Geology and Ground-Water Resources of Rice County, Kansas

By

O. S. FENT

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BULLETIN 85

GEOLOGY AND GROUND-WATER RESOURCES OF RICE COUNTY, KANSAS

By O. S. FENT

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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GEOLOGY AND GROUND-WATER RESOURCES OF RICE COUNTY, KANSAS

By O. S. Fent

ABSTRACT

This report describes the geography, geology, and ground-water resources of Rice County in central Kansas. The county has an area of about 721 square miles and had a population of 14,608 in 1945. The area lies in the Plains Border section of the Great Plains province and comprises dissected uplands and filled valleys that present low topographic relief. It is drained largely by Arkansas River and its tributaries. The average annual precipitation is about 26 inches. The mean annual temperature is about 56° F. Farming is the principal occupation, with wheat as the major crop. Small-scale irrigation is practiced on a few farms in dry years. Petroleum and salt are important mineral products.

All the exposed rocks in Rice County are of sedimentary origin, ranging in age from late Permian to Quaternary. A map showing the surface geology and cross sections showing the distribution of the unconsolidated material are included in this report. Pleistocene deposits of Nebraskan, Kansan, and Wisconsinan Ages reach a thickness of more than 200 feet and are composed mostly of unconsolidated material. Four major cycles of erosion and deposition are recorded in the Pleistocene rocks. The sand and gravel of the Pleistocene Series, and the sandstones of the Dakota formation and of the Kiowa shale of the Cretaceous System are the most important aquifers in the area. Descriptions of the ground-water conditions are given by formations and areas.

All public and industrial water supplies and most domestic, stock, and irrigation supplies are obtained from wells. The water is moderately hard to hard over most of the area. Water with a high chloride content is found in some of the Permian rocks, in deep Pleistocene channels, and in shallow deposits near points of disposal of highly mineralized industrial wastes.

Hydrologic and geologic data, which are the basis of this report, include records of 266 water wells, 64 test holes, chemical analyses of 43 samples of water, the determination of the chloride content of 89 samples of water, and periodic measurements of the water level in 22 observation wells.

INTRODUCTION

Purpose and Scope of the Investigation

An investigation of the geology and ground-water resources of Rice County was begun in 1945 by the United States Geological Survey 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.

Ground water is one of the principal natural resources of the State. An understanding of the occurrence and movement of ground water and of the quantity and quality of water available is necessary for efficient development of water supplies in Rice County to fill the expanding needs of municipal, industrial, and agricultural activities.

The investigation was made under the general administration of A. N. Sayre, geologist in charge of the Ground-Water Branch of the Federal Geological Survey.

Location and Extent of the Area

Rice County is in central Kansas (Fig. 1). It is bordered on the west by Barton and Stafford Counties, on the north by Ellsworth

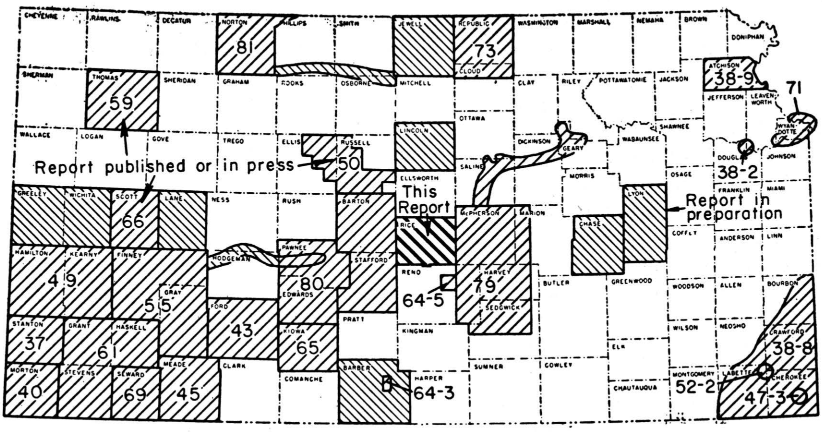

Fig. 1.—Index map of Kansas showing area covered by this report and areas for which coöperative ground-water reports have been published or are in preparation.

County, on the south by Reno County, and on the east by McPherson County. It contains about 20 townships and has an area of about 721 square miles.

Previous Investigations

A report by Parker in 1911 included analyses of ground-water and stream samples from Rice County and a brief discussion of ground-water conditions in the county.

Coöperative investigations of the intrusion of salt water into fresh-water aquifers were made by the U. S. Bureau of Mines and the Kansas State Board of Health (Wilhelm and Schmidt, 1935;

Wilhelm and others, 1936). Stream samples and water from wells near oil-producing areas in Rice County were included in these investigations.

Investigations of the geology and ground-water resources of other areas in central Kansas have been made by the State and Federal Geological Surveys in coöperation with the Division of Sanitation of the Kansas State Board of Health and the Division of Water Resources of the Kansas State Board of Agriculture. These include oil-field areas of Ellis and Russell Counties (Frye and Brazil, 1943), the vicinity of Hutchinson (Williams, 1946), part of south-central Kansas (Williams and Lohman, 1949), and the Smoky Hill River Valley near Salina (Latta, 1949).

Methods of Investigation

A reconnaissance of Rice County was made by C. C. Williams and me in August 1945. Four days were spent in the field outlining the problems to be studied. In November and December of 1945, I spent 7 weeks in the field. Work was resumed in July 1946 and continued through September 1946, during which time the 266 wells listed in Table 6 were inventoried. All water-level measurements were made with a steel tape from a fixed measuring point at the top of the well. Wells in the southern part of the county were measured by J. W. Sears, who also made periodic measurements of the 22 observation wells in 1946. They were measured by D. W. Berry in 1947 and 1948. Water samples were collected from 14 representative wells, 9 test holes, and 12 stream sampling points. They were analyzed by Howard Stoltenberg, chemist, in the Water and Sewage Laboratory of the Kansas State Board of Health. Mr. Stoltenberg also made determinations of the chloride content of 89 water samples from other wells and test holes in the county. Sixty-four test holes were drilled by the hydraulic rotary drilling machine owned by the State Geological Survey and operated by James B. Cooper, D. W. Berry, W. T. Connor, and J. G. Votaw.

Altitudes of the measuring points of wells and test holes were determined by use of a plane table and an alidade, by C. K. Bayne, W. W. Wilson, and D. W. Berry. The wells shown on Plate 2 were located within the section by use of an odometer.

The base maps for Plates 1 and 2 were made from an enlargement of a drainage map prepared by the Soil Conservation Service of the U. S. Department of Agriculture.

Well-numbering System

The well and test hole numbers used in this report give the location of wells according to General Land Office surveys and according to the following formula: township, range, section, 160-acre tract within that section, and the 40-acre tract within the quarter section. This system of numbering wells and test holes is shown on Figure 2.

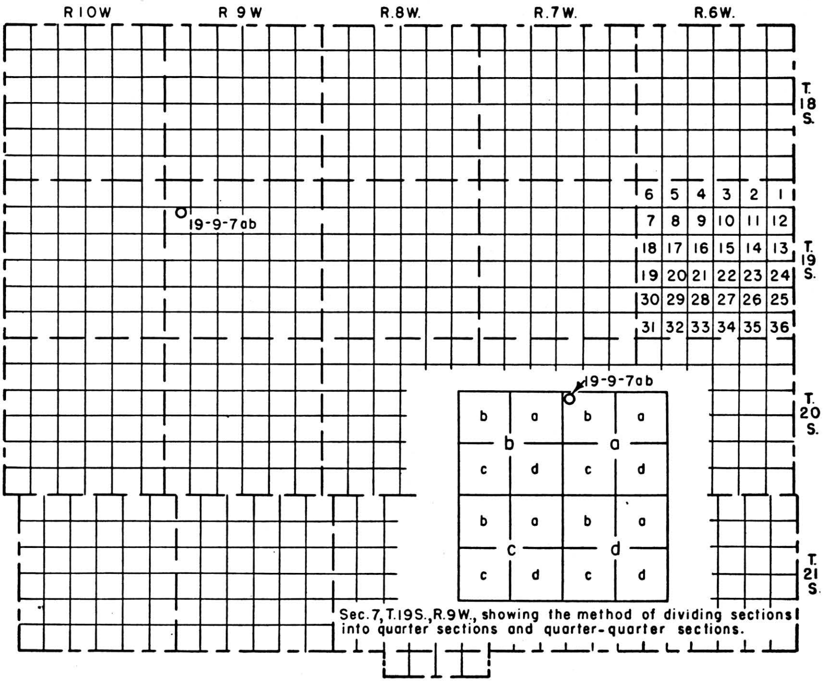

Fig. 2.—Map of Rice County illustrating the well-numbering system used in this report.

If two or more wells are located within a 40-acre tract, the wells are numbered serially according to the order in which they were inventoried. The 160-acre and 40-acre tracts are designated a, b, c, or d in a counter-clockwise direction beginning in the northeast quarter. For example: well 19-9-7ab2 is located in NW¼ NE¼ sec. 7, T. 19 S., R. 9 W., and was the second of two wells inventoried in that 40-acre tract.

Acknowledgments

The writer is indebted to the many residents of Rice County who furnished information about their wells and permitted measurements to be taken and water samples to be collected. City officials and owners of industrial wells furnished much information about municipal and industrial wells. Drillers supplied information concerning materials penetrated in the drilling of oil and water wells in the county.

The manuscript of this report has been read critically by several members of the Federal Geological Survey and the State Geological Survey of Kansas; by George S. Knapp, chief engineer, and Robert Smrha, senior engineer, Division of Water Resources of the Kansas State Board of Agriculture; and by Dwight Metzler, chief engineer, and Ogden S. Jones, geologist, Division of Sanitation of the Kansas State Board of Health.

Figure 6, which shows the saturated thickness of the Tertiary and Quaternary deposits in Rice County, was prepared by Glenn C. Prescott. The illustrations were drafted by W. W. Wilson and Paul Carlos.

GEOGRAPHY

Topography and Drainage

Rice County is at the eastern edge of the area designated by Fenneman (1931, Pl. 1) as the Plains Border section of the Great Plains province. In this classification it is a part of the erosional transition belt between the receding High Plains to the west and the broadening Central Lowland to the east. Previously, in a more detailed division of the surface features of Kansas, Moore (1930), included the southern part of Rice County in the depositional plain of the Great Bend Prairie and the northern part in the erosional Smoky Hills Upland.

At the surface in most of the county is a series of depositional units directly related to the Great Bend Prairie province which, in the northern part, is underlain by the erosional surface of the Smoky Hills Upland. Small erosional remnants of the High Plains surface in the central and western part of the county are shown on the geologic map (Pl. 1) as Tertiary areas. On the geologic map, areas which are properly classed as inliers of the Smoky Hills Upland are shown as isolated outcrops of Cretaceous rocks. The Cretaceous and Permian rocks exposed in the drainage basin of Arkansas River also may be considered as part of the Smoky Hills Upland or Plains Border.

In this report the physiographic divisions of Rice County are subdivided into geologic regions and lithologic areas with similar ground-water characteristics, and are shown on Plate 2. The water-bearing characteristics of each area are discussed in the section on ground-water regions.

The development of the present depositional surface from the High Plains surface is a record of the Pleistocene history of Rice County. A detailed discussion of the Pleistocene history of the county is presented in the section on history of drainage.

Most of Rice County is drained by Arkansas River and its tributaries, Cow Creek and Little Arkansas River. A small part of northeastern Rice County drains into the Smoky Hill River system.

CLIMATE

The climate of Rice County is of the middle-latitude continental type, with a moderately wide range in temperature. The mean annual temperature for Alden, in the southwestern part of the county, is 56° F. and for Geneseo, in the north-central part, 55.7° F.

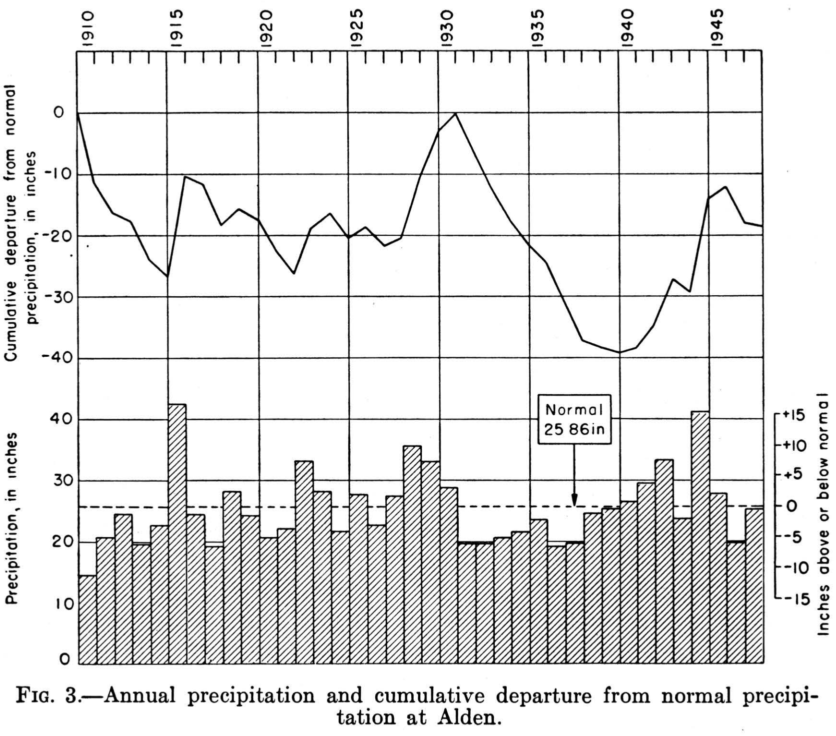

FIG. 3.—Annual precipitation and cumulative departure from normal precipitation at Alden.

The normal annual precipitation at Alden, computed from records covering the period from 1898 to 1942, is 25.86 inches (Fig. 3). The monthly normals at Lyons for the same period (Fig. 4) show that

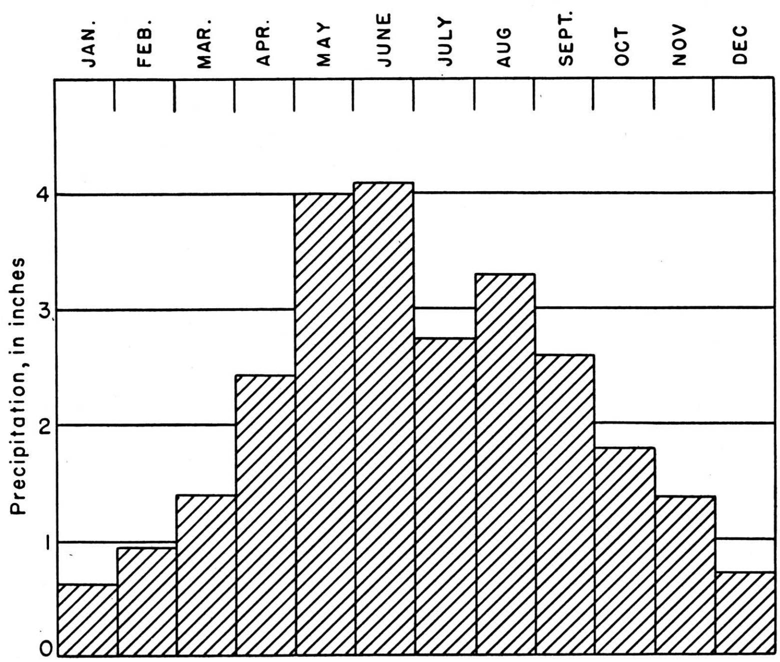

FIG. 4.—Monthly distribution of precipitation at Lyons.

January has the lowest precipitation, with a normal of 0.61 inch, and June has the highest with a normal of 4.10 inches.

The average growing season is 181 days; this has ranged from 135 days in one year to 223 days in another. The latest day in the spring on which a killing frost has been recorded is May 17, while the earliest date in the fall is September 20.

POPULATION

Rice County, with an area of 721 square miles, had a population of 14,608, or about 20 inhabitants to the square mile, according to the 1945 census. Lyons, population 3,711, is the largest city in the county; Sterling has a population of 1,984. Other city population figures, according to the 1945 census, are: Chase, 690; Geneseo, 554; Little River, 587; Bushton, 540; Alden, 294; Frederick, 62. No population figures were available for Raymond, Silica, Mitchell, Saxman, Crawford, and Pollard.

Transportation

Rice County is served by branch lines of the Atchison, Topeka, & Santa Fe Railway, the Missouri Pacific Railroad, and the St. Louis & San Francisco Railway. The main line of the Missouri Pacific's Kansas City, Missouri, to Pueblo, Colorado, line passes through the northern part of the county.

U. S. Highway 50 North passes in an east-west direction through the middle of the county. Kansas Highway 14 passes in a north-south direction through the center. Both of these highways are paved. Kansas Highway 96 is routed over Kansas Highway 14 south of Lyons and over U. S. Highway 50 west of Lyons. Kansas Highway 4 is a graded, graveled road paralleling the Missouri Pacific Railroad through the northern part of the county. Kansas Highway 46 consists of 1½ miles of pavement between Little River and U. S. Highway 50 North.

County and township roads are good most of the year. Roads on most section lines are open except in parts of the sand-dune areas in the southwestern and southeastern parts of the county.

Agriculture

Rice County has a total of 1,487 farms comprising 461,440 acres. According to the report of the Kansas State Board of Agriculture for June 1946, there were 269,220 acres of crops harvested in Rice County in 1945. The principal crops harvested in Rice County in 1945 were as follows:

Crop distribution in Rice County in 1945

	Acres
Wheat	206,000
Corn	6,300
Oats	5,190
Barley	1,730
Flax	30
Soybeans	10
Sorghums	35,100
Alfalfa	12,200
Hay, not including alfalfa	2,660

Natural Resources and Industries

Oil and Gas

Oil and gas are important natural resources of Rice County. Gas was produced here as early as 1888 and oil was first discovered in the Welch pool in 1924. In 1944 the 36 gas and oil pools of the county produced a total of 8,026,135 barrels of oil and 7,276,755,000 cubic feet of gas. Pools that extend across the county boundaries of Barton, Ellsworth, and McPherson Counties, produced 13,498,005 barrels of oil. Total cumulative production credited to Rice County by the end of 1944 was 86,582,907 barrels of oil (Ver Wiebe, 1945).

Oil has been found in the Shawnee and Kansas City-Lansing groups and the basal conglomerate of the Pennsylvanian; the Mississippian; the Simpson of Ordovician age; the Arbuckle of Cambro-Ordovician age; and Pre-Cambrian rocks (Moore and Jewett, 1942).

The major structural element controlling the occurrence of oil and gas in Rice County is the Central Kansas uplift which extends into Rice County from the north-northwest. Rocks of Mississippian age do not occur over this structural high and production from them in Rice County is limited to the flanks of the uplift, in the southeastern part of the county.

Directly dependent upon the oil and gas production in Rice County are well and pipe line maintenance industries, compressor stations, and retail oil-well supply stores.

SALT

Since 1888 salt has been produced commercially in Rice County. The earliest record of salt found in large quantities is in the log of a well at Lyons in December, 1887. Soon after this discovery, brine wells at Sterling and shaft mining and brine wells at Lyons were developed. Salt is produced by two plants at Lyons by shaft mining of the rock salt and by evaporation of brines produced by pumping water into the salt zone and forcing out the brine. Records of shafts and wells show the top of the first salt beds to be about 790 feet below the surface at Lyons and about 700 feet below the surface at Sterling. The salt, with interbedded shales, has a thickness of 300 to 350 feet (Taft, 1946). It is found in the Hutchinson salt member of the Wellington shale of Permian age.

SAND AND GRAVEL

Thick deposits of sand and gravel in the Arkansas River Valley are used extensively for road-surfacing material and concrete aggregate. Four gravel pits were in operation in Rice County in 1946.

STONE

Sandstone has been quarried in several places in the county for use as building stone. The Stone Corral dolomite of Permian age is quarried along the southwestern bluff of Little Arkansas River. It is used as crushed rock and has had some use as building stone. Hard, calcareous sandstone, which is quarried at several points in the county, is used as crushed rock for road-surfacing material and for concrete aggregate.

GENERAL GEOLOGY

Summary of Stratigraphy *

The rocks cropping out in Rice County are of sedimentary origin. The oldest rocks exposed at the surface are classed as the Sumner group, Leonardian Series, Permian. Red and green Ninnescah shale is exposed in the bluff bordering the lower part of Little Arkansas River Valley. Capping these bluffs is the resistant Stone Corral dolomite and a thin remnant of the Chikaskia member of the Harper sandstone. Siltstone and fine-grained sandstone of the Cheyenne sandstone unconformably overlie the Permian in northwestern Rice County. Dark shales and fine-grained sandstones of the Kiowa shale overlie the Cheyenne and Permian and are exposed in the Little Arkansas River drainage system, and at isolated points along the northern border of the Arkansas River Valley. Sandstone and highly colored clays of the Dakota formation crop out above the Kiowa in the headwater drainage of Little Arkansas River and at scattered points throughout the northern part of the county. Isolated erosional remnants of Tertiary rocks occur in at least three points in the western part of the county. Pleistocene to Recent loess, silt, sand, and gravel cover most of the area.

A generalized section of the geologic formations of this area is given in Table 1. More detailed descriptions of these units are given in the section on geologic formations and their water-bearing characteristics.

Geologic History

PALEOZOIC ERA

Records of deep drilling in Rice County have shown that a thick section of Paleozoic rocks is present above the pre-Cambrian surface. The pre-Cambrian surface has been encountered at depths of 3,240 to 4,100 feet. Marine Cambrian and Ordovician rocks were deposited over this igneous and metamorphic floor. Silurian and Devonian rocks are absent over most of the county. They either were not deposited over much of the area or were removed by erosion following the pre-Mississippian uplift of the Ellis arch. The southeastern tip of the Ellis arch extends into Rice County and pre-Mississippian rocks in part of northwestern Rice County were removed by erosion, leaving the pre-Cambrian surface exposed. Cambrian and Ordovician rocks in the southeastern part of the county

* The stratigraphic classification used in this report is that of the State Geological Survey of Kansas.

TABLE 1.—*Generalized section of the geologic formation of Rice County, Kansas*

System	Series	Subdivisions	Thickness (feet)	Character	Water Supply
Quaternary	Recent	Alluvium	0–30 (?)	Silt, sand, and gravel in a mile-wide strip along Arkansas River.	Yields brackish water to a few domestic and stock wells.
		Dune sand	0–40	Sand, medium; some fine sand and silt.	Generally above the water table. Yields water to a few wells in the large dune tracts.
	Pleistocene	Late Wisconsinan terraces	0–60	Gravel and sand; contains some silt in Arkansas River Valley and consists mostly of silt in tributary valleys to the north.	Yields large supplies of moderately hard water in Arkansas River Valley.
		Sanborn formation	0–120	Silt, massive; contains some sand and locally thick gravel and sand. (Contains Loveland, Peoria, and Bignell silt members, and Todd Valley sand member).	Does not yield water to wells in most of the area, but yields large supplies of water of good quality to wells in the area of Chase Channel and small supplies to domestic and stock wells locally.
		Meade formation	0–40±	Sand and gravel at base, locally cemented by calcium carbonate; massive silt and caliche in upper part. Locally contains volcanic ash. (Contains Grand Island and Sappa members).	Yields small supplies of moderately hard water to domestic and stock wells in northern Rice County.
		Chase Channel formation	0–70	Sand and gravel at base; silt and caliche in upper part. (Contains Holdrege and Fullerton members).	Yields meager supplies of moderately hard water to very few domestic and stock wells. Thick channel gravels contain highly mineralized water.
Tertiary	Pliocene	Ogallala	0–20	Sand, gravel, silt, and limestone.	Yields little or no water to wells in this area.
Cretaceous	Gulfian	Dakota formation	0–150	Brown, yellowish-brown, and light-gray, medium-grained sandstone and varicolored clay.	Yields moderate to large supplies of good water to domestic, stock, municipal, and industrial wells in northern Rice County.
	Comanchean	Kiowa shale	0–130	Brown, yellowish-brown and light-gray, medium- to fine-grained sandstone in upper part. Dark-gray to black fissile shale in lower part.	Upper part yields moderate supplies of good water to domestic, stock, and municipal wells. Lower part yields little water to wells.
		Cheyenne sandstone	0–40	White, light-gray, and greenish-gray siltstone and fine sandstone.	Generally yields no water to wells in Rice County

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

SYSTEM	Series	Subdivisions	Thickness (feet)	Character	Water Supply
Permian	Leonardian	Harper sandstone	0–200±	Red siltstone and very fine silty sandstone.	Yields small quantities of mineralized water to domestic and stock wells in area of outcrop.
		Stone Corral dolomite	0–30	White and light-gray anhydrite and dolomite.	Yields little or no water to wells in Rice County.
		Ninnescah shale	200–300±	Red and light greenish-gray shale, siltstone, and very fine, silty sandstone.	Yields small quantities of mineralized water to domestic and stock wells in area of outcrop.

on the flanks of the uplift were tilted and beveled by erosion. They are angularly unconformable with the overlying Mississippian rocks, which were later deposited in at least part of the area (Moore and Jewett, 1942).

The Mississippian rocks were later tilted and uplifted by the crustal movements that formed the central Kansas uplift which extends into Rice County from the north-northwest. Mississippian rocks were removed by erosion over most of the county. Tilted Mississippian rocks are encountered in the southeastern and extreme eastern part of the county on the flanks of the uplift. The area was again submerged (Moore and Jewett, 1942, p. 483), and more than 3,500 feet of Pennsylvanian and Permian beds were deposited on the beveled erosional surface of the earlier rocks. Lower Pennsylvanian beds are in contact with pre-Cambrian igneous and metamorphic rocks in parts of northwestern Rice County. Cambro-Ordovician beds overlie most of the area with Mississippian rocks in the southeastern and extreme eastern parts of the county.

Another major period of emergence and erosion followed the deposition of the Permian. Thick red shales, salt, gypsum, and anhydrite occur in the upper part of the Permian. A major unconformity at the contact of the Permian with the overlying Cretaceous rocks indicates a long period of erosion.

Mesozoic Era

The area was probably land during Triassic and Jurassic time. Deposition was renewed in early Cretaceous time when fine-grained sandstones and siltstones of the Cheyenne sandstone were deposited on the eroded surface of the Permian.

The dark marine shales of the Kiowa were deposited above the Cheyenne. At many points in the county, the Kiowa rests directly on Permian rocks. There is evidence of a minor erosional interval between the Cheyenne and Kiowa rocks.

As the comparatively shallow Kiowa seas receded, the area was covered by near-shore marine sandstone and beach deposits. Alternating marine and continental deposits near the close of Early Cretaceous time indicate near-shore conditions and an oscillating shore line. Plummer and Romary (1942, p. 342) have compared the conditions of deposition of the sandstones and clays of the Dakota, which immediately overlies the Kiowa, to conditions of sedimentation existing in the lower Mississippi River delta. In such an environment, shifting stream channels deposited sand, silt, and clay over a wide area slightly above sea level. Deposition barely balanced submergence of the land mass. Such conditions of sedimentation can be postulated for most of the Dakota formation.

That marine Cretaceous beds were deposited over the Dakota formation in the county is indicated by the presence of Graneros and Greenhorn beds a short distance to the north and west. It is estimated that at least 900 feet of Cretaceous beds were removed by erosion following the uplift at the close of the Cretaceous.

Cenozoic Era

Rice County probably was subjected to erosion during most of the Tertiary Period and by late Tertiary it was an area of low relief. Remnants of late Tertiary sediments are found in the western, northwestern, and central parts of the county. Twenty feet of partially cemented sand, silt, and gravel, capped by "Algal" limestone, is the greatest thickness of Tertiary material recorded in the county.

Renewed erosion in early Pleistocene deeply dissected this surface. Deep valleys were carved into Cretaceous and underlying Permian beds. The extent of the topographic relief in early Pleistocene time was as great as 230 feet within 5 miles, as indicated by the difference between the altitude of the top of the Tertiary and the base of the earliest Pleistocene deposits. At least four major changes in the relative effectiveness of the forces of erosion and deposition during the Pleistocene are recorded in the thick unconsolidated deposits mantling the rugged early Pleistocene topography.

History of Drainage

The development of drainage patterns in Rice County during Pleistocene time was controlled by the low base level afforded by the deep channels to the southeast. It was modified by the northward migrations of through-flowing streams from the Rocky Mountains.

At the close of the Tertiary, Rice County was an area of low relief. Before the close of the Nebraskan (glacial) Age, a low base level had been developed in the McPherson channel area to the southeast. Two streams traversing Rice County eroded to depths of about 230 feet below the top of the Tertiary. One channel cuts through only the extreme southwestern corner of the county. The other channel runs through the Chase Channel (Pl. 2, G2a), which enters Rice County at the west in T. 19 S., R. 10 W., just north of Silica and extends southeast, underlying Chase, passes just northeast of Sterling, and leaves the county in T. 21 S., R. 7 W. (Fig. 5).

Both channels follow a southeasterly course. These deep channels were partly filled during Nebraskan and Aftonian time with gravel, sand, and silt. The upper part of the silt shows some evidence of prolonged soil development.

Renewed erosion in Kansan time followed approximately the same pattern. More lateral erosion and deposition and less downcutting

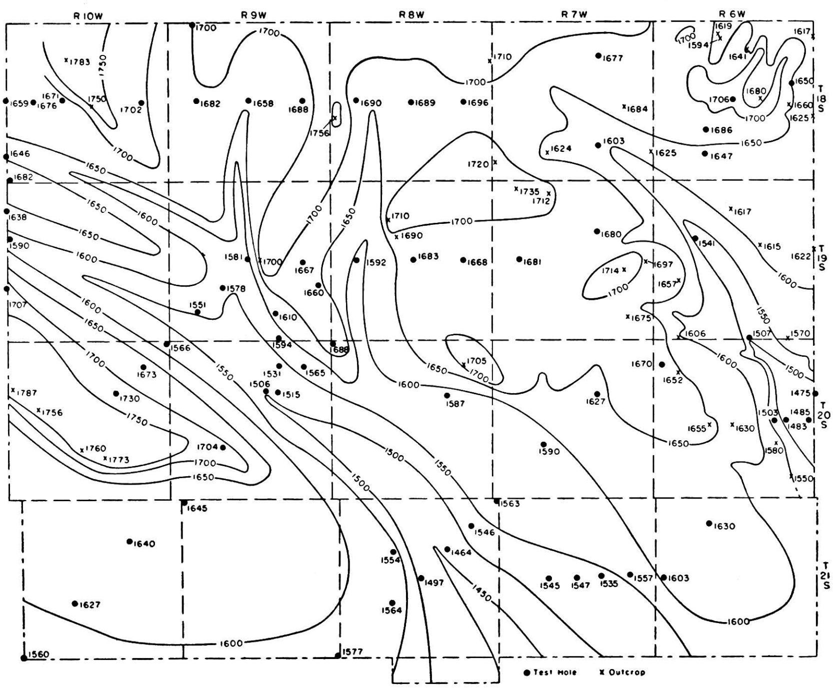

Fig. 5.—Map of Rice County showing the general topography of the Cretaceous and older rocks. Except where Cretaceous and older rocks are exposed at the surface, these contours show the base of the Pleistocene or, where present, the base of the Tertiary deposits.

was produced by Kansan streams in comparison to those of Nebraskan age. A through-flowing stream carrying gravel of the Rocky Mountain type, flowed through the southwestern part of the county. Erosion was again renewed in the Chase Channel, which was still in tributary relationship to the main drainage. Locally derived gravel was deposited in the Chase Channel and granitic gravel was deposited in the southern trunk stream. Smaller tributaries north of the Chase Channel reduced the Cretaceous bedrock to its present level over most of this area (Fig. 5).

The period from late Kansan to the beginning of Wisconsinan was mainly one of silt deposition. Loess, silt, and sandy silt were deposited over most of the area. Volcanic ash was deposited in local low areas above the sand or sandy silt. Records of erosion and channel filling in Illinoian time, if present in Rice County, are not identifiable from present data. Silt of Illinoian age rests on the silt of late Kansan age over most of the county without a recognizable intervening channel stage. Climatic changes during the Illinoian Age may have left no appreciable record in Rice County.

In early Wisconsinan time renewed erosion resulted in the capture of the ancestral Arkansas River through the Chase Channel. At the time of deposition of gravel and sand of early Wisconsinan age, Arkansas River in Rice County reached a point several miles north of its present northernmost position in Kansas. The early Wisconsinan gravel in the Chase Channel marks the northern extremity reached by a major through-flowing stream in Rice County.

In later Wisconsinan time Arkansas River abandoned the Chase Channel and migrated southward, leaving a broad alluvial plain from Lyons to the present position of Arkansas River. Remnants of three small terrace scarps below the early Wisconsinan terrace are present in this area, representing three stages of downcutting and deposition from middle Wisconsinan to Recent time.

The present northern tributaries in Rice County follow roughly the drainage patterns established in Kansan time. Cow Creek flows along the northeastern border of Arkansas River terrace deposits. In its upstream part, it flows at the extreme northern boundary of the old abandoned Chase Channel. Its pattern is an illustration of the northward migration of streams in this area. Throughout its entire course, it is bordered on the south by thick deposits of sand and gravel, and on the north by thick silt deposits filling valleys in the maturely dissected Cretaceous beds. Tributary streams are numerous north and northeast of this creek, but southern and southwestern tributaries are few and poorly developed. The explanation for this condition may lie in the difference between the permeability of the upland silt and the coarse gravel of the terrace deposits. There is very little surface runoff from the sand and gravel of the river terraces. Rain falling on the surface percolates downward and becomes part of the ground-water body. Therefore, development of streams and their consequent dissection is retarded. On the north side of the stream, the unconsolidated silt of the upland offers ideal conditions for erosion. The low permeability of the silt diverts most of the rainfall to surface runoff. The silt and loess is easily removed by downcutting, slope movement, and lateral migration of the resultant gullies and streams.

Northward shifting sand dunes on the old river terraces also act to interrupt and pond tributaries on the south. Examples of this are seen in the dune-interrupted drainage and ponding 3 miles south of Lyons, along Cow Creek south of Bushton, and south of Rattlesnake Creek southwest of Alden, especially in sec. 14, T. 21 S., R. 10 W. (Pl. 11).

A drainage map of the county (Pl. 1) shows the intricate dissection by numerous streams north of Cow Creek and a slight development of tributaries south of the creek. The abrupt northward bend in the creek in sec. 12, T. 19 S., R. 10 W. is evidence of a minor piracy of the stream by one of its own tributaries and demonstrates the general northward migration.

The present Arkansas River has a braided channel. Its channel becomes choked with sand and gravel in times of flood, and in lower-water stages the river flows through, rather than over, its pervious channel. In contrast, the northern tributary streams are actively downcutting the deep, easily eroded Pleistocene fills over which they flow. The northward migration of the ancestral Arkansas River in this area is linked with the deep valleys eroded in early Nebraskan time and the later filling of these valleys with material susceptible to erosion. In recurrent humid cycles the overloaded stream from the Rocky Mountain region was subjected to a series of captures by rapidly downcutting streams to the north.

GROUND WATER

Principles of Occurrence

The general principles of occurrence of ground water are discussed below as they apply to the rocks yielding water to wells in Rice County. For a more detailed treatment of the principles of occurrence of ground water the reader is referred to Meinzer (1923). A discussion of the occurrence of ground water as applied to Kansas was given by Moore and others (1940).

