THE UNIVERSITY OF KANSAS
STATE GEOLOGICAL SURVEY OF KANSAS

BULLETIN 95

GEOLOGY AND GROUND-WATER RESOURCES OF LINCOLN COUNTY, KANSAS

By DELMAR W. BERRY
(U. S. Geological Survey)

with a chapter on the chemical quality of the ground water

By WALTON H. DURUM
(U. S. GEOLOGICAL SURVEY)

This report is a joint product of the program of the Interior Department for development of the Missouri River Basin and the cooperative ground-water program of the United States Geological Surv[illegible] State Geological Survey of Kansas, the Division of Sanitation [illegible] Kansas State Board of Health, and the Division of Water Reso[illegible] Kansas State Board of Agriculture.

Printed by authority of the State of Kansas
Distributed from Lawrence

UNIVERSITY OF KANSAS PUBLICATIONS
JULY, 1952

PRINTED BY
FERD VOILAND, JR., STATE PRINTER
TOPEKA, KANSAS
1952

24-3081

CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY AND GROUND-WATER RESOURCES OF LINCOLN COUNTY, KANSAS

By Delmar W. Berry

ABSTRACT

This report describes the geography, geology, and ground-water resources of Lincoln County, north-central Kansas. The hydrologic and geologic data were obtained in the field during the years 1947 to 1950. Records for 175 wells were collected and 43 test holes were drilled to determine the thickness and character of the water-bearing materials. These data were used to prepare a water-table contour map for the major valley area and to determine the depth to water level in the county. The outcropping rock formations were studied in the field and by aid of test-hole data, and from these studies a geologic map and cross sections were prepared.

The area covered by this report lies in the Smoky Hills Upland area and is drained by Saline River, a tributary to Smoky Hill River, by Smoky Hill River, and by Rattlesnake Creek, a tributary to Solomon River. In general, the drainage pattern is fine-textured and the area is maturely dissected, small flat areas occurring along the terraces of the major valleys and at a few places on the upland divides. The climate is subhumid, the normal annual precipitation being slightly less than 25 inches. The principal mineral resources of the area are ground-water, construction materials, ceramic raw materials, and volcanic ash.

All the rocks exposed in Lincoln County are of sedimentary origin and range in age from Cretaceous to Recent. The oldest Cretaceous rocks exposed at the surface are Gulfian in age and are represented by the Dakota formation. Other Cretaceous rocks that are exposed in the uplands of the county are Graneros shale, Greenhorn limestone, and Carlile shale.

"Algal limestone" of the Ogallala formation (Pliocene) caps some of the highest hills.

Deposits of silt, sand, and gravel of the Meade formation (early Pleistocene) are exposed in the southwest corner of the county, where they overlie the eroded surface of the Dakota formation. The Sanborn formation of Pleistocene age mantles the flat upland areas, and alluvium underlies the channels of the major streams and their tributaries.

Supplies of potable water adequate for domestic and stock use are obtained from the alluvial fill of the valleys, and water supplies of variable quality and quantity are obtained from sandstones in the Dakota formation.

Saline River and Rattlesnake Creek are permanent streams in the area; nevertheless, wells supply all water for domestic and municipal uses. The City of Barnard obtains its water supply from a well penetrating the alluvium of Rattlesnake Creek, and Lincoln and Sylvan Grove obtain water supplies from wells penetrating the Dakota formation. Although adequate supplies of water for small irrigation projects may be obtained from the alluvium in local areas, supplies are generally not adequate for extensive irrigation.

A discussion of the principal chemical constituents of ground water in relation to the use and geologic occurrence of the water is based on analyses of 116 samples of ground water. These range from moderately mineralized hard water in both the Pleistocene deposits and the Dakota formation to highly mineralized hard water in other stratigraphic units. Soft water (less than 50 parts per million hardness) is pumped generally from deep wells in the Dakota formation.

Water containing more than 2,900 parts per million dissolved solids was obtained from one well in the alluvium; these dissolved solids may be related either to surface-water pollution or to the upward movement of more highly mineralized water from underlying formations. Most of the waters are hard; in all but four samples the hardness exceeded 130 parts per million.

Approximately 62 percent of the supplies have some domestic use. Undesirably high amounts of nitrate, in excess of 45 parts per million, were observed in 27 percent of the supplies sampled. Undesirable quantities of iron are present in the water of both shallow and deep wells, and the fluoride content in some samples from deep wells in the Dakota formation exceeds recommended limits for drinking water. A brief discussion of the municipal supplies is presented in this report.

INTRODUCTION

Purpose and Scope of the Investigation

During the spring of 1947 the U. S. Geological Survey, at the request of the Bureau of Reclamation, began a study of the groundwater resources of Saline River Valley in Lincoln County, Kansas. In 1948 this investigation was expanded to include a study of the geology and ground-water resources of Lincoln County and was co-ordinated with the co-operative program of ground-water investigations that was started in 1937 by the Federal Geological Survey, the State Geological Survey of Kansas, the Division of Sanitation of the Kansas State Board of Health, and the Division of Water Resources of the Kansas State Board of Agriculture. This investigation was carried out under the general administration of A. N. Sayre, Chief, Ground Water Branch, Federal Geological Survey, and George H. Taylor, Regional Engineer in charge of the groundwater investigations of the Missouri Basin, and under the immediate supervision of V. C. Fishel, District Engineer in charge of groundwater investigations in Kansas. The quality-of-water studies were made under the general administration of S. K. Love, Chief, Quality of Water Branch, and under the supervision of P. C. Benedict, Regional Engineer in charge of Missouri Basin quality-of-water investigations.

The increasing demand for ground water, one of the most important natural resources of Kansas, warrants studies to determine the quality and quantity of the available supply. Farmers are becoming irrigation conscious as the demand for agricultural products increases, and the public in general is recognizing the need for developing local industry. Development in any locality depends upon a water supply; consequently, investigations relative to the character and thickness of water-bearing formations and to the quality of the water are necessary. At the present rate of withdrawal, the danger of seriously depleting the ground-water supply seems very slight, but there is definite need for an adequate understanding of the quantity and quality of the available supply, where additional supplies can be obtained, and what measures may be necessary to safeguard their continuance.

Location and Extent of the Area

Lincoln County is in the Smoky Hills Upland (Adams, 1903) in the north-central part of Kansas (Fig. 1). The county is bounded

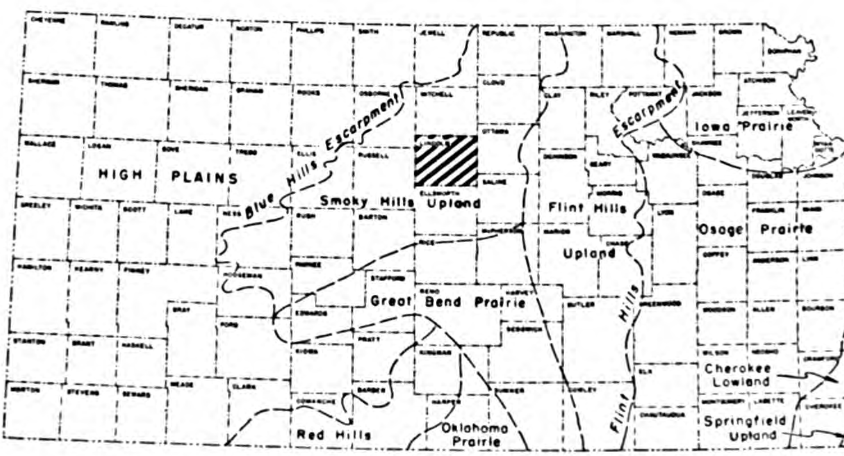


Fig. 1.—Physiographic subdivisions of Kansas (after Adams, 1903).

on the north by Mitchell County, on the east by Ottawa County, on the south by Ellsworth County, and on the west by Russell County. The area lies between 38° 53′ and 39° 13′ north latitude and 97° 55′ and 98° 29′ west longitude. It contains 20 townships, Ts. 10, 11, 12, and 13 S., Rs. 6, 7, 8, 9, and 10 W., having an area of about 726 square miles. Lincoln County is rectangular in shape, extending about 30 miles east and west and about 24 miles north and south. The locations of this county and other areas in which co-operative ground-water investigations have been made are shown in Figure 2.

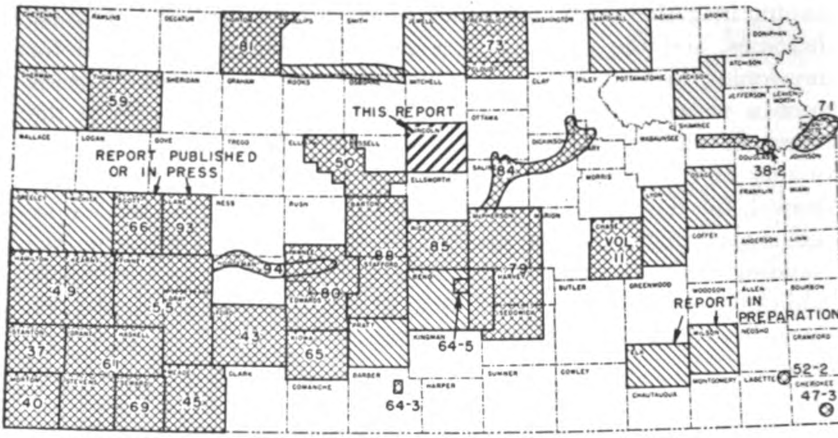


Fig. 2.—Area described in this report and other areas in Kansas for which co-operative ground-water reports have been published or are in preparation.

Methods of Investigation

Field work for this investigation was done during the years 1947 to 1950. During this time all the wells listed in Table 14 were visited and the data regarding them obtained. Water-level measurements were made with a steel tape from a fixed measuring point at the top of the well.

In 1947 John Sears collected data on 50 wells in the Saline River Valley in Lincoln County. Sixteen of these wells were selected as observation wells and periodic measurements of the water levels in them have been made since March 1947. During the field seasons of 1948 and 1949 records of 125 additional wells throughout Lincoln County were collected.

In the fall of 1947, 15 water samples for complete analysis were collected from typical domestic and stock wells and were analyzed in the Quality of Water laboratory of the U. S. Geological Survey at Stillwater, Oklahoma. During the fall of 1948 and the summer of 1949 water samples were collected from 101 additional domestic and stock wells. Of the 101 samples, 88 were analyzed to determine the chloride and nitrate contents and 13 were given complete analyses by Howard Stoltenberg, chemist in the Water and Sewage laboratory of the Kansas State Board of Health.

