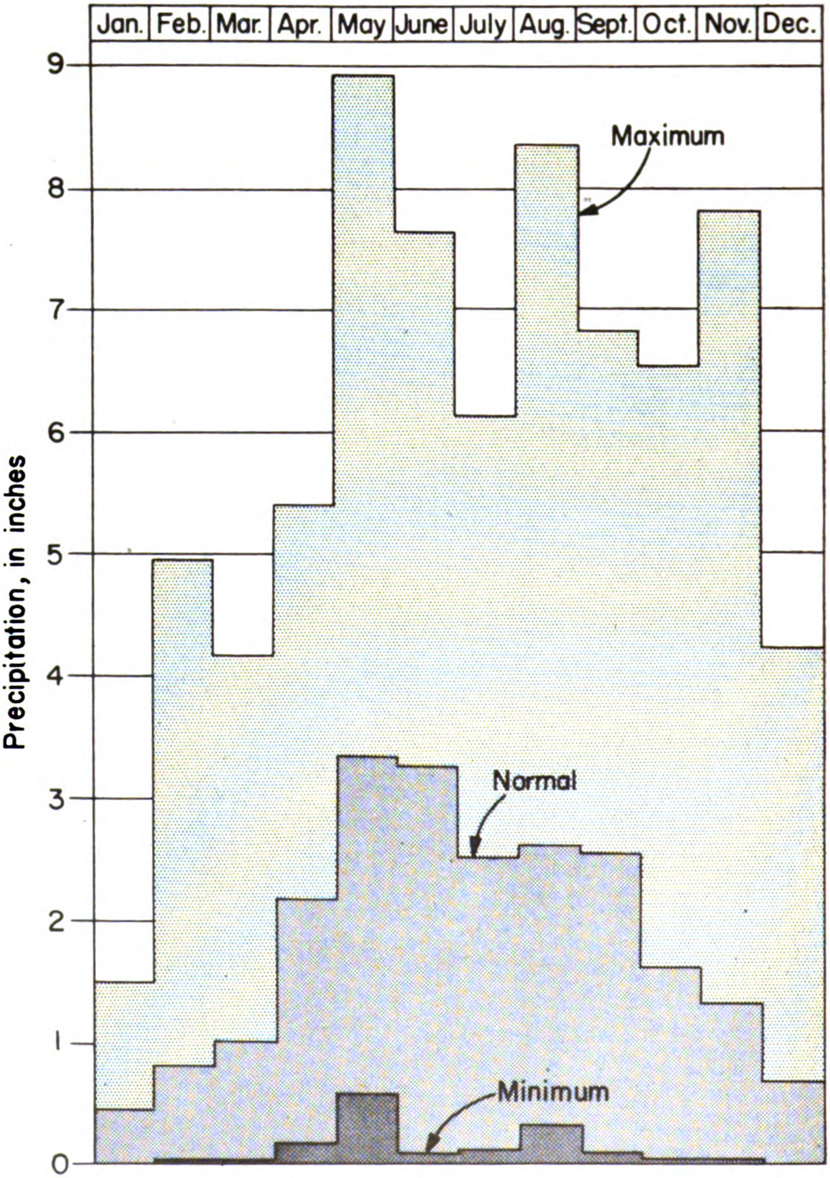

FIG. 3. Monthly distribution of normal, minimum, and maximum rainfall at Greensburg.

Normal precipitation during May and June, the wettest months, is about 6.59 inches, or about 28 percent of the annual total; during January and December, the driest months, it is only about 1.1 inches, or about 5 percent of the annual total.

Precipation in Kiowa County seems to follow more or less irregular cycles in which wet periods alternate with dry periods. Since 1907, when rainfall records were started at Greensburg, there have been 17 years of above-normal rainfall and 20 years of deficient rainfall. The annual precipitation and the cumulative departure from normal precipitation at Greensburg are shown graphically in Figure 4.

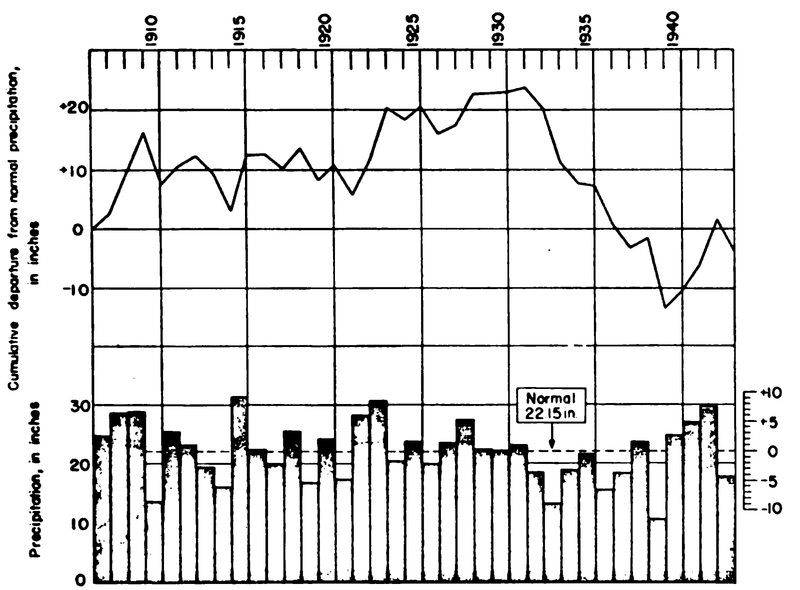

FIG. 4. Annual precipitation and cumulative departure from normal precipitation at Greensburg, Kiowa County, Kansas. (From records of U. S. Weather Bureau.)

SUMMARY OF ROCK FORMATIONS

The rocks that crop out in Kiowa County are of sedimentary origin and range in age from Late Permian to Recent. Their areal extent is shown on Plate 1 and a generalized section of the geologic formations of the county is given in Table 1.

The oldest rocks exposed in Kiowa County are of Permian age and comprise the Medicine Lodge gypsum member of the Blaine formation, the Dog Creek shale, and part of the overlying White-

TABLE 1.—*Generalized section of the geologic formations of Kiowa County, Kansas*

System	Series	Subdivision	Thickness (feet)	Physical character	Water supply
Quaternary	Recent and Pleistocene	Alluvium	0–40±	Very coarse gravel, sand, and silt comprising stream deposits in Medicine Lodge Valley and the valleys of smaller streams.	Yields moderate amounts of water to wells in the larger stream valleys. (Well 73 in Soldier Creek Valley is reported to yield 180 gallons a minute.) Waters are very hard—three samples had from 316 to 1,782 parts per million of hardness.
		unconformable on older formations			
		Terrace deposits	0–20 (?)	Sandy silt containing small amounts of sand and gravel occur as terrace deposits along Medicine Lodge Valley. These deposits together with certain slope-wash deposits probably are equivalent to the Gerlane formation. Coarse terrace gravels are believed to occur beneath dune sand in the northern part of the county.	Are believed to occur everywhere above the water table; therefore they probably would not yield water to wells.
		unconformable on older formations			
		Dune sand	0–60+	Fine- to medium-grained wind-blown sand. Covers approximately the northern third of Kiowa County.	Occurs above the water table; therefore it yields no water to wells. Serves as an important catchment area for recharge from local precipitation, however.
		unconformable on older formations			
		Kingsdown silt	0–100+	Light-tan to brown silt and sandy silt containing some clay and stringers, nodules, and thin beds of lime carbonate; contains loess of Pleistocene and Recent age in upper part, and minor amounts of sand and gravel in lower part. Underlies the surface in the upland area and in the Mule Creek drainage area.	Is above the water table everywhere in this area; hence does not supply water to wells.
		unconformable on older formations			
	Pleistocene	Meade formation	300+	Interbedded lenses of clay, silt, sand, and gravel that are lithologically similar to materials of the Ogallala formation, and are both consolidated and unconsolidated. Contains nodules, stringers, and irregular beds of caliche and locally volcanic ash.	Sand and gravel beds of the Meade and Ogallala formations are the most important sources of water in Kiowa County, and yield large supplies. Most of the domestic, stock, and industrial wells and all of the irrigation and public supply wells derive water from these deposits, and they also supply water to numerous springs in the southern part of the county. The water, although hard, is satisfactory for most purposes.
		unconformable on older formations			
Tertiary	Pliocene	Ogallala formation	65+	Consolidated and unconsolidated, calcareous silt, sand, and gravel. Caliche occurs as cementing material, pipy concretions, nodules, or beds.	
		unconformable on older formations			

TABLE 1.—Generalized section of the geologic formations of Kiowa County, Kansas—*Concluded*

System	Series	Subdivision	Thickness (feet)	Physical character	Water supply
Cretaceous	Gulfian*	Dakota formation	90+	Light-gray, blue-gray, yellow, yellow-tan, red, and mottled red and gray shale, sandy shale, and clay and tan to white and dark-brown, fine- to coarse-grained sandstone that is in part cemented with iron. Contains nodules, concretions, and thin beds of ironstone.	No wells are known to obtain water from the Dakota formation in this area, as adequate supplies of water of good quality are obtained from deposits above the Dakota.
	Comanchean*	Kiowa shale	300	Dark gray to black thinly laminated shale in lower part and gray, tan, brown, and red clay and clay shale in upper part. Contains thin beds of shell limestone and light- to dark-gray and white fine-grained sandstone. Large lense of yellow-tan to buff cross-bedded fine-grained sandstone occurs locally at top of formation. Also contains crystals of gypsum. Is exposed over a wide area in the southeastern part of the county.	Most of the materials of the Kiowa shale are relatively impermeable and will not yield water to wells. The large sandstone lense at the top of the formation supplies moderate amounts of water to one well (91) and several springs. The water is similar in quality to that from the Meade and Ogallala formations.
		—local disconformity (?)—			
		Cheyenne sandstone	20-94	Light-colored fine- to coarse-grained friable cross-bedded sandstone and lenses of gray to black sandy carbonaceous shale. Contains lenses of pebble conglomerate at or near base, and also contains crystals of selenite, pyrite, nodules of iron, and remains of plants. Exposed in the southeastern part of the county.	Supplies water to a few stock and domestic wells in the south-central and southeastern parts of the county. Water in the Cheyenne sandstone is highly mineralized and locally is unfit for ordinary purposes.
		—unconformity—			
Permian	Guadalupian*	Whitehorse sandstone	60+	Red poorly bedded fine-grained friable sandstone and siltstone containing minor amounts of shale. Crops out in the southeastern part of Kiowa County and in two small areas in the southwestern part.	Supplies small quantities of very hard water to a few wells (74, 81, and 82) in southeastern Kiowa County.
	Leonardian*	Nippewalla group: Dog Creek shale	50±	Red shale containing thin beds of light-gray and mottled red and light-gray fine-grained sandstone. Contains thin bed of light-gray shaly dolomite in lower part. Exposed in narrow bands along the sides of Medicine Lodge Valley in the southeastern part of Kiowa County.	Relatively impermeable; not known to yield water to wells in Kiowa County.
		Nippewalla group: Blaine formation (Medicine Lodge gypsum member)	22±	White massive gypsum; weathers to light gray. Other members of the Blaine formation are missing in this area.	Not known to yield water to wells.
		Nippewalla group: Flowerpot shale	200−	Dark red-brown to reddish-purple shale containing many thin and a few thick beds of sandstone. Contains gypsum in veins and as cementing material. Not exposed in Kiowa Co.	Supplies highly mineralized water to one well (55) in this area, but is not an important water-bearer.

* The classification here shown, which is used by the State Geological Survey of Kansas, differs somewhat from that employed by the Federal Geological Survey.

horse sandstone. These formations are exposed along Medicine Lodge Valley in the southeastern part of the county; the Whitehorse sandstone also crops out in two small areas in the southwestern part of the county. Overlying the Permian rocks in southeastern Kiowa County are the Cheyenne sandstone and Kiowa shale (Comanchean) and the Dakota formation (Gulfian), all of Cretaceous age. Silt, sand, and gravel comprising the Ogallala formation (Pliocene) and Meade formation (Pleistocene) unconformably overlie the Permian and Cretaceous rocks and are exposed in the eastern and western parts of the dissected area (Fig. 2). The central part of the dissected area and the upland plains are mantled by Kingsdown silt (Pleistocene and Recent) and the northern half of Kiowa County is mantled by dune sand. Terrace deposits and alluvium occur in the larger valleys.

The sectional diagram on Plate 5, which was plotted from test-hole and well-log data, shows the stratigraphic relationships of the rock formations in Kiowa County.

GROUND WATER

Principles of Occurrence

In order to assist the reader in a better understanding of the ground-water conditions in Kiowa County, certain basic principles of the occurrence of ground water adapted from Meinzer (1923, pp. 2-102) are discussed briefly in the pages that follow. For a more detailed treatment of the subject the reader is referred to Meinzer's report and also to a report by Moore (1940).

Ground water, or underground water, is the water that supplies springs and wells. The rocks that form the outer crust of the earth are at very few places solid throughout, but contain numerous open spaces, called voids or interstices. These open spaces are the receptacles that hold the water that is found below the surface of the land and is recovered in part through wells and springs. There are many kinds of rocks, and they differ greatly in the number, size, shape, and arrangement of their interstices and hence in their properties as containers of water. Therefore, the character, distribution, and structure of the rocks of any region determine the occurrence of water.

The amount of water that can be stored in any rock depends upon the volume of rock occupied by open spaces—that is, the porosity of the rock. Porosity is expressed as the percentage of the total volume of rock that is occupied by interstices. A rock is said to be saturated when all its interstices are filled with water. The porosity of a sedimentary rock is controlled by (1) the shape and arrangement of its constituent particles, (2) the degree of assortment of its particles, (3) the cementation and compaction to which it has been subjected since its deposition, (4) the removal of mineral matter through solution by percolating waters, and (5) the fracturing of the rock, resulting in joints and other openings. Well-sorted deposits of unconsolidated silt, sand, or gravel have a high porosity, regardless of the size of the grains. Poorly sorted deposits have a much lower porosity because the small grains fill the voids between the large grains, thus reducing the amount of open space. The pore space in some well-sorted deposits of sand or gravel may gradually be filled with cementing material, gradually reducing the porosity.

The capacity of a rock to hold water is determined by its porosity, but its capacity to yield water is determined by its permeability. The permeability of a rock may be defined as its capacity for transmitting water under hydraulic head. It is measured by the rate at which the rock will transmit water through a given cross section under a given difference of head per unit of distance. Rocks that will not transmit water may be said to be impermeable. Some deposits, such as well-sorted silt or clay, may have a high porosity but because of the minute size of the pores will transmit water only very slowly. Other deposits, such as well-sorted gravel containing large openings that communicate freely with one another, will transmit water very readily. If a force greater than the force of gravity were applied to the water in the silt or clay it would probably move more readily. Part of the water in any deposit is not available to wells because it is held against the force of gravity by molecular attraction—that is, by the cohesion of the water itself and by its adhesion to the walls of the pores. The ratio of the volume of water that a rock will yield by gravity, after being saturated, to its own volume is known as the specific yield of the rock.

Below a certain level, which in Kiowa County ranges from the land surface to about 200 feet below the surface, the permeable rocks are saturated with water under hydrostatic pressure. These saturated rocks are said to be in the zone of saturation, and the upper surface of this zone is called the water table. Wells dug or drilled into the zone of saturation will become filled with ground water to the level of the water table.

The permeable rocks that lie above the zone of saturation are said to be in the zone of aeration. As water from the surface percolates slowly downward to the zone of saturation, part of it is held in the zone of aeration by the molecular attraction of the walls of the open spaces through which it passes. In fine-grained material there is invariably a moist belt in the zone of aeration just above the water table; this moist belt is known as the capillary fringe. Although water in the zone of aeration is not available to wells, much of the water in the upper part of the zone may be withdrawn by the transpiration of plants and by evaporation from the soil.

Rock Types and Their Water-bearing Properties

The outer crust of the earth is made up of various kinds of material ranging from unconsolidated deposits, such as clay, silt, sand, and gravel, to consolidated rocks, such as shale, limestone, and sandstone. All these materials are called "rocks," whether they are firm and hard or loose and soft. All of the rocks within a practical drilling depth in Kiowa County are of sedimentary origin and consist chiefly of clay, shale, silt, sand, gravel, and sandstone. These rocks vary greatly in character and in their ability to store and transmit water, as brought out in the discussion below.

Sand and gravel.—Sand and gravel consist of unconsolidated grains or pebbles of minerals or rocks greater than 0.062 mm in diameter. Sand ranges in grain size from 0.062 to 1 mm in diameter and gravel consists of grains and pebbles greater than 1 mm in diameter. Sand and gravel are found in the Ogallala and Meade formations and in the alluvium of the larger stream valleys. In Kiowa County more wells obtain water from sand and gravel than from any other source.

The water-bearing properties of sand and gravel differ widely and are controlled by the size of the particles, the degree of assortment, and the degree of cementation. Coarse clean well-sorted gravel is an ideal water-bearing material in that it has a high porosity, high permeability, and high specific yield; hence it absorbs water readily, stores it in large quantities, and yields it to wells freely. In some deposits, however, clay, silt, or sand mixed with the gravel reduces its porosity, permeability, and specific yield. Most of the gravel deposits in Kiowa County contain some silt and sand but nevertheless yield water very freely. Some of the gravel deposits in the Ogallala and Meade formations have been tightly cemented with lime carbonate and are therefore worthless as producers of water. The tightly cemented beds, however, are relatively thin.

Sand ranks next to gravel as a water bearer and differs from gravel in having smaller interstices; hence it will conduct water less readily and will give up a smaller proportion of its water to wells. Grains of sand, particularly fine sand, are more readily carried by water into wells. This fact raises problems in connection with the drilling and pumping of wells.

The distribution, character, thickness, and water-yielding capacity of the sand and gravel deposits in this area are described under water-bearing characteristics of rock formations.

Sandstone.—Sandstone, as the name implies, is a consolidated rock composed of cemented sand grains. Quartz generally is the most common mineral in sandstone though it may consist of cemented fragments of other minerals or rocks (Allen, 1936, p. 39). The chief cementing agents of sandstone are silica, calcite, and iron oxide.

In Kiowa County sandstone occurs in the Flowerpot shale, Dog Creek shale, and Whitehorse sandstone of Permian age and in the Cheyenne sandstone, Kiowa shale, and Dakota formation of Cretaceous age. A few wells in the southeastern part of the county obtain water from sandstone in the Cheyenne and Whitehorse. One well (55) is believed to tap a sandstone bed in the Flowerpot shale and one well (91) is believed to tap a sandstone lens at the top of the Kiowa shale. No wells are known to obtain water from sandstones in the Dakota formation.

Sandstone ranks next to sand in its ability to store and transmit water. The factors determining the water-bearing properties of a sandstone are size of grain, degree of assortment, and degree of cementation. A coarse-grained well-sorted sandstone will yield water freely, whereas an equally well-sorted very fine-grained sandstone holds a relatively large part of its water and surrenders the rest very slowly. A loosely cemented very fine-grained sandstone also is undesirable because of the tendency of the grains to enter wells, thus causing damage to the pumps and often clogging the wells. The degree of assortment of the sand grains in a sandstone affects the water-bearing properties of the sandstone in the same way as in a gravel deposit. Fine sand, silt, or clay in a coarse-grained sandstone greatly decreases the porosity and permeability of the sandstone. The interstices of sandstone are small and are therefore easily closed by precipitation from percolating water. Many sandstones are so thoroughly cemented that they will not yield water. Tightly cemented sandstone may, however, contain joints and fractures that carry water.

Silt and clay.—Silt and clay are composed of the very finest grained products of erosion. Silt is made up of particles from 0.005 to 0.062 mm in diameter and clay consists of particles that are less than 0.005 mm in diameter.

Silt and clay occur in all the rock formations in Kiowa County in varying amounts, and silt is the chief constituent of the Kingsdown silt. Although silt and clay generally have a high porosity and therefore contain considerable water, the water is held in the small interstices by molecular attraction; hence little or no water can drain out into wells under the incompetent force of gravity. No wells in this area obtain water from silt or clay.

Shale.—Shale is an indurated clay that, upon weathering, exhibits lamination along planes that are approximately parallel to the bedding. Unlike silt or clay, most shale will not fall apart on wetting. Shale is a very poor source of water, as the available water in shale is found only in sandy zones or in joints and along open bedding planes. No wells are known to obtain water from shale in Kiowa County.

Artesian Conditions

Artesian water is ground water that rises above the level at which it is encountered in wells (Meinzer and Wenzel, 1942a, p. 451). Artesian conditions exist where a water-bearing bed is overlain by an impermeable or relatively impermeable confining bed and dips from the point of recharge to the discharge area. When a well is drilled into an artesian water-bearing bed the pressure is released and the water rises in the well. If the water rises high enough to flow at the surface the well is called a flowing artesian well.

Water in the Cheyenne sandstone is under artesian head nearly everywhere in Kiowa County except in the immediate area of outcrop. The water in the Cheyenne sandstone is confined beneath the Kiowa shale, which dips from an altitude of about 2,500 feet in the southern part of the county to an altitude of less than 1,750 feet at the northern edge of the county (Pl. 5 and Fig. 9). The water level in wells that tap the Cheyenne sandstone generally rises from several tens of feet to more than 100 feet above the point at which the water is first encountered. For example, well 66 encountered the

Cheyenne at approximately 250 feet beneath the land surface, but on August 19, 1941, the measured depth to water level in the well was about 93 feet below the surface, or approximately 155 feet above the top of the water-bearing sandstone. There are no flowing artesian wells in Kiowa County and it is doubtful whether the head of the water in the Cheyenne sandstone is great enough anywhere in the county to cause a well to flow. Water from the Cheyenne sandstone generally is highly mineralized in this area (p. 86); therefore water from other sources is utilized wherever possible.

Although data are scanty, it is believed that the water in the Permian formations in this area also is under slight artesian head, but because of the poor quality of the water few wells have been drilled into Permian rocks (pp. 71-75).

The Water Table and Movement of Ground Water

The upper surface of the zone of saturation in ordinary permeable rock has been defined as the water table, but the water table is absent where the upper surface is formed by impermeable material, as it is in parts of Kiowa County. The water table is not a static, level surface, but generally it is a sloping surface having many irregularities. The causes of the irregularities of the water table in Kiowa County are discussed on the following pages.

SHAPE AND SLOPE

The shape and slope of the water table in Kiowa County are shown on Plate 1 by means of contour lines. Each point on the water table along a given contour line has the same altitude; hence these water-table contours show the configuration of the water surface just as topographic contours show the configuration of the land surface. Ground water moves in the direction of slope of the water table, at right angles to the water-table contours.

Plate 1 shows that ground-water enters Kiowa County from the west and moves through the county in a general easterly direction, but that the direction of movement and slope are not everywhere the same. The average gradient of the water table beneath the sand hills and upland plains (Fig. 2) is about 10 feet to the mile and ranges from about 5 feet to the mile in the central part of T. 27 S., R. 16 W. to about 15 feet to the mile along the southern edge of the upland plains. In the dissected area (Fig. 2) south of the upland plains the gradient of the water table averages approximately

20 feet to the mile and the maximum slope exceeds 40 feet to the mile.

In the northern half of Kiowa County the water table slopes to the east and maintains a nearly constant gradient across the county. In this area the water is moving through highly permeable sand and gravel, which accounts for the nearly uniform slope of the water table, although there are a few minor irregularities. The downslope flexure of the contours in T. 27 S., R. 20 W. represents a low ground-water divide that is caused by the movement of ground water toward Arkansas River, which flows northeastward just beyond the northwestern corner of Kiowa County. The downslope flexure of the contours in T. 27 S., Rs. 16, 17, and 18 W. indicates a broad relatively low ridge on the water table. This area is underlain by porous dune sand so that a large part of the water that falls as rain seeps downward to the underground reservoir where it has built up the low ridge. Influent seepage from Rattlesnake Creek has aided in forming this ridge. Ridges such as this are formed because the frictional resistance offered by the small openings in the water-bearing material prevents the water from spreading out as rapidly as it would in a body of free water, such as a lake.

In the eastern part of the sand hills and upland plains the movement of ground water changes direction from nearly east to southeast because of the discharge of ground water into Thompson, Spring, and Soldier Creeks.

Other things being equal, the slope of the water table in any area varies inversely with the permeability of the water-bearing material; that is, the water assumes a steeper gradient in flowing through fine material than through coarse material, providing the same quantity of water is moving through both types of material. This probably explains, at least in part, the minor differences in the slope of the water table beneath the sand hills area and upland plains.

In the dissected area in the southern part of the county the water table has many irregularities. It will be noted that ground water enters this area from the west-northwest, but soon after entering the dissected area it encounters a ground-water divide that causes part of the water to move northeastward, part eastward, and a part southward. On nearing the point of discharge in the dissected area the water also assumes a much steeper gradient than it has to the west and north. The shape and slope of the bedrock floor formed by the underlying Cretaceous rocks may control the direction of movement and slope of the ground water in this area to a small extent, for the shape of the water table in the dissected area roughly conforms with the shape of the pre-Ogallala surface shown in Figure 10. The discharging of ground water into Turkey, Middle Kiowa, Wiggins, and East Kiowa Creeks in the southwestern part of the dissected area, into Medicine Lodge River in the central part of the area, and into Mule Creek in northern Comanche County probably is the chief factor controlling the direction of movement and slope of the water table in this area, but a lower permeability of the water-bearing materials is responsible in part for the steeper slopes. This is particularly true near Medicine Lodge Valley where part of the ground water enters fine sandstone in the Dakota formation and Kiowa shale. The water moving toward the area of exposed bedrock is discharged through springs and seepage areas and leaves the county as runoff.

Much of the southeastern part of Kiowa County is underlain by relatively impermeable beds; therefore there is no water table in this area and water table contours are not shown. A few wells in this area obtain supplies from perched bodies of water in shallow stream alluvium or from the Cheyenne sandstone or Permian beds.

RELATION TO TOPOGRAPHY

The depth of water level below land surface in Kiowa County is controlled largely by the configuration of the land surface. Plate 2 shows the depth of the water level in wells in Kiowa County by means of isobath lines—lines of equal depths to water level. As shown on the plate, this depth ranges from less than 25 to nearly 200 feet. For purposes of detailed description of ground-water conditions, the county may be divided into the following four areas: sand hills, upland plains, eastern dissected area, and western dissected area.

Sand hills.—The location and areal extent of the sand hills are described under topography and drainage and are shown in Figure 2. The water table in this area is from 10 to about 80 feet below the land surface but in most of this area it is less than 50 feet below the surface. In the northwestern corner of the area, where the land surface slopes toward Arkansas River, and in a wide area along Rattlesnake Creek the depth to water level is less than 25 feet.

Most of the wells in the sand hills are from about 25 to 90 feet deep. The principal water-bearing beds are the sands and gravels of the Meade formation. Ground water suitable for most purposes in sufficient quantity to supply irrigation or industrial wells can be obtained from wells in the sand hills.

Upland plains.—The greatest depths to water level in the county are found in the upland plains area (Fig. 2). In a large part of the upland plains the water table is from 60 to 150 feet below the surface, and in a relatively large area in T. 29 S., Rs. 19 and 20 W. it is more than 150 feet below the surface. Wells in the upland plains are 65 to 210 feet deep and most of them obtain water from the sands and gravels of the Meade formation, but a few wells may obtain at least a part of their supply from sands and gravels of the Ogallala formation. Domestic and stock water supplies are available in all parts of this area and in some places larger supplies for irrigation or industrial use can be obtained. The quality of the water makes it suitable for most purposes.

Eastern dissected area.—The eastern dissected area includes that part of the dissected area (Fig. 2) that lies within the Medicine Lodge River drainage system. No attempt was made to show the depth to water level in this area, as the relatively impermeable Kiowa shale underlies most of it. Normal water-table conditions therefore do not exist here. In many parts of this area potable water is difficult to find. Wells near the margin of the eastern dissected area tap sands and gravels of the Meade and Ogallala formations and have depths to water level ranging from about 15 to 120 feet. Wells within the area underlain by Cretaceous and Permian rocks tap shallow stream alluvium, the Cheyenne sandstone (Cretaceous), or the Whitehorse sandstone (Permian), and one well (55) probably taps the Flowerpot shale (Permian). The water level in the wells (72, 73, 75, 76, 77, 79, and 88) tapping alluvium is from 4 to about 20 feet below the surface; in wells (59, 66, 80, and 100) tapping the Cheyenne sandstone it is from 55 to 142 feet below the surface; and in wells (74, 81, and 82) tapping the Whitehorse sandstone it is from about 45 to 75 feet below the surface.

Many springs and seeps occur near the northern and western margins of the eastern dissected area, the locations of which are shown in Figure 6 and on Plate 2. Their presence indicates the intersection of the water table with the land surface, as described on p. 44.

Western dissected area.—The western dissected area includes that part of the dissected area lying west of the Medicine Lodge River drainage basin (Fig. 2). The depth to water level in the western dissected area is controlled almost entirely by the shape of the land surface. The shallowest water levels are found in the valleys, where the water table generally is less than 25 feet below land surface. The water table intersects the land surface in all of the larger valleys in the southwestern part of the area and forms many seepage areas (Fig. 6 and Pl. 2). The water table is deepest below the intervalley divides, where it reaches a maximum depth of approximately 180 feet.

The wells in the western dissected area range in depth from 22 to about 190 feet, and except for well 99, which taps shallow stream alluvium, all of the wells obtain water from sands and gravels of the Meade and Ogallala formations. Domestic and stock water supplies can be obtained in most parts of this area and limited supplies of water for industrial use could be obtained locally.

FLUCTUATIONS OF THE WATER TABLE

The water table in any area does not remain in a stationary position but fluctuates much like the water in a surface reservoir. Whether the water table rises or declines depends upon the amount of recharge into the ground-water reservoir and the amount of discharge. If the inflow to the underground reservoir exceeds the draft, the water table will rise; conversely, if the draft exceeds the inflow the water table will decline. Thus the net rate at which the underground reservoir is replenished or depleted controls the rate and magnitude of fluctuation of the water table.

The principal factors controlling the rise of the water table in Kiowa County are the amount of precipitation that passes through the soil and descends to the water table, the amount of water added to the ground-water reservoir by seepage from streams, and the amount of water entering the county beneath the surface from areas to the west. Factors controlling the decline of the water table are the amount of water pumped from wells, the amount of water absorbed directly from the water table by plants (transpiration), the amount of water lost from the ground-water reservoir by evaporation, the loss of water from springs, the amount of water discharged by effluent seepage into streams, and the amount of water leaving the county beneath the surface toward the east. The factors causing the water table to rise are discussed in detail under ground-water recharge, and the factors causing the water-table to decline are discussed under ground-water discharge.

To determine the character and magnitude of fluctuations of the water table, seven observation wells (11, 14, 15, 23, 35, 52, and 91) were selected in Kiowa County and monthly measurements of the water levels were begun in October, 1940. Measurements for wells

35 and 52 were discontinued January 1, 1941, and those for well 11 on March 1, 1944. The wells were selected by J. C. Frye and measurements were made by the following persons during the periods indicated: J. C. Frye, October, 1940; R. B. Christy, September, 1940 to March, 1941; W. W. Wilson, April, 1941 to June, 1943; A. A. Graffham, June, 1943 to April, 1944; K. D. McCall and Howard Palmer, after April, 1944.

The descriptions and the 1940 water-level measurements for the seven original observation wells are given in the 1940 annual water-level report of the Federal Geological Survey (Meinzer and Wenzel, 1942, pp. 136-137) and subsequent water-level measurements have been published in ensuing water-level reports (Meinzer and Wenzel, 1943, pp. 119-120; 1944, pp. 135-136). Table 2 correlates the observation-well numbers used in this report with those given in Water-Supply Papers 908, 938, and 946. The location and description of each well is given in Table 8.

TABLE 2.—*Numbers of Kiowa County observation wells used in this report and corresponding numbers given in Water-Supply Papers 908, 938, and 946*

Well No. in this report	Well No. in Water-Supply Papers 908, 938, and 946
11	5
14	8
15	7
23	4
35	6
52	3
91	10

Fluctuations of the water levels in observation wells 11, 14, 15, 23, and 91 are shown by hydrographs in Figure 5. Wells 11, 14, 15, and 23 are in the sand hills in northern Kiowa County and tap the Meade formation. Well 91 is in the south-central part of the county in the dissected area and taps the Kiowa shale. Although a log is not available for well 91, it is believed to tap a lens of sandstone in the Kiowa.

The water level in well 11 showed a net gain of 0.36 foot from October, 1940 to March, 1944, and wells 14, 15, 23, and 91, respectively showed net gains in water level of 1.80, 3.27, 0.65, and 1.82 feet from October, 1940 to December, 1944. The magnitude of the

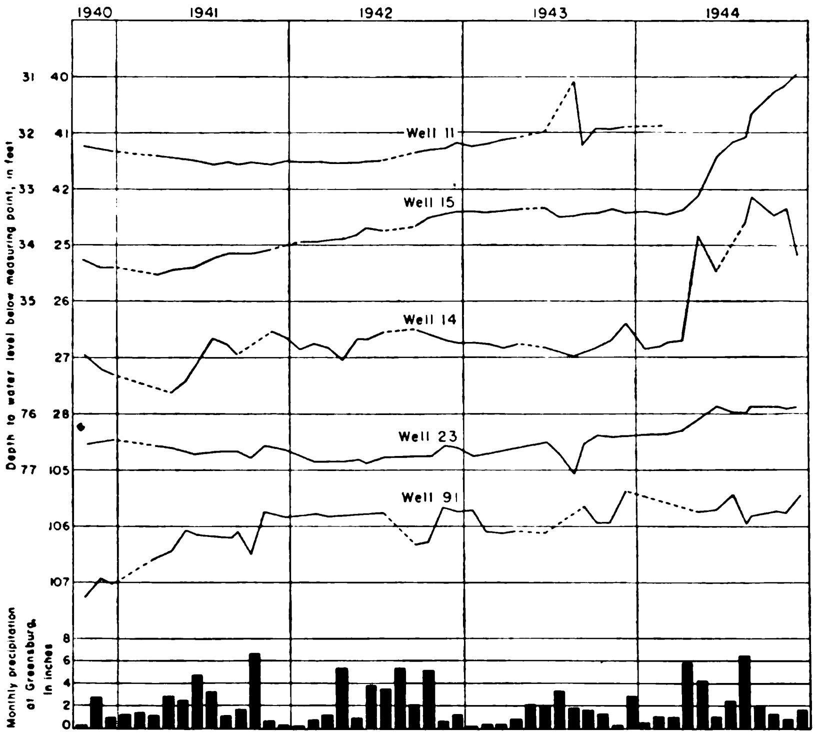

FIG. 5. Hydrographs showing the fluctuations of the water levels in five wells in Kiowa County and the monthly precipitation at Greensburg.

fluctuations of water level in these five observation wells for the period of record ranged from 1.23 to 3.53 feet and averaged 2.55 feet.

GROUND-WATER RECHARGE

The foregoing discussion of water-level fluctuations shows that the amount of water in storage in the underground reservoir does not remain the same for any long period. There is visible evidence that water is continually being discharged from the underground reservoir through springs, seepage areas, and wells; and the addition of water to the ground-water reservoir is clearly indicated by the fact that the water levels in the observation wells rise in response to precipitation. If there were no additions to the underground reservoir the water levels would show only declines.

The addition of water to the underground reservoir is termed recharge and may be accomplished in several different ways. All ground water within a practical drilling depth beneath Kiowa County is derived from the water that falls as rain or snow either within the county or on near-by areas west of the county. A discussion of the source of the water in each of the principal water-bearing formations is given on the following pages.

RECHARGE OF THE MEADE AND OGALLALA FORMATIONS

Because the lithology and water-bearing properties of the Meade and Ogallala formations are so nearly the same and because there is no barrier between the two, it seems best to consider them as a hydrologic unit. The Meade and Ogallala formations in Kiowa County are recharged by local precipitation, by seepage from streams, and by subsurface percolation from the west.