Rocks yielding potable water in Rice County are all of sedimentary origin. Most of the water available to wells occurs in the primary interstices, left between the particles or grains at the time of deposition. The large quantities of water available in the gravel, sand, and sandstone in the county are common examples of this type of occurrence. Smaller quantities of water are available to wells from the primary interstices in the finer-grained rocks, siltstone, and shales. Siltstones and shales of the Permian formations and Kiowa shale yield only meager supplies of water to many wells in the east-central part of the county. Most of the water from the finer-grained rocks, however, comes from secondary openings developed after the rocks were deposited. Openings of this type are developed by weathering along bedding planes, by fracture, and by solution of soluble minerals in the rocks.

Secondary modification of rocks after deposition also may act to decrease the size and number of interstices by compaction and by deposition of cementing materials between the grains. In many sandtsones in the Kiowa shale and Dakota formation the original interstices have been completely filled by iron minerals or calcium carbonate.

The source of water in the aquifers of the county is precipitation in the area and immediately adjacent areas. Streams in the area contribute to the ground-water recharge only at flood stage. Some of the precipitation percolates downward and reaches the zone of saturation. This is the zone in which all interconnecting interstices are filled with water. The upper surface of the zone of saturation is called the water table, except where this surface is formed by an impermeable bed. In some small areas within the county conditions of perched water table are found. This occurs when the water is interrupted in its downward percolation by a more impermeable bed above the water table and a relatively small zone of saturation is maintained, at least temporarily, at a higher level.

The percentage of the volume of a rock occupied by openings or interstices is termed its porosity, and determines the capacity of the rock to contain water. The capacity of the rock to transmit water under pressure is expressed as the permeability of the rock. The rate at which an aquifer will yield water to a well is largely dependent upon the permeability. Very fine-grained material such as silt and clay may have a high porosity and be saturated with water, but may yield little or no water to wells because of its low permeability. Sand and gravel may have a lower porosity and thus contain less water than the silt and clay, but, being more permeable because of the larger size of its openings, will transmit water readily to wells. Rocks in which the openings are so small that under ordinary conditions water will not pass through them appreciably are called impermeable.

The Water Table

The surface configuration of the water table is shown on Plate 1 by water-table contours. All points on the water table along the same contour are at equal altitude. The contours show the shape and slope of the water table in the same manner that a topographic map shows the surface of the land. The movement of ground water is at right angles to the contours in the direction of slope. The topography of the area usually controls the general shape and slope of the water table. This general surface of the ground-water body is modified by differences in the permeability of the surface and subsurface material. A hill in the water table may be found under sand-dune areas, because of the high rate of ground-water recharge made possible by the permeable nature of the sand. Examples of these ground-water highs are found in the sand-dune area north of Raymond in western Rice County and in the Hutchinson sand-dune area in the southeastern corner of the county. Depressions in the water table due to surface discharge by streams are evident wherever the stream channels are cut below the water table. Depressions in the water table may also be caused by subsurface discharge through material of higher permeability. Special examples of this condition are found in underflow conduits which consist of permeable deposits underlying surface streams and surrounded by rocks of relatively low permeability. An example of this is indicated by the broad upstream flexures of contours along Little Cow Creek. The Recent shallow alluvium of Little Cow Creek is underlain by a deeper, wider channel containing sand and gravel and separated from the present stream alluvium by a thick section of silt and clay.

The water table is not a fixed surface but rises and falls in response to varying conditions. The chief cause for these fluctuations is the irregularity in the rate at which water is added to and taken from the ground-water body. The fluctuations of the water level in five wells in Rice County and the monthly precipitation at the U. S. Weather Bureau station at Lyons are shown in Figure 6. The graphs of the water level show close correlation with the seasonal variations in precipitation. The most immediate response to precipitation was found to be in those wells in which the permeable material of the aquifer extended to the surface. The five wells were selected to show the range in variations under different topographic and lithologic conditions. Well 19-7-34ab taps a sandstone aquifer that is overlain by a thick section of relatively impermeable silt. Well 19-7-24ab is in sandstone that extends to the surface and the

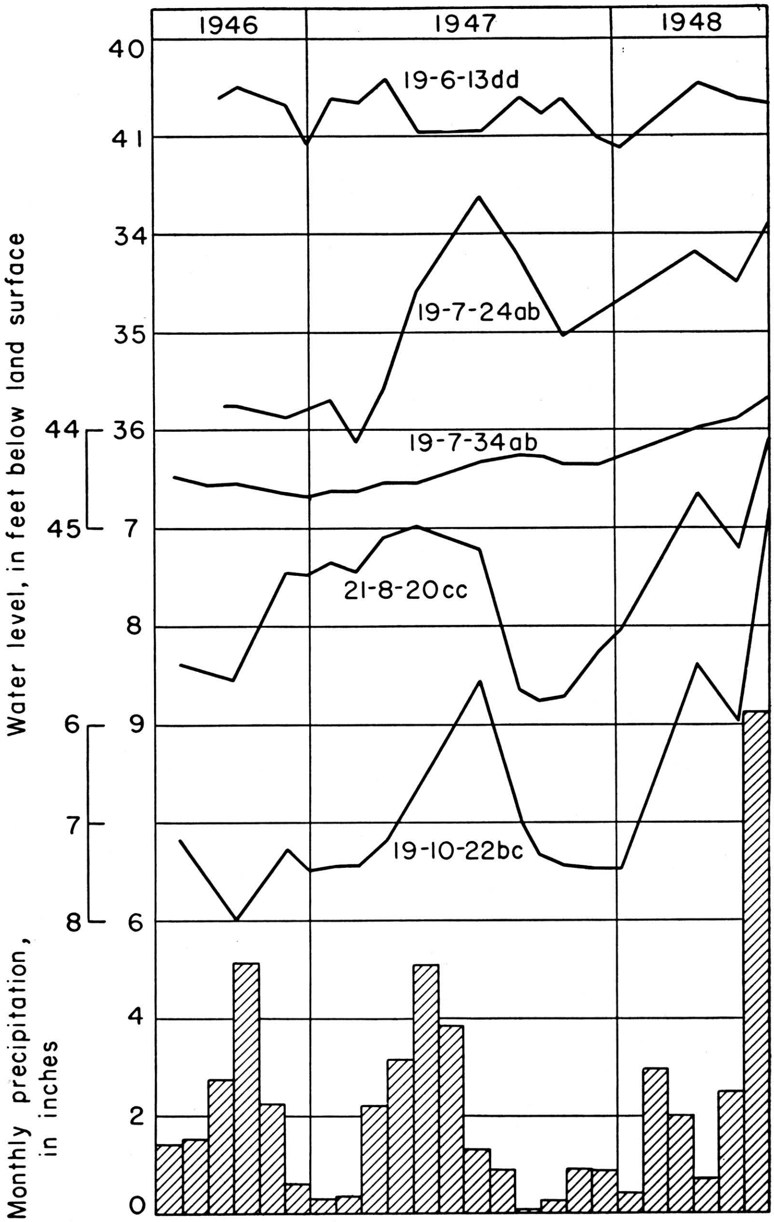

FIG. 6.—Hydrographs showing fluctuations of the water level in five wells in Rice County and monthly precipitation at Lyons.

response of the water level to precipitation is more easily discerned. Also, well 19-7-24ab is near the border of a dissected area where discharge through springs accentuates the ground-water lows. The aquifer tapped by well 19-6-13dd is siltstone which is overlain by impermeable shale. Well 20-6-23cdd has a similar siltstone aquifer and the siltstone extends to the surface. Well 19-6-13dd is in an area of gentle slope. The 11-foot rise in water level in well 20-6-23cdd from February to May 1947 was the largest rise in water level observed in wells in Rice County. Wells 21-8-20cc and 19-10-22bc are in gravel aquifers which extend nearly to the surface. Well 21-8-20cc, however, is overlain by a thin silt mantle; well 19-10-22bc is covered by thin dune sand and shows a more abrupt response to precipitation. Both wells are in undissected areas.

Records of measurements of 22 observation wells in Rice County are being published in annual water-level reports of the U. S. Geological Survey. The well numbers used in this report are correlated with those used in the annual water-level reports (Table 2).

TABLE 2.—*Observation wells in Rice County*

Well number in this report	Well number in water-level reports of U. S. Geological Survey
19-7-34ab	1
19-7-24ab	2
19-6-13dd	3
20-6-23cdd	4
20-6-36bb	5
21-6-11bb	6
18-6-13bc	7
18-7-10ad	8
18-8-10dc	9
18-9-22ad	10
18-10-2ca	11
19-10-22bc	12
20-10-28ba	13
21-9-28ad	14
21-8-20cc	15
20-9-13cc	16
19-8-9cd	17
18-8-33ba	18
19-6-17ba	19
18-6-29ddd(N)	20N
18-6-29ddd(C)	20C
18-6-29ddd(S)	20S

RECOVERY

Ground water is recovered by wells penetrating the zone of saturation or by springs developed at the outcrop of an aquifer. A few springs have been developed in the Cretaceous outcrop area in the county. All springs visited in the county are simple gravity springs. Most of them are depression springs in which dissection by streams has reached the water table and cut into permeable beds in the zone of saturation. Contact springs occur in many places where permeable beds overlie beds of low permeability. These are common at the contact of the Dakota and underlying Kiowa, where medium to coarse sandstone overlies finer sandstone or tightly cemented sandstone, and in the Dakota formation and Kiowa shale, where sandstone beds overlie relatively impermeable clay and shale. Several contact springs in the Kiowa occur at Little River Lake 2 miles west of Little River (Pl. 9B). The springs issue as seeps over a wide area, the water emerging from many openings between grains in the sandstone.

In order to increase the available supply of water, several methods of spring development are used. The method most used in the county is that of constructing dams in the drainageways below the point of issue of the spring or seep. A number of supplies of this type for stock water and recreational facilities have been developed in the Cretaceous outcrop area in the northeastern part of the county. Several depression and contact springs from dune sand and terrace deposits occur in other parts of the county, but their period of activity is usually confined to a few days or weeks following a rain. There are a few exceptions to this, notably the springs along Spring Creek east of Chase, which are reported to have flowed continuously through years of low rainfall. Extensive sand dunes and terrace deposits in the Chase area are the source for this flow. The impounded flow from these springs is used to some extent in irrigation of crops during periods of insufficient rainfall.

A common method of utilizing springs for domestic and stock use consists of concentrating the flow at the point of issue. This is done by cleaning out a small gathering pit, with walls for diverting the flow into a single channel, or by driving or boring a hole or series of lateral holes into the aquifer, and by collecting the flow into a single outlet. The permanence of springs depends upon the capacity of their reservoirs to store and transmit water. The flow of all springs in the area fluctuates with local precipitation.

Wells in the county are bored, dug, drilled, or driven. Wells can be driven from the surface into the Arkansas River alluvial deposits where not overlain by great thicknesses of silt and clay. Often the wells are dug or bored through the soil zone and silt and driven into the water-bearing sand and gravel. Most of the domestic and stock wells in the Arkansas River Valley are constructed by driving a 3-foot brass screen sand point of 1¼-inch diameter into the gravel. The 1¼-inch pipe is added in sections as the point is driven downward. The water is within suction limit of the surface over most of the valley and pitcher pumps and surface cylinders are used to some extent. It is common practice, however, to dig a pit below the frost zone to prevent the cylinder from freezing in the winter. Similar driven wells are used over much of the area of the Chase Channel. Higher yields are obtained in this material by properly constructed drilled wells.

The domestic and stock wells in the rest of the county are dug or drilled. Thirty- to fifty-inch hand-dug wells are common over most of the Sanborn and Cretaceous area. In general, wells are dug through the unconsolidated silt and to or into a sandstone zone in the Cretaceous. In many places a thin rubble zone, just above the Cretaceous rocks, yields water to the wells. Most of the domestic and stock wells developed in recent years have been drilled, usually by the percussion method. Usually the drilled wells extend farther below the water table and are less likely to fail in times of drought.

In a few places in the county, in silt and sand deposits along tributary streams, shallow wells are bored by hand augers.

Utilization

Industrial Supplies

Much ground water is used in Rice County for industrial supplies. The Missouri Pacific Railroad has an independent water supply in the City of Bushton. This supply consists of two wells penetrating sandstone of the Dakota formation. The wells are reported to be 100 feet deep and cased with 5- and 7-inch casings and are equipped with cylinder pumps. The use of water from this source is reported to range from 10,000 to 30,000 gallons a day.

Water used at the Bushton Compressor Station of the Northern Natural Gas Company is pumped from wells penetrating sandstones in the Dakota formation and Kiowa shale. Three wells are located at the plant 2½ miles east of Bushton (wells 18-9-6aa1, 2, and 3 in Table 6). The wells range in depth from 160 to 210 feet. The inner casing of the wells is reported to be of 10-inch diameter, perforated opposite the upper sandstone. The hole is uncased in the lower sandstone. At the time of completion, well 18-9-6aa1 was pumped for 10 hours at 70 gallons a minute and well 18-9-6aa2 was pumped for 10 hours at 75 gallons a minute. The average daily pumpage from the group of three wells was reported to be about 85,000 gallons.

Much ground water is used in the production of salt. The American Salt Company, south of Lyons, has three wells in the Pleistocene alluvium of Arkansas River Valley in sec. 10, T. 20 S., R. 8 W., for boiler use and for use in the brine-evaporation process. Two of these wells are reported to be 80 feet deep, cased with 12-inch perforated iron casing, and the reported pumpage is 500 gallons a minute from each well. The third well is reported to be 80 feet deep and cased with 30-inch concrete ring casing and to have a yield of 1,500 gallons a minute.

Many wells have been drilled in Rice County to supply water for oil- and gas-drilling operations. Most of these wells are cased with 8-inch steel casing. The depths depend upon the location of the well and the kind of material penetrated, but they range from about 60 to 200 feet. The average depth of these wells is probably about 80 feet. Most of the wells are abandoned and the casing pulled after completion of the oil wells, but some are kept for other uses. Records of a few of these wells are found in Table 6 at the end of this report.

IRRIGATION SUPPLIES

Irrigation has never been practiced extensively in Rice County. A few small wells are used each year for irrigating farm gardens. Other, larger wells have been used, mostly for irrigating feed crops during years of drought. All the irrigation wells visited were located in the Arkansas River Valley and their water supply originates in Pleistocene alluvium. In 1945 and 1946 none of these wells was in operation. Motors and pumps set in pits over many of these wells were flooded by a rise of the water table after two seasons of above normal precipitation, in 1944 and 1945. The wells are usually constructed with a pit or cellar for a centrifugal pump, with a hole of smaller diameter for the casing and intake pipe.

The casing diameter of the irrigation wells in Rice County ranges from 8 to 20 inches, the depth from 30 to 60 feet, and the reported yield from 200 to 800 gallons a minute. Gasoline motors or tractors are used for power. One pumping plant consists of a battery of four wells supplying a centrally located centrifugal pump. None of the pumps was in operating condition at the time of the investigation and accurate pumpage figures are not available. Records of seven irrigation wells are given in Table 6.

PUBLIC SUPPLIES

The cities of Lyons, Sterling, Chase, Geneseo, Little River, and Bushton have public water supplies obtained from wells.

Lyons.—The water supply of Lyons is obtained from two stations which pump from wells in the Pleistocene alluvium of the Arkansas River Valley. The wells are located 1¼ miles south of the city limits on Kansas Highway 14. At station 1 (well 20-8-9dd1) a battery of seven wells, 8 inches in diameter, is pumped from a single point by electrically driven centrifugal pumps. Station 2 (well 20-8-9dd2), 400 feet south of station 1, is equipped with a single gravel-packed well, 24 inches in diameter, pumped by an electrically driven turbine pump. A third well (20-8-16aa) was drilled in 1947 to supplement the supply. The water is pumped through two feeder mains into the distribution system, the excess going into a 250,000-gallon elevated steel tank. The water is moderately hard (Table 3) but is below the average hardness of water of Kansas municipal supplies. The average daily consumption is about 1,500,000 gallons.

Sterling.—A battery of seven wells (21-8-21ba) in Sterling supplies water from the Pleistocene alluvium in the Arkansas River Valley. The wells are near the municipal power plant in the north-central part of Sterling. A stand-by well (21-8-21bb) is maintained for emergency and peak use. The battery of wells is pumped by electrically driven centrifugal pumps. The stand-by well is equipped with an electrically driven turbine pump. The water is pumped directly into the mains; there are no facilities for extra storage of water. The water is moderately hard (Table 3) and contains 1.4 parts per million of fluoride. The average daily consumption is 500,000 gallons.

Chase.—One well (19-9-31), which obtains water from the Todd Valley sand and gravel, supplies Chase. The well is located in the northern part of Chase at Cedar Street and A Avenue. The well is equipped with a 250 gallon-a-minute electrically driven turbine pump. The water is pumped directly into the distribution system, the excess going into a 50,000-gallon elevated steel tank. The water is of good quality, being only moderately hard (Table 3).

Geneseo.—The City of Geneseo is supplied by three wells penetrating sandstone of the Dakota formation. The wells are located near a spring site 1½ miles north and half a mile west of Geneseo, in Ellsworth County. The wells are reported to be 10 inches in diameter and about 80 feet deep and are equipped with electrically driven turbine pumps. One well is reported to yield 77 gallons a minute with a drawdown of 30 feet at the end of a 25-hour test. The water is pumped into the distribution system, the excess going into a 50,000-gallon elevated steel tank. The water is moderately hard, but otherwise is of good quality. The average daily consumption is about 50,000 gallons.

Little River.—Little River is supplied by two wells (18-6-29dda and 18-6-29ddd), located 3 miles north of town, which obtain water from the sandstone of the Marquette member of the Kiowa shale. The north well is 55 feet deep and the south well is 48 feet deep; both were dug 15 feet in diameter and lined with concrete. The diameter of the casing is reduced to 8 feet near the water level to accommodate a gravel pack between the casing and the sandstone. Each well is equipped with a turbine pump, driven by a 3-horsepower electric motor. The wells are pumped intermittently at 50 gallons a minute. Well 18-6-29ddd was pumped 6 hours at 54 gallons a minute with a drawdown of 12 feet, at which point the water level was at the lower end of the intake pipe. The water is pumped 3 miles into Little River and into the distribution system which includes a 50,000-gallon elevated steel tank. The water is moderately hard, but otherwise is of good quality. The average daily consumption is 35,000 gallons.

Two wells, which are a quarter of a mile north of the city, are maintained on a stand-by basis for emergency and peak use. The wells are about 47 feet deep and 12 feet in diameter and are walled with brick. The water is obtained from the Pleistocene alluvium of the Little Arkansas River Valley. These wells supplied the city until 1945, at which time the wells in the Kiowa were constructed to obtain a supply of water of better quality.

Bushton.—The City of Bushton is supplied by two gravel-packed wells (18-10-2ac1 and 18-10-2ac2), located in the northern part of town, which obtain water from sandstone of the Dakota formation. The wells are reported to be 103 and 99.2 feet deep and are cased with 8-inch iron casing. Each well is equipped with an electrically driven turbine pump with a rated capacity of 70 gallons a minute against a pressure of 50 pounds. The drawdown is reported to be about 13 feet. The water is pumped directly into the distribution system, the excess going into a 50,000-gallon elevated steel tank. The water is of good quality and only moderately hard. The average daily consumption is 40,000 gallons.

POSSIBILITIES OF DEVELOPING ADDITIONAL SUPPLIES

The development of additional water supplies in Rice County depends on the saturated thickness of the water-bearing materials and the specific yield of the material. The amount of water that can be pumped perennially depends also on the periodic ground-water replenishment from precipitation, on percolation from streams, and movement of ground water into the area from the sides.

The saturated thickness of the Tertiary and Quaternary deposits in Rice County is shown in Figure 7. The contours showing satu-

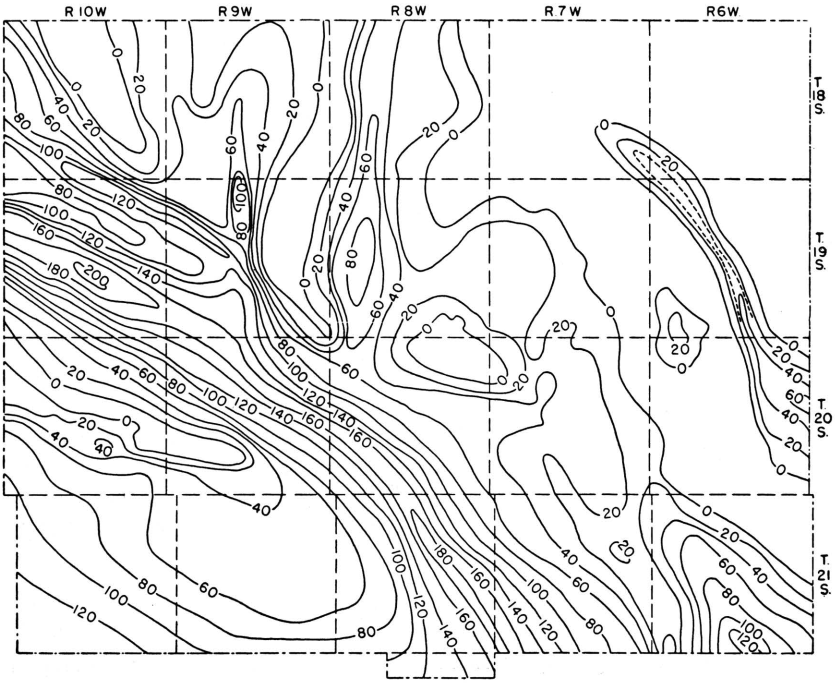

FIG. 7.—Saturated thickness of the Tertiary and Quaternary deposits in Rice County. Prepared by Glenn C. Prescott.

rated thickness were prepared by superimposing the water-table contour map (Pl. 1) on the map showing the configuration of the Pre-Tertiary surface (Fig. 5) and drawing the contours through points of equal thickness. The water-bearing materials have a saturated thickness of as much as 200 feet in Chase Channel and 180 feet in Arkansas River Valley. In part of the county, the water table occurs in the Cretaceous deposits, which are shown on Figure 7 as occurring between contour lines representing zero thickness of saturated material.

Additional wells with yields of several hundred to a thousand gallons a minute for irrigation, industrial, and municipal use could be developed at many points in the Arkansas River Valley in Rice County. Over most of the valley the static water level is not more than 10 feet below the land surface and the thickness of saturated material ranges from 50 to about 100 feet, except in the extreme southern part of the county where it has a thickness of as much as 180 feet. Ground-water recharge facilities in the valley are good. Sandy soil, sand dunes, and coarse terrace material with a hummocky topography provide ideal conditions for intake of precipitation. Ground water in excess of needs and in sufficient amount to hamper agricultural and industrial activities is a problem in years of above normal rainfall in the south-central part of this area. A high water table in the years of 1944 and 1945 caused overtaxing of the sewer system in Sterling and presented drainage problems for farms in the area.

A thickness of as much as 180 feet of saturated material is found in the Chase Channel, but careful test drilling must be done to determine the most favorable locations for wells. Large supplies can be developed in this area, but there are many areas in and near the oil fields where brine is encountered in the normally fresh-water zones. Consequently, careful sampling of the water from different gravel and sand zones is a necessary precaution before constructing expensive wells. Conditions favorable for recharge from rainfall are present over much of this area. The extensive sand dunes south and north of Chase are efficient precipitation catchment and infiltration areas.

Wells of small yield, 10 to 50 gallons a minute, can be developed over most of the rest of the county from sandstone in the Dakota and Kiowa. Where a favorable thickness of sandstone is encountered, as in the Bushton area, these rocks will yield 70 to 80 gallons a minute from properly constructed wells.

The terrace deposits of the smaller streams in the area will yield 5 to 30 gallons a minute in many places, but careful test boring is necessary to locate the irregular sand lenses. The only area where at least small potable supplies are often absent is in and near the outcrop of lower Kiowa and Permian shales east and south of Little River.

QUALITY OF WATER

The chemical character of ground water in Rice County is indicated by the analyses of 31 samples of water given in Table 3. The analyses were made by Howard A. Stoltenberg in the Water and Sewage Laboratory of the Kansas State Board of Health. The samples were collected from different water-bearing formations, and from some of the areas of possible contamination by mineralized water from industrial wastes. Analyses of all municipal supplies are given in Table 3.

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 and the State Geological Survey of Kansas.

DISSOLVED SOLIDS

Ground water dissolves some of the rock materials with which it comes in contact. The kind and quantity of these materials present in the water, which reflect the conditions of its environment, determine its suitability for various uses. Water containing less than 500 parts per million of dissolved solids generally is satisfactory for domestic use, except for difficulties resulting from hardness or from some elements that may have adverse effects when occurring in only minor quantities. Water containing dissolved solids in concentrations of more than 1,000 parts per million is likely to be unsuitable for most uses.

Determination of the dissolved solids was made for 31 samples of water from wells and test holes in Rice County. Fourteen of the samples contained less than 500 parts per million of dissolved solids, 11 contained more than 500 parts per million, but less than 1,000, and 5 samples contained more than 1,000 parts per million of dissolved solids.

HARDNESS

The hardness of water is caused largely by the salts of calcium and magnesium. These materials react with soap to form a sticky curd and also cause scale on vessels in which water is heated. Carbonate hardness, sometimes called temporary hardness, is caused largely by calcium and magnesium bicarbonates and can be removed by boiling. Noncarbonate hardness, often called permanent hardness, is caused by the sulfates or chlorides of calcium and magnesium and is not removed by boiling. Water having a hardness of less than 50 parts per million is generally considered soft and treatment for removal of hardness is usually unnecessary. A hardness of between 50 and 150 parts per million, though satisfactory for most purposes, increases the consumption of soap and causes considerable scale in boilers. If the hardness of a water is as much as 200 or 300 parts per million, it is often treated to reduce hardness to the point where it is suitable for household use. Water for municipal supplies, where softening treatment is used, is usually reduced in hardness to 60 or 80 parts per million.

Ground water in Rice County is generally quite hard. None of the 31 wells sampled yielded water with a hardness below 179 parts per million. Only 13 samples contained less than 300 parts per million and 10 samples contained more than 400 parts per million of hardness.

IRON

A small quantity of iron gives the water a disagreeable taste and causes stain on vessels in which it is heated. The presence of more than 0.3 parts per million of iron usually results in a reddish sediment which precipitates after the water is exposed to air. Iron can usually be removed by simple aeration and filtration, but a few waters require additional treatment.

A high iron content is common in Rice County ground water. Fifteen of the 31 samples collected for analysis contained more than 0.3 parts per million of iron.

FLUORIDE

Usually only small quantities of fluoride are present in ground waters. It is desirable to know the amount of fluoride in water that is to be consumed by children as fluoride in drinking water has been shown to be associated with a dental defect known as mottled enamel. Water containing about 1.5 parts per million or more of fluoride is likely to produce mottled enamel (Dean, 1936). If as much as 4 parts per million of fluoride is present, 90 percent of the children drinking the water are likely to have mottled enamel and 35 percent or more of the cases will be classed as moderate or worse. The presence of fluoride in quantities less than about 1.5 parts per million will not have a measurable effect upon the quality of tooth enamel and may have a beneficial effect in decreasing the incidence of dental caries (Dean, Arnold, and Elvove, 1942).

Water from wells 21-8-21bb and 21-8-21ba contained 1.1 and 1.4 parts per million of fluoride, respectively. Water from well 21-8-22bb contained 1 part per million. All other samples tested contained less than 1 part per million.

Sanitary Considerations

The analyses of water in Table 3 give only the dissolved mineral constituents and do not show the sanitary quality of the water. An abnormal amount of certain minerals, such as nitrates or chlorides, however, may indicate pollution of the water.

Wells in which a considerable thickness of relatively impermeable silt or clay overlies the aquifer, if properly cased and protected at the top from surface drainage, are less subject to pollution than shallow dug or driven wells or wells in which the permeable material extends to the surface. A high nitrate content is present in many poorly sealed dug wells in Rice County penetrating the Cretaceous sandstone where this formation crops out at the surface around the well.

Quality in Relation to Stratigraphy

The quality of the water in relation to the principal water-bearing formations is shown graphically in Figure 8. The softest water with the lowest mineral content is found in the late Wisconsinan terraces in south-central Rice County and in the Chase Channel. Highly mineralized water may be encountered locally, however. The mineral content is objectionable at many places near Arkansas River, in a belt 1 to 3 miles wide on both sides of the river, and is usually high at the base of gravel deposits resting on Permian shale. The sandstones of the Dakota formation and of the Marquette member of the Kiowa shale usually yield water of uniformly good quality, second only to the gravels of the Wisconsinan terraces. The sandstones of the Windom and Natural Corral members of the Kiowa and the shales and siltstones of Permian Age yield highly mineralized water.

Quality Affected by Industrial Wastes

At the request of Ogden S. Jones, geologist in charge, Oil Field Section, Division of Sanitation, Kansas State Board of Health, special attention was given to the contamination of ground water by industrial wastes in Rice County. Many water samples were collected for analysis from test holes, wells, and streams near possible

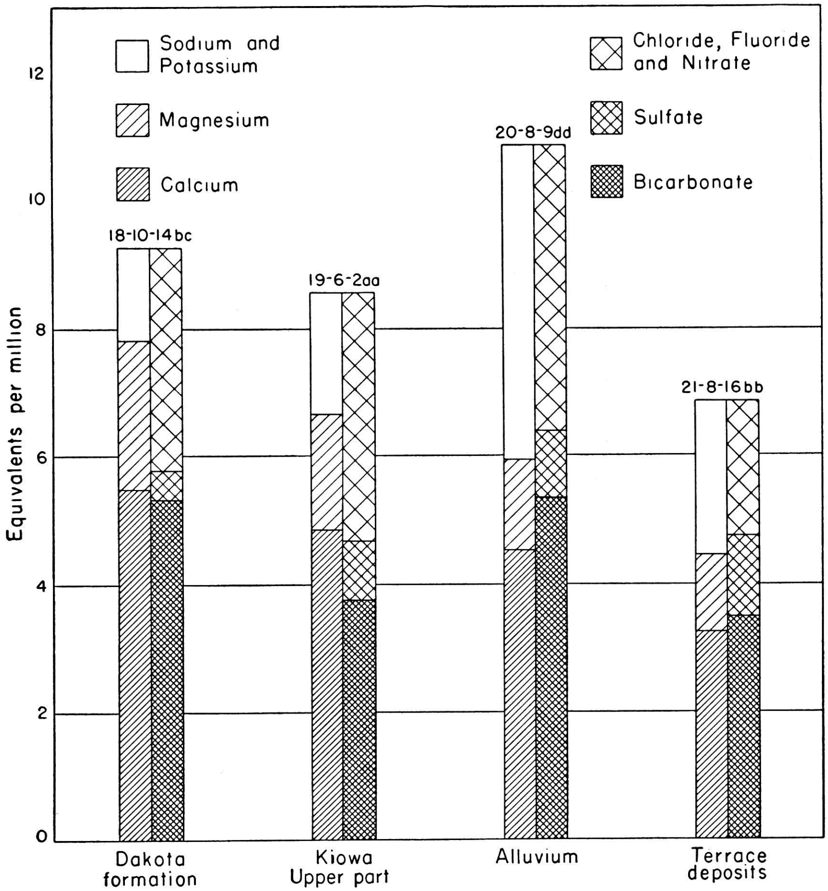

FIG. 8.—Analyses of waters from the principal water-bearing formations in Rice County.

sources of contamination by industrial wastes. Samples collected from other areas in the county served as controls and helped to indicate the amount of natural mineralization of ground water. In most of the samples only the chloride content was determined as mineralization by either natural or industrial sources in Rice County is usually indicated by a high chloride content.