During the field seasons of 1948 and 1949 a geologic investigation of the county included the following types of work: determination of the thickness and extent of loess; drilling of auger holes at various locations; measurement of stratigraphic sections to determine the thickness of the exposed Cretaceous rocks; and marking all outcrops on aerial photographs and base maps. John Frye spent one week in the summer of 1948 and one week in the fall of 1949 in the field with me helping to work out the stratigraphy. From these data a geologic map (Pl. 1) was prepared. Geologic cross sections (Pl. 3) were prepared from data obtained by drilling 43 test holes through the water-bearing silt, sand, and gravel of Pleistocene age.

These test holes were drilled with the hydraulic rotary drilling machine owned by the State Geological Survey and operated by William T. Connor, Kenneth L. Walters, and Max Yazza. Logs of the test holes were prepared in the field by Walters and the samples were examined microscopically in the office. The wells and test holes shown on Plate 2 were located within the section by use of the odometer and are believed to be accurate to within 0.1 mile. The altitudes of the measuring points of the measured wells and test holes were determined with a plane table and alidade or dumpy level by level parties from the U. S. Bureau of Reclamation and a Geological Survey level party headed by Charles K. Bayne.

Field data used for preparing Plates 1 and 2 were recorded on a base map modified from a map prepared by the State Highway Commission of Kansas. The roads and drainage on these base maps were corrected by field observations and by use of aerial photographs obtained from the U. S. Department of Agriculture.

Well-Numbering System

The well and test-hole numbers in this report give the location of wells according to General Land Office surveys and in the following order: township, range, section, 160-acre tract within that section, and the 40-acre tract within that quarter section. If two or more wells are in a 40-acre tract, the wells are numbered serially in the order in which they were inventoried. The 160-acre and 40-acre tracts are designated a, b, c, or d in a counterclockwise direction beginning in the northeast quarter. For example, as shown in Figure 3, well 10-7-7bb is located in the NW¼ NW¼ sec. 7, T. 10 S., R. 7 W.

Acknowledgments

Appreciation is extended to the many well drillers, well owners, tenants, and city officials in Lincoln County for their co-operation. This included supplying data relative to the character of materials

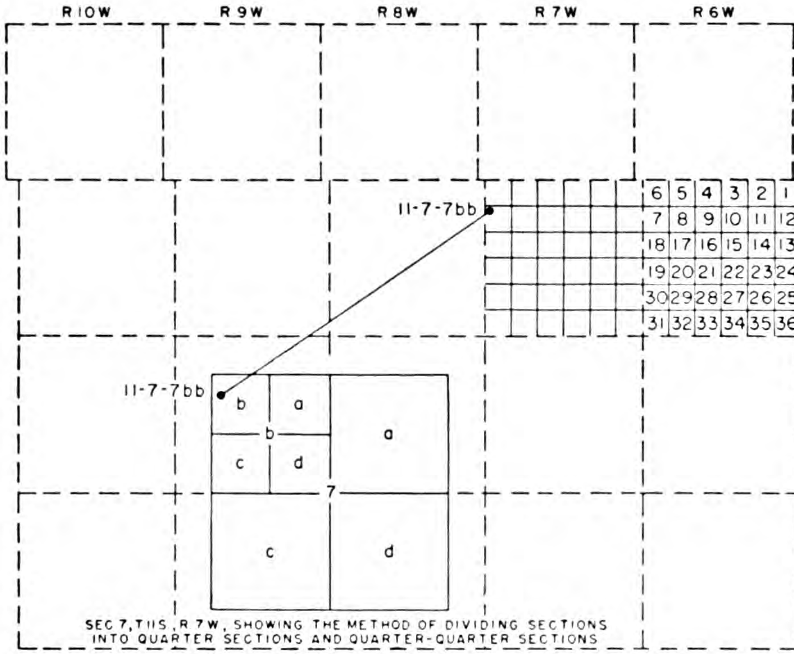


FIG. 3.—Diagram of Lincoln County illustrating the well-numbering system used in this report.

penetrated in drilling wells, permitting measurement of wells, permitting test drilling on their lands, and supplying data on city-supply wells.

The manuscript for this report has been reviewed critically by several members of the Federal and State Geological Surveys; by Dwight Metzler, Director and Chief Engineer, and Willard O. Hilton, Geologist, Division of Sanitation, Kansas State Board of Health; and by Robert V. Smrha, Chief Engineer, and George S. Knapp, Engineer, Division of Water Resources, Kansas State Board of Agriculture.

The illustrations were drafted by W. W. Wilson of the U. S. Geological Survey. Analyses of the water samples were made by J. Crittendon, R. H. Langford, and L. R. Kister, Chemists, Federal Geological Survey, and Howard Stoltenberg, Chemist, Kansas State Board of Health.

GEOGRAPHY

Topography and Drainage

Lincoln County lies in the area designated by Adams (1903) as the Smoky Hills Upland of the Great Plains physiographic province. The topography of this area is related to the differential weathering characteristics of the Cretaceous clay, sandstone, shale, and limestone which account for the prominent topographic features of Lincoln County such as the broad flat alluvial valleys along the major streams, the deep, narrow channels of the tributary valleys, the bold escarpments of the deeply dissected uplands, and the long gently sloping pediments of the uplands.

The highest altitude is 1,800 feet, on the divide between Saline and Smoky Hill Rivers at the Lincoln-Ellsworth County line. The lowest altitude is 1,280 feet, where the valley of Rattlesnake Creek enters Ottawa County. This gives a county-wide relief of 520 feet but the local maximum relief is about 300 feet.

Lincoln County, except locally along the flat terrace of Saline River, is well drained by three major streams and their tributaries: Rattlesnake Creek in the northeast corner, Saline River which is centrally located west to east, and Smoky Hill River which passes through Ellsworth County to the south and drains a small area along the southwestern boundary of Lincoln County. Rattlesnake Creek heads in northwestern Lincoln County, flows in an easterly direction across the northern part of the county, and then southeast to its junction with the Solomon River in Ottawa County. Saline River heads in Thomas County, enters Lincoln County about 7 miles north of the southwest corner, flows in an easterly direction across the county, and then joins Smoky Hill River east of Salina. Smoky Hill River heads in Colorado, flows eastward to a point near Lindsborg, northward to Salina, and again eastward joining with Republican River at Junction City to form Kansas River.

Climate

Lincoln County has moderate precipitation, a wide temperature range, moderately high average wind velocity, and comparatively rapid evaporation. The summer, especially during July and August, is generally hot. The winters are moderately cold, but generally free from excessive snowfall. Climatic data presented below are based on records of the U. S. Weather Bureau.

The normal annual mean temperature is 55.3° F. at Lincoln. January, with a normal mean temperature of 29.2° F., generally has the lowest temperature of the year; July, with a normal mean temperature of 80.5° F., generally has the highest temperature. The highest recorded temperature at this station is 119° F., recorded in July 1934, and the lowest temperature is —25° F., recorded in January and December 1912. The average date of the last killing frost in the spring is April 27, but killing frosts have been recorded as late as May 24. The average date of the first killing frost in the fall is

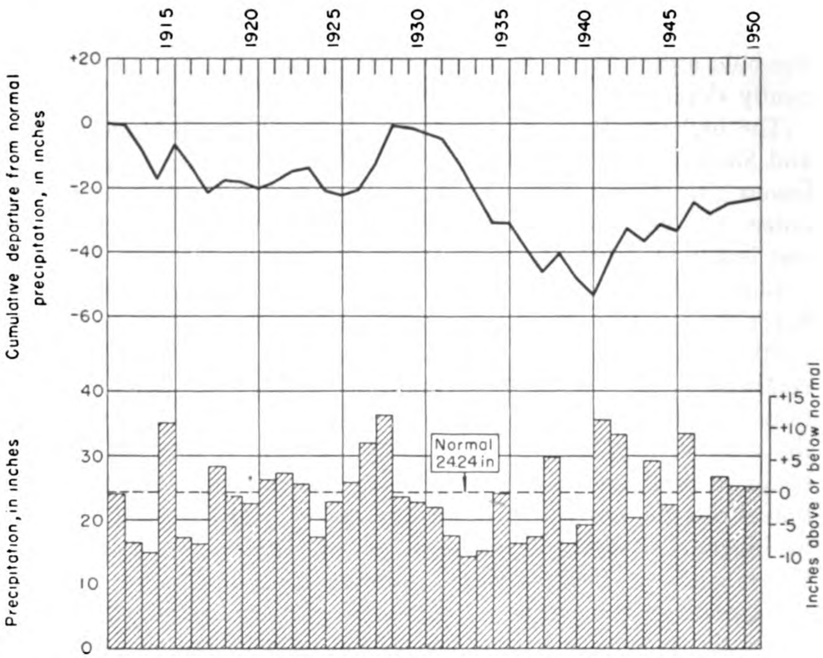


Fig. 4.—Annual precipitation and cumulative departure from normal precipitation at Lincoln.

October 14, although killing frosts have been recorded as early as September 20. The average length of the growing season is 170 days.

The normal annual precipitation is 24.24 inches; the lowest recorded annual precipitation at Lincoln was 16.37 inches in 1936, and the highest was 35.02 inches in 1915. The annual precipitation and the cumulative departure from normal precipitation at Lincoln are shown graphically in Figure 4. As indicated, deviations from the normal are frequent, and precipitation in the area seems to follow irregular cycles in which periods of excessive precipitation alternate with periods of deficient precipitation or drought. Much of the precipitation falls as heavy rains which are followed by periods of scanty rainfall. Approximately 74 percent of the total annual precipitation falls during the crop-growing season from April through September.

In this area the prevailing wind is from the south, but north winds prevail during January and February. The greatest wind velocity is in March and April after which it decreases until August, which is the least windy month of the year.

Population

According to the 1951 county assessors report to the Kansas State Board of Agriculture, the population of Lincoln County is 7,258, an average of 9.9 people per square mile in comparison with 23.6 for the State. In 1951 approximately one-half of the residents of the county lived in four cities. Lincoln, the county seat and largest city, has a population of 1,893. The three other cities, Sylvan Grove, Beverly, and Barnard, have populations of 547, 305, and 298, respectively.

Transportation

The railroad network in Lincoln County consists of two branch lines of the Atchison, Topeka, & Santa Fe Railway Co. and one branch line of the Union Pacific Railroad. One branch of the Santa Fe extends from Abilene across the northeast corner of the county to Barnard; the other branch takes a northwest coarse from Salina through Lincoln to Osborne. A branch of the Union Pacific enters the county at Beverly, passes westward through Lincoln, and extends northwestward to Colby in Thomas County, where it joins the main line of the Chicago, Rock Island, & Pacific Railroad Co.

Two hard-surfaced State highways pass through Lincoln County, State Highway 14 through the central part from north to south, and State Highway 18 from east to west through the central part (through Beverly, Shady Bend, Lincoln, Vesper, and Sylvan Grove). The rest of the county is served by improved county and township roads.