Recharge from local precipitation.—A part of the precipitation that falls on the surface of Kiowa County recharges the Meade and Ogallala formations. The average annual precipitation in the county is about 22 inches, but only a small percentage of this amount passes through the soil and reaches the zone of saturation. Of the total precipitation, part is lost by evaporation and transpiration, part leaves the county as runoff, and the remainder eventually finds its way to the underground reservoir.

The amount of water lost through evaporation into the air varies from one season to another, the rate of evaporation being highest in summer when temperatures are highest. In an average year most of the total precipitation in the county comes during the summer, when the rate of evaporation is greatest. It is reasonable to assume, therefore, that a large proportion of the annual precipitation in Kiowa County returns to the atmosphere through evaporation.

A part of the precipitation that falls is used by plants through the process of transpiration. The amount consumed in this way is obviously greatest during the growing season, which closely coincides with the period of the maximum rainfall.

The amount of water leaving the county by runoff in streams is determined principally by the duration and intensity of the rainfall, the slope of the land surface, and the type of soil and vegetation. The runoff from a gentle rain as a rule is much smaller than the runoff from a heavy downpour; hence the amount of ground-water recharge from a gentle rain of long duration generally is greater than the recharge from a heavy downpour of short duration, providing all other factors are equal. The slope of the land is an important factor in determining the amount of runoff, and in general the steeper the slope the greater the runoff. Runoff is also greater in places where the surface is underlain by fine relatively impermeable material than in places where the surface material is sandy and loosely compacted. The latter type of material allows a part of the water to percolate into the ground, thus decreasing the amount of surface runoff. Vegetation tends to decrease the velocity of the runoff, thereby offering a better opportunity for the water to seep into the ground.

The most favorable area for recharge of the Meade and Ogallala formations from precipitation is the sand hills. Because of the high porosity of the dune sand and the presence of many undrained basins that serve as catchment areas for the rainfall, much water percolates downward to the zone of saturation. The sandy surficial material and the gentle slopes in this area reduce runoff to a minimum, so that very little water is lost by runoff in the sand hills except in a narrow belt along Rattlesnake Creek and its tributaries. Throughout most of this area the material between the land surface and the water table is sufficiently permeable to allow water to percolate downward with little interruption (see logs 1, 2, 4, 5, 6, and 9). In a few places lenses of relatively impermeable material probably hinder downward movement of water. Such lenses, however, are believed to be of limited horizontal extent so that the water probably detours around them and eventually reaches the water table.

The hydrographs of wells 15 and 23 in Figure 5 indicate that during periods of abundant rainfall a large amount of water is added to the Meade and Ogallala formations by precipitation in the sand hills. The rainfall as recorded at Greensburg was above average each year except 1943 for the period 1940 to 1944. As a result the water levels in wells 15 and 23 rose 3.27 and 0.65 feet, respectively, from October, 1940 to December, 1944.

If it is assumed that the porosity of the water-bearing materials within the zone of fluctuation of the water table is 20 percent, then each foot of rise in the water table would represent an addition of approximately 40 million gallons of water for each square mile. If the average net rise of the water table over the entire sand hills for this 4-year period was 1 foot, which probably is a conservative estimate, then the net addition to the underground reservoir during the 4 years would amount to 2.3 inches of water or about 2.2 percent of the total precipitation. The amount of water discharged from the ground-water reservoir beneath the sand hills during this same period must be added to this to obtain the total amount of water added to the ground-water reservoir by recharge.

The amount of water that reaches the water table from precipitation on the upland plains probably is very small compared with the sand hills, for the upland plains are underlain by thick deposits of silt (Kingsdown) that transmits water very slowly. After heavy rains the broad shallow depressions in the uplands are filled with water that may remain for several days or weeks. Part of this water is evaporated, but a part probably percolates downward. Although the soil forming the floor of such depressions has a fairly low permeability, the water has access to the soil for such a long period of time that a part of the water seeps downward and eventually reaches the water table.

Most of the area underlain by the Meade and Ogallala formations in the dissected area consists of moderate to steep slopes that favor high runoff and low ground-water recharge. Where coarse sands and gravels of the Meade formation are exposed at the surface and where the slopes are gentle, however, the amount of recharge from precipitation probably equals or exceeds that in the sand hills. These conditions exist in the upper divide areas between Haviland and Belvidere, where a large proportion of the water falling on the highly permeable sands and gravels percolates downward almost immediately. The amount of water added to the ground-water reservoir by this means is necessarily limited by the relatively small area in which these conditions exist.

Recharge from streams.—The ridges on the water-table contour map (Pl. 1) indicate that along part of their courses West Fork of Rattlesnake Creek, Rattlesnake Creek, and East Fork of Rattlesnake Creek are losing water to the ground-water reservoir. The channels of these streams lie above the water table throughout Kiowa County, and the deposits beneath the channels in most places are sufficiently permeable to allow the water to percolate downward. During times of heavy rains these streams carry large volumes of water, a large part of which flows into Edwards County, though part of it seeps into the ground before reaching Edwards County. The magnitude and frequency of the water-level fluctuations in well 14 (Fig. 5), which is only a short distance west of West Fork of Rattlesnake Creek, indicate that the ground-water reservoir in the vicinity of this well is receiving water from the creek.

Although no evidence of recharge from other streams is apparent on the water-table contour map, it seems probable that some of the others also are supplying water to the underground reservoir. The channels of Turkey, Middle Kiowa, Wiggins, and East Kiowa Creeks in the southwestern part of the county and of Thompson, Spring, and Soldier Creeks in the east-central part of the county are above the water table in the upper part of their courses and below the water table in the lower part of their courses. These streams probably furnish a small amount of water to the ground-water reservoir where their channels lie above the water table, but where their channels lie below the water table they are receiving water from the ground-water reservoir (p. 44). The channel of Mule Creek is above the water table throughout Kiowa County and may lose water to the ground-water reservoir. The same is true of the extreme upper part of Medicine Lodge River.

Recharge from outside of county.—The water-table contours on Plate 1 show that the ground water in this area is moving from west to east, indicating that water percolates into the Meade and Ogallala deposits of this area from Ford and Clark Counties.

RECHARGE OF THE DAKOTA FORMATION

The Dakota formation in Kiowa County occurs beneath the Meade and Ogallala formations in an irregular belt about 10 miles wide that extends northwestward from the south-central part of the county (Pl. 5). The regional dip of the Dakota formation is northeastward; therefore there probably is subsurface movement of water into the Dakota in the northwestern part of the county from the Dakota of Ford County. A part of this water probably migrates into the overlying Meade and Ogallala formations in places where the head of the water in the Dakota is greater than the head in the Meade and Ogallala.

Most of the Dakota formation cannot receive water from outside the county because it has been truncated by erosion in the southern and southwestern parts of the county; therefore it must derive its water largely from the Meade and Ogallala formations. Probably only a negligible amount is derived from precipitation on the small area of outcrop within the county (Pl. 1). Water in the Dakota probably returns to the Meade and Ogallala formations near the southeast and northwest edges of the formation.

RECHARGE OF THE CHEYENNE SANDSTONE

The addition of water to the Cheyenne sandstone is achieved in at least three ways: (1) by water migrating from the Meade and

Ogallala formations into the Cheyenne where they are in contact; (2) by recharge from local precipitation; and (3) by subsurface percolation from outside the county.

In the southwestern part of Kiowa County the Dakota formation and Kiowa shale were completely removed during the period of erosion that preceded deposition of the Ogallala formation so that sediments of the Meade and Ogallala formations are in contact with the Cheyenne sandstone in this area (Pl. 5). Water in the Meade and Ogallala formations moves southward over the Cheyenne sandstone, and the water that migrates into the Cheyenne sandstone probably moves northeastward down the dip of the formation (Fig. 9).

The Cheyenne sandstone is exposed in southeastern Kiowa County and undoubtedly absorbs some water directly from the rains that fall on its outcrops. The amount of water added in this way is probably small, however, because the steepness of the slopes, the sparseness of the vegetation, and the relatively low permeability of the Cheyenne sandstone favor a high rate of runoff and a low rate of absorption.

A part of the water that enters the Cheyenne sandstone in other areas probably travels down the dip of the sandstone into Kiowa County, but the amount carried is limited by the low permeability of the sandstone. The Cheyenne is exposed in parts of Comanche and Clark Counties where it probably absorbs some water directly from rainfall and from streams that cross the outcrops. Some water also may enter Kiowa County by subsurface percolation in the Cheyenne from Ford County.

Ground-water Discharge

GENERAL FEATURES

Ground water is discharged from the underground reservoir in Kiowa County by springs and seepage areas, evaporation and transpiration, subsurface movement from the county, and by wells.

Before any water was pumped from wells in Kiowa County, it is probable that the annual discharge of ground water by natural processes was approximately equal to the annual recharge. Artificial discharge by pumping represents an additional amount of water taken from the ground-water reservoir without any increase in the amount of replenishment; hence the state of approximate equilibrium between annual recharge and annual discharge is disrupted. Approximate equilibrium is again attained by a gradual regional

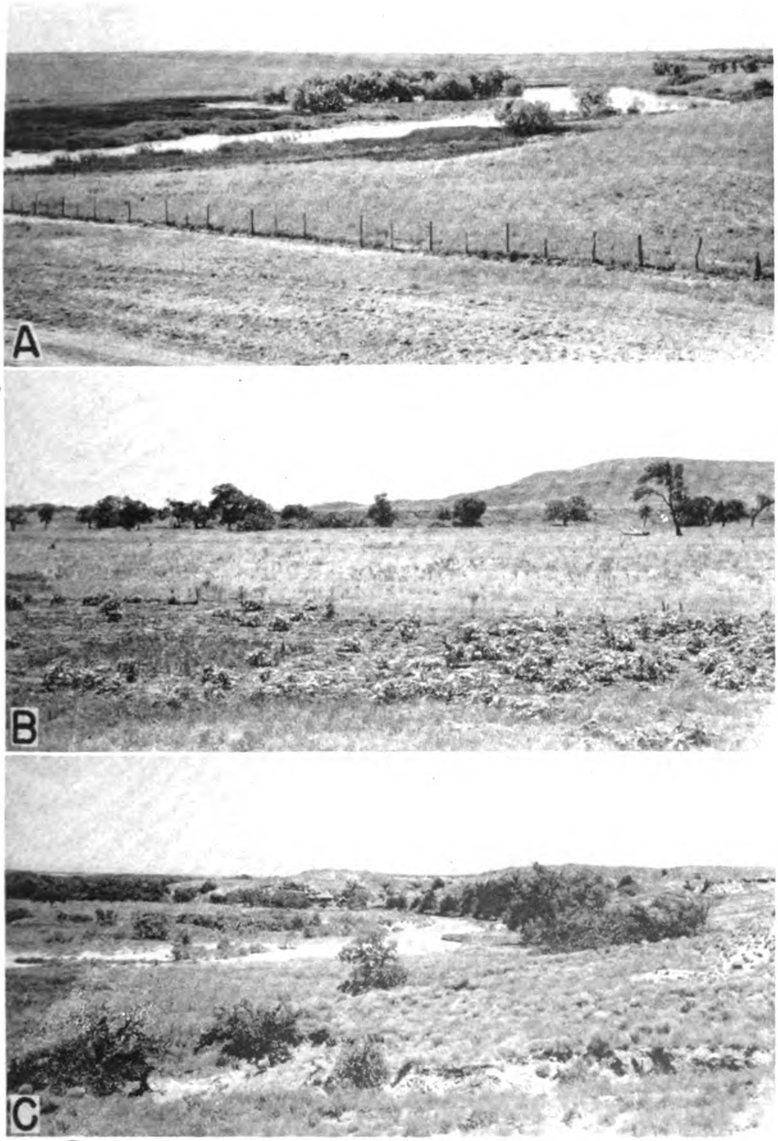

PLATE 6. *A,* Seepage area near the head of Spring Creek in the NW¼ NW¼ sec. 15, T. 29 S., R. 16 W. (No. 1 in Fig. 6); the water is impounded behind a dam. *B,* Terraces along the south side of Medicine Lodge Valley about 4 miles west of Belvidere; surface of lower terrace is in foreground and just beyond the trees may be seen the upper terrace. *C,* Medicine Lodge Valley about 2 miles southeast of Belvidere; the steep bluff in the distance is formed by Dog Creek shale (Permian).

lowering of the water table until the natural discharge is decreased by an amount equal to the artificial discharge. The amount of water annually withdrawn from the ground-water reservoir in Kiowa County by pumping from wells is small compared with the natural discharge. Consequently only a slight adjustment of the water table probably was required to restore approximate equilibrium.

SPRINGS AND SEEPAGE AREAS

Character and distribution.—Springs in Kiowa County are of two types: (1) seepage springs, in which the water percolates to the surface from numerous small openings in permeable material because the surface extends down to the water table; (2) contact springs, in which the water flows to the surface from permeable material over the outcrop of less permeable or impermeable material that prevents the ground water from percolating downward and deflects it to the surface. The term "seepage area" is used to denote any large area in which water is seeping to the surface at many points from permeable material (Pl. 6A). The distinction between these three types is somewhat arbitrary and each may grade into another. The term "spring" is restricted to individual and definite points of discharge where water can be seen flowing from the rocks. Although the discharge from any one point in a seepage area is not great enough to cause a surface flow of water, the aggregate discharge from a seepage area may result in a comparatively large surface flow.

The locations of most of the springs and seepage areas in Kiowa County are shown on Plate 2 and in Figure 6.

Descriptions of all springs and some of the seepage areas (by numbers shown in Fig. 6) visited in the county are given in Table 9, and chemical analyses of four samples of water collected from springs (6, 10, 16, and 18) are given in Table 5.

All of the springs and seepage areas occur in the dissected area in the southern part of the county, where many of the valleys have been cut below the water table. Most of the springs are along the sides of the main valleys, at or near the base of the valley bluffs, or at the head of tributary draws; the seepage areas are generally in the bottoms of the valleys or draws.

The springs along Soldier, Spring, and Thompson Creeks (2-6, 9-14) are seepage springs whose waters flow from permeable sand and gravel of the Meade formation (Pleistocene). They were formed at places where valleys have been cut below the water table.

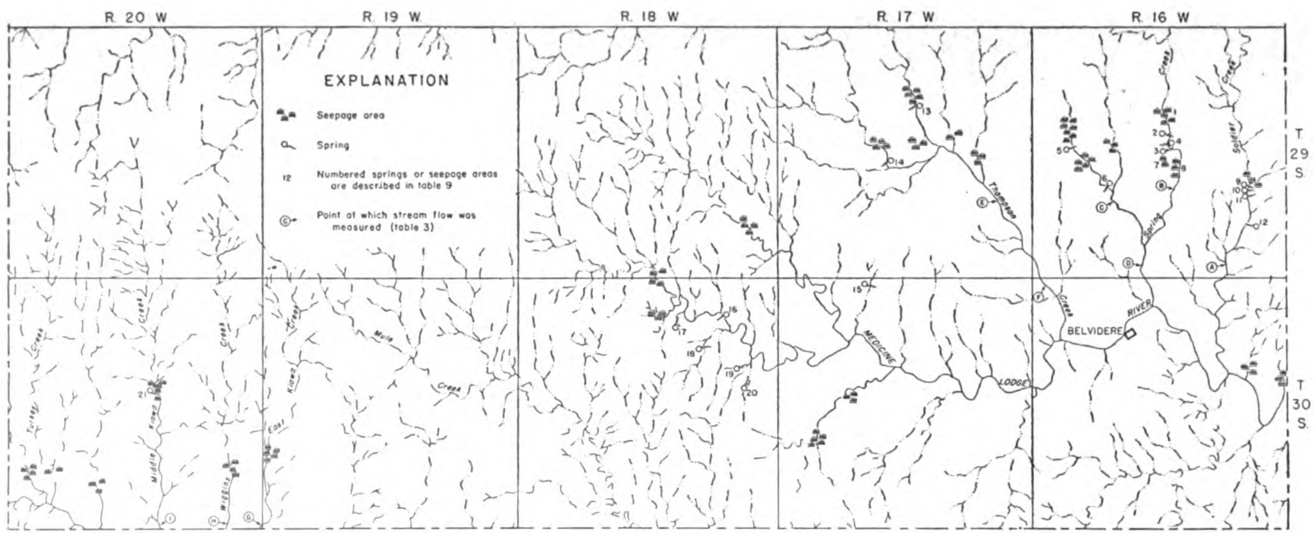

Fig. 6. Location of springs, seepage areas, and points where stream-flow measurements were made in southern Kiowa County.

The proximity of relatively impermeable shale (Kiowa) beneath the sands and gravels is a contributing factor in that it prevents the downward precolation of the ground water and deflects it to the surface. Spring 21 in Middle Kiowa Creek Valley in the southwestern part of the county has a similar source and origin. The water at most of these springs percolates upward from the sand and gravel and forms small pools of water; at springs that have a sufficiently large discharge, small surface flows occur.

Contact springs (15-20) are found along Medicine Lodge River Valley and in draws tributary to the Medicine Lodge in the south-central part of the county (Fig. 6). The water at springs 15, 19, and 20 issues from permeable sand of the Meade formation at the contact of the Meade and the underlying Kiowa shale. Springs 16, 17, and 18 occur at the base of a sandstone lens in the Kiowa shale that is underlain by relatively impermeable clay. The water issues from pore spaces in the sandstone or from small fractures or from both.

According to reports of local residents, numerous springs existed years ago along the outcrop of the Cheyenne sandstone south of Medicine Lodge Valley in T. 30 S., R. 16 W., but no springs were found in this area at the time the investigation was made in 1941. The recent series of dry years or clogging of the openings by silt may have caused the drying up of these springs.

Yield.—The yields of most of the springs in Kiowa County are relatively small, generally less than 5 gallons a minute. The largest known spring in the county is Greenleaf Spring (19) whose measured discharge in November, 1941 was 130 gallons a minute. The second largest known spring is Thompson Creek Spring (13), near the head of Thompson Creek, whose measured discharge in November, 1941 was 98 gallons a minute. Estimated discharges of some of the smaller springs are given in the table of spring records.

Although the yield of individual springs is relatively small, the aggregate yield of all the springs and seepage areas is rather large. Measurements of the flow of most of the streams fed by springs and seepage areas in the county were made in November, 1941 by Woodrow W. Wilson of the Federal Geological Survey and Melvin Scanlan of the Division of Water Resources, Kansas State Board of Agriculture, and are given in Table 3.

The measured flow of the streams ranged from 54 gallons a minute for Wiggins Creek to 6,063 gallons a minute for Thompson Creek. The aggregate discharge of the streams measured amounts

TABLE 3.—*Discharge measurements of spring-fed streams in Kiowa County, Kansas*[1]

Letter on Fig. 6	Stream	Locality	Date of measurement	Discharge (gallons a minute)	Method of measurement[2]
		T. 29 S., R. 16 W.			
A	Soldier Creek	S½ sec. 35	Nov. 5, 1941	1,723	C
B[3]	East Branch Spring Creek	S½ sec. 22	1940	1,580	W
C	West Branch Spring Creek	NE¼ sec. 29	Nov. 5, 1941	1,167	W
D	Spring Creek	S½ sec. 33	do	3,698	C
		T. 29 S., R. 17 W.			
E	Thompson Creek	NW¼ sec. 25	do	5,009	C
		T. 30 S., R. 16 W.			
F	do	NW¼ sec. 6	do	6,063	C
		T. 30 S., R. 20 W.			
G	East Kiowa Creek	SE¼ sec. 36	Nov. 4, 1941	382	W
H	Wiggins Creek	SW¼ sec. 36	do	54	W
I	Middle Kiowa Creek	S½ sec. 34	do	1,176	C

1. Measured by W. W. Wilson, U. S. Geological Survey, and Melvin Scanlan, Division of Water Resources of Kansas State Board of Agriculture, unless otherwise noted.
2. C, current meter; W, wier.
3. Measured by Charles Razeau, local rancher.

to about 19 million gallons a day, or nearly 7 billion gallons a year. These figures represent only a part of the total amount of ground water that is discharged from the underground reservoir by springs and do not include the amount of water discharged from springs and seepage areas in the upper part of Medicine Lodge Valley, in Turkey Creek, and in two unnamed creeks in the southwestern corner of the county.

TRANSPIRATION AND EVAPORATION

Transpiration is the process by which water is taken into the roots of plants directly from the zone of saturation or from the capillary fringe, and is discharged into the atmosphere. The depth from which plants will lift the ground water varies with different plant species and different types of soil. Ordinary grasses and field crops will not send their roots more than a few feet in the search for water, but alfalfa and certain desert plants may send their roots several tens of feet to reach the water table.

In Kiowa County the discharge of ground water by transpiration and evaporation is restricted to the valley areas where the water table is shallow. The greatest loss of ground water by these two processes occurs in the valley areas in the southeastern and southwestern parts of the county, where the water table is only a few feet below the land surface. Discharge by transpiration and evaporation is particularly high in areas where the water table intersects the land surface or where the capillary fringe extends to the surface. Such areas are rather common in the valleys of Soldier, Spring, Thompson, East Kiowa, Wiggins, Middle Kiowa, and Turkey Creeks (Fig. 6), where springs, seepage areas, and marshy lands with abundant vegetation are characteristic. The vegetation includes plant species that habitually draw ground water, such as salt grass, reed grass, and cattails, and that are not found elsewhere in the county (Pl. 6A).

Some loss of ground water by transpiration and evaporation probably occurs in the valleys of West Fork of Rattlesnake, Rattlesnake, and East Fork of Rattlesnake Creeks in the northern part of the county. Transpiration and evaporation are confined almost exclusively to the channels of these ephemeral streams and to a narrow belt bordering the channels where the water table is very shallow.

The amount of ground water discharged annually by plant transpiration and evaporation in Kiowa County is not known, but in the areas described above the loss is thought to be rather large.

WELLS

In 1941, there were 5 irrigation, 6 public-supply, 4 industrial, 1 railroad, 1 domestic and irrigation, and a large but unknown number of domestic and stock wells in the county. The amount of water annually discharged from the underground reservoir by wells is not known, but it probably is small compared with the amount discharged by natural processes. The recovery of ground water from wells is discussed in the following section.

Recovery of Ground Water

SPRINGS

Improvements have been made at some of the springs in southern Kiowa County to recover the water for domestic and stock use. The water from springs 3, 10, 11, and 14 is piped to farm houses for domestic use; and springs 1, 2, 9, 18, and 19 have been improved by tanks or dams to recover water for stock use. Spring 15, although unimproved, is being used as a stock and domestic water supply.

Although many of the springs and seepage areas in the county are unimproved, the water is not wasted, but flows into draws or perennial streams where it is utilized in part for watering cattle.

WELLS

Principles of recovery from wells

The following discussion on the principles of recovery of ground water has been adapted in part from Lohman (1938, pp. 54-56).

When water is withdrawn from a well there is a difference in head between the water inside the well and the water in the surrounding material at some distance from the well. The water table in the vicinity of a well that is discharging water has a depression resembling in form an inverted cone, the apex of which is at the well. This depression of the water table is known as the cone of influence or cone of depression and the surface area affected by it is known as the area of influence. In any given well a higher pumping rate produces a greater drawdown (depression of the water level, commonly expressed in feet) and the diameter of the cone of influence and of the area of influence will be greater.

The specific capacity of a well is its rate of yield per unit of drawdown. It is generally stated in gallons a minute per foot of drawdown.

When a well is pumped the water level drops rapidly at first and then more slowly, but it may continue to drop for several hours or days. In testing the specific capacity of a well, therefore, it is important to continue pumping until the water level remains approximately stationary. When the pump is stopped the water level rises rapidly at first, then more slowly, and may continue to rise long after pumping has ceased.

The character and thickness of the water-bearing materials have a definite bearing on the yield and drawdown of a well, and in turn on the specific capacity of a well. Drawdown increases the height that the water must be lifted in pumping a well and thus increases the cost of pumping. If the water-bearing material is coarse and of a fairly uniform size it will readily yield large quantities of water to a well with a minimum drawdown, but if the water-bearing material is fine and poorly sorted it will offer more resistance to the flow of water into a well, thereby decreasing the yield and increasing the drawdown. Other things being equal, the drawdown of a well varies inversely with the permeability of the water-bearing material.

The specific capacity of wells, particularly in unconsolidated materials, generally can be greatly increased by the employment of special methods of well construction, as described on pages 52 and 53.

In Kiowa County ground water is recovered principally from drilled wells, but in part from dug and driven wells.

Dug Wells

Dug wells are excavated by hand, generally by use of pick and shovel. Of the 101 wells visited in Kiowa County in 1941 only 4 were dug wells (30, 36, 60, and 64), and two of these (30 and 64) were no longer being used. Wells 30, 60, and 64 are 4 feet in diameter and from 24 to 66 feet in depth. Wells 30 and 60 are cribbed with rock, but well 64 has no cribbing.

Well 36 in Greensburg has attracted much attention because of the early date of its construction and its size. Construction of the well was started in 1887 and completed in 1888. The well, which is 32 feet in diameter and 109 feet deep, was dug entirely by hand and was curbed with native stone hauled from quarries along Medicine Lodge River, about 12 miles south of Greensburg. The stone curbing was assembled a little at a time on a circular wooden platform at the ground level. As the well was deepened the curbing, or caisson, was lowered into the well until the desired depth was reached. The well supplied Greensburg with water for household and commercial purposes until 1932, when, because of increased demand for water, it was replaced by drilled wells (31-34). Well 36 is now used to supply water for irrigating the lawn and trees in the city park and as an attraction for tourists, being advertised as the "world's largest hand-dug well." It may be the largest dug well in Kansas, but it is not the largest in the world. St. Patrick's well at Orvieto, Italy, is a dug well 42 feet in diameter and 200 feet deep (Tolman, 1937, pp. 11-12).

Dug wells generally are inferior to other types of wells. Most dug wells are poorly sealed and may be contaminated by the entrance of surface waters. Because of the difficulties of digging by hand below the water table, dug wells generally are excavated only a few feet below the water table and therefore are more likely to fail during a drought than are drilled wells, which generally extend many feet below the water table.

Driven Wells

A few wells (3, 75, 77, and 99) in Kiowa County are driven. This type of well is made by driving a small-diameter pipe (equipped at the bottom with a screened drive point) down below the water table. Such wells can be put down only where the water-bearing material is sufficiently permeable to permit water to flow freely into the pipe, where the material is soft enough, and where the water table is shallow. Usually a hole is first augered by hand as deep as possible; then the pipe and screened drive point are put in and driven into the water-bearing material. Most driven wells are equipped with hand-operated pitcher pumps and are used for domestic and stock purposes.

Drilled Wells

A drilled well is one that is excavated wholly or in part by means of a drill, either percussion or rotary, which operates either by cutting or by abrasion. Most of the domestic and stock wells and all of the public-supply, industrial, and irrigation (except 36) wells in Kiowa County are drilled wells. Most of them were drilled by means of portable cable-tool or hydraulic-rotary drilling rigs. The drilled domestic and stock wells in the county are 2 to 7 inches in diameter and those used for public-supply, irrigation, industrial, and railroad purposes are 6 to 19 inches in diameter. Drilled wells generally are cased with galvanized-iron, wrought-iron, or steel casing.

Construction of wells in consolidated rocks.—Most of the wells in the eastern half of the dissected area obtain water from consolidated rocks. Many of the wells are open-end wells; that is, the hole is cased through the overlying unconsolidated deposits and a few feet into the consolidated rocks, but the lower part of the hole is not cased. Holes drilled into consolidated rocks will as a rule stand open without casing, but it is sometimes necessary to extend the casing to the bottom of the hole to prevent the walls from caving. Small perforations are sometimes cut in the casing opposite the water-bearing beds in wells that are cased from top to bottom.

Construction of wells in unconsolidated rocks.—About 90 percent of the wells visited in Kiowa County obtain water from unconsolidated sand and gravel. It is necessary to case these wells the full depth of the hole in order to prevent caving of the walls. In some wells the casing is open only at the bottom, but in many wells the lower part of the casing is perforated. Perforating the casing greatly increases the area of intake, and thus the specific capacity of the well is increased and the entrance velocity of the water is reduced. Well screens are used in some wells to prevent fine sand from entering the well and to increase the intake area.

There are two types of drilled domestic and stock wells in Kiowa County. One type consists of a cased well with a separate pipe and cylinder for conducting the water to the surface. The other type, known as a tubular well, is a drilled well in which the pipe that conducts the water to the surface acts also as the casing and there is no separate pump pipe. Tubular wells generally are 2 to 3 inches in diameter and consist of a galvanized-iron pipe at the bottom of which is attached a screened point and a brass-lined cylinder. The submerged cylinder is connected with a pump at the surface by rods within the pipe. The principal advantage of tubular wells is their lower cost. The chief disadvantage is the difficulty in pulling the pipe to repair the cylinder, and (to the ground-water geologist) the impossibility of measuring the water level.

Many of the municipal, industrial, and irrigation wells in the county are gravel-packed wells. In constructing this type of well, a hole of large diameter is first drilled and temporarily cased. A well screen or perforated casing of a smaller diameter than the hole is then lowered into place and centered opposite the water-bearing beds. Blank casing extends from the screen to the surface. The annular space between the inner and outer casings then is filled with carefully sorted gravel, preferably having a grain size just slightly larger than the openings in the screen or perforated casing, and also just slightly larger than that of the water-bearing material. The outer casing is then withdrawn part way in order to uncover the screen and allow the water to flow through the gravel packing from the water-bearing material.

The logs of some of the test holes drilled during the investigation reveal that in some places the water-bearing materials are sufficiently coarse and well sorted that gravel-packed wells are not required in order to obtain large yields. In such places less expensive wells employing well screens or slotted casings, but without gravel packing, may be used satisfactorily. In places where the water-bearing materials are fine-grained, however, the gravel-packed wells have several advantages that offset the greater initial cost. The envelope of selected gravel that surrounds the screen increases considerably the effective diameter of the well, and therefore decreases the velocity of the water entering the well. This reduction in velocity prevents the movement of fine sand into the well and increases the production of sand-free water. Owing to the increased effective area offered by this type of construction, the entrance friction of the water is reduced and the drawdown may be reduced appreciably. As stated above, a reduction in drawdown, at a given yield, increases the specific capacity and reduces the cost of pumping.

Most of the large wells in Kiowa County have been drilled by the hydraulic-rotary method. In drilling a well by this method no casing is used until the drilling has been completed, as the drilling mud plasters the walls of the hole and prevents them from caving. A casing slightly smaller than the hole is placed in the well after the well has been drilled to the desired depth. If it is to be a gravel-packed well the space between the hole and the casing is filled with gravel of the proper size, or the hole may be reamed to larger diameter before placing the screen and gravel. Some of the large wells have been drilled by the cable-tool method, in which the casing is installed as the hole is drilled.

If a well of the best possible construction is employed, then the maximum amount of water that can be withdrawn from the well is fixed by nature and nothing can be done to make the well yield more than the water-bearing material will provide. The problem for the driller then is to construct each individual well in such a manner as to obtain the greatest yield with the smallest amount of drawdown that is possible under the existing conditions.

According to McCall and Davison (1939, p. 29) drawdown can be kept to a minimum in several ways:

> First, the well should be put down through all valuable water-bearing material. Secondly, the casing used should be properly perforated so as to admit water to the well as rapidly as the surrounding gravel will yield the water. Third, the well should be completely developed so that the water will flow freely into the well. . . . Increasing the depth of a well will have a greater effect on reducing the drawdown than will increasing the diameter, so long as additional water-bearing formations are encountered.

A report (Davison, 1939) containing a description of different types of pumping plants, the conditions for which each is best suited, construction methods, and a discussion of construction costs is available from the Kansas State Board of Agriculture, Topeka, Kansas. The reader is referred to this publication for details of well construction. A report by Rohwer (1940) describes the various methods of constructing irrigation wells. This report may be obtained from the Superintendent of Documents, Washington, D. C.

Methods of Lift

Most of the domestic and stock wells in Kiowa County are equipped with lift or force pumps in which the cylinders or working barrels are below the pump heads and may be far below the surface. A few lift or force pumps are operated by hand, but most of them are operated by windmills. A few wells are equipped with hand-operated pitcher pumps that have their working parts at the base of the pump heads.

All the large irrigation wells in the area are equipped with deep-well turbine pumps operated by gasoline engines, but cylinder pumps are used in the smaller irrigation wells (23 and 35). The municipal and industrial wells are equipped with turbine pumps operated by natural-gas engines or by electric motors, or are pumped by air-lift. Plunger-type pumps operated by gasoline engines are used to lift the water in the Santa Fe Railroad wells (72 and 73) near Belvidere.

Utilization of Water

Records for 97 wells and 21 springs in Kiowa County and 4 wells outside the county were obtained and are tabulated on pages 107-116. Of the 97 wells in the county for which records are given, 77 are or have been used for domestic and stock purposes, 7 are used for irrigation, 6 are used for public supplies, 4 are industrial wells, 2 are used by a railroad, and 1 is used for air conditioning. Records for all the large wells in Kiowa County were obtained, but no attempt was made to obtain records for all domestic and stock wells.

DOMESTIC AND STOCK SUPPLIES

Most of the domestic and stock water supplies in the county are obtained from wells. Springs were being used for domestic purposes at only five of the farms visited. In the southeastern and southwestern parts of the county where there are large cattle ranches, springs and seepage areas are important sources of stock water.

The ground water in the sand hills, the upland plains, and in part of the dissected area is moderately hard but generally is satisfactory for domestic and stock use. Ground water in parts of the eastern dissected area, however, is highly mineralized and locally is unfit for domestic use. The highly mineralized waters are found in the alluvium of Medicine Lodge Valley, in the Cheyenne sandstone, and in the Permian formations (see Quality of Water).

PUBLIC SUPPLIES

Only two communities in Kiowa County, Greensburg and Haviland, have public water supplies, both of which are supplied from wells. The residents of Belvidere use water pumped from the Atchison, Topeka and Santa Fe Railway wells, which are located about 2 miles northeast of town. There is no distribution system in Belvidere. Residents haul or carry water from a tap near the railroad station. Private wells supply water to the residents of Mullinville, Joy, Brenham, and Wellsford.

A large dug well formerly supplied Greensburg with water (see p. 50), but it was replaced by four drilled wells (31-34). Three of the wells (32-34) were drilled in 1925. They are 250 feet deep and are equipped with air-lift pumps. One well (31), drilled in 1938, is 125 feet deep, and is equipped with a turbine pump operated by an electric motor. The wells are gravel packed and are reported to yield from 150 to 500 gallons a minute. The water is pumped from the wells into a 45,000-gallon settling reservoir, from which it is pumped directly into the mains by a horizontal centrifugal pump, and the excess water is stored in an elevated steel tank with a capacity of 55,000 gallons. The maximum daily water consumption at Greensburg is about 650,000 gallons and the average daily consumption is about 250,000 gallons. Of these amounts, about 20,000 gallons a day is purchased by the Chicago, Rock Island and Pacific Railroad. An analysis (31) of a composite sample of water from the four wells is given in Table 4. The water is of good quality and is not treated.

The water supply for Haviland is obtained from two drilled wells (24 and 25), each 160 feet deep and equipped with a turbine pump. One pump is operated by a natural-gas engine and the other by a gasoline engine. Each well has a reported yield of 200 gallons a minute. The water is pumped directly into the mains, and the excess flows into a 50,000-gallon elevated steel tank. Figures on the consumption of water at Haviland are not available. The water is only moderately hard (analysis 24) and is not treated.

INDUSTRIAL SUPPLIES

The principal industrial use of ground water in Kiowa County is for cooling and condensing. Ground water is used for cooling condensers at the booster stations of the Panhandle Eastern Gas Company, about one mile west of Greensburg, and the Northern Natural Gas Company, about 3 miles east of Mullinville. The

Atchison, Topeka and Santa Fe Railway uses ground water from wells near Belvidere for filling locomotive boilers and for depot facilities. The Chicago, Rock Island and Pacific Railroad uses ground water purchased from the city of Greensburg for filling locomotive boilers. The Miller Cafe at Belvidere uses the water from a small shallow well (76) for air-conditioning.