TABLE 3.—*Analyses of water from typical wells and test holes in Rice County*

Analyzed by H. A. Stoltenberg. Dissolved constituents given in parts per million,[1] and in equivalents per million [2] [in italics]

Well Designation	Depth (feet)	Geologic source	Date of collection	Temperature (°F.)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$		
																Total	Carbonate	Noncarbonate
17-8-26dd	80[3]	Dakota	1- 7-47	....	274	13	0.02	73 *3.64*	6 *.49*	12 *.51*	203 *3.33*	11 *.23*	28 *.79*	0.3 *.02*	17 *.27*	206	166	40
18-6-8ba	72.2	Dakota and Kiowa	12-20-45	56	1,176	12	1.9	219 *10.93*	40 *3.29*	130 *5.66*	234 *3.84*	161 *3.35*	383 *10.80*	.7 *.04*	115 *1.85*	711	192	519
18-6-22cd	35.2	Dakota	12-17-45	54	465	20	.34	107 *5.34*	8.6 *.71*	36 *1.57*	165 *2.71*	45 *.94*	105 *2.96*	.2 *.01*	62 *1.0*	302	136	166
18-6-29dd	47.9[3]	Kiowa	3-22-46	....	289	16	.06	68 *3.39*	8.2 *.67*	17 *.73*	227 *3.72*	15 *.31*	18 *.51*	.2 *.01*	15 *.24*	203	186	17
18-7-14dd	25	do	12-17-45	51	404	9.2	.25	75 *3.74*	17 *1.40*	50 *2.18*	278 *4.56*	30 *.62*	60 *1.69*	.9 *.05*	25 *.40*	257	288	29
18-8-17cc	55.7	Dakota	12-17-45	51	590	22	.36	152 *7.58*	14 *1.15*	34 *1.49*	289 *4.74*	23 *.48*	141 *3.98*	.3 *.02*	62 *1.00*	436	237	199
18-9-1db	50	do	2-22-47	....	655	19	.70	150 *7.48*	17 *1.40*	64 *2.80*	294 *4.82*	34 *.71*	206 *5.81*	.6 *.03*	19 *.31*	444	241	203
18-9-7da	85	do	12-17-45	57	396	21	.75	93 *4.64*	10 *.82*	37 *1.59*	336 *5.51*	21 *.44*	26 *.73*	.3 *.02*	22 *.35*	273	273d	0
18-10-2ac	99[3]	do	12-16-46	....	365	16	.03	97 *4.84*	11 *.90*	20 *.87*	329 *5.40*	14 *.29*	27 *.76*	.4 *.02*	8.9 *.14*	287	270	17
18-10-14bc	95	do	12-17-45	56	500	13	4.7	110 *5.49*	16 *1.32*	56 *2.45*	324 *5.31*	22 *.46*	122 *3.44*	.7 *.04*	.62 *.01*	340	266	74
18-10-16bb	40	Sanborn	2-21-47	....	1,004	24	.23	254 *12.67*	20 *1.64*	78 *3.40*	306 *5.02*	34 *.71*	400 *11.28*	.2 *.01*	43 *.69*	716	251	465

TABLE 3.—*Analyses of water from typical wells and test holes in Rice County—Continued*

Well Designation	Depth (feet)	Geologic source	Date of collection	Temperature (°F.)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$		
																Total	Carbonate	Noncarbonate
19–6–2aa.............	12	Kiowa............	12–20–45	55	521	14	.63	97 *4.84*	22 *1.81*	44 *1.93*	229 *3.76*	44 *.92*	72 *2.03*	.4 *.02*	115 *1.85*	332	188	144
19–6–17ab............	47.3	Alluvium..........	1–13–40	....	685	29	.76	164 *8.18*	20 *1.64*	32 *1.41*	427 *7.00*	84 *1.75*	84 *2.37*	.1 *.01*	7.1 *.11*	491	350	141
19–7–6aa.............	65	Dakota...........	12–17–45	51	413	17	3.2	116 *5.79*	16 *1.32*	13 *.56*	378 *6.20*	12 *.25*	29 *.82*	.6 *.03*	23 *.37*	356	310	46
19–8–9bc.............	25	do.............	12–17–45	64	537	20	.13	129 *6.44*	12 *.99*	34 *1.46*	298 *4.89*	31 *.64*	58 *1.64*	.2 *.01*	106 *1.71*	372	244	128
19–9–15dc............	80	do.............	12–17–45	57	569	18	.59	105 *5.24*	20 *1.64*	80 *3.46*	316 *5.18*	28 *.58*	161 *4.54*	.3 *.02*	.97 *.02*	344	259	85
19–9–30dd (TH)	164	Chase Channel......	8– 2–46	61	5,431	33	.63	203 *10.13*	130 *10.69*	1,644 *71.47*	288 *4.72*	652 *13.56*	2,620 *73.88*	.6 *.03*	6.2 *.10*	1,041	236	805
19–9–31ac............	62	Todd Valley........	12–11–46	....	372	15	.08	66 *3.29*	7.6 *.62*	57 *2.49*	256 *4.20*	23 *.48*	58 *1.64*	.3 *.02*	3.5 *.06*	196	196f	0
20–6–6cd.............	24.3	Kiowa............	12–20–45	53	1,259	16	1.6	170 *8.48*	41 *3.37*	186 *8.11*	373 *6.12*	140 *2.91*	207 *5.84*	.6 *.03*	314 *5.06*	592	306	286
20–6–16dd............	....	do.............	12–20–45	58	936	15	.10	185 *9.23*	34 *2.79*	68 *2.96*	383 *6.28*	89 *1.85*	90 *2.54*	.5 *.03*	266 *4.28*	601	314	287
20–8–9dd.............	60[3]	Alluvium..........	1–14–47	....	639	21	0	91 *4.54*	17 *1.40*	113 *4.90*	326 *5.35*	49 *1.02*	156 *4.40*	.3 *.02*	3.1 *.05*	297	267	30
20–9–2dd (TH)........	106	Chase Channel......	10– 3–46	60	2,281	33	.06	177 *8.83*	74 *6.08*	551 *23.95*	274 *4.49*	346 *7.20*	960 *27.07*	.5 *.03*	4.4 *.07*	746	224	522
20–9–10cd (TH)........	118	Meade............	10–12–46	59	472	32	.11	78 *3.89*	9.8 *.80*	81 *3.53*	312 *5.12*	24 *.50*	90 *2.54*	.3 *.02*	2.5 *.04*	234	234g	0

TABLE 3.—*Analyses of water from typical wells and test holes in Rice County—Concluded*

WELL DESIGNATION	Depth (feet)	Geologic source	Date of collection	Temperature (°F.)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$		
																Total	Carbonate	Noncarbonate
21-7-15dd (TH).......	61	Alluvium...........	9-26-46	59	366	16	.27	54 *2.69*	13 *1.07*	62 *2.70*	244 *4.00*	49 *1.02*	48 *1.35*	.5 *.03*	3.8 *.06*	188	188h	0
21-7-20aa (TH)........	65	Terrace............	9-27-46	59	392	16	.25	54 *2.69*	14 *1.15*	70 *3.05*	242 *3.97*	56 *1.16*	60 *1.69*	.6 *.03*	2.7 *.04*	192	192i	0
21-8-11aa (TH)........	88	do.............	11-13-46	59	323	15	0	52 *2.59*	12 *.99*	50 *2.16*	224 *3.67*	37 *.77*	43 *1.21*	.5 *.03*	3.8 *.06*	179	179j	0
21-8-16bb (TH).......	39	Terrace...........	10- 1-46	58	390	12	.75	63 *3.14*	12 *.99*	60 *2.59*	210 *3.44*	61 *1.27*	47 *1.32*	.7 *.04*	23 *.37*	206	186	20
21-8-16bb (TH).......	87	do.............	10- 1-46	60	397	11	.66	65 *3.24*	15 *1.23*	58 *2.52*	212 *3.48*	61 *1.27*	58 *1.64*	.7 *.04*	15 *.24*	224	190	34
21-8-21ba.............	38[3]	do.............	5-31-46	....	683	15	.06	92 *4.59*	22 *1.81*	111 *4.81*	310 *5.08*	112 *2.33*	121 *3.41*	1.4 *.07*	20 *.32*	320	254	66
21-8-21bb.............	92	do.............	8-21-46	....	721	13	.04	96 *4.79*	23 *1.89*	126 *5.48*	310 *5.08*	115 *2.39*	147 *4.15*	1.1 *.06*	30 *.48*	334	254	80
21-8-22bb (TH).......	86	do.............	9-30-46	59	1,871	21	.85	221 *11.03*	60 *4.93*	314 *13.67*	222 *3.64*	847 *17.62*	292 *8.23*	1.0 *.05*	5.8 *.09*	798	182	616

1. 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.
2. An equivalent per million is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing the concentration in parts per million by the chemical combining weight of the substance or ion.
3. Composite sample of more than one well.

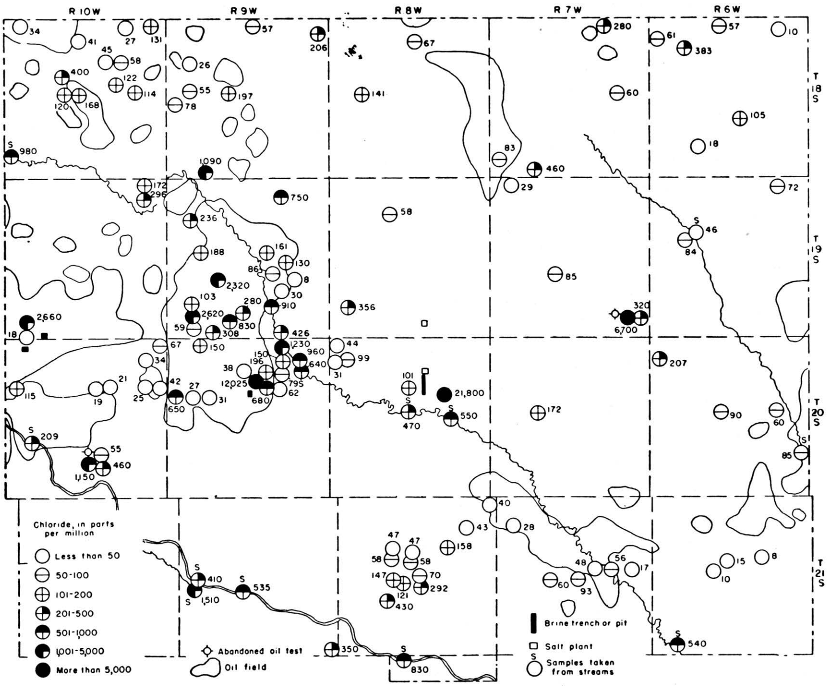

FIG. 9.—Map of Rice County showing the chloride content of water from wells, test holes, and streams.

The chloride content, in parts per million, of 119 samples of water collected in Rice County is shown on Figure 9. Possible sources of contamination are shown by symbols given in the legend. The depths of wells and test holes from which samples were taken, as well as the points sampled and their position relative to possible sources of chloride, are given in Table 4. Complete analyses of the samples collected from streams are given in Table 5.

Figure 10 shows three test holes near a surface disposal pond for oil-field brine that were sampled at several horizons, and the chloride content of the ground water in parts per million at the points sampled. A fourth test hole outside the contaminated area is included for control. At this locality three zones of sand and gravel are separated by thick silt and clay bodies. The brine-disposal ponds are constructed in silt assumed to be relatively impermeable. The brine discharged into the pits contained 12,600 parts per million of chloride. The water pumped from the test hole nearest the pits, from a depth of 36 feet, contained 12,025 parts per million of

TABLE 4.—*Chloride content of water samples collected from wells and test holes in Rice County*

LOCATION	Depth, feet[1]	Chloride, parts per million	Remarks
T. 18 S., R. 6 W.			
SE cor. NE sec. 2	....	10	
SW NE sec. 4	22.0	57	
SW cor. sec. 6	....	61	
NE NW sec. 8	72.2	383	
SE SW sec. 22	35.2	105	
SE SE sec. 29	47.9	18	
T. 18 S., R. 7 W.			
SE SE sec. 14	25.0	60	
NW NW sec. 21	....	280	
SW NW sec. 31	30.0	83	
SW SE sec. 32	58.4	460	
T. 18 S., R. 8 W.			
SW cor. sec. 3	....	67	
SW SW sec. 17	55.7	141	
T. 18 S., R. 9 W.			
NW SE sec. 1	50	206	
NW NW sec. 3	31.2	57	
NE SE sec. 7	85	26	
SW SW sec. 16	45	197	
SE SE sec. 18	50	55	
NW NW sec. 19	55	78	
SE SW sec. 32	38.8	1,090	
T. 18 S., R. 10 W.			
NE cor. NW sec. 1	90	131	
SW SE sec. 4	71.0	41	
NW NE sec. 6	59.7	34	
NE SE sec. 10	175	45	
NW SW sec. 11	30	58	
SW NW sec. 14	95	122	
SE SE sec. 14	70	114	
NW NW sec. 16	40	400	
SW SE sec. 16	38.2	168	
SE SW sec. 16	44.0	120	
NE NE sec. 22	....	326	
NW NW sec. 22	50.3	167	
T. 19 S., R. 6 W.			
NE NE sec. 2	12	72	
NW NE sec. 17	47.3	84	
T. 19 S., R. 7 W.			
NE NE sec. 6	65	29	
NE SW sec. 21	....	85	
NW NW sec. 36	22.2	6,700	Near abandoned oil well.
Do	13.4	320	
T. 19 S., R. 8 W.			
SW NW sec. 9	25	58	
SW SE sec. 30	52.8	356	

TABLE 4.—*Chloride content of water samples collected from wells and test holes in Rice County—Continued*

Location	Depth, feet[1]	Chloride, parts per million	Remarks
T. 19 S., R. 9 W.			
SE SE sec. 2	25.5	750	
NE SE sec. 7	64.0	236	
SW SE sec. 15	80	161	
SW SW sec. 17	....	188	
SE cor. sec. 20	46–48	2,320	
NE SE sec. 22	55.4	86	
SW SE sec. 23	61.4	8	
NE NW sec. 23	72.0	130	
NW NW sec. 26	69.1	30	
SE cor. sec. 27	76–78	910	
SE cor. sec. 30	44–46	103	
Do	162–164	2,620	Channeled into Permian rocks.
SE NE sec. 31	62	58	
SW SE sec. 32	....	308	
NW NE sec. 33	35	280	
SW cor. sec. 35	89–91	426	
T. 19 S., R. 10 W.			
NW NW sec. 1	88.0	296	
Do	65.0	172	
SE SE sec. 31	96.0	18	
T. 20 S., R. 6 W.			
SW SW sec. 6	24.3	207	
SE SE sec. 16	....	90	
T. 20 S., R. 7 W.			
NW SW sec. 6	47.3	31	
SE cor. sec. 20	52–54	172	
T. 20 S., R. 8 W.			
SW SW sec. 6	52	99	
NW cor. sec. 6	54–55	44	
SE SE sec. 9	60	156	
NW cor. NE NW sec. 14	65–67	21,800	Near commercial salt-producing plant.
T. 20 S., R. 9 W.			
SW cor. sec. 2	139–141	1,230	Channeled into Permian rocks.
Do	31–33	150	
SE cor. sec. 2	104–106	960	Do.
NW NW sec. 5	62.0	150	
NE NE sec. 9	....	39	
Do	38	38	
SW SW sec. 10	34–36	12,055	Near brine-disposal pond.
SE SW sec. 10	116–118	90	
SE cor. sec. 10	28–30	62	
Do	101–103	45	
Do	166–168	800	Channeled into Permian rocks.
SW SE sec. 10	188–190	945	Do.
Do	115–117	107	
Do	42–44	196	
Do	118–120	72	
Do	38–40	680	

TABLE 4.—*Chloride content of water samples collected from wells and test holes in Rice County—Concluded*

LOCATION	Depth, feet[1]	Chloride, parts per million	Remarks
T. 20 S., R. 9 W.—Cld.			
NW NW sec. 11	31	79	
NE NW sec. 17	45	31	
NE NE sec. 18	75	27	
NE NW sec. 18	50	25	
T. 20 S., R. 10 W.			
NE cor. sec. 1	28–50	67	
SW cor. sec. 1	36	34	
Do	122	28	
SE SW sec. 7	52.7	115	
SE SW sec. 9	20.51	19	
SE cor. sec. 10	78–80	21	
SW SE sec. 12	....	42	
SW SW sec. 12	62	25	
NE SW sec. 27	39.5	49	
Do	25	55	
NE SE SW sec. 27	....	460	
SW NE SW sec. 27	....	1,150	Near abandoned oil well.
T. 21 S., R. 6 W.			
SE SW sec. 16	....	10	
SW SE sec. 16	....	15	
T. 21 S., R. 7 W.			
NW cor. NE sec. 7	30	28	
SW cor. sec. 13	59–61	17	
SE cor. sec. 15	38–40	56	
Do	59–61	48	
NE cor. sec. 20	63–65	60	
NW cor. sec. 22	51–53	56	
Do	26–28	93	
T. 21 S., R. 8 W.			
NE cor. sec. 1	50–53	40	
NE cor. sec. 11	86–88	43	
SW cor. sec. 11	88–90	158	
NW cor. sec. 16	37–39	47	
Do	85–87	58	
SE cor. sec. 20	26–27	430	
NW NW sec. 21	92	147	
NE NW sec. 21	38	121	
NW cor. sec. 22	24–26	70	
Do	84–86	292	
T. 21 S., R. 9 W.			
SE cor. sec. 36	39–37	350	
Do	27–29	270	

1. Reported depths given to nearest foot, measured depths to the nearest tenth of a foot. Depth of samples taken from test holes given as interval at which screen was placed.

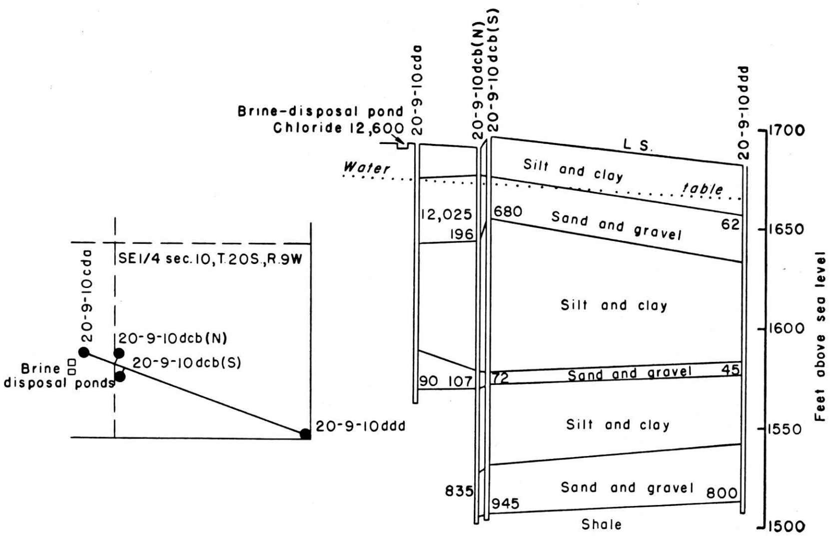

FIG. 10.—Sketch map showing the location of ponds and test holes, and cross section showing sampling points in test holes near brine-disposal ponds and chloride content of water at the horizon from which the sample was taken.

chloride. This sample was taken from the Todd Valley sand and gravel which is the aquifer for most of the farm wells in the area. The chloride content of water from this aquifer from a farm well about 1 mile northwest of this test hole was 38 parts per million. Many other samples of water from this aquifer show a low chloride content where distant from sources of contamination. Figure 10 indicates that the second aquifer (Grand Island) is not affected by the highly mineralized water. The chloride content in the lowest aquifer (Holdrege) was found to be generally high in the Chase Channel where sampled. The high chloride content in this sand and gravel may be derived from the lower Kiowa and Permian rocks which form the channel floor and sides. Surface disposal of brine at this locality is reported to have been carried on continuously from 1936 to the time of this investigation in 1946. This group of tests and other chloride analyses from wells and test holes throughout the county indicate that surface disposal pits, even though constructed in silty soil, may cause local contamination.

There are many examples of contamination by brines where surface disposal pits or ditches are constructed in sand or sandy alluvium. Surface pits in dune sand in secs. 3 and 10, T. 21 S., R. 6 W. are receiving brine containing up to 89,500 parts per million of chloride. Water wells in sec. 3, T. 21 S., R. 6 W. are reported to have been abandoned as early as 1936, because of the intrusion of objectionable salt water. In sec. 2, T. 21 S., R. 6 W., wells also are reported to have become contaminated and in one well potable water is reported to have been found in the Permian shale beneath the contaminated fresh-water aquifer. Water samples from wells located upgrade from the oil field in this locality contained only 8 to 15 parts per million of chloride.

A quarter of a mile south of Silica, in western Rice County, oil-field brines were discharged into natural depressions in the sand dunes. Residents of Silica report that brine disposal into these ponds was discontinued about a year before the time of this investigation in 1946. A water sample taken from a well at the Wolf Mill in Silica in the NE¼ SE¼ sec. 31, T. 19 S., R. 10 W., which was reported to be 76 feet deep and to end in sand and gravel, contained 2,660 parts per million of chloride. This well and others in the vicinity were abandoned after surface disposal of brines was begun in the area. One well in the SE cor. sec. 31, T. 19 S., R. 10 W., in the center of the area of contamination, which is reported to be cased to sandstone, yielded water containing only 18 parts per million of chloride. This indicates that the underlying Cretaceous sandstones in this area are probably not contaminated by the high-chloride water in the overlying unconsolidated deposits.

Several cases of contamination of ground water in Rice County are evidently the result of improperly plugged abandoned oil wells. In the NW cor. sec. 36, T. 19 S., R. 7 W., a domestic and stock well was abandoned in 1943 when it became too salty for use. The water from this well contained 6,700 parts per million of chloride in 1946. The well is in sandstone of the Marquette member of the Kiowa shale. An abandoned oil test well, just west of the salty water well in the NE cor. sec. 35, is the only known possible source for the high chlorides. The movement of ground water, as shown by the water table contours (Pl. 1), is from west to east at this point.

Brine used by salt-processing plants in Lyons is allowed to flow in a surface ditch between the plant in sec. 10, T. 20 S., R. 8 W., and the brine recovery wells in sec. 15, T. 20 S., R. 8 W. In dry seasons white saline deposits occur at the borders of this ditch and in Owl Creek, east of the ditch. Farm wells east of this ditch have been abandoned progressively eastward. Water pumped from the base of the alluvial materials in a test hole 0.8 of a mile east of this ditch and brine-recovery field contanied 21,800 parts per million of chloride in 1946. The Lyons municipal wells, about half a mile west of the brine ditch, which obtain water from the entire thickness of saturated alluvial material, contained only 101 parts per million of chloride. The movement of ground water in this area is to the southeast.

The supposed principle of operation of surface disposal pits for brine is evaporation. The evaporation of water from a free surface in Rice County during the months of highest evaporation, April to October, is about 76 inches. The average rainfall during the same period is about 21 inches. This leaves an effective evaporation from surface storage ponds of 55 inches. The two brine pits in sec. 10, T. 20 S., R. 9 W., near which the test holes shown in Figure 10 were drilled, have a combined surface area of 23,100 square feet. Assuming the same rate of evaporation as from a free water surface, these pits would lose about 791,369 gallons by evaporation. The measured rate of 7 gallons a minute for brine flowing into the ponds would add 1,814,400 gallons in the 6-month period, an excess of 1,023,031 gallons over effective evaporation in the summer months. This figure is probably low, because the brine will evaporate slower than fresh water and the surface of both pits is usually partly covered by a thin film of oil, which retards evaporation. The excess in the winter months, with a lower evaporation rate, also would be greater than the April to October excess. The excess brine must be released at the surface or seep into the soil and eventually into the underlying aquifers.

A striking demonstration of the fact that seepage into the soil predominates over evaporation as the factor in brine disposal in surface pits is found in the comparison of size of the pits in silt in sec. 10, T. 20 S., R. 9 W., which are 165 by 70 feet each, and the pit in dune sand shown in Plate 4C, which is less than 10 feet in diameter.

Data collected during the course of this investigation seem to indicate, in general, that (1) wells in areas of dune sand over materials of low permeability are most susceptible to contamination by surface discharge of brine; (2) wells in well-sorted, very permeable alluvium and near the source of contamination are affected, but wells a short distance away from the source are affected only slightly, probably because of dilution; (3) wells in silt in contaminated regions are likely to have a very high chloride content or are seemingly entirely unaffected; (4) wells in fine sand or poorly sorted sand, silt, and gravel are more likely to be affected, but dilution is greater than in silt areas.

Quality of Water in Streams

Water samples for analysis were taken from streams at 12 points in Rice County. These samples were taken at low water stage when most of the water was derived from ground water. Because each point was sampled only once, the samples may not represent the average chemical characteristics of the streams. The results of these analyses, however, are in accord with the chloride tests made on streams in this area in 1934-36 by the U. S. Bureau of Mines and the Kansas State Board of Health (Wilhelm and others, 1936, pp. 17-19). The analyses of samples taken are given in Table 5.

LITTLE ARKANSAS RIVER

Two samples were taken from Little Arkansas River. The downstream sample, taken where the stream crosses the east county line, contained a greater concentration of solids than the upstream sample, taken near the town of Little River. All minerals for which tests were made, except fluoride, increased in concentration in the downstream sample. The stream, in its headwater area, receives water of low mineral content from the sandstones of the upper Kiowa and in the lower part of its course receives water from the shales of lower Kiowa and the Permian.

COW CREEK

Five water samples were taken from Cow Creek. At the point of entrance of Cow Creek on the west county line, the stream was carrying a high concentration of dissolved solids. The concentration decreased downstream to Lyons, probably because of dilution by water from the dune sand and alluvial sand and gravel of the Chase Channel. Below the drainage from Lyons, the water contained an increased concentration of dissolved solids, increasing in sodium, chloride, and sulfate. This increase is ascribed to the municipal and industrial wastes from Lyons, which includes wastes from two salt-producing plants. The calcium, magnesium, bicarbonate, and total hardness decrease consistently downstream in Cow Creek in its course through the county.

ARKANSAS RIVER

Samples were taken from Arkansas River at four points in Rice County, and one sample was taken in Rattlesnake Creek near its junction with the river. The total hardness of water in Arkansas River decreases downstream; the calcium, magnesium, and sulfate show a consistent decrease from west to east. The dissolved solids

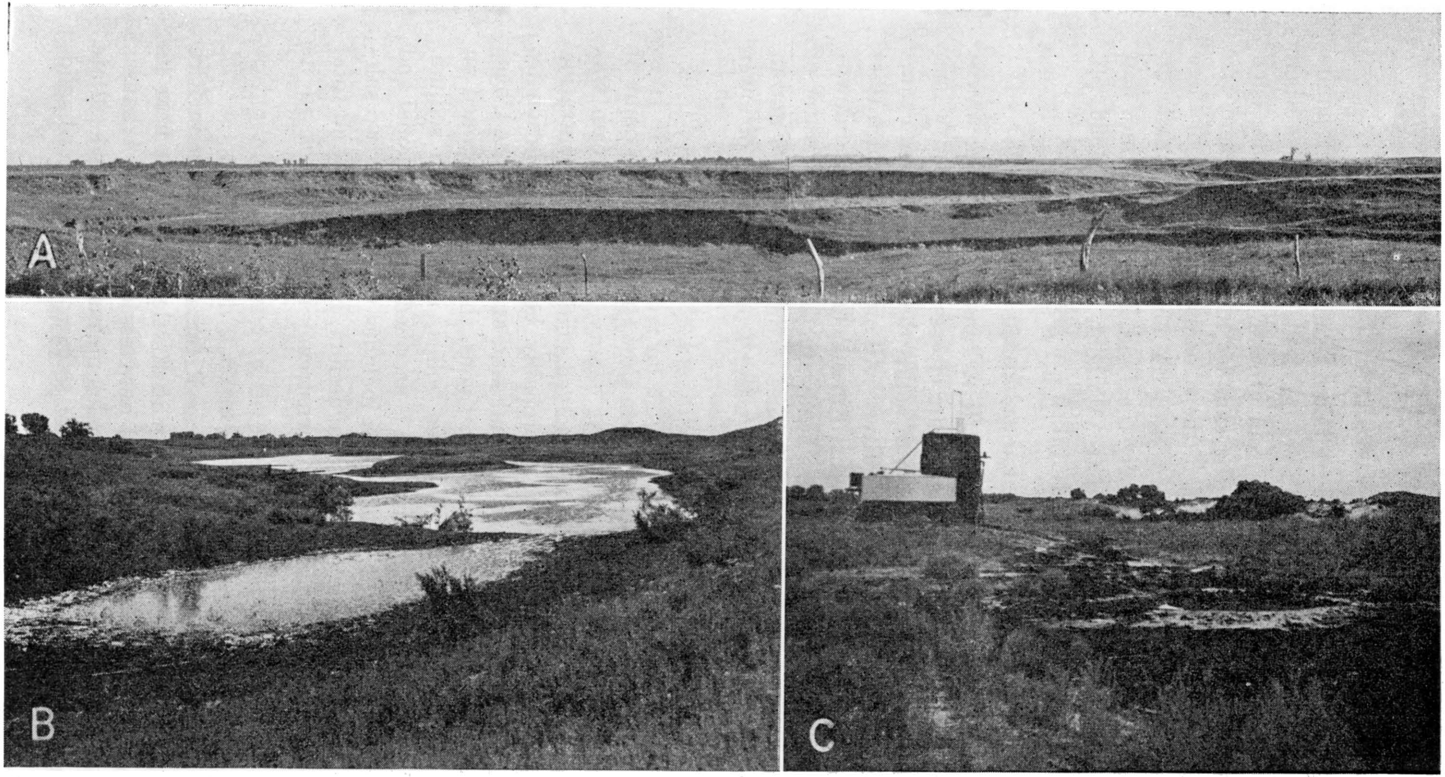

Plate 4.—*A,* Tributary stream valley in the NE¼ sec. 33, T. 18 S., R. 10 W., showing meandering stream incised into the late Wisconsinan terrace material. The flat upland typical of northern Rice County is shown by the level sky line in the background. *B,* Interdune water-table pond in the NE¼ sec. 17, T. 20 S., R. 10 W. *C,* Disposal pit in the NE¼ NE¼ sec. 10, T. 21 S., R. 6 W. Oil-field brine containing 89,500 parts per million of chloride is being discharged into a small "evaporation" pit constructed in dune sand. Farm wells in the area have been abandoned because of salt water intrusion. (Photograph by B. F. Latta.)

Table 5.—*Analyses of water from streams in Rice County*

Analyzed by H. A. Stoltenberg. Dissolved constituents given in parts per million [1], and in equivalents per million [2] [in italics]

Location number[3]	Name of Stream	Date of collection	Temperature (°F.)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$ Total	Carbonate	Noncarbonate
18-10-31bb....	Cow Creek........................	12-17-45	32	2,130	22.0	0.20	215 *10.73*	54 *4.44*	512 *22.28*	421 *6.90*	136 *2.83*	980 *27.64*	0.3 *.02*	3.6 *.06*	758	345	413
19-16-17ab....	Little Arkansas River...............	12-20-45	32	516	16	.16	124 *6.19*	20 *1.64*	43 *1.88*	461 *7.56*	38 *.79*	46 *1.30*	.3 *.02*	2.2 *.04*	392	378	14
20-6-25da.....	do............................	12-20-45	32	680	20	.84	152 *7.58*	30 *2.47*	60 *2.61*	543 *8.90*	62 *1.29*	85 *2.40*	.3 *.02*	3.0 *.05*	502	445	57
20-8-16dd.....	Cow Creek, at highway bridge south of Lyons.	12-19-45	32	1,217	19	.21	167 *8.33*	31 *2.55*	245 *10.65*	386 *6.33*	89 *1.85*	470 *13.25*	.3 *.02*	5.3 *.08*	544	316	228
20-8-23ba.....	do............................	12-20-45	32	1,347	21	.18	163 *8.13*	30 *2.47*	300 *13.06*	373 *6.12*	93 *1.93*	550 *15.51*	.3 *.02*	5.3 *.08*	530	306	224
20-9-11aa.....	do............................	12-19-45	32	1,538	24	.06	206 *10.28*	39 *3.21*	314 *13.66*	415 *6.81*	107 *2.22*	640 *18.05*	.3 *.02*	3.2 *.05*	674	340	334
20-10-19d.....	Arkansas River.....................	12-19-45	32	1,473	18	.22	175 *8.73*	54 *4.44*	245 *10.64*	303 *4.97*	618 *12.85*	209 *5.89*	.8 *.04*	3.9 *.06*	658	248	410
21-6-31dd.....	Cow Creek........................	12-19-45	32	1,242	15	.27	121 *6.04*	24 *1.97*	315 *13.68*	288 *4.72*	79 *1.64*	540 *15.23*	.3 *.02*	5.3 *.08*	400	236	164
21-9-19b......	Arkansas River, 300-yards up stream from mouth of Rattlesnake Creek.	12-19-45	32	1,724	17	.46	168 *8.38*	51 *4.19*	362 *15.75*	306 *5.02*	556 *11.56*	410 *11.56*	.7 *.04*	8.8 *.14*	628	251	377
21-9-19b......	Rattlesnake Creek, 200 yds. up stream from the Arkansas River.	12-19-45	32	3,015	18	1.4	129 *6.44*	33 *2.71*	981 *42.67*	334 *5.48*	168 *3.49*	1,510 *42.58*	.6 *.03*	5.3 *.08*	458	282	176
21-9-21bd.....	Arkansas River.....................	12-19-45	32	1,895	17	.49	167 *8.33*	51 *4.19*	434 *18.87*	315 *5.17*	526 *10.94*	535 *15.09*	.7 *.04*	9.3 *.15*	626	258	368
22-8-4ab......	do............................	12-19-45	32	2,171	17	.38	150 *7.48*	41 *3.37*	593 *25.77*	315 *5.17*	372 *7.74*	830 *23.41*	.7 *.04*	8.8 *.14*	542	264	278

1. 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.
2. An equivalent per million is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing the concentration in parts per million by the chemical combining weight of the substance or ion.
3. Location number: Numbers give the location of the stream sampling points according to General Land Office surveys and according to the following formula: Township—Range—Section, 160-acre tract within that section, and the 40-acre tract within the quarter section. The 160-acre and 40-acre tracts are designated a, b, c, or d in a counter-clockwise direction, beginning in the northeast quarter. For example: 18-6-29dd is located in SE¼ SE¼ sec. 29, T. 18 S., R. 6 W.

show a consistent rise, due to increasing amounts of sodium and chloride. Most of the added chloride and sodium is believed to come from natural sources. The sample taken from Rattlesnake Creek, 200 yards upstream from the point where it empties into Arkansas River, contained 1,510 parts per million of chloride. The source of the chloride in Rattlesnake Creek is the Permian rocks in Stafford County (personal communication from B. F. Latta, who has made a study of the ground-water resources of Stafford County).

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS

Permian System

Permian rocks of Leonardian age are the oldest rocks exposed at the surface in Rice County. These rocks crop out along the lower Little Arkansas River Valley.

Ninnescah Shale

The Ninnescah shale, the oldest formation exposed at the surface in Rice County, is composed of shale, silty shale, and siltstone in beds of alternating red and light greenish gray. Thin beds of very fine, silty sandstone and minor amounts of gypsum are present in a few exposures. Slope detritus covers most of the steep bluffs in which the Ninnescah shale occurs (Pl. 5A), but a few clean exposures are to be found along the southwestern border of Little Arkansas River Valley (Pl. 1).

The Ninnescah shale yields small quantities of hard and generally highly mineralized water to a few domestic and stock wells in Rice County in the area of outcrop and beneath the dune sand in the southeastern part of the county.

Stone Corral Dolomite

The type locality for the Stone Corral dolomite is in Rice County in sec. 11, T. 20 S., R. 6 W., where it conformably overlies the Ninnescah shale. The dolomite is massive at the base and slabby in the upper part. Numerous small clear calcite crystals in the matrix of light-gray dolomite give the rock a sandy appearance. The formation is about 6 feet thick at the outcrop (Pl. 5B), but increases in thickness westward in the subsurface to about 30 feet. Thicknesses of 30 feet of the Stone Corral, composed mostly of anhydrite, are indicated in logs and samples from oil wells drilled in western Rice County. Solution of the anhydrite by circulating ground water may

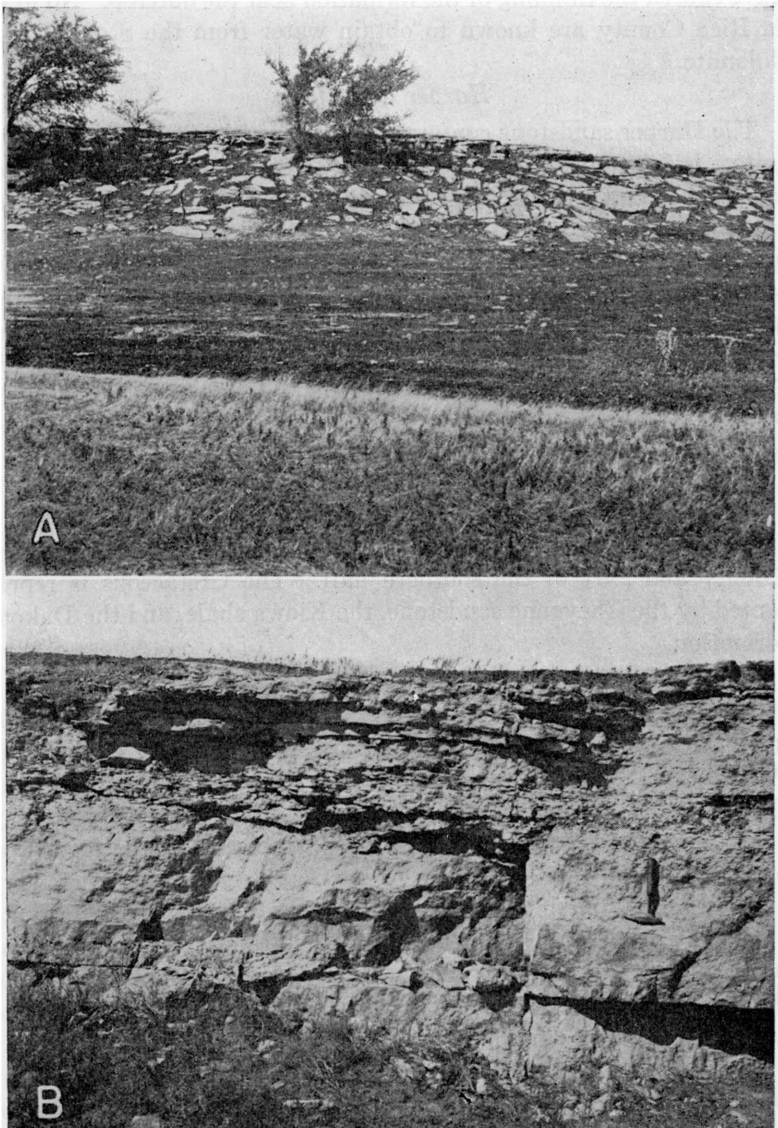

PLATE 5.—*A*, Slump blocks of the Stone Corral dolomite covering slope on the Ninnescah shale in the SW¼ NW¼ sec. 11, T. 20 S., R. 6 W. *B*, Stone Corral dolomite in quarry in the SW¼ NW¼ sec. 11, T. 20 S., R. 6 W.

have caused the thinning of the formation near the outcrop. No wells in Rice County are known to obtain water from the Stone Corral dolomite.