Agriculture

Agriculture is the chief industry in Lincoln County. Wheat, sorghum, corn, oats, and hay are the principal crops; the acreage of each for the years 1939, 1944, and 1946 is given in Table 1.

Lincoln County, which has 1,239 farms, comprises 464,640 acres, of which 35 percent is pasture land. Cattle are the predominant livestock; during 1946, 34,000 cattle were raised in or marketed from the county.

The distribution of cultivated and grazing land is controlled by the topography and stratigraphy. Nearly all the crop land lies on the flat loess-mantled uplands and in the alluvial valleys. The grazing land is generally the rolling areas underlain by shale, sandstone, and limestone of Cretaceous age.

Natural Resources

Mineral resources of Lincoln County include clay, construction materials, volcanic ash, and sand and gravel. These resources are fairly extensive, but they are not being developed as fully as is possible.

Clay resources.—The clay resources of this area are restricted primarily to the Dakota formation. Plummer and Romary (1947, p. 38) indicate that these clays are important ceramicly because they differ mineralogically from the majority of the clays in Kansas in that they are composed dominantly of the clay mineral kaolinite. Common clay products are bricks, floor, wall, roofing, and sewer tile, refractories, pottery, and whiteware.

The Kiowa shale, which underlies the Dakota formation, and the Graneros shale, which overlies the Dakota, are not desirable for standard structural clay products but are satisfactory for the production of lightweight aggregate. Lincoln County has large quantities of clay and shale suitable for these products.

Table 1.—*Acreage of principal crops grown in Lincoln County*

Crop	1939	1944	1946
Wheat	67,000	164,000	170,000
Sorghum	37,890	38,670	30,370
Corn	13,400	17,700	12,200
Oats	7,030	5,630	6,470
Hay	3,740	6,220	5,030
All other crops	7,686	1,832	2,607
Totals	136,746	234,052	226,677

Construction materials.—Besides clay, Lincoln County has several other native materials suitable for construction purposes. Three principal materials are Greenhorn limestone, Dakota quartzite, and sand and gravel.

The Fencepost limestone, an 8- to 10-inch bed at the top of the Greenhorn limestone, is easily recognized by the iron-stained band at the center of the bed. In many parts of Lincoln County quarries have been opened in the Fencepost to obtain material for fence posts and building blocks. The durability of this limestone is demonstrated by the numerous stone buildings throughout the county constructed during pioneer days. This limestone is also crushed and used as road metal.

The Dakota formation contains many thick lenticular channel sandstones. Locally many of these channel sandstones are cemented by calcite, iron oxide, or dolomite (Swineford, 1947). At some localities in Lincoln County sandstones cemented with each of these minerals are found. The calcite-cemented sandstone is known locally as "Lincoln quartzite" because of its abundance near the town of Lincoln. It has been used extensively for road metal, railroad ballast, and high-quality concrete aggregate. The iron oxide-cemented sandstone, which has a tendency to case-harden upon exposure to the atmosphere, has been used for building stone, road metal, and riprap on stock-pond dams. Another type, dolomitic calcite-cemented sandstone, has essentially the same occurrence and use.

At the present time quartzite is produced from two quarries, one 1 mile south of Lincoln and the other 5 miles west of Sylvan Grove. The county has large reserves of this material.

Both quartz gravel and locally derived gravel are produced in the county. The principal source of the quartz sand and gravel is the channel fill of Meade age in southwestern Lincoln County. This sand and gravel is also used as road-surfacing material and for concrete aggregate.

The locally derived gravel contains more silt and clay than the quartz gravel and is more common throughout the county. It occurs in terraces along the major streams and tributaries. This type of gravel is satisfactory only for road surfacing; many of the county and township roads have been surfaced with it.

Volcanic ash.—The only extensive deposits of volcanic ash in Lincoln County are in sec. 27, T. 13 S., R. 10 W. (Carey and others, 1952). Surface exposures indicate that the deposit extends under a large part of this section and ranges from 3 to 12 feet in thickness. Two pits have been opened and a small quantity of ash is mined for ceramic uses.

Volcanic ash has been used as an abrasive, particularly in scouring compounds and soaps; as an important ingredient of ceramic glazes and in ceramic bodies; as an additive to cement; as a raw material for manufacture of several types of lightweight aggregates; as a sweeping compound; as a dressing for some types of bituminous-mat highways; and it may be usable as a raw ingredient in glass, as a filler, and for many potential future uses.

The uncertainty with which an explorer may find deposits of volcanic ash may be explained by the theory explaining the source and distribution of volcanic dust. Volcanic dust was thrown explosively into the air somewhere in the Rocky Mountain belt, perhaps in north-central New Mexico (Swineford, 1949), and was carried by winds over Kansas and adjacent areas. The ash shards settled to the ground, or were carried down by rains, resulting in a thin layer of fine-textured ash spread extensively over the surface. This thin surface layer of material served to overload the streamlets leading into ponds or depressions on aggrading valley flats and rarely in upland situations. These small tributaries were able to carry material which was predominantly ash into the depressions until they had cleared at least a part of their drainage areas. Thus deposits of volcanic ash are found in or adjacent to abandoned streamlets or valley fills.

GEOLOGY IN RELATION TO GROUND WATER

Summary of Stratigraphy*

The rocks that crop out or are present immediately beneath the surface in Lincoln County are sedimentary in origin. They range in age from early Cretaceous (Comanchean Series) to Quaternary (Moore and others, 1951). The areal distribution of the surficial deposits is shown on Plate 1. Although the Cheyenne sandstone and Kiowa shale of early Cretaceous age do not occur at the surface, they are referred to in this report because of their water-supply potentialities. The Cheyenne sandstone pinches out toward the east and is absent beneath much of the eastern part of the county. The Kiowa shale lies immediately below the Dakota formation which crops out in large areas adjacent to Saline River and its tributaries. The Graneros shale overlies the Dakota formation and caps the lower hills adjacent to the valley. The Graneros shale forms a

* The geologic classification and nomenclature of this report follow the usage of the State Geological Survey of Kansas and do not conform in all respects to the usage of the U. S. Geological Survey.

gentle grade from the top of the Dakota formation to the overlying Greenhorn limestone. The resistant limestone beds of the Greenhorn form the prominent escarpments along the tributaries of Saline River and extend over large upland areas in the northern and southwestern part of the county. The Carlile shale caps the uppermost hills in the northern and southwestern parts of the county; however, it crops out only where the loess has not been deposited or where the loess has been eroded.

The Ogallala formation of Pliocene age is represented by small deposits of "Algal limestone," which cap some of the uppermost hills in the central-southwest and central parts of the county.

Deposits of the Meade formation of Pleistocene age fill an abandoned stream channel (Wilson Valley) in the southwest corner of the county. Other Pleistocene deposits in the county are the loesses of the Sanborn formation, which extend over much of the uplands, and the terrace deposits adjacent to Saline River and its tributaries. Alluvium of late Pleistocene age is deposited in the present stream channels and is also found as a thin veneer over much of the bottom land.

The character and ground-water supply of the geologic formations in Lincoln County are described briefly in the generalized section (Table 2).

Cretaceous System

comanchean series

Cheyenne Sandstone

Character.—The Cheyenne sandstone was named by Cragin (1889, p. 65) from Cheyenne Rock—an indurated mass of sandstone that forms a prominent ledge on the north side of the Medicine Lodge Valley about three-fourths of a mile west of Belvidere, Kiowa County, Kansas.

The Cheyenne sandstone does not crop out in Lincoln County; hence, little is known of its lithologic character in this area except as determined by the cuttings from a domestic well drilled in the extreme western part of the county (Table 14). The formation has been described in detail by Latta (1946) at the type locality near Belvidere. Latta (1946, p. 235) states:

> The Cheyenne consists chiefly of light-colored fine- to medium-grained friable cross-bedded sandstone and lenses of sandy shale and conglomerate. Minor amounts of clay, selenite crystals, iron nodules, and pyrite occur in different parts of the formation. The bedding is extremely irregular and dis-

TABLE 2.—*Generalized section of the geologic formations of Lincoln County*

SYSTEM	Series	Subdivisions	Thickness, feet	Character	Water supply
Quaternary	Pleistocene	Recent alluvium Unconformable on older formations	0–60	Sand, gravel, clay, and silt; buff to tan. Predominantly fine sand and silt.	Yields supplies of water for domestic and stock use. Quantities are limited.
		Sanborn formation Unconformable on older formations	0–35	Loess, sand, and locally, colluvium at the base; tan to gray-buff. Sand and gravel locally cemented.	Yields little or no water to wells in this area.
		Meade formation	0–40	Gravel, sand, silt, clay, volcanic ash, and caliche; gray, tan, and buff.	Yields meager supplies of water to wells.
Tertiary	Pliocene	Ogallala formation Unconformable on older formations	0–4	"Algal limestone," pink, gray, and tan. Fresh-water limestone and caliche.	Yields no water to wells.
Cretaceous	Gulfian	Carlile shale	0–20	Shale, chalky to black, fissile. Contains some limestone interbedded.	Yields no water to wells.
		Greenhorn limestone	65–90	Shale and limestone interbedded. Shale is calcareous, tan to blue-gray; limestone is thin-bedded, fossiliferous, gray.	Weathered limestone yields some potable water to shallow wells.
		Graneros shale	20–35	Shale, blue-gray, locally contains clay, siltstone, and sandstone. Contains selenite and pyrite.	Yields little or no water to wells.
	?	Dakota formation	140–200 ±	Clay, shale, siltstone, and sandstone interbedded and varicolored. Contains abundant siderite, hematite, limonite, and some lignite.	The sandstone yields moderate quantities of water of variable quality. Generally, shallow wells yield good water and deep wells yield poor water.

Table 2.—*Generalized section of the geologic formations of Lincoln County*—Concluded

System	Series	Subdivisions	Thickness, feet	Character	Water supply
Cretaceous	Comanchean	Kiowa shale	75–100±	Shale, black, containing thin beds of sandstone and siltstone, and crystals of gypsum and pyrite.	Yields little or no water to wells.
		Cheyenne sandstone	0–100±	Sandstone, medium to fine-grained, gray; some shale and siltstone.	Yields no water to wells.

continuous so that it is impossible to trace any one bed for more than a short distance. Most of the beds are merely lenses of limited extent.

The material penetrated in the drilling of the domestic well described above consisted of fine- to medium-grained sandstone and ranged from white to gray in color.

Distribution and thickness.—The Cheyenne sandstone probably underlies only parts of extreme western Lincoln County. A test hole drilled to the Permian red beds in the central part of the county did not penetrate any Cheyenne sandstone. Although large areas in the southwestern part of Kansas are underlain by the Cheyenne, it crops out in only a very few localities. The principal outcrops are in the Belvidere area of southwestern Kiowa County.