The Panhandle Eastern Gas Company obtains its industrial water supply from two drilled wells (37 and 38), each 131 feet deep and equipped with a turbine pump powered by an electric motor. Both are gravel-packed wells that tap the Meade and Ogallala formations. The log (22) of well 37 is given on page 142. According to Wayne Cole, superintendent of the station, at the time well 37 was drilled it had a measured yield of 160 gallons a minute with a drawdown of 2.25 feet after 12 hours pumping. From 75,000 to 100,000 gallons of water a day are pumped from these wells. The water is treated to reduce the hardness.

Two deep wells (42 and 43) supply water for cooling the condensers at the Northern Natural Gas Company's booster station. The wells are reported to be from 350 to 400 feet deep and are equipped with airlift pumps. Well 43 acts as a stand-by well and is seldom pumped, but well 42 is reported to yield 250 gallons a minute and is pumped almost continuously. The water is treated for removal of excessive hardness.

The Atchison, Topeka, and Santa Fe Railway Company has two shallow wells (72 and 73) that tap the alluvium in Soldier Creek Valley. The wells are 14 inches in diameter and are equipped with plunger pumps operated by gasoline engines. Well 72 is used only for emergencies, whereas well 73 is pumped daily and is reported to yield 180 gallons a minute. The water, which is pumped to an elevated wooden storage tank in Belvidere, is used in locomotive boilers and for domestic purposes by residents of Belvidere. The average daily pumpage is reported to be about 10,000 gallons. The water is hard and is treated for boiler use.

The Miller Cafe well (76) at Belvidere is 30 feet deep and taps alluvium in the Medicine Lodge Valley. The well is equipped with a hand-operated lift pump and supplies water for a home-made air conditioning unit. An analysis (76) of the water from well 76 shows it to be a very hard calcium sulphate water that is too highly mineralized for domestic use.

IRRIGATION SUPPLIES

In 1941, there were six irrigation wells (10, 11, 14, 15, 35, and 36) and one irrigation and domestic well (23) in Kiowa County, descriptions of which are given in Table 8. All wells used for irrigation are in the sand hills in the northern half of the county.

Well 35 is a 6-inch drilled well, 100 feet deep, equipped with a cylinder pump powered by a windmill. The water level in the well stands about 85 feet below the surface. It is used to supply water for irrigating a private lawn in Greensburg. Well 36 is Greensburg's large dug well that was formerly used to furnish the city's water supply but is now used to irrigate the lawn and trees in the city park (p. 50). Detailed descriptions of the larger irrigation wells follow.

Williamson well.—The irrigation well (10) of C. Williamson is in the SE¼ NE¼ sec. 21, T. 27 S., R. 17 W. It was drilled in the fall of 1939, is 90 feet deep, is cased with 18-inch galvanized iron casing, and is equipped with a turbine pump operated by a gasoline engine. The measured water level on July 11, 1941, was 38.98 feet below the surface. According to the owner, water-bearing coarse sand to very coarse gravel (Meade formation) was encountered between depths of 38 and 92 feet during the drilling of the well. Approximately 40 acres of crops are irrigated with this well.

Grimes well.—The well (11) of L. W. Grimes is in the NW¼ NW¼ sec. 34, T. 27 S., R. 17 W. It was drilled in 1936, is 87.5 feet deep, is cased with 19-inch steel casing, and is equipped with a turbine pump operated by a gasoline engine. The measured water level was 41 feet below the surface October 23, 1940. The well has a reported yield of 1,800 gallons a minute, but this figure probably is too high. In 1941 the well was used to irrigate about 35 acres, but the owner reported that he plans in the future to irrigate about 60 acres.

Miller well.—The well (14) of E. E. Miller is an unused irrigation well in the SW¼ SE¼ sec. 18, T. 27 S., R. 18 W. It is a 16-inch well 75 feet deep. On October 23, 1940, the water level was 26.96 feet below the measuring point. No pump was in the well in 1941.

Weaver well.—A. C. Weaver's well (15) in the SW¼ NW¼ sec. 23, T. 27 S., R. 18 W., was drilled in 1939. It is 80 feet deep and the water level, as measured October 23, 1940, was 34.25 feet below the measuring point, which is about 2 feet above land surface. The well is from 48 to 19 inches in diameter and is cased with wrought iron casing. It is equipped with a turbine pump operated by a gasoline engine. Mr. Weaver reports that the well encountered very coarse gravel (Meade formation) between depths of 33.5 and 80 feet. About 20 acres of crops are irrigated by this well.

A pumping test was made on the Weaver well in 1941 to determine the yield, drawdown, and permeability of the water-bearing materials. During the test the yield of the well was 712 gallons a minute with a drawdown of 17.8 feet.

Davis well.—The well (23) of H. E. Davis is a 6-inch drilled well in the SE¼ NE¼ sec. 4, T. 28 S., R. 16 W., and supplies water for both irrigation and domestic use. It is reported to be 120 feet deep and is equipped with a cylinder pump that can be operated by a gasoline engine or by a windmill. The yield of the well when operated by the gasoline engine is reported to be 36 gallons a minute.

POSSIBILITIES OF DEVELOPING ADDITIONAL IRRIGATION SUPPLIES FROM WELLS

The quantity and availability of ground water, type of soil, and relief of the land surface are the most important factors in determining whether or not an area is suitable for irrigation from wells. The chief factors controlling the quantity and availability of ground water are character of the water-bearing materials, depth to water, and amount of annual recharge to the underground reservoir.

In most of the southern half of Kiowa County the depth to water is too great or the land surface is too irregular for the successful development of irrigation.

The five existing irrigation wells are in the sand hills area in the northern part of Kiowa County (Pl. 2). Here the water-bearing deposits, the Meade and Ogallala formations, are capable of supplying water to many more irrigation wells without excessive lowering of the water table. The water table is nearly everywhere less than 100 feet below the surface and in a large part of this area it is less than 50 feet below the surface. The deposits of the Meade and Ogallala formations in the sand hills area range in thickness from more than 100 feet to about 290 feet. The water-bearing materials of the two formations range in texture from fine sand to coarse gravel, but the character and thickness of these materials vary from place to place even within a short distance. The logs of nine test holes drilled in this area indicate that the thickness of saturated sand and gravel ranges from about 45 feet (log 8) northwest of

Greensburg to about 170 feet (log 1) in the eastern part. In addition to the large quantity of water in storage in the Meade and Ogallala formations in this area, the conditions for recharge are more favorable here than elsewhere in Kiowa County (pp. 39-40).

The extent of future irrigation development in the sand hills area will be limited not by the amount of available ground water, but probably by the amount of land suitable for irrigation. In a large part of this area the soils are too sandy and the land surface is too irregular for irrigation, but there are small areas in which the soils and surface relief are suitable for irrigation.

Land surface conditions in the upland plains area (Fig. 2), which borders the sand hills area on the south, are more favorable for irrigation. Most of the soils here are relatively thick and consist of silt loams and silty clay loams. Furthermore, there are large tracts of land that are sufficiently level for irrigation. The depth to water, however, is greater in the upland plains than in the sand hills and ranges from about 60 to more than 150 feet. The thickest and coarsest water-bearing deposits are found in the eastern part of this area where test hole 7 (log 7) penetrated about 175 feet of saturated sand and gravel in the Meade formation. Test hole 10 (log 10) at the western edge of the area encountered only 25 feet of saturated sand and gravel and test hole 8 (log 8) southwest of Greensburg encountered less than 10 feet of saturated sand and gravel.

If the drilling of an irrigation well is contemplated it is wise to drill several test holes of small diameter first, in order to determine whether or not saturated materials of the proper character and thickness are available. The information gained from the test holes will also indicate what type of well should be constructed, whether gravel packing is necessary, and, if not, what size screen should be used or what size perforations should be made in the casing.

POSSIBILITIES OF DEVELOPING ADDITIONAL INDUSTRIAL SUPPLIES FROM WELLS

The above areas favorable for the development of irrigation wells are also favorable for the development of industrial wells. Smaller industrial wells tapping sand and gravel of the Meade formation could also be developed in places in the western dissected area.

CHEMICAL CHARACTER OF GROUND WATER

The chemical character of the ground waters in Kiowa County is shown by the analyses of water from 27 representative wells and

Table 4.—*Analyses of waters from typical wells in Kiowa County, Kansas*

Analyzed by H. A. Stoltenberg. Parts per million[a] and equivalents per million[b] (in italics).

No. on plate 2	Location	Depth (feet)	Geologic subdivision	Date of collection, 1941	Temperature (F°)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)[a]	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness (calculated as $CaCO_3$) Total	Carbonate	Noncarbonate
3	*T. 27 S., R. 16 W.* SE NE sec. 6	38	Meade	Sept. 19	60	0.21	40 *2.00*	6.5 *.53*	1.2 *.05*	129 *2.12*	4.5 *.09*	4.2 *.12*	0.2 *.01*	15 *.24*	136	126	106	20
8	*T. 27 S., R. 17 W.* SW SW sec. 8	30	do	do	61	.54	37 *1.85*	5.2 *.43*	4.6 *.20*	110 *1.80*	8.2 *.17*	2.5 *.07*	.3 *.02*	26 *.42*	139	114	90	24
13	*T. 27 S., R. 18 W.* SE cor. SW sec. 8	43.5	do	do	61	.86	62 *3.09*	6.3 *.52*	4.8 *.21*	207 *3.39*	1.6 *.03*	4.5 *.13*	.2 *.01*	16 *.26*	200	180	170	10
18	*T. 27 S., R. 19 W.* SE SW sec. 30	60.5	do	do	60	.5	56 *2.79*	7.6 *.62*	8.5 *.37*	192 *3.15*	7.8 *.16*	5 *.14*	.4 *.02*	19 *.31*	201	170	158	12
19	*T. 27 S., R. 20 W.* SE NE sec. 1	46	do	do	61	.04	25 *1.25*	5.6 *.46*	5.1 *.22*	79 *1.30*	20 *.42*	5 *.14*	.2 *.01*	3.9 *.06*	104	86	65	21
24	*T. 28 S., R. 16 W.* SW SW sec. 8	160	do	Feb.	......	.01	50 *2.50*	5.7 *.47*	9.6 *.45*	175 *2.87*	3.7 *.08*	10 *.28*	.1 *.01*	11 *.18*	224	150	144	6
27	*T. 28 S., R. 17 W.* SW SE sec. 8	100	do	Sept. 20	61	1.2	46 *2.30*	5.6 *.46*	13 *.57*	169 *2.77*	7.6 *.16*	7 *.20*	.3 *.02*	11 *.18*	176	138	138	0
31	*T. 28 S., R. 18 W.* SW NE sec. 16	125-250	Meade and Ogallala (Composite sample from wells 31-34)	Dec.	......	0	60 *2.99*	6.8 *.56*	18 *.78*	211 *3.46*	19 *.4*	11 *.31*	.2 *.01*	9.3 *.15*	267	178	173	5
44	*T. 28 S., R. 19 W.* SW NW sec. 22	107.5	Meade	Sept. 19	61	1.2	80 *3.99*	11 *.90*	11 *.49*	267 *4.38*	16 *.33*	20 *.56*	.2 *.01*	6.2 *.1*	279	244	219	25
49	*T. 28 S., R. 20 W.* SE SW sec. 23	83.8	Meade and/or Ogallala	do	59	4.8	72 *3.59*	12 *.99*	13 *.57*	251 *4.12*	21 *.44*	14 *.39*	.3 *.02*	11 *.18*	274	229	206	23

	T. 29 S., R. 16 W.																	
55	NW NE sec. 33	100	Flowerpot	Oct. 1	60	.91	71 *3.54*	32 *2.63*	1,548 *67.32*	210 d *3.44*	1,722 *35.88*	1,210 *34.12*	1.9 *.1*	.71 *.01*	4692	308	172	136
	T. 29 S., R. 17 W.																	
56	NW NE sec. 5	130	Meade	Sept. 19	60	.08	74 *3.69*	11 *.9*	13 *.58*	281 *4.61*	9.6 *.2*	9.5 *.27*	.2 *.01*	4.9 *.08*	263	230	230	0
58	NW NE sec. 23	40	(?)	Oct. 1	60	5.6	83 *4.14*	9.6 *.79*	11 *.47*	296 *4.85*	12 *.25*	9 *.25*	.4 *.02*	2.1 *.03*	281	246	242	4
59	SW SW sec. 33	190.5	Cheyenne	Sept. 20	61	5.8	256 *12.77*	110 *9.04*	3,068 *133.48*	128 *2.10*	1,141 *23.73*	4,588 *129.38*	1.3 *.07*	.75 *.01*	9235	1090	105	985
60	NE SE sec. 34	59.4	Meade	Sept. 19	61	.47	82 *4.09*	20 *1.64*	45 *1.95*	309 c *5.07*	38 *.79*	61 *1.72*	.4 *.02*	4.9 *.08*	406	286	254	32
	T. 29 S., R. 18 W.																	
61	NW NW sec. 7	180.5	Ogallala	Oct. 1	60	.64	68 *3.39*	12 *.99*	14 *.61*	265 *4.35*	12 *.25*	8.2 *.23*	.3 *.02*	8.8 *.14*	256	219	218	1
65	SE NE sec. 30	94.5	Meade and/or Ogallala	Sept. 19	60	2.7	120 *5.99*	10 *.82*	5.3 *.23*	370 *6.07*	11 *.23*	6.5 *.18*	.1 *.01*	34 *.55*	375	340	304	36
66	NW SE sec. 35	275	Cheyenne	Sept. 20	62	8.5	70 *3.49*	38 *3.12*	1,075 *46.75*	215 *3.53*	277 *5.76*	1,560 *43.99*	1.2 *.06*	1 *.02*	3138	330	176	154
	T. 30 S., R. 16 W.																	
75	NW SW sec. 3	18	Recent (alluvium)	do	66	.14	91 *4.54*	25 *2.06*	74 *3.23*	345 *5.66*	128 *2.66*	50 *1.41*	.7 *.04*	3.8 *.06*	545	330	283	47
76	SW NW sec. 9	30	do	Oct. 1	60	1.0	520 *25.95*	118 *9.7*	59 *2.56*	428 *7.02*	1,454 *30.24*	31 *.87*	1.2 *.06*	1.1 *.02*	2400	1782	351	1431
82	NE SW sec. 23	55	Whitehorse	Sept. 20	62	22	321 *16.02*	83 *6.82*	80 *3.50*	213 *3.49*	1,032 *21.47*	47 *1.32*	.8 *.04*	1.3 *.02*	1694	1142	174	968
	T. 30 S., R. 17 W.																	
84	SW SW sec. 20	36	Meade	do	60	0	57 *2.84*	11 *.9*	14 *.63*	219 *3.59*	9.5 *.2*	9.2 *.26*	.6 *.03*	18 *.29*	229	187	180	7
86	SE SW sec. 34	96	do	do	60	.22	63 *3.14*	10 *.82*	16 *.71*	262 *4.30*	6 *.12*	7.8 *.22*	.3 *.02*	.89 *.01*	235	198	198f	0
	T. 30 S., R. 18 W.																	
87	NW SW sec. 1	24	do	do	60	.22	70 *3.49*	16 *1.32*	23 *1.01*	318 *5.22*	2.2 *.04*	18 *.51*	.4 *.02*	1.9 *.03*	291	240	240g	0
88	NW NW sec. 3	18	Recent (alluvium)	do	62	.29	100 *4.99*	16 *1.32*	42 *1.85*	388 *6.36*	37 *.77*	28 *.79*	.3 *.02*	14 *.22*	432	316	316h	0
90	NW NW sec. 20	59.3	Meade	do	59	.36	113 *5.64*	7.5 *.62*	5.7 *.25*	333 *5.46*	9.6 *.2*	6.5 *.18*	.1 *.01*	41 *.66*	350	313	273	40
	T. 30 S., R. 20 W.																	
97	NE NE sec. 2	94.5	do	Sept. 19	60	.04	61 *3.04*	17 *1.4*	14 *.59*	270 *4.43*	11 *.23*	10 *.28*	.4 *.02*	4.4 *.07*	253	222	222	0

a. One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.
b. An equivalent per million (e. p. m.) is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing concentration in parts per million by the chemical combining weight of the substance or ion.
c. Calculated.
d. Includes 7.2 parts per million of carbonate (CO_3).
e. Includes 3.6 parts per million of carbonate (CO_3).
f. Total alkalinity, 215 parts per million; excess alkalinity, 17 parts per million.
g. Total alkalinity, 261 parts per million; excess alkalinity, 21 parts per million.
h. Total alkalinity, 318 parts per million; excess alkalinity, 2 parts per million.

5 springs given in Tables 4 and 5, respectively. The analyses, which were made by Howard Stoltenberg in the Water and Sewage Laboratory of the Kansas State Board of Health, show only the dissolved mineral content of the waters and do not in general indicate the sanitary condition of the waters. The constituents given were determined by the methods used by the U. S. Geological Survey.

CHEMICAL CONSTITUENTS IN RELATION TO USE

The following discussion of the chemical constituents of ground water has been adapted from publications of the United States Geological Survey.

Dissolved solids.—The residue left after a natural water has evaporated consists of rock materials which may include some organic material and some water of crystallization. Waters containing less than 500 parts per million of dissolved solids are generally entirely satisfactory for domestic use, except for the difficulties resulting from their hardness and, in some areas, excessive iron corrosiveness. Waters having more than 1,000 parts per million are as a rule not satisfactory, for they are likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable in some other respects.

The ground waters from more than half of the wells and all of the springs sampled in Kiowa County contained less than 300 parts per million of dissolved solids, and are entirely satisfactory for most ordinary purposes. The waters from five of the wells sampled (60, 65, 75, 88, and 90) contained between 300 and 550 parts per million of dissolved solids, the waters from four wells (55, 66, 76, and 82) contained between 1,000 and 5,000 parts, and the water from well 59 contained 9,235 parts.

Hardness.—The hardness of water, which is the property that generally receives the most attention, is most commonly recognized by its effects when soap is used with the water. Calcium and magnesium cause virtually all the hardness of ordinary waters. These constituents are also the active agents in the formation of the greater part of the scale in steam boilers and in other vessels in which water is heated or evaporated.

In addition to the total hardness the table of analyses shows the carbonate hardness and the noncarbonate hardness. The carbonate hardness is that due to the presence of calcium and magnesium bicarbonates. It is almost completely removed by boiling. In some reports this type of hardness is called temporary hardness. The

TABLE 5.—*Analyses of waters from typical springs in Kiowa County, Kansas*

Analyzed by H. A. Stoltenberg. Parts per million[a] and equivalents per million[b] (in italics).

No. on Fig. 8	LOCATION	Geologic subdivision	Date of collection, 1941	Temperature (°F)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)[c]	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness (calculated as $CaCO_3$)		
															Total	Carbonate	Noncarbonate
	T. 29 S., R. 16 W.																
6	SW SE sec. 20	Meade	Oct. 1	60	0.26	83 *4.14*	9 *.74*	20 *.89*	315 *5.17*	14 *.29*	10 *.28*	0.4 *.02*	0.58 *.01*	295	244	244d	0
10	NE SE sec. 23	do.	Sept. 19	64	.04	58 *2.89*	8 *.66*	14 *.61*	216 *3.54*	9.4 *.2*	9.8 *.28*	.3 *.02*	7.5 *.12*	215	178	177	1
	T. 29 S., R. 17 W.																
13	SE SW sec. 10	do.	Sept. 20	60	0	67 *3.34*	9.6 *.79*	9.7 *.42*	248 *4.07*	7.2 *.15*	7 *.2*	.2 *.01*	7.5 *.12*	232	206	204	2
	T. 30 S., R. 18 W.																
16	SW SE sec. 2	Kiowa	Oct. 1	60	.06	61 *3.04*	14 *1.15*	37 *1.59*	273 *4.48*	21 *.44*	28 *.79*	.6 *.03*	2.4 *.04*	300	210	210e	0
18	NW SW sec. 11	do.	Sept. 20	66	.6	48 *2.40*	9.8 *.8*	15 *.64*	207 *3.39*	13 *.27*	4.2 *.12*	.9 *.05*	.84 *.01*	196	160	160f	0

a. One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.
b. An equivalent per million (e. p. m.) is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing concentration in parts per million by the chemical combining weight of the substance or ion.
c. Calculated.
d. Total alkalinity, 258 parts per million, excess alkalinity, 14 parts per million.
e. Total alkalinity, 224 parts per million, excess alkalinity, 14 parts per million.
f. Total alkalinity, 170 parts per million; excess alkalinity, 10 parts per million.

noncarbonate hardness is due to the presence of sulfates or chlorides of calcium and magnesium, but it cannot be removed by boiling and has sometimes been called permanent hardness. With reference to use with soaps there is no difference between the carbonate and noncarbonate hardness. In general the noncarbonate hardness forms harder scale in steam boilers.

Water having a hardness of less than 50 parts per million is generally rated as soft, and its treatment for removal of hardness under ordinary circumstances is not necessary. Hardness between 50 and 150 parts per million does not seriously interfere with the use of water for most purposes, but it does slightly increase the consumption of soap, and its removal by a softening process is profitable for laundries or other industries using large quantities of soap. Waters in the upper part of this range of hardness will cause considerable scale in steam boilers. Hardness of more than 150 parts per million can be noticed by anyone, and if the hardness is 200 or 300 parts per million it is common practice to soften water for household use or to install cisterns to collect soft rain water. Where municipal water supplies are softened, an attempt is generally made to reduce the hardness to 50 or 80 parts per million. The additional improvement from further softening of a whole public supply is not deemed worth the increase in cost.

Water samples collected in Kiowa County ranged in hardness from 86 to 1,782 parts per million. Twelve of the samples of water had less than 200 parts per million of hardness, eleven had between 201 and 300 parts, six had between 301 and 400 parts, and three (59, 76, and 82) had more than 500 parts. The water in neither of the two public water supplies in the county is treated, but it is necessary to treat the industrial supplies to reduce the hardness.

Iron.—Next to hardness, iron is the constituent of natural waters that in general receives the most attention. The quantity of iron in ground waters may differ greatly from place to place, even though the waters are derived from the same formation. If a water contains much more than 0.1 part per million of iron the excess may separate out and settle as a reddish sediment. Iron, which may be present in sufficient quantity to give a disagreeable taste and to stain cooking utensils, may be removed from most waters by simple aeration and filtration, but a few waters require the addition of lime or some other substance.

Of the 32 samples of water analyzed from Kiowa County, nine contained less than 0.1 part per million of iron, 15 contained between 0.1 and 1.0 part, four (wells 27, 44, 49, and 65) contained between 1.1 and 5 parts, and four (wells 58, 59, 66, and 82) contained more than 5 parts.

Chloride.—Chloride is an abundant constituent of sea water. It is dissolved in small quantities from rock materials and in some localities comes from sewage. The sources of chloride are many, however, and its presence in large quantities cannot be taken as a definite indication of pollution. Chloride has little effect on the suitability of water for ordinary use unless there is enough to give the taste of salt. Waters high in chloride may be corrosive when used in steam boilers.

All of the samples of water collected in Kiowa County had a low chloride content except those from wells 55, 59, and 66, which contained 1,210, 4,588, and 1,560 parts per million of chloride, respectively.

Fluoride.—Although determinable quantities of fluoride are not so common as fairly large quantities of the other constituents of natural waters, it is desirable to know the amount of fluoride present in waters that are likely to be used by children. Fluoride in water has been shown to be associated with the dental defect known as mottled enamel, which may appear on the teeth of children who drink water containing fluoride during the period when their permanent teeth are formed. It has been said that waters containing 1 part per million or more of fluoride are likely to produce mottled enamel, although the effect of 1 part per million is not usually very serious (Dean, 1936, pp. 1269-1272). If the water contains as much as 4 parts per million of fluoride, 90 percent of the children who drink it are likely to have teeth with mottled enamel, and 35 percent or more of these cases will be classified as moderate or worse. Small quantities of fluoride, not sufficient to cause mottled enamel, are likely to be beneficial by decreasing dental caries (Dean, Arnold, and Elvove, 1942, pp. 1155-1179).

The fluoride content of the water samples from Kiowa County was low. Of the 32 samples analyzed, 28 contained less than 1 part per million of fluoride and four (55, 59, 66, and 76) contained between 1 and 2 parts.

Water for irrigation.—The suitability of water for use in irrigation is commonly thought to depend mainly on the total quantity of soluble salts and the ratio of the quantity of sodium to the total quantity of sodium, calcium, and magnesium together. The quantity of chloride may be large enough to affect the use of the water, and in some areas other constituents, such as boron, may be present in sufficient quantity to cause difficulty. With reference to the quality of irrigation waters in southern California, Scofield (1933) suggests that if the total concentration of dissolved salts is less than 700 parts per million there is not much probability of harmful effects in irrigation use, but if it exceeds 2,000 parts per million there is a strong probability of damage to either the crops or the land, or both. Water containing less than 50 percent sodium (the percentage being calculated as 100 times the ratio of the total bases, in equivalents) is not likely to be injurious, but if it contains more than 60 percent its use is inadvisable. A chloride content of less than 142 parts per million is not objectionable, but more than 355 parts per million is undesirable. Similarly, a sulfate content of less than 192 parts per million is not objectionable, but more than 480 parts per million may be injurious. The harmfulness of these various salts in irrigation water is so dependent on the nature of the land and crops, the manner of use, and drainage that no hard and fast limits can be adopted.

Five of the samples (55, 59, 66, 76, and 82) collected in Kiowa County had mineral concentrations in excess of the safe limits given by Scofield and therefore are unsuitable for irrigation use. The concentration of dissolved solids, sulfate, and chloride, and percent sodium for each of these samples are given in Table 6. All but one

TABLE 6.—*Concentration of dissolved solids, sulphate, and chloride, and percent sodium in five samples of water collected from wells in Kiowa County, Kansas*

Well No.	Dissolved solids (parts per million)	Sulphate (SO_4) (parts per million)	Chloride (Cl) (parts per million)	Sodium (percent)[1]
55	4,692	1,722	1,210	91.6
59	9,235	1,141	4,588	85.9
66	3,138	277	1,560	87.6
76	2,400	1,454	31	6.7
82	1,694	1,032	47	13.3

1. Percent sodium = $\frac{100 \text{ Na}}{\text{Na} + \text{Ca} + \text{Mg}}$, in which the three chemical constituents are expressed in equivalents per million.

(76) of these samples were obtained from wells that draw water from consolidated deposits in areas where irrigation is not feasible. The water in well 76 comes from alluvium and is used in an air-conditioning unit.

SANITARY CONSIDERATIONS

Every precaution should be used to protect domestic and public water supplies from pollution by organic material. A large percentage of the population of Kiowa County is dependent on private water supplies from wells, and it rests chiefly with the drillers and individual well-owners to observe precautions to insure a safe and wholesome water supply. It is obvious that a well should not be located where there are possible sources of pollution nor where surface water can descend directly to the water table. Drainage from cesspools and privies is particularly dangerous. Every well should be so constructed as to seal off all surface water. As a general rule dug wells are more subject to contamination from surface water than are drilled wells, mainly because they are generally not effectively sealed at the surface.

RELATION TO STRATIGRAPHY

Samples of water were collected from wells and springs that are supplied by the following water-bearing formations: Flowerpot shale and Whitehorse sandstone (Permian), Cheyenne sandstone and Kiowa shale (Cretaceous), Ogallala and Meade formations (Pliocene and Pleistocene), and alluvium (Recent). The quality of the water from each formation is shown graphically in Figure 7 and is discussed in more detail by formations under water-bearing characteristics of rock formations. Since the quality of water in the Meade and Ogallala formations is similar and since it is difficult to determine from which sediments some wells obtain water, it seems best to discuss the waters of the two formations as a unit. Moreover, some wells obtain water from both formations.

The samples of water from the different water-bearing formations differed widely in their content of dissolved mineral matter. The lowest concentrations of mineral matter were found in the waters from the Meade and Ogallala formations. The two samples of water from the Kiowa shale fall in the middle range of concentration of the waters from the Meade and Ogallala. Waters from the Permian redbeds and the Cheyenne sandstone had the greatest concentrations of dissolved mineral matter and are in general the poorest waters found in the county. The concentration of the three

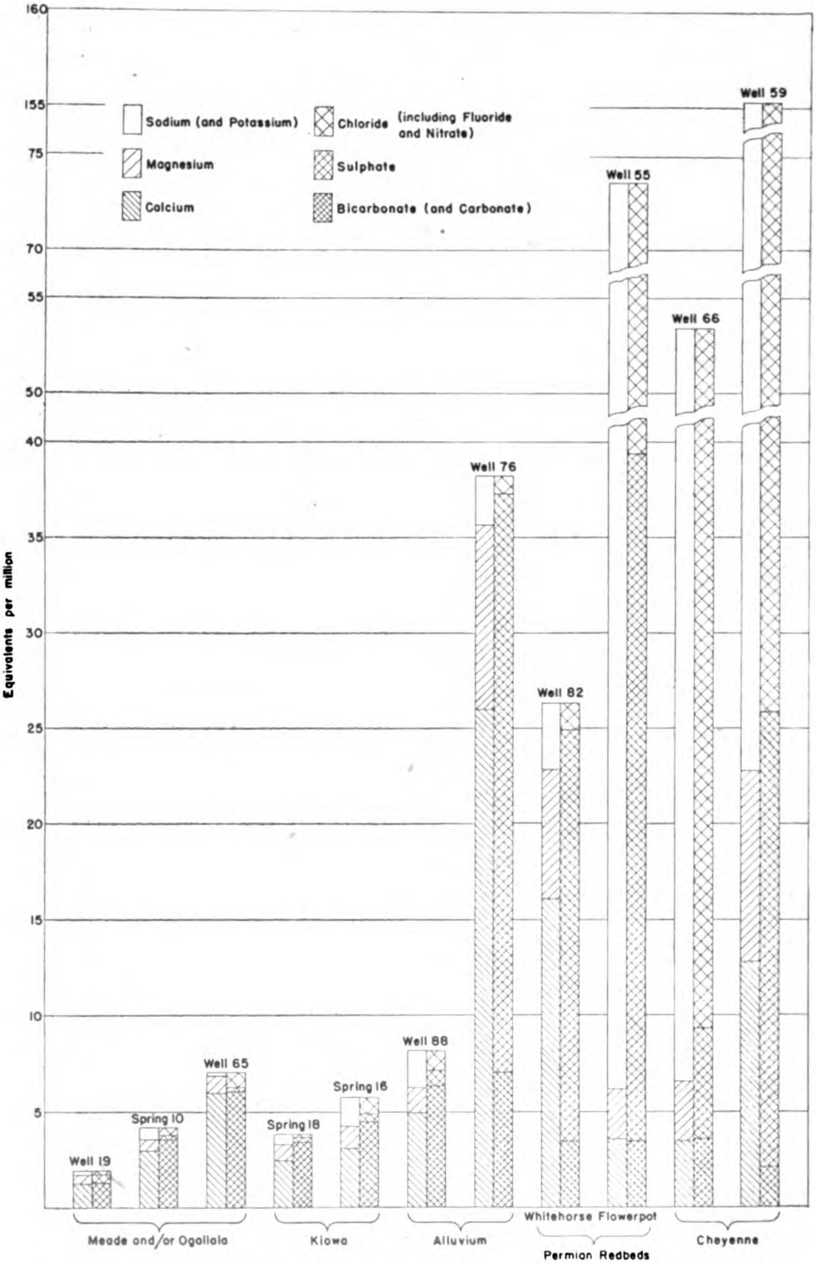

FIG. 7. Analyses of waters from the principal water-bearing formations in Kiowa County.

samples from alluvium differed greatly. Two of the samples were only slightly more concentrated than the poorest waters from the Meade and Ogallala formations, but one sample was as highly mineralized as one sample from the Permian.

The difference in the amount of mineral concentration in the two waters from the Permian redbeds is due to the difference in the mineral content of the deposits from which they came. The Flowerpot shale consists predominantly of gypsiferous shales but in some places contains beds of gypsum, gypsiferous sandstone, or rock salt (Norton, 1939, p. 1792); it yields mineralized water that is high in sodium, chloride, and sulfate (analysis 55). The Whitehorse consists almost entirely of iron-cemented fine-grained sandstone and yields very hard water that is high in sulfate and iron but relatively low in sodium and chloride (analysis 82).

WATER-BEARING CHARACTERISTICS OF ROCK FORMATIONS

The quantity of water that a rock formation will yield to wells depends on the lithology, structure, thickness, and distribution of the formation. The quality of water that a formation yields depends largely on the kind of minerals in the rocks. Rocks containing large amounts of soluble minerals, such as salt and gypsum, generally yield water that is highly mineralized whereas rocks composed chiefly of quartz or other relatively insoluble minerals generally yield water that has a low concentration of dissolved mineral matter. The various rock formations in Kiowa County differ widely in the amount and quality of water they yield. Sand and gravel beds of the Ogallala and Meade formations are the principal source of ground water in the county and yield moderate to large supplies of good quality water to wells and springs. Alluvium in the large valleys in the southern part of the county is capable of furnishing small to moderate supplies of water, but in many places the water is very hard. The Kingsdown silt and dune sand lie above the water table everywhere in Kiowa County and are therefore unimportant as water-bearing formations. The Cretaceous and Permian rocks are poor water bearers in Kiowa County. The Kiowa shale and Cheyenne sandstone of Cretaceous age and Whitehorse sandstone and Flowerpot shale of Permian age furnish small supplies of water to a few wells in the southern part of the county, but in most places the water from these formations is highly mineralized. In some localities the water is too highly mineralized for ordinary purposes.

Following are detailed descriptions of each formation, giving the lithologic character, thickness, distribution, and the quality and quantity of water that they yield. The formations are discussed in the order in which they were laid down, from the oldest to the youngest.

Permian System

Excellent reviews of early work on the Permian rocks of southern Kansas have been given by Prosser (1897, pp. 75-83) and Knight (1929, pp. 80-98). For many years the redbeds of southern Kansas were assigned by various authors to the Dakota sandstone, Triassic, or Jura-Trias. Hay (1893, p. 101) correlated the redbeds in Kansas with similar rocks in northern Texas and placed them in the Permian. Cragin (1896, pp. 2-5) named and described the redbeds and subdivided them into ten formations. Although a few important changes have been made, his classification serves as a basis for that now in use. The classification followed in this report is that in use by the Kansas Geological Survey (Moore, Frye, and Jewett, 1944, pp. 157, 158) and differs somewhat from other classifications. One of the most comprehensive of recent reports on the Permian redbeds of Kansas is that by Norton (1939).

Permian redbeds are exposed in two small areas along Wiggins and East Kiowa Creeks in the southwestern part of Kiowa County and in a larger area along Medicine Lodge River and its tributaries in the southeastern part of the county (Pl. 1). From the areas of outcrop the redbeds dip beneath younger sediments and are found beneath the surface everywhere in the county. Only part of the Blaine formation, Dog Creek shale, and Whitehorse sandstone are exposed at the surface and it is unlikely that any Permian beds younger than the Whitehorse are present anywhere in the county. The Taloga formation, Day Creek dolomite, and upper part of the Whitehorse sandstone were removed during the time of erosion that followed Permian deposition, and beds down to the Medicine Lodge gypsum member of the Blaine formation were removed in the southeastern corner of the county during later times of erosion.

FLOWERPOT SHALE

General features.—The Flowerpot shale was differentiated as a formation by Cragin (1896, p. 24), who named it from Flowerpot Mound southwest of Medicine Lodge at the divide between East Cedar and West Cedar Creeks in Barber County. It includes all strata from the top of the Cedar Hills sandstone to the base of the lower gypsum bed (Medicine Lodge gypsum member) of the Blaine formation. The outcrop area of the Flowerpot in Kansas is confined to the western half of Barber County and the southeastern part of Comanche County. It is not exposed in Kiowa County but underlies the southeastern part at relatively shallow depths.