Harper Sandstone

The Harper sandstone conformably overlies the Stone Corral dolomite. It is composed mainly of red siltstone and very fine-grained, silty sandstone. Some light-gray to white shale and siltstone are present in most exposures. Test hole 18-6-16dd, near the eastern margin of this formation in Rice County, encountered 12 feet of siltstone, brick red with white mottling, below the Kiowa shale and above the Stone Corral. Exposures of the Harper sandstone are poor; they are found in a small gully in the SE¼ sec. 25, T. 19 S., R. 6 W., and in gullies southwest of Little Arkansas River in T. 20 S., R. 6 W. A few wells in eastern Rice County obtain meager supplies of highly mineralized water from the Harper sandstone.

Cretaceous System

Cretaceous rocks underlie most of the northern half of Rice County and part of the southern half. The Cretaceous is represented by the Cheyenne sandstone, the Kiowa shale, and the Dakota formation.

Cheyenne Sandstone

The Cheyenne sandstone is present in the subsurface in northwestern Rice County, pinching out to the southeast against the Permian rocks. The Cheyenne sandstone unconformably overlies the Harper sandstone and Stone Corral dolomite and is unconformably overlain by the Kiowa shale. Test hole samples show the formation to be composed predominantly of siltstone, containing much very fine sand and ranging in color from white through light gray to greenish gray. Minor quantities of fine-grained white sandstone containing much charcoal occur in the Cheyenne. The basal part of the formation contains variegated silty sandstone with red-brown to purplish colors predominating.

Twenty-four feet of Cheyenne sandstone was encountered on the west county line in test hole 18-11-13dd. Four miles northwest of Lyons, samples from an oil-exploration well indicate approximately 19 feet of Cheyenne sandstone. Test hole 18-8-23aa in north-central Rice County encountered 42.5 feet of Cheyenne, the greatest thickness recorded in the county. Five and a half miles east of this location no Cheyenne was found; the Kiowa shale rests directly on Permian rocks (Pl. 3, cross section B-C).

PLATE 6.—*A*, Cobble zone at base of the Cretaceous in the SW¼ SW¼ sec. 32, T. 19 S., R. 6 W. *B*, Clay conglomerate in sandstone at base of the Dakota formation in the NW¼ NW¼ sec. 24, T. 18 S., R. 6 W.

No surface exposures definitely identified as Cheyenne are known in Rice County. However, the purplish, red-brown, and greenish-gray sandstone and shale forming the matrix for a cobble zone at the base of the Cretaceous at a few localities in Rice County may be Cheyenne. An outcrop of these beds may be seen in a ravine in the SW¼ SW¼ sec. 32, T. 19 S., R. 6 W. (Pl. 6A). Cobbles from this zone are also numerous on weathered slopes in secs. 34 and 35, T. 20 S., R. 6 W. Test hole 18-8-23aa contained coarse gravel conglomerate at the base of the Cheyenne. Sandstone and shale containing fragments of plants are associated with the cobble zone in sections 27 and 28, T. 20 S., R. 6 W., and may be Cheyenne sandstone. These beds are a few feet above the near-by contacts of the Permian rocks and Kiowa shale and seem to represent inliers of the Cheyenne in the lower Kiowa shale, indicating a local unconformity between the two formations. Evidence of an unconformity, at least locally between the Cheyenne and Kiowa in southern Kansas, is mentioned by Moore and others (Twenhofel, 1924, p. 21).

A few wells in T. 20 S., R. 6 W., obtain quantities of water sufficient for domestic and stock use from sandstone which may be Cheyenne. Over most of the area of occurrence in Rice County the Cheyenne is deeply buried and consists of siltstone of low permeability, which yields no water to wells. It is generally covered by younger Cretaceous sandstones which yield adequate supplies of water.

Kiowa Shale

The Kiowa shale in Rice County is composed predominantly of dark-gray to black thin-laminated shales in the lower part and blue-gray to yellowish clay and shale in the upper part. Sandstones occur throughout, but are coarser-textured and more widespread in the upper part of the formation. Pyrite, glauconite, and marine shells are common in the sandstone beds. Marine shells are abundant also in two thin limestone beds in the lower part of the Kiowa. Along its outcrop in eastern Rice County the Kiowa shale is divisible into units which may be correlated with the members of Twenhofel's Belvidere formation in his Natural Corral section in northwestern McPherson County (Twenhofel, 1924, p. 31). Twenhofel proposed these members merely for convenience, to designate the occurrence of fossils and the stratigraphic position of exposures. The various units of the section at Natural Corral are similarly used here for local stratigraphic correlation. Regional significance to the local subdivisions is not implied.

This division of the Kiowa shale into members is applicable to the formation along the outcrop and in the subsurface in Rice County. The Kiowa-Dakota contact is arbitrarily drawn at the top of Twenhofel's Mentor member, because marine fossils are common in and below the Mentor and are not found in Rice County above this horizon. Fossil leaves of terrestrial plants occur below the Mentor of Twenhofel, but are more common in the overlying sandstone; thus the contact between the predominately marine beds of the Kiowa shale and the nonmarine beds of the Dakota formation is arbitrarily placed at the top of the uppermost zone known to contain abundant marine fossils. It is recognized that some marine beds placed in the Kiowa may be equivalent in age to, or younger than, nonmarine beds that have been correlated with the Dakota formation farther north. Intercalated near-shore marine and nonmarine deposits can be recognized in the area. The probable conditions of deposition of the Kiowa shale and Dakota formation in central Kansas have been discussed by Plummer and Romary (1942, pp. 340-347).

The horizon of the Kiowa-Dakota contact at many places in Rice County, where the fossiliferous Mentor of Twenhofel is absent, is marked by an abrupt irregular change from the fine- to medium-grained sandstone of Twenhofel's Marquette member of the Kiowa to the coarse sandstone in the lower part of the Dakota. In a few places, this basal zone of the Dakota contains cobbles and boulders of clay and shale in a matrix of soft sandstone (Pl. 6B). The underlying Marquette of Twenhofel is usually topped by a zone of highly concretionary concentrically banded, calcareous or ferruginous sandstone (Pls. 7 and 8A). Very resistant concretionary calcareous sandstone, often called quartzite (Swineford, 1947), is found also at two other zones in the Kiowa (Pl. 8B) and in the Dakota formation in other areas (Plummer and Romary, 1942, pp. 329-333). The two lower zones are in Twenhofels Windom member of the Kiowa and occur in association with, or as replacements of, the coquinas or shell beds. Also associated with the three zones of calcareous sandstone concretions are beds of cone-in-cone limestone which may occur in place of either the shell beds or quartzites. A generalized section of the Kiowa in Rice County is given below.

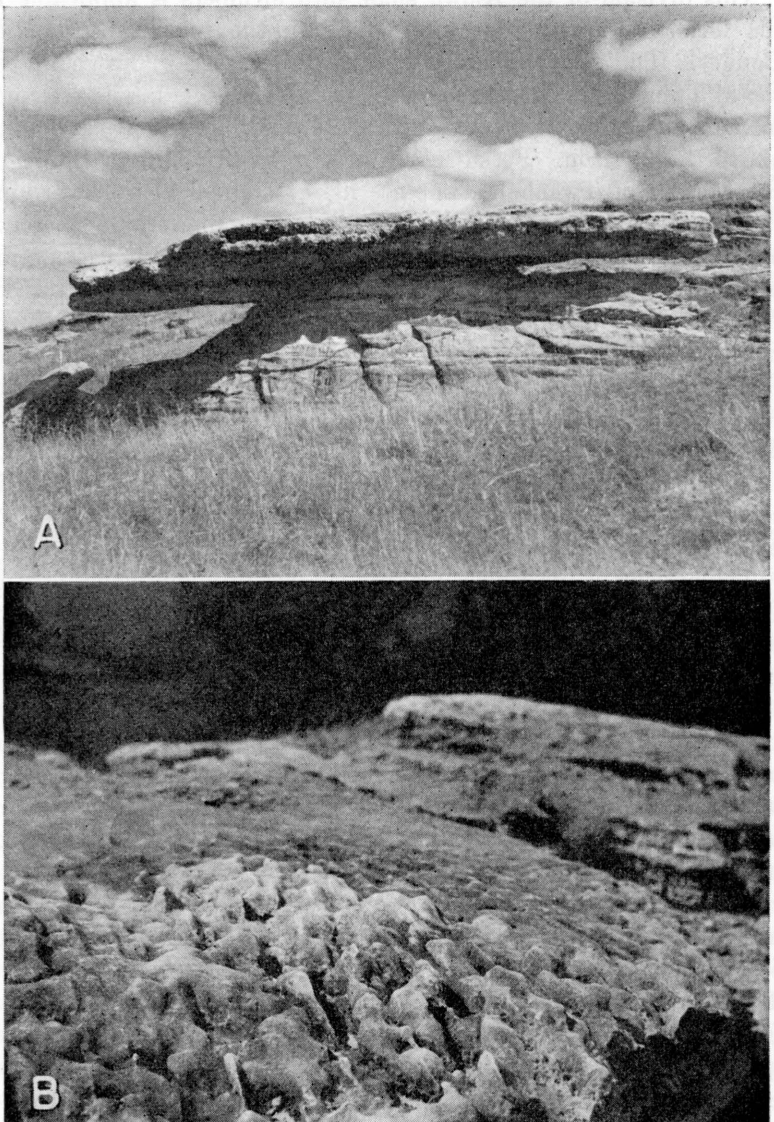

PLATE 7.—*A,* Erosional remnant of resistant calcareous sandstone near the top of Twenhofel's Marquette member of the Kiowa shale in the NE¼ NW¼ sec. 28, T. 18 S., R. 7 W. *B,* Close up of weathered surface shown in A.

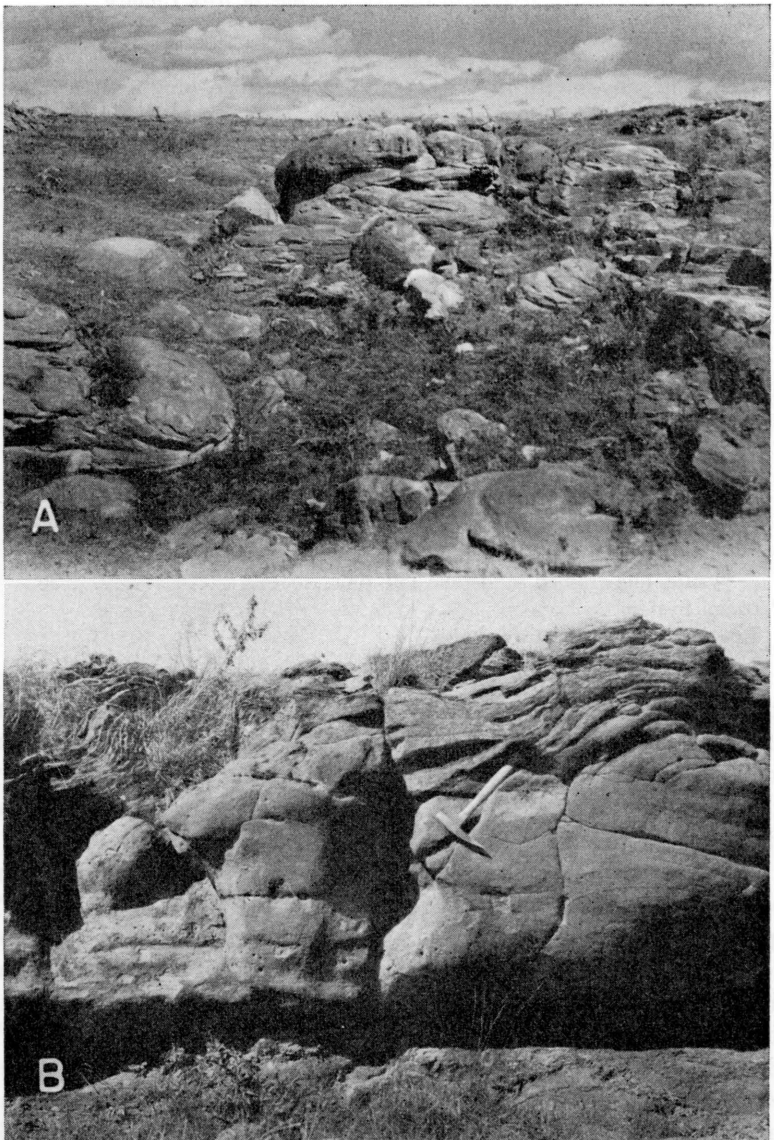

PLATE 8.—*A,* Calcareous sandstone concretions weathered from Twenhofel's Windom member of the Kiowa shale in the NW¼ SE¼ sec. 16, T. 20 S., R. 6 W. Springs issue from the base of the sandstone at this locality. *B,* Concretionary, iron-cemented zone near the top of Twenhofel's Marquette member of the Kiowa shale in the SE¼ SW¼ sec. 3, T. 18 S., R. 6 W. A zone of abundant fossils from Twenhofel's Mentor member is 5 feet above the top of this sandstone on the same slope. Many springs in this area issue from this part of the sandstone.

Generalized section of the Kiowa shale in Rice County

	Thickness, feet
Dakota formation	
Clay, blue gray, mottled red and white, or sandstone, brown, often coarse, containing boulders and cobbles of clay or shale	
Kiowa shale	
Sandstone, medium to fine. (Twenhofel's Marquette and Mentor members) Zone of calcareous quartzite concretions or concentrically banded, highly ferruginous zone often occurs near the top. Mentor fossils, where present, are in this upper strongly cemented zone. Thin cone-in-cone zone occurs sporadically above the quartzite nodules. The sandstone grades downward into yellow to blue-gray clay or shale. Sandstone and shale are often interbedded near the base	60
Shale, gray to dark gray. (Twenhofel's Windom member) A coquina limestone, and/or cone-in-cone and/or zone of calcareous sandstone concretions occur at the top and bottom of the member	20
Shale, thin-bedded, gypsiferous, dark gray. (Twenhofel's Natural Corral member) Selenite crystals are common on the outcrop. The lower part of the shale may contain thin lenses of silty, pyritic, fine-grained sandstone (Pl. 9A)	30
Permian System	
Red, gray, and blue-gray shales	

The thickness of the Kiowa shale in Rice County, as shown by logs of test holes and by the measured section, ranges from about 95 to 130 feet. The Kiowa shale is exposed extensively along tributaries on both sides of Little Arkansas River Valley and sporadically along the northern bluff of Arkansas River Valley, east of Lyons and between Raymond and Silica.

The sandstone in the upper part of Twenhofel's Marquette member of the Kiowa is an important aquifer in Rice County. Many springs issue from this sandstone and most of the farm wells in the northeastern part of the county obtain abundant supplies of relatively soft water from it. Little River Lake, 2 miles west of the town of Little River, is fed by contact springs where Twenhofel's Marquette sandstone overlies shale. Large-diameter wells in the Marquette sandstone, 3½ miles north of Little River, furnish the municipal water supply for that city (wells 18-6-29dda and 18-6-29ddd, Table 6, log 2, Table 7).

The lower shaly part of Twenhofel's Marquette member and his Windom and Natural Corral members furnish only meager supplies of highly mineralized water. The area designated S2b on the ground-water map (Pl. 2) is the outcrop area of the lower part of

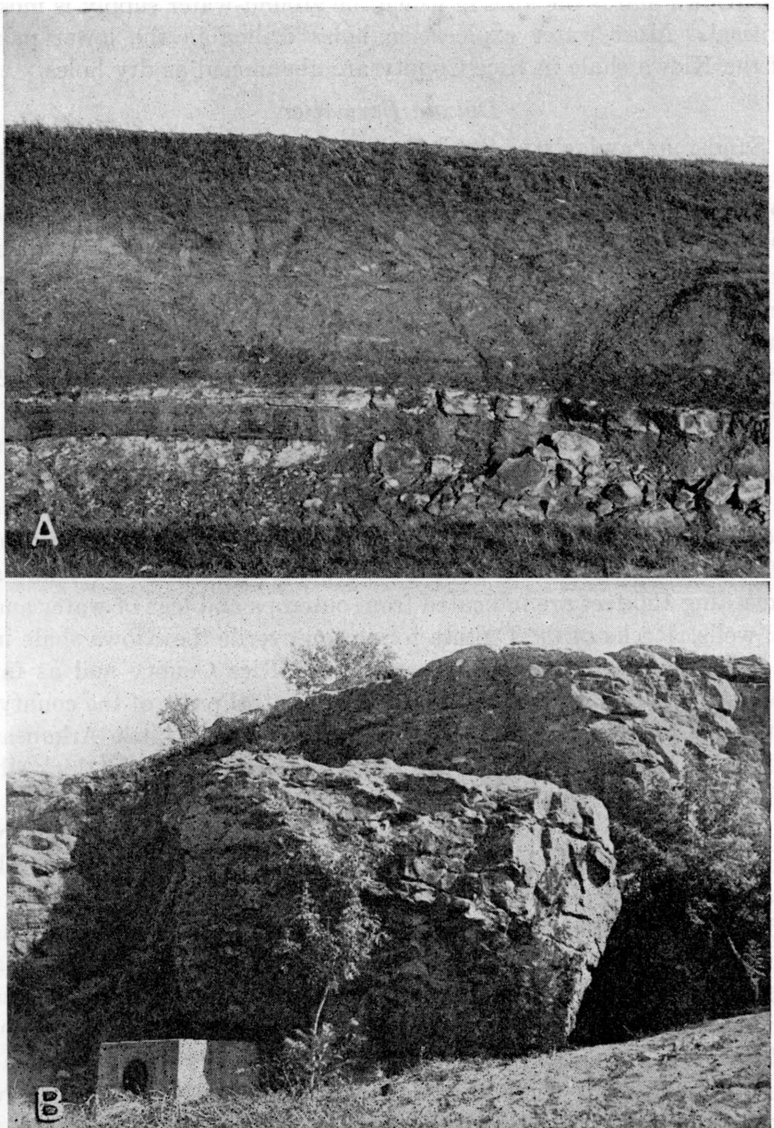

PLATE 9.—*A*, Contact between Permian rocks and overlying Kiowa shale in stream cut in the NE¼ SE¼ sec. 17, T. 20 S., R. 6 W. A sandstone lens pinching out to the left toward a local high in the Permian is 8 inches thick at the right of the picture. Sharp contact of the black fissile shale and the underlying light-gray siltstone of the Permian is seen at the left about 18 inches below the sandstone. *B*, Twenhofel's Marquette sandstone member of the Kiowa shale south of Little River Lake in the NW¼ sec. 13, T. 19 S., R. 7 W. A spring is shown at the lower left.

the Kiowa and is the area in which the ground-water supply is most critical. Most water exploration holes drilled in the lower part of the Kiowa shale in Rice County are abandoned as dry holes.

Dakota Formation

Sandstone and clay of the Dakota formation are the youngest Cretaceous rocks in Rice County. The uppermost beds of the Dakota formation do not occur in the county. In Rice County the Dakota formation is composed of variegated clay, shale, siltstone, and irregularly distributed channel sandstones. "Ironstone," highly ferruginous, hard cemented nodules or beds, is common throughout the formation. For a generalized section of the Dakota in north-central Kansas the reader is referred to Plummer and Romary (1942, pp. 328-329).

In sec. 16, T. 18 S., R. 6 W., 75 feet of the Dakota formation, mostly channel sandstone, overlies the Kiowa shale. This is the maximum thickness of the Dakota formation in eastern Rice County. No test holes were drilled through the maximum section of Dakota in northwestern Rice County, but thicknesses of Dakota exceeding 150 feet are indicated from outcrops and logs of water and oil wells. Rocks of the Dakota formation overlie the Kiowa shale in most of the northern tier of townships in Rice County and as far south as Mitchell in the east-central and central parts of the county. Outcrops are not common, however, except in the Little Arkansas River basin, because most of the Dakota is overlain by the thick silt of the Sanborn formation.

Most of the wells in north-central and northwestern Rice County obtain water from sandstones in the Dakota formation. In general, water from these sandstones is softer than water from the deposits of gravel within the county, but in many places the water contains an objectionable amount of iron. The chloride content of Dakota waters is usually higher than that of water from the gravel, but it is low enough to be satisfactory for domestic use in most of the area. Many chemical analyses of water samples from the Dakota formation are given in Table 5 and additional chloride determinations are given in Table 3. The quantity of water available from the Dakota formation, where favorable thicknesses of channel sandstone are present, is second only to the late Pleistocene channel and terrace gravels. The Cities of Bushton and Geneseo obtain municipal water supplies from the Dakota, and several industrial wells obtain yields of 50 to 70 gallons a minute from wells in the Dakota formation in the northwestern part of the county (see records of wells, Table 6).

TERTIARY SYSTEM

Ogallala Formation

The Ogallala formation in Rice County consists of gravel, sand, silt, and limestone preserved as erosional remnants lying on resistant Cretaceous beds. "Algal limestone" rubble is found on the shoulders of hills in the NW¼ SW¼ sec. 19, T. 18 S., R. 8 W., and the SW¼ SE¼ sec. 10, T. 18 S., R. 10 W., and overlies Tertiary sand and silt capping the bluff half a mile north of Raymond. The best exposure of Ogallala north of Raymond is in a road cut at the cen. N½ sec. 27, T. 19 S., R. 10 W. Test hole 20-10-10dd passed through 19.5 feet of Ogallala resting on sandstone of the Kiowa shale. This Tertiary material is composed of fine sand and gray, yellow, and greenish-gray silt with a small amount of fine gravel (Log 60).

The three small areas mentioned above are the only known occurrences of Tertiary deposits in Rice County. These beds are assigned to the Ogallala formation primarily because of the "Algal limestone" cap rock and topographic position. The limestone shows concentric banding and oölitic structure which is typical of the "Algal limestone" at the top of the Ogallala in Kansas and adjoining states. The easternmost outcrop of "Algal limestone" in Rice County is in R. 8 W. The easternmost location noted by Frye (1945, p. 90) in Ellsworth County is also in R. 8 W. The three isolated outcrops in Rice County are at approximately the same altitude, 1,750 feet, as determined by topographic maps. This corresponds with the nearly level surface postulated for the Ogallala at the time of "Algal limestone" deposition.

No wells are known to obtain water from the Ogallala formation north of Raymond, which is the only area in Rice County where Ogallala rocks of permeable nature occur below the water table.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

Unconsolidated sand, gravel, and silt deposits of Pleistocene age lie at the surface in most of Rice County. The lower part of the Pleistocene beds in the county consists of sand, gravel, and silt deposited in narrow valleys incised 150 to 200 feet below the present surface. The fillings of these deep valleys offer an unusually complete record of Pleistocene deposition.

Chase Channel Formation

The lowermost Pleistocene deposit is designated the Chase Channel formation because of its subsurface occurrence in a complete section in the Chase Channel. The type locality for the Chase Channel formation is the buried filled valley named Chase Channel from its development at the town of Chase in Rice County. The type section is well shown in test hole cuttings (no. 20-9-10dd) drilled through these deposits in the vicinity of Chase. The formation is shown in cross sections A-B, D-E, G-H, and I-J on Plate 3. Descriptions of the Chase Channel formation are given in logs 54, 55, 56, 73, and 78 at the end of this report.

The Chase Channel formation is considered to be of Nebraskan and Aftonian age and equivalent to the Holdrege and Fullerton formations of Nebraska classification for the following reasons:

1. The depth of dissection below the top of the Ogallala (230 feet in the Chase Channel) indicates that it is post-Pliocene.
2. Its position below the Meade formation of late Kansan and Yarmouthian age indicates early Pleistocene age.
3. The widespread occurrence of silt containing nodular caliche below the basal gravels of the Meade formation suggests a time of soil development prior to deposition of the Meade.
4. There is a recognizable difference between the lithology of the gravel of the Chase Channel and gravel of the Meade formation.
5. The consistent lithology of the gravel of the Chase Channel formation beneath lateral lithologic variations in the Meade indicates a major change of drainage pattern between the time of deposition of the Chase Channel gravel and the time of Meade deposition.

Holdrege member.—The basal material in these channels is medium to fine gravel and sand composed mostly of fragments of Cretaceous "ironstone, sandstone, and limestone." Many of the larger granules are fragments of Cretaceous shells. The small proportion of well-rounded granitic gravel in most of the samples was probably derived from the thin Tertiary deposits on the uplands surrounding the area and to the west. Fragments of red shale and siltstone are common in the gravel and sand where it rests on Permian rocks. The maximum thickness of this gravel and sand is 28 feet in the Chase Channel and 56 feet in the buried channel in the extreme southwest corner of the county.

Fullerton member.—The coarse channel material grades upward into a gray silty clay containing much sand. Twenty to 30 feet of this material was encountered in test holes. Tan silt, containing large caliche nodules suggestive of an illuvial zone [1] of a soil developed on fine-textured material, is present in many areas overlying the finer channel material. In a few localities this silt directly overlies the gravel. A maximum thickness of 22 feet of the silt was encountered in the Chase Channel.

Silt of an age comparable to part of the channel facies may be present in the terrace deposits of Little Arkansas River. Where exposed in a narrow strip in the SE¼ SE¼ sec. 27, T. 18 S., R. 7 W., it contains many fragments of vertebrate fossils (Pl. 10A). One tooth and several tooth fragments were identified by C. W. Hibbard (oral communication) as *Plesippus simplicidens.*

A few wells in Rice County in the Little Arkansas River terrace area obtain meager supplies of moderately hard water from basal rubble deposits which may be equivalent to part of the Chase Channel formation. No wells in Rice County obtain water from the thick buried channel gravels of this formation and water samples taken from two test holes show that the water is highly mineralized. The Chase Channel formation in most of its area of occurrence is overlain by younger gravel deposits from which adequate supplies of potable water can be obtained.

Meade Formation

The Meade formation in Rice County unconformably overlies the Chase Channel formation. It is composed of a basal gravel member and an upper silt member. The gravel member and the silt member are equivalent to the Grand Island formation and Sappa formation of late Kansan and Yarmouthian age (as classified by the Nebraska Geological Survey). The Grand Island and Sappa are assigned to member rank in this paper. The association of the Pearlette ash with the upper silt member of the Meade formation in Rice County indicates close correlation with material of late Kansan and Yarmouthian age in Kansas and adjacent states. The Pearlette ash with associated fossil zones has been traced from Texas to Iowa and established as a marker bed for correlation of this part of the Pleistocene deposits of the southern and central plains region with the northern glacial section (Frye, Swineford, and Leonard, 1948).

1. Illuvial soil contains constituents, such as colloids, added to the soil from outside sources. In contrast, eluvial soil comprises the residue of soil materials after removal of materials, such as colloids.

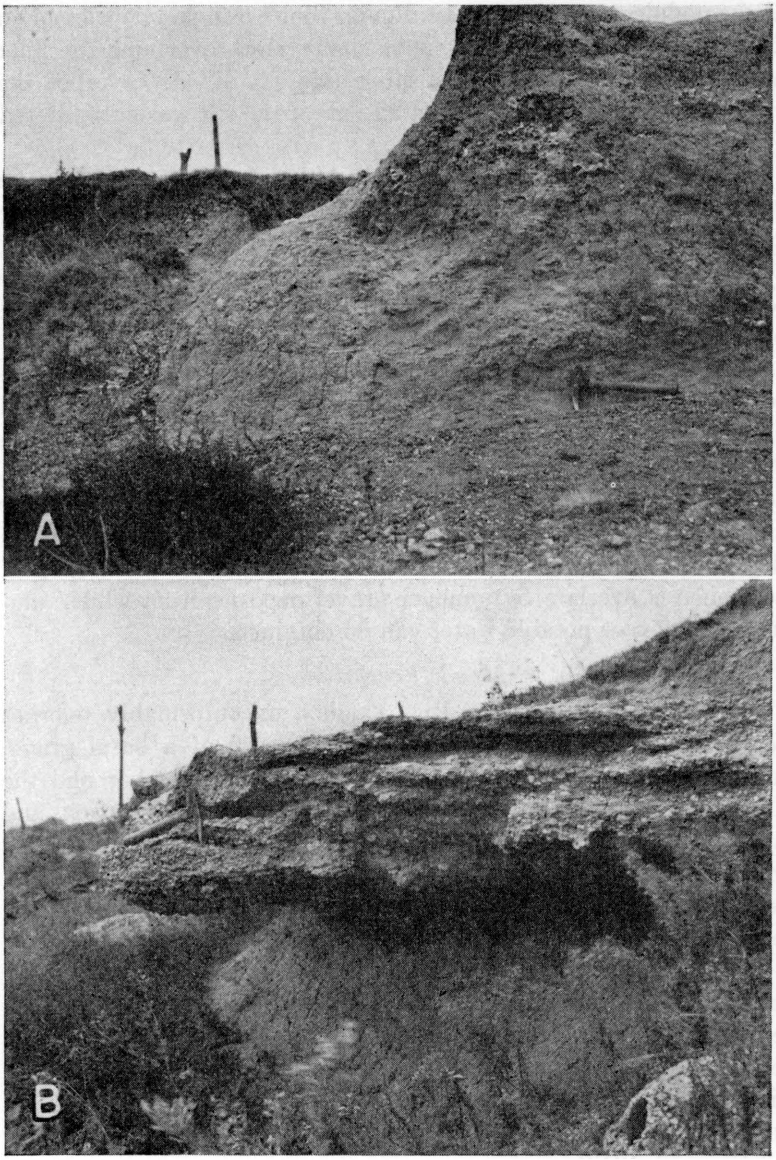

PLATE 10.—*A*, Silt of the Chase Channel formation in the SE¼ SE¼ sec. 27, T. 18 S., R. 7 W., overlying the Kiowa shale. The hammer rests on the surface of the shale. Teeth of *Plesippus simplicidens* were taken from the basal part of the silt. *B,* Conglomerate of the Meade formation in the terrace east of Little Arkansas River in the NE¼ SE¼ sec. 27, T. 18 S., R. 7 W.

Grand Island member.—Distinct lithologic differences within the Grand Island member are recognized. The more widespread gravel in the southern and southwestern parts of the county is fine to medium, composed mainly of granitic material of Rocky Mountain type. This gravel was deposited by a major stream that flowed east across the southern part of the county. The Grand Island member of the Meade formation in the northern part of the county is confined to narrow tributary channels which flowed southeastward into the trunk stream. The gravel in the tributary channels is composed of fragments of Cretaceous rocks, water-worn caliche nodules, and minor quantities of finer granitic gravel, probably representing reworked Tertiary material. This gravel resembles the gravel of the Holdrege member of the Chase Channel formation in Rice County, except for the common occurrence of water-worn caliche nodules in the Grand Island. The source of these caliche gravels is probably the nodular caliche in the Fullerton member of the Chase Channel formation. The abundance of caliche gravels in the Grand Island in most of the test-hole samples and the striking absence of this type of material in the Holdrege suggest that the Fullerton represents the earliest Pleistocene occurrence of the thick silt that was deposited under conditions favorable to the development of a widespread illuvial soil zone and the formation of abundant calcium carbonate nodules. This interpretation is consistent with the recognition of the Fullerton as the earliest interglacial deposit in the area.

The Grand Island member in the narrow Chase Channel attains a thickness of 25 feet. The thickness of the granitic facies of the Grand Island in the southwestern part of the county probably exceeds 25 feet, but accurate identification of the top of the Grand Island member in that part of the area is not possible from well samples because of its lithologic similarity to the gravel overlying, and deposited in channels cut into, the Meade. The granitic facies of the Grand Island member does not crop out in Rice County and is known only from drill cuttings from wells and test holes.

Sappa member.—The basal gravel (Grand Island member) of the Meade grades upward into sand, sandy silt, and silt classed as the Sappa[1] member of the Meade formation. Volcanic ash lentils 2 to 5 feet thick were encountered a few feet above the top of the Grand Island member of the Meade in 6 test holes in the county. This ash is identified as Pearlette ash, which occurs in the Meade forma-

1. The Nebraska Geological Survey is now using the name Sappa to designate deposits formerly called Upland (Reed, 1948); throughout this report the name Sappa will be applied to beds called Upland in earlier literature.

tion of Kansas and from Iowa to Texas. The silt is gray to tan and buff and large nodules of caliche are abundant in the upper part. It overlies the Grand Island gravel and is seemingly continuous over much of the upland area of the county. The exact thickness of the Sappa member in Rice County is not known as it is overlain by the thick tan Loveland silt member of the Sanborn formation, from which it is not distinguishable in test holes. Drill cuttings and outcrops indicate a greater concentration of calcium carbonate and development of larger nodules of caliche in the Sappa as compared to overlying silts. Positive identification of the Sappa member in Rice County, however, except in close association with the Pearlette ash, is not considered feasible from available data. Volcanic ash was encountered in test hole 20-5-18bb in the terrace area of Little Arkansas River. Lenses of conglomerate of the Meade formation are found in the terrace northwest of Little River (Pl. 10B).

Many wells in the loess-covered upland area of northern Rice County and along the Little Arkansas River terrace obtain small supplies of hard water from a zone of lag gravels of the Meade resting on the eroded surface of Cretaceous and Permian rocks. Most of the wells drilled in recent years in the central and northern parts of the upland area, however, have been drilled into the underlying Cretaceous sandstone to obtain a larger supply of water. The thicker gravel and sand of the Meade formation in the Chase Channel and Arkansas River Valley areas are overlain by later gravel and sand zones, from which adequate water supplies can be obtained. Consequently, most wells in these areas do not extend into the Meade formation. A few wells in southwestern Rice County in the uplands south of Arkansas River probably penetrate gravel of the Meade formation.

Sanborn Formation

The Sanborn formation (Frye and Fent, 1947) in Rice County is represented by three widespread silt members separated in the uplands by buried soil zones and in the major drainage ways by gravel deposits. The upland silt facies of the silt members of the Sanborn formation are considered to be largely loess of eolian and fluvio-eolian deposition. The physiographic relationships of the upland facies of this material to the valley facies indicate that wind played a major part in the transportation of this material to its point of deposition. The three silt members and associated gravel members are discussed below in ascending order.

Loveland silt member.—The Loveland silt is composed of tan to buff silt and sandy silt and is identifiable over most of northern Rice County, where a thickness of 40 to 60 feet is common on the uplands and as much as 90 feet is known to exist in the filling of the buried channel southwest of Bushton (cross section on B-C, Pl. 3). As much as 25 feet of Loveland was encountered in test holes in the Chase Channel where the Todd Valley gravel and sand member is channeled into the upper part of the Loveland member.

The well-developed Loveland soil is developed in the upper part of the Loveland silt on the uplands. This soil is easily recognized in test holes and road cuts immediately below the Loveland-Peoria contact. The best exposure in Rice County of this buried soil zone and the associated silt members of the Sanborn formation is seen in a road cut in the NW cor. SW¼ sec. 7, T. 18 S., R. 7 W., 1 mile southeast of Geneseo. A measured section of this cut is given below.

Measured section in a road cut in the NW cor. SW¼ sec. 7, T. 18 S., R. 7 W.

	Thickness, feet
Sanborn formation	
Bignell silt member	
4. Silt, light tan to yellow gray; thin soil developed at top....	1.5
Peoria silt member	
3. Silt, light tan, shows faint columnar cleavage; contains some very fine to fine sand and irregular nodules and tubules of calcium carbonate. Prominent Brady soil at top.........	6.4
Loveland silt member	
2. Silt, dark brown to gray, blocky; contains fine sand and tubules and root casts of calcium carbonate. A and upper B horizons of Loveland soil	2.0
1. Silt, tan; contains very fine sand and calcium carbonate nodules and a few snails	4.5
Dakota formation	
Clay and shale	

The Loveland silt is the most widespread member of the Sanborn formation in Rice County. It covers most of the northern half of the county and is probably present in the subsurface south of Arkansas River. The thick tan silt encountered in test holes and observed at a few exposures south of Sterling is tentatively assigned to the Loveland. In Rice County the Loveland is correlated with the Loveland silt member of northern Kansas and the Loveland formation of Nebraska.