The thickness of the Cheyenne sandstone in Lincoln County has not been determined; however, it has been reported by Latta (1946) to range from 32.5 to 94 feet in the Belvidere area and to average about 45 feet.

Water supply.—Only one well is believed to derive water from the Cheyenne sandstone. The material penetrated in this well was permeable enough to supply water for domestic and stock use. However the uncertainty as to the occurrence of the formation beneath the surface in Lincoln County makes it inadvisable to depend on it for a water supply.

Kiowa Shale

Character.—The Kiowa shale was named by Cragin (1894, p. 49) from exposures in Kiowa County, Kansas. As used in this report, the term Kiowa shale includes the thick series of marine shale, sandstone lenses, and fossiliferous limestones between the Cheyenne sandstone or Permian rocks and the Dakota formation. In the western part of the county, the Kiowa shale conformably overlies the Cheyenne sandstone and in the remainder of the county unconformably overlies Permian rocks. The Kiowa shale, overlain conformably by the Dakota formation, does not crop out in Lincoln County. Data presented here are compiled from well logs.

The Kiowa shale consists of thinly laminated dark-gray to black shale in the lower part, grading upward into gray, tan, and brown clay and clay shale (Latta, 1946, p. 244). The shale in the lower part is generally black and has been called a "paper" shale because it is very thinly laminated. Thin beds of shell limestone—so called because they consist almost wholly of fossil shells—are a conspicuous feature of the formation, especially of the lower part.

These beds are from 3 to 18 inches thick, generally light gray in color, and locally contain gypsum or pyrite. The matrix consists of shell fragments and sand or sand and clay. In some places, where oxidation of the pyrite has caused the rock to disintegrate, and the fossils are largely decomposed, the shell bed is stained with iron which gives it a red-brown or rusty color. Lenses of sandstone ranging in thickness from 1 to 18 inches and in color from light to dark gray, occur throughout the formation. Generally they are fine-grained and in many places are cemented.

Distribution and thickness.—The Kiowa shale is not exposed in Lincoln County but crops out in Ellsworth County, which adjoins Lincoln County on the south. One measured section near Kanopolis has a thickness of 57 feet (Plummer and Romary, 1942, pp. 324-325). In the subsurface of Russell County, which adjoins Lincoln County on the west, the Kiowa shale attains a thickness of 105 feet in sec. 33, T. 13 S., R. 15 W. (Swineford and Williams, 1945, p. 164.)

At a test hole drilled in the NE¼ sec. 21, T. 12 S., R. 6 W., in Lincoln County the Kiowa shale was approximately 80 feet thick. Indications are that the Kiowa shale underlies the county.

Water supply.—Some wells in the county may derive water from the Kiowa shale. Wells penetrating a lens of sandstone in the Kiowa shale may produce quantities of water adequate for domestic or stock supplies. Because adequate water supplies can be obtained at shallower depths, most of the wells do not penetrate the Kiowa shale.

GULFIAN SERIES

Dakota Formation

Character.—The Dakota formation of Kansas has been referred to as or included in the "Dakota Group" (Meek and Hayden, 1862); "Dakota Sandstone" (Prosser, 1897); "Dakota formation" (Twenhofel, 1924); "Rocktown channel sandstone member" (Rubey and Bass, 1925); "Cockrum Sandstone" (Latta, 1941); and "Omadi formation" (Condra and Reed, 1943). The term "Dakota Group" (Meek and Hayden, 1862) was first applied to the sandstones, various colored clays, and lignite beds that underlie the "Benton Group" in exposures near Dakota City, Dakota County, Nebraska.

In this report, the Dakota formation includes the strata between the Kiowa shale (below) and the Graneros shale (above). The Dakota consists largely of gray to dark-gray shale, sandy shale, and varicolored clays containing lenticular beds of siltstone and sandstone. Owing to the resistant sandstone beds or lenses (Pl. 4A), it

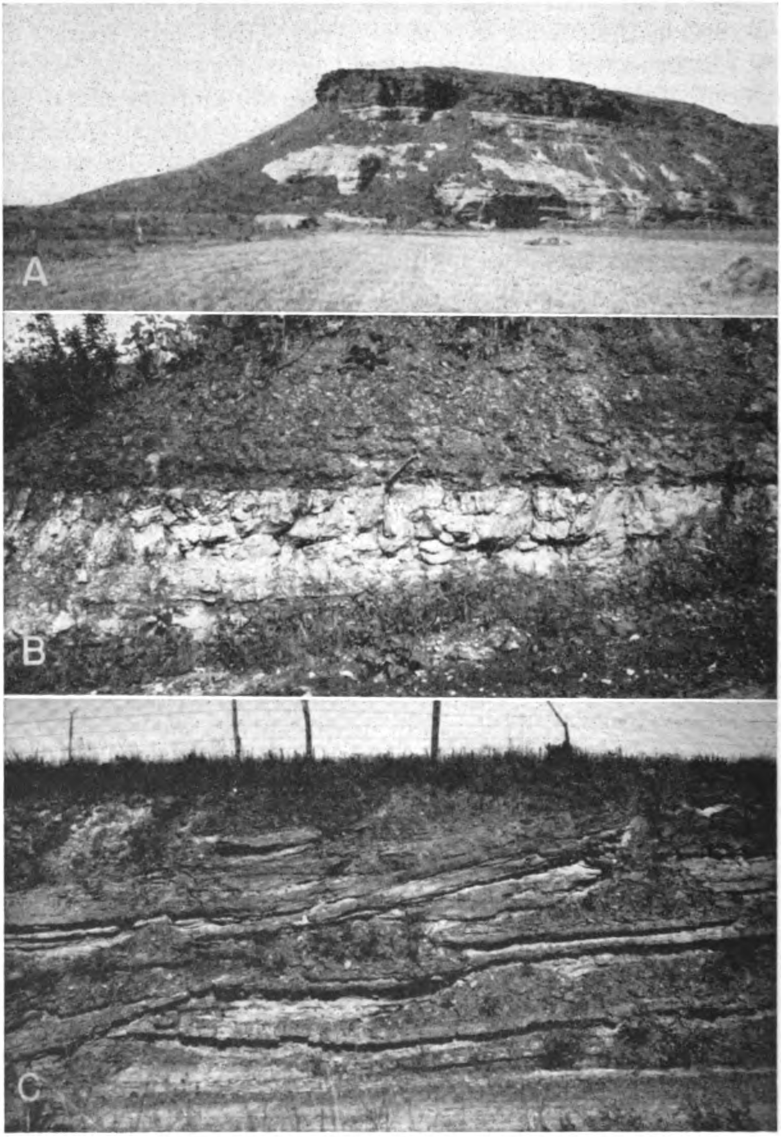


PLATE 4. **A**, Terra Cotta and Janssen Clay members of the Dakota formation in valley wall of Hell Creek, SE¼ sec. 19, T. 13 S., R. 10 W. **B**, Uppermost part of the Dakota formation and lowermost part of the Graneros shale, NW¼ sec. 13, T. 13 S., R. 9 W. Pick handle marks the contact. **C**, Fine-grained sandstone in the upper part of the Terra Cotta clay member of the Dakota formation, NW¼ sec. 13, T. 12 S., R. 9 W. (Photos by John C. Frye.)

is generally believed that most of the Dakota formation is sandstone; however, investigations show that much of the formation is composed of clay and shale. Plummer and Romary (1942) describe the Dakota formation as consisting largely of clay of various colors, containing irregular lenticular beds of siltstone and sandstone. In their opinion the Dakota was deposited in a dominantly continental and near-shore environment, whereas the underlying and overlying formations were deposited under marine conditions.

Surficial exposures and drill cuttings from the Dakota formation of this area contain concretions of limonite, siderite, and hematite. The Dakota also contains lignite, carbonaceous material, and calcium-cemented sandstone, or "quartzite."

The Dakota formation in Kansas consists of two members, the upper called Janssen clay member and the lower called Terra Cotta clay member.

Distribution and thickness.—The Dakota formation in Lincoln County crops out over widespread areas adjacent to Saline River and its tributaries and underlies the rest of the county. Some of the best exposures are in the southern and southeastern parts of the county (Pl. 4B, 4C). Throughout much of the northern and southwestern parts of the county, the Dakota formation is overlain by Graneros shale and Greenhorn limestone, which in turn are overlain by Carlile shale or loess, or both.

The Dakota formation ranges in thickness from about 140 feet on the eastern side of the county to 200 feet at the western side. At a test hole drilled in the NE cor. sec. 21, T. 12 S., R. 6 W., the Dakota formation, because of the absence of the upper member, was only 135 feet thick.

Water supply.—Many wells in Lincoln County obtain their water supply from the Dakota formation. A typical well deriving water from the Dakota is shown in Plate 5A. Although much of the water from the Dakota formation is mineralized, the quantity generally is adequate for domestic and stock supplies. The water in most of the wells is under artesian pressure but flows at the surface from only a few of them. Data for determining the areas where water of good quality can be obtained are not available. Indications are that the water in the upper part of the Terra Cotta clay member of the Dakota has a high chloride concentration. Shallow wells in areas where the Janssen clay member of the Dakota formation is absent yield water with as much as 1,400 parts per million of chloride, whereas wells penetrating 100 feet of the Terra Cotta clay