At the type locality in Barber County the Flowerpot consists of dark red-brown to reddish-purple shale and many thin and a few thick beds of sandstone (Knight, 1929, p. 69; Norton, 1939, p. 1,792). Gypsum is common in the formation and occurs as a cement in many of the sandstones and in a network of veins in the shale. The gypsum-cemented beds of sandstone occur in most parts of the formation, but are most common near the top. A thin lentil of dolomite occurs near the middle of the formation. The vein material in the Flowerpot probably was deposited by percolating ground water that was heavily charged with calcium sulfate and other minerals. Beds of gypsum, dolomite, and anhydrite (Blaine formation) that overlie the Flowerpot shale probably were the source of the vein material. According to Norton (1939, p. 1,792), the amount of selenite veining commonly varies in the subsurface, and in some places rock salt is found at the horizon of the Flowerpot.

The thickness of the Flowerpot shale in Kiowa County is not known, but it probably is somewhat less than 200 feet. It is reported to be 173 feet thick at Lake City in northwestern Barber County (Knight, 1929, p. 70) and 190 feet thick southwest of Medicine Lodge (Norton, 1939, p. 1,792).

Water supply.—Because of the low permeability of the materials making up the Flowerpot shale and because the water from the formation is so highly mineralized, it is unimportant as a source of ground water. Well 55 is the only well visited in Kiowa County that taps the Flowerpot shale. An analysis of the water from this well is given in Table 5 and is shown graphically in Figure 7. Chemically, the water from well 55 was one of the poorest of those sampled in the county. It contained 4,692 parts per million of dissolved solids, 1,548 parts of sodium and potassium, 1,722 parts of sulfate, 1,210 parts of chloride, and had a hardness of 308 parts.

BLAINE FORMATION

General features.—In his original classification, Cragin (1896, pp. 2-5) called the gypsum-bearing beds between the top of the Flowerpot shale and the base of the Dog Creek shale the Cave Creek gypsums and divided the formation into three members—the Medicine

Lodge gypsum at the bottom separated from the overlying Shimer gypsum by the Jenkins shale. Gould (1902, pp. 42, 47) introduced the name Blaine for this sequence of beds, taking the name from Blaine County, Oklahoma, and the term Blaine is now generally accepted because of wide usage.

The Blaine formation as defined by the Kansas Geological Survey (Moore, Frye, and Jewett, 1944, p. 158) includes four members, which are, in ascending order, the Medicine Lodge gypsum, Nescatunga gypsum, Shimer gypsum, and the Haskew gypsum. All four gypsum members are present in southern Kansas and northern Oklahoma, but in the Medicine Lodge River drainage basin in Barber and Kiowa Counties only the Medicine Lodge member remains. According to Norton (1939, p. 1,798), slumpage in overlying beds is evidence of the wasting away by solution of beds that were at one time present in this area.

Medicine Lodge gypsum member.—The rocks that make up the Medicine Lodge gypsum member of the Blaine formation are the oldest rocks exposed in Kiowa County. Outcrops of this member occur at or near the base of the bluffs that border Medicine Lodge Valley at the eastern edge of the county (Pl. 1). Less than 5 feet of the member is exposed in this area. The gypsum is white on a fresh surface but light gray when weathered, and is massive. Westward the gypsum passes beneath younger sediments and lies several hundred feet below the surface in other parts of Kiowa County. An oil test drilled in the SE cor. SW¼ sec. 25, T. 30 S., R. 17 W., encountered 22 feet of gypsum (Medicine Lodge) between depths of 320 and 342 feet (log 26).

The Medicine Lodge gypsum member is best developed southwest of Sun City in Barber County, where it is mined and used in making Keene's cement. A thin bed of gray to buff granular dolomite occurs at the base of the member throughout most of this area of outcrop in Barber County and is separated from the overlying gypsum by a thin bed of greenish shale (Knight, 1929, p. 71). The gypsum is relatively pure and is white to gray. In the lower part it is coursely crystalline and contains clusters of selenite crystals. The texture of the gypsum is progressively finer and the color lighter from the bottom to the top of the member. The average thickness of the Medicine Lodge in Barber County is 21 to 25 feet. Because of its solubility, numerous caves and solution channels have been developed in the gypsum.

The Medicine Lodge gypsum member does not supply water to any wells in Kiowa County. Water probably could be found in joints and solution openings in the gypsum, but it would be too highly mineralized for ordinary purposes.

DOG CREEK SHALE

The Dog Creek shale was named by Cragin (1896, p. 39) from exposures on Dog Creek south of Lake City, Barber County. Cragin gave the Dog Creek shale the rank of a formation and it has been used in that sense by most geologists. Norton (1939, p. 1801) followed Cragin's definition of the Dog Creek shale, but qualified it by stating that:

In few places in the subsurface, can the Dog Creek shale be distinguished from the beds of the underlying Blaine because of the increase in gypsum content of the Dog Creek. Actually the Blaine-Dog Creek is a single gypsiferous formation both at the surface and underground, in Kansas, either one thickening at the expense of the other depending on the presence or prior removal of anhydrite or gypsum.

In the past the Kansas Geological Survey classified the Dog Creek shale as the uppermost member of the Blaine formation (Moore, 1940, p. 42), but in the most recent classification (Moore, Frye, and Jewett, 1944, p. 158) the Dog Creek shale is given formational rank.

The Dog Creek shale includes the stata from the base of the Whitehorse sandstone to the top of the Medicine Lodge gypsum member of the Blaine formation. In Kiowa County the Dog Creek (see measured section 6, page 120) is composed chiefly of red shale but contains some sandstone and dolomite. The sandstone occurs in thin beds generally less than 2 feet in thickness, is fine-grained, and is light gray or mottled red and light gray. A bed of gray shaly dolomite about 1.5 feet thick occurs in the lower part of the formation. According to Knight (1929) the Dog Creek shale contains several thin beds of impure granular dolomite throughout most of the area of outcrop in Barber County, but in places in the northwestern part of the county the dolomites are absent and at about the same stratigraphic positions thin beds of gypsiferous sandstone occur.

The Dog Creek shale is exposed in narrow bands along the sides of Medicine Lodge Valley in the southeastern corner of Kiowa County, and it is present beneath younger rocks in all other parts of the county. Where exposed the Dog Creek forms gentle slopes that rise above the more resistant ledges of the Medicine Lodge gypsum member of the Blaine. The thickness of the Dog Creek shale in this area probably does not exceed 50 feet. At the type locality on Dog

Creek in Barber County it is 53 feet thick, but in the southern part of Barber County near the Kansas-Oklahoma line it is only 14 feet thick (Norton, 1939, p. 1,799).

Except for the thin beds of sandstone, the materials of the Dog Creek are relatively impermeable and would yield little or no water to wells. No wells are known to obtain water from these rocks in Kiowa County.

WHITEHORSE SANDSTONE

General features.—The uppermost Permian beds in Kiowa County belong to the Whitehorse sandstone. They seem to be conformable on beds of the Dog Creek shale, but this is in doubt. Many geologists conclude that the two are conformable, whereas others working in Oklahoma contend there is evidence suggesting a major unconformity at the horizon. Neither Knight (1929, p. 86) nor Norton (1939, pp. 1,802—1,803) found any evidence of an unconformity at the base of the Whitehorse in the southern Kansas area. In Kiowa County the Whitehorse sandstone is unconformably overlain by the Cheyenne sandstone (Comanchean) or, locally, by the Meade formation (Pleistocene).

The Whitehorse sandstone is exposed along Medicine Lodge Valley in the southeastern part of Kiowa County and in two small areas along Wiggins and East Kiowa Creeks in the southwestern part of the county (Pl. 1). Only the lower part of the sandstone is represented by exposures in the southeastern area. Here the Whitehorse is composed of red poorly bedded fine-grained friable sandstone and siltstone containing only minor amounts of shale. Although red is the dominant color, a light-gray to white zone near the top occurs in some places, and it is especially prominent on the south side of Medicine Lodge Valley about 1.5 miles southeast of Belvidere where the lower bluffs are composed of Whitehorse sandstone. Sandstones of the Whitehorse form relatively steep-sided canyons and massive bluffs. The total thickness of the Whitehorse sandstone in southern Kansas is somewhat less than 300 feet, but only the lower 50 or 60 feet is present in southeastern Kiowa County, and less than 10 feet is exposed in the two small areas in the southwestern part of the county. The outcrop along East Kiowa Creek (Pl. 7B) is composed of red fine-grained silty sandstone and red silty and sandy shale and represents a higher horizon in the Whitehorse sandstone than do the outcrops in the southeastern part of the county.

Water supply.—The Whitehorse sandstone yields small quantities of very hard water to a few wells (74, 81, and 82) in southeastern

Kiowa County. An analysis of a sample of water from well 82 is given in Table 4 and is shown graphically in Figure 7. The water is a hard calcium sulfate water that contained 1,694 parts per million of total solids, 321 parts of calcium, and 1,032 parts of sulfate and had hardness of 1,142 parts.

Cretaceous System

The stratigraphy of the rocks lying beneath the Graneros shale and above the Permian redbeds in Kansas and adjacent areas has been studied by numerous geologists for many years. Although the character of these sediments is fairly well known, their relationship to one another and hence their proper classification has been a matter of controversy. Southeastern Kiowa County is the type area for the lower part (Comanchean series) of these Cretaceous rocks as developed in Kansas, inasmuch as the type localities for 17 group, formation, and member names are located within this area. Only two of the 17 names, however, have come into general use—the Cheyenne sandstone and the Kiowa shale, which together comprise all of the Comanchean series of Kansas. The development of the present classification of the Cretaceous rocks of southern Kansas will be discussed in detail in a report to be published by the State Geological Survey of Kansas.

The Cretaceous rocks of Kiowa County have been subdivided in this report according to the present classification of the State Geological Survey of Kansas.

COMANCHEAN SERIES

Cheyenne Sandstone

Character.—The Cheyenne sandstone was named by Cragin (1889, p. 65) in 1889 from Cheyenne Rock—an indurated mass of this sandstone that forms a prominent ledge on the north side of Medicine Lodge Valley about three-fourths of a mile west of Belvidere (Pl. 8A). A short distance west of Cheyenne Rock is another prominent ledge of sandstone called Osage Rock. According to tradition this locality was the scene of a famous battle between the Cheyenne and Osage Indians.

The Cheyenne sandstone unconformably overlies the eroded surface of the Permian Whitehorse sandstone in this area and is conformably overlain by the Kiowa shale. The upper contact in most places is sharply defined and abrupt, although Moore (in Twenhofel, 1924, fn., p. 21) believes there is evidence, at least locally, of an unconformity.

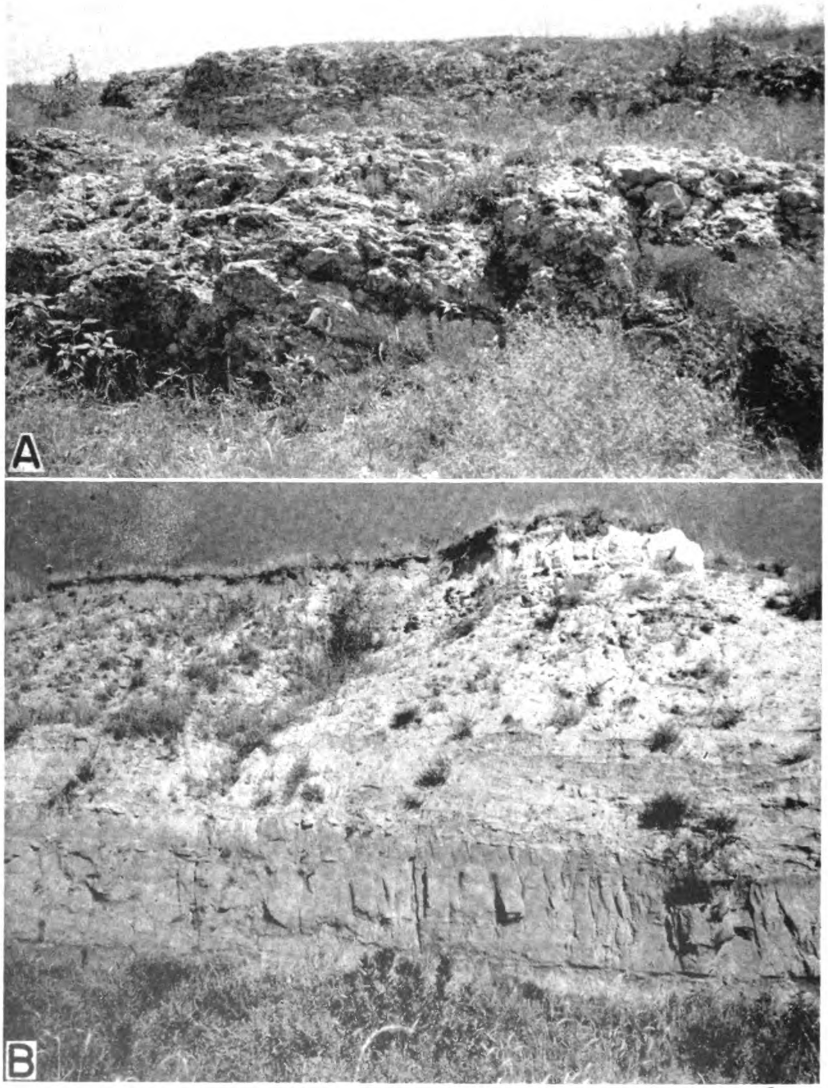

PLATE 7. *A,* "Mortar beds" of the Ogallala formation in the NW¼ SW¼ sec. 25, T. 29 S., R. 18 W. *B,* Redbeds of the Whitehorse sandstone (Permian) unconformably overlain by the Meade formation (Pleistocene); exposure is on the east side of East Kiowa Creek in the SW¼ sec. 31, T. 30 S., R. 19 W. (See measured section 17.)

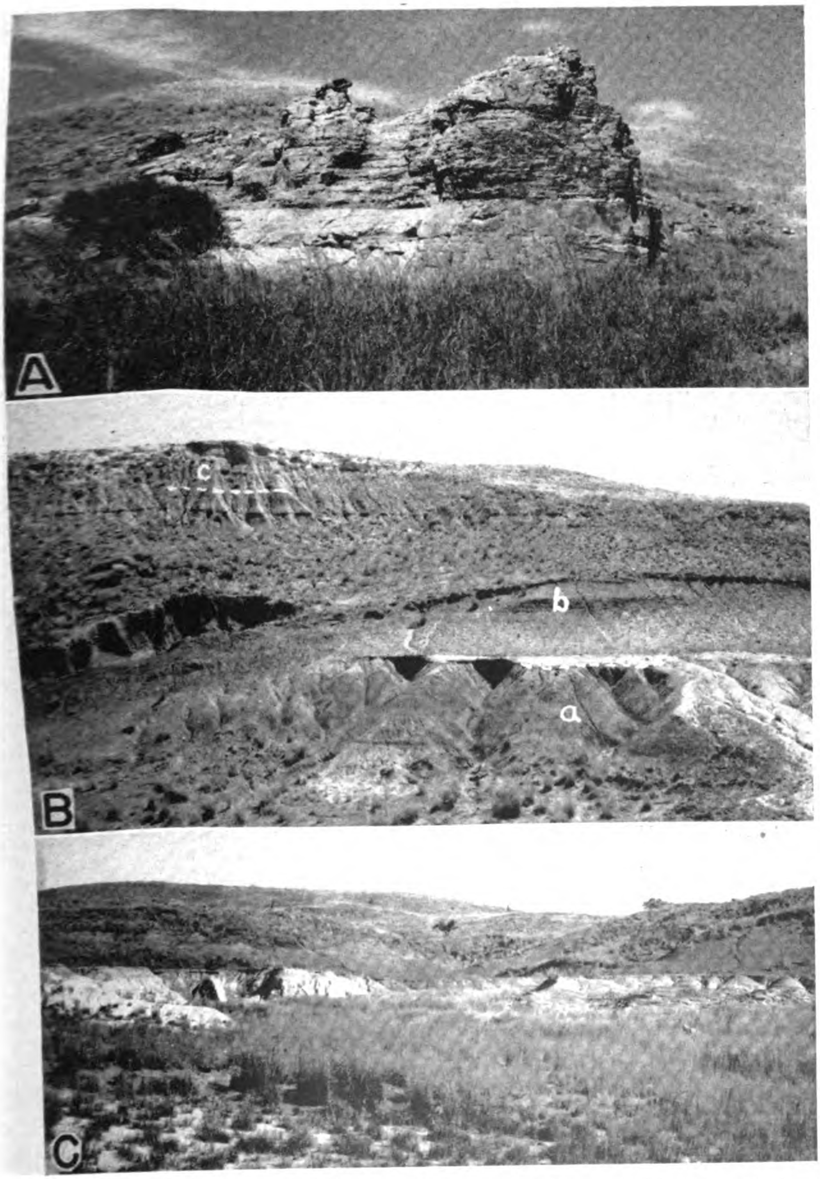

Plate 8. *A*, Prominent ledge of Cheyenne sandstone known as Cheyenne Rock, from which the Cheyenne received its name. Cheyenne-Permian contact is concealed by weeds in foreground. Kiowa shale forms rounded hill in background. North bluff of Medicine Lodge Valley about three-quarters of a mile west of Belvidere. *B*, Exposure of Cheyenne sandstone (a), Kiowa shale (b), and Meade formation (c), in the NE¼ sec. 5, T. 30 S., R. 16 W., about 1¼ miles north of Belvidere. The light colored ledge at the top of the bluff is volcanic ash in the Meade formation. *C*, Cheyenne sandstone and Kiowa shale in Champion draw. The thin bed in the middle of the picture is the shell limestone ("Champion shell-bed") at the base of the Kiowa. Note how the top of the Cheyenne grades laterally from light-colored sandstone (at left) into dark-colored sandy shale (at right).

The Cheyenne sandstone consists chiefly of light-colored fine- to medium-grained friable cross-bedded sandstone and lenses of sandy shale and conglomerate. A zone of pebbles and cobbles occurs locally at the base and minor amounts of clay, selenite crystals, iron nodules, and pyrite occur in different parts of the formation. The bedding is extremely irregular and discontinuous, making it impossible to trace any one bed for more than a short distance (Pls. 8A, 8C, and 9A). Most of the beds are merely small lenses.

Sandstone is the dominant type of rock in the Cheyenne. The most common colors of the sandstone are white, light gray, and tan, but in some places iron staining has produced beautiful shades of yellow, red, purple, and brown along bedding and lamination planes or in irregular splotches. The brightly colored zones are most common in the upper half of the formation. The texture of the sandstone ranges from flourlike material of silt and clay size to fine gravel, but fine- to medium-grained sandstone is most common. The degree of assortment varies from one part of the formation to another and from one locality to another, but in general the material is well sorted. Quartz grains comprise the greater part of the sandstone although minor amounts of other minerals are also present. Pyrite and small pellets or concretions of limonite are locally present in the sandstone. Where present, pyrite is generally found near the top of the formation, and limonite concretions, which are small and of irregular shapes, are more common in the lower part.

The sandstone as a whole is loosely cemented and is therefore easily eroded, but there are hard zones or layers that resist erosion. Cragin (1895, p. 361) and Twenhofel (1924, p. 15) report the occurrence of lenses or zones of quartzite in the Cheyenne sandstone. Differential erosion of the hard and soft layers by rain wash, running water, and wind has produced many fantastic and oddly shaped forms in the sandstone. Buttes, badland areas, steep-walled canyons, box canyons, high steep-sided ledges, overhanging cliffs, "chimney-rocks," "pulpit rocks," and many other forms may be seen in the outcrop area of the Cheyenne sandstone (Pls. 8A, 9A, and 10C), many of which have been given names. Several of the badland areas, such as that shown in Plate 10C, are known as Hell's Half Acre. The most widely known area by this name in Kansas is in the northeastern corner of Comanche County. The name Natural Corral has been applied to a box canyon in the middle of sec. 36, T. 30 S., R. 16 W. Another well-developed but un-

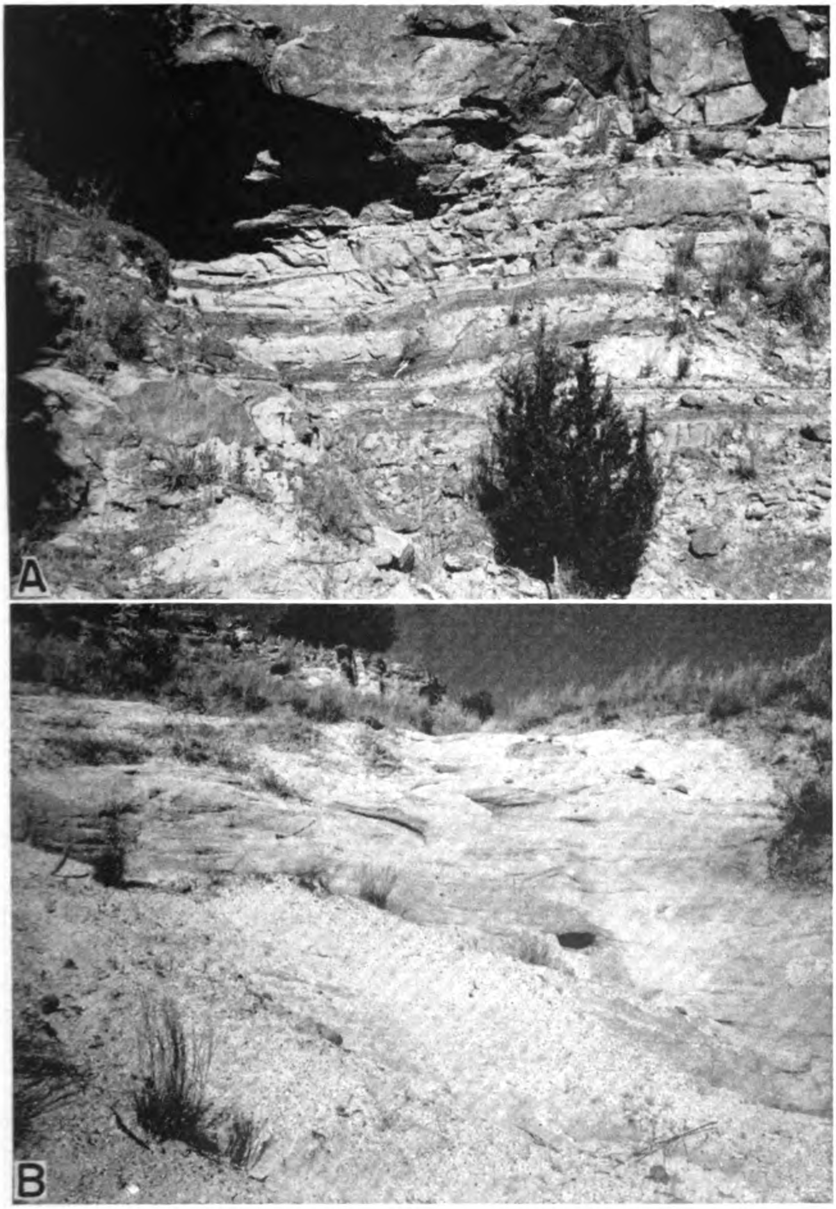

PLATE 9. Exposure of the Cheyenne sandstone in the SW¼ sec. 26, T. 30 S., R. 16 W. *A,* Massive sandstone containing thin lenses of sandy shale (see measured section 8a). *B,* Part of thick lense of conglomerate overlain by massive fine- to medium-grained sandstone (see measured section 8).

named box canyon occurs in the SE¼ sec. 9, T. 30 S., R. 16 W. Both of these box canyons have been used in the past as corrals by putting a fence across the open end. The prominent ledges of sandstone west of Belvidere, to which the names Cheyenne Rock and Osage Rock have been given, have been mentioned.

Lenses of pebble conglomerate were found at or near the base of the Cheyenne sandstone at nearly every exposure examined in Kiowa County (see measured sections 3, 4, 5, 8, 8a, and 11). The conglomerate is poorly cemented and consists of pebbles of red, gray, and clear quartz and weathered white to gray chert in a matrix of fine to coarse quartz sand. The abundance of white chert causes the conglomerate to appear white when viewed from a distance. Most of the chert pebbles are subangular to subrounded, but a few are well rounded; the quartz pebbles are subrounded to well rounded. The pebbles range in size from about 2 mm to about 10 mm in diameter. Most of the lenses of conglomerate range from only a few inches to 1 foot in thickness. The thickest section was found in the SW¼ sec. 26, T. 30 S., R. 16 W., where 45.5 feet of conglomerate was measured at the base of the Cheyenne (Pl. 9B and measured section 8). At this same locality pockets of conglomerate were found immediately below the Permian-Cheyenne contact in what appear to be pot holes in the Permian.

A thin zone of well-rounded pebbles and cobbles occurs locally at the base of the Cheyenne sandstone in Champion draw about one-half mile south of Belvidere. The pebbles are from 1 to 3 inches in diameter, are composed of gray and pink quartzite, quartz, and chert, and are embedded in a matrix of gray to yellow-tan medium sand. Some of the chert pebbles have weathered into soft gray to white granular masses that may be easily broken by hand. A similar zone of pebbles and cobbles occurs in some places at the Permian-Cretaceous contact in central and northern Kansas. Charles C. Williams (personal communication) has observed this zone in western McPherson County where it occurs at the contact between the Permian beds and the Kiowa shale, and Plummer and Romary (1942, p. 320) report its occurrence at the contact between the Permian beds and the Dakota formation in northern Clay County.

Thick lenses of gray to black sandy and silty carbonaceous shale are common in the upper part of the Cheyenne sandstone, and thinner lenses of shale are found near the base. In some places the upper 5 to 16 feet consists almost entirely of shale, which if

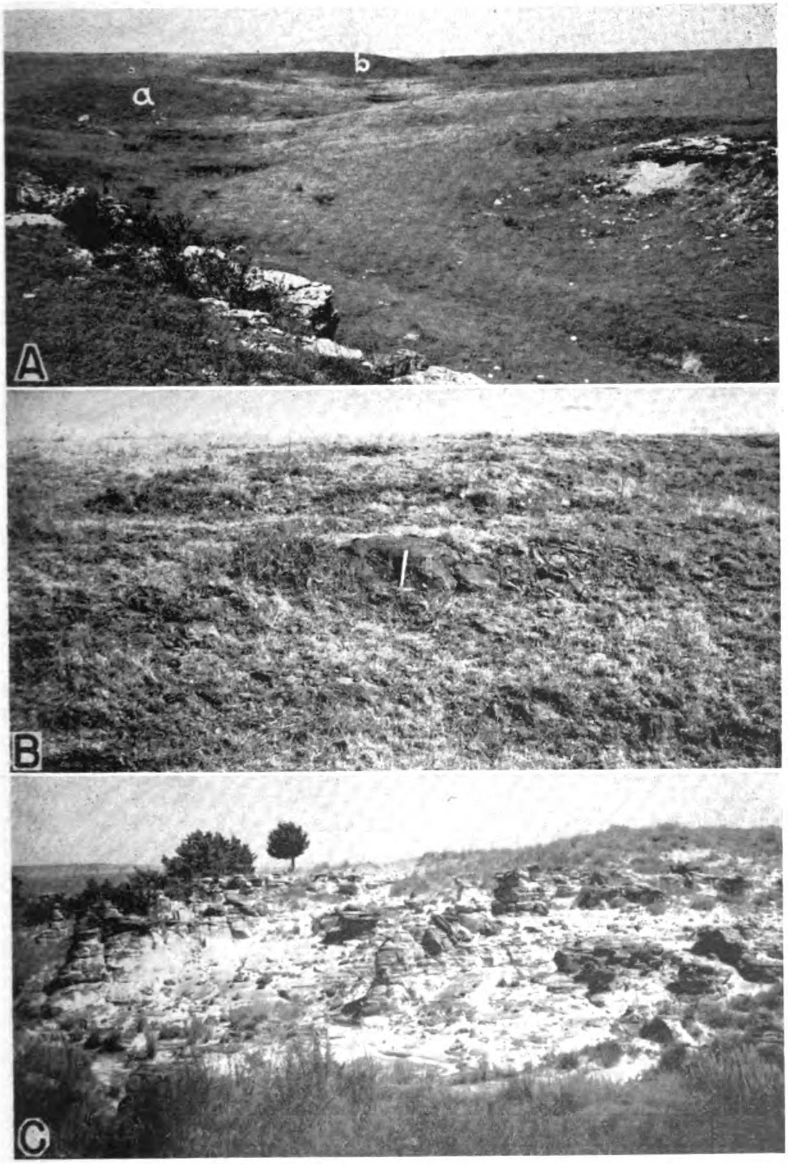

PLATE 10. *A,* The Dakota formation (a, Gould's Kirby clays; b, Cragin's Reeder sandstone) at the head of Spring draw in the SE¼ sec. 4, T. 30 S., R. 18 W; in the foreground are "mortar beds" of the Ogallala formation. *B,* Hard iron-cemented sandstone of the Dakota formation; type locality of Cragin's Reeder sandstone; exposure is at the head of Spring draw opposite "b" in the above photograph. *C,* Small badland area in the SW¼ sec. 22, T. 30 S., R. 16 W., produced by differential erosion of the Cheyenne sandstone.

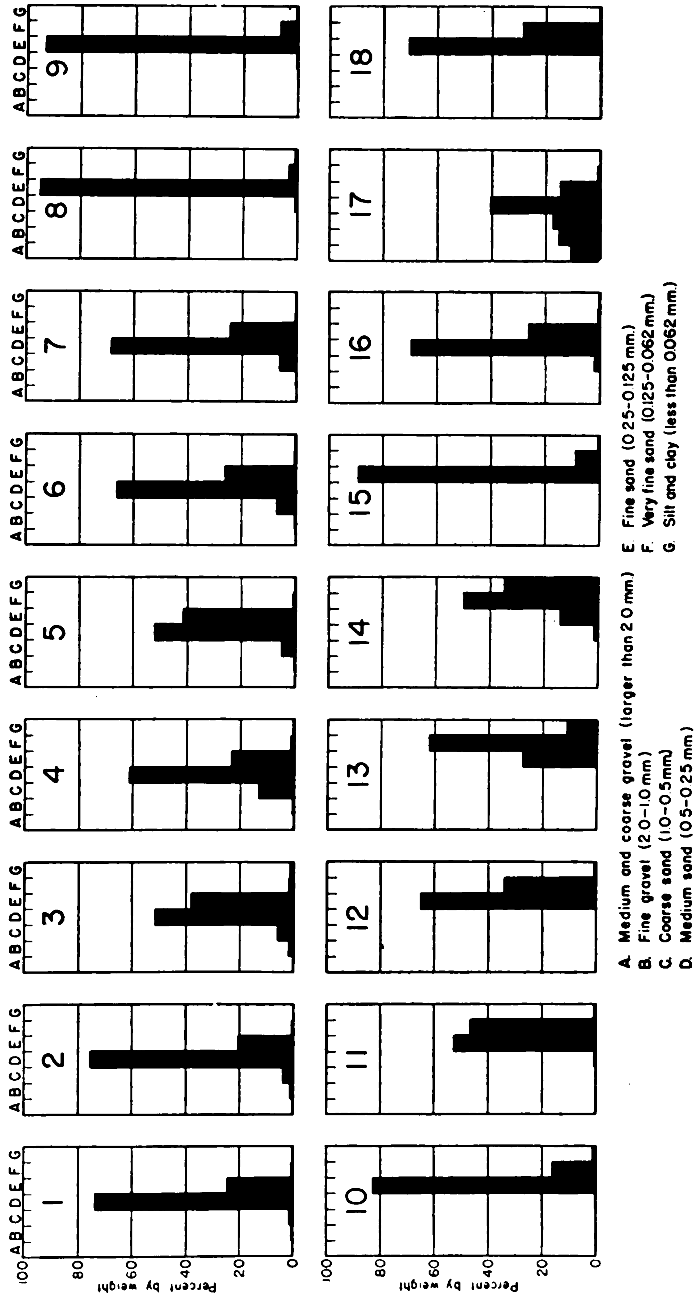

FIG 8. Results of mechanical analyses of 18 samples of Cheyenne sandstone from Kiowa County, Kansas. The source of each sample is given in Table 7.

traced laterally will be found to grade into sandstone (Pl. 8C). Remains of fossil plants, lignite, and selenite crystals are common in the shales in the upper part of the formation.

Clay was found in the Cheyenne sandstone at only one locality in Kiowa County—in the NE¼ sec. 12, T. 30 S., R. 16 W. (measured section 5), where thin beds and lenses of dark-red sandy and silty clay occur in the sandstone about 14 or 15 feet below the top of the formation.

The Cheyenne is identified in well logs by the predominence of sandy beds (logs 1, 6, 15, 16, 18, and 19). The beds of sandstone generally are light gray to white or brown. Interbedded with the sandstone are thinner beds or lenses of gray to black sandy shale. Gypsum, pyrite, and fossil charcoal were found in abundance in the samples from test hole 1 (log 1), but were not found in samples from the other test holes. A 6-foot bed or lens of gray to white conglomerate was encountered in test hole 19 (log 19), and sandy siltstone or very fine-grained sandstone was encountered at the base of the Cheyenne in test holes 1 and 19 (logs 1 and 19).

Mechanical analyses.—The degree of sorting of a sandstone or other granular rock is determined by mechanical analysis, which consists of separating the mineral grains according to size by means of sieves and determining what percent, by weight, each size con-

TABLE 7.—*Source of the samples of Cheyenne sandstone represented by histograms in Figure 8*

Sample No.	Location of section sampled	Position of sample in the formation
1	Draw, SE¼ sec. 9, T. 30 S., R. 16 W.	1 foot above base
2	do	2 feet above base
3	do	3 feet above base
4	do	4 feet above base
5	do	6 feet above base
6	do	7 feet above base
7	do	8 feet above base
8	do	12 feet above base
9	do	19 feet above base
10	do	21 feet above base
11	do	22 feet above base
12	do	24 feet above base
13	do	29 feet above base
14	Champion draw, SW¼ sec. 9, T. 30 S., R. 16 W.	5 feet below top
15	do	13 feet below top
16	do	4 feet above base
17	SW¼ sec. 26, T. 30 S., R. 16 W.	14.5 feet above base
18	do	72 feet above base

stitutes. Mechanical analyses of 18 samples of Cheyenne sandstone from Kiowa County have been made and are shown graphically in Figure 8 as histograms. The source of each sample is given in Table 7. Samples 1 to 14 were collected and analyzed by Ada Swineford and Harold Williams of the State Geological Survey of Kansas in connection with an investigation of the Cheyenne sandstone and associated formations in a part of Russell County, Kansas; samples 15 to 18 were collected by me. Laurence P. Buck made the mechanical analyses of samples 15, 16, and 17 and Swineford and Williams analyzed sample 18. Carefully weighed parts of each sample were put into a set of standard sieves, the sieves were then subjected to vigorous shaking, and the fractions were weighed on a precision balance. The samples analyzed by Swineford and Williams were shaken for 10 minutes in a Rotap shaker and those analyzed by Buck were shaken for 25 minutes in a rotary shaker.

The histograms (Fig. 8) show the degree of sorting and the size of the material of each sample. Most of the samples consisted of well-sorted fine to medium sand. Samples 8, 9, and 10 were very well sorted and consisted almost entirely of fine sand. The largest amount of silt and clay was found in sample 14, which was collected from near the top of the formation. The material making up the conglomerate lenses of the Cheyenne sandstone is very poorly sorted, as shown by the histogram of sample 17. The size of the material in the conglomerate ranged from fine sand to coarse gravel.