There is little evidence of extensive channel deposition at the base of the Loveland. The channel facies, which would be equivalent to the Crete formation of Nebraska, is not identifiable in the northern part of the county. Some of the sand bodies encountered in the

Chase Channel near the Loveland-Sappa contact may represent minor Crete channeling and deposition. It is also possible that granitic gravel deposits above the Meade formation in the southern and southwestern parts of the county may be equivalent to the Crete (cross section I-J, Pl. 3). There gravel channeled into the zone of volcanic ash and probably extending beneath the Todd Valley sand gravels member (by projection) may be equivalent to Crete.

The Loveland silt is made up almost entirely of silt of very low permeability, which yields little or no water to wells. A few wells in northwestern Rice County, however, obtain water from zones of calcium carbonate accumulation in the silt of the Loveland member. Wells obtaining water supplies from the silt were found in the buried valley southwest of Bushton. This unusual water-bearing capacity of a silt is ascribed to secondary openings in a partly indurated section rather than to original permeability of the silt.

Todd Valley sand member.—The Todd Valley sand member of the Sanborn formation in Rice County is represented by coarse to fine gravel and sand channeled into the Loveland silt. The gravel is derived from granites of the Rocky Mountains. In the Chase Channel, 15 to 80 feet of sand and gravel identified as the Todd Valley sand member was encountered in test holes. The greatest thickness was found near the west county line (section A-B, Pl. 3). The sand deposit occurs over most of the Chase Channel and is preserved in the broad area of alluvial deposits between Arkansas River and the City of Lyons. Three miles south of Lyons, the north border of a terrace remnant 3 miles wide and 7 miles long is the fourth terrace above the alluvium of Arkansas River. This terrace has been dissected on the north and northwest by Cow Creek and its tributaries and on the south by the ancestral Arkansas River. The present surface of the terrace is clearly deflationary. Small low dunes are present on the terrace, but most of the surface is composed of hummocky areas of coarse sand to fine gravel lag beneath a thin soil.

Sand and gravel of the Todd Valley member yields large supplies of water of good quality to wells in the Chase Channel and in the terrace remnant 3 miles south of Lyons. The City of Chase obtains its water from a well penetrating the Todd Valley gravel and sand member (well 19-9-31, Table 6).

Peoria silt member.—The Peoria silt overlies the Todd Valley member in the Chase Channel and overlies the Loveland member over most of the uplands in the northern part of the county. This silt occurs typically as loess on the uplands where it is light gray to greenish gray in color and contains some very fine to fine sand and small nodules and tubules of caliche. The thickness in the uplands is 4 to 7 feet. The Brady soil occurs at the top of the silt. In the Chase Channel the Peoria is red-tan silt, 10 to 40 feet in thickness, and contains much sand and nodular caliche. A good exposure of valley facies of Peoria silt is seen in a cut a quarter of a mile south of Chase beneath a thin dune-sand deposit.

The Peoria silt yields no water to wells in Rice County. Over most of the county it is above the water table and in the Chase Channel it is relatively impermeable, acting as a barrier to downward percolation of water from the overlying dune sand.

Bignell silt member.—The Bignell silt is identifiable in only a few scattered localities in Rice County. About 1.5 feet of light-tan to yellow-gray silt identified as Bignell occurs in a road cut in the NW cor. SW¼ sec. 7, T. 18 S., R. 7 W. At that locality the Bignell silt has a thin soil at the top and overlies the Brady soil developed on the Peoria silt. A light-gray silt 2 to 3 feet thick overlying the soil developed on the Peoria in the Chase Channel is considered to be equivalent to the Bignell of the uplands. The Bignell in the Chase Channel area occurs north and east of the sand dunes which are west and south of the city of Chase. The Bignell silt is considered to be of late Wisconsinan age. This silt is everywhere above the water table in Rice County and yields no water to wells.

Late Wisconsinan terraces

The alluvial deposits younger than the Todd Valley member of the Sanborn formation and older than Recent alluvium are grouped together in this report as the late Wisconsinan terraces. Three terraces are identifiable between Sterling and Raymond in the broad alluvial plain north of Arkansas River. The second and third terrace borders are marked by rounded scarps 5 to 10 feet high. The first terrace is a small incipient terrace that begins in an abrupt scarp that rises 2 to 5 feet above the present alluvial plain. Over most of the valley these terrace scarps are masked by dune sand or obscured by erosion. Near Raymond, where Arkansas River is still near the northern bluff of the valley, only one terrace level is found above the flood plain north of the river. This may be equivalent to all or one of the three terraces found between Raymond and Sterling. The material in these terraces is mostly coarse to fine gravel and sand.

Pebble concentration resembling lag gravels, especially in the area northeast of Sterling, probably indicates extensive lowering of the terrace surface by wind deflation or action of streams incompetent to move the larger material (logs 70 and 73).

The broad alluvial terraces mapped along Cow, Calf, Plum, Lost, and Little Cow Creeks and Little Arkansas River are considered to be late Wisconsinan in age. The present streams in these valleys are small incompetent streams that are incised in the deep silt filling of the broad alluvial deposits (Pl. 4A). The channel fill beneath the broad terrace surfaces is much deeper than the present depth of stream scour. The late Wisconsinan alluvial plain is much wider than the present meander belt. The late Wisconsinan alluvium of Cow Creek is cut through the Todd Valley sand member of the Sanborn and into the underlying loess of the Loveland member (cross sections D-E and G-H, Pl. 3). This Pleistocene alluvium joins the third terrace in Arkansas River Valley, seemingly without a topographic break. The material that fills these deep tributary valleys is mostly sandy silt with lenses of fine to medium sand. Some coarser material is present locally.

The sand and gravel deposits underlying the Wisconsinan terraces in Arkansas River Valley yield large supplies of water of variable quality to wells in Rice County. All the larger irrigation wells obtain water from gravel of this age. The municipal wells of Sterling are located on the second terrace surface, although part of the water supply may come from pre-Wisconsinan sand and gravel. The municipal wells at Lyons are located in the late Wisconsinan terrace of Cow Creek where most of the terrace material is derived from Todd Valley and older granitic gravel. These wells probably also penetrate undisturbed Todd Valley material in their lower part.

The quality of water is determined by several factors. In the first 2 or 3 miles north of Arkansas River, the water generally has a high chloride and sulfate content. As the distance from the river increases, the chloride and sulfate content gradually diminishes. Local recharge facilities and the amount of local precipitation modify these conditions.

The effect of precipitation variations on the chloride content of the ground water under different conditions of recharge is strikingly demonstrated by a comparison of the variations in the chloride content of the municipal water of Sterling and Lyons. The source of chloride in the Sterling area is probably recharge from Arkansas River at high-water stages and the chloride in water from the Lyons

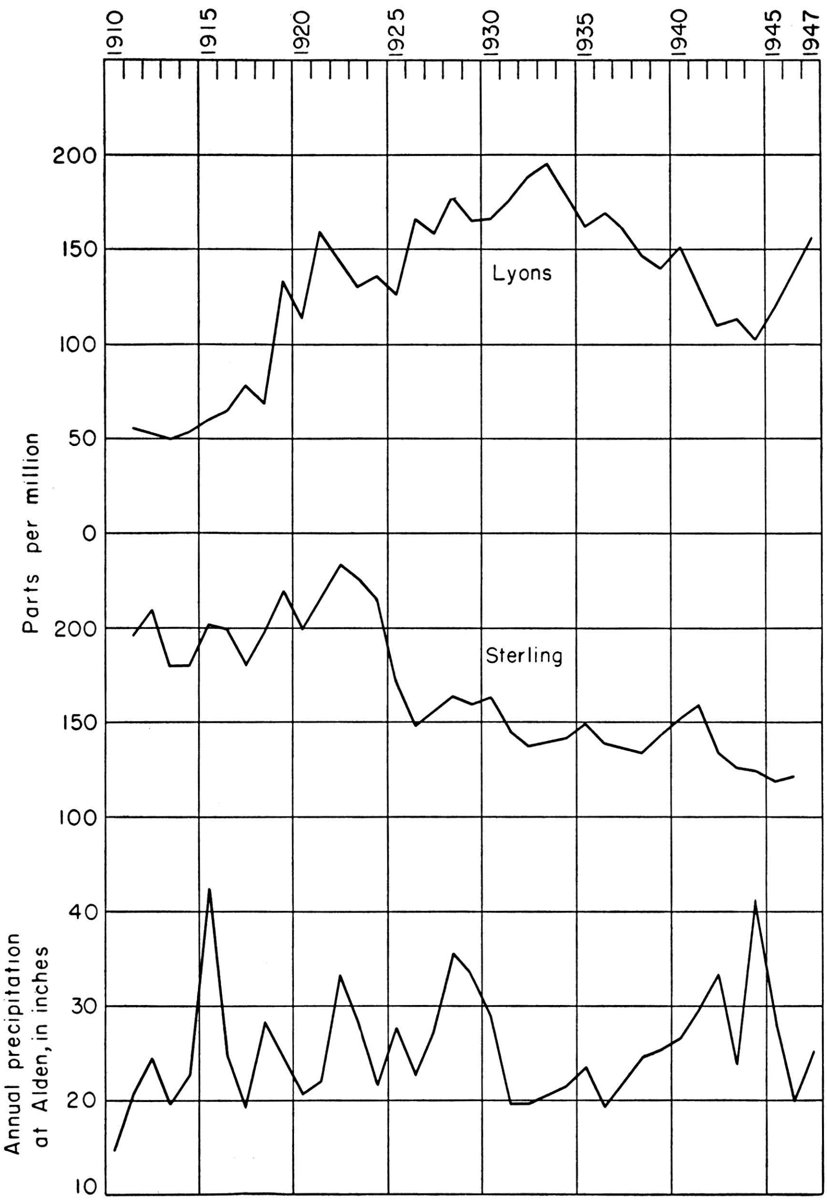

FIG. 11.—Graphs showing variations of the chloride content of water from the municipal wells at Lyons and Sterling and the annual precipitation at Alden.

municipal wells is probably from the thin zone of high-chloride water at the base of the alluvium. The original source of the chloride is the Cretaceous or Permian rocks at the sides or base of the channel.

The record of annual chemical analyses of the two municipal wells shows that the chloride content of the water from the Sterling wells tends to vary directly with annual precipiation, while the chloride content of the water from the Lyons wells tends to vary inversely (Fig. 11). These variations do not completely correspond with the precipitation variations, because the total annual precipitation figures do not always indicate either high-river stage, which raises the chloride content in the river alluvium, or the amount of ground-water recharge, which lowers, by dilution, the proportion of chloride in alluvial material farther from the river at Lyons.

The Wisconsinan terraces, mostly dune covered and with gravel near the surface in many places, offer excellent conditions for recharge from precipitation. Wells of 500 to more than 1,000 gallons a minute could be developed at many points in this broad area where adequate thicknesses of gravel are present.

PLEISTOCENE AND RECENT SERIES

Dune Sand

Some of the sand-dune deposits in Rice County are considered to be of Wisconsinan age. The dune deposits consist mostly of medium to fine sand with local deposits of gray to greenish-gray silt that probably represent areas of interdune pond sedimentation. Most of the southwestern part of the county south of Arkansas River is covered by a thin veneer of dune sand (Pl. 11). Low dunes occupy large areas on the terraces north of the river. Thicker deposits of dune sand exist in the southeastern part of the county. This area is covered by a northwestward extension of the Hutchinson dune tract. Logs 61 and 62 show thicknesses of 19 and 43 feet respectively for dunes in this area.

Three or possibly four stages of dune building, ranging in age from Peorian to Recent, are indicated in Rice County by superposition and areal distribution relative to the silt members of the Sanborn formation.

High-level dune sand exceeding 30 feet in thickness occurs on the upland area north of Raymond between Chase Channel and Arkansas River Valley. This area is underlain by resistant Cretaceous rocks which crop out on the southern bluff of the divide. Beneath

PLATE 11.—Aerial photograph of Rattlesnake Creek Valley southwest of Alden. Stream ponding by northward drifting dune sand in sec. 14, T. 21 S., R. 10 W. is seen in the center of the photograph.

the dunes and overlying the Cretaceous rocks are deposits of Pleistocene and Tertiary age, shown by test drilling to reach a combined thickness of 44 feet. A test hole in the SE cor. sec. 10, T. 20 S., R. 10 W. passed through 20 feet of dune sand and interbedded silt, 25 feet of Pleistocene silt and sand, and 19 feet of Tertiary sand and silt capped by "Algal limestone."

Outcrops along the dissected south border of the dune area show dunes resting on Cretaceous sandstones, Tertiary material, and loess of the Loveland unit with a well-developed Loveland soil. None of the large stabilized dunes in this divide area was found to overlie deposits younger than the Loveland soil, although the younger loess deposits of the Peoria unit are extensive over similar upland areas in other parts of the county and occur around the margins of the dune tract. The dunes, at least in the basal part, are therefore considered to be equivalent to the Peoria silt member of the Sanborn formation.

A thin hummocky dune area, in places a sheetlike deposit, extends northward from the high-level dunes over the Chase Channel proper. This sand overlies an eroded or deflationary surface on the Peoria silt and Todd Valley sand members, and seems to grade laterally to the northeast into the typical Bignell silt member of the Sanborn. These thinner dunes and sheet-sand deposits are considered to be the coarser-textured equivalent to part of the Bignell silt and to be reworked in part from the dune sand of the Peoria to the south.

Small tongues of dune sand extending northward from the main body of the dunes of the Bignell member overlie the late Wisconsinan terrace of Cow Creek. In secs. 32 and 33, T. 18 S., R. 10 W., a northward extension of the sand is cut by the present channel of Cow Creek.

The source of the sand forming the thick high-level dune sand of the Peoria north of Raymond may have been the Todd Valley sand unit northwest of the dunes. Sand and gravel deposits of the Todd Valley are near the surface over much of the area north and northwest of Silica and deposits of the Peoria do not overlie the sand in this area. As the nearest obvious source for this dune sand, its position relative to the place of sand accumulation indicates a prevailing northwesterly direction for the dune-building winds. The post-Peoria dunes in the Chase area seem to have been derived principally from the larger sand dunes of the Peoria, extending northward from these dunes and indicating prevailing southerly wind directions. Sharp dunes, clearly of Recent age, and some actively moving areas are evident on most of the older dune deposits and obviously are derived from blow-outs in the once stabilized dunes. Sharp coarse-textured dunes occur just south of Cow Creek, 2½ miles south of Lyons. The source of these dunes is probably the deflationary area of terrace deposits (Todd Valley) immediately south of the dunes.

A few wells in Rice County obtain water from dune sand. In the large dune tract in the southeastern part of the county, where dune sand overlies beds of Permian siltstone and shale of low permeability, wells ending in the sand are common. Even in this area, however, it is common practice to obtain water from a thin zone of rubble on top of the Permian where this is present, or to drill into the Permian shale and siltstone to avoid the mechanical difficulties attending development of wells ending in unconsolidated, medium- to fine-grained sand.

The water in the dune sand is of good quality except for excessive quantities of iron in much of the dune area near Hutchinson. The excessive iron content of water in the dune sand in the southeastern part of Rice County is indicated by the accumulation of iron around small seeps and springs near the margins of the area. The iron is precipitated by oxidation and forms a coating of iron oxide on the surface. At several localities the dune sand has become tightly cemented to form a resistant sandstone, which is often mistaken for sandstone of the Dakota formation. Sandstone of this type may be seen capping hills of dune sand in the SW¼ SW¼ sec. 18 and the SW¼ SW¼ sec. 3, T. 21 S., R. 6 W. Other less accessible exposures are found in secs. 9 and 10 of the same township. Some of these deposits are roughly oval in outline and are assumed to have been formed in the bottoms of the interdune water-table ponds which are common in the area (Pl. 48). Mud samples taken from the bottom of three water-table ponds in sec. 15, T. 21 S., R. 6 W. contained 0.74, 0.32, and 0.83 percent iron. A sample of the sandstone capping on erosional remnant of dune sand in the SW¼ SW¼ sec. 18, T. 21 S., R. 6 W. contained 15.9 percent iron.

RECENT SERIES

Alluvium

Deposits of Recent age in Rice County are confined to parts of the dune sand discussed above and to the narrow strip of alluvium along Arkansas River. These deposits are outlined by the first terrace scarp on the north and a cut terrace in the dune sand and older alluvial material on the south. Recent alluvial materials along most of the tributary streams are thin transient deposits confined to the stream channels.

Very few wells in the county obtain water from Recent alluvium. Wells in Arkansas River alluvium yield water that is objectionably high in chloride and sulfate.

GROUND-WATER REGIONS OF RICE COUNTY

For purposes of discussion of the ground-water resources of Rice County, the county has been divided into two major ground-water subdivisions—the Great Bend Prairie province and the Smoky Hills Upland province. These two provinces are divided into regions and areas, in each of which the ground water occurs under similar conditions. The provinces, regions, and areas in Rice County and the symbols shown on Plate 2 are as follows:

Symbols used for ground-water discussion

Division	Symbol used on Plate 2
Great Bend Prairie province	G
Arkansas River Valley region	G-1
Chase Channel region	G-2
Channel gravel area	G-2a
Cow Creek terrace area	G-2b
Channel border area	G-2c
Little Arkansas River Valley region	G-3
Alluvial terrace area	G-3a
Silt terrace area	G-3b
Smoky Hills Upland province	S
Mantled upland region	S-1
Upland loess area	S-1a
Hutchinson dune-sand area	S-1b
Dissected border region	S-2
Cretaceous sandstone area	S-2a
Lower Kiowa shale area	S-2b
Permian shale and siltstone area	S-2c

Great Bend Prairie Province (G)

The Great Bend Prairie province shown by the prefix G on Plate 2 is characterized by a low-lying flat or gently rolling surface of thick, unconsolidated fill. Stream erosion has removed the Tertiary-capped upland and reduced the Cretaceous and Permian rocks to the low base level afforded by the valleys to the southeast. The lowlands were later covered with gravel, sand, and silt carried into the area by stream and wind action to produce broad depositional plains.

The Great Bend Prairie province has been subdivided into three ground-water regions, namely, the Arkansas River Valley region, G-1; the Chase Channel region, G-2; and the Little Arkansas River Valley region, G-3.

ARKANSAS RIVER VALLEY REGION (G-1)

Most of southern Rice County west of the Hutchinson dune-sand area is placed in the Arkansas River Valley region, because of the similarity of origin of the alluvial material composing the aquifers and the uniform depth to water over the entire region. The area embraces terrace deposits of early to late Wisconsinan age and buried channel deposits of early and middle Pleistocene age (cross sections D-E and G-H, Pl. 3). Adequate supplies for industrial, municipal, and domestic use can be developed at almost any point in this region. Wells yielding 500 to more than 1,000 gallons a minute have been developed at several points in the Arkansas River Valley. Dune sand, terrace sand, and gravel exposed at the surface provide excellent facilities for recharge from precipitation. The water table is from 7 to 10 feet below the surface in most places, although it may range to about 30 feet beneath some of the higher terrace surfaces and more than 40 feet below the high sand dunes. The water table fluctuates greatly in response to local precipitation. The annual change in water level near Sterling and Alden has been as much as 4 feet.

The quality of water in this area is discussed under Late Wisconsinan terraces in the section on geologic formations and their water-bearing properties.

CHASE CHANNEL REGION (G-2)

The Chase Channel region is essentially an extension of conditions in the Arkansas River Valley region, but is at a higher altitude and includes areas with different lithology and ground-water conditions. It is separated from Arkansas River Valley by the upland divide on the southwest and constitutes an independent precipitation catchment and ground-water basin region.

Channel gravel area (G-2a).—Pleistocene channel deposits in the Chase Channel area are shown on cross sections A-B, D-E, and G-H (Pl. 3). There are three channel zones above the consolidated rocks. The lowermost zone (Holdrege) yields highly mineralized water and is not used for water supply in this area. The middle zone (Grand Island) yields potable water but is generally not exploited because abundant supplies are available in most places from the overlying gravel (Todd Valley). This upper gravel is the aquifer for most of the wells in this area and yields large supplies of moderately hard water. The municipal well at Chase obtains its supply from this gravel. The water table ranges from a few feet to about 20 feet below the surface in most of the area.

Cow Creek terrace area (G-2b).—The Cow Creek alluvial terrace contains poorly sorted silty sand and gravel which yields small supplies of water, generally adequate for domestic and stock use. These water-bearing beds are usually encountered between 20 and 60 feet below the surface. The water level in wells in this area ranges from a few feet to about 20 feet below the surface.

Channel border area (G-2c).—Small supplies of water are obtainable from a variety of aquifers in the Channel border area. Some shallow wells end in dune sand. Others get small supplies from poorly sorted fine-grained slope deposits. Many wells in this area are drilled into the underlying Cretaceous rocks, especially where oil-field brines have contaminated the upper aquifers. The depth to water varies widely owing to the uneven topography. Depths of 2 and 58 feet below the surface have been recorded. Fluctuations of the water level are large. The water level in most wells in the area shows a marked response to precipitation, owing to the good recharge facilities afforded by the dune sand. Interdune low areas may contain water-table ponds for years during a humid cycle which go dry in years of insufficient precipitation.

LITTLE ARKANSAS RIVER VALLEY REGION (G-3)

The part of the Great Bend Prairie, known as the Little Arkansas River Valley region is distinct from the rest of the lowlands of Rice County in that the alluvial material of the valley fill is derived entirely from rocks in the valley sides and headwater drainage area within the county. The sediments found in the valley are mostly fine grained and poorly sorted.

Alluvial terrace area (G-3a).—Moderate supplies of hard water are available from the medium to fine sand in the alluvial terrace of Little Arkansas River. The old Little River municipal supply was obtained from large-diameter wells in this material. The thickness of the alluvium is 30 to 50 feet over most of the area, and the water table is 10 to 20 feet below the land surface in most places.

Silt terrace area (G-3b).—The wide loess-covered terrace deposits, mostly east of the present Little Arkansas River, contain irregular lenses of poorly sorted, locally derived sand and gravel. Many test holes drilled in this material, especially toward the eastern margins in Ts. 19 and 20 S., fail to encounter water-bearing beds. The thickness of the terrace fill, including the overlying loess, ranges from 90 feet to a featheredge at the margins.

Smoky Hills Upland Province (S)

Areas in Rice County included in the Smoky Hills Upland province are shown on the ground-water map (Pl. 2) and are indicated by the prefix S in the area index number. This province is made up of those areas that have been dissected by Pleistocene erosion, but have not reached the level of erosion of the central low-lands. It is the transition zone from the High Plains and is characterized by uneven to rugged topography of the dissected Cretaceous rocks and by isolated erosional remnants of the High Plains surface.

MANTLED UPLAND REGION (S-1)

This region, comprising most of the Smoky Hills Upland province in Rice County, is characterized by a mantle of late Pleistocene eolian deposits which mask the character of the dissected Cretaceous rocks of the Smoky Hills Upland. Only the altitude of the area, relative to the lowlands, and the occasional exposures of resistant sandstone which project above the mantle rocks reveal the nature of the region. This region includes all the high-level loess and dune-sand tracts. The Raymond sand-dune area, just north and northwest of the town of Raymond, belongs in this region in the physiographic division of the county. It is not differentiated on Plate 2 because the water-bearing characteristics of the Raymond sand-dune area are intimately related to other features.

Several small isolated areas, which should be included in the dissected border region, are not differentiated on Plate 2, but are shown on the geologic map, Plate 1, as Cretaceous outcrop areas.

Upland loess area (S-1a).—The Upland loess area is the largest ground-water division of Rice County. This area is characterized by a thick silt mantle which overlies the water-bearing material. The silt rests on the irregular surface of Cretaceous sandstone, clay, and shale. The most extensive aquifer in the area is the underlying Cretaceous sandstone, although many wells, especially the older dug wells, obtain water from a rubble zone at the base of the silt. This rubble zone is a lag concentrate of Cretaceous sandstone, "ironstone" fragments, and caliche nodules.

Near present small intermittent or temporary streams, irregular lenses of sand and locally-derived gravel in Pleistocene alluvial channels yield water sufficient in quantity for domestic and stock wells. The depth of Pleistocene channeling in the valleys of these now incompetent streams is illustrated in Little Cow Creek Valley, on cross section E-F on Plate 3 and log 26 (Table 7).

In the northwestern part of this area, wells of moderate yield (30 to 70 gallons a minute) can be developed from thick channel sandstones underlying the silt. In a few places channel sandstones are absent in the entire section of underlying Cretaceous rocks, and ground-water supplies are meager.

Over most of the area the thick silt mantle acts as a confining bed over the aquifers and water rises as much as 30 feet when the water-bearing beds are encountered.

Hutchinson dune-sand area (*S-1b.*)—This dune area is separated from other dune tracts in Rice County because it rests on material of low permeability and therefore is locally important as a source of water. The dune sand rests on silt and Permian shale, separated in places by a thin rubble zone. The dune sand yields relatively soft water to wells, but the water generally contains an objectionable quantity of iron. A few wells in this area are drilled into the Permian shale to avoid the mechanical troubles involved in developing water supplies from unconsolidated fine to medium sand and in the northeastern part of the area to avoid water polluted by oil-field brines discharged into the sand. The depth to water ranges from a few feet to more than 50 feet, owing to the irregularity of the dune topography.

DISSECTED BORDER REGION (S-2)

This region is characteristic of the Smoky Hills Upland province. The eroded surface of Cretaceous and Permian rocks is at the surface or under a very thin cover of mantle rock. Most of the region is characterized by rugged topography and rocky slopes. The depth to water throughout the entire region varies widely owing to the uneven topography.

Cretaceous sandstone area (*S-2a*).—A number of outcrop areas of Cretaceous sandstone are included in this designation. Sandstones in the lower part of the Dakota formation and the upper part of the Kiowa shale generally provide abundant supplies of relatively soft water to wells in this area. Springs are common and small valley fills yield water to shallow wells. The new wells of the Little River municipal supply are located in this area.

Lower Kiowa shale area (S-2b).—The outcrop area of the Kiowa shale is the largest area in the county that is nearly devoid of groundwater in quantities sufficient for domestic use. The dark-gray shale of the lower part of the Kiowa yields very little water to a few wells in the area. Cisterns for domestic supply and ponds for stock supply are common. Exceptions to this are the few wells in small alluvial fills or streams, a few wells obtaining highly mineralized water from the underlying Permian, and wells in the southern-most part of the area, in the south-central part of T. 20 S., R. 6 W., where some Cretaceous sandstone zones occur just above the Permian rocks.

Permian shale and siltstone area (S-2c).—This area ranks next above area S-2b in dearth of available ground water. The Permian shales and siltstones have low permeability and yield small supplies of highly mineralized water to wells. Wells in this area are mostly large-diameter dug wells which provide space for storage of water.

WELL RECORDS

Information pertaining to water wells in Rice County is tabulated on the following pages (Table 6). The well numbers used in this report give the location of wells according to General Land Office surveys as described on page 10. The measured depths of water levels are given to the nearest 0.01 foot, whereas reported depths are given only to the nearest foot and are subject to error.

TABLE 6.—*Records of wells in Rice County*

WELL DESIGNATION (1)	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet) (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
18-6-4bc........	I. Teichgraber....	Du	22.0	36	R	Sandstone	Kiowa.......	CY, W	D	Top of manhole box, east side...	1.4	1,593.8	19.90	9-23-46	
18-6-8ba........	A. L. Miller......	Du	70.2	48	R	do.......	Dakota and Kiowa.	CY, W	S	Top of wooden cover, south side	2.0	1,686.3	36.20	12-20-45	
18-6-10cd.......	E. M. Swenson....	Dr	60.6	6	GI	do.......	do...........	N	N	Top of concrete curb, north side	.7	1,708.2	58.14	9-18-46	Unused domestic and stock well.
18-6-12bc.......	E. J. Akers.......	Du	36.7	48	R	do.......	Dakota......	CY, W	S	Top of concrete curb, east side..	1.0	1,663.1	29.69	9-16-46	
18-6-13bc.......	F. Kasparek......	Dr	107.4	6	I	do.......	Kiowa.......	N	N	Top of casing, south side.......	.9	1,659.5	12.88	11-10-45	Used for water for drilling oil test well; now unused; observation well 7.
18-6-14aa.......	J. E. Hanna......	Dr	60.0	6	GI	do.......	do...........	CY, W	S	do.........................	1.3	1,690.2	50.20	9-16-46	
18-6-15dd.......	School District....	Dr	57.8	6	GI	do.......	Dakota......	CY, W	C	Top of casing, north side.......	.5	1,683.9	36.29	12-14-45	
18-6-16bb.......	F. D. Long.......	Du	17.1	......	......	Sand.....	Alluvium.....	CY, W	S	Base of pump, south side.......	.5	1,640.0	5.42	9-18-46	
18-6-16cc.......	S. B. Smith.......	Dr	110.0	6	GI	Sandstone	Kiowa.......	CY, W	S	Top of casing, south side.......	.2	1,708.9	56.97	9-19-46	
18-6-17cd.......	S. Taylor.........	Dr	47.0	10	T	do.......	do...........	CY, W	S	do.........................	1.4	1,703.2	38.29	9-19-46	
18-6-18cd.......	A. Rehme........	Du	29.4	30	R	do.......	do...........	N	N	Top of curb, north side.........	.5	1,667.3	14.01	9-26-46	Unused domestic well.
18-6-22cd.......	P. M. McMillan...	Du	35.2	36	R	do.......	Dakota......	CY, W	D, S	Top edge of manhole, west side	1.5	1,678.7	32.02	12-14-45	
18-6-23da.......	C. F. Downing....	Dr	29.0	6	GI	do.......	Kiowa.......	CY, W	S	Top of casing, west side........	.5	1,655.0	18.05	9-20-46	
8-6-26bb.......	Wm. McMillan....	Du	41.0	24	R	do.......	do...........	CY, W	S	Top of rock curb, north side....	1.0	1,682.2	37.69	12-14-45	
8-6-26dd.......	School District....	Dr	33.0	4.5	GI	do.......	do...........	CY, H	S	Top of casing, east side........	.1	1,659.4	19.37	12-15-45	

18-6-29dd 1	City of Little River	Du	55.0	89	C	do	do	T, E	P	Floor of pump house	1.0	1,678.6	40.92	10-20-46	Gravel-packed well; diameter of hole 168 inches.
18-6-29dd 2	do	Du	47.9	......	C	do	do	T, E	P	do	1.0	1,668.5	30.75	12- 1-46	Pumped 19,370 gallons in 6 hours; drawdown 12.08—to bottom of pump column
18-6-29dd (C)	Geological Survey	Dr	50.0	1¼	I	do	do	N	O	Top of pipe	1.0	1,673.3	33.35	9-22-46	Observation well, No. 20C
18-6-29dd (N)	do	Dr	50.0	1¼	I	do	do	N	O	do	1.0	1,675.6	34.83	9-22-46	Observation well, No. 20N
18-6-29dd (S)	do	Dr	50.0	1¼	I	do	do	N	O	do	1.0	1,669.9	30.60	9-22-46	Observation well, No. 20S
18-6-30ad	School District	Dr	41.0	6	GI	do	do	CY, H	C	Top of curb, south side of hole	.5	1,666.2	31.80	12-14-45	
18-6-32dd	do	Dr	52.1	6	GI	do	do	CY, H	C	do	.5	1,657.6	32.73	12-14-45	
18-6-35cc	E. Zojic	Du	51.4	48	R	Sandstone	Kiowa	CY, W	N	Top of curb, east side of manhole	.7	1,691.3	47.87	9-20-46	Unused domestic and stock well.
18-7-1da	Community	Dr	150.0	6	......	do	do	CY, H	C	Land surface	0	....	....	....	K. E. R. C. well; reported yield 20.
18-7-2cc	J. W. Newkirk	Dr	61.0	6	GI	do	Dakota and Kiowa.	CY, G	S	Top of casing, south side	1.0	1,684.4	48.60	9-13-46	
18-7-6ab	H. F. Jansen	Du	39.0	36	......	do	Dakota	CY, W	S	Top of curb, west side of hole	.5	1,727.9	29.19	9-13-46	
18-7-10ad	G. J. O'Neill	Du	47.0	48	R	do	Kiowa	N	N	Top of concrete curb, south side	.2	1,680.5	43.73	9-16-46	Unused domestic and stock well; observation well 8.
18-7-14dd	A. Newkirk	Du	25.0	......	......	do	do	CY, W	D, S	Land surface	0	1,683.6	20.00	12-17-45	
18-7-16aa	N. Alexander	Du	31.0	......	......	do	Dakota	CY, H	N	Top of concrete curb, north side	.4	....	15.95	9-13-46	Unused domestic and stock well.
18-7-20ad	S. Ainsworth	Du	49.8	24	R	do	Kiowa	N	N	Top of curb, north side	1.0	1,688.8	47.72	9-13-46	Unused stock well.
18-7-26aa	C. Schoenig	Du	48.4	......	......	do	do	N	N	Top of curb, west side	.7	1,668.1	26.76	9-26-46	Unused domestic well.
18-7-27da	J. W. Major	Du	29.6	48	B	Sandstone rubble.	Meade and/or Chase Channel.	CY, H	D	Top of wooden platform, west side of manhole.	.7	1,633.9	24.27	7-11-46	
18-7-28dd	W. D. Thompson	Dr	22.2	6	GI	Sandstone	Kiowa	CY, W	S	Top of curb, east side of hole	.5	1,641.9	17.29	9-16-46	
18-7-31bc	J. Powell	Du	30.0	......	......	do	Dakota	CY, W	S	Base of pump, east side	1.5	1,720.2	17.29	9-13-46	

TABLE 6.—*Records of wells in Rice County*—*Continued*

Well designation	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
18–7–32dc	E. L. Manwarren	Du	58.4	36	R	Sandstone	Dakota	CY, H	D	Top of curb, east side of manhole	1.5	1,719.0	31.75	7–27–46	
18–8–1ac	Wiggins	Dr	50.6	8	T	do	do	N	N	Top of casing, east side	.6	1,754.3	27.92	9–19–46	Unused domestic well.
18–8–2da	C. A. Gray	Du	24.8	40	R	Sandy silt	Sanborn	CY, W	S	Top of curb, north side	.7	1,742.5	19.10	9–13–46	
18–8–4bb	J. W. Hawkins	Du	53.2	30	R	Sandstone	Dakota	CY, W	N	do	0	1,777.9	47.70	9–11–46	Unused domestic and stock well.
18–8–7cd	V. E. Miller	Dr	62.1	6	GI	do	do	CY, W	N	Top of casing, south side	1.0	1,762.3	42.40	7– 6–46	Unused stock well.
18–8–10bb	E. Froning	Du	52.1	36	R	do	do	CY, W	S	Top of curb, north side	.5	1,769.1	41.10	9–11–46	
18–8–10dc	C. Dobrinski	Du	59.2	36	......	do	do	CY, W	N	Top of wooden platform, east side.	0	1,772.0	42.13	9–13–46	Unused stock well; observation well 9.
18–8–12ad	O. N. Dale	Dr	49.9	8	GI	do	do	N	N	Top of curb, east side of hole	.3	1,733.2	38.10	9–13–46	Unused domestic well.
18–8–13bc	J. A. Lewis	Du	27.8	36	R	do	do	N	N	Top of wooden platform, north side.	.3	1,725.8	15.34	9–13–46	Unused stock well.
18–8–16cc	B. Baldwin	Dr	46.3	8	T	do	do	CY, W	S	Top of wooden platform, east side of opening.	1.0	1,743.8	28.39	7– 3–46	
18–8–17cc	H. Scheib	Dr	55.8	6	GI	Sandstone	Dakota	....	D	Top of casing, east side	4.5	1,746.4	26.48	11–15–45	
18–8–21ad	D. Patterson	Dr	53.7	12	T	do	do	CY, W	S	Base of pump	1.5	....	33.29	9–11–46	
18–8–26cd	School District 57	Dr	94.7	4½	GI	do	do	CY, H	C	Top of casing, south side	.5	1,757.2	53.48	11–19–45	
18–8–28cc	I. Van Natter	Du	37.5	36	R	do	do	CY, W	N	Top of wooden platform, west of pump base.	.0	1,735.7	31.84	7– 3–46	