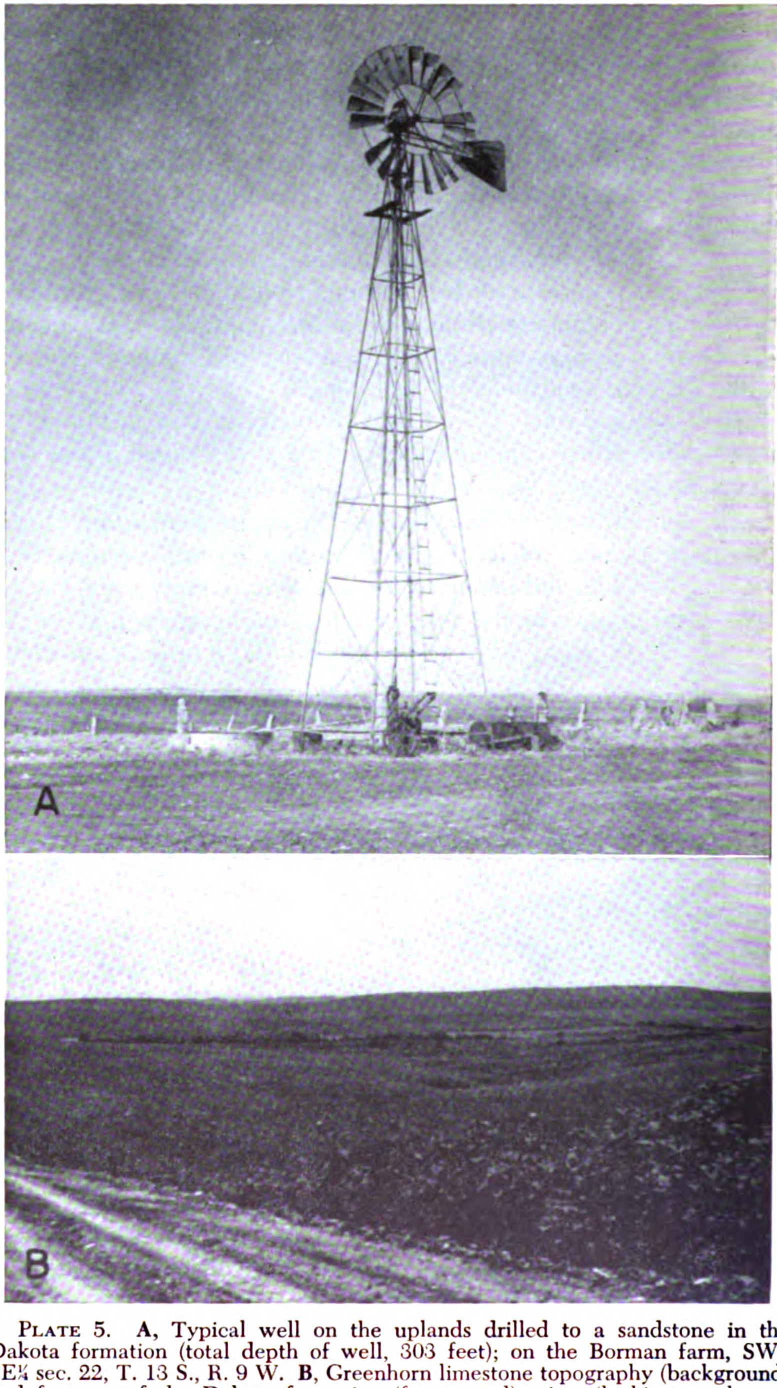


PLATE 5. **A**, Typical well on the uplands drilled to a sandstone in the Dakota formation (total depth of well, 303 feet); on the Borman farm, SW¼ SE¼ sec. 22, T. 13 S., R. 9 W. **B**, Greenhorn limestone topography (background) and features of the Dakota formation (foreground); view (looking southwest) from sec. 9, T. 11 S., R. 6 W.

member yield water containing as little as 22 parts per million of chloride.

Graneros Shale

Character.—The Graneros shale was named by Gilbert (1896) for Graneros Creek, Pueblo County, Colorado. The Graneros shale consists of blue-black fissile noncalcareous clay shale that is locally interbedded with sandy limestone, sandstone, and sandy shale. In Lincoln County the base is marked generally by a thin ironstone bed (Pl. 4B). A bentonite bed about 15 inches thick occurs near the top. Selenite crystals may be present throughout the formation.

The Graneros shale lies between the Dakota formation (below) and the Greenhorn limestone (above). The shale forms a gentle slope from the base of the Greenhorn limestone to the top of the Dakota formation (Pl. 5B).

Distribution and thickness.—The Graneros shale ranging in thickness from 20 to 35 feet, underlies the northern and southwestern parts of the county. Most of the outcrops are in areas that have been exposed to stream erosion. These areas lie adjacent to Saline River and its major tributaries. The areal distribution of the Graneros shale is shown on Plate 1.

Water supply.—No wells in Lincoln County are known to obtain water from the Graneros shale, which is impermeable. A water supply might be obtained if a sandstone lens in the shale were penetrated below the water table. As an adequate supply of water generally is obtained from either the Dakota formation or alluvial fills, no need has developed for wells in the Graneros shale.

Greenhorn Limestone

Character.—Gilbert (1896, p. 564) named the Greenhorn limestone from exposures of interbedded limestone and shale near Greenhorn Station and along Greenhorn Creek about 15 miles south of Pueblo, Colorado. Tentative correlation of the Colorado section with central Kansas rocks referred to as "Benton" was made by Logan (1897, pp. 232-234). Rubey and Bass (1925) were the first to use the term Greenhorn as a mapping unit in Kansas. Working in Russell County, they subdivided the Greenhorn of Kansas into four members. They are, in ascending order, Lincoln limestone member, an unnamed shale member, Jetmore chalk member, and an unnamed upper shale member. In 1926 Bass named the lower shale member the Hartland shale and applied the term Pfeifer shale to the upper shale member. In central Kansas the top of the Greenhorn limestone is marked by the Fencepost limestone bed. The Greenhorn limestone rests on the noncalcareous shale of the Graneros shale.

The upper part of the Greenhorn limestone consists of interbedded thin chalky limestone and calcareous shale containing bentonite seams. The middle part of the formation is calcareous shale containing a few concretionary limestones and thin bentonite seams. The lower part consists of calcareous shale interbedded with thin dark crystalline limestones containing shark teeth and other vertebrate remains. These limestones are "petroliferous," giving off a strong oily odor when freshly exposed.

Distribution and thickness.—The Greenhorn limestone extends over most of the upland and divide areas of Lincoln County; however, in many places it is concealed by the Carlile shale that immediately overlies it, or the loess that mantles part of the uplands and divides. Areal distribution of the Greenhorn limestone is shown on Plate 1. The Jetmore member is shown on Plate 6B. The formation ranges from 65 to 90 feet in thickness. The uppermost bed (Fencepost limestone) of the Greenhorn ranges from 8 to 10 inches in thickness and is marked by a narrow iron-stained band centrally located within the bed. Numerous quarries in the area indicate the extent of the Fencepost limestone bed.

Water supply.—In general, the chalky limestone and shales that make up the Greenhorn limestone are impervious and do not yield much water to wells. Where the upper part of the limestone lies at shallow depths and is subject to weathering it may contain openings large enough to hold small amounts of water. A few wells in the area may obtain water from the upper part of this limestone or from weathered shale immediately overlying it. In general, adequate supplies of water are obtained from other formations and no attempts have been made to develop the Greenhorn limestone as an aquifer.

Carlile Shale

Character.—The Carlile shale was named by Gilbert (1896) from exposures of gray argillaceous shale along Arkansas River near Carlile Station west of Pueblo, Colorado. Logan (1897, pp. 232-234) compared Gilbert's section with the rocks lying below the Niobrara in Kansas and suggested their correlation. Rubey and Bass (1925) used the Carlile shale as a mapping term in Russell County, where they divided the formation into two members, the Blue Hill shale member above and the Fairport chalky shale mem-

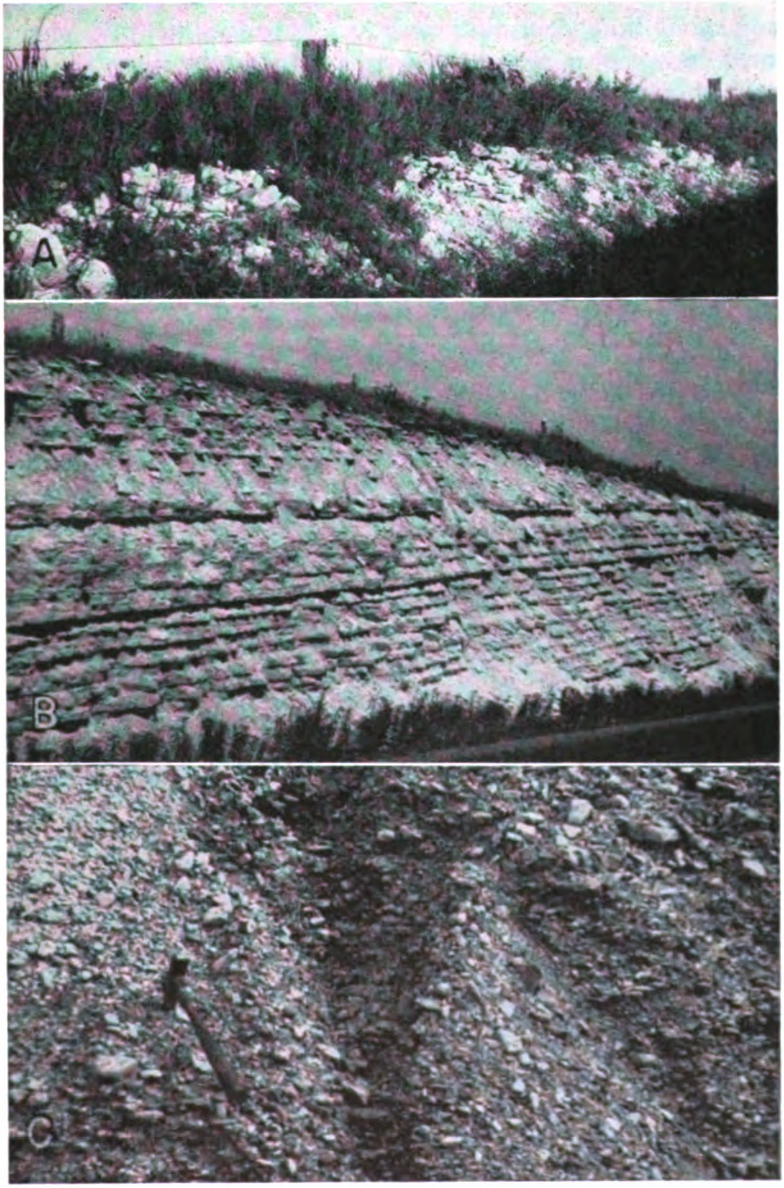


Plate 6. A, "Algal limestone" (Ogallala formation) on Carlile shale; sec. 24, T. 13 S., R. 10 W. B, Jetmore chalk member of the Greenhorn limestone in a road cut in sec. 13, T. 10 S., R. 8 W. C, Gravel underlying Pleistocene terrace of Elkhorn Creek Valley; exposure in a pit in the SE¼ sec. 5, T. 13 S., R. 7 W. (Photos by John C. Frye.)

ber below. Bass (1926, p. 28) applied the same units to geologic mapping in Ellis County and named and described the Codell sandstone zone from exposures in the upper part of the Blue Hill shale member along Saline River in northern Ellis County.

In Lincoln County only the lower part of the Fairport chalky shale member of the Carlile shale is present. It resembles the upper part of the Greenhorn limestone, consisting of alternating beds of thin concretionary limestone and calcareous shale. The lower 20 feet contains thin bentonite layers. In fresh exposures the shale beds are bluish gray, but they weather to a yellow clay and contain many *Ostrea* shells.

Distribution and thickness.—Although the Carlile shale underlies much of the upland and divide areas, the shale is rarely found as a surficial exposure because it is covered generally with a loess mantle. The only outcrops are along tributaries of major streams. The Carlile shale ranges in thickness from a featheredge to about 20 feet.

Water supply.—Because the Carlile shale is impervious and is situated well above the water table it does not yield water to wells in Lincoln County.