Distribution and thickness.—Southern Kansas is the only place in the state where the Cheyenne sandstone is exposed. Here it crops out as an irregular narrow band around the headwaters of Medicine Lodge River, Mule Creek, Bluff Creek, and other streams in Barber, Kiowa, and Comanche Counties. Exposures of sandstone in Clark County are of undetermined age, but may belong to the Cheyenne sandstone. The best exposures are found in Kiowa County where the Cheyenne crops out in irregular bands on both sides of Medicine Lodge Valley in the southeastern part of the county and in a small area on the west side of Wiggins Creek in the SW¼ sec. 36, T. 30 S., R. 20 W., in the southwestern part of the county (Pl. 1). Erosion has removed the Cheyenne in Medicine Lodge Valley and its larger tributary valleys from a point a few miles above Belvidere to the east county line. Results of the test drilling indicate that the Cheyenne is present beneath younger formations in all but the southeastern part of the county (Pl. 5 and logs 1, 6, 15, 16, 18, and

19) and is extensively distributed in the subsurface of central and western Kansas.

There is considerable variation in the thickness of the Cheyenne sandstone owing chiefly to the uneven erosion surface on which the sediments were deposited. The measured thicknesses of the sandstone in southeastern Kiowa County ranged from 32.5 feet in Champion draw (measured section 3) south of Belvidere to more than 94 feet in the SW¼ sec. 26, T. 30 S., R. 16 W. (measured section 8). The top of the formation was not present at the latter section. The thickness of the Cheyenne in the subsurface as determined from test drilling ranged from 17 feet in test hole 18 (log 18) in the southwestern part of the county to 59 feet in test hole 6 (log 6) in the northwestern part of the county. The average thickness of the Cheyenne sandstone in Kiowa County as determined by measured sections and logs of test holes is about 45 feet. The thickness of the Cheyenne is 55 feet in Barber County (Knight, 1929), 60 feet or more in northwestern Morton County (McLaughlin, 1942, p. 75), about 55 to 60 feet in Stanton County (Latta, 1941, p. 71), 33 to 66 feet in Hamilton and Kearny Counties (McLaughlin, 1943, p. 118), and more than 200 feet in Ellis County (Frye and Brazil, 1943, p. 17). It is 5 feet thick in Texas County, Oklahoma (Schoff, 1939, p. 54), less than 35 to 70 feet thick in Cimarron County, Oklahoma (Schoff, 1943, p. 74), and 30 to 45 feet thick at Two Buttes, in southeastern Colorado (Sanders, 1934, p. 865).

Water supply.—The Cheyenne sandstone is permeable enough in most places to supply water for stock and domestic purposes, but the greath depth at which it lies in much of the county and the poor quality of the water it contains have prevented much development of its water supply. In most places in Kiowa County, adequate supplies of water of good quality can be obtained from younger formations above the Cheyenne sandstone. Water in the Cheyenne probably is under artesian pressure nearly everywhere in this area except in and near the areas of outcrop, but nowhere is the head great enough to cause wells to flow (pp. 30-31).

Four of the 101 wells (59, 66, 80, and 100) visited in Kiowa County tap the Cheyenne sandstone, and all are in the south-central and southeastern parts of the county (Pl. 2). Only one (well 66) of the 4 wells was in use at the time of my visit in 1941. The depths of these wells range from 60.8 feet (well 100) to about 275 feet (well 66), and in 1941 the depth to water level in them ranged from about 54 to 142 feet below land surface.

Springs have been reported in the Cheyenne sandstone in this area by Cragin (1895, p. 361) and Gould (1900, p. 16). Springs that formerly existed in the Cheyenne have since dried up (p. 46).

Analyses of the waters from two wells (59 and 66) that tap the Cheyenne sandstone in Kiowa County are shown graphically in Figure 7. The waters from both wells are highly mineralized, having respectively 9,235 and 3,138 parts per million of total dissolved solids, 3,068 and 1,075 parts of sodium and potassium, 1,141 and 277 parts of sulfate, 4,588 and 1,560 parts of chloride, and 1,090 and 330 parts of hardness. Both waters also contained undesirable amounts of iron and fluoride (Table 4). The high mineral content of these waters causes them to have a disagreeable taste. The owner of well 59 reports that the water from his well is unfit for domestic or stock use.

Kiowa shale

The Kiowa shale, as the term is used in this paper, includes the thick series of marine shale, sandstone lenses, and fossiliferous limestones that occur above the Cheyenne sandstone and below the Dakota formation. No members of the formation are recognized, but it includes units formerly called Champion shell bed, Spring Creek clay, Greenleaf sandstone and the lower part of Gould's (1900) Medicine Beds. It is equivalent to Twenhofel's (1924) Belvidere formation. The Kiowa shale was named by Cragin (1894a, p. 49) from exposures in Kiowa County, Kansas.

Character.—The contact between the Kiowa shale and the underlying Cheyenne sandstone is conformable in most placs, but locally it may be unconformable. The Kiowa shale is overlain conformably by the Dakota formation or unconformably by the Meade and Ogallala formations. Although many good exposures of the Kiowa are found in the county, the top and bottom of the formation are nowhere found in the same exposure. The lower part of the formation and its contact with the Cheyenne sandstone are well exposed in the vicinity of Belvidere (measured sections 3, 4, 5, and 10). The upper part and contact with the Dakota formation are exposed in Medicine Lodge Valley and its tributary valleys several miles upstream from Belvidere (measured sections 12 and 15).

The Kiowa shale consists dominantly of thinly laminated dark-gray to black shale in the lower part, grading upward into gray, tan, mottled gray, red, and brown or tan, red and brown clay and clay shale. The shale in the lower part generally is black and has been called a paper-shale because it is so thinly laminated. A conspicuous feature of the formation, especially of the lower part, is the presence of thin beds of shell limestone—a name that has been given to these beds because they consist almost wholly of fossil shells. These limestone beds are from 3 to 18 inches thick, generally are light gray, and locally contain gypsum or pyrite. The matrix consists of shell fragments and sand or of sand and clay. In some places oxidation of the pyrite has caused the rock to disintegrate and the fossils have been largely decomposed. Where this has happened the shell bed is stained with iron giving it a red-brown or rusty color. A shell bed at the base of the Kiowa shale was named the Champion shell bed by Cragin (1895, p. 368), who gave it a rank equivalent in stratigraphic value to the Cheyenne sandstone and Kiowa shale. The term "Champion shell bed," however, has only local value in designating this basal shell bed. It is persistent in parts of the Belvidere area, where it forms a prominent bench above the Cheyenne sandstone (Pl. 8B and 8C) but was not recognized in any of the test holes drilled in other parts of the county. There appears to be no essential difference between the Champion shell bed and other shell beds in the Kiowa, although Cragin believed the fauna of the Champion shell bed was different from that of the rest of the Kiowa shale.

A large lens of cross-bedded yellow-tan to buff fine-grained sandstone occurs in some places at the top of the Kiowa shale on the Greenleaf and Parkin ranches about 10 miles west of Belvidere. The thickness of the sandstone lens in Spring draw in the SE¼ sec. 4, T. 30 S., R. 18 W., is 29 feet (measured section 15). Smaller lenses of yellow-tan angular clay pebbles occur in the sandstone, and a thin bed of iron-cemented sandstone that contains small clay pellets and shark teeth caps the sandstone in the SE¼ sec. 2, T. 30 S., R. 18 W. Gould (1898, p. 174) named this sandstone the Greenleaf sandstone from exposures on the Greenleaf ranch. Inasmuch as the sandstone is merely a lens of limited extent, differentiation of it as a stratigraphic unit is not justified. The same applies to the Spring Creek clay—the term Gould (1898, p. 174) used to describe the clay underlying the Greenleaf sandstone. These units have not been recognized with certainty outside of their type areas. Near the top of a high hill on the south side of Medicine Lodge River in the E½ sec. 16, T. 30 S., R. 17 W., about 5 feet of cross-bedded tan to buff fine-grained sandstone is exposed (measured section 12) at the top of the Kiowa shale; it may be the thinned extension of the sandstone lens exposed on the Greenleaf and Parkin ranches or it may be a part of another lens. Thinner beds or lenses of sandstone occur throughout the Kiowa shale. They are from less than an inch to about 18 inches thick and consist of white or light- to dark-gray fine-grained sandstone. The Champion shell bed in many places is capped by a thin bed of sandstone.

Gypsum, generally in the form of selenite, is common throughout the formation and occurs both in the beds of shell limestone and at many different places in the shale. A layer of fibrous aragonite having a cone-in-cone structure was found capping beds of shell limestone in two (3 and 10) of the sections measured and was found interbedded between gray to tan shale and black shale in one section (12). Small red-brown iron concretions are found in various parts of the Kiowa shale, but are more abundant in the clay and clay shale near the top of the formation (measured section 15). Ironstone, occurring in beds from less than an inch to about 20 inches in thickness, is also common in the upper part of the formation.

Distribution and thickness.—The Kiowa shale is extensively exposed on both sides of Medicine Lodge Valley in the southeastern part of Kiowa County (Pl. 1) and is found beneath younger sediments everywhere in the county except the southwestern part (Pl. 5). Erosion has removed much of the Kiowa shale in the eastern and southern parts of the county and has completely removed it in the southwestern part (Pl. 5). A complete section of the Kiowa is not exposed anywhere in the county, but the thickness of the Kiowa in test hole 6 (log 6) in the NW. cor. sec. 26, T. 27 S., R. 20 W., was 262 feet and in test hole 15 (log 15) in the SE¼ sec. 4, T. 30 S., R. 18 W., it was 293 feet.

The Kiowa shale is exposed over a wide area in central Kansas where the maximum thickness is reported to be 100 to 125 feet (Plummer and Romary, 1942, p. 323).

Water supply.—The Kiowa shale consists predominantly of relatively impermeable shale and clay and in general is a poor water-bearing formation. The large lens of sandstone at the top of the formation supplies moderate amounts of water to well 91 (Pl. 2) and to springs 16, 17, and 18 (Fig. 6) in the northeastern part of T. 30 S., R. 18 W. Well 91 is an unused stock well 154 feet deep in which the water level stands about 107 feet below the land surface.

Springs 16 and 18 issue from the sandstone above its contact with the underlying clay. The estimated discharge of spring 16 is 1 to 2 gallons a minute. Spring 18, which discharges into a large concrete box built against the bluff of sandstone, is reported to yield adequate water for 100 cattle. Spring 17 issues from the sides and bottom of a small steep-walled draw that has been cut in the sandstone. The estimated yield of this spring is about 5 gallons a minute.

Analyses of samples of water from springs 16 and 18 are shown graphically in Figure 7 and are given in Table 5. The waters from springs 16 and 18 are moderately hard calcium bicarbonate waters and are very similar in quality to the waters in the Meade and Ogallala formations.

GULFIAN SERIES

Dakota Formation

Character.—The Dakota formation as herein described includes those Cretaceous beds of continental origin in Kiowa County that lie above the Kiowa shale. It includes all the beds formerly classed as Kirby clay and Reeder sandstone and in addition higher beds found only in the subsurface in this area. The line of division between the Dakota formation and the Kiowa shale is arbitrarily placed at the top of the highest bed of predominantly marine origin. The Dakota formation in Kiowa County is overlain unconformably by silt, sand, and gravel of Tertiary and Quaternary age.

The best exposures are found at the head of Spring draw (Pl. 10A, measured section 15), where about 10 feet of hard dark-brown iron-cemented sandstone containing large nodular concretions (Pl. 10B) is underlain by about 12 feet of tan and brown fine to medium loose sand. Below the sand is red and light-gray silty shale that grades downward into tan clay shale containing small red iron concretions, mottled red and gray clay shale, and light-gray silty shale containing thin beds of yellow-buff fine-grained sandstone. The clay and clay shale is about 20 feet thick and is underlain by sandstone of the Kiowa shale.

In an exposure in the E½ sec. 16, T. 30 S., R. 17 W., at the top of a high hill on the south side of Medicine Lodge Valley, the Dakota consists of 2 feet of hard dark-brown sandstone underlain by 5 feet of tan to gray clay (measured section 12). No plant remains have been found at this locality.

In the subsurface the Dakota formation consists of light-gray to blue-gray, yellow, yellow-tan, and mottled red and gray clay; light-gray to blue-gray shale; and tan to white and dark-brown fine- to coarse-grained sandstone (logs 6, 8, 9, 10, 13, and 15). The clay is commonly silty or sandy, generally contains small pellets or concretions of hematite, and in some places contains thin beds of hard red-brown to dark-brown iron-cemented sandstone. Lenses and thin beds of gray fine-grained sandstone occur locally in the beds of clay and shale. Test hole 6. (log 6) in the northwestern part of the county encountered above the Kiowa shale 78 feet of light-tan to white sandstone which is composed predominantly of fine to coarse angular to subrounded grains of clear quartz and contains numerous small pellets or concretions of hematite. Thin dark-gray shale partings occur near the base of the sandstone. The lower 5 feet in test hole 13 (log 13) consisted of hard dark-brown iron-cemented sandstone containing thin beds of light-gray shale. Test hole 15 (log 15), drilled at the head of Spring draw, encountered the same sequence of Dakota beds as that measured in the draw (measured section 15).

Distribution and thickness.—The Dakota formation is exposed in only two small areas in Klowa County; in the SE¼ sec. 4 and in the SW¼ sec. 3, T. 30 S., R. 18 W. (Pl. 1). As a result of post-Dakota erosion the formation is not present everywhere in this area. Results of the test drilling indicate that the Dakota is present in central and northwestern Kiowa County but is absent in all other parts of the area (Pl. 5).

Mortar beds of the Ogallala formation (Tertiary) are exposed along the sides of Spring draw in the SE¼ sec. 4, T. 30 S., R. 18 W., topographically below the Dakota formation, indicating that during a part or all of Ogallala time the Cretaceous rocks formed a hill around which Ogallala sediments were deposited (Pl. 10A). The form of the hill is shown by the contour map of the pre-Ogallala surface in Figure 10.

The Dakota formation attains a maximum known thickness of 90 feet in the northwestern part of Kiowa county, where it was penetrated by test hole 6 (log 6). From here it thins to a featheredge toward the south, southeast, and east, and it probably thickens toward the northwest, for Waite (1942, p. 144) reported a thickness of 235 feet for the Dakota in the northeastern part of Ford County.

Water supply.—No wells in Kiowa County are known to tap the Dakota formation for water, as adequate supplies of water of good quality generally are obtainable from deposits above the Dakota. Wells 32-34 at Greensburg and wells 42 and 43 at the booster station of the Northern Natural Gas Company were drilled into the Dakota formation merely to deepen the wells so that air-lift pumps could be installed. It is believed that these wells obtain most of their water from the Meade and Ogallala formations but possibly obtain some water from the Dakota formation.

Many of the domestic and stock wells in northeastern Ford County obtain water from the Dakota formation (Waite, 1942, p. 145), and some wells in Edwards County, which adjoins Kiowa County on the north, also obtain water from this formation.

TERTIARY SYSTEM

PLIOCENE SERIES

Ogallala formation

The clay, silt, sand, and gravel below the dune sand and alluvium and above the Cretaceous bedrock in Kiowa County have in the past been referred to the Ogallala formation of Pliocene age. Courtier (1934, pp. 33-38) recognized the presence of Quaternary deposits older than the dune sand and alluvium in this area and placed them in the Sanborn formation. Sufficient evidence is now available to show that a large part of the material formerly assigned to the Ogallala formation is Pleistocene in age and belongs to the Meade formation and Kingsdown silt.

The materials of the Ogallala and Meade formations are lithologically so similar that in some areas it was not possible to differentiate between them (Pl. 1). Certain exposures in the county are known to belong to the Meade formation and other exposures are known to belong to the Ogallala formation, but many other exposures have not been assigned definitely to one formation or the other.

Character.—The Ogallala formation consists chiefly of calcareous silt, sand, and gravel, the proportions of which differ greatly from place to place. The materials are generally poorly sorted, vertical and lateral gradations from one lithologic type to another may take place within short distances, and in general the lenses of silt, sand, and gravel overlap one another irregularly. Some of the beds have been cemented with calcium carbonate, and in places the silt and fine to coarse sand is tightly cemented and forms a hard gray bed resembling old mortar (Pl. 7A).

The finer materials of the Ogallala formation consist of silt and some fine sand containing only very small amounts of clay. The silt and fine sand generally are tan, yellow-tan, brown, or gray, but many of the beds of silt are impregnated with lime and as a result are white to light gray.

Few beds that do not contain some sand are found, and many beds consist predominantly of sand. In general the beds of sand are poorly sorted, the texture ranging from fine- to coarse-grained. The sand beds are light gray, gray, tan, and brown and are composed chiefly of well-rounded to subangular grains of quartz. Silt generally is found intermixed with the sand, and in some beds it is difficult to determine whether silt or sand is most predominant. Minor amounts of gravel also are commonly found in the beds of sand.

Fine to coarse gravel constitutes the coarser materials of the Ogallala formation. The gravel is rarely clean, but generally contains much sand or silt. Gravel found at or near the base of the formation commonly contains abundant pebbles of weathered Cretaceous sandstone, ironstone, chert, and limestone, but the gravel higher up in the formation is composed almost entirely of material derived from igneous and metamorphic rocks, such as granite, quartz, and feldspar.

Caliche or lime carbonate is a common constituent of the Ogallala formation and occurs as cementing material, pipy concretions, nodules, or beds. The caliche is white to gray and generally is fairly soft. The bedded caliche is very irregular in thickness in this area, ranging from a few inches to a few feet. Test hole 6 (see log 6) penetrated a 7-foot bed of silty and sandy caliche—the greatest thickness encountered in this area. No beds of caliche belonging to the Ogallala formation were recognized at the surface in Kiowa County.

The general lithology of the Ogallala formation is indicated by the logs of several test holes given on pages 126-140—especially logs 6, 8, 9, 10, and 13.

Distribution and thickness.—Because of the difficulty of distinguishing the Ogallala formation from the Meade formation, it is possible to give only the approximate areal distribution and thickness of the Ogallala. The only known exposures of the Ogallala formation in this area are found above the Cretaceous rocks along tributaries of Medicine Lodge River in the southeast part of T. 29 S., R. 18 W., in the northeast part of T. 30 S., R. 18 W., and along Middle Kiowa Creek in the central part of T. 30 S., R. 20 W., but there may be other exposures of the Ogallala formation in southern Kiowa County. Most of the upland surface in Kiowa County is underlain by deposits of Pleistocene age, but in test holes the Ogallala formation has been found beneath these younger sediments over much of the central, western, and northwestern parts of the county. It is believed to be absent in the buried lowland areas in the eastern and southwestern parts of the county (Fig. 10). The Ogallala formation at one time probably covered all of Kiowa County and subsequently was removed entirely in parts of the county and partly in other parts by post-Ogallala erosion.

The thickness of the Ogallala ranges from a featheredge to about 65 feet. The formation attains its greatest thickness in the western and northwestern parts of the county where test holes 6, 9, and 10 encountered, respectively, 61, 65, and 64 feet of sediments that have been assigned to the Ogallala.

Water supply.—Because the water-bearing properties of the Ogallala and Meade formations are similar and because it is difficult and in many places impossible to differentiate between the two in the subsurface, the description of their water-bearing properties is combined in the following paragraphs.

The sand and gravel of the Ogallala and Meade formations are the most important sources of ground water in Kiowa County. Most of the domestic and stock wells and all of the irrigation, industrial, and public-supply wells, with the exception of the Atchison, Topeka, and Santa Fe Railway wells (72 and 73) near Belvidere, derive water from these deposits. These formations also supply water to numerous springs in the southeastern and southwestern parts of the county (Table 9 and Fig. 6).

The finer materials of the Ogallala and Meade formations are generally porous and hold much water but are not permeable enough to yield water freely. The beds of sand and gravel, particularly the latter, are very good water bearers and generally yield abundant supplies of water. The yields of wells tapping these deposits range from a few gallons a minute for small domestic and stock wells to several hundred gallons a minute for the larger irrigation, industrial, and public-supply wells. The measured yield of irrigation well 15 was 712 gallons a minute with a drawdown of 17.8 feet. Irrigation well 11 is reported to yield 1,800 gallons a minute, but this figure may be too high.

The Ogallala and Meade formations form a large underground reservoir that is only partly filled with water. A greater thickness of the reservoir was saturated at one time, but streams have cut below the zone of saturation and are draining part of the water from the reservoir. Discharge measurements of the streams in Kiowa County indicate that in this area alone more than 19 million gallons of water a day is being drained out of this underground reservoir through springs and seepage areas (pp. 46-47). The thickness of the saturated material differs greatly, as shown by the diagrammatic section on Plate 5. More than 100 feet of saturated material is present in the northern and eastern parts of Kiowa County, and the greatest thickness of saturated material, about 260 feet, is in the northeastern part of the county. Logs of test holes indicate that a large part of the saturated zone in the Meade and Ogallala formations is composed of sand and gravel; therefore the amount of water available is large, particularly in the eastern part of the county where test holes 1 and 7 (logs 1 and 7) each encountered about 175 feet of saturated sand and gravel.

Analyses of 22 samples of water from the Ogallala and Meade formations were made; 19 of them were collected from wells (Table 4) and 3 from springs (Table 5). Analyses of typical waters from the two formations are shown graphically in Figure 7. All of the waters analyzed were moderately hard to hard calcium bicarbonate waters. Of the 22 samples of water analyzed from the Ogallala and Meade formations, 5 had less than 200 parts per million of dissolved solids, 14 had between 201 and 300 parts, and 3 had between 350 and 406 parts. The hardness of the samples ranged from 86 to 340 parts per million.

The iron content of the water in the Ogallala and Meade formations in general seems to be relatively low. Of the 22 samples, 18 had less than 1 part per million of iron, 3 had from 1.2 to 2.7 parts, and 1 had 4.8 parts. The fluoride content of the samples analyzed was negligible; all of the samples contained 0.6 part per million of fluoride or less.

Quaternary System

PLEISTOCENE SERIES

Meade formation

Character.—The Meade formation consists of interbedded lenses of clay, silt, sand, and gravel that is in part calcareous. The proportion of the different sediments varies from place to place, and gradations from one lithologic type to another generally take place within short distances, both laterally and vertically.

The finer materials of the Meade formation consist of clay and silt. The greatest thickness of clay exposed in this area was found on the side of a hill in the NE¼ sec. 12, T. 30 S., R. 16 W., where about 11 feet of mottled green and brown sandy blocky clay crops out (bed 12, measured section 5). Thin beds and nodules of caliche and some volcanic ash were found in the clay at this locality. Clay was also found exposed on the side of a hill in the NE¼ sec. 5, T.

30 S., R. 16 W. (bed 2, measured section 2), in a road cut in the SE¼ sec. 32, T. 30 S., R. 17 W. (bed 1, measured section 14), and in a draw in the SE¼ sec. 13, T. 30 S., R. 18 W. (bed 1, measured section 16). The clay generally is silty or sandy and is variegated—gray, brown, and green are the dominant colors. The individual beds range in thickness from about 3 feet to 11 feet. Clay was encountered in only one test hole (12), which penetrated 27 feet of tan, gray, and blue-gray silty and sandy clay near the base of the Meade formation. Small invertebrate fossils were found in samples of clay from this test hole (see log 12). Much of the clay in the Meade formation seems to be reworked clay and shale from the Kiowa shale and Dakota formation.

Lenses of silt and sandy silt ranging in thickness from a few inches to about 50 feet were penetrated in test drilling. Silt may be encountered in any part of the Meade formation, but seems to be more abundant in the upper part. The silt is tan, yellow tan, brown, or gray. Many of the lenses are very calcareous and are white to light gray (Pl. 7B).

The sand in the Meade formation generally is poorly sorted and ranges in texture from very fine to coarse grained. Sand rarely occurs in a bed by itself, but generally contains some silt or gravel or both. The dominant colors of the sand are tan, brown, and red brown or, where lime carbonate is present, light gray to white. A thin bed of black sand occurs in the bluff of a creek in the NW¼ sec. 19, T. 30 S., R. 20 W. (measured section 18); the black color is due to staining of the individual grains.

The coarser materials of the Meade formation consist of fine to very coarse gravel in which cobbles up to 3 or 4 inches in diameter are not uncommon. Lenses of clean gravel are uncommon, but lenses of intermixed sand and gravel make up a large part of the formation. The Meade formation at test holes 1, 2, 4, 6, 7, 9, 11, and 18 is composed of about 60 to 90 percent intermixed sand and gravel. Individual lenses of sand and gravel range in thickness from a few feet to more than 100 feet, and thin lenses of silt and sand occur within the thick lenses of sand and gravel. The gravel is composed chiefly of granite, feldspar, and quartz pebbles but includes a few pebbles of sandstone, ironstone, and limestone and some water-worn pebbles of caliche and "mortar bed" that were derived from the Ogallala formation. Cross-bedding in the sand and gravel is extremely common (Pl. 11A). In some places the beds of sand and gravel are loosely to tightly cemented by calcium carbonate. Coarse gravel of the Meade formation is found exposed along the southern boundary of the county, in the southwest corner, and over a wide area between Thompson Creek and the east county line.

Caliche occurs in the Meade formation as nodules, stringers, pipy concretions, or as irregular beds in the clay, silt, sand, and gravel. The color of the caliche is gray to white.

In some places the Meade formation contains beds of volcanic ash, and a lens of white massive volcanic ash forms a ledge at the top of a hill in the NE¼ sec. 5, T. 30 S., R. 16 W. (Pl. 8B and measured section 2). The ash weathers to a gray tan. Volcanic ash also was found in the NE¼ sec. 12, T. 30 S., R. 16 W., where it occurs as thin beds and nodules in clay (bed 12, measured section 5), and may occur elsewhere in Kiowa County. At a locality a few miles south of Kiowa County in sec. 12, T. 31 S., R. 18 W., Comanche County, ash of the Meade formation has been mined commercially. The maximum thickness of the ash here as indicated by core drilling is 22 feet (Hibbard, 1944, p. 743). Several large deposits of ash in Meade County are also mined commercially.

Distribution and thickness.—The Meade formation is present nearly everywhere in Kiowa County except in the southeastern part, where Medicine Lodge River and its tributaries have removed it and exposed Pliocene and Cretaceous rocks. Most of the area indicated as being underlain by the Ogallala and Meade formations undifferentiated on the geologic map (Pl. 1) is believed to be underlain by deposits of the Meade formation, but in other parts of the county the Meade is covered by the Kingsdown silt or by dune sand. The Meade formation probably is thin in the area in south-central and west-central Kiowa County occupied by the buried Cretaceous highland (Fig. 10), and probably is missing entirely in the extreme western part of this area (log 10). All of the material from the base of the Kingsdown silt or the dune sand to the Cretaceous bedrock in the buried lowland areas in the eastern and southwestern parts of the county (Fig. 10 and Pl. 5) probably belongs to the Meade formation.

The thickness of the Meade formation ranges from a featheredge to nearly 300 feet. The thickest deposits in this area occur in the buried lowland area in the eastern part of the county, where test holes 1 and 7 encountered, respectively, 289 and 186 feet of sediments that have been assigned to the Meade. In the buried valley in the southwestern part of Kiowa County the Meade attains a maximum thickness of about 152 feet (test holes 16 and 18).

Water supply.—The water supply of the Meade and Ogallala formations is discussed on pages 93 and 94.

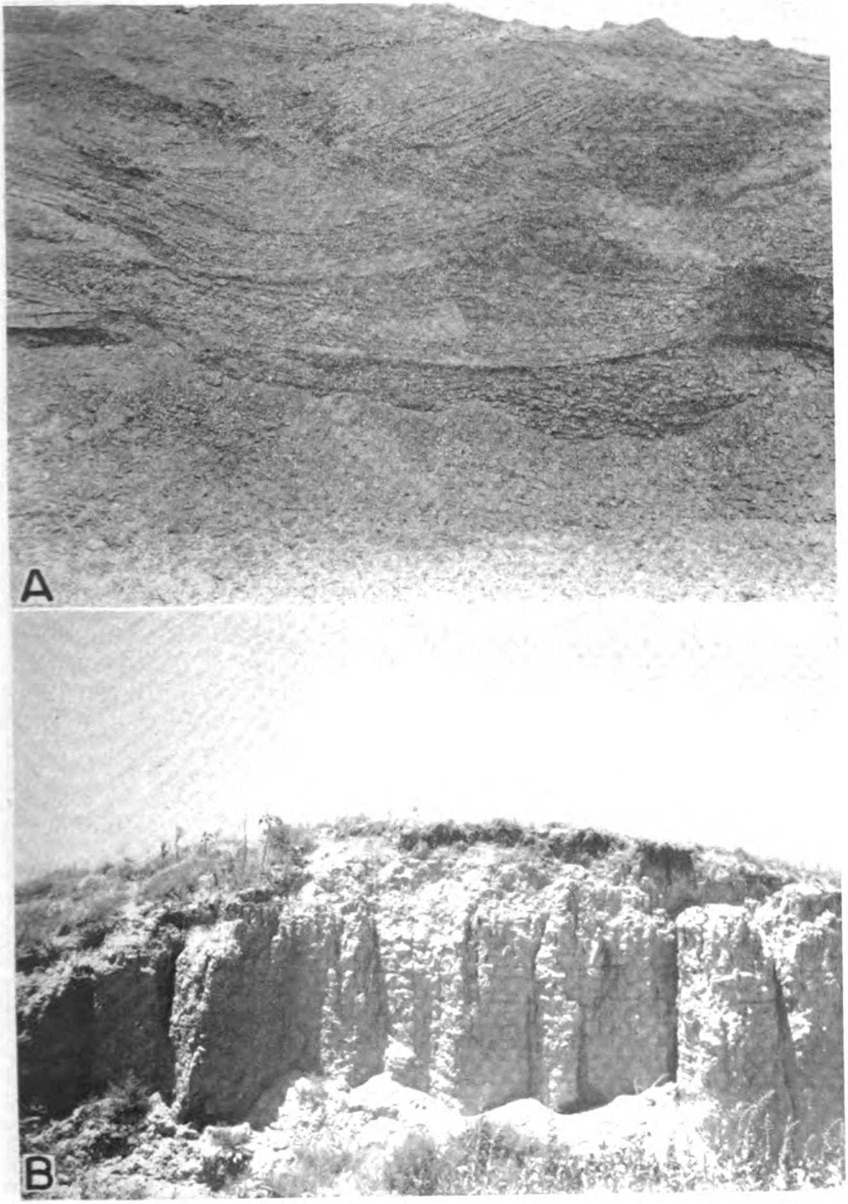

PLATE 11. *A*, Cross-bedded sand and gravel of the Meade formation in gravel pit in the NE¼ sec. 9, T. 29 S., R. 17 W; *B*, outcrop of loess in road cut in the SE¼ sec. 23, T. 29 S., R. 18 W.

PLEISTOCENE AND RECENT SERIES

Kingsdown silt

Character.—Overlying the Meade formation in parts of southwestern Kansas is a series of beds known as Kingsdown silt. In Kiowa County it consists dominantly of silt and sandy silt but also contains minor amounts of clay, fine to coarse sand, and fine gravel. The coarser material is generally found at or near the base of the formation. Stringers, nodules, and thin beds of caliche occur in all parts of the formation, although many beds contain no limy material. Loess or massive silt is common in the upper part of the Kingsdown (Pl. 11B). The Kingsdown silt is dominantly light tan to brown, although some light-gray beds were observed.

The thickest and best exposures of the Kingsdown silt are found at the head of East Kiowa Creek on the Weaver ranch in the southwestern part of Kiowa County. The formation is loosely consolidated and is easily eroded to form rather narrow steep-sided gulches having rounded divides and abrupt edges. Plate 3B shows the typical topographic expression of the Kingsdown silt.

Distribution and thickness.—The Kingsdown silt is the surface formation over the entire upland area and the Mule Creek drainage area in the southern half of Kiowa County (Pl. 1). It probably also underlies the dune sand in places in the northern half of the county.

The thickness of the formation ranges from a featheredge to a known maximum of 91 feet (test hole 17), but is believed to be more than 100 feet in parts of southwestern Kiowa County (Pl. 5). Waite (1942, p. 165) reported a maximum thickness of 123 feet of Kingsdown silt in southern Ford County and stated that it is 90 to 118 feet thick in the southwestern corner of that county.

Water supply.—The Kingsdown silt does not supply water to any wells or springs in Kiowa County. The materials composing the Kingsdown are relatively impermeable and would yield little or no water; moreover, the formation is believed to be above the water table everywhere in the county.

Terrace deposits

Two terraces occur along Medicine Lodge Valley in southern Kiowa County. They have been mapped with the alluvium on the geologic map (Pl. 1). The lower terrace is 3 to 5 feet above the level of the flood plain and the upper and more prominent terrace is 10 to 15 feet above the flood plain (Pl. 6B). Remnants of the two terraces are found on both sides of the valley but are more prominently displayed on the south side. The materials comprising the terrace deposits were derived from local sources and consist mainly of sandy silt and minor amounts of sand and gravel. Gray and tan brown are the dominent colors, but red or red-tan beds are common below Belvidere where a part of the material was derived from red Permian sediments. The gravel ranges from fine to very coarse in texture and is composed of pebbles and cobbles of reworked Pleistocene, Pliocene, Cretaceous, and Permian rocks.

The terrace deposits along Medicine Lodge Valley in Kiowa County may be equivalent in part to the Gerlane formation of Barber County which Knight (1934, p. 91) named and described from exposures near the town of Gerlane in southeastern Barber County. The deposit, Knight says (p. 91):

> . . . is of alluvial origin, the material having been derived from the Permian and the Tertiary formations in the area. The Gerlane occurs both as valley filling and as surface wash. The former type is best developed in the larger valleys, giving them smooth broad floors. Where partly removed by erosion, the Gerlane forms terraces along the sides of the valleys. The surface-wash phase of the formation covers much of the inter-valley areas of the lower slopes.

The slopes of some of the larger valleys in southeastern Kiowa County are underlain by a variable thickness of reworked and redeposited Permian sediments that probably also are equivalent to the Gerlane formation. Such deposits are generally thin and nonpersistent in this area; therefore, they have not been shown on the geologic map.

No wells are known to obtain water from the terrace deposits along Medicine Lodge Valley, and it is unlikely that these deposits would yield water to wells for they probably are everywhere above the water table.

Terrace gravel of late Pleistocene age is known to occur at the surface and beneath dune sand along Arkansas Valley west of Kiowa County (Waite, 1942, p. 168; Latta, 1944, pp. 177-180; McLaughlin, 1943, p. 141). Part of the gravel found beneath the dune sand in the northern part of Kiowa County probably is equivalent to the terrace gravel farther west, but as it is not exposed and because of its similarity to gravel of the Meade formation it was not possible to separate the terrace gravel from the Meade formation.

Dune sand

Dune sand of Quaternary age covers approximately the northern third of Kiowa County, and in the eastern part of the county a relatively narrow area of dune sand extends southward to within about 5 miles of Belvidere (Pl. 1). The dune sand is composed predominantly of fine- to medium-grained quartz sand and contains minor amounts of clay, silt, and coarse sand. The sand has been accumulated by the wind to form low mounds and small hills, some of which are 60 feet or more high (Pl. 3A).

No wells obtain water from the dune sand in Kiowa County for it is everywhere above the water table, but, owing to the looseness and relatively high permeability of the sand, it serves as an important catchment area for ground-water recharge from local rainfall.

Alluvium

Recent alluvium occurs in most of the stream valleys in Kiowa County (Pl. 1). The alluvium in all of the valleys except Medicine Lodge is thin and occurs only as very narrow bands along the present channels; therefore it is not shown on the geologic map.

The alluvium consists of stream-laid deposits that range in texture from clay and silt to sand and very coarse gravel. The upper few feet of alluvium in Medicine Lodge Valley consists of silt and fine to coarse sand that were deposited over the flood plains in time of flood or under normal conditions in the channel of the stream. Coarse sand and gravel, which occurs beneath the finer surficial deposits, is poorly sorted and is composed of pebbles of igneous rocks, sandstone, shale, and mortar bed and fragments of shells from the Cretaceous rocks. The material was derived locally from Pleistocene, Pliocene, Cretaceous, and Permian formations. The thickness of the alluvium in Medicine Lodge Valley is not known with certainty but is believed to range from a few feet to about 40 feet.