18-8-30aa.......	R. E. Schoonover	Dr	47.0	8	T	do.......	do...........	CY, H	N	Top of tile casing, south side....	.1	1,740.1	32.03	7- 6-46	
18-8-33ab.......	L. M. Rickard....	Dr	41.2	8	T	....	do...........	N	N	Top of concrete curb, north side	.0	1,734.1	31.46	11-19-45	Unused domestic well; observation well 18.
18-9-1bd........	O. Brownleewe....	Dr	51.2	6	GI	do.......	do...........	CY, H	D	Top of casing, south side.......	.2	1,706.2	33.01	12- 7-45	
18-9-1ca........	....	Dr	66.0	6	GI	do.......	do...........	CY, H	D	Top of casing, north side.......	.2	1,761.3	38.44	12- 7-45	
18-9-1db........	....	Dr	50.0	......	......	do.......	do...........	CY, H	D	Land surface..................	.0	....	....	....	
18-9-3aa........	T. Schmidt.......	Du	41.5	36	R	do.......	do...........	CY, W	S	Base of pump, north side.......	.0	1,754.1	25.27	7- 6-46	
18-9-3bb........	F. H. Schlick.....	Dr	31.2	8	T	do.......	do...........	CY, W	D, S	Top of galvanized iron casing, west side.	.5	1,743.1	20.64	7- 6-46	
18-9-4aa........	W. D. Marshall...	Dr	41.4	......	......	do.......	do...........	CY, H	N	Land surface..................	.0	1,744.1	20.52	7- 6-46	
18-9-6aa........	Northern Natural Gas Co.	Dr	185.0	10	S	do.......	Dakota and Kiowa.	T, E	In	do...........................	.0	1,755.5	40.00	7-28-46	Reported test pumped at 70 for 10 hours; see log 8.
18-9-6aa 2......	do..............	Dr	160.0	10	S	do.......	do...........	T, E	In	....	....	....	....	....	300 feet north of well 1; abandoned 1946, plugged. Reported test pumped at 75 for 10 hours; see log 9.
18-9-6aa 3......	do..............	Dr	210.0	10	S	do.......	do...........	T, E	In	....	....	....	....	....	250 feet north, 75 feet west of well 2; see log 10.
18-9-7ad........	School District....	Dr	41.5	6	T	do.......	Dakota......	CY, H	C	Top of casing, west side........	.5	1,745.4	26.72	12-11-45	
18-9-7da........	H. A. Shroeder....	Dr	85.0	......	......	do.. ..	do..........	CY, W	D	....	....	1,744.4	30.00	....	
18-9-8dd........	O. Habinger......	Dr	43.5	6	T	do.......	do...........	CY, H	D	Top of curb, west side.........	.5	1,740.8	25.12	12-11-45	
18-9-9da........	School District....	......	34.5	6	GI	do.......	do...........	CY, H	D	Top of concrete curb, east side	.0	1,731.9	18.74	12-11-45	Abandoned school supply well.
18-9-14cc.......	L. Rowlison......	Dr	43.5	6	GI	do.......	do...........	CY, W	D, S	Top of casing, north side.......	.5	1,728.4	15.18	7- 5-46	
18-9-14dd.......	R. S. McElwain...	Du	25.0	36	R	....	Sanborn......	CY, W	N	Top of concrete at northeast corner of square, manhole west of pump.	.2	1,734.3	20.86	7- 3-46	
18-9-16ba.......	R. B. Guldner....	Dr	38.3	4	GI	do.......	Dakota......	CY, H	N	Top of corregated iron casing, east side.	.5	1,738.5	25.32	12-11-45	

Table 6.—*Records of wells in Rice County—Continued*

Well Designation	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
18–9–16cc	F. E. Murphy	Dr	45	......	......	Sandstone	Dakota	CY, W	D, S	....	....	1,740.1	....	....	
18–9–21aa	C. W. Burch	Dr	17.7	8	T	Sand	Late Wisconsinan terrace	N, W	N	Top of tile, north side	.0	1,719.2	7.63	7– 5–46	
18–9–22ad	O. Brownleewe	Du	13.1	36	R	....	Sanborn	CY, H	D, S	Top of concrete at southeast corner of square manhole.	.5	....	11.20	7– 3–46	Abandoned; observation well 10.
18–9–25bb	H. E. Kottman	Du	38.5	36	R	Sandstone	Dakota	CY, W	S	Top of plank, southwest of pump base.	.1	1,727.8	18.55	7– 5–46	
18–9–26cd	Weihe	Dr	51	6	GI	do	do	J, E	D	Top of casing, north side	....	1,727.8	24.78	12–17–45	
18–9–26dd	E. M. Burley	Dr	52.0	5	GI	do	do	CY, W	D	Top of east side of concrete curb	.7	1,738.8	37.13	11–19–45	
18–9–30cc	M. Moelscher	Dr	34.4	6	GI	Sand	Sanborn	CY, H	D	Top of concrete curb at north edge of well opening.	.7	1,723.9	16.87	....	
18–9–32dc	W. F. Valkland	Dr	38.8	10	GI	do	do	CY, W	S	Top of wooden cover	.3	1,725.3	21.14	8– 9–46	
18–9–35ad	do	Du	49.1	36	R	Sandstone	Dakota	CY, H	N	Top of wooden platform	.3	1,741.2	42.00	7– 5–46	
18–10–2ac 1	City of Bushton	Dr	99	8	I	do	do	T, E	P	Land surface	....	1,770.3	....	....	Gravel-packed well; reported average use from 2 wells is 40,000 gallons per day.
18–10–2ac 2	do	Dr	103	8	I	do	do	T, E	P	do	....	1,770.6	....	....	Reported drawdown under ordinary operation, 13. Wells equipped with 70-gpm-capacity pumps. See logs 14 and 15.
18–10–2ca	The News	Dr	51.0	6	GI	do	do	CY, H	N	Top of casing	.0	1,765.5	32.53	12– 7–45	Abandoned domestic well; Observation well 11.

18-10-2dd......	Bushton Cemetery	Dr	68.6	6	GI	do......	do..........	CY, H	C	do..........................	.2	1,764.0	33.80	12- 7-45	
18-10-4dc......	A. Zink..........	Dr	71.0	6	GI	do......	do..........	CY, W	S	do..........................	.3	1,786.6	37.47	8- 9-46	
18-10-6ab......	B. E. Stout.......	Dr	59.7	8	T	do......	do..........	CY, W	D	Top of concrete curb..........	.2	1,793.2	34.00	8- 9-46	
18-10-8bc......	School District....	Dr	26.7	6	GI	do......	do..........	CY, H	N	Top of casing, south side......	.2	1,770.7	16.90	12- 6-45	
18-10-10cc.....	John Appel.......	Du	43.5	.....	.....	do......	do..........	CY, W	S	Top of concrete curb, west side	.5	1,776.1	29.98	12- 6-45	
18-10-14bc.....	D. W. Mehl......	Dr	95	.....	.....	do......	do..........	CY, H	.....	Land surface..................	......	1,764.6	35	....	
18-10-16bb.....	....	Dr	40	.....	.....	Calcareous silt.	Sanborn......	CY, W	D, S	do..........................	.0	....	8	....	
18-10-16cd.....	J. Hertach........	Dr	44.0	6	GI	Sandstone	Dakota......	CY, W	S	Top of limestone curb.........	.3	1,765.1	23.47	7- 5-46	
18-10-16dc.....	W. L. Schmidt....	Dr	38.2	6	GI	do......	do..........	CY, W	S	Top of casing.................	.3	1,762.6	19.97	7- 5-46	
18-10-17dc.....	J. Hertach........	Du	17.2	36	R	Calcareous silt.	Sanborn......	CY, W	S	Top of wooden brace below plank cover.	.0	1,751.9	10.62	12-10-45	
18-10-17cd.....	J. Hertach........	Dr	30.3	6	T	....	....	CY, W	.....	Top of wooden platform, south side.	1.2	....	5.68	12- 6-45	
18-10-22bb.....	W. P. Schultz.....	Dr	50.3	6	GI	Sandstone	Dakota......	CY, W	D	Top of limestone curb.........	.6	1,755.6	16.14	7- 5-46	
18-10-24bb.....	F. W. Roelf.......	Dr	144.0	6	S	do......	Dakota and Kiowa.	CY, W	S	Top of casing, south side......	.4	1,755.2	32.29	7- 5-45	
18-10-26cc.....	W. F. Godfrey....	Dr	76.6	6	GI	do......	Dakota......	CY, W	D	Top of concrete curb..........	.0	1,748.3	27.94	12- 6-45	
18-10-27ad.....	School District....	Dr	55.0	6	GI	do......	do..........	CY, H	N	Top of casing, north side......	.2	1,746.4	26.90	12- 6-45	
18-10-28bc.....	do..............	Dr	50.5	6	GI	do......	do..........	CY, H	N	Top of casing, west side.......	.5	1,744.8	14.04	12-10-45	
18-10-28dd.....	Casper Heinz.....	Dr	43.0	6	GI	do......	do..........	N	N	Top of GI casing, west side....	.0	1,749.5	24.38	12- 7-45	
18-10-31bb.....	N. A. Mans.......	Du	24.2	36	C	Sand....	Late Wisconsinan terrace	CY, W	N	Top of concrete casing........	.0	....	20.50	8- 8-46	
18-10-34dc.....	A. L. Zink........	Dr	36.6	6	GI	do......	do..........	CY, W	N	Top of casing.................	.1	1,734.7	21.00	8- 9-46	
18-10-36bb.....	M. J. Behnke.....	Dr	62.4	6	GI	do......	do..........	CY, H	D	do..........................	.5	1,748.2	35.09	8- 9-46	

TABLE 6.—*Records of wells in Rice County—Continued*

WELL DESIGNATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
19–6–2aa	Spoon	Du	12.0	......	......	Sand	Kiowa	CY, H	D	....	....	1,645.8	....	....	
19–6–3cc	F. C. King	Dr	71.0	......	......	do	do	CY, W	N	Top of wooden platform	.5	1,621.8	8.59	9–20–46	
19–6–4bc 1	F. Kasparek	Du	27.3	36	R	do	do	CY, H	N	Top of concrete curb	.5	1,638.4	15.73	12–14–45	
19–6–4bc 2	do	Du	21.2	36	R	....	....	CY, H	N	do	1.0	1,631.7	8.24	12–14–45	
19–6–9dc	J. Habiger, Sr.	Dr	27.0	8	T	Sand	Late Wisconsinan terrace	CY, W	S	Top of tile casing	.3	1,590.1	9.72	9–20–34	
19–6–12dc	H. P. Gelman	Du	25.3	48	R	do	do	CY, W	S	Top of concrete curb	5.0	1,614.5	11.32	12–14–45	Well dug through earth fill dam of small impounding reservoir.
19–6–13ba	L. Morris	Du	39.0	24	R	Shale	Kiowa	CY, W	S	Top of wooden cover	.5	1,606.8	12.55	12–14–45	
19–6–13dd	W. M. Myers	Dr	77.2	8	GI	Siltstone	Harper	N	N	Top of casing	3.0	1,623.2	43.65	12–14–45	Abandoned oil-drilling supply well; observation well 3.
19–6–17ab 1	City of Little River	Du	47.3	144	B	Sand	Late Wisconsinan terrace	CY, D	P	Top of concrete floor, east side of manhole.	....	1,584.0	12.52	12– 1–45	Old city supply well now on stand-by basis; reported 18-foot recovery from full drawdown in 10 hours.
19–6–17ab 2	do	Du	47.0	144	B	do	do	CY, D	P	....	....	....	....	....	Do.
19–6–17ba	do	Dr	39.0	12	T	do	do	N	N	Top of tile casing	1.0	1,581.9	13.43	10– 4–46	Abandoned; observation well 19.
19–6–19dd	N. P. Enberg	Du	9.15	36	N	Sandstone	Kiowa	....	D	Sandstone well curbing, east side.	.0	1,656.7	2.83	8–22–45	

19–6–24da	A. Swanson	Du	54.6	30	R	Siltstone	Harper	CY, W	N	Top of wooden cover	.2	1,626.7	41.63	9–17–46	
19–6–24cb	A. S. Neal	Du	21.8	36	R	Sand	Late Wisconsinan terrace	CY, W	S	Top of rock and concrete curb southeast corner.	1.3	1,578.3	15.00	12–14–45	
19–6–30bb	J. W. Thompson	Du	51.3	36	R	Sandstone	Kiowa	CY, W	......	Top of center south side of first plank from north side of well.	.5	....	40.63	9– 3–46	
19–6–34dc	Q. E. Reamer	Dr	48.7	6	GI	Sand	Sanborn	CY, W	D, S	Top of curb, west side of manhole.	.5	1,558.7	20.98	7–11–46	
19–6–35cd	G. Peterson	Dr	50.3	8	T	do	do	N	N	top of tile, south side	.0	1,557.5	16.50	9–21–46	
19–7–3bd	C. D. Rife	Du	16.6	40	......	do	Late Wisconsinan terrace	CY, W	S	Top of wooden cover at northeast corner of well.	.5	1,661.2	8.99	9–16–46	
19–7–4bc	L. Peterson	Du	51.6	36	R	Sandstone	Dakota	CY, W	S	Top of wooden platform center west side.	.6	1,712.0	45.06	7–27–46	Supply reported as meager
19–7–5dd	C. Totten	Du	25.3	36	R	do	do	CY, W	S	Top of wooden cover, 8 inches west of base of pump.	.5	....	19.68	7–27–46	
19–7–6aa	A. Shepherd	Dr	65.0	6	GI	do	do	CY, W	D	....	......	1,734.7	......	......	Supply reported as meager
19–7–8bc	J. P. Pulliam	Du	53.4	36	R	do	do	CY, W	N	Top of concrete curb, center east side of manhole.	.7	1,757.7	47.16	7–27–46	
19–7–8cc	L. Kinderkick	Du	58.5	36	R	do	do	CY, H	N	Top of concrete curb, southwest corner of manhole.	.2	1,764.0	53.69	7–27–46	
19–7–10dd	J. Habiger	Du	43.2	36	R	do	Kiowa	N	N	Top of wooden cover, center, north side of 2d board from north.	.3	1,689.3	34.60	7–27–46	
19–7–16aa	C. P. Rite	Du	39.0	36	R	do	Dakota	N	S	Top of wooden cover	2.0	1,732.6	34.28	7–27–46	
19–7–22dd	F. Thomas	Du	45.0	48	R	do	do	N	N	Top of rock wall casing	.0	1,743.3	43.00	7–27–46	
19–7–23ad	G. W. Fuller	Dr	70.5	6	GI	do	Kiowa	CY, H	N	Top of casing	.1	1,713.7	27.58	7–26–46	
19–7–24ab	V. P. Pulliam	Du	41.2	36	R	do	do	N	N	Top of brick casing	.1	1,697.0	35.89	7–20–46	Abandoned domestic well; observation well 2.
19–7–27da	P. E. Pulliam	Du	47.0	24	R	do	do	N	N	Top of concrete curb	.5	1,742.6	41.19	7–27–46	

TABLE 6.—*Records of wells in Rice County—Continued*

Well Designation	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
19-7-29da	J. Habinger	Du	46.0	30	R	Sandstone	Kiowa	CY, W	S	do	.2	1,729.4	40.85	8- 1-46	
19-7-29dd	C. R. Munter	Dr	......	6	GI	do	do	CY, W	S	Top of casing	.9	1,692.9	10.08	8- 1-46	
19-7-34ab	B. J. Good	Du	53.0	36	R	do	do	CY, H	N	Top of wooden platform	1.0	1,733.4	45.45	7-27-46	Abandoned domestic well; observation well.
19-7-35ba	School Dist. No. 20	Dr	37.7	6	GI	do	do	CY, H	C	Concrete curb	.5	1,718.5	32.14	11-24-45	
19-7-36bb 1	C. O. Heinley	Du	22.2	48	R	Sandstone	Kiowa	CY, W	N	Top of concrete curb	.5	1,677.6	17.87	7-26-46	Well abandoned because of salt-water intrusion.
19-7-36bb 2	do	Du	13.4	48	R	Sand and rubble.	Late Wisconsinan terrace	CY, E	D, S	Top of wooden cover	2.0	1,661.2	9.74	7-26-46	
19-8-1bb	J. R. Connery	Du	53.8	......	......	Sandstone	Dakota	CY, W	N	Top of concrete curb	1.0	1,752.1	46.09	9-11-46	
19-8-4ad	J. Janssen	Du	40.0	36	R	do	do	Cy, H	N	Base of pump	.7	1,729.3	35.74	7- 6-46	
19-8-5aa	F. J. Smith	Dr	31.3	8	T	do	do	CY, W	N	Lowest point in broken tile, northeast corner.	.5	1,715.8	16.32	7- 3-46	
19-8-6dd	H. R. Chennell	Du	39.7	42	R	do	do	N	N	Top of concrete curb	1.5	1,730.1	37.17	7- 8-46	
19-8-9bb	F. J. Smith	Dr	27.0	8	T	do	do	N	N	Top of tile casing	.7	1,706.1	16.43	12-17-45	
19-8-9bc	S. F. Bethers	Du	25.0	48	N	do	do	CY, W	D	......	......	1,708.8	......	......	
19-8-9cd	J. A. Roesler	Du	38.4	30	R	do	do	CY, W	S	Top of concrete curb, center of east side of square opening.	.0	1,723.5	34.10	7- 3-46	Observation well 17.
19-8-10ad	W. O. Bolten	Du	68.7	36	R	do	do	CY, H	S	Top of wooden guard	3.0	1,758.8	61.70	12-17-45	
19-8-12dc	M. M. Weeks	Du	39.5	......	......	do	do	CY, W	S	Top of tube in concrete cover	.6	1,742.9	32.94	9-13-46	

19-8-22ad	M. Johnston	Du	45.4	36	R	do	do	N	N	Top of concrete curb	.5	1,742.4	43.95	9-11-46	
19-8-24aa	L. C. Watkins	Dr	60.0	10	C	do	do	CY, W	N	Top of casing	.4	1,747.3	46.40	8- 1-46	
19-8-28da	D. Goodfellow	Du	49.0	36	R	do	do	CY, W	S	Top of concrete curb	.4	1,720.5	41.90	9-11-46	
19-8-30dc	H. Parker	Dr	52.8	8	T	do	do	CY, W	D	South side of manhole, top of concrete curb.	......	1,692.2	......	......	
19-8-33bd	......	Dr	52.0	8	......	do	do	CY, W	S	Top of concrete curb	.3	1,704.0	34.62	7- 9-46	
19-8-33cc	......	Dr	61.6	8	T	do	do	CY, W	S	Top of casing	.0	1,690.0	32.38	7- 9-46	
19-8-34ab	H. Bargdill	Du	45.7	36	R	do	do	N	D	Top of wooden cover	2.0	1,716.2	35.90	9-11-46	
19-8-36bc	B. R. Wills	Dr	63.0	6	......	do	do	CY, W	S	Base of concrete curb	.0	1,737.8	42.59	8- 1-46	
19-9-2cc	......	Du	25.5	24	R	do	do	CY, H	N	Top of concrete curb	.5	1,715.6	18.50	7- 3-46	
19-9-6cc	L. J. Beyer	Dr	58.8	10	T	Sand and gravel.	Late Wisconsinan terrace	CY, W	S	Top of casing	.3	1,725.5	15.76	7- 8-46	
19-9-7da	J. M. Revel	Dr	64.0	8	T	do	Todd Valley	CY, W	D	......	......	1,721.9	......	......	
19-9-8cd	M. Hutchins	Dr	105.5	6	S	Sand and gravel.	Chase Channel	N	N	Top of casing, north side	.7	......	2.73	12- 8-45	Abandoned oil-drilling supply.
19-9-10ba	H. Soeken	Du	19.1	18	T	Sandstone	Dakota	N	N	Top of casing	1.2	1,709.1	14.14	7- 8-46	
19-9-12bb	M. A. Berkley	Dr	69.0	6	GI	do	do	N	N	Top of concrete curb	.3	1,751.6	57.62	7- 5-46	
19-9-14aa	J. T. Gibson	Dr	76.3	6	GI	do	do	CY, H	N	do	.4	1,747.2	59.07	7- 5-46	
19-9-14dd	M. E. Meyers	Dr	74.4	10	S	do	do	CY, H	N	Top of concrete platform	.0	1,737.5	54.97	7- 5-46	
19-9-15dc	Cromm	Dr	80.0	......	......	do	do	CY, W	D	......	......	1,727.2	......	......	
19-9-22da	C. E. Collis	Du	55.4	30	R	do	do	CY, W	N	Top of concrete curb	.2	1,728.7	50.13	7- 3-46	
19-9-23ba	M. Patterson	Du	72.0	36	R	do	do	CY, H	N	do	.4	1,748.5	66.36	7- 3-46	
19-9-23dc	School District	Dr	61.4	6	GI	do	do	CY, H	C	Top of casing	.5	1,721.3	42.25	7- 3-46	
19-9-24cd	Iron Drilling Co.	Dr	78.4	6	S	do	do	CY, G	In	do	.4	1,719.0	37.66	7-12-46	Oil drilling supply well.
19-9-26bb	F. R. Seeley	Dr	69.1	8	T	do	do	CY, W	D	Top of wooden platform	.7	1,724.5	47.86	7- 3-46	

TABLE 6.—*Records of wells in Rice County—Continued*

Well designation	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
19-9-27cd	E. Hullman	Dr	18.0	6	......	Sand and gravel.	Late Wisconsinan terrace	CY, H	N	Top of wooden cover	.8	1,681.1	8.04	7- 8-46	
19-9-27dd	L. N. Six	Dr	45.0	......	......	do	Todd Valley	CY, H	D	Top of brick foundation	.2	1,707.8	38.22	7-12-46	
19-9-30cb	M. Collis	Dr	57.8	6	S	do	do	N	N	Top of casing	.6	1,731.3	14.13	7- 8-46	
19-9-31ad	City of Chase	Dr	65.0	10	S	do	do	T, E	P	Land surface	....	1,720.9	22	7- 3-40	Municipal supply well; see log 34.
19-9-35aa	A. M. Keesling	Du	55.3	30	R	Sandstone	Dakota	CY, H	N	Top of concrete curb	.4	1,714.2	47.45	7-12-46	
19-10-1bb	E. Allinger	Dr	88.0	6	GI	do	do	CY, W	N	do	.7	1,743.9	32.50	8- 9-46	
19-10-4dd	Walter Schmidt	Du	19.2	36	R	Sand	Todd Valley	CY, W	S	do	.5	1,755.3	6.05	12- 7-45	
19-10-10aa	Henry Schmidt	Dr	100	6	GI	do	do	CY, W	D, S	....	....	....	12.00	....	
19-10-12ba	F. Altenbaumer	Dr	58.0	6	T	do	Late Wisconsinan terrace	CY,W	D, S	Top of tile casing	.3	1,739.4	29.90	7- 8-46	
19-10-13da	L. Doran	Dr	74.9	6	S	do	Todd Valley	CY, W	In	Top of casing	1.1	1,755.0	32.51	7- 8-46	
19-10-14bc	Henry Anberholy	Dn	60.0	1¼	GP	Sand and gravel.	do	CY, W	D	....	....	....	18.00	....	
19-10-22bc	J. R. Bowman	Dr	68.0	8	S	Sand and gravel.	Todd Valley	N	N	Top of steel casing, south side	1.0	1,754.1	5.38	12- 7-45	Abandoned oil drilling supply; observation well 12.
19-10-24ab	G. Ruhl	Dr	74.0	6	S	do	do	....	In	Top of casing	1.0	....	17.10	7- 8-46	
19-10-30ad	T. Dueser	Dr	71.3	6	S	do	do	N	N	Top of steel casing, east side	.6	....	9.39	12- 8-45	Abandoned oil drilling supply.
19-10-30bb	....	Dr	43.2	6	OW	do	do	CY, G	In	Top of casing, south side	.3	1,768.2	8.67	10- 9-42	

19–10–31dd......	Krampe..........	Dr	96.0	6	S	Sandstone	Kiowa.......	CY, H	D	Top of casing.................	1.3	1,795.6	15.14	9–30–46	Drilled through unconsolidated material, which is locally polluted by oil-field brines.
19–10–32bb......	A. J. Stolz........	Dr	69.7	6	GI	....	....	W	S	do..........................	.2	....	15.52	8– 6–46	
20–6–2aa........	R. D. Shilling.....	Du	20.4	36	......	Rubble...	Sanborn......	CY, W	N	Top of concrete curb...........	1.0	1,554.5	12.86	9–21–46	
2–6–6ca.........	James C. Bush....	Du	24.3	48	R	Sandstone	Kiowa.......	CY, W	D, S	Wooden well cover, pump platform.	.5	1,678.9	17.67	12–20–45	Reported meager supply.
20–6–9da........	M. L. Rose.......	Dr	31.8	6	GI	Siltstone	Harper.......	CY, W	S	Top of casing.................	.4	1,580.0	14.46	9–21–46	
20–6–11ad.......	School District....	Dr	41.5	6	GI	Sand.....	Late Wisconsinan terrace	N	N	Top of concrete step...........	1.5	1,542.8	18.72	9– 5–46	
20–6–11bb.......	C. W. Conrad.....	Dr	62.2	6	GI	do.......	do..........	CY, W	S	Top of casing.................	2.8	1,547.7	22.09	7–11–46	
20–6–16dd.......	J. T. Moll........	Dr	....	......	......	Sandstone	Kiowa.......	CY, W	S	....	....	1,646.9	....	....	
20–6–19bc.......	W. H. Bailey.....	Dr	32.7	6	T	do.......	do..........	CY, H	N	Top of GI curb, east side.......	.5	1,684.6	20.08	11–26–45	
20–6–21aa.......	A. C. Fry........	Dr	40.0	......	......	do.......	do..........	CY, W	N	Top of wooden braces..........	1.5	1,629.9	15.00	9–21–46	
20–6–21cc.......	Ed Burke........	Dr	48.0	6	......	do.......	do..........	CY, W	......	Top of casing.................	.1	1,626.3	11.45	9– 4–46	
20–6–23cd 1.....	P. O. Hubenett....	Du	24.0	......	......	Siltstone	Ninnescah....	CY, W	S	Top of wooden cover...........	.0	1,565.9	15.09	9– 4–46	
20–6–23cd 2.....	School District....	Dr	74.7	......	......	do.......	do..........	CY, H	N	Top of concrete curb...........	.3	1,593.9	17.25	9– 4–46	Observation well 4.
20–6–36bb.......	J. W. Harder.....	Du	21.4	48	R	do.......	do..........	CY, W	S	Base of pump.................	1.3	1,549.6	9.65	11–29–45	Observation well 5.
20–7–2ba........	A. Wills..........	Du	46.4	36	R	Sandstone	Kiowa.......	N	N	Top of rock wall casing........	1.0	1,724.6	39.19	11–23–45	
20–7–6cb........	I. E. Cline........	......	47.3	......	......	do.......	do..........	CY, W	S	Top of wooden platform........	2.0	1,713.5	24.18	8– 5–46	
20–7–10aa.......	W. Rabine........	Dr	52.2	8	GI	do.......	do..........	CY, H	N	Top of concrete curb...........	.6	1,712.1	36.18	7–26–46	
20–7–14ba.......	J. J. Wills........	Dr	60.25	8	......	do.......	do..........	CY, H	N	Top of concrete well curb.......	.5	1,705.3	36.09	8–22–45	
20–7–16bb.......	G. A. Monroe.....	Dr	50.0	6	......	Sandstone	Kiowa.......	CY, W	S	Top of concrete curb...........	.5	1,695.8	39.89	7–26–46	
20–7–21bb.......	L. W. Harp.......	Dr	50.8	6	......	do.......	do..........	CY, W	D	do..........................	.6	1,688.2	40.76	7–26–46	
20–7–28ac.......	R. Williams.......	Du	34.6	36	R	do.......	do..........	CY, W	D, S	do..........................	.5	1,654.4	34.48	7–26–46	

TABLE 6.—*Records of wells in Rice County—Continued*

Well Designation	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
20–7–34ab	F. B. Runyan	DD	42	48	R	Sand	Dune sand	CY, W	S	Top of wooden cover	.6	1,650.8	15.28	7–26–46	
20–7–34bb	E. J. Hammel	Dr	49.30	6	GI	do	do	CY, H	S	Top of wooden platform	.2	1,645.7	35.80	7–26–46	
20–8–1cc	School	Dr	119.4	6	GI	Shale	Harper	CY, H	C	Top of casing	.3	1,711.7	41.45	8– 5–46	
20–8–2dc	P. T. Lyon	Du	20.5	36	R	Rubble	Sanborn	CY, H	N	Top of wooden platform	.0	1,685.6	12.96	8– 2–46	
20–8–5da	S. Wilson	Dr	47.7	......	......	Sand and silt.	do	CY, W	D, S	Top of wooden cover	.3	1,673.4	28.53	7– 9–46	
20–8–6aa	County Farm	Dr	58.9	6	GI	Sandstone	Kiowa	CY, W	S	do	1.0	1,681.3	27.38	7– 9–46	
20–8–7da	S. Longen	Du	13.3	48	R	Sand and gravel.	Late Wisconsinan terrace	CY, W	S	Top of concrete platform	1.3	1,663.6	12.15	9–17–46	
20–8–9dd 1	City of Lyons	Dn	65	8	S	do	do	C, E, D	P	Land surface	....	1,657.0	20	....	Battery of 7 wells pumped from single station; reported yield 275 at drawdown of 5, and 900 at drawdown of 10.
20–8–9dd 2	do	Dr	64	24	I	do	do	T, E	P	do	....	1,656.3	19	....	Gravel-packed well; reported yield, 1,000, drawdown 27
20–8–10bd	American Salt Co.	Dr	80	12	I	do	do	T, E	In	....	....	....	....	....	One of group of 3 wells used for salt processing; reported yield 500.
20–8–16aa	City of Lyons	Dr	65.2	18	I	do	do	T	P	Top of casing	1.8	1,657.5	18.2	6–10–47	Gravel-packed well; see log 50.
20–8–23ad	J. E. Edwards	Dn	53.5	......	GP	do	do	N	D, S	Top of concrete curb	1.2	1,643.3	13.55	9–18–46	

20-8-29cd	W. E. Ball	B	47.7	12	R	do	Todd Valley	CY, W	D, S	Top of wooden cover	.1	1,679.6	26.9	9-12-46	
20-8-35bc	A. J. McFarland	Dn	27.5	1¼	GP	do	do	P, H	S	Pump check valve	2.4	1,651.8	16.3	9-12-46	
20-9-1ba	J. L. Gray	Du	46.8	36	I	Sandstone	Kiowa	CY,W,E	D	Top of concrete curb	.5	1,702.8	43.51	7-12-46	
20-9-2dd	C. T. Grizzell	Du	....	18	R	Sand and gravel.	Late Wisconsinan terrace	N	N	do	.0	1,675.6	18.70	12- 5-45	
20-9-5bb	J. Proffitt	Dr	62	8	I	do	Todd Valley	CY, G	In	Hole in south side of casing	.0	1,713.7	13.18	8- 5-46	
20-9-8bb	C. O. Sharp	Dr	39.6	8	I	do	do	CY, G	In	Top of casing	.6	1,732.2	21.68	8- 5-46	
20-9-9dc	E. M. Dewitt	Du	40	36	R	do	do	CY, W	N	Top of wooden cover	.2	1,726.0	39.50	7-25-46	
20-9-9dd	School District	Dr	87.2	6	GI	Sand and gravel.	Todd Valley	J, E	C	Top of concrete curb	.0	1,713.4	32.42	7-25-46	
20-9-10cb	W. H. Keesling	Dr	62.6	6	I	do	do	CY, W	S	Top of casing	1.0	1,710.5	32.20	12-11-45	
20-9-10cd	B. E. Keesling	Dr	76.5	6	I	do	do	CY, G	In	do	.2	1,697.3	23.10	7- 9-46	Oil drilling supply.
20-9-11bb	Wayne Markle	Dn	31	1¼	GP	do	Late Wisconsinan terrace	....	......	....	....	1,672.0	....	....	
20-9-13cc	J. H. Fair	Dn	17.9	1¼	GP	do	do	N	N	Top of concrete platform	1.1	1,670.2	10.52	9-17-46	Abandoned domestic well; observation well 16.
20-9-20aa	J. M. McGliny	Dr	60.7	8	C	Sand and silt.	Sanborn	CY, H	N	Top of casing	.5	1,767.8	58.87	7- 9-46	
20-9-26dd	J. H. Fair	Dn	....	1¼	GP	Sand and gravel.	Late Wisconsinan terrace	N	N	Top of concrete platform	1.0	1,679.9	16.66	9-12-46	
20-9-28db	K. W. Myers	Dr	....	6	I	do	do	N	N	Top of casing	.4	1,693.0	17.28	9-12-46	
20-10-7cd	W. Peters	Dr	52.7	6	GI	Sandstone	Kiowa	CY, W	S	do	.0	1,779.3	15.76	8- 6-46	
20-10-9cd	J. Shubert	Dr	59	8	GI	Sand	Dune sand	N	N	do	.5	1,820.0	19.8	8- 6-46	
20-10-10ad	C. Koenig	Du	24.3	36	R	do	do	CY, W	S	Top of wooden cover	.8	1,790.8	16.92	12-11-45	
20-10-13ba	E. J. Proffitt	Dr	38.5	6	GI	do	do	CY, W	S	Top of casing	.5	1,780.0	24.49	7- 9-46	
20-10-22dc	A. Loesch	Dr	14	6	GI	do	do	P, H	D, S	do	.7	1,791.5	9.05	8- 6-46	
20-10-23aa	R. Proffitt	Dr	37	6	GI	do	do	CY, W	N	do	.4	1,810.7	22.73	8- 6-46	