Tertiary System

PLIOCENE SERIES

The only rocks in Lincoln County that may be correlated with deposits of the Tertiary Period are the "Algal limestone" deposits (Pl. 6 A), which mark the top of the Ogallala formation.

Ogallala Formation

Character.—The Ogallala formation was named by Darton in 1899 (pp. 734-735, 741-742) from a locality in southwestern Nebraska. In 1920 Darton (p. 6) referred to the type locality as near Ogallala Station in western Nebraska. Elias (1931) made a detailed study of the Ogallala formation in Wallace County and adjacent areas of western Kansas and later (1937) briefly described the Ogallala in Rawlins and Decatur Counties. In 1942 he described Tertiary fossil seeds and other plant remains of the central Great Plains. In Kansas Ogallala is used as a formation comprised of the Kimball, Ash Hollow, and Valentine members.

The Ogallala formation in Lincoln County is represented only by "Algal limestone" or "capping" limestone, which is the uppermost deposit of the Ogallala formation. It generally consists of pink-white or gray-green limestone containing concentrically banded structures.

Distribution and thickness.—Exposures of "Algal limestone" of the Ogallala formation (Pl. 6A) have been recognized in the area at 12 locations (Pl. 1). This limestone is seen in road cuts and as "float" in plowed fields. Underlying the "Algal limestone" are weathered limestone and shale of the Greenhorn limestone or the Carlile shale. Where found as a bed, the "Algal limestone" ranges in thickness from a featheredge to 2 feet.

Water supply.—As the limestone lies above the water table in Lincoln County it furnishes no water to wells in this area.

Quaternary System

PLEISTOCENE SERIES

Throughout Pleistocene time alternating periods of erosion and deposition took place. In Lincoln County, Pleistocene deposits are represented by the Meade formation, the Sanborn formation, and the alluvium. The last was formed by a continuous process of deposition and redeposition of the silt, sand, and gravel along and adjacent to the present streams during late Pleistocene time.

Meade Formation

Character.—The Meade formation is restricted in distribution to the southwestern corner of Lincoln County, where it overlies the Dakota formation unconformably. The Meade formation is composed of a basal gravel member and an upper silt member, which are equivalent to the Grand Island and Sappa formations of late Kansan and Yarmouthian age as classified by the Nebraska Geological Survey. The Grand Island and Sappa are classified as members by the Kansas Geological Survey. The Pearlette ash bed in the upper silt member of the Meade formation in Lincoln County facilitates correlation with deposits of late Kansan and Yarmouthian age elsewhere in Kansas and in adjacent states. The Pearlette ash bed and associated fossil zones have been traced from Texas to Iowa, constituting a marker bed for correlation of the Pleistocene deposits of the plains region with the glacial section (Frye, Swineford, and Leonard, 1948).

Distribution and thickness.—The Meade formation in Lincoln County is confined to the southwest corner of the county where the ancestral Saline River flowed into the Smoky Hill Valley during Kansan time. In this channel fill, named Wilson Valley (Frye, Leonard, and Hibbard, 1943, pp. 36-37), the deposits range in thickness from a thin veneer to as much as 40 feet. In Wilson Valley the Meade formation is overlain by the younger Loveland and Peoria silt members of the Sanborn formation; thus the unconsolidated material ranges in thickness from 30 to 65 feet.

Water supply.—The Meade formation in Wilson Valley may yield some water to wells. However, the thickness of the Pleistocene silt, sand, and gravel does not exceed 65 feet and the depth to the water table is about 62 feet; therefore the saturated thickness of the unconsolidated Pleistocene deposits generally is not more than 3 feet. Many wells in this area penetrate the Dakota formation in order to obtain an adequate water supply.

Because it generally lies above the water table, the Meade formation in this area yields little water to wells but it serves as a good catchment area for the underlying Dakota formation.

Sanborn Formation

Character.—In 1931 Elias (pp. 163-181) described unconsolidated Pleistocene deposits consisting mostly of silt in northwestern Cheyenne County, Kansas, and named these deposits the Sanborn formation from the town of Sanborn, Nebraska, just north of the type area. In Kansas, four members are recognized in a complete section of the Sanborn formation—the Crete sand and gravel member at the base, grading upward into the Loveland silt member, which is overlain by the Peoria silt member and the Bignell silt member.

In general, the formation consists of three prominent lithologic types, which indicate three environments of deposition. The first type consists of stream deposits of sand and gravel representing the major channel fills of earliest Sanborn time; the second consists of eolian silts transported by winds from the flood plains of the major valleys during periods of alluviation; and the third consists of colluvial materials on slopes.

The first lithologic type, which is represented by sand and gravel deposited in channels of earliest Sanborn (Illinoian) time, possibly is represented in Lincoln County by sand and gravel composed of fragments of locally derived Cretaceous rocks. Locally the sand and gravel are cemented with calcium carbonate to form rocks or lenticular masses that superficially resemble the "mortar beds" of the Ogallala formation. These unconsolidated deposits occupy terrace positions along Saline River, Rattlesnake Creek, and their tributaries. Lower gravel beds on Saline River in Russell County (Rubey and Bass, 1925, p. 19) are very similar to the deposits described in Lincoln County in position and cementation; however, the deposits in Lincoln County are derived primarily from local material

—limestone, sandstone, and shale—whereas those of Russell County consist chiefly of quartz. The deposits in Lincoln County possibly are of the same age as those described by Logan (1897, pp. 218-219) as the "Salt Creek gravel beds." Owing to the position of these deposits above (5 to 40 feet) the flood plains of the major streams and their tributaries and the position they occupy with respect to the Meade formation in southwestern Lincoln County and northwestern Ottawa County, they are believed to be of Crete age. These deposits range in thickness from a thin veneer to 20 feet and are shown on Plate 1 as the Crete member of the Sanborn formation.

The second lithologic type is represented by eolian silts that range in age from Illinoian through Recent. In other areas where the upland loess sequence is well developed, the Loveland silt member is reddish brown and contains the well-developed Sangamon soil at the top. The Sangamon soil in central Kansas commonly contains a prominent zone of caliche accumulation. The Peoria silt member of early Wisconsinan age generally overlies the Loveland silt member and constitutes the bulk of the upland loess mantle in Lincoln County. Elsewhere the Peoria silt member is terminated upward by the Brady soil and is overlain by the Bignell silt member; however, the Bignell silt member has not been recognized in Lincoln County.

Colluvial deposits, which form the third lithologic type, are composed of a mixture of unsorted Cretaceous rock fragments and eolian silt. The rock fragments are generally large and angular because of the short distance over which they are moved. These deposits occur at many places along the steep slopes bordering Saline Valley.

Distribution and thickness.—The areal distribution of the Sanborn formation is shown on Plate 1. The members of the formation are not mapped as separate units; the Loveland and Peoria silt members are mapped as one unit and the colluvium, because of its relative unimportance as a source of ground water, is mapped with the bedrock that underlies it. The deposits of silt and colluvial material are distributed over the flat upland area and on the slopes of the hills that grade into the valleys. The silt ranges in thickness from a thin veneer to 15 feet and is mapped only in areas where the thickness exceeds 3 feet. The colluvial material that mantles the long sweeping slopes between the valleys and the uplands generally does not exceed 10 feet in thickness. Throughout most of the area silt and colluvial material overlap.

Water supply.—The Sanborn formation, which is generally above the water table, is not an aquifer. In areas where the earliest Sanborn deposits immediately overlie the Dakota formation, conditions are favorable for ground-water recharge to the Dakota. The wells for the city of Sylvan Grove are in such a location.

Alluvium

Character.—Deposits of alluvium occur in the major and tributary valleys of this area. The alluvium consists of sand and gravel with some silt and clay (Pl. 6C). Generally the flood plain contains less sand and more silt and clay. Deposits of very compact silt and clay in the alluviated area along the major streams retard recharge and cause ponds of water to remain on the surface for long periods after rainfall.

Distribution and thickness.—The alluvium in the Saline River Valley ranges in width from less than 0.5 mile to 2.5 miles and ranges in thickness from a few feet to 60 feet. Alluvial deposits along Rattlesnake Creek and its tributaries range in thickness from 5 to 20 feet. The areal distribution is shown on the geologic map (Pl. 1).

Water supply.—Most of the domestic and stock water supplies in the valleys are obtained from alluvium. In areas where alluvium has a low permeability, supplies of water are obtained from the underlying Dakota formation. Wells penetrating the alluvium are reported to yield from 5 to 50 gallons of water a minute, which generally is adequate for domestic and stock use.

GEOMORPHOLOGY

The events that created the present topographic features started at the close of Pliocene deposition and the beginning of Pleistocene erosion. During early Pleistocene time streams began cutting into the consolidated Cretaceous materials. No deposits of Nebraskan age have been recognized in Lincoln County; events that took place here during that time are therefore deduced only from deposits of known Nebraskan age in other areas. By Kansan time the major streams followed very nearly the same pattern as do the present streams, except for Saline River which flowed through Wilson Valley into Smoky Hill River. Deposits of Kansan age fill the Wilson Valley channel in the southwest corner of the county.

A period of erosion and downcutting followed the deposition of the Kansan channel deposits of the Meade formation. During this erosional period, a stream flowing in the lower Saline Valley cut down and captured the stream in upper Wilson Valley, causing it to flow in approximately the present Saline River Valley. This downcutting produced channels 30 to 50 feet below the bedrock surface. As the downcutting diminished during late Illinoian time, the streams were again depositing over the valley floors of this area. These deposits may have been a source of some of the material of Loveland age that occurs on the small upland areas adjacent to the valley. During the following period (Sangamonian time) there seems to have been a comparatively small amount of erosion and deposition. Thus ideal conditions for the development of Sangamon soil were present.

Another erosional cycle which cut channels into the older material occurred during early Wisconsinan time. In many places much of the older material has been eroded and, owing to the late Wisconsinan alluviation, has been replaced by more recent deposits. During early Wisconsinan time, while the valley floors were being covered by alluvial material, a loess mantle (Pl. 7) was deposited over much of the upland area of northwestern and north-central Kansas. This loess material has been correlated with the Peoria silt member of the Sanborn formation. The Peorian loess probably originated from the Platte and Republican River Valleys. (Swineford and Frye, 1951).

At the close of Wisconsinan time another period of erosion formed the gullies, canyons, and erosional features of the present upland area. Saline River was rejuvenated and it cut the present stream channel. Alternating short periods of erosion and deposition during late Pleistocene time have covered the older deposits immediately adjacent to Saline River with an alluvial veneer.

GROUND WATER

Source

The following discussion on the source and occurrence of ground water has been adapted from Meinzer (1923), to which the reader is referred for a more detailed discussion. A summary of ground-water conditions in Kansas has been made by Moore and others (1940).

Water in the pores or openings of rocks and in the zone of saturation is called ground water. The amount of ground water that is present below the surface in any region and the manner and rate of its movement to wells or springs is controlled largely by the character of the rocks.