The alluvium in the tributary valleys of Medicine Lodge River probably is similar to the alluvium in Medicine Lodge Valley, but in general it is much thinner. The alluvium in Rattlesnake Creek, Mule Creek, and Sand Creek Valleys and in valleys tributary to them was derived chiefly from Pleistocene and Pliocene formations and therefore consists dominantly of granitic material.

Records of five wells (75, 76, 77, 79, and 88) that obtain water from the alluvium of Medicine Lodge Valley were obtained. They are small drilled or driven wells and range in depth from 8 to 30 feet. The water level in them ranges from about 5 to 20 feet below the surface.

The analyses of three samples of water collected from wells (75, 76, and 88) tapping the alluvium in Medicine Lodge Valley indicate that the water in the alluvium generally is hard. The samples from two of the wells (75 and 88) were hard calcium bicarbonate waters containing, respectively, 545 and 432 parts per million of total solids and 330 and 316 parts of hardness. The fluoride and iron content of these two samples was relatively low. The sample from well 76 was a very hard calcium sulfate water that contained 2,400 parts per million of total solids and had a hardness of 1,782 parts. The sample contained one part per million of iron and 1.2 parts per million of fluoride.

Records on one well (99) that obtains water from the alluvium in a tributary valley of Sand Creek and two wells (72 and 73) that tap the alluvium in Soldier Creek valley (Pl. 2) were also obtained. Well 99 is a driven domestic well 22 feet deep in which the water level stands about 10 feet below the surface. Wells 72 and 73 are 13 and 12 feet deep, respectively, and the water level in them stands about 4 feet below the surface. Well 72 was not in use in 1941. Well 73 is owned by the Atchison, Topeka and Santa Fe Railway and is used to supply water for filling locomotive boilers at Belvidere. It has a reported yield of 180 gallons a minute. The water is treated for use in boilers.

GEOLOGIC HISTORY

Paleozoic Era

Paleozoic rocks older than the Permian are not exposed in Kiowa County; therefore, comparatively little is known of the events during the early Paleozoic. A few test wells drilled in search for oil have penetrated thick deposits of Pennsylvanian, Ordovician, and Cambrian marine limestones and shales below the Permian, indicating that the area was covered by seas during much of the Paleozoic era. No rocks of Silurian and Devonian age are known to have been encountered in the oil test wells drilled in Kiowa County. This fact indicates either that this was a land area during the Silurian and Devonian periods or that any sediments that may have been deposited were later removed by erosion, possibly during early Mississippian time. Marine conditions during early Permian time were followed by an interval of alternating marine and continental deposition, but near the end of Permian time continental deposition became predominant, forming the redbeds that are now exposed in southern Kiowa County. The presence of salt and gypsum (Medicine Lodge gypsum member of the Blaine formation) in beds of Late Permian age indicates that the climate was somewhat more arid than it is at the present. The deposition of these evaporites probably took place in shallow basins of inland seas. According to Norton (1939, p. 1809) the red silts of the Whitehorse sandstone represent desert sediments.

Mesozoic era

TRIASSIC AND JURASSIC PERIODS

A general uplift of the Paleozic rocks of this region terminated Paleozoic deposition, and the streams that had been depositing began to erode the Permian surface. Erosion probably continued throughout all of Triassic and Jurassic time, for sediments of these periods are not known to occur in Kiowa County.

CRETACEOUS PERIOD

The Permian surface at the time Cretaceous sedimentation began was one of little relief (Pl. 5). During the Comanchean epoch of the Cretaceous period the sea once more invaded this area, and clastic sediments composed chiefly of sand, but containing minor amounts of finer material, were deposited on or near the shore line of this advancing sea. These sediments make up the Cheyenne sandstone—a dominantly continental deposit. As the Comanchean sea advanced northward all of the Kiowa County area was inundated, and the marine sediments composing the Kiowa shale were deposited.

A general withdrawal of the sea marked the end of Early Cretaceous time. Interbedded marine and continental beds indicate that the retreat of the sea was not continuous but was marked by minor readvances. After the retreat of the Early Cretaceous sea, continental deposits of clay and sand (Dakota formation) accumulated in stream channels, on floodplains, beaches, and in lagoons. More detailed descriptions of the origin of the Cheyenne sandstone, Kiowa shale, and Dakota formation are given in the chapter on Geologic formations and their water-bearing properties.

After the deposition of the Dakota formation the sea again invaded western and central Kansas, and great thicknesses of clay and limestone (Graneros shale, Greenhorn limestone, Carlile shale, Niobrara formation, and Pierre shale) accumulated in this Late Cretaceous sea. Although no Cretaceous rocks younger than the Dakota formation are now present in Kiowa County, the Graneros shale and Greenhorn limestone occur in nearby areas to the west and northwest and probably also were deposited in part or all of Kiowa County, but have since been eroded away. At the close of the Cretaceous period great orogenic movements produced the Rocky Mountains and affected at least a part of the Great Plains. During this time, or possibly during early Tertiary time, the Cretaceous and older beds in Kiowa County underwent moderate folding, as shown by contour lines drawn on the top of the Cheyenne sandstone in Figure 9. A broad synclinal trough trends northwest-southeast

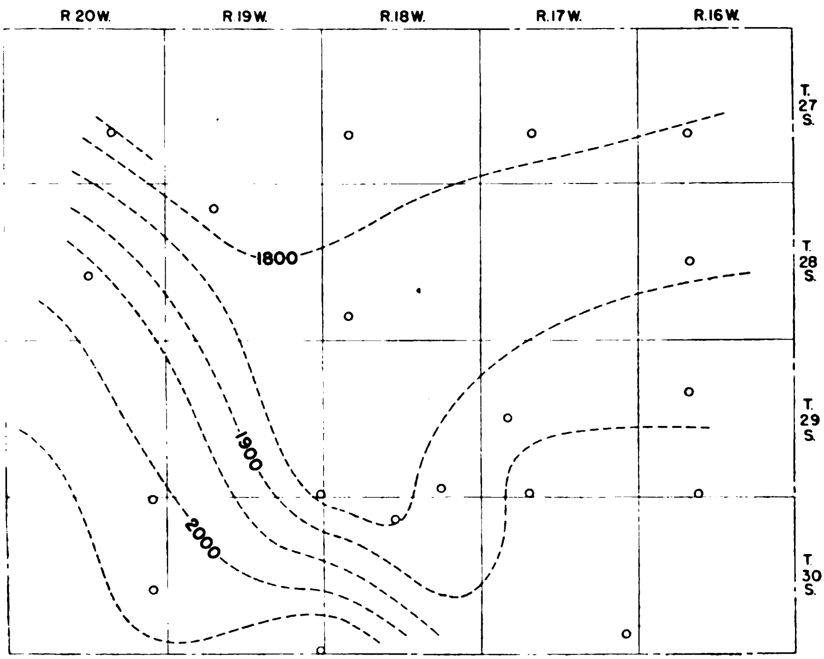

FIG. 9. Structure of Kiowa County shown by contours drawn on top of the Cheyenne sandstone. The location of test holes, oil test well, and a core hole are indicated by circles.

across the central part of the county. The southwest flank of the trough rises steeply at the rate of 25 to 40 feet to the mile; the northeast flank rises very gently and gradually flattens out. A part of the structure shown in Figure 9 may be primary, as the Cheyenne sandstone was laid down on an erosional surface.

Cenozoic Era

TERTIARY PERIOD

During the early part of the Tertiary period extended erosion truncated the Cretaceous sediments. In parts of southern Kiowa County all the Cretaceous strata down to and including some Cheyenne sandstone were removed (Pl. 5); in the central, south-central, and northwestern parts of the county the Dakota formation was deeply eroded; and in other parts of the county the Dakota formation entirely wasted away and the underlying Kiowa shale was deeply eroded. Late in Tertiary time, during the Pliocene epoch, there was a reversal of conditions from stream erosion to stream deposition, and rock debris from the mountains to the west was deposited over this entire area by aggrading and laterally shifting streams. These deposits, consisting of silt, sand, and gravel, make up the Ogallala formation. The surface on which these sediments were laid down was an erosional surface of hills and valleys, as shown in Figure 10.

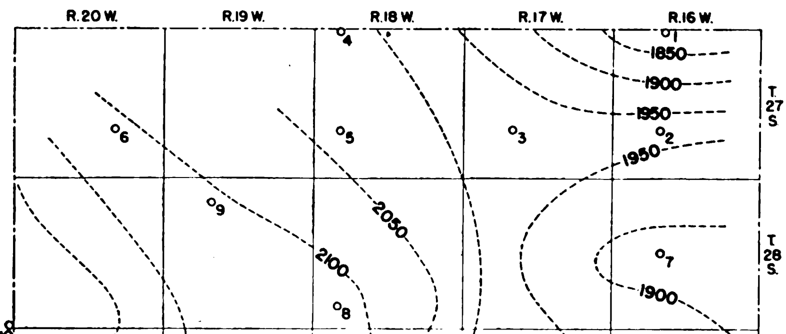

FIG. 10. Configuration of the pre-Ogallala surface in Kiowa County and location of test holes (numbered circles).

Figure 10 indicates that a broad highland existed in the south-central and western parts of the county in Ogallala time, and valley or lowland areas existed in the southwestern and eastern parts of the county. Ogallala sedimentation probably started in the lowland areas and, as it filled these, extended over the highlands.

QUATERNARY PERIOD

Pleistocene epoch.—Erosion in Late Tertiary or early Pleistocene time removed much of the Ogallala formation from Kiowa County, and in the eastern and southwestern parts and in a few other parts of the county the Ogallala was completely removed. After this erosion, there was another long age of deposition by aggrading and laterally shifting streams that produced thick deposits of clay, silt, sand, and gravel (Meade formation) resembling those of the Ogallala formation. These sediments probably were deposited by eastward-flowing streams carrying material from the Rocky Mountains and from the areas of Tertiary rock to the west.

Thick deposits of coarse gravel (Meade formation) in northern and eastern Kiowa County strongly suggest that a major stream, possibly the ancestral Arkansas river, flowed across this area during the Pleistocene epoch. Norton (1939, p. 1,798) suggests that the ancestral Arkansas River followed approximately the present course of Medicine Lodge River. At the present time the Arkansas follows a general easterly course from the state line to eastern Ford County, where it makes an abrupt turn to the northeast to form the "great bend." Lateral shifting, which is a common characteristic of an aggrading stream, and stream piracy probably were responsible for the change in the course of Arkansas River from that of Pleistocene time to the present location. Thick deposits of coarse gravel in the southwestern part of Kiowa County suggest that another major stream crossed that area during Meade time.

Another time of erosion followed deposition of the Meade formation, but it was shorter and less severe than those preceding. During late Pleistocene time stream-laid silt and fine sand comprising most of the Kingsdown silt were deposited over the Meade surface, and these are now widely distributed throughout Kiowa County.

Erosion has dominated the geologic history of this area since the water-laid part of the Kingsdown silt was deposited, but it has not been the only active geologic agent. Cutting of the present valleys probably started in late Pleistocene time. Pleistocene terraces along Medicine Lodge Valley indicate that the major part of that valley was cut and partly filled with sediments before the close of the Pleistocene epoch. Later erosion has removed much of the terrace deposits. The accumulation of wind-blown loess comprising the upper part of the Kingsdown silt probably started in late Pleistocene time and has continued into Recent time. Contemporaneous with or soon after loess deposition, sand dunes were developed in the northern half of Kiowa County. Where the dunes are not protected by a cover of vegetation, the sand is still being shifted and redeposited by strong winds.

Recent epoch.—Much of the present topography of Kiowa County is the result of erosion and deposition that started during the latter part of the Pleistocene epoch and has continued to the present time. Erosion has progressed so far as to lay bare Cretaceous and Permian rocks in southeastern and parts of southwestern Kiowa County. Although downcutting and headward erosion by streams have been the dominant erosional processes, the wasting away of the unconsolidated deposits above the Cretaceous bedrock was accelerated by the sapping action of many strong springs that developed at the base of the unconsolidated deposits along the escarpment when the streams cut below the water table.

In addition to the deposition of loess and dune sand during Recent time, alluvium has also been deposited in all the major streams.

RECORDS OF TYPICAL WELLS AND SPRINGS

Descriptions of the wells and springs visited in Kiowa County are given in Tables 8 and 9, respectively. The wells and springs are listed in order by townships from north to south and by ranges from east to west. Within a township they are listed in the order of the sections. All information classed as "reported" was obtained from the owner, tenant, or driller. Depths of wells not classed as "reported" are measured and given to the nearest tenth of a foot below the measuring point described in the tables, and depths to water level not classed as "reported" are measured and given to the nearest hundredth of a foot.

TABLE 8.—*Records of wells in Kiowa County, Kansas*

...on 2	LOCATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed		Method of lift (5)	Use of water (6)	Measuring point			Depth to water level below measuring point (feet) (7)	Date of measurement	Remarks (Yield of wells given in gallons a minute; drawdown in feet)
							Character of material	Geologic subdivision			Description	Distance above (+) or below (−) land surface (feet)	Height above sea level (feet)			
	T. 26 S., R. 18 W. (S) SW SW sec. 35	V. Cooper	Dr	79	19	GI	Coarse gravel	Meade	T,G	I	Lower edge of pump base, northeast side	0.0	2,175.7	37.96	7- 9-41	Gravel-packed well; reported yield 700-800, drawdown 9.
2	*T. 27 S., R. 16 W.* SE NE sec. 3	J. M. Welch	Dr	47.6	2	GP	Sand and gravel	do	Cy,W	N	Top edge of pump jacket	+3.5	2,092.2	42.77	7-22-41	Unused domestic and stock tubular well.
)	SE NE sec. 6	John MacKay	Dn	38	2	GP	Gravel	do	Cy,W	S	....	....	....	25	....	Tubular well.
1	SE NE sec. 13	A. L. Burns	Dr	43.8	2	GP	Sand and gravel	do	Cy,W	N	Lower edge of opening, north side of pump	+3.0	2,072.3	37.62	7-21-41	Unused domestic and stock tubular well.
	NE NW sec. 18	L. J. Woodard	Dr	45.6	2	GP	do	do	Cy,W	N	Top of 2-inch pipe	+6.2	2,120.1	41.13	7-11-41	Unused stock tubular well.
	NW NE sec. 22	E. J. Miner	Dr	67.0	2	GP	do	do	N	N	Top of 2-inch pipe	+3.8	2,098.2	37.39	7-22-41	Do
	NW NE sec. 32	C. W. Isham	Dr	61.5	2	GP	do	do	Cy,W	N	Top of 2-inch pipe	+2.2	2,111.5	53.66	7-11-41	Do; reported depth, 90 feet.
	T. 27 S., R. 17 W. SW SW sec. 8	R. P. Allison	Dr	30	2	GP	do	do	Cy,W	D	....	....	....	10	....	Tubular well.
	SW SW sec. 9	do	Dr	27	6	GI	do	do	Cy,W	S	....	....	....	20	....	
	SE NE sec. 21	C. Williamson	Dr	90	18	GI	do	do	T,G	I	Lower edge of pump base, north side	+ .5	2,140.3	39.48	7-11-41	Sand to coarse gravel reported between depths of 38 and 92 feet.
	NW NW sec. 34	L. W. Grimes	Dr	87.5	19	S	do	do	T,G	I	Opening in pump base, east side	+ .2	2,132.9	41.23	10-23-40	Reported yield, 1800; observation well.
	T. 27 S., R. 18 W. NE NE sec. 6	J. L. Tucker	Dr	49.5	3	GP	do	do	Cy,W	N	Top of pump jacket	+3.0	2,212.3	47.92	7- 9-41	Unused domestic and stock tubular well.
)	SE cor. SW sec. 8	School district	Dr	43.5	6	GI	do	do	Cy,H	D	Top of casing, south side	+ .8	2,197.5	37.95	7-19-41	School well.

14	SW SE sec. 18	E. E. Miller	Dr	75	16	GI	do.	do.	N	N	Top edge concrete curb, south side	+1.0	2,102.4	26.96	10-23-40	Unused irrigation well; observation well.
15	SW NW sec. 23	A. C. Weaver	Dr	80	48-19	WI	Coarse gravel	do.	T,G	I	Top edge of manhole, west side	+2.0	2,177.0	34.25	10-23-40	Measured yield, 712, draw-down 17.8 (9); coarse gravel containing little clay reported between depths of 33.5 and 80 feet; observation well.
16	T. 27 S., R. 19 W. NW SW sec. 18	J. D. Zimmerman	Dr	48.5	14-4	T,GI	Sand and gravel	do.	Cy,H	D	Top of 4-inch galvanized iron casing	+1.0	2,266.6	46.55	7-19-41	
17	NW NE sec. 29	Wilber Stevens	Dr	52.0	6	GI	do.	do.	Cy,W	S	Top of casing, north side	+ .6	2,252.6	43.56	9-22-41	
(18)	SE SW sec. 30	W. M. Krug	Dr	69.5	6	GI	do.	do.	Cy,W	D,S	Lower edge of hole in pump base	+ .3	2,282.7	66.36	7-19-41	
(19)	T. 27 S., R. 20 W. SE NE sec. 1	H. A. Barnes	Dr, Dn	46	5	GI	Gravel	do.	Cy,W	D				38		
20	SE SE sec. 4	E. B. Corse	Dr	43.0	5	GI	Sand and gravel	do.	Cy,W	S	Top of casing, south side	+ .5	2,280.1	39.57	9-28-41	
21	NW NE sec. 21		Dr	54.5	2	GP	do.	do.	Cy,H	N	Top of pump jacket	+4.5	2,307.2	40.97	7-22-41	Unused domestic tubular well.
22	NE NW sec. 35	T. J. Zimmerman	Dr	54.6	6	GI	do.	do.	Cy,W	N	Top of casing, east side	+ .3	2,280.0	46.04	7-12-41	Unused stock well.
23	T. 28 S., R. 16 W. SE NE sec. 4	H. E. Davis	Dr	120	6	GI	do.	do.	Cy,G,W	D,I	Top of casing, south side	+1.0	2,116.9	76.52	10-23-40	Reported yield, 36; observation well
(24)	SW SW sec. 8	City of Haviland	Dr	160	6	S	do.	do.	T,NG	P				120		Reported yield, 200.
25	do.	do.	Dr	160	6	S	do.	do.	T,G	P				120		Do
26	SE SE sec. 20	E. H. Heath	Dr	131.6	2¼	GP	do.	do.	Cy,W	N	Top of pump jacket	+3.8	2,149.1	105.80	7-21-41	Unused domestic and stock tubular well.
(27)	T. 28 S., R. 17 W. SW SE sec. 8	T. E. Rinkle	Dr	100	2¼	GP	do.	do.	Cy,W	D				95		Tubular well.
28	NE NW sec. 11	Z. D. Griffin	Dr	87.3	2	GP	do.	do.	Cy,H	N	Lower edge of hole, west side of pump	+2.0	2,147.5	72.43	7-11-41	Unused domestic tubular well.
29	NE SW sec. 28	F. M. Shuck	Dr	137.0	2½	GP	do.	do.	Cy,W	N	Top of 2½-inch pipe	+3.5	2,193.8	116.69	9-18-41	Do
30	SW SW sec. 34	Erma Larkin	Du	66.0	48	C	do.	do.	N	N	Top of 10-inch galvanized iron casing	+5.2	2,125.6	63.59	7-21-41	Unused stock well.

TABLE 8.—*Records of wells in Kiowa County, Kansas—Continued*

o. on Pl. 2 (1)	LOCATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic subdivision	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above (+) or below (—) land surface (feet)	Measuring point: Height above sea level (feet)	Depth to water level below measuring point (feet) (7)	Date of measurement	Remarks (Yield of wells given in gallons a minute; drawdown in feet)
	T. 28 S., R. 18 W.															
(31)	SW NE sec. 16	City of Greensburg	Dr	125	18	OW	Gravel	Meade	T,E	P				70		Gravel-packed well; reported yield 500.
32	do	do	Dr	250	12	OW	Sand	Meade and Ogallala	A	P				70		Gravel-packed well; reported yield, 150.
33	do	do	Dr	250	12	OW	do	do	A	P				70		Gravel-packed well; reported yield, 150.
34	do	do	Dr	250	18	OW	do	do	A	P				70		Gravel-packed well; water-bearing sand reported between depths of 70 and 110 feet; reported yield 400, drawdown 5.
35	SW NW sec. 16	J. A. Crowe	Dr	100	6	GI	Sand	Meade	Cy,W	I	Top edge concrete curb, west side	0	2,240.6	84.83	10-23-40	Used to water lawn.
36	NE SW sec. 16	City of Greensburg	Du	109	384	R	do	do	C,E	I	Top edge of concrete platform, south side	—85.0		1.07	10-24-40	Dug in 1887-1888; originally used to supply City of Greensburg; now used to irrigate city park; advertised by city as "World's largest hand-dug well."
37	NE NE sec. 18	Panhandle East. Gas	Dr	131	12	C	Sand and gravel	do	T,E	In				67		Gravel-packed well; reported yield 160, drawdown 2.25; water reported hard.
38	do	do	Dr	131	12	C	do	do	T,E	In				67		Gravel-packed well; water reported hard.
39	NE SW sec. 36	Kesigner and Tucker	Dr	135.5	2	GP	do	do	Cy,N	N	Top cf pump jacket	+3.5	2,231.1	131.13	9-18-41	Unused domestic and stock tubular well.
	T. 28 S., R. 19 W.															
40	NE SE sec. 16	L. W. and H. E. Hill	Dr	87.5	3	GP	Sand	do	Cy,W	N	Top of 3-inch pipe	+7.2	2,273.8	83.65	7-12-41	Unused stock tubular well.

41	SE SE sec. 20	North'n Nat. Gas Co.	Dr	210	6	S	Fine sand	Meade and Ogallala	T,E	D				130		Reported yield 40; also used for fire protection.
42	do.	do.	Dr	350–400	6	S	(?)	do.	A	In						Reported yield 250; water reported hard.
43	do.	do.	Dr	350–400	6	S	(?)	do.	A	In						Do
(44)	SW NW sec. 22	Security Elev. Co.	Dr	107.5	4	OW	Sand and gravel	Meade	Cy,H	D	Top of casing, north side	+1.0	2,287.3	99.60	7-16-41	
45	NW SW sec. 27	Anna Sleif	Dr	117.5	6	GI		Meade and/or Ogallala	Cy,W	S	Top of lower wooden pipe clamp	+1.8	2,294.5	110.99	7-12-41	
46	SE NW sec. 30	C. E. Sherer	Dr	104.5	5	GI		do.	Cy,W	S	Top of casing, west side	+1.0	2,317.3	99.88	7-17-41	
	T. 28 S., R. 20 W.															
47	NW NE sec. 1	C. E. Sherer	Dr	72.8	5	OW	Sand and gravel	Meade	Cy,W	S	Top of casing	+1.0	2,282.9	58.58	7-17-41	
48	SW cor. NE sec. 5	E. Ochs	Dr	49.0	2	GP	do.	do.	Cy,W	N	Top of 2-inch pipe	+2.0	2,316.8	45.44	7-22-41	Unused stock tubular well.
(49)	SE SW sec. 23	J. P. Fellers	Dr	83.8	5	GI	do.	Meade and/or Ogallala	Cy,W	D	Top of tin plate over casing	—4.4	2,322.2	77.70	7-16-41	Situated in Mullinville.
50	NE NW sec. 29	Emma Olson	Dr	75.5	5	GI	do.	do.	Cy,W	N	Top of casing, west side	+1.0	2,341.7	69.04	7-12-41	Unused stock well.
51	*T. 28 S., R. 21 W. (10)* NE NW sec. 12	E. L. Hicks	Dr	36.5	2	GP	do.	Meade	N	N	Top of 2-inch pipe	+3.8	2,328.5	34.89	7-22-41	Unused stock tubular well.
	T. 29 S., R. 16 W.															
52	NW NE sec. 8	E. M. Pyle	Dr	126.0	9	WI	Gravel	do.	N	N	Top of casing, north side	+1.2	2,082.7	68.99	10-19-40	Formerly used to supply water for drilling oil test.
53	SE SE sec. 11	L. E. Fontron	Dr	26.0	6.5	WI	Sand and gravel	do.	Cy,W	N	Top of casing, west side	+1.5	1,994.6	18.63	8- 7-41	Unused stock well.
54	NE NE sec. 16	Morris Pyle	Dr	46.5	5	WI	Gravel	do.	Cy,W	S	Top of casing, north side	+1.7	2,023.1	28.46	9-13-41	
(55)	NW NE sec. 33	Cyrus Miller	Dr	100	?	?	Red sand	Flowerpot	Cy,H	D				80		
	T. 29 S., R. 17 W.															
(56)	NW NE sec. 5	M. C. Smith	Dr	130	6	GI	Sand	Meade	Cy,W	D,S				115		
57	SW cor. sec. 18	C. A. Hubert	Dr	116.0	2	GP	Sand and gravel	do.	Cy,W	N	Top of pump jacket	+2.5	2,202.7	112.47	7-18-41	Unused stock tubular well.
(58)	NW NE sec. 23	R. W. Robbins	Dr	40	6	GI	(?)	?	Cy,W,H	D,S				30		
(59)	SW SW sec. 33	H. R. Barstow	Dr	190.5	5	WI	Sandstone	Cheyenne	Cy,W	N	Top of casing, south side	+ .3	2,092.1	141.94	9-12-41	Unused domestic and stock well; water of very poor quality; sandstone reported between depths of 180 and 191 feet.
(60)	NE SE sec. 34	J. B. Jantz	Du	59.4	48	R	Sand	Meade	Cy,W	D,S	Top edge of concrete platform	+ .3	2,122.8	56.74	7-11-41	

TABLE 8.—*Records of wells in Kiowa County, Kansas—Continued*

No. on Pl. 2 (1)	LOCATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic subdivision	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above (+) or below (—) land surface (feet)	Measuring point: Height above sea level (feet)	Depth to water level below measuring point (feet) (7)	Date of measurement	Remarks (Yield of wells given in gallons a minute; drawdown in feet)
	T. 29 S., R. 18 W.															
(61)	NW NW sec. 7	I. J. Unruh	Dr	181	?	?	Sand and gravel	Ogallala	Cy,W	D,S	....	....	....	160	....	
62	NW NW sec. 16	C. A. Miller	Dr	109.5	2	GP	do	Meade and/or Ogallala	Cy,W	N	Top of 2-inch pipe	+3.3	2,234.4	100.33	7-17-41	Unused domestic and stock tubular well.
63	NE NE sec. 21	Helen Marshall	Dr	72.5	6	GI	do	do	Cy,W	S	Top of casing, south side	0	2,190.2	64.85	7-18-41	
64	NW NE sec. 26	Helen Kruse	Du	24.0	48	N	Sand	do	N	N	Top of wooden platform over well	0	2,092.8	22.10	7-18-41	Unused stock well.
(65)	SE cor. NE sec. 30	J. C. Unruh	Dr	94.5	6	GI	Sand and gravel	do	Cy,W	D	Top edge of pipe coupling	+ .3	2,248.8	75.36	7- 9-41	Water dripped on tape; water-level measurement questionable.
(66)	NW SE sec. 35	H. T. Koehn	Dr	275	?	?	Sandstone	Cheyenne	Cy,W	D,S	Top of tin can over casing	+1.0	2,146.7	94.23	8-19-41	
	T. 29 S., R. 19 W.															
67	SE cor. SW sec. 15	A. D. Huls	Dr	209.5	2	GP	Sand and gravel	Meade and/or Ogallala	Cy,W	N	Top of 2-inch pipe	+6.0	2,345.4	165.80	7-17-41	Unused domestic and stock tubular well.
68	NE cor. NW sec. 25	Frank Newby	Dr	137.5	6	GI	do	do	Cy,W	D,S	Top of opening, north side of pump base	+ .2	2,295.7	116.53	7- 9-41	
	T. 29 S., R. 20 W.															
69	NW SE sec. 11	B. F. Neier	Dr	192.0	5	GI	do	do	Cy,W	D,S	Top of pipe flange	+1.3	2,410.3	186.97	9-23-41	
70	SE SE sec. 20	Delia McLaughlin	Dr	158.0	1.5	GP	do	do	N	N	Top of pipe coupling	+1.0	2,394.7	145.84	10-18-40	Unused stock tubular well.
71	NW NW sec. 25	E. Briggs	Dr	191.0	5.5	GI	do	do	Cy,W	S	Top of casing, southwest side	+1.6	2,400.5	179.30	9-17-41	
	T. 30 S., R. 16 W.															
72	SE SW sec. 2	Santa Fe	Dr	13.0	14	WI	Sand	Recent (alluv'm)	Pl,G	N	Top of concrete curb, east side	+1.1	1,844.8	5.56	9-12-41	Unused railroad well; see well 73.

73	do	do	Dr	12	14	WI	do	do	Pl,G	P,R	....	....	....	4	....	Situated 150 feet west of well 72; reported yield 180; supplies water to Belvidere and railroad; water treated for use in engines.
74	SW SW sec. 2	R. W. Robbins	Dr	92.0	?	?	(?)	Whitehorse	Cy,W	S	Top of wooden pipe clamp	+1.0	1,865.2	48.90	9-10-41	
(75)	NW SW sec. 3	B. Frank McQuay	Dn	18	2	GP	Sand and gravel	Recent (alluv'm)	P,H	D	....	....	....	12-15	....	Well reported to end in "second" sand.
(76)	SW NW sec. 9	Miller cafe	Dr	30	5	GI	Sand	do	Cy,H	A	....	....	....	20	....	Water is too hard for domestic use.
77	NE NW sec. 10	W. M. Thompson	Dn	8	2	GP	Sand	do	P,H	D	....	....	....	5	....	Well reported to end in "first" sand; water reported hard.
78	NE NW sec. 13	R. W. Robbins	Dr	65.5	5.5	GI	(?)	(?)	N	N	Top of casing, west side	+ .3	1,848.4	62.24	9-10-41	Unused stock well.
79	NE NW sec. 14	J. H. Wright	Dr	15.2	5.5	GI	Sand	Recent (alluv'm)	Cy,W	S	Top of casing, west side	+2.5	1,791.3	8.92	9-13-41	Water reported soft.
80	SE SE sec. 16	R. W. Robbins	Dr	105.0	5	GI	....	Cheyenne	Cy,W	N	Top of iron pipe clamp	+1.0	1,957.1	79.71	8- 9-41	Unused stock well.
81	SW SW sec. 22	do	Dr	83.5	5	GI	Sandstone	Whitehorse	Cy,W	S	Top of plank over casing	+ .7	1,915.4	75.35	9- 5-41	
(82)	NE SW sec. 23	do	Dr	55	6	GI	Fine red sand	do	Cy,W	D	....	....	....	45	....	
83	SE SW sec. 35	do	Dr	102.5	5	GI	....	....	Cy,W	N	Top of casing, east side	+1.3	1,934.4	64.85	9- 5-41	Unused stock well; windmill dismantled.
	T. 30 S., R. 17 W.															
(84)	SW NW sec. 20	Henry Booth	Dr	36	4	GI	Sand	Meade	Cy,W	D,S	....	....	....	13	....	
85	SE SW sec. 31	A. Sealey	Dr	93.0	4	GI	Sand and gravel	do	Cy,W	S	Top of casing, west side	+ .4	2,137.5	76.65	7-15-41	
(86)	SE SW sec. 34	Harvey Walters	Dr	96.0	5	GI	do	do	Cy,W	S	Top of casing, north side	+ .5	2,142.3	71.89	8-20-41	
	T. 30 S., R. 18 W.															
(87)	NW SW sec. 1	Carl Green	Dr	24	6	WI	Sand	do	Cy,W	D,S	Top of casing	+1.0	2,085.4	18.10	7-18-41	
(88)	NW NW sec. 3	John Parkins	Dr	18	5	GI	Coarse gravel	Recent (alluv'm)	Cy,W	D	....	....	....	14	....	
89	NE SW sec. 4	S. D. Reager	Dr	86.8	4.5	OW	(?)	Ogallala or Dakota (?)	Cy,W	N	Top of casing	+1.3	2,210.0	68.54	7-18-41	Unused stock well.
(90)	NW NW sec. 20	W. R. Cobb	Dr	59.3	5	GI	Sand and gravel	Meade	Cy,W	D,S	Lower edge of opening, west side of pump	+1.9	2,162.4	20.64	7-15-41	
91	SW NW sec. 23	J. E. Ely	Dr	154.0	6	GI	(?)	Kiowa	N	N	Top of casing, south side	+ .5	2,205.5	107.27	10-24-40	Unused stock well; observation well.
92	SW SE sec. 33	W. R. Cobb	Dr	68.5	5	GI	Sand and gravel	Meade	Cy,W	D,S	Lower edge of pump base	+ .3	2,123.6	36.27	7-15-41	

TABLE 8.—*Records of wells in Kiowa County, Kansas*—*Concluded*

). on 1.2 (1)	LOCATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic subdivision	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above (+) or below (—) land surface (feet)	Measuring point: Height above sea level (feet)	Depth to water level below measuring point (feet) (7)	Date of measurement	Remarks (Yield of wells given in gallons a minute; drawdown in feet)
	T. 30 S., R. 19 W.															
93	SE cor. sec. 9	School district	Dr	100.8	4	OW	Sand and gravel	Meade	Cy,W	D	Top of casing, south side	+ .3	2,276.6	95.20	7-15-41	School well.
94	NW NE sec. 12	V. Kane	Dr	43.5	6	GI	do	do	Cy,W	N	Top of northwest bolt hole in pump base	0	2,229.7	40.93	7- 9-41	Unused domestic and stock well.
95	NW NW sec. 28	J. A. McLaughlin	Dr	91.0	5	GI	do	do	Cy,W	D,S	Lower edge of pump base, east side	+ .5	2,200.0	84.67	7-15-41	Reported depth, 100 feet.
96	NE cor. sec. 35	Reeder school dist. 13	Dr	144.5	6	GI	do	do	Cy,W	D	Top of casing, east side	+ .3	2,217.1	116.03	7- 9-41	School well.
	T. 30 S., R. 20 W.															
97)	NE NE sec. 2	O. L. Stockwell	Dr	94.5	7	GI	Sand	do	Cy,W	S	Top of casing, south side	0	2,272.5	85.03	8-22-41	
98	NE cor. sec. 23	H. E. Thomas	Dr	40.2	5	GI	do	do	N	N	Top of casing, north side	+ .5	2,170.0	29.69	7-14-41	Unused stock well.
99	NW cor. NE sec. 31	B. E. Ayers	Dn	22	2	GP	do	Recent (alluv'm)	Cy,W	D				10-11		
	T. 31 S., R. 16 W.(11)															
00	NE NW sec. 6		Dr	60.8	5	GI	(?)	Cheyenne (?)	N	N	Top of casing, south side	+ .5	1,999.1	54.61	7-15-41	Unused domestic well.
	T. 31 S., R. 19 W.(1)															
01	NW NE sec. 6	Fred Winkler	Dr	38.8	6	GI	Sand and gravel	Meade	Cy,W	S	Top of casing, south side	+1.0	2,112.4	29.22	7-15-41	

1. Parentheses around well number indicate that analysis of water is given in Table 4.
2. Dn, driven; Dr, drilled; Du, dug.
3. Reported depths given in feet below the land surface; measured depths given in feet and tenths below measuring points. Depths of tubular wells are questionable.
4. C, concrete; GI, galvanized sheet iron; GP, galvanized-iron pipe; N, none; OW, oil-well casing; R, rock; S_1 steel; T, title; WI, wrought iron.
5. Type of pump: A, air lift; C, centrifugal; Cy, cylinder; N, none; P, pitcher pump; Pl, plunger pump; T, turbine.
6. A, air conditioning; D, domestic; I, irrigation; In, industrial; N, not being used; P, public supply; R, railroad; S, stock.
7. Reported depths given in feet; measured depths given in feet and in tenths and hundredths of feet.
8. Located in Edwards County.
9. Pumping test conducted by Woodrow Wilson of the Federal Geological Survey and Melvin Scanlan of the Division of Water Resources, Kansas State Board of Agriculture.
10. Located in Ford County.
11. Located in Comanche County.