TABLE 6.—*Records of wells in Rice County*—*Continued*

Well designation	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
20-10-24da	H. Newton	Dr	59.0	6	GI	Sand and silt.	Dune sand and Sanborn.	N	N	Top of pump base	1.5	1,794.5	20.13	8- 3-46	
20-10-25ab	R. J. Engle	Dr	35.0	6	GI	do	do	CY, W	S	Top of wooden cover	.4	1,722.8	15.75	8- 3-46	
20-10-26ad	P. G. Loesch	Du	11.0	15	GI	do	do	P, H	N	Top of casing	1.5	1,752.9	6.55	8- 3-46	
20-10-27ca	J. D. Ashley	Dr	31.7	6	GI	Sand and gravel.	Late Wisconsinan terrace	....	D	do	—4.8	1,743.0	23.18	8- 7-46	
20-10-28ba	H. Thompson	Dr	22.9	8	GI	do	do	CY, H	D	do	.8	1,741.0	14.13	9-17-46	Observation well 13.
21-6-1cc	School District	Dr	32.5	6	GI	Shale	Ninnescah	CY, H	C	Top of concrete platform	.2	1,543.2	12.00	9-20-46	
21-6-4dd	J. P. Freeman	Dr	24.1	12	I	Sand	Dune sand	CY, W	S	Top of casing	1.7	1,620.1	15.9	9-20-46	
21-6-11bb	J. C. Brown	Dn	13.20	1¼	GP	do	do	P, H	N	Top of pitcher pump	2.7	1,571.7	10.43	8-31-46	Abandoned stock well; observation well 6.
21-6-16dc	J. C. Brown	B	18.7	8	GI	Sand	Dune sand	CY, W	S	Top of casing	1.8	1,691.3	6.16	9-21-46	
21-6-17cc	J. S. Brothers	Dr	119.1	6	I	Shale	Ninnescah	CY, W	S	do	1.5	1,676.7	50.6	9-21-46	
21-6-23aa	F. Wernet	Du	13.8	30	I	Sand	Dune sand	CY, W	S	Top of iron barrel	1.0	1,626.7	7.67	9-20-46	
21-6-25dd	....	Dr	....	6	GI	do	do	CY, W	S	Top of casing	.6	1,621.9	12.3	9-20-46	
21-6-27aa	C. W. McGonigal	Du	11.9	36	C	do	do	CY, W	S	Top of wooden platform	1.3	1,678.2	7.9	9-21-46	
21-6-31bc	H. Meschke	Dn	27.6	1¼	GP	Sand and gravel.	Late Wisconsinan terrace	N	D	Top of pipe	5.2	1,609.7	16.48	9-13-46	
21-6-33ab	H. Manges	Dr	38.1	12	R	Sand	Dune sand	CY, H	S	Top of casing	.7	1,714.6	16.64	9-20-46	

21-7-11cc	A. Househchild	Dr	25.2	6	I	Sand and gravel.	Late Wisconsinan terrace	N	N	Top of concrete platform	.3	1,598.6	10.00	9-13-46	
21-7-19aa	H. Evans	B	28.15	8	GI	do	do	C, E	I	Top of casing	—5.28	1,611.6	3.38	9-14-46	
21-7-24aa	H. S. Vagts	Dn	32.0	1¼	GP	do	do	CY, H	D	Top of concrete platform	.0	1,613.0	9.67	9-14-46	
21-7-27aa	J. Sterret	Dn	32.2	1¼	GP	do	do	P, H	D	Top of pipe	1.85	1,601.7	15.26	9-13-46	
21-7-32bb	M. Miller	Dn	21.0	1¼	GP	do	do	P, H	S	do	1.8	1,612.1	8.65	9-13-46	
21-8-7bb	Shaffer	Dn	26.5	1¼	GP	do	do	P, H	N	do	.2	1,661.4	9.6	9-18-46	
21-8-13cc	J. R. Adams	Dn	15.3	1¼	GP	do	do	N	N	do	1.65	1,628.5	10.8	9-13-46	
21-8-20cc	Bob Dills	Dr	39.0	14	GI	do	do	C, I	I	Top of concrete curb	.0	1,647.0	8.38	7-30-46	One of battery of 4 wells pumped from central station with 8-inch centrifugal; observation well 15.
21-8-21aa	C. O. Wertz	Dr	30.9	8	I	do	do	C, G	I	Top of casing	—2.9	1,638.7	5.4	7-31-46	Two wells 5 feet apart; reported battery yield 800.
21-8-21ba	City of Sterling	Dr	38.0	16	I	do	do	C, E	P	Land surface	....	1,640.9	....	....	Battery of 7 wells pumped from central station.
21-8-21bb	do	Dr	92.0	15	I	do	do	T, E	P	do	....	1,642.6	....	....	Well maintained on stand-by basis for peak use; reported yield 800, drawdown 20. See log 72.
21-8-22bc	Max Bourgain	Dr	35.0	8	I	do	do	C, G	I	do	....	1,635.4	8.0	....	Reported yield, 400.
21-8-28cb	E. T. Maris	Du	17.0	12	I	do	do	C, G	I	Top of casing	.0	1,640.7	8.86	7-30-46	Used for irrigating small truck farm.
21-8-35aa	G. Martin	Dn	25.7	1¼	GP	do	do	N	N	Top of pipe	1.2	1,619.3	8.04	9-13-46	
21-9-5ba	Marion Steinmetz	Dr	31.0	20	GI	do	do	C, T	I	Top of concrete wall	.1	1,691.1	9.12	7-31-46	Reported yield 500; drawdown 16.
21-9-13ba	M. Doenzer	Dn	....	1¼	GP	Sand and gravel.	Late Wisconsinan terrace	P, H	D, S	Top of pitcher pump	3.1	1,664.2	10.64	9-18-46	
21-9-16ad	G. Ross	Dr	23.0	7	GI	do	do	C	I	Top of casing	.6	1,677.2	9.5	9-18-46	

TABLE 6.—*Records of wells in Rice County—Concluded*

WELL DESIGNATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well, inches	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
21-9-28ad	J. H. Fair	Dn	17.6	1¼	GP	do	Mead (?)	N	N	Top of pipe	1.6	1,678.9	13.35	9-20-46	Abandoned stock well; observation well 14.
21-9-32ba	R. S. Halton	B	26.25	8	GI	do	do (?)	N	I	Top of casing	.5	1,701.2	16.4	9-20-46	
21-10-7cc	....	Dn	14.0	1¼	GP	do	Late Wisconsinan terrace	N	N	Top of pipe	.4	1,730.7	2.45	10-10-42	
21-10-8bc	Miller Estate	Dr	53.2	12	R	Sand	Dune sand	CY, W	D, S	Top of wooden platform	1.0	1,763.8	44.6	9-17-46	
21-10-10cb	Township	Dn	12.2	1¼	GP	Sand and gravel.	Late Wisconsinan terrace	P, H	D	Top of pitcher pump	3.0	1,714.6	10.56	9-17-46	
21-10-12ab	W. C. Isern	Dr	57.0	......	......	do	do	C, T	I	Top of concrete curb	.3	1,699.0	9.74	7-31-46	Well equipped with 8-inch centrifugal; maximum of 13 acres irrigated.
21-10-23db	Geo. Heckel	B	....	6	GI	do	Mead (?)	C, E	D	Top of casing	—3.5	....	6.99	9-20-46	Sand point driven inside of casing.

1. Location number: Well numbers give the location of wells according to General Land Office surveys and according to the following formula: Township—range—section, 160-acre tract within that section, and the 40-acre tract within the quarter section. If two or more wells are located within a 40-acre tract, the wells are numbered serially according to the order in which they were inventoried. The 160-acre and 40-acre tracts are designated a, b, c, or d in a counter-clockwise direction, beginning in the northeast quarter. For example, well 18-6-29dd2 is located in SE¼, SE¼, sec. 29, T. 18 S., R. 6 W., and was the second of two wells inventoried in that 40-acre tract.
2. B, bored well; DD, dug and drilled well; Dn, driven well; Dr, drilled well; Du, dug well; Sp, spring.
3. Reported depths below the land surface are given in feet; measured depths are given in feet and tenths below measuring points.
4. B, brick; Bs, boiler steel; C. concrete; GI, galvanized sheet iron; GP, galvanized-iron pipe; I, iron; N, none; OB, oil barrels; OW, oil-well casing; R, rock; T, tile; W, wood.
5. Method of lift: C, horizontal centrifugal; CY, cylinder; F, natural flow; N, none; P, pitcher pump; S, submersible turbine; T, turbine; VC, vertical centrifugal.
Type of power: B, butane; D, Diesel engine; E, electric; G, gas engine; H, hand-operated; T, tractor; W, windmill.
6. C, community; D, domestic; I, irrigation; In, industrial; N, not being used; O, observation; P, public supply; S, stock.
7. Measured depths to water level are given in feet, tenths, and hundredths; reported depths to water level are given in feet.

LOGS OF WELLS AND TEST HOLES

Listed in the following pages are the logs of 78 wells and test holes in Rice County, including 64 logs of test holes drilled by the State Geological Survey of Kansas and 14 logs of test holes of wells furnished by private drillers. The locations of the test holes are shown on Plate 2 and most of the wells are shown on Plate 1. The logs of test holes drilled by the Geological Survey are classed as sample logs, as a complete set of samples was collected from each test hole. The test hole numbers used in this report follow the same system as the well numbers. They give the locations of wells according to General Land Office surveys as described on page 10.

1.—*Sample log of test hole 18-6-16dd in the SE cor. sec. 16, T. 18 S., R. 6 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,709.8 feet.*

	Thickness, feet	Depth, feet
Soil, sandy, gray brown	1	1
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, brown, and very fine to medium sand	2	3
Silt, tan, and fine to medium sand; contains many fragments of sandstone	1	4
CRETACEOUS		
Dakota formation (Gulfian)		
Sandstone, medium-grained, soft, tan	15	19
Clay, light gray and yellow; interlaminated with fine to medium yellow and gray sandstone	15	34
Sandstone, medium-grained, yellow gray; contains some light-gray clay and "ironstone"	9	43
Sandstone, coarse, yellow brown	27	70
Kiowa shale (Comanchean)		
Clay, silty, light blue gray to white, interbedded with some white fine sandstone; contains much "ironstone"	20	90
Sandstone, medium to fine, yellow brown, and light-gray clay; contains some "ironstone" and small amount of pyrite	23	113
Shale, carbonaceous, dark blue gray; contains minor quantities of gray-white fine sandstone, calcareous light gray siltstone, limonite, pyrite, and glauconite,	20	133
Limestone, coquinoid, sandy, light gray; interval includes zone of cone-in-cone limestone	1	134
Shale, dark gray; contains some pyrite and charcoal	6	140
Shale, dark gray	10	150
Sandstone, coquinoid, calcareous, fine, light gray; interval includes zone of cone-in-cone limestone	2	152
Shale, fissile, dark gray; contains small amount of pyrite,	33	185

	Thickness, feet	Depth, feet
PERMIAN—Leonardian		
Harper sandstone		
Siltstone, brick red and mottled white	12	197
Stone Corral dolomite		
Anhydrite, gypsum, and dolomite, white	1	198

2.—*Sample log of test hole 18-6-29dd(C) in the SE¼ SE¼ sec. 29, T. 18 S., R. 6 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,672.3 feet.*

	Thickness, feet	Depth, feet
Top soil, fine, sandy, gray	1	1
QUATERNARY—Pleistocene		
Sanborn formation		
Silt and clay, gray brown	3	4
Silt, tan; contains much fine sand	4	8
Silt, calcareous, buff; contains some fine to medium sand and much nodular caliche	17	25
CRETACEOUS—Comanchean		
Kiowa shale		
Sandstone, soft, fine to medium, yellow brown	28.5	53.5
Shale, blue gray; contains many thin zones of light-gray; hard calcareous siltstone and a little pyrite	15.5	69
"Shell bed," sandstone, fine-grained, coquinoid, calcareous, gray; contains many glauconite grains and much pyrite	4	73
Clay, silty, blue gray, and lignite; contains a little pyrite,	4	77
Clay, light gray and gray; contains some blue-white bentonite	13	90
"Shell bed," limestone, silty, light gray; contains many fossil shells and a zone of cone-in-cone limestone	0.5	90.5
Shale, fissile, dark gray; contains a little very fine to medium glauconitic sandstone	33.5	124
PERMIAN—Leonardian		
Harper sandstone		
Shale, silty, light greenish gray and red brown	6	130

3. *Sample log of test hole 18-6-29aa in the NE cor. sec. 29, T. 18 S., R. 6 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,696.0 feet.*

	Thickness, feet	Depth, feet
Top soil, silty, dark brown; contains a little very fine sand	2	2
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, brown; contains a little very fine sand	3	5
Silt, tan; contains a little very fine sand	2	7
Silt, tan; contains much nodular caliche and a little very fine sand	1	8
Silt and clay, white and buff; contains much nodular caliche	2	10

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota formation (Gulfian)		
Clay, yellow and white. contains much fine sand	4	14
Sandstone, silty, yellow; contains a little brown "ironstone"	2	16
Clay, light blue gray	7	23
Sandstone, fine to medium, yellow and gray, and light-gray clay	4	27
Clay, silty, light gray	3	30
Sandstone, medium, yellow and brown, and light blue-gray clay	14	44
Clay, silty, light blue gray and yellow; contains thin charcoal zone at base	12	56
Clay, light gray, red, and yellow	5	61
Kiowa shale (Comanchean)		
Sandstone, medium to fine, firmly cemented by iron	2	63
Sandstone, medium to fine, brown	7	70
Clay, gray white	2	72
Sandstone, medium to fine, yellow brown	13	85
Shale, blue gray	11	96

4. *Sample log of test hole 18-8-18dd in the SE cor. sec. 18, T. 18 S., R. 8 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,746.4 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt and clay, slightly calcareous, light gray, and very fine sand	2	4
Loveland silt member		
Silt, gray brown; contains much very fine sand (Loveland soil)	2	6
Silt, light brown; contains much very fine to fine sand,	9	15
Silt, calcareous, buff to tan; contains much nodular caliche and some very fine to medium sand	41	56
CRETACEOUS—Gulfian		
Dakota formation		
Clay, light gray, red, and yellow; contains some yellow fine to medium silty sandstone near base	24	80

5.—*Sample log of test hole 18-8-22bb in the NW cor. sec. 22, T. 18 S., R. 8 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,753.9 feet.*

	Thickness, feet	Depth, feet
Soil, gray	2.5	2.5
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, light gray; contains some nodular caliche	1.5	4
Loveland silt member		
Silt, tan and buff, and very fine sand; contains much nodular caliche	36	40
Silt, calcareous, gray white, and very fine to medium sand	10	50
Silt, calcareous, buff and tan; contains much very fine to coarse sand and many fragments of Cretaceous "ironstone"	15	65
CRETACEOUS—Gulfian		
Dakota formation		
Clay, gray white; contains some fine sand	1	66

6. *Sample log of test hole 18-8-23aa in the NE cor. sec. 23, T. 18 S., R. 8 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,717.5 feet.*

	Thickness, feet	Depth, feet
Road fill	3	3
QUATERNARY—Pleistocene		
Sanborn formation		
Silt and clay, buff to tan; contains some fine to medium sand and nodular caliche	9	12
Sand, fine to medium, silt, and calcareous buff and yellow clay; contains much nodular caliche	6.5	18.5
Clay, slightly calcareous, gray, and very fine sand; contains a few fragments of Cretaceous rocks	3	21.5
CRETACEOUS		
Dakota formation (Gulfian)		
Clay, light gray, mottled red, yellow, and purple; contains a few sandy zones	36.5	58
Sandstone, fine, brown; contains a small amount of "ironstone"	12	70
Sandstone, fine, light gray brown	41.5	111.5
Kiowa shale (Comanchean)		
Sandstone, hard, calcareous, medium to fine, translucent white	1.5	113
Sandstone, medium to fine, light brown; contains a small amount of glauconite and pyrite	7	120
Sandstone, fine to medium, light gray; contains a small amount of glauconite	18	138

	Thickness, feet	Depth, feet
Shale, dark blue gray; contains a small amount of light-gray fine sandstone	3	141
Siltstone, hard, glauconitic, light gray, and medium-grained sandstone	5	146
Sandstone, silty, partly calcareous, very fine, light gray; contains some pyrite and glauconite	4	150
Shale, dark blue gray	15	165
Siltstone, soft, light gray; contains much very fine sand,	9	174
Sandstone, medium-grained, firmly cemented by calcium carbonate 174 to 177 feet and 189 to 190 feet, light gray; contains a small amount of pyrite	16	190
Shale, silty, gray; contains cone-in-cone-limestone and coquina zone near base	10	200
Shale, fissile, dark gray; contains some white fine sandstone and charcoal near base	44	244
Cheyenne sandstone (Comanchean)		
Siltstone, white and light gray; contains much very fine sand and some charcoal	30	274
Sandstone, silty, very fine to fine, white; contains much charcoal	2	276
Siltstone, light gray green, mottled red brown	5	281
Siltstone, red brown, gray, yellow, and purplish; contains much very fine to medium sand and many coarser quartz and limestone fragments	5.5	286.5
PERMIAN—Leonardian		
Stone Corral dolomite		
Dolomite, finely crystalline, white	0.5	287

7. *Driller's log of water well 18-9-1bd in the SE¼ NW¼ sec. 1, T. 18 S., R. 9 W., drilled to supply water for oil-exploration drilling operations, 1945.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Yellow clay	12	12
CRETACEOUS		
Dakota formation (Gulfian) and Kiowa shale (Comanchean)		
Red clay	108	120
Sandstone; yields some water	10	130
Blue shale	30	160
Sandstone; yields some water	20	180
Blue shale	20	200

8. *Driller's log of water well 18-9-6aa in the NE¼ NE¼ sec. 6, T. 18 S., R. 9 W., drilled for Northern Natural Gas Company, May 1936. Surface altitude, 1,755.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Top soil	1	1
Brown clay	37	38
Sandy clay	13	51

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota formation (Gulfian) and Kiowa shale (Comanchean)		
Water sand	17	68
Shale and red bed	21	89
Yellow shale	2	91
Light gray shale	18	109
Red bed	26	135
Sandy gray shale	5	140
Water sand	45	185

9.—*Driller's log of water well 18-9-6aa(2) in the NE¼ NE¼ sec. 6, T. 18 S., R. 9 W., drilled for Northern Natural Gas Company, 1936.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Top soil	1	1
Brown clay	39	40
Sandy clay	6	46
CRETACEOUS		
Dakota formation (Gulfian) and Kiowa shale (Comanchean)		
Water sand	26	72
Blue shale	41	113
Water sand	47	160

10.—*Driller's log of water well 18-9-6aa(3) in the NE¼ NE¼ sec. 6, T. 18 S., R. 9 W., drilled for Northern Natural Gas Company, July 1945.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Top soil	2	2
Clay, dark yellow	33	35
Sandy clay, yellow	5	40
CRETACEOUS		
Dakota formation (Gulfian) and Kiowa shale (Comanchean)		
Sandstone, brown and yellow	20	60
Shale, red	10	70
Shale, gray	10	80
Shale, red	10	90
Sand, gray, medium	5	95
Shale, blue	20	115
Sand, blue	35	150
Sand, gray	40	190
Sand, blue	5	195
Sand, gray	15	210

11.—*Sample log of test hole 18-9-14dd in the SE cor. sec. 14, T. 18 S., R. 9 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,731.3 feet.*

	Thickness, feet	Depth, feet
Road fill	3	3
QUATERNARY—Pleistocene		
Sanborn formation		
Silt and clay, light gray and tan; contains some very fine to medium sand	7	10
Silt and clay, tan and buff; contains some nodular caliche	24	34
Silt and clay, buff; contains a small amount of medium to coarse sand and a few fragments of sandstone	7.5	41.5
Silt, buff, and red clay; contains much sand and coarse to fine gravel. Gravel is composed of fragments of sandstone and "ironstone"	1.5	43
CRETACEOUS		
Dakota formation (Gulfian) and Kiowa shale (Comanchean)		
Clay, gray white, mottled yellow, and red; contains many pellets of limonite near base	5	48
Clay, light gray and mottled yellow; contains some fine sand	10	58
Sandstone, silty, fine, brown, yellow, and white	8	66
Clay, light blue gray and mottled yellow, and fine sand,	6	72
Shale, gray, interbedded with white fine sandstone; contains some glauconite	34	106
Shale, fissile, dark gray, some white fine hard sandstone and light gray-brown hard siltstone; contains a small amount of charcoal, glauconite, and pyrite	12	118

12.—*Sample log of test hole 18-9-16dd in the SE cor. sec. 16, T. 18 S., R. 9 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,714.9 feet.*

	Thickness, feet	Depth, feet
Soil, silty, dark gray	3	3
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt and clay, gray	7	10
Silt, light gray, and very fine to fine sand; contains many snail shells	13	23
Silt, calcareous, buff; contains some nodular caliche	12	35
Silt, light gray; contains a few shell fragments	11	46
Silt, light gray, and very fine to fine sand	6	52
Silt, calcareous, buff, and very fine sand; contains a few "ironstone" fragments and some nodular caliche	5	57
CRETACEOUS—Gulfian		
Dakota formation		
Clay, light gray and mottled yellow	8	65

13.—*Sample log of test hole 18-9-17cc in the SW cor. sec. 17, T. 18 S., R. 9 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,740.5 feet.*

	Thickness, feet	Depth, feet
Soil, gray brown	3	3
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt and clay, light gray; contains some fine sand	2	5
Loveland silt member		
Silt, blocky, brown (Loveland soil)	2	7
Silt, tan and buff; contains some nodular caliche and a small amount of very fine to medium sand. Gravel of "ironstone" and caliche occur in lower 3 feet	51	58
CRETACEOUS—Gulfian		
Dakota formation		
Clay, light gray and yellow; contains some fine sand,	2	60
Sandstone, fine, brown, and light gray and yellow clay	5	65
Clay, light gray and mottled yellow	3	68

14.—*Driller's log of water well 18-10-2ac (N) in the SW¼ NE¼ sec. 2, T. 18 S., R. 10 W., drilled for the city of Bushton. Surface altitude, 1,770.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Soil, black	5	5
Clay, yellow	37	42
CRETACEOUS—Gulfian		
Dakota formation		
Red rock	7	49
Clay, yellow	8	57
Clay, yellow, sandy	10	67
Sand rock	36	103

15.—*Driller's log of water well 18-10-2ac (S) in the SW¼ NE¼ sec. 2, T. 18 S., R. 10 W., drilled for the city of Bushton.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Soil, black	5	5
Clay, yellow	32	37
CRETACEOUS—Gulfian		
Dakota formation		
Red rock	18	55
Sand rock	44	99

16.—*Sample log of test hole 18-10-16cc in the SW cor. sec. 16, T. 18 S., R. 10 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,756.2 feet.*

	Thickness, feet	Depth, feet
Soil, dark gray brown; contains some fine sand	3	3
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, tan and buff; contains some fine sand and nodular caliche	82	85
CRETACEOUS—Gulfian		
Dakota formation		
Clay, light gray, and mottled red and yellow	8	93
Sandstone, fine, light gray and white	7	100
Shale, fissile, blue gray; contains some white very fine sandstone	10	110

17.—*Sample log of test hole 18-10-19aa in the NE cor. sec. 19, T. 18 S., R. 10 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,761.6 feet.*

	Thickness, feet	Depth, feet
Soil, dark gray	2	2
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, calcareous, light gray and tan; contains some fine sand and nodular caliche	81.5	83.5
Gravel, medium to fine, sand, and gray silt; contains "ironstone," sandstone, and caliche fragments	2.5	86
CRETACEOUS—Gulfian		
Dakota formation		
Clay, gray white and mottled yellow; contains much very fine sand	6	92
Siltstone, soft, yellow brown; contains much very fine to fine sand	20	112
Shale, silty, gray; contains some pyrite	8	120

18.—*Sample log of test hole 18-10-24bb in the NW cor. sec. 24, T. 18 S., R. 10 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,757.6 feet.*

	Thickness, feet	Depth, feet
Road fill	1	1
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, light gray; contains a little very fine to medium sand	7	8
Loveland silt member		
Silt, gray brown; contains some very fine to medium sand (Loveland soil)	1	9

	Thickness, feet	Depth, feet
Silt, buff tan; contains much very fine to medium sand and some nodular caliche. Many fragments of Cretaceous rocks near base of interval	47	56
CRETACEOUS—Gulfian		
Dakota sandstone		
Sandstone, fine, yellow and white, and some yellow and white clay	14	70

19.—*Sample log of test hole 18-10-31cc in the SW cor. sec. 31, T. 18 S., R. 10 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,760.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Sand, very fine to medium, and dark-gray and gray-brown silt	3	3
Silt and clay, light greenish gray; contains some fine to medium sand	5	8
Silt, calcareous, buff and tan; contains much medium to fine sand	20	28
Sand, fine to very fine	9	37
Silt, light gray and buff, and medium to fine sand	14	51
Silt, calcareous, tan; contains some fine sand and concretionary calcium carbonate	27	78
CRETACEOUS		
Dakota formation (Gulfian) and Kiowa shale (Comanchean)		
Clay, light gray, and mottled red and yellow	12	90
Sandstone, silty, very fine to fine, gray and yellow brown	15	105
Shale, fissile, blue gray	1	106

20.—*Sample log of test hole 18-11-13dd at the SE cor. sec. 13, T. 18 S., R. 11 W., Barton County, drilled by the State Geological Survey, 1945. Surface altitude, 1,768.0 feet.*

	Thickness, feet	Depth, feet
Road fill	2.5	2.5
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt and clay, dull greenish gray	2.5	5
Loveland silt member		
Silt and clay, tan, brown, light gray, and greenish gray. Contains some caliche nodules below 16 feet and a 3-foot Loveland soil zone at top of interval	102	107
Gravel, fine to coarse, sand, and gray silt	2	109

	Thickness, feet	Depth, feet
CRETACEOUS		
Dakota formation (Gulfian) and Kiowa shale (Comanchean)		
Sandstone, fine- to medium-grained, white to yellow, and light blue gray and pale yellow shale; contains bedded "ironstone" in upper part	75	184
Clay, dull yellow	2	186
Shale, fissile, blue gray; contains limonite and pyrite	11.5	197.5
Claystone, very hard, gray	.5	198
Shale, light blue gray, and thin beds of hard limestone and sandstone	15	213
Shale, gray and light gray, interbedded with fine-grained gray-white sandstone; contains a very hard calcareous zone at 213-214 feet and pyrite	11	224
Shale, dark gray; contains shell fragments 224-233 feet and gypsum at 249 feet	25	249
Cheyenne sandstone (Comanchean)		
Shale, sandy, white	2	251
Siltstone, hard, white	3	254
Shale, sandy, gray pink and gray white	4	258
Shale, light greenish gray, interbedded with fine-grained sandstone	15	273
PERMIAN		
Shale, red	7	280

21.—*Sample log of test hole 18-11-36aa in the NE cor. sec. 36, T. 18 S., R. 11 W., Barton County, drilled by the State Geological Survey, August 1946. Surface altitude, 1,750.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Sand, very fine to fine, and dark-gray silt	3	3
Sand, very fine to fine, and light-gray silt, buff; contains some concretionary calcium carbonate	4	7
Silt, light gray; contains much very fine to fine sand	29	36
Gravel, fine to coarse, and sand	7	43
Sand, very fine to medium, and gray silt	5	48
Sanborn formation		
Loveland silt member		
Silt, calcareous, buff, and very fine sand; contains some concretionary calcium carbonate	30	78
Meade formation		
Silt, light gray, and very fine sand; contains a few "ironstone" pebbles	7	85
Gravel, fine to medium, and sand	9	94
Sand, fine, and silt, light buff	6	100
Gravel, medium to fine, and sand	5	105

	Thickness, feet	Depth, feet
CRETACEOUS—Comanchean		
Kiowa shale		
Sandstone, fine, white	13	118

22.—*Sample log of test hole 19-7-17cc in the SW cor. sec. 17, T. 19 S., R. 7 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,751.5 feet.*

	Thickness, feet	Depth, feet
Top soil, gray brown	3	3
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, light gray; contains some fine sand	5	8
Loveland silt member		
Silt, light tan; contains some fine sand and nodular caliche	58	66
Silt, light tan; contains many sandstone fragments	4	70
CRETACEOUS—Comanchean		
Kiowa shale		
Sandstone, fine, yellow brown; contains a little "ironstone"	10	80

23.—*Driller's log of water well 19-8-10ad in the SE¼ NE¼ sec. 10, T. 19 S., R. 8 W., drilled to supply water for oil-exploration drilling, 1945. Surface altitude, 1,755.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Surface clay	15	15
Yellow clay	55	70
CRETACEOUS		
Dakota formation (Gulfian) and Kiowa shale (Comanchean)		
Sand; yields some water	5	75
Blue shale	30	105
Sand; yields water	10	115
Blue shale	5	120
Continuation of log from partial sample log of oil well at same location.		
(No samples)	80	200
Shale, thin-bedded, dark gray	80	280
PERMIAN—Leonardian		
Harper sandstone		
Sandstone, silty, very fine to fine, dull red brown and greenish gray	30	310
Stone Corral dolomite		
Dolomite and anhydrite, gray-white	20	330
Ninnescah shale		
Shale, red	20	350

24.—*Sample log of test hole 19-8-14dd in the SE cor. sec. 14, T. 19 S., R. 8 W., drilled by the State Geological Survey, July 1945. Surface altitude, 1,732.1 feet.*

	Thickness, feet	Depth, feet
Road fill	1	1
QUATERNARY—Pleistocene		
Sanborn formation		
Loveland silt member		
Silt, tan; contains some nodular caliche and a little fine sand. Many "ironstone" fragments at base of interval	63	64
CRETACEOUS—Comanchean		
Kiowa shale		
Sandstone, silty, very fine, yellow	6	70

25.—*Sample log of test hole 19-8-15cc in the SW cor. sec. 15, T, 19 S., R. 8 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,735.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, dark gray brown	7	7
Silt, tan; contains some nodular caliche and a little fine sand	45	52
CRETACEOUS—Comanchean		
Kiowa shale		
Sandstone, fine, yellow brown, and light-gray and yellow clay	8	60

26.—*Sample log of test hole 19-8-18dd in the SE cor. sec. 18, T. 19 S., R. 8 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,692.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, dark gray brown; contains some fine sand	4	4
Silt, buff to tan; contains some fine sand and nodular caliche	34	38
Silt, gray buff; contains some fine sand and nodular caliche	7	45
Silt, light gray, and very fine to fine sand; contains shell fragments	7	52
Sanborn formation		
Loveland silt member		
Silt, buff; contains much nodular caliche and some fine sand	8	60
Silt, light gray and buff; contains some fine sand. Contains a few sandstone and "ironstone" fragments in lower 4 feet	24	84
Silt, buff, and very fine to medium sand	6	90
Meade formation		
Gravel, coarse to fine, and sand	10	100

	Thickness, feet	Depth, feet
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, dark blue gray; contains a zone of cone-in-cone limestone and fossil shells	10	110

27.—*Driller's log of the Carey Salt Company shaft in the SE¼ NW¼ sec. 34, T. 19 S., R. 8 W., dug for the Bevis Rock Salt Company, 1890.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Soil and sandy loam	45	45
CRETACEOUS—Comanchean		
Kiowa shale		
Sand rock	10	55
Variegated clays	12	67
Blue clays	13	80
Black shale	30	110
Gray sand rock	10	120
PERMIAN—Leonardian		
Harper sandstone		
Red sand rock	78	198
Red sandy shale	56	254
Red clay	18	272
Stone Corral dolomite		
Soft lime rock	3	275
Gypsum and lime rock	9	284
Ninnescah shale		
Interbedded red, blue, and gray shale	386	670
Wellington formation		
Dark gray shale	123	793
Salt with many thin shale partings	275	1,068
Dark gray shale; contains shells at top	15.5	1,083.5

28.—*Sample log of test hole 19-9-16dd in the SE cor. sec. 16, T. 19 S., R. 9 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1688.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, dark gray; contains some fine to medium sand	3	3
Silt and clay, buff and light gray; contains much fine to medium sand	4	7
Silt, light gray	3	10
Sand, fine to coarse, and gray silt	17	27
Silt, gray; contains much fine to coarse sand and pebbles of calcium carbonate in lower part of interval	12	39
Sanborn formation		
Loveland silt member		
Silt, calcareous, buff to tan; contains some nodular caliche	57	96

	Thickness, feet	Depth, feet
Chase Channel formation		
Holdrege member		
Sand, medium to fine, and calcareous silt, buff; contains some medium gravel	11	107
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, dark gray	9	116

29.—*Sample log of test hole 19-9-20dd in the SE cor. sec. 20, T. 19 S., R. 9 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,716.5 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt and clay, light gray, and very fine sand	1.5	3
Silt, tan; contains some fine to medium sand and concretionary calcium carbonate	13	16
Clay, calcareous, yellow buff and gray white; contains some concretionary calcium carbonate	22	38
Todd Valley sand member		
Gravel, fine to coarse, and sand	12	50
Loveland silt member		
Silt and clay, buff	9	59
Silt, light gray	9	68
Silt, tan and buff; contains some concretionary calcium carbonate. (Lower part of interval is probably Sappa member of Meade.)	30	98
Meade formation		
Grand Island member		
Gravel, coarse to fine, sand and calcareous silt, buff	14	112
Chase Channel formation		
Fullerton member		
Silt, calcareous, buff; contains much concretionary calcium carbonate. Many shale and sandstone pebbles in lower part of interval	26	138
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, fissile, gray	3.5	141.5
PERMIAN—Leonardian		
Siltstone, red brown and light gray green	8.5	150

30.—*Sample log of test hole 19-9-23aa in the NE cor. sec. 23, T. 19 S., R. 9 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,735.6 feet.*

	Thickness, feet	Depth, feet
Road fill	1	1
QUATERNARY—Pleistocene		
Sanborn formation		
Top soil	2	3
Silt, tan; contains some fine sand and nodular caliche. A few "ironstone" fragments in lower 10 feet of interval	66	69
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, light gray green; contains much limonite	7	76

31.—*Partial sample log of oil-exploration well 19-9-24cd in the SE¼ SW¼ sec. 24, T. 19 S., R. 9 W., drilled by the Iron Drilling Company, July 1946. Surface altitude, 1,723.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, buff and tan; contains some nodular caliche and fine sand	60	60
CRETACEOUS—Comanchean		
Kiowa shale		
Sandstone, fine to medium, gray white, and yellow; contains a hard calcareous zone at top of interval	12	72
Shale, blue gray; contains some yellow medium sandstone and yellow clay near top of interval	18	90
Shale, gray; contains some pyrite and thin zones of gray brown siltstone	15	105
Sandstone, coquinoid, calcareous; contains some pyrite, glauconite, and a thin zone of cone-in-cone limestone	2	107
Shale, fissile, dark gray; contains some gypsum and charcoal	23	130
Sandstone, coquinoid, calcareous, gray; contains some pyrite, glauconite, and a thin zone of cone-in-cone limestone	1	131
Shale, dark gray	24	155
Cheyenne sandstone		
Clay, gray white and light green; contains much fine sand	19	174
PERMIAN—Leonardian		
Harper sandstone		
Shale, dull red and pink	11	185

32.—*Sample log of test hole 19-9-27dd(S) in the SE cor. sec. 27, T. 19 S., R. 9 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,689.4 feet.*

	Thickness, feet	Depth, feet
Road fill	3	3
QUATERNARY—Pleistocene		
Sanborn formation		
Todd Valley member		
Sand, fine to coarse; contains some brown silt in upper part of interval	12	15
Gravel, fine to medium, and sand; contains a little silt, tan and gray	10	25
Gravel, medium to fine, and sand	7	32
Loveland silt member		
Silt, calcareous, tan to buff; contains some nodular caliche. Many sandstone fragments at base of interval	47	79
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, light blue gray and yellow	7	86
"Shell bed," siltstone, yellow; contains many fossil shells	1.5	87.5
Shale, silty, light gray	2.5	90

33.—*Sample log of test hole 19-9-30dd in the SE cor. sec. 30, T.19 S., R. 9 W., drilled by the State Geological Survey, August 1946. Surface altitude 1,716.5 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, calcareous, buff and tan; contains much fine to medium sand	4	6
Silt, light gray and buff, and very fine to medium sand; contains some concretionary calcium carbonate	16	22
Todd Valley member		
Silt, light gray and buff; contains much fine to medium gravel and sand	5	27
Sand, fine to coarse; contains some fine gravel	16	43
Gravel, fine to coarse, and sand	4	47
Loveland silt member		
Silt, calcareous, tan, and very fine to medium sand	23	70
Meade formation		
Grand Island member		
Sand, very fine to medium, and calcareous silt, gray,	60	130