In Lincoln County, as in other parts of the Great Plains, ground water is derived almost entirely from local precipitation in the form

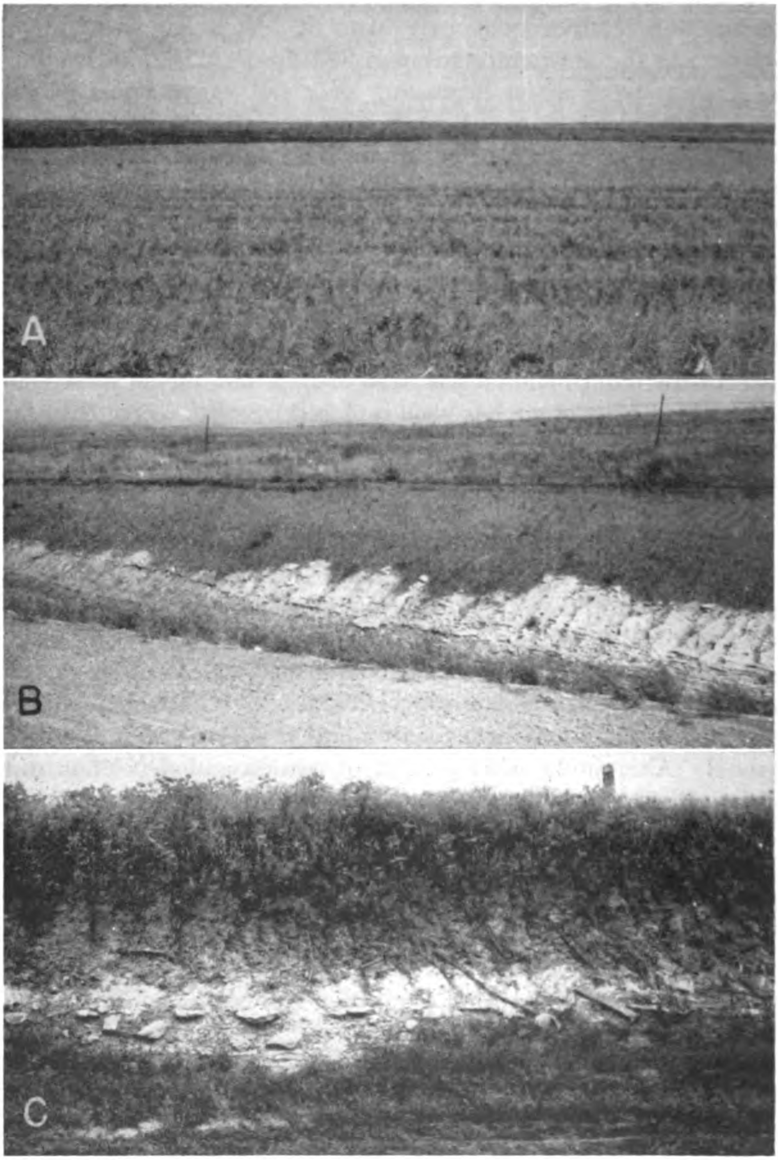


PLATE 7. A, Loess-mantled upland divide area in sec. 24, T. 10 S., R. 10 W. Loess is about 8 feet thick and overlies Cretaceous Greenhorn limestone. B, Loess and colluvium on Greenhorn limestone exposed in road cut in graded pediment surface south of Sylvan Grove. C, Thin loess mantle over Carlile shale capping upland divide area; exposed in a road cut in the SW¼ sec. 18, T. 10 S., R. 7 W. (Photos by John C. Frye.)

of rain or snow. Part of the water that falls as rain or snow is carried away by surface runoff and is lost to streams; part of it may evaporate or be absorbed by vegetation and transpired into the atmosphere. The water that escapes surface runoff, evaporation, and transpiration percolates downward through the soil and underlying strata until it reaches the water table, where it joins the body of ground water in the zone of saturation.

Ground water moves slowly through the rocks in directions determined by the shape and slope of the water table (Pl. 2), which is controlled by the permeability and thickness of the water-bearing materials, the topography, local variations in the quantity of recharge and discharge, and the stratigraphy and structure of the geologic formations. The ground water is eventually discharged through springs or wells, through seeps into streams, or by evaporation and transpiration.

Occurrence

Most rocks that underlie the surface of the earth at depths shallow enough to be penetrated by drilling contain voids or interstices. These range in size from microscopic openings to the large caverns developed in limestones. The percentage of the volume of the open spaces or voids to the total volume of the rock is the porosity. It is desirable when considering problems of ground-water supply to know the porosity of the water-bearing materials, but the permeability of the materials controls the amount of ground water that can move through them. The permeability of a rock is its capacity for transmitting water under pressure and is determined by the size, shape, and arrangement of the openings. For example, a bed of fine silt or clay may have a relatively high porosity, but because of the size of the particles each opening is very small. As the force known as molecular attraction holds a thin layer of water on the surface of each grain, these layers of water that are not free to move may fill or almost fill the openings in such a fine-textured sediment; thus the permeability, or water-yielding capacity of the rock, is very low even though its porosity, or water-holding capacity, is quite high. Likewise, larger openings that are not connected or are poorly connected may produce a high porosity and a low permeability. Water moves most freely through a rock that has relatively large and well-connected openings. Several common types of openings or interstices and the relation of rock texture to porosity are shown in Figure 5.

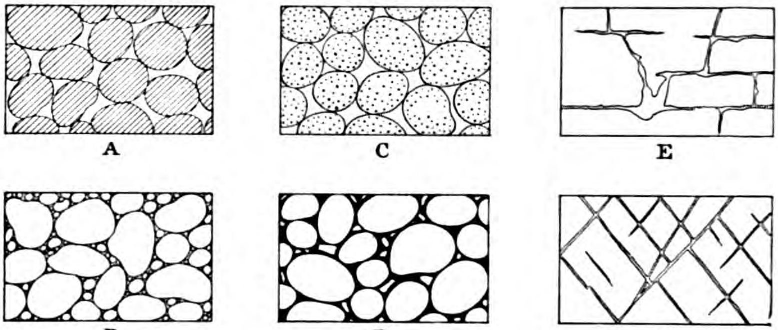


FIG. 5.—Diagram showing several types of rock interstices and the relation of rock texture to porosity. **A**, Well-sorted sedimentary deposits having a high porosity; **B**, poorly sorted sedimentary deposits having low porosity; **C**, well-sorted sedimentary deposits consisting of pebbles that are themslves porous so that the deposit as a whole has a very high porosity; **D**, well-sorted sedimentary deposits whose porosity has been diminished by the deposition of mineral matter in the interstices; **E**, rock rendered porous by solution; **F**, rock rendered porous by fracturing. (From Meinzer, 1923, fig. 1.)

Artesian Conditions

Ground water may be said to have normal pressure, subnormal pressure, or artesian pressure. The static level of ground water under normal pressure coincides with the water table or the upper surface of the zone of saturation. Under subnormal pressure the static level is below the water table and under artesian pressure, above it. A well that flows at the land surface is known as a flowing artesian well.

Artesian or confined water exists where a water-bearing bed is overlain by an impermeable or nearly impermeable bed that dips from its recharge area toward the discharge area. Water enters the water-bearing bed at the outcrop and percolates slowly down dip to be held by the overlying confining bed. Down dip from the outcrop area, the water exerts pressure against the confining bed. In a well penetrating the water-bearing formation the water level rises above the top of the formation. This water level is called the piezometric surface. If the altitude of the land surface at the well is lower than the altitude of the outcrop or recharge area of the aquifer, the water may rise high enough to flow at the surface.

In Lincoln County some wells that tap the Dakota formation are artesian; a few of these are flowing wells. The known flowing wells are in the southern and southeastern parts of the county. In 1948 a well 96 feet deep in the NW¼ SE¼ sec. 28, T. 12 S., R. 7 W. flowed with sufficient artesian pressure to cause the water to rise 9 feet above the land surface.

The Water Table and Movement of Ground Water

SHAPE AND SLOPE

The water table is defined as the upper surface of the zone of saturation except where that surface is formed by an impermeable body (Meinzer, 1923a, p. 32). The water table is also the boundary between the zone of saturation and the zone of aeration. It is not a level surface but is a generally sloping surface having many irregularities. These irregularities are caused by several factors. In places where the amount of recharge is exceptionally high, the water table may build up and form a mound or low ridge from which the water slowly spreads out. In material of low permeability these mounds or ridges may be pronounced, but in very permeable material they generally are small. Depressions in the water table may indicate places where ground water is discharging, usually occurring along streams that are below the normal level of the water table or in places where water is withdrawn by wells or plants.

The shape and slope of the water table in the Saline River Valley are shown on the map (Pl. 2) by means of contour lines, just as the configuration of the land surface is shown on a topographic map. Each point on the water table along a given contour line has the same altitude. The direction of ground-water movement is at right angles to these contour lines—in the down-slope direction.

Plate 2 also shows the location of wells in which the depth to water was measured, the location of test holes drilled, and the altitude of the water surface at points along the channels of the main streams. These data were utilized in the preparation of the water-table contour map.

The contour map indicates that the water table slopes toward Saline River from both sides and that ground water is discharging into the river. Near the middle of the valley the contours trend almost at right angles to the axis of the valley, and the spacing of the contours indicates an average downstream hydraulic gradient of about 2 feet to the mile.

RELATION TO TOPOGRAPHY

The depths to water level in Lincoln County are given on Plate 2. In wells that obtain water from the terrace deposits or alluvial deposits the depth to water is generally less than 30 feet; where it is more than 40 feet the water is obtained from the Dakota formation. Artesian pressures in the Dakota formation may cause water to rise relatively high with respect to the depth at which it was first found. The maximum depth to water in wells measured in this area was 249 feet. In general the shape of the water table in the areas of alluvium and terrace deposits conforms to the topography; where the Dakota is the principal aquifer, the depth to water is affected little by the topography.

FLUCTUATIONS OF THE WATER TABLE

The water table does not remain in a stationary position but fluctuates much like the water level in a surface reservoir. If the inflow to the underground reservoir exceeds the draft, the water table rises. Conversely, if the draft exceeds the inflow, the water table declines. Thus, the rate and magnitude of fluctuation of the water table depend upon the rate and magnitude at which the underground reservoir is replenished or depleted.

The amount of precipitation that percolates through the soil to the water table, the amount of seepage that reaches the underground reservoir from surface streams whose channels are above the water table, and the amount of underflow from adjacent areas cause the rise of the water table in this area. These factors depend largely upon precipitation, either in this area or immediately adjacent to it.