TABLE 9.—*Records of typical springs in Kiowa County, Kansas*

No. on Fig. 8 (1)	Location	Owner	Character	Topographic situation	Character of material	Geologic subdivision	Yield (gallons a minute (2)	Date, 1941	Use of water (3)	Altitude of water surface (feet)	Remarks
	T. 29 S., R. 16 W.										
1	NW NW sec. 15	Charles Razeau	Seepage area	Valley bottom	Sand and gravel	Meade	(4)	....	S	....	Ponded by dam.
2	NW SW sec. 15	do.	Seepage spring	Head of draw	do.	do.	(4)	....	S	....	Do
3	SW SW SW sec. 15	do.	do.	Valley side	do.	do.	(4)	....	D	1,968.0	Piped to house.
4	NE SW SW sec. 15	do.	Seepage springs	do.	do.	do.	(4)	....	N	....	Includes 5 separate seepage springs along side of valley.
5	SE SE sec. 18	C. E. Millar	Seepage spring	Head of draw	do.	do.	5e	Sept. 27	N	....	Discharges into draw.
(6)	SE SE sec. 20	do.	do.	Base of valley bluff	Sand	do.	2–3e	Oct 1	N	....	Barrel sunk in ground. Water piped to channel of stream.
7	NW NW sec. 22	Charles Razeau	Seepage area	Head of draw	Sand and gravel	do.	(4)	....	N	....	Discharges into draw.
8	SE NW sec. 22	do.	do.	Valley side	do.	do.	(4)	....	N	....	Water collected by ditch along valley side. Flows into Spring Creek.
9	SW SW sec. 24	C. C. Piester	Seepage spring	do.	do.	do.	2–4e	July 18	S	1,934.9	Barrel sunk in ground. Water piped to stock tank.
(10)	do.	do.	do.	do.	do.	do.	(?)	....	D	1,950.9	Pit dug and cribbed with stone. Windmill pumps water to reservoir on top of bluff.
11	do.	do.	do.	do.	do.	do.	2–3e	July 18	D	....	Barrel sunk in ground. Water piped to house.
12	SW SW sec. 25	do.	do.	Head of draw	do.	do.	4–5e	Aug. 11	S	....	Tile casing set 2 feet in ground.
	T. 29 S., R. 17 W.										
(13)	SE SW sec. 10	H T. Conklin	do.	Base of valley bluff	do.	do.	98m	Nov. 5	N	2,022.1	Discharges from shallow pit.
14	NW NE sec. 21	S. B. Jantz	do.	Valley side	Sand	do.	(?)	....	D,S	2,042.3	Water piped to house.
	T. 30 S., R. 17 W.										
15	NW NW sec. 4	H. R. Barstow	Contact spring	Head of draw	do.	Meade or Ogallala	(?)	....	D,S	2,064.6	At contact of Meade or Ogallala formations and Kiowa shale.

TABLE 9.—*Records of typical springs in Kiowa County, Kansas*—*Concluded*

No. on Fig. 8 (1)	LOCATION	Owner	Character	Topographic situation	Character of material	Geologic subdivision	Yield (gallons a minute (2)	Date, 1941	Use of water (3)	Altitude of water surface (feet)	Remarks
	T. 30 S., R. 18 W.										
(16)	SW SE sec. 2	Perry Fincham et al.	do	Base of bluff	Sandstone	Kiowa	1-2e	July 29	S	2,054.9	Sandstone is underlain by impermeable clay.
17	NW NE sec. 10	John Parkins	do	Bottom of draw	do	do	5e	do	N	....	Do
(18)	NW SW sec. 11	J. W. Greenleaf	do	Base of bluff	do	do	(?)	....	S	....	Discharges into large concrete tank; reported to yield enough to water 100 cattle.
19	NW NW sec. 13	do	do	Side of draw	Sand (?)	Meade	130m	Nov. 5	S	2,044.6	Ponded by dam.
20	NW SW sec. 13	do	do	do	do	do	(?)	....	N	....	
	T. 30 S., R. 20 W.										
21	NE SW sec. 15	E. Briggs	Seepage spring	Base of bluff	Sand	do	(?)	....	N	....	

1. Parentheses around number indicate that analysis of water is given in Table 5.
2. E, estimated; M, measured.
3. D, domestic; N, none; S, stock.
4. Aggregate yield of Nos. 1, 2, 3, 4, 7, and 8, as measured by weir by owner in 1940, was 1,580 gallons a minute.

MEASURED STRATIGRAPHIC SECTIONS

The following stratigraphic sections were measured in Kiowa County by me unless otherwise noted. They are listed in order by townships from north to south and by ranges from east to west. Within a township they are listed in the order of the sections. Stratigraphic names that are no longer in use have been placed in parentheses.

1. *Section of Meade formation in draw in the cen. E½ sec. 22, T. 29 S., R. 18 W.*

	Thickness, feet
4. Soil silty, gray	4.0
QUATERNARY—Pleistocene	
Meade formation	
3. Sand, fine, limy, red brown	6.0
2. Sand, fine to coarse, tan and red	3.0
Thickness of Meade formation exposed	9.0
(Unconformity)	
CRETACEOUS—Comanchean	
Kiowa shale	
1. Clay, blocky, gray, yellow, and brown; contains two beds of concretionary ironstone, each about 3 inches thick	8.0

2. *Section of the Meade formation in the NE¼ sec. 5, T. 30 S., R. 16 W., about 1.25 miles north of Belvidere, Kansas.*

	Thickness, feet
Surface covered with gravel and cobbles of igneous rocks; composed chiefly of granite and Cretaceous sandstone and shale	...
QUATERNARY—Pleistocene	
Meade formation	
4. Silt, sandy, tan brown, contains stringers and nodules of caliche	3.0
3. Volcanic ash, massive, lensing, white, weathers gray ton; forms ledge	5.0
2. Clay, silty, structureless; contains sand and gravel. Seems to be reworked Kiowa shale	4.0
Thickness of Meade formation exposed	12.0
(Unconformity)	
CRETACEOUS—Comanchean	
Kiowa shale	
1. Shale, thin-bedded, black	20.0

3. *Section of Kiowa shale and Cheyenne sandstone in east branch of Champion draw about 0.5 mile south of Belvidere, Kansas. (Measured by Bruce F. Latta, John C. Frye, and Claude W. Hibbard.)*

	Thickness, feet
CRETACEOUS—Comanchean	
Kiowa shale	
13. Shale, black; contains few thin beds of sandstone (mostly covered)	43.0
12. Shale, thinly laminated, black	10.0
11. Shell bed, capped by 1-inch layer of aragonite	0.3
10. Shale, thinly laminated, black; contains small red to brown concretions of iron (limonite)	9.9
9. Shell bed; capped by thin bed of tan fine-grained sandstone	0.3
8. Shale, thinly laminated, black	8.4
7. Sandstone, fine-grained, light gray	0.5
6. Shale, thinly laminated, black	1.8
5. Shale, fissile, thinly laminated, black, contains a few thin lenses of fine-grained sandstone	16.7
4. Shell bed (Champion); capped by thin layer of white fiine-grained sandstone	0.8
Thickness of Kiowa shale exposed	91.7
Cheyenne sandstone	
3. Sandstone, fine- to medium-grained, tan, buff, and brown; grades laterally into blue-gray lensing shale containing crystals of selenite and fossil plant material	6.0
2. Sandstone, fine- to medium-grained, cross-bedded, white, gray, tan, buff, and brown; streaked locally with brighter colors such as red, yellow, and purple; contains small lenses of weathered chert conglomerate and lenses and partings of blue-gray shale. A 3- to 4-inch zone of pebbles and cobbles of quartzite, quarts, and chert is at the base	26.5
Thickness of Cheyenne sandstone exposed	32.5
(Unconformity)	
PERMIAN—Guadalupian	
Whitehorse sandstone	
1. Sandstone, silty, red and gray	10.1

4. *Section of Kiowa shale and Cheyenne sandstone in draw in the SE¼ sec. 9, T. 30 S., R. 16 W.*

	Thickness, feet
CRETACEOUS—Comanchean	
Kiowa shale	
13. Shale (covered)	15.0
12. Shell-limestone, hard, gray and brown	0.3
11. Clay shale, blocky, black; contains thin beds of buff to tan fine-grained sandstone	10.8
10. Shell-limestone, hard, gray to brown	0.2
9. Shale, thinly laminated, black; contains irregular yellow and brown streaks	11.0
8. Sandstone, fine-grained, buff to tan	0.1
7. Shale, thinly laminated, black	23.0
6. Sandstone, fine-grained, white	0.2
5. Shell-limestone, weathered, red brown; contains crystals of selenite. Fossils are poorly preserved. (Champion shell bed),	0.8
Thickness of Kiowa shale exposed	61.4
Cheyenne sandstone	
4. Clay shale, lensing, dark gray; contains crystals of selenite...	6.0
3. Sandstone, fine- to medium-grained, cross-bedded, massive, gray, white, tan, buff, red, and purple; contains white conglomeratic zones of pebbles of quartz and chert in lower part,	39.0
2. Shale, fissile, light gray	3.3
Thickness of Cheyenne sandstone exposed	48.3
PERMIAN—Guadalupian	
Whitehorse sandstone	
1. Sandstone, fine-grained and shale, sandy, brick-red	...

5. *Section exposed on side of hill and in draw in the NE¼ sec. 12, T. 30 S., R. 16 W. (Measured by Bruce F. Latta and Perry M. McNally).*

	Thickness, feet
QUATERNARY—Pleistocene	
Top of hill covered with thin mantle of coarse granitic gravel and cobbles	
Meade formation	
12. Clay, sandy, block, mottled green and brown; volcanic ash occurs as thin beds and nodules in clay about 6 feet from bottom of interval and nodules of caliche occur near top	11.4
11. Sand, fine, to gravel, fine, loosely consolidated, yellow brown; contains flakes of gray shale	0.5
Thickness of Meade formation exposed	11.9

CRETACEOUS—Comanchean	
Kiowa shale	
10. Shale, thinly laminated, black; grades upward into soft blue-gray sale containing yellow streaks and splotches	26.3
9. Sandstone, fine-grained, shaly in places, light to dark gray	0.5
8. Shell-limestone, brown. Composed almost entirely of fossil shells (Champion shell bed)	1.6
Thickness of Kiowa shale exposed	28.4
Cheyenne sandstone	
7. Shale, silty, blue gray to black; grades upward into light- to medium-gray silty sale; contains large crystals of selenite	11.2
6. Sandstone, very fine-grained, shaly, light to medium gray; contains veins and lenses of dark-red sandy and silty clay	5.2
5. Sandstone, massive, cross-bedded, fine-to- coarse-grained, gray, yellow, tan, white, and purple. Contains lenses of coarse weathered chert and quartz. Small nodules of iron weather out on surface. White to gray fine-grained sandstone is most prominent	21.6
4. Sandstone, soft, shaly, very fine-grained, light gray to yellow brown; contains yellow streaks and splotches	2.8
Thickness of Cheyenne sandstone exposed	40.8
PERMIAN—Guadalupian	
Whitehorse sandstone	
3. Siltstone, red brown; weathers to small shaly blocks or flakes	0.5
2. Silt, sandy, very fine, light gray	1.5
1. Siltstone, sandy, and sandstone, very fine; brick red	15.0
Thickness of Whitehorse sandstone exposed	17.0

6. *Section of Dog Creek shale in road cut in the NW¼ sec. 13, T. 30 S. R. 16 W.*

	Thickness, feet
PERMIAN—Leonardian	
Dog Creek shale	
11. Clay shale, block, red	6.0
10. Sandstone, fine-grained, massive, mottled red and light gray	1.5
9. Clay shale, blocky, red	10.0
8. Sandstone, fine-grained, massive, mottled red and light gray	2.0
7. Clay shale, blocky, mottled red and gray	1.0
6. Shale, silty, thinly bedded, light blue gray	1.0
5. Clay shale, blocky, red; contains thin beds of light-gray fine-grained sandstone	5.0
4. Dolomite, saly, thinly bedded, gray	1.5
3. Clay shale, blocky, red	3.0
2. Covered, probably red clay shale	10.0
Thickness of Dog Creek shale exposed	41.0
Blaine formation—Medicine Lodge gypsum member	
1. Gypsum, massive, white	4.0

7. *Section of Pleistocene and Permian rocks in the SW¼ sec., 14, T. 30 S., R. 16 W.*

	Thickness, feet
QUATERNARY—Pleistocene	
Terrace deposits (Gerlane(?) formation)	
4. Silt, sandy, tan, brown, and gray, and gravel, very coarse; contains pebbles of granite, sandstone, and shell fragments. Fossil deer tooth (Pleistocene) found 3 feet below top of interval....	9.0
3. Silt and sand, red; contains blocks of Permian sandstone and gravel and red shale....	5.0
PERMIAN—Leonardian	
Dog Creek shale	
2. Siltstone, sandy, red....	3.0
Blaine formation—Medicine Lodge gypsum member	
1. Gypsum, massive, white....	3.0

8. *Section of Cheyenne sandstone in the SW¼ sec. 26, T. 30 S., R. 16 W. (Measured by Bruce F. Latta and Claude W. Hibbard.)*

	Thickness, feet
CRETACEOUS—Comanchean	
Cheyenne sandstone	
4. Sandstone, fine to medium-grained, cross-bedded, white, tan, buff, and brown; contains a few lenses of weathered chert gravel in lower part....	48.5
3. Conglomerate, cross-bedded, white to gray. Consists of loosely cemented fine to coarse sand containing pebbles of white to gray weathered chert and quartz. Coarser in upper part....	45.5
Thickness of Cheyenne sandstone exposed....	94.0
(Unconformity)	
PERMIAN—Guadalupian	
Whitehorse sandstone	
2. Siltstone, sandy, red; contains pockets of white to gray weathered chert and quartz conglomerate....	3.5
1. Siltstone, sandy, red....	20.0
Thickness of Whitehorse sandstone exposed....	23.5

8a. *Section of Cheyenne sandstone in the SW¼ sec. 26, T. 30 S., R. 16 W., about 50 yards north of measured section 8. (Measured by Bruce F. Latta and Claude W. Hibbard.)*

	Thickness, feet
CRETACEOUS—Comanchean	
Cheyenne sandstone	
4. Sandstone, fine to medium-grained, cross-bedded, white, gray, buff, tan, and brown....	36.5
3. Sandstone, fine to medium-grained, yellow, buff, tan, and gray, and shale, fissile, black; interlensing. The maximum thickness of the shale lenses is about 2 feet and of the sandstone lenses about 4 feet....	30.0
2. Sandstone (same as bed 4 in section 8)....	8.5
1. Conglomerate (same as bed 3 in section 8)....	6.0
Thickness of Cheyenne sandstone exposed....	81.0

9. *Section of undifferentiated Pleistocene deposits in road cut in the SW¼ sec. 31, T. 30 S., R. 16 W.*

	Thickness, feet
QUATERNARY—Pleistocene (undifferentiated)	
5. Silt, tan and gray, contains nodules of caliche	3.0
4. Sand, fine to medium, lime-cemented, light gray to white	1.0
3. Sand, fine to coarse, brown	2.5
2. Sand, fine blue green	1.0
1. Clay, sandy, blue green and brown; contains few scattered pebbles	5.0
Thickness exposed	12.5

10. *Section of Kiowa shale, and Cheyenne sandstone in draw in the N½ sec. 36, T. 30 S., R., 16 W. (Measured by Bruce F. Latta and Claude W. Hibbard.)*

	Thickness, feet
CRETACEOUS—Comanchean	
Kiowa shale	
14. Shale (covered)	
13. Shell-limestone, gray. Fossils are larger than those found in lower shell-beds. Thin layer of fibrous aragonite occurs above shell-bed	1.1
12. Shale, thinly laminated, black; contains concretions of iron near top of interval	7.8
11. Shell-limestone, brown	0.3
10. Shale, thinly laminated, black	6.2
9. Shell-limestone, hard	0.2
8. Shale, thinly laminated, black	11.2
7. Shell-limestone, weathered. Breaks apart easily	0.2
6. Shale, thinly laminated, black	4.3
5. Sandstone, fine-grained, white, and shale, thinly laminated, black. Forms ledge	1.5
4. Shale, thinly laminated, black	14.6
3. Shell-limestone, gray (Champion shell bed)	0.5
Thickness of Kiowa shale exposed	47.9
Cheyenne sandstone	
2. Clay shale, sandy, gray (Stokes sandstone)	1.5
1. Clay shale, blue gray; contains crystals of selenite. A thin bed of white to gray fine-grained sandstone occurs about 2 feet below top of interval (Lanphier beds)	15.0
Thickness of Cheyenne sandstone exposed	16.5

11. *Section of Cheyenne sandstone in box canyon in the Cen. sec. 36, T. 30 S., R. 16 W. (Measured by Bruce F. Latta and Claude W. Hibbard.)*

	Thickness, feet
CRETACEOUS—Comanchean	
Cheyenne sandstone	
4. Sandstone, fine- to medium-grained, gray to white, contains fossil plants and pyrite. Weathered surface is brown owing to iron staining (Stokes sandstone)	1.5
3. Clay shale, blue gray, sandy at top; contains yellow streaks and splotches (Lanphier beds)	9.5
2. Sandstone, fine-grained, gray to white; contains zones of pebbles of weathered chert in lower part and lenses of gray to black shale. (Corral sandstone)	34.0
1. Clay shale, blue gray to yellow	1.5
Thickness of Cheyenne sandstone exposed	46.5

12. ***Secion of Kiowa shale along the south bluff of Medicine Lodge River in the E½ sec. 16, T. 30 S., R. 17 W. (Measured by Bruce F. Latta, Claude W. Hibbard, and John C. Frye.)***

	Thickness, feet
CRETACEOUS	
Dakota (?) formation (Gulfian)	
16. Sandstone, hard, dark brown	2.0
15. Clay shale, tan to gray	5.0
Kiowa shale (Comanchean)	
14. Sandstone, fine-grained, cross-bedded, tan to buff	5.2
13. Shale (covered)	20.8
12. Shale, fissile, black; contains crystals of selenite	31.2
11. Shale, gray to black; contains thin bed of tan to buff sandstone near top. Mostly covered	15.6
10. Shell-limestone, gray	0.2
9. Shale, blue black to tan; contains beds of thinly laminated sandstone and crystals of selenite	21.2
8. Aragonite (?), fibrous, having cone-in-cone structure	0.2
7. Shale, thinly bedded, gray to tan	2.5
6. Shell-limestone, gray	0.8
5. Shale, fissile, black to dark gray	5.2
4. Shell-limestone, gray	0.4
3. Shale, fissile, black; contains thin beds of gray to tan shale	15.6
2. Shell-limestone, gray	0.9
1. Shale, fissile, black	2.5
Thickness of Kiowa shale exposed	122.3

13. *Section of Mead formation in draw in the SW cor. sec. 19, T. 30 S., R. 17 W.*

	Thickness, feet
4. Soil, silty, dark gray; contains scattered pebbles of igneous rock	2.0
QUATERNARY—Pleistocene	
Meade formation	
3. Caliche, soft, write to gray	.5
2. Silt, clayey, tan and yellow brown	4.0
1. Sand, fine to coarse, granitic; contains some scattered coarse gravel	12.0
Thickness of Meade formation exposed	16.5

14. *Section of the Meade formation in road cut in the SE¼ sec. 32, T. 30 S., R. 17 W.*

	Thickness, feet
3. Soil, silty, gray	1.0
QUATERNARY—Pleistocene	
Meade formation	
2. Sand and gravel, loose, tan and brown; contains pebbles and cobbles of granite, quartz, and feldspar	6.0
1. Clay, sandy, blocky, mottled gray and brown; contains soft caliche	3.0
Thickness of Meade formation exposed	9.0

15. *Section of the Dakota formation and Kiowa shale in Spring draw in the SE¼ sec. 4 and E½ sec. 3, T. 30 S., R. 18 W. (Measured by Bruce F. Latta, John C. Frye, and Claude W. Hibbard.)*

	Thickness, feet
CRETACEOUS	
Dakota formation (Gulfian)	
(Reeder sandstone)	
7. Sandstone, iron-cemented, hard, massive, dark brown	10.0
6. Sand, loose, fine to medium, tan and brown	12.0
(Kirby clay)	
5. Clay, mottled red and gray, and shale, silty, red and light gray; contains thin seams of yellow fine-grained sandstone in lower part. Mottled clay contains small red concretions of iron that have weathered out and cover the slope	20.0
Thickness of Dakota formation exposed	42.0
Kiowa shale (Comanchean)	
(Greenleaf sandstone)	
4. Sandstone, fine-grained, cross-bedded, lensing, yellow tan and buff	29.0
(Spring Creek clay)	
3. Clay shale, silty, mottled gray tan, red, and red brown; contains small concretions and thin beds of ironstone. Weathered slope is strewn with red-brown ironstone rubble	11.0

2. Sandstone, iron-cemented, silty, irregularly bedded, red brown to gray tan. Contains concretions, nodules, and wavy bands of ironstone. Weathers brownish black	1.7
1. Clay shale, silty, massive to thin-bedded, mottled gray, red, and red brown; contains concretions of iron. Grades laterally into blue-gray siltstone and shale which contain beds lenses of light-gray fine-grained sandstone................	17.8
Thickness of Kiowa shale exposed...........................	59.5

16. *Section of the Meade formation in a draw in the SE¼ sec. 13, T. 30 S., R. 18 W.*

QUATERNARY—Pleistocene	Thickness, feet
Meade formation	
7. "Mortar bed," hard, fine-grained, gray. Forms ledge..........	0.3
6. Silt and sand, fine, loose, gray	1.0
5. "Mortar bed," hard, fine-to medium-grained, gray. Forms ledge	0.3
4. Sand, fine, loose, gray to white, and silt; contains volcanic ash (?)	2.0
3. Caliche, silty, medium hard, white	1.0
2. Silt, sandy, red brown	8.0
1. Clay, silty, blocky, mottled gray, green, red, and blue........	10.0
Thickness of Meade formation exposed	22.6

17. *Section of the Meade formation along East Kiowa Creek in the SW¼ sec. 31, T. 30 S., R. 19 W.*

6. Gravel, very coarse; contains pebbles of quartz, feldspar, and granite. Caps upland surface as thin mantle	...
QUATERNARY—Pleistocene	
Meade formation	
5. Silt and sand, fine; lime-cemented, white to light gray.......	5.0
4. Sand, fine to coarse, loose; contains thin lime-cemented zones, lenses and balls of clay (reworked Cretaceous shale), and lenses of coarse gravel composed of pebbles of shale, sandstone, and shells	15.0
3. Clay, gray to yellow gray (reworked Cretaceous shale).......	5.0
2. Sand, fine to coarse, granitic, lime-cemented.................	0.3
Thickness of Meade formation exposed........................	25.3
PERMIAN—Guadalupian	
Whitehorse sandstone	
1. Sandstone, silty, fine-grained, red, and shale, silty and sandy..	6.0

18. *Section of the Meade formation in east bluff of creek in the NW¼ sec. 19, T. 30 S., R. 20 W.*

	Thickness, feet
QUATERNARY—Pleistocene	
Meade formation	
9. Gravel, fine to coarse, tan	8.5
8. Sand, silty, limy; contains nodules of lime and thin lenses of silt	20.0
7. Sand and gravel, poorly sorted, lime-cemented	7.5
6. Sand, coarse, to gravel, coarse, loose, tan to red brown, cross bedded	12.0
5. Silt, clayey, tan	0.5
4. Sand, coarse to gravel, coarse, tan to red brown, cross-bedded,	6.0
3. Sand, fine to medium, silty, limy, tan to light gray	6.0
2. Sand, fine to coarse, cross-bedded, stained black	0.5
1. Silt and sand; tan	3.0
Thickness of Meade formation exposed	64.0

LOGS OF TEST HOLES AND WELLS

On the pages that follow are listed the logs of 25 test holes and wells in Kiowa County and one test hole (10) in Ford County. Logs 1 to 19 are of test holes drilled by the State and Federal Geological Surveys (Fig. 6), logs 20 to 23 are of water wells drilled by private drillers, and logs 24 to 26 are partial logs of oil tests. Except where noted samples of test holes were studied by Perry McNally and Bruce F. Latta.

1. *Sample log of test hole 1 at the NW cor. sec. 4, T. 27 S., R. 16 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,094.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, fine to medium, gray and brown	4	4
Meade formation (Pleistocene)		
Sand, fine to medium, gray and brown; contains some fine gravel	7	11
Silt, sandy, gray; contains orange-brown streaks	8	19
Sand, fine, silty, greenish gray	20	39
Gravel, fine to coarse, tan; contains some sand	24	63
Silt and sand, fine; yellow tan to light gray; in part cemented with lime	7	70
Gravel, fine to very coarse, silty	5	75
Silt, sandy, limy, tan, greenish gray to light gray, and white	22.5	97.5
Silt and sand, fine, limy, tan and light gray to white	28.5	126

Gravel, fine to coarse, tan; contains some sand and tan sandy silt	24	150
Sand, fine to coarse, brown contains some gravel	7	157
Gravel, fine to coarse, and some sand, medium to coarse, tan,	18	175
Silt, sandy, limy, light gray	5	180
Gravel, fine to very coarse, tan; contains some sand, silt, and pebbles of brown ironstone	84	264
Silt and sand, fine, tan, gray, and orange brown	13	277
Gravel, fine to medium, tan and brown; contains some sand and pebbles of ironstone	16	293
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, dark gray to black; contains gypsum, pyrite, and thin beds of shell-limestone between 310 and 317 feet	24	317
Cheyenne sandstone		
Sandstone, fine- to medium-grained, hard, gray, and shale, hard, sandy	3	320
Shale, sandy, hard, blue gray, and sandstone, fine-grained; contains gypsum, pyrite, and charcoal	13	333
Sandstone, fine- to medium-grained, gray; contains abundant small grains of pyrite and charcoal	7	340
Siltstone, light gray; contains charcoal	9	349
PERMIAN—Leonardian		
Shale, silty, dull red	11	360

2. *Sample log of test hole 2 at the SE cor. sec. 20, T. 27 S., R. 16 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,095.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, fine to medium, silty, gray and greenish gray	16	16
Meade formation (Pleistocene)		
Sand and gravel, poorly sorted, tan	4	20
Sand, fine to medium, silty, greenish gray	6	26
Sand and silt, light gray	9	35
Gravel, fine to coarse, tan; contains abundant pebbles of granitic rocks, a few pebbles of sandstone and ironstone, and a little sand	93	128
Silt and clay, sandy, yellow and tan	2	130
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, silty, light gray and yellow tan; contains thin beds of shell-limestone at 146, 147.5, and 149 feet	20	150
Shale, blue gray and yellow tan; contains bed having cone-in-cone structure, thin beds of shell-limestone, and gypsum	10	160

3. ***Sample log of test hole 3 at the NE cor. sec. 29, T. 27 S., R. 17 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,150.3 feet.***

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, fine to medium, gray	3	3
QUATERNARY AND TERTIARY (?).—Pleistocene and Pliocene (?)		
Meade and Ogallala (?) formations		
Silt, clayey, gray	4	7
Silt, sandy, gray to brown; contains fine gravel in lower part	16	23
Silt, sandy, gray to tan	8	31
Gravel, medium to coarse, brown; contains some sand and silty clay. Gravel is composed of quartz, granite, and pebbles of brown sandstone	79	110
Silt, sandy, brown and yellow brown; contains intermixed sand and gravel	9	119
Gravel, coarse, brown; consists chiefly of quartz and granite, but also contains some sandstone. Contains some finer gravel and sand	20	139
Sand, fine to coarse, silty, tan	6	145
Silt, gray to tan; contains some sand and gravel, and pubbles and fragments of white caliche	15	160
Gravel, brown, poorly sorted; consists chiefly of pebbles of brown ironstone	3	163
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, light blue gray and yellow tan	13	176
Shale, gray and yellow tan; contains thin beds of shell-limestone at 176, 178, 181, and 183 feet	9.5	185.5
Shale, black	4.5	190

4. *Sample of test hole 4 in the NW cor. sec. 5, T. 27 S., R. 18 W.,* ***drilled by the*** *State and Federal Geological Surveys, 1941. Surface altitudes,* ***2,205.5 feet.***

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, fine to medium, gray tan and brown	9	9
Meade (?) formation (Pleistocene)		
Silt, sandy, tan brown	7	16
Sand, coarse, to gravel, coarse; consists predominantly of medium gravel but contains a few balls of yellow-tan silt	14	30
Silt and sand, fine gray tan	9	39
Sand, fine, to gravel, coarse; consists predominantly of medium and coarse gravel. A few pebbles in lower part are 1 inch in diameter	39.5	78.5
Sand, fine, silty, tan to light gray; contains lime-cemented zones and a few large pebbles of "mortar bed"	11.5	90
Gravel, fine to coarse, tan; contains little sand	14	104

Caliche, soft, sandy, light gray to white	2	106
Silt and sand, fine; tan brown	4	110
Silt and clay, sandy, tan and yellow gray	4	114
Gravel, fine to coarse, tan; consists predominantly of medium gravel but contains some sand	7	121
Silt and sand, fine, lime-cemented, light gray to white	8	129
Silt, sandy, tan and yellow tan; contains some silty clay	11	140
Gravel, fine to coarse, tan; contains some sand and a few pebbles of abraded sandy caliche	35	175
CRETACEOUS—Comanchean		
Kiowa shale		
Clay shale, silty, sandy, gray tan. Poor sample	9	184
Shale, sandy, light gray, and fine-grained hard gray sandstone	16	200
Shale, silty, yellow tan; contains thin beds or concretions of ironstone	10	210
Shale, silty, light gray; contains brown streaks	16	226
Shale, sandy, blue gray	6	232

5. *Sample log of test hole 5 in the NE cor. sec. 30, T. 27 S., R. 18 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,211.5 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, gray	3	3
QUATERNARY AND TERTIARY (?)—Pleistocene and Pliocene (?)		
Meade and Ogallala (?) formations		
Silt, sandy, gray and brown	2	5
Silt and sand, fine; gray tan	7	12
Sand, fine to medium, silty, tan and yellow brown	13	25
Gravel, fine to coarse, limy, gray; contains pebbles of abraded white caliche	5	30
Gravel, fine to coarse, gray tan; contains some sand and a few pebbles about 1 inch in diameter	65	95
Silt, lime-cemented, soft, light gray and tan; contains some sand and beds of thin hard sandy caliche	4	99
Sand, coarse, to gravel, coarse; gray tan; consists predominantly of fine to medium gravel	11	110
Gravel, fine to very coarse, gray tan	10	120
Gravel, fine to coarse, gray tan; consists predominantly of medium gravel but contains some sand	44	164
Silt and sand, fine, lime-cemented, light gray to white	4	168
CRETACEOUS—Comanchean		
Kiowa shale		
Clay shale, sandy, light gray, yellow tan, and yellow brown; contains thin beds or concretions of red ironstone	26.5	194.5
Shale, blue gray; contains pyrite and thin beds or concretions of red ironstone; also a hard sandy shale bed at 209 feet	15.5	210

6. *Sample log of test hole 6 in the NW cor. sec. 26, T. 27 S., R. 20 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude 2,281.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, fine to medium, silty, gray brown	12	12
Meade formation (Pleistocene)		
Silt, sandy, gray tan	5	17
Gravel, fine to very coarse, brown; contains some sand, a few clay balls, and some pebbles 1 inch or more in diameter. Gravel consists predominantly of quartz, feldspar, and granite	69	86
Silt, sandy, limy, light gray	5	91
Sand and gravel, poorly sorted, brown	23	114
Silt and sand, fine, limy, tan to white	3	117
TERTIARY—Pliocene		
Ogallala (?) formation		
Silt and sand, fine, lime-cemented, hard, light gray to white; contains sandy hard white caliche	5	122
Silt and sand, fine, lime-cemented, white	7	129
Silt, sandy, tan brown; contains nodules and stringers of lime	4	133
Caliche, silty and sandy, white; grades downward into tan sandy silt	7	140
Silt and sand, fine, limy, tan	20	160
Silt, sandy, tan and greenish gray. At base is thin lens of medium to coarse gravel consisting of pebbles of red and red-brown ironstone, sandstone, and a few granules of quartz	18	178
CRETACEOUS		
Dakota formation (Gulfian)		
Clay, sandy, light gray; contains nodules of soft red hematite	12	190
Sandstone, fine- to medium-grained, light tan to white; consists predominantly of angular to subrounded grains of clear quartz and contains rounded pellets and fibrous fragments of hematite	44	234
Sandstone, fine- to coarse-grained, tan; contains rounded pellets of ironstone which may be partly cemented with iron. Also contains drak-gray shale between 250 and 260 feet	34	268
Kiowa shale (Comanchean)		
Shale, blue gray	2	270
Shale, sandy, light to dark gray; contains thin beds of yellow hard fine-grained sandstone at 276.5 and 292.5 feet	40	310
Shale, dark gray; contains thin beds of hard shaly sandstone and a little pyrite	30	340

	Thickness, feet	Depth, feet
Shale, dark gray, contains thin bed of white fine-grained sandstone at about 345 feet and thin beds of shell-limestone from 378 to 382 feet. A few shell fragments found above 378 feet	46	386
Shale, dark gray; contains thin beds of white to light gray fine-grained sandstone between 386 and 390 feet	14	400
Shale, thin-bedded, light gray to blue gray, contains a few thin beds of gray fine-grained sandstone	70	470
Sandstone, fine-grained, hard, light gray	2.5	470.5
Shale, blue gray; contains a few fragments of shells and some pyrite	49.5	520
Shale, sandy, light gray. Poor sample	10	530
Cheyenne (?) sandstone (Comanchean)		
Sandstone, fine-grained, light gray and brown, and sandy hard gray shale. Samples very poor	59	589
PERMIAN		
Undifferentiated redbeds		
Sandstone, very fine-grained, red brown, and silty shale	31	620

7. *Sample log of test hole 7 at the NE. cor. sec. 20, T. 28 S., R. 16 W., drilled by the State and Federal Geological Survey, 1941. Surface altitude, 2,158.4 feet.*

	Thickness, feet	Depth, feet
Soil, silty, dark-gray	4	4
QUATERNARY—Pleistocene		
Kingsdown silt		
Silt, sandy, light gray, tan, and brown; contains limy zones and nodules of caliche	45	49
Silt and sand, fine, brown; contains coarse sand and fine gravel in upper part and lime-cemented zones in lower part	27	76
Silt, sandy, tan; contains some gravel	14	90
Meade formation		
Gravel, fine to coarse, tan; contains some sand and tan sandy silt	40	130
Gravel, medium to coarse, tan; contains some fine sand to fine gravel, sandy silt, and balls of clay	12	142
Gravel, fine to medium, sandy, tan; contains a few balls of clay	8	150
Sand and gravel; tan; consists predominantly of medium to coarse gravel; contains some pebbles and cobbles	40	190
Gravel, fine to medium, tan, in part cemented by lime carbonate; contains some sand and silt	39	229
Silt, sandy, yellow tan	1	230
Sand, fine to coarse, tan; contains some fine gravel	30	260
Sand and gravel, poorly sorted, tan to brown; contains pebbles of red-brown sandstone and ironstone and white chert	16	276