	Thickness, feet	Depth, feet
Chase Channel formation		
Sand, fine to coarse, and silt, tan	30	160
Gravel, medium to fine, sand, and silt, buff	5	165
PERMIAN—Leonardian		
Siltstone, brick red	5	170

34.—*Driller's log of test hole for well 19-9-31ad in the SE¼ NE¼ sec. 31, T. 19 S., R. 9 W., drilled for the city of Chase, July 1940. Surface altitude, 1,720.9. feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Brown sandy loam and clay	18	18
Yellow clay	3	21
Todd Valley member		
Sand-bearing yellow clay	4	25
Clay-bearing yellow sand	2	27
Water-bearing fine sand	10	37
Brown clay	5	42
Water-bearing coarse sand	3	45
Water-bearing coarse gravel	18	63
Loveland silt member		
Brown clay	11	74

35.—*Sample log of test hole 19-9-35cc in the SW cor. sec. 35, T. 19 S., R. 9 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,684.0 feet.*

	Thickness, feet	Depth, feet
Road fill	1	1
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt and clay, gray and light brown	1	2
Silt, dark gray	3	5
Silt, light brown; contains much very fine to medium sand	4	9
Silt and clay, gray to dark gray	10	19
Silt, light gray, and very fine to fine sand	3	21
Sand, fine to medium, and silt, gray	4	25
Sand, medium to fine, gray	5	30
Sanborn formation		
Loveland silt member		
Silt, calcareous, buff and tan; contains some nodular caliche and fine sand	58	88
Chase Channel formation		
Gravel, coarse to fine, sand, and silt, buff	2	90
PERMIAN—Leonardian		
Siltstone, light greenish gray	3	93
Siltstone, brick red and light gray green	5	98

36.—*Sample log of test hole 19-10-18bb in the NW cor. sec. 18, T. 19 S., R. 10 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,782.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand—Pleistocene and Recent		
Sand, fine to medium, and dark-gray silt	7	7
Sanborn formation—Pleistocene		
Todd Valley sand member		
Silt, light gray, and very fine to medium sand	8	15
Sand, very fine to medium	25	40
Sand, coarse to fine	35	75
Gravel, fine to medium, sand, and buff silt	21	96
Gravel, fine to coarse, sand, and buff silt	7	103
Loveland silt member		
Silt, calcareous, buff, and very fine sand. (Lower part of interval may be Sappa member of Meade formation)	32	135
Meade formation—Pleistocene		
Sappa member		
Volcanic ash, partly indurated, white (Pearlette ash lentil)	2	137
Silt, gray, and very fine to fine sand	15	152
Grand Island member		
Gravel, fine to medium, and sand	5	157
Chase Channel formation—Pleistocene		
Fullerton member		
Silt, gray, and very fine to coarse sand	22	179
Holdrege member		
Gravel, fine to coarse, and sand	14	193
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, gray, and fine white sandstone; contains some charcoal	4.5	197.5

37.—*Sample log of test hole 19-11-12aa in the NE cor. sec. 12, T. 19 S., R. 11 W., Barton County, drilled by the State Geological Survey, August 1946. Surface altitude, 1,778.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, dark gray; contains some fine to medium sand	1.5	1.5
Silt and clay, gray; contains some fine sand	1.5	3
Silt, light gray and buff, and very fine to medium sand; contains much concretionary calcium carbonate in lower part of interval	35	38
Loveland silt member		
Silt, calcareous, buff; contains some very fine sand	18	56
Silt, light tan and buff; contains some very fine to fine sand	9	65

	Thickness, feet	Depth, feet
Silt, calcareous, light tan and buff; contains some concretionary calcium carbonate	65	130
Silt, calcareous, light tan; contains some very fine to fine sand and many Cretaceous-derived pebbles	9.5	139.5
Gravel, medium to fine, sand, and silt, light tan	1.5	141
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, fissile, gray	5	146

38.—*Sample log of test hole 19-11-24dd in the SE cor. sec. 24, T. 19 S., R. 11 W., Barton County, drilled by the State Geological Survey, August 1946. 1946. Surface altitude, 1,566.6 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY—Pleistocene		
Sanborn formation		
Todd Valley sand member		
Silt, light gray, and fine to medium sand	4.5	6
Silt, light gray and buff; contains much fine to coarse sand, fine gravel, and some concretionary calcium carbonate	10	16
Sand, fine to coarse, and much calcareous silt, buff; contains much concretionary calcium carbonate	11	27
Gravel, fine to coarse, and sand	29	56
Gravel, fine to coarse, and sand	6.5	62.5
Loveland silt member		
Silt, calcareous, buff; contains much fine to medium sand	6	68.5
CRETACEOUS—Comanchean		
Kiowa shale		
Sandstone, silty, fine, white	29.5	98
Shale, micaceous, yellow gray	6	104
Sandstone, fine, brown, and shale, gray; contains some charcoal	2	106

39.—*Sample log of test hole 20-5-18bb in the NW cor. sec. 18, T. 20 S., R. 5 W., McPherson County, drilled by the State Geological Survey, September Surface altitude, 1,775.7 feet.*

	Thickness, feet	Depth, feet
Road fill	2.5	2.5
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, gray; contains some very fine to fine sand	2.5	5
Loveland silt member		
Silt, tan and buff; contains some very fine sand	7	12
Silt, light tan; contains much nodular caliche and many small fragments of Cretaceous and Permian rocks	42	54

	Thickness, feet	Depth, feet
Crete member (?)		
Gravel, medium to fine, and silt, tan; partly cemented by calcium carbonate	16	70
Meade formation		
Sappa member		
Silt, calcareous, buff	7	77
Volcanic ash, very fine sand, and calcareous silt, buff (Pearlette ash lentil)	11	88
Grand Island member		
Gravel, medium to fine	3	91
PERMIAN—Leonardian		
Ninnescah shale		
Shale, silty, greenish gray and red brown	9	100

40.—*Sample log of test hole 20-6-23aa in the NE cor. sec. 23, T. 20 S., R. 6 S., drilled by the State Geological Survey, September 1946. Surface altitude, 1,539.4 feet.*

	Thickness, feet	Depth, feet
Road fill	3	3
QUATERNARY—Pleistocene		
Sanborn formation		
Loveland silt member		
Silt, tan, and very fine to fine sand	17	20
Silt, calcareous, tan, and fine to medium sand	15	35
Silt, light gray, and very fine sand	12	47
Silt and clay, dark gray to black	6	53
Silt, light gray, and very fine to medium sand	2	55
Gravel, medium to fine, and sand	1	56
PERMIAN—Leonardian		
Ninnescah shale		
Shale and siltstone, brick red and gray green	14	70

41.—*Sample log of test hole 20-6-23ba in the NE cor. NW¼ sec. 23, T. 20 S., R. 6 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,556.3 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, dark gray, and very fine to medium sand	1.5	3
Silt, light tan, and very fine to medium sand	9	12
Silt, tan; contains much very fine to medium sand. Much shale rubble in lower part of interval	18	30
Silt, calcareous, light tan; contains much very fine sand. Much shale rubble in lower part of interval	23	53
PERMIAN—Leonardian		
Ninnescah shale		
Shale, red and gray green, little white to buff dolomite	7	60

42.—*Sample log of test hole 20-6-24aa in the NW cor. NE¼ NE¼ sec. 24, T. 20 S., R. 6 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,557.1 feet.*

	Thickness, feet	Depth, feet
Road fill	1	1
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, dark brown grading downward to tan; contains much very fine to medium sand; sand content increases downward	22	23
Silt, light gray, and very fine sand	16	39
Silt, buff and light gray	24	63
Gravel, coarse to fine, sand, and silt, buff	9	72
PERMIAN—Leonardian		
Ninnescah shale		
Shale, light gray green	2	74

43.—*Sample log of test hole 20-6-24ba in the NE cor. NW¼ sec. 24, T. 20 S., R. 6 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,528.1 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, dark gray brown	2.5	4
Silt, light gray brown; contains some medium sand in the lower part	6	10
Sand, fine to medium	9	19
Sand, medium to fine, and some silt, light brown	7	26
Silt, gray; contains some fine to medium sand	24	50
Gravel, coarse to fine, sand, and silt, gray	4	54
PERMIAN—Leonardian		
Ninnescah shale		
Shale, gray green and red	6	60

44.—*Sample log of test hole 20-6-24bb in the NE cor. NW¼ NW¼ sec. 24, T. 20 S., R. 6 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,531.0 feet.*

	Thickness, feet	Depth, feet
Road fill	3	3
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, buff and light gray, and very fine to medium sand	15	18
Silt and clay, light gray and tan; contains much very fine to fine sand	6	24
Silt, light gray, and very fine to fine sand	5	29
Sand, very fine to medium, and silt, light gray brown	9	38
Silt, dark gray, and very fine to fine sand; contains a few shells	11	49
Sand and gravel, fine to coarse	2	51
PERMIAN—Leonardian		
Ninnescah shale		
Shale, red brown and gray green	9	60

45.—*Sample log of test hole 20-7-15aa in the NE cor. sec. 15, T. 20 S., R. 7 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,702.6 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, dark brown; contains much fine to medium sand,	4.5	6
Loveland silt member		
Silt, tan and light gray, and very fine to medium sand. Loveland soil zone at top of interval	16	22
Silt, light tan; contains much very fine sand	15	37
Silt, tan; contains much fine to coarse sand and some nodular caliche. (Lower part of interval probably Sappa member of Meade formation.)	32	69
Meade formation		
Gravel, very coarse to fine, and sand	7	76
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, light blue gray and yellow	4	80

46.—*Sample log of test hole 20-7-20dd in the SE cor. sec. 20, T. 20 S., R. 7 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,646.0 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, tan, and very fine to medium sand	22.5	24
Silt, tan and light gray; contains much very fine to medium sand	2	26
Todd Valley sand member		
Sand, coarse to fine, and medium to fine gravel	9	35
Gravel, fine to coarse, and sand	21	56
PERMIAN—Leonardian		
Harper sandstone		
Siltstone, brick red and light greenish gray	19	75

47.—*Sample log of test hole 20-8-6bb in the NW cor. sec. 6, T. 20 S., R. 8 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,687.8 feet.*

	Thickness, feet	Depth, feet
Road fill	1	1
QUATERNARY—Pleistocene		
Sanborn formation		
Silt and clay, light gray; contains some fine to coarse sand in the lower part	3.5	4.5

	Thickness, feet	Depth, feet
Silt, light brown; contains much very fine to coarse sand	8.5	13
Silt, calcareous, buff; contains some very fine to fine sand	43	56
CRETACEOUS—Comanchean		
Shale, light blue gray and yellow	9	65

48.—*Sample log of test hole 20-8-14ba in the NW cor. NE¼ NW¼ sec. 14, T. 20 S., R. 8 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,651.3 feet.*

	Thickness, feet	Depth, feet
Top soil, dark gray	2	2
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, brown; contains some very fine to medium sand	2	4
Silt and clay, gray brown	6	10
Silt, gray	6	16
Gravel, fine to medium, sand, and some silt, gray	4	20
Silt, gray	1	21
Gravel, fine, and sand; contains a little medium gravel,	34	55
Silt, yellow gray; contains some coarse to fine sand	2	57
Silt, gray; contains much carbonaceous material	6	63
Gravel, medium to fine, and sand	4	67
PERMIAN—Leonardian		
Harper sandstone		
Siltstone, brick red	3	70

49.—*Driller's partial log of brine well in NW¼ NE¼ sec. 15, T. 20 S., R. 8 W., drilled for the American Salt Company.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Soil	24	24
Sand	44	68
PERMIAN—Leonardian		
Harper sandstone		
Red shale	125	193
Stone Corral dolomite		
Lime	12	205
Ninnescah shale		
Blue shale	23	228
Red shale	65	293
Blue shale	52	345
Gray, blue, and red shale	253	598
Wellington formation		
Lime	2	600
Blue shale	96	696
Lime	9	705
Salt and blue shale	279	984

50.—*Driller's log of test hole for water well 20-8-16aa in NE¼ NE¼ sec. 16, T. 20 S., R. 8 W., drilled for the City of Lyons, February 1947. Surface altitude, 1,657.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan Terrace		
Top soil	1	1
Brown clay	2	3
Yellow clay	5	8
Dirty sand	3	11
Coarse to medium coarse sand, loose	4	15
Medium to coarse sand and gravel	12	27
Clay	1	28
Coarse sand and gravel	16	44
Soft clay	1	45
Sand and gravel, loose	19	64
Brown clay	13	77
PERMIAN—Leonardian		
Harper sandstone		
Rock		77

51.—*Sample log of test hole 20-9-2dd(S) in the SE cor. sec. 2, T. 20 S., R. 9 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,671.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, dark gray; contains some fine to medium sand	2	2
Silt, brown; contains some fine to medium sand	2	4
Silt, gray; contains some fine sand	14	18
Sand, fine to coarse; contains some fine gravel	10	28
Gravel, fine to medium, and sand	4	32
Gravel, fine to coarse, sand, and silt, gray and buff	6	38
Sand, fine to medium	12	50
Sand, fine to coarse, and silt, buff	12	62
Chase Channel formation		
Silt, calcareous, buff; contains some fine to coarse sand and nodular caliche	39	101
Gravel, medium to fine, sand, and silt, pink and buff	5	106
PERMIAN—Leonardian		
Harper sandstone		
Siltstone, red	3	109

52.—*Sample log of test hole 20-9-2cc in the SW cor. sec. 2, T. 20 S., R. 9 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,672.0 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, gray; contains some fine to medium sand	1.5	3.5
Silt, light gray, and very fine to fine sand	4.5	8

	Thickness, feet	Depth, feet
Sand, fine to coarse	10	18
Gravel, medium fine, and sand; contains a little gray and gray-green silt and a little coarse gravel	15	33
Meade formation		
Sappa member		
Silt, calcareous, buff, and very fine sand	9	42
Silt, calcareous, gray; contains much fine sand and blue-gray clay	9	51
Grand Island member		
Sand, very fine to fine	26	77
Silt, light gray; contains much light blue-gray clay and many caliche pebbles	8	85
Chase Channel formation		
Fullerton member		
Silt, light tan; contains some fine sand	20	105
Silt, calcareous, light tan; contains many caliche nodules	34	139
Holdrege member		
Gravel, fine to medium, sand, and silt, buff	3	141
PERMIAN—Leonardian		
Harper sandstone		
Siltstone, red	4	145

53.—*Sample log of test hole 20-9-10cd in the SE¼ SW¼ sec. 10, T. 20 S., R. 9 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,692.5 feet.*

	Thickness, feet	Depth, feet
Road fill	2.5	2.5
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, gray, and very fine to medium sand	4	6.5
Silt, buff; contains a little fine sand	8.5	15
Silt, calcareous, light tan; contains much fine gravel, sand, and a little nodular caliche	2.5	17.5
Todd Valley sand member		
Gravel, fine to medium, and sand	5.5	23
Loveland silt member		
Silt, calcareous, buff; contains much coarse to fine sand	18	41
Sand, fine, and silt, light tan	9	50
Meade formation		
Sappa member		
Silt, buff; contains some fine sand and nodular caliche	28	78
Volcanic ash, white (Pearlette ash lentil)	1	79
Silt, buff; contains some fine sand and nodular caliche	26.5	105.5
Grand Island member		
Sand, fine to coarse; contains some medium gravel	15.5	121

	Thickness, feet	Depth, feet
Chase Channel formation		
Fullerton member		
Clay and silt, light and dark gray; contains much very fine sand and a little pyrite	9	130

54.—*Sample log of test hole 20-9-10dc (N) in the SW¼ SE¼ sec. 10, T. 20 S., R. 9 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,690.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, dark gray brown, and very fine to fine sand	3	3
Silt and clay, blocky, light gray	4.5	7.5
Silt, calcareous, light tan; contains some very fine to fine sand	12.5	20
Silt, buff, and very fine to fine sand	5	25
Silt, gray and buff, and very fine to coarse sand	7.5	32.5
Todd Valley sand member		
Gravel, fine to coarse, and sand	14.5	47
Loveland silt member		
Silt, calcareous, buff; contains some nodular caliche	16	63
Meade formation		
Sappa member		
Silt, calcareous, light tan; contains sporadic volcanic ash fragments throughout	13	76
Sand, coarse to fine	3	79
Silt, blue gray	3.5	82.5
Volcanic ash, partly indurated, white and greenish gray (Pearlette ash lentil)	5.5	88
Sand, fine	12	100
Silt, light and dark gray	10	110
Grand Island member		
Gravel, fine, and sand	9	119
Chase Channel formation		
Fullerton member		
Silt and clay, buff to light gray	6	125
Silt and clay, light greenish gray	10	135
Silt, light gray and buff	5	140
Holdrege member		
Sand, medium to fine	21	161
Gravel, fine to coarse, and sand	23	184
PERMIAN—Leonardian		
Harper sandstone		
Siltstone, red	6	190

55.—*Sample log of test hole 20-9-10dc(S) in the SW¼ SE¼ sec. 10, T. 20 S., R. 9 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,697.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt, dark gray brown, and very fine sand	5	5
Silt and clay, light gray	9	14
Silt, buff; contains some fine sand	12	26
Todd Valley sand member		
Gravel, fine to medium, and sand	15	41
Loveland silt member		
Silt, calcareous, light tan; contains some nodular caliche	29	70
Meade formation		
Sappa member		
Silt, calcareous, light tan, and white clay; contains much volcanic ash	9	79
Volcanic ash, white; contains a few fine quartz grains,	5	84
Sand, very fine, and silt, light gray; contains many shell fragments	30.5	114.5
Grand Island member		
Sand, fine to medium	11.5	126
Chase Channel formation		
Fullerton member		
Silt, calcareous, light gray	14	140
Silt, buff, and fine sand	10	150
Holdrege member		
Sand, medium to fine	16	166
Gravel, fine to coarse, and sand	10	176
Silt, calcareous, buff; contains much coarse to fine sand	2	178
Gravel, fine to coarse, and sand	12	190
PERMIAN—Leonardian		
Harper sandstone		
Siltstone, dark red	4	194

56.—*Sample log of test hole 20-9-10dd in the SE cor. sec. 10, T. 20 S., R. 9 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,683.9 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Sanborn formation		
Peoria silt member		
Silt and clay, gray; contains a little fine to coarse sand	2	4
Silt, light tan; contains a little fine to coarse sand	13	17

	Thickness, feet	Depth, feet
Silt and clay, calcareous, light gray and light tan; contains some nodular caliche	9	26
Todd Valley sand member		
Sand, coarse to fine; contains some fine to medium gravel	9	35
Gravel, fine to medium, and sand	12	47
Loveland silt member		
Silt and clay, calcareous, buff; contains some nodular caliche	18	65
Meade formation		
Sappa member		
Silt, calcareous, buff; contains much fine to coarse sand and nodular and tubular caliche	15	80
Sand, very fine, and silt, light gray	20	100
Grand Island member		
Gravel, medium to coarse; contains much fine gravel and sand	7	107
Silt, buff, and very fine to fine sand	10	117
Chase Channel formation		
Fullerton member		
Silt, tan; contains many large caliche nodules	24	141
Holdrege member		
Gravel, medium to fine, and sand	28	169
PERMIAN—Leonardian		
Harper sandstone		
Siltstone, dull red	6	175

57.—*Sample log of test hole 20-9-20dd in the SE cor. sec. 20, T. 20 S., R. 9 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,731.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Loveland silt member		
Silt, calcareous, buff; contains much fine sand and nodular caliche	27	27
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, yellow and light gray	2	29
Shale, light gray	11	40

58.—*Sample log of test hole 20-10-1aa in the NE cor. sec. 1, T. 20 S., R. 10 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,724.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, fine to medium, and silt, gray and brown	16	16
Sanborn formation (Pleistocene)		
Peoria silt member		
Silt, calcareous, light tan, and medium to fine sand	8	24
Todd Valley sand member		
Sand, fine to coarse; contains some fine to medium gravel	21	45
Gravel, fine to medium, and sand	6	51
Loveland silt member		
Silt, light gray and tan	12	63
Silt, tan; contains much coarse to fine sand	13	76
Silt, calcareous, light gray and tan; contains much coarse to fine sand and concretionary calcium carbonate	14	90
Chase Channel formation		
Fullerton member		
Silt, calcareous, tan	56	146
Holdrege member		
Sand, fine, tan silt, and fine to medium gravel	13	159
PERMIAN—Leonardian		
Siltstone, red	6	165

59.—*Sample log of test hole 20-10-1cc in the SW cor. sec. 1, T. 20S., R. 10 W., drilled by the State Geological Survey, August 1946. Surface altitude, 1,757.7 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, fine, and silt, dark gray	1.5	3
Sanborn formation (Pleistocene)		
Todd Valley sand member		
Sand, medium to fine, and silt, gray and buff; contains some fine to medium gravel in upper part of interval	22	25
Loveland silt member		
Silt, buff, and very fine to medium sand; contains much concretionary calcium carbonate	56	81
Sand, medium, and silt, tan; contains many sandstone pebbles	4	85
CRETACEOUS—Comanchean		
Kiowa shale		
Shale, dull gray green and yellow	5	90
Sandstone, very fine, yellow and white	10	100
Shale, silty, blue gray; contains much very fine sand and a few charcoal fragments	10	110

60.—*Sample log of test hole 20-10-10dd in the SE cor. sec. 10, T. 20 S., R. 10 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,804.8 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, fine to medium; contains some gray-brown and light-gray silt	18.5	20
Sanborn formation (Pleistocene)		
Loveland silt member		
Silt, buff to tan, and very fine to fine sand; contains much concretionary calcium carbonate	35.5	55.5
TERTIARY—Pliocene		
Ogallala formation		
Limestone, partly brecciated, pink to yellowish; contains a small amount of sand ("Algal limestone")	0.5	56
Sand, very fine, silt, and clay, greenish gray to yellow; loosely cemented by calcium carbonate	2	58
Gravel, coarse, composed mostly of angular Cretaceous fragments; contains fine to medium sand and some clay, yellow gray	3	61
Sand, very fine to medium, and silt, gray; contains many sandstone and shale fragments	14	75
CRETACEOUS—Comanchean		
Kiowa shale		
Sandstone, fine, light brown	6.5	81.5
Shale, blue gray	8.5	90

61.—*Sample log of test hole 21-6-8aa in the NE cor. sec. 8, T. 21 S., R. 6 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,657.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, medium to fine	5	5
Sand, medium to fine, and silt, light gray	7.5	12.5
Sand, medium to fine, and silt, tan	3.5	16
Sand, medium to fine, and silt, light gray	3	19
Meade formation (Pleistocene)		
Sappa (?) member		
Silt, buff, and very fine to medium sand; contains many pebbles of sandstone, Cretaceous shells, and caliche	8	27
PERMIAN—Leonardian		
Shale, micaceous, pink and greenish gray; contains much very fine sand	5	32
Siltstone, red brown; contains much very fine sand	4	36

62.—*Sample log of test hole 21-6-19ba in the NE¼ NW¼ sec. 19, T. 21 S., R. 6 W., 0.3 mile east of NW corner of section, drilled by the State Geological Survey, September 1946. Surface altitude, 1,645.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, medium to fine	4	4
Sand, medium to fine, and silt, light greenish gray; contains yellow-brown iron-stained zone	4	8
Silt, buff and tan, and fine to medium sand	5	13
Sand, medium to fine, and silt, light greenish gray; loosely cemented by calcium carbonate	11	24
Sand, medium to fine, light gray	11	35
Silt, and clay, gray, and fine to medium sand; partly firmly cemented by calcium carbonate	8	43
PERMIAN—Leonardian		
Siltstone, red; contains much very fine sand	7	50

63.—*Sample log of test hole 21-7-13cc in the SW cor. sec. 13, T. 21 S., R. 7 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,596.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, dark gray; contains some fine sand	3	3
Silt and clay, gray; contains some fine sand	2	5
Silt, light gray and buff; contains some fine to medium sand	2	7
Silt, light gray and buff; contains some fine to coarse sand	2	9
Sand, coarse to fine; contains some fine to medium gravel	2	11
Gravel, fine, sand, and some gray silt	19	30
Gravel, fine to coarse, and sand; contains a little gray silt	25	55
Gravel, fine to medium, and sand	6	61
PERMIAN—Leonardian		
Shale, red; contains a little gray-green shale	9	70

64.—*Sample log of test hole 21-7-15dd in the SE cor. sec. 15, T. 21 S., R. 7 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,596.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, dark gray	3	3
Silt, buff; contains some fine to medium sand in lower part	5	8
Silt, gray; contains some coarse to fine gravel and sand,	2	10
Gravel, medium to fine, and sand; contains some coarse gravel	32	42

	Thickness, feet	Depth, feet
Sand, coarse to fine; contains some fine gravel	13	55
Gravel, medium to fine, and sand	6	61
PERMIAN—Leonardian		
Shale, light gray green	1	62
Shale, red brown	8	70

65.—*Sample log of test hole 21-7-20aa in the NE cor. sec. 20, T. 21 S., R. 7 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,610.3 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, buff, and coarse to fine sand	3	5
Sand, fine to coarse	2	7
Gravel, medium to fine, and sand; contains a little coarse gravel	7	14
Sand, coarse to fine	13	27
Silt, buff	2	29
Sand, coarse to fine; contains a little fine to medium gravel	33	62
Gravel, fine to coarse, and sand	3	65
PERMIAN—Leonardian		
Shale, red	1.5	66.5
Shale, light gray green	1	67.5

66.—*Sample log of test hole 21-7-22bb in the NW cor. sec. 22, T. 21 S., R. 7 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,602.9 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, light gray	4	6
Silt, calcareous, light gray	4	10
Silt, light gray, and very fine sand	6	16
Sand, coarse to fine; contains a little fine to medium gravel	4	20
Gravel, coarse to fine, and sand	9	29
Silt, yellow gray	2	31
Silt and clay, dark gray	4	35
Silt, calcareous, light gray to white; contains much fine to coarse sand	7.5	42.5
Gravel, fine, and sand	12.5	55
PERMIAN—Leonardian		
Siltstone, red and light gray	5	60

67.—*Sample log of test hole 21-8-1aa in the NE cor. sec. 1, T. 21 S., R. 8 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,626.1 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY—Pleistocene		
Sanborn formation		
Todd Valley sand member		
Silt, light brown; contains much coarse to fine sand	3.5	5
Sand, coarse to fine	5	10
Gravel, fine, and sand; contains some medium to coarse gravel	20	30
Gravel, coarse to fine, and sand	10	40
Gravel, medium to fine, and sand	14	54
Silt and clay, yellow buff to light blue gray	6	60
Sand, fine, and silt, light tan; contains many red shale fragments	3	63
PERMIAN—Leonardian		
Siltstone, dull red	7	70

68.—*Sample log of test hole 21-8-11aa in the NE cor. sec. 11, T. 21 S., R. 8 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,634.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Sand, medium fine, and silt, black	2	2
Sand, coarse to fine, and silt, brown; contains a little fine to medium gravel	5	7
Sand, coarse to fine; contains some fine gravel	9	16
Gravel, fine to coarse, and sand	2	18
Gravel, coarse to fine, and sand	36	54
Silt, yellow brown; contains some coarse to fine sand	2.5	56.5
Gravel, medium to fine, and sand	23.5	80
Sand, coarse to fine; contains some fine gravel	17	97
Gravel, coarse to fine, and sand	1.5	98.5
PERMIAN—Leonardian		
Shale, red	1.5	100

69.—*Sample log of test hole 21-8-11cc in the SW cor. sec. 11, T. 21 S., R. 8 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,636.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, dark gray, and coarse to fine sand	3	3
Silt, light gray; contains some fine sand	2.5	5.5
Sand, coarse to fine; contains some coarse to fine gravel,	50.5	56
Meade formation		
Gravel, fine, and sand	43	99
Sand, medium to fine, and silt, buff	31	130

	Thickness, feet	Depth, feet
Chase Channel formation		
Fullerton member		
Silt, gray; contains some fine to coarse sand	24	154
Silt, calcareous, buff, and very fine sand	6	160
Silt, calcareous, buff and gray; contains some medium to fine gravel and sand	2	162
Holdrege member		
Gravel, coarse to fine, sand, and silt, tan	11	173
PERMIAN—Leonardian		
Dolomite, light gray	2	175

70.—*Sample log of test hole 21-8-16bb in the NW cor. sec. 16, T. 21 S., R. 8 W., drilled by the State Geological Survey, October 1946. Surface altitude, 1,648.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand (Pleistocene and Recent)		
Sand, medium to fine; contains some dark gray silt	2	2
Sand, medium to fine; contains a little brown silt	1	3
Silt and clay, light gray; contains a little very fine sand,	5.5	8.5
Late Wisconsinan terrace (Pleistocene)		
Gravel, fine to coarse, and sand; contains many pebbles,	19.5	28
Silt, yellow gray; contains much fine to coarse sand	4	32
Silt, calcareous, yellow gray; contains much fine to coarse sand	4.5	36.5
Gravel, medium to fine, and sand; contains a little coarse gravel	2.5	39
Clay and silt, blue gray and buff	5	44
Gravel, medium to fine, and sand	43.5	87.5
Meade formation (Pleistocene)		
Silt, tan	1.5	89
Silt and clay, gray	2	91
Silt, calcareous, tan	2.5	93.5
PERMIAN—Leonardian		
Siltstone, dull red and light gray green	6.5	100

71.—*Sample log of test hole 21-8-20dd in the SE cor. sec. 20, T. 21 S., R. 8 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,636.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Sand, medium to fine, and silt, dark gray	1.5	1.5
Gravel, fine to medium, and sand	23.5	25
Gravel, medium to fine, and sand; contains a little coarse gravel	19.5	44.5
Meade formation		
Sand, fine to coarse, and silt, buff	21.5	66
Sand, fine to medium, and silt, tan	6	72
PERMIAN—Leonardian		
Siltstone, dark red	4	76

72.—*Driller's log of water well 21-8-21bb in the NW¼ NW¼ sec. 21, T. 21 S., R. 8 W., drilled for the City of Sterling. Surface altitude, 1,642.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Close soil	6	6
Sandy soil	8	14
Water-bearing fine sand	16	30
Mud balls	4	34
Coarse sand	19	53
Meade (?) formation		
Mud balls	3	56
Coarse sand and gravel	36	92

73.—*Sample log of test hole 21-8-22bb in the NW cor. sec. 22, T. 21 S., R. 8 W., drilled by the State Geological Survey, September 1946. Surface altitude, 1,638.5 feet.*

	Thickness, feet	Depth, feet
Road fill	1.5	1.5
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, calcareous, light gray; contains much nodular caliche	1.5	3
Gravel, fine to medium, and sand; contains many pebbles	4	7
Silt, dark gray	0.5	7.5
Gravel, fine to coarse; contains a few pebbles	6.5	14
Silt, dark gray	0.5	14.5
Gravel, coarse to fine, and sand; contains many pebbles,	5.5	20
Gravel, fine to medium, and sand	6	26
Silt, yellow brown; contains much fine to coarse sand	4	30
Silt, calcareous, buff; contains much medium to fine sand	7	37
Gravel, fine to medium, and sand	38	75
Gravel, medium to fine, and sand; contains a little coarse gravel	11	86
Meade formation		
Sappa member		
Volcanic ash, white; contains some fine sand (Pearlette ash lentil)	1.5	87.5
Silt and clay, dark gray	17.5	105
Chase Channel formation		
Fullerton member		
Silt, calcareous, buff; contains many caliche nodules in lower part	27	132
Holdrege member		
Gravel, fine, sand, and silt, tan	9.5	141.5
PERMIAN—Leonardian		
Shale, dull red	3.5	145

74.—*Sample log of test hole 21-9-6bb in the NW cor. sec. 6, T. 21 S., R. 9 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,697.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Sand, fine to coarse, and silt, dark gray	2.5	2.5
Sand, coarse to fine; contains a little fine to coarse gravel	17.5	20
Gravel, coarse to fine, and sand	10	30
Silt and clay, light gray and yellow brown; contains much coarse to fine sand	5	35
Gravel, coarse to fine, and sand; contains a few pebbles,	18	53
PERMIAN—Leonardian		
Shale, red	7	60

75.—*Sample log of test hole 21-9-36dd in the SE cor. sec. 36, T. 21 S., R. 9 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,655.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Sand, fine to coarse, and silt, dark gray	3	3
Sand, medium to fine, and silt, buff	1.5	4.5
Silt, calcareous, light gray; contains much coarse to fine sand and nodular caliche	1.5	6
Sand, coarse to fine; contains a little fine to medium gravel	22	28
Gravel, fine to medium, and sand	17.5	45.5
Meade formation		
Silt, calcareous, buff; contains some nodular caliche	24.5	70
Sand, coarse to fine, and fine to medium gravel; contains much silt, buff	8	78
PERMIAN—Leonardian		
Shale, red	2	80

76.—*Sample log of test hole 21-10-11cc in the NW cor. SW¼ SW¼ sec. 11, T. 21 S., R. 10 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,706.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Late Wisconsinan terrace		
Silt, gray, and very fine to medium sand	4	4
Silt, light and dark gray; contains a little fine to medium sand	4	8
Gravel, fine to medium, and sand	21	29
Silt, calcareous, buff; contains much coarse to fine sand	4	33
Gravel, fine to medium, and sand	27	60
Gravel, fine to medium, and sand; contains a little coarse gravel	6	66
PERMIAN—Leonardian		
Shale, dark red	4	70

77.—*Sample log of test hole 21-10-20dd in the SE cor. sec. 20, T. 21 S., R. 10 W., drilled by the State Geological Survey, July 1946. Surface altitude, 1,734.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Sand, medium to fine	3	3
Sand, coarse to fine; contains some fine to medium gravel	24.5	27.5
Silt, calcareous, yellow gray, and fine to medium sand	8.5	36
Gravel, fine, and sand	16	52
Silt, light gray and yellow gray, and fine to coarse sand,	11	63
Sand, fine to coarse	9	72
Gravel, fine to medium, sand, and silt, gray	10	82
Sand, medium to fine	17	99
Silt, gray, and very fine sand	3	102
Sand, fine to coarse	5	107
PERMIAN—Leonardian		
Siltstone, dull red	3	110

78.—*Sample log of test hole 21-11-36dd in the SE cor. sec. 36, T. 21 S., R. 11 W., Stafford County, drilled by the State Geological Survey, July 1946. Surface altitude, 1,763.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Sand, fine to coarse, and some silt, dark gray	1.5	1.5
Sand, coarse to fine; contains a small amount of fine gravel	4	5.5
Silt, light gray	9.5	15
Gravel, fine, and sand	11	26
Silt, calcareous, buff, and fine to medium sand	12	38
Silt and clay, calcareous, gray and buff; contains some fine sand; much concretionary calcium carbonate in lower part	12	50
Gravel, fine, and sand; contains a small amount of medium gravel	12	62
Meade formation		
Silt and clay, yellow gray and gray; contains some fine sand	13	75
Silt, calcareous, buff; contains much very fine to medium sand	21	96
Sand, fine to coarse, and some silt, buff	14	110
Sand, medium to fine	16	126
Chase Channel formation		
Fullerton member		
Clay, blue gray	21	147
Holdrege member		
Gravel, fine, sand, and silt, light gray	10	157
Gravel, fine to medium, and sand	46.5	203.5
PERMIAN—Leonardian		
Shale, red	6.5	210

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