CRETACEOUS—Comanchean		
Kiowa shale		
Shale, silty, dark gray	4	280

8. *Sample log of test hole 8 in the SW cor. sec. 29, T. 28 S., R. 18 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,284.3 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, gray	5.5	5.5
QUATERNARY—Pleistocene		
Kingsdown silt		
Silt, sandy, tan	28.5	34
Meade formation		
Sand, fine to coarse, tan	6	40
Silt and sand, fine, tan	2	42
Sand, fine to coarse, tan; contains some silt	50	92
Sand and gravel, poorly sorted; contains balls of yellow-tan silty clay	28	120
Gravel, medium; contains some sand	18	138
TERTIARY—Pliocene		
Ogallala (?) formation		
Silt and sand, fine, yellow tan	10	148
Silt and sand, fine, lime-cemented, light gray to white	4	152
Sand, fine to medium, lime-cemented, light gray	6	158
Silt and sand, fine, tan	2	160
Silt, sandy, limy, tan	2	162
Silt, clayey, gray, brown, and yellow tan; contains some gravel	4	166
CRETACEOUS—Gulfian		
Dakota formation		
Clay, gray	5	171
Clay shale, light blue gray; contains gypsum and a thin bed of gray hard sandstone at 171 feet	9	180
Clay shale, light to dark blue gray, sandy in lower part	20	200

9. *Sample log of test hole 9 in the NW cor. sec. 9, T. 28 S., R. 19 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,281.9 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, gray	1	1
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, fine to coarse, tan	19	20
Meade formation (Pleistocene)		
Sand, medium, to fine gravel, tan	19	39
Silt, sandy, tan	9.5	48.5
Silt, sand, and gravel; tan to brown, poorly sorted; containing a few nodules of lime	9.5	58
Gravel, fine to coarse, sandy, tan and brown	52	110
Sand, fine, to medium gravel; poorly sorted	5	115

TERTIARY—Pliocene		
Ogallala (?) formation		
Silt and sand, fine, limy, tan and light gray	12	127
Sand, fine, to medium gravel; poorly sorted; contains balls of limy sandy silt	10	137
Silt and sand, fine, tan and light gray; contains fine red-brown sand and white caliche	9	146
Sand, fine to medium, tan	5	151
Sand, fine, to coarse gravel; consists mostly of coarse sand and fine gravel	13	164
Silt, sandy, limy, light gray and yellow tan	16	180
CRETACEOUS—Gulfian		
Dakota formation		
Clay, silty, light gray	10	190
Clay, gray and yellow tan; contains pellets of hematite and iron-cemented sandstone	15.5	205.5
Shale, light gray to blue gray; contains pyrite	4.5	210
Shale, blue gray; contains thin beds or lenses of gray fine-grained sandstone in lower part	20	230

10. *Sample log of test hole 10 at the SE cor. sec. 36, T. 28 S., R. 21 W., Ford County, drilled by the State and Federal Geological Surveys, 1940. Surface altitude, 2,372.2 feet. (Samples studied by Perry McNally and H. A. Waite.)*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Kingsdown silt		
Top soil, silty, brown	2	2
Clay, soft, silty, limy brown	3	5
Silt, soft, limy, light brown; contains nodules of lime	65	70
Sand, fine, brown	3	73
Silt, fine, sandy, brown; contains a few reddish-brown streaks	7	80
Silt, fine, sandy, brown; contains a few pebbles	9	89
TERTIARY—Pliocene		
Ogallala formation		
Sand, fine to fine gravel	6	95
Gravel, very coarse; comprises pebbles of quartz, granite, feldspar, basalt, and Greenhorn limestone, a few of which are as large as one-half inch in diameter	23	118
Silt, limy, gritty, light gray	12	130
Silt, limy, light gray; contains fragments of lime	18	148
Silt, limy, and caliche; contains lenses of fine sand	2	150
Silt, fine sandy, brown	1	151
Gravel, fine to coarse, poorly sorted; contains fragments of brown sandstone and limestone	2	153
CRETACEOUS—Gulfian		
Dakota formation		
Shale, clayey, fine sandy, limonitic, yellow. Drilled easily,	3	156
Shale, clayey, light gray and green, sticky. Drilled fairly hard	4	160

11. *Sample log of test hole 11 at the SW cor. sec. 9, T. 29 S., R. 16 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude 2,072.7 feet.*

	Thickness, feet	Depth, feet
Soil, silty and sandy, tan	4	4
QUATERNARY—Pleistocene		
Kingsdown silt		
Silt, sandy, tan; contains a little gravel	4	8
Silt, limy, light gray to tan	7	15
Meade formation		
Gravel, medium to coarse, tan; contains some medium to coarse sand and a few thin beds or lenses of yellow-tan silt	45	60
Gravel, coarse, tan; contains some coarse sand to medium gravel and cobbles	55	115
Silt, sandy, tan	10	125
Silt and sand, fine; dark-tan; contains thin bed of lime-cemented fine sand at top	5	130
Sand and gravel; silty; tan; contains pebbles of limestone, sandstone, ironstone, and igneous rocks	8.5	138.5
Silt, sandy, yellow tan	4.5	143
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, silty, blue gray to black	7	150

12. *Sample log of test hole 12 at the SE cor. sec. 18, T. 29 S., R. 17 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,167.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Kingsdown silt		
Silt, sandy, dark gray	2	2
Silt, sandy, tan to brown; contains nodules and thin beds of light gray to white caliche	49	51
Silt, limy, brown	2	53
Silt, limy, sandy, light gray and tan; contains nodules and thin beds of sandy caliche	20.5	73.5
Meade formation		
Gravel, fine to coarse, brown; contains pebbles as much as 1 inch in diameter	27.5	101
Silt, clayey, dark tan	8	109
Sand and gravel, poorly sorted, brown	14	123
Silt, sandy, light gray; contains thin lenses of fine sand to medium gravel	7	130
Sand, fine, silty, tan	2	132
Caliche, hard, white	.5	132.5
Silt, fine, sandy, tan and gray tan; contains 4-inch bed of hard caliche at 139.5 feet	13.5	146
Clay, sandy, silty, blue gray; contains snails in lower part,	16	162
Clay, silty, tan and gray	6	168

Clay, silty, blue gray; contains fine to coarse sand and fine gravel	5	173
Sand, fine, to medium gravel, brown; contains fragments of shell	8	181
CRETACEOUS—Comanchean		
Kiowa shale		
Clay shale, dark blue; contains 3-inch bed of shells at 183 feet and 6-inch bed of shells at 185.5 feet	9	190

13. *Sample log of test hole 13 in the SE cor. sec. 36, T. 29 S., R. 19 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,285.4 feet.*

	Thickness, feet	Depth, feet
Soil, silty, brown	0.5	0.5
QUATERNARY—Pleistocene		
Kingsdown silt		
Silt, tan; contains small nodules of caliche	3.5	4
Silt, limy, tan	6	10
Silt, tan; contains a few pebbles of caliche between 14 and 20 feet	24	34
Silt, limy, tan; contains a few nodules of caliche	5	39
Silt, brown	2	41
Silt, limy, tan	13	54
Silt, brown	3	57
Silt, limy, tan and light gray	1.5	58.5
Silt, sandy, lime-cemented, white	1.5	60
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Meade and Ogallala formations		
Silt, sandy, brown; contains a little coarse sand to medium gravel and pebbles of caliche	7	67
Sand, fine, to medium gravel, brown; contains some silt	4.5	71.5
Caliche, hard, white	1.5	73
Silt, sandy, tan brown	3	76
Caliche, hard, white	1	77
Silt, sandy, tan	5	82
Sand, coarse, to medium gravel, brown; contains some fine to medium sand	7	89
Sand and gravel, loosely cemented, brown; contains some brown sandy silt	7	96
Sand, lime-cemented, light gray; contains a few thin beds of tan sandy silt	4	100
Silt, sandy, limy, tan; contains thin lenses of light-gray to white lime-cemented fine sand in upper part	17	117
CRETACEOUS—Gulfian		
Dakota formation		
Shale, silty, light gray; contains a few thin beds or concretions of dark-brown to red-brown ironstone and yellow fine-grained sandstone	3	120
Sandstone, iron-cemented, hard, dark brown; contains thin beds of light-gray shale	5	125

14. *Sample log of test hole 14 in the NE cor. sec. 2, T. 30 S., R. 18 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitudes, 2,137.6 feet.*

	Thickness, feet	Depth, feet
Soil, silty, dark gray	4	4
QUATERNARY (?) AND TERTIARY—Pleistocene (?) and Pliocene		
Meade (?) and Ogallala formations		
Caliche, light gray to white, and lime-cemented fine sand,	6	10
Sand, fine to medium, lime-cemented, white	7	17
Silt, tan	5	22
Silt, sandy, limy, tan; contains thin beds and nodules of caliche	5	27
Silt and fine sand, lime-cemented, tan and white	1	28
Silt and fine sand, tan	2	30
Silt, sandy, limy, pale blue green	5	35
Silt and sand, fine; lime-cemented; light gray to white	3.5	38.5
Silt and fine sand, limy, tan and light gray	2.5	41
Silt, sandy, limy, light tan; contains a few pebbles of red-brown ironstone	5.5	46.5
CRETACEOUS—Comanchean		
Kiowa shale		
Clay, gray and yellow tan; contains thin bed of ironstone at top	3.5	50
Shale, blue gray, and clay, silty, yellow tan	4	54
Shale, blue gray, gray tan, and yellow tan	6	60
Shale, light blue gray; contains thin beds (2 to 6 inches) of dark red-brown hard ironstone	4.5	64.5
Shale, light blue gray	9.5	74
Shale, sticky, dark gray at top becoming dark blue at base	16	90

15. *Sample log of test hole 15 in SW¼ NE¼ SE¼ sec. 4, T. 30 S., R. 18 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,201.0 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, dark-gray	1	1
TERTIARY—Pliocene		
Ogallala (?) formation		
Sand and gravel, limy; contains pebbles of caliche	1	2
Silt, sandy, tan; contains pebbles of granite, caliche, and ironstone	1	3
CRETACEOUS		
Dakota formation (Gulfian)		
Sandstone, fine- to medium-grained, iron-cemented, hard, dark brown; contains small nodules of weathered yellow to light-gray clay. Thin beds of light gray clay in lower part	15	18
Shale, silty, light gray	2	20
Clay, mottled red and gray	6	26
Clay, gray; contains small concretions of red iron	6	32
Clay, mottled red and gray	4	36

Clay, silty, bright red; contains mottled red and gray clay	4	40
Clay, mottled red, gray, purple, and yellow	4	44
Ironstone, clayey, hard, red brown to dark brown	.3	44.3
Siltstone, sandy, light gray and yellow gray	5.7	50
Clay, silty, light gray and some yellow	9	59
Kiowa shale (Comanchean)		
Sandstone, fine-grained, yellow brown	24.5	83.5
Clay, sandy, silty, light gray; contains mottled gray, red, and yellow silty clay in lower part	5.5	89
Ironstone, clayey, hard, dark red brown and yellow	2	91
Clay, silty, light gray and yellow gray; contains a little fine sand	6	97
Clay shale, silty, light gray	3	100
Shale, silty, blue gray	10	110
Shale, silty, blue gray; contains thin beds of brown hard very fine-grained sandstone at 111, 114, 122, and 136 feet	30	140
Shale, sticky, blue gray; contains beds of hard sandstone or shell-limestone at 162, 173, 182, and 188 feet	60	200
Shale, sticky, blue gray, and blue gray sandy shale; contains gypsum	20	220
Shale, blue gray; contains gypsum, pyrite, and zones of hard sandy shale	20	240
Shale, blue gray; contains thin beds of shell-limestone and hard sandy shale, and a little gypsum and pyrite	14	254
Shale, dark blue gray	16	270
Shale, dark blue gray; contains thin beds of brown fine-grained sandstone	10	280
Shale, dark blue gray; contains thin beds of shell-limestone at 282, 296, 308, and 317 feet, and a thin bed of gray fine-grained sandstone at 324.5 feet	60	340
Shale, dark blue gray and black	12	352
Cheyenne sandstone (Comanchean)		
Shale, sandy, blue gray to black	12	364
Sandstone, fine- to medium-grained, light gray	36	400
PERMIAN—Guadalupian		
Whitehorse-sandstone		
Shale, silty and fine sandy, red	8	408

16. *Sample log of test hole 16 in the SE cor. sec. 36 T. 30 S., R. 19 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,230.9 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, gray	2	2
QUATERNARY—Pleistocene		
Meade formation		
Silt and fine sand, lime-cemented, soft, light gray to white; contains thin bed of hard white caliche at 7 feet	10.5	12.5
Silt and fine sand, gray, tan, and brown; contains thin bed of white caliche at 17 feet	5.5	18

Silt and fine to medium sand, pink red; contains nodules and stringers of lime	8	26
Silt and sand; contains fine to medium gravel	6	32
Sand and gravel, poorly sorted, silty; contains thin "mortar beds" in lower part	18	50
Sand, fine, to medium gravel, lime-cemented, hard, gray	8	58
Sand, medium, to coarse gravel, brown, consists predominantly of fine to medium gravel	22	80
Sand, fine, medium to gravel; consists predominantly of coarse sand and contains pebbles of abraded sandy caliche and some gray and red sandy silt	43.5	123.5
Silt, sandy, limy, light gray and tan	26.5	150
Silt, sandy, red and gray, contains some medium to coarse gravel	4	154
CRETACEOUS—Comanchean		
Cheyenne sandstone		
Sandstone, fine-grained, light gray, and sandy light gray shale; contains thin bed or concretion of iron-cemented sandstone between 170 and 180 feet. Also contains gypsum	36	190
Sandstone, fine- to medium-grained, gray	6	196
Clay, silty and sandy, yellow green	3	199
PERMIAN—Guadalupian		
Whitehorse sandstone		
Shale, silty, red; contains sandy zones	11	210

17. *Sample log of hole 17 in the NE cor. NW¼ sec. 1, T. 30 S., R. 20 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,315.1 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, gray tan	5	5
QUATERNARY—Pleistocene		
Kingsdown silt		
Silt, tan; contains nodules of white caliche	23	28
Silt, tan brown, tan, and buff; contains clay	18.5	46.5
Silt and clay; sandy; red brown	5.5	52
Silt, limy, tan; contains soft light gray to white caliche and sand	26.5	78.5
Silt and fine sand, limy, tan and light gray	17.5	96
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Ogallala and Meade formations		
Caliche, hard, white	1	97
Silt and fine sand, tan to light gray; contains thin beds of white caliche	9.5	106.5
Silt, sand, and gravel, poorly sorted	2.5	109
Sand and gravel, silty; consists predominantly of fine gravel	12	121
Sand, fine, silty, limy, light gray	3	124
Sand and gravel, limy, tan	12	136

Sand, fine, silty, tan	4	140
Sand, fine, to fine gravel, poorly sorted	10	150
Sand, fine, silty, tan; contains thin lime-cemented lenses,	16	166
Silt, sand, and fine gravel, tan and gray, poorly sorted	1	167
Silt and sand, lime-cemented, tan and gray	1.5	168.5
Sand, coarse, to coarse gravel, limy and silty	17.5	186
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, silty, sandy, pale blue green	6.5	192.5
Shale, sandy, blue black; contains thin beds of shell-limestone at 194.5, 196.5, and 198 feet	7.5	200

18. *Sample log of test hole 18 in the NW cor. sec. 6, T. 30 S., R. 20 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,376.3 feet.*

	Thickness, feet	Depth, feet
Soil, silty, gray	3	3
QUATERNARY—Pleistocene		
Kingsdown silt		
Silt, tan and light gray; contains limy zones and a little sand	67	70
Sand, fine, and silt, tan; contains thin bed of caliche at 73 feet	5	75
Sand, fine, lime-cemented, red tan; contains a little caliche	8	83
Meade formation		
Sand and gravel, poorly sorted; tan	4	87
Silt and sand, fine to medium, lime-cemented, light gray to white	9	96
Sand and gravel, gray, limy	10	106
Sand and gravel, lime-cemented, hard, light gray to tan	1.5	107.5
Sand and gravel, tan; consists predominantly of fine to medium gravel	2	109.5
Silt, sandy, limy, tan and light gray	8.5	118
Sand, medium, to coarse gravel, tan; contains some silty clay in lower part	29	147
Silt and fine sand, limy, tan and light gray	3	150
Sand and gravel, lime-cemented, soft, light gray	13.5	163.5
Silt, sandy, tan and light gray to white	11.5	175
Sand, fine, to fine gravel, tan; contains abraded pebbles of caliche and some silty clay	15	190
Sand, fine, to coarse gravel; consists predominantly of fine to medium gravel and contains abraded pebbles of "mortar bed" and caliche	40	230
Sand and gravel, poorly sorted, tan; contains lenses of gray sandy and silty clay	4.5	234.5
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, silty, tan, yellow tan, and gray	2.5	237

	Thickness, feet	Depth, feet
Shale, silty, dark gray to black; contains thin beds of fine-grained sandstone and sandy shale	43	280
Cheyenne sandstone		
Sandstone, fine-grained, light gray to white, tan, and yellow	3	283
Shale, sandy and silty, light gray and cream gray	7	290
Sandstone, fine-grained, silty, light gray to white and red; contains thin bed or lens of blue gray silty shale at 294 feet	7	297
PERMIAN—Guadalupian		
Whitehorse sandstone		
Siltstone, sandy, red	13	310

19. *Sample log of test hole 19 in the NE cor. NW¼ sec. 24, T. 30 S., R. 20 W., drilled by the State and Federal Geological Surveys, 1941. Surface altitude, 2,179.5 feet.*

	Thickness, feet	Depth, feet
Soil, silty and sandy, gray	3.5	3.5
QUATERNARY—Pleistocene		
Kingsdown silt		
Silt, sandy, brown to tan; contains sand and gravel	6.5	10
Silt and clay, gray tan	5	15
Silt, tan; contains a few pebbles of caliche	5	20
Silt, tan; contains some sand	12.5	32.5
Silt, limy, sandy, and light gray to white caliche	1.5	34
Silt and fine to medium sand, tan to brown; contains thin bed of hard caliche at 39.5 feet	7	41
Meade formation		
Sand, fine to coarse, tan; contains nodules of lime	3	44
Silt and fine to medium sand, lime-cemented, tan, light gray, and white	17.5	61.5
Silt, sandy, greenish gray	4	65.5
Sand, fine, to coarse gravel, tan; consists predominantly of fine gravel	12.5	78
Silt, sandy, tan and light gray; grades downward into fine to coarse sand	12	90
Sand, fine to fine gravel, tan; consists predominantly of coarse sand and contains a few abraded grains of white caliche	10	100
Sand, fine, to coarse gravel, tan; consists predominantly of medium gravel and contains abraded pebbles of caliche and "mortar bed" and fragments of bone	12	112
Silt and fine sand, greenish gray; contains gray clay	4	116
Sand, fine to coarse gravel, tan; consists predominantly of medium gravel	54	170
CRETACEOUS—Comanchean		
Cheyenne sandstone		
Sandstone, fine-grained, yellow, yellow brown, brown, and gray	14	184
Clay, silty, light blue gray	1	185

Sandstone, fine-grained, light gray; contains light blue-gray silty shale in lower part	8	193
Conglomerate, gray to white; composed of fine to medium sand and abraded pebbles of white chert and quartz of medium gravel size	6	199
Siltstone, sandy, hard, light gray, yellow, and yellow green	5	204
PERMIAN—Guadalupian		
Whitehorse sandstone		
Shale, silty, red; contains thin beds of hard red sandstone	4.5	208.5
Sandstone, fine-grained, silty, light gray	1	209.5
Shale, silty and sandy, light to dark red; contains light-gray fine-grained sandstone in lower part	10.5	220

20. *Driller's log of irrigation well (10) of C. Williamson, in the SW¼ SE¼ NE¼ sec. 21, T. 27 S., R. 17 W.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Loam, sandy	4	4
Meade formation (Pleistocene)		
Clay, joint	8	12
Silt, sandy	26	38
Sand and gravel, very coarse; contains pebbles 3 inches diameter	54	92
Clay	(?)	

21. *Driller's log of water well of E. B. Corse, in the NE cor. sec. 18, T. 27 S., R. 20 W.*

	Thickness, feet	Depth, feet
Soil, sandy	5	5
QUATERNARY AND TERTIARY—Pleistocene and Pliocene		
Meade and Ogallala formations		
Sand and clay	5	10
Sand and gravel, dry	20	30
Sand and gravel, water bearing	17	47
Clay, light-colored	2	49
Sand, fine, and clay	21	70
Clay, light colored	3	73
Clay, yellow	14	87
Shale, blue	4	91
Shale, yellow	4	95
Clay, greenish yellow	3	98
Shale, light colored	59	157
Shale, brown	2	159
Iron rock, brown	1	160
Sandstone	2	162
Shale, brown	3	165
Shale, gray	7	172
Shale, blue	2	174
Shale, brown	8	182

22. *Driller's log of well (37) of Panhandle Eastern Gas Company, in the NE¼ NE¼ sec. 18, T. 28 S., R. 18 W.*

	Thickness, feet	Depth, feet
Soil	13	13
QUATERNARY AND TERTIARY		
Pliocene and Pleistocene deposits (undifferentiated)		
Clay and sand	7	20
Clay	2	22
Sand, fine, and clay	6	28
Sand, fine	9.5	37.5
Clay	8	45.5
Clay, sandy	2	47.5
Lime	.5	48
Sand, fine	17	65
Sand, coarse, water bearing	3	68
Clay, limy	5	73
Sand rock	3	76
Sand, coarse	14	90
Sand, fine	12	102
Sand and gravel	11	113
Sand, fine	2	115
Sand, coarse, and gravel	13	128
Sand, fine, and clay	.5	128.5
Sand, hard	2.5	131

23. *Driller's log of well (42) of the Northern Natural Gas Company, in the center of the SE¼ sec. 20, T. 28 S., R. 19 W.*

	Thickness, feet	Depth, feet
QUATERNARY AND TERTIARY		
Pliocene and Pleistocene deposits (undifferentiated)		
Clay, yellow	80	80
Clay and sand; consolidated	10	90
Gravel, coarse	37	127
Sand, water bearing	11	138
Sand rock, soft	4	142
Sand, coarse, water bearing; contains some gravel	23	165
CRETACEOUS		
Dakota (?) formation (Gulfian)		
Clay, yellow	15	180
Clay and sand, consolidated	20	200
Redbeds	15	215
Sand, water	8	223
Kiowa (?) shale (Comanchean)		
Clay, blue	97	320
Limestone, black	6	326

24. *Part of driller's log of oil test on the W. A. Woodard farm in the NE cor. sec. 35, T. 27 S., R. 17 W.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Meade formation		
Cellar	18	18
Sand	2	20
Sand and gravel	95	115
Sand	20	135
Sand and gravel	16	151
Sand	20	171
CRETACEOUS		
Clay, yellow	10	181
Shale, blue	85	266
Slate, dark	19	285
Lime (?), water bearing	25	310
Redrock	10	320
Sand, water bearing	30	350
Slate, blue	6	356
Shale, blue	14	370
PERMIAN		
Redrock	355	725

25. *Part of driller's log of oil test on the B. Bean ranch, in the NE cor. SE¼ sec. 10, T. 30 S. R. 17 W. Surface altitude, 1,980± feet.*

	Thickness, feet	Depth, feet
CRETACEOUS—Comanchean		
Kiowa shale		
Cellar	15	15
Clay, soft, yellow	10	25
Gumbo, soft, black	10	35
Mud gumbo, soft, blue	90	125
Shale, soft, light	20	145
Cheyenne sandstone		
Sand, soft, white	20	165
PERMIAN		
Redrock, soft	65	230
Sand and gravel, soft, light	20	250
Sand, soft, gray	10	260
Redrock, soft	40	300
Lime, hard, white	10	310
Redrock and gravel, soft	164	474
Lime, hard, white	3	477
Redrock, soft	323	800
Sand, soft, red	10	810
Redrock	40	850

26. *Part of driller's log of oil test in the SE cor. SW¼ sec. 25, T. 30 S., R. 17 W.*

	Thickness, feet	Depth, feet
Soil	4	4
CRETACEOUS—Comanchean		
Kiowa shale		
Sand	10	14
Clay, brown	6	20
Sand	3	23
Slate, green	13	36
Mud, black	24	60
Lime, hard	4	64
Mud, black	46	110
Slate, black	41	151
Cheyenne sandstone		
Sand	14	165
Clay, yellow	8	173
Sand, water bearing	15	188
PERMIAN		
Whitehorse sandstone and Dog Creek shale (Guadalupian and Leonardian)		
Redrock	62	250
Sand, water bearing	5	255
Redrock	6	261
Sand, red	9	270
Redrock	50	320
Medicine Lodge gypsum (Leonardian)		
Gypsum, crystalline	22	342

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INDEX

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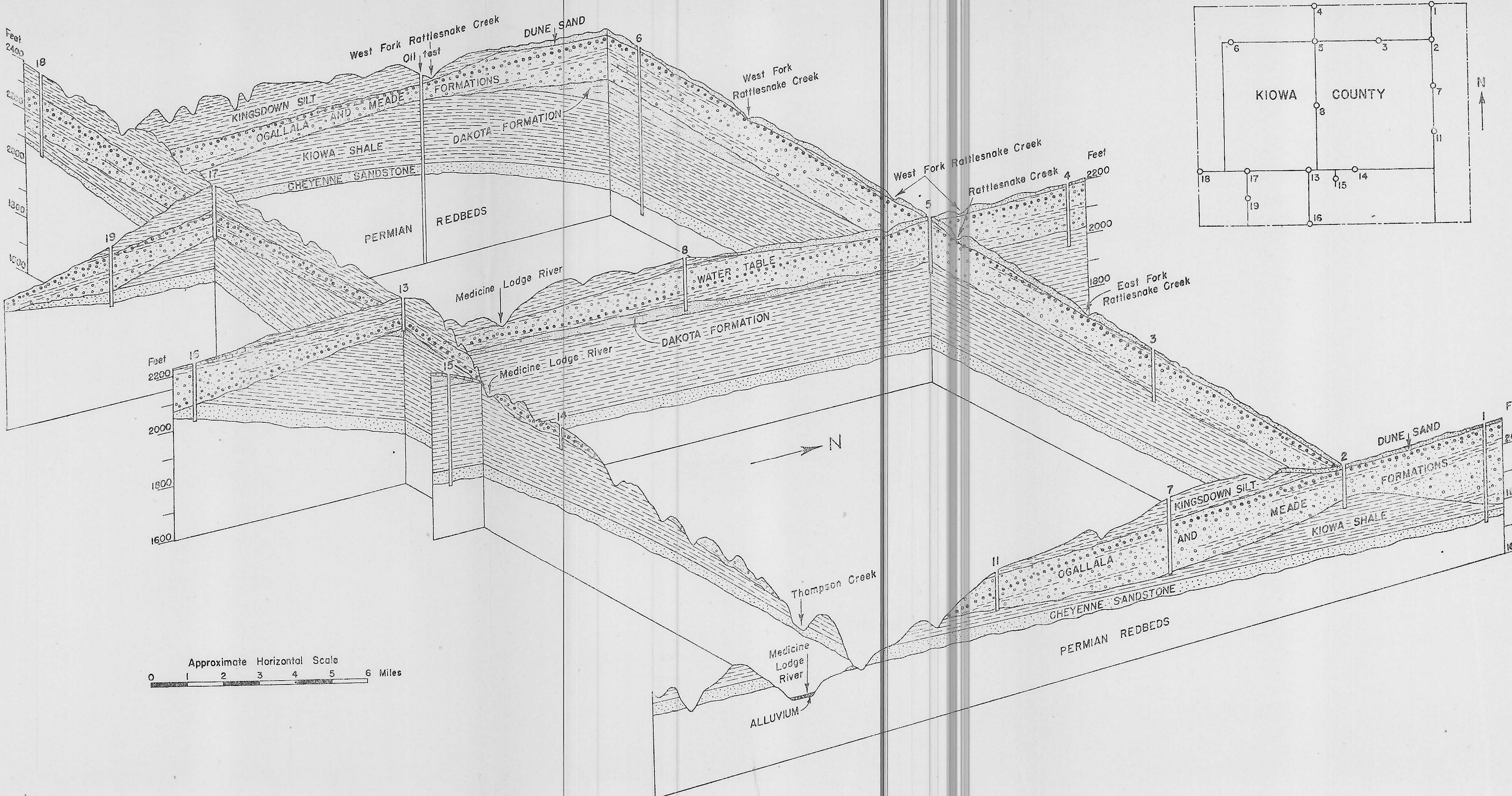
Sectional diagram showing the geologic features of Kiowa County, Kansas

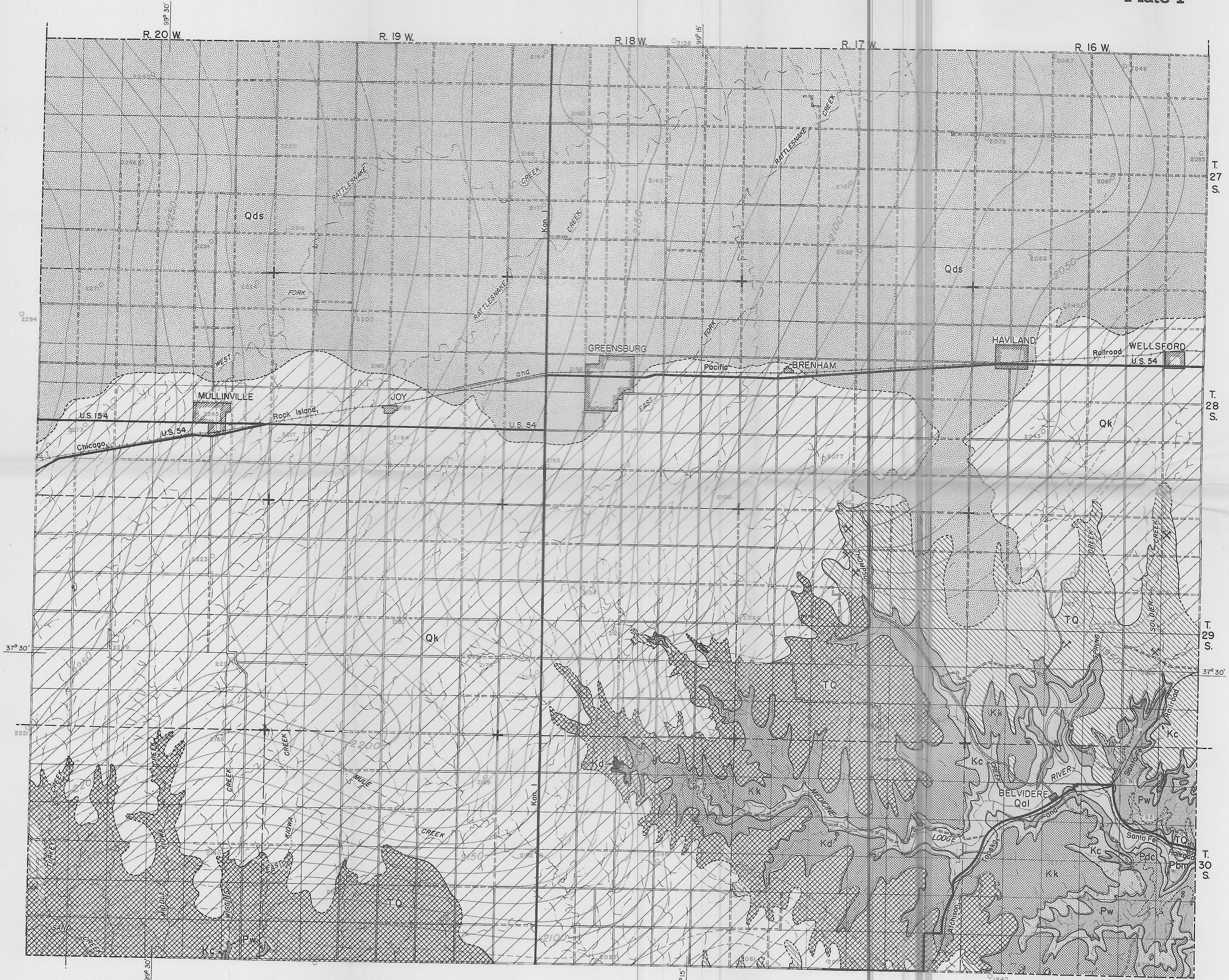


State Geological Survey
of Kansas

MAP OF KIOWA COUNTY
Showing Geology and Water-Table Contours, 1941

by Bruce F. Latta

Bulletin 65
Plate 1



Base modified from map prepared by
Kansas State Highway Department

0 1 2 3 4 5 6
Scale in miles

Drainage from aerial photographs
of the U. S. Dept. of Agriculture

EXPLANATION

QUATERNARY

Qal
Alluvium
Gravel, sand, silt, and clay comprising stream deposits in the Medicine Lodge and in the smaller stream valleys; also includes terrace deposits. The alluvium yields small to moderate supplies of water to wells in the Medicine Lodge and its larger tributary valleys. Waters from the alluvium are generally very hard and in some places are too highly mineralized for domestic use.

Qds
Dune sand
Quartz sand. Sand dunes are above water table and do not furnish water directly to wells, but are important catchment areas for ground-water recharge.

Qk
Kingsdown silt
Silt and sandy silt, containing minor amounts of clay, fine to coarse sand, and fine gravel. Does not yield water to any wells or springs in this area. It is believed to be above the water table everywhere in the county.

Qm
Meade formation
Interbedded lenses of clay, silt, sand, and gravel, mainly unconsolidated. Contains some lime-cemented beds, caliche, and locally volcanic ash.

TQ
Meade and Ogallala formations undifferentiated.
Sand and gravel beds of the Meade and Ogallala formations are the most important sources of ground water in Kiowa county, and supply adequate water of good quality to domestic, stock, irrigation, industrial, and public supply wells.

TERTIARY

To
Ogallala formation
Consolidated and unconsolidated, calcareous silt, sand, and gravel that are lithologically similar to materials of the Meade formation.

CRETACEOUS

Kd
Dakota formation
Sandstone, dark-brown, iron-cemented, hard; sand, tan and brown, fine to medium; and shale, red, light-gray, and tan, silty and clayey. No wells in Kiowa county are known to obtain water from this formation.

Kk
Kiowa shale
Shale, thinly laminated, dark-gray to black and clay and clay shale, gray, tan, brown, and red. Contains thin beds of shell limestone and light to dark-gray and white fine-grained sandstone. A large lense of yellow-tan to buff cross-bedded fine-grained sandstone occurs locally at top of formation. Most of the formation is relatively impermeable and will not yield water to wells. The sandstone lens at top supplies moderate amounts of water to one well and several springs.

Kc
Cheyenne sandstone
Sandstone, light colored, fine to coarse grained, friable, cross-bedded, and lenses of shale, gray to black, sandy, carbonaceous. Supplies water to a few stock and domestic wells in the south-central and southeastern parts of the county. Water is highly mineralized and locally is unfit for ordinary purposes.

PERMIAN

Pw
Whitehorse sandstone
Sandstone and siltstone, red poorly bedded fine-grained friable, containing minor amounts of shale. Supplies small quantities of very hard water to a few wells in southeastern Kiowa county.

Pdc
Dog Creek shale
Shale, red, containing thin beds of light gray and mottled red and light gray fine-grained sandstone. Relatively impermeable; not known to yield water to wells in Kiowa county.

Pbm
Blaine formation
(Medicine Lodge gypsum member)
Gypsum, white massive; weathers to light gray. Not known to yield water to wells.

Contour interval 10 feet

2100 — Water-table contours based on instrumental levels (dashed where position is inferred)
2101 — Well location. Number refers to altitude of water level
Federal or State highway
Graded road
Ungraded road
Section line (no road)
Township line (no road)
Perennial stream
Intermittent stream
Gravel pit

MAP OF KIOWA COUNTY

Showing the depths to Water Level and the Location of Wells for which Records are given, 1941

by Bruce F. Latta

State Geological Survey of Kansas

Bulletin 65
Plate 2