The amount of water pumped from wells, the amount of water absorbed directly from the water table by plants (transpiration), the amount of water lost from the ground-water reservoir by evaporation, the amount of ground water entering surface streams by channel-bank seepage, and the amount of water passing beneath the surface into adjacent areas, as well as deficient precipitation, result in a decline of the water table.

Fluctuations of the water table caused by recharge and discharge are reflected by the rise and fall of water levels in wells. A group of wells was selected for observation of the character and magnitude of water-level fluctuations in this area, and periodic measurement of the water levels in them was begun in 1947. Records of these water levels are published annually by the Federal Geological Survey (Sayre and others).

The fluctuations of water level in three observation wells in Lincoln County and the monthly precipitation near Lincoln for the period 1946 through 1950 are shown graphically in Figure 6. The period of measurement of these wells is as yet too short to permit definite correlation between precipitation and recharge. Nevertheless, a general correlation between rising water levels and high precipitation is indicated.

Recharge

Recharge is the addition of water to the underground reservoir. Ground water within a practicable drilling depth in Lincoln County is derived from precipitation that falls as snow or rain either in the area or in near-by areas to the west and northwest.

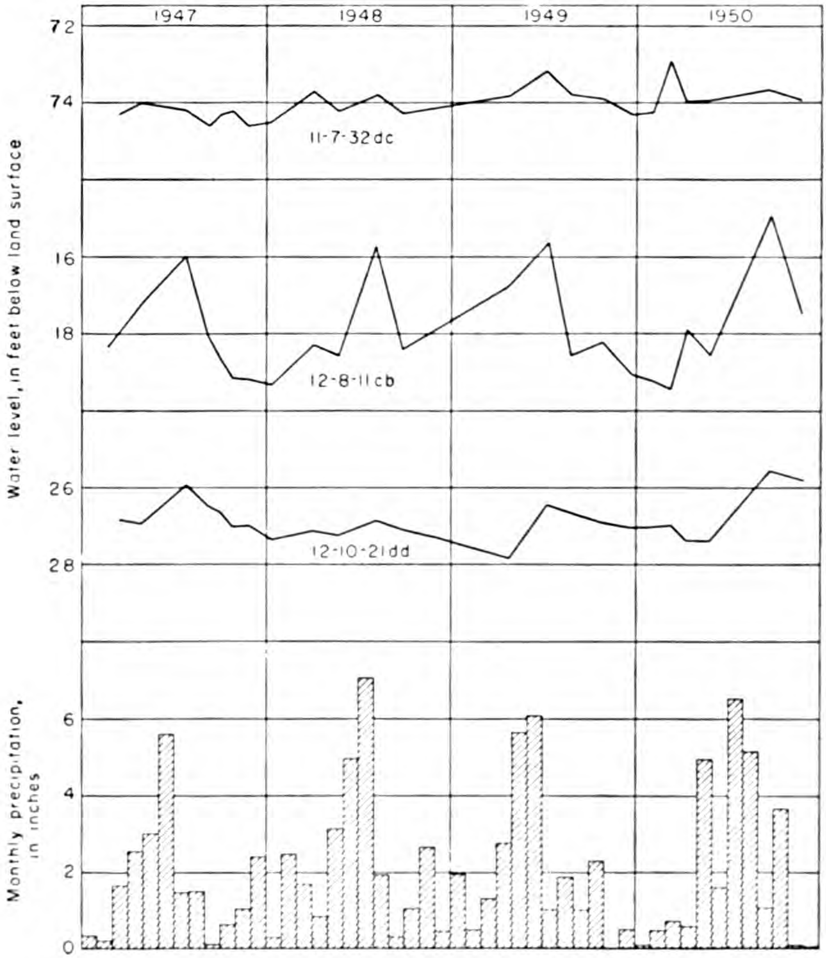


Fig. 6.—Hydrographs of three observation wells and monthly precipitation (1946-1950) near Lincoln.

Recharge from local precipitation.—The normal annual precipitation in this area is about 24 inches, but only a small fraction of this amount enters the zone of saturation as recharge to the ground-water reservoir. The depth to the water table and the type of material above the water table greatly influence the amount and frequency of recharge. The flat terraces and flood plains of Saline River and Salt Creek and their major tributaries, where the water table lies near the land surface and is overlain by unconsolidated deposits of sand and sandy silt, represent areas of high recharge. Maturely dissected divide areas characterized by channels and steep slopes, where the water table lies at a considerable depth below the land surface and is overlain by the impervious Carlile shale, Greenhorn limestone, or Graneros shale, represent areas of low recharge. Recharge into outcropping Cretaceous rocks varies widely, as the formations range from chalky shale and black fissile shale to sandstone. Recharge may be somewhat more in areas where faulting has occurred, where interstices have formed from the weathering of the shale and limestone, or where solution has opened small channelways in the limestone.

Recharge from streams and ponds.—The stream surface of Saline River is below the water table and receives water from the ground-water reservoir. Therefore, the river is not a source of recharge to the ground-water body. The upper courses of the tributary streams, however, are above the water table, and during and after rains when these valleys are carrying surface flow some water probably seeps into the alluvial deposits and percolates downward to recharge the ground-water reservoir.

A large number of surface ponds have been constructed in Lincoln County. Where these ponds are above the water table and are underlain by permeable material they constitute a source of recharge to the ground-water body. Where the ponds are well sealed to prevent downward leakage, recharge to the ground-water reservoir is negligible.

Recharge from subsurface inflow.—As indicated by the slope of the water table (Pl. 2), the movement of ground water under the valley area is in an easterly to southeasterly direction. Hence, a small amount of water from precipitation in central and eastern Russell County moves into western Lincoln County and contributes to the available supply of ground water.

Much of the recharge to the water-bearing zones in the Cretaceous rocks may be derived from areas outside Lincoln County. The Cretaceous rocks in Lincoln County generally dip eastward toward the outcrop areas. The wells that penetrate Cretaceous rocks toward the outcrop area tap artesian water, so that the piezometric surface at some places is as much as 75 feet above the level at which the water was found. These conditions indicate that the source of the water in these beds is west of the area under discussion.

Discharge

Ground-water discharge is the release of water directly from the zone of saturation or from the capillary fringe; it may take place through evaporation and transpiration or through springs, seeps, wells, or infiltration galleries.

Natural discharge.—Before artificial discharge was introduced in Lincoln County the ground-water reservoir in that area was in a state of approximate equilibrium—that is, the average annual recharge was approximately balanced by the average annual discharge, and the water table was moderately stable except for seasonal fluctuations. Water was added to the ground-water reservoir by movement from the west and northwest, by recharge from precipitation, and by seepage from streams. Ground water was discharged from the area principally by movement to the east and southeast and by discharge into Saline River. The discharge into the river is illustrated by the water-table contour map (Pl. 2).

Other methods of ground-water discharge in this area are transpiration and evaporation. Water may be taken into the roots of plants directly from the zone of saturation or from the capillary fringe, and be discharged from the plants by transpiration. The depth from which plants will lift ground water in an area of given climate varies with different plant species and different types of soil. The lift by ordinary grasses and field crops is not more than a few feet; however, alfalfa and certain types of desert plants have been known to send their roots to depths of 60 feet to reach the water table (Meinzer, 1923, p. 83).

Transpiration in Lincoln County probably is slight owing to the small percentage of the total land area in the valleys. However, transpiration in the Saline River and Rattlesnake Creek Valleys is considerable, because of the shallow water table and the growth of crops such as alfalfa.

The amount of ground water discharged by direct evaporation is very small; however, in an area of a few square miles west of the city of Lincoln the water table is shallow enough for some evaporation to take place. Other places where the water table is sufficiently shallow for direct evaporation are along the banks of the streams and in parts of the stream beds.

Discharge from wells.—Much of the discharge from the ground-water reservoir is from wells. All city supplies (quantities are shown in the section on utilization) and most of the domestic and stock supplies in the rural areas are obtained from wells. The total quantity of water pumped annually from wells is not known.

Recovery

PRINCIPLES OF RECOVERY

When water is standing in a well, the head or pressure of the water inside the well and the head of the water outside the well are in equilibrium. Whenever the head inside a well is reduced, a differential head is established and water moves into the well. The head of the water inside a well may be reduced in two ways: (1) by lowering the water level by a pump or some other lifting device, and (2) by reducing the head at the source of a well that discharges by artesian pressure. Whenever water is removed from a well there is a resulting drawdown or lowering of the water level or, in a flowing artesian well, an equivalent reduction in artesian head. When water is being discharged from a well, the water table is lowered in an area around the well to form a depression resembling an inverted cone. This depression of the water table is known as the cone of depression, and the distance that the water level is lowered is called the drawdown. In any well, within certain limits, the greater the rate of pumping the greater will be the drawdown.

The capacity of a well is the rate at which it will yield water after the water stored in the well has been removed. The capacity depends upon the thickness and permeability of the water-bearing bed and the construction and condition of the well. The capacity of a well generally is expressed in gallons a minute.

The specific capacity of a well is its rate of yield per unit of drawdown and it is determined by dividing the tested capacity in gallons a minute by the drawdown in feet. If a well yields 1,000 gallons a minute, for example, and has a drawdown of 10 feet when pumped at that rate, then the specific capacity of the well would be 1,000 divided by 10, or 100 gallons a minute per foot of drawdown, or simply 100.

When water is withdrawn from a well, the water level drops rapidly at first and then more slowly until it finally becomes nearly stationary. When the withdrawal of water from a well ceases, the water level rises rapidly at first and then more slowly until eventually it reaches approximately its original position.

METHODS OF RECOVERY

Ground water is recovered by wells penetrating the zone of saturation or by springs developed at the outcrop of an aquifer.

Wells in the county are bored, dug, or drilled. Generally the dug and bored wells are in the valleys where the water table is shallow, and the drilled wells are in areas where consolidated material is penetrated before the aquifer is reached.

A few springs have been developed in the Cretaceous outcrop area in the county. Those visited, with the exception of one artesian spring in the extreme southeastern part of the area, are gravity springs. They are of two types: (1) contact springs, and (2) seepage springs. The contact springs issue at the contact of the sandstone and clay in the Dakota formation or at the contact of the Greenhorn limestone and Graneros shale, where permeable beds overlie the relatively impermeable clay or shale. Seepage springs issue from the porous sandstone of the Dakota formation and along slopes or streams where the Pleistocene sand and gravel is saturated.

Several methods of spring development are used to increase the available supply of water. 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. Several water supplies for stock have been developed in this way in the Dakota outcrop area in the southeastern part of the county. Although some of the springs are wet-weather springs, they serve as a supplemental supply.

A common method of utilizing springs for domestic and stock supplies 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 most of the springs in the area fluctuates with local precipitation.

UTILIZATION

During this investigation, data on 175 wells in Lincoln County were obtained. All types of wells in all parts of the area were visited. Most of them were domestic or stock wells; five were municipal wells. At the time of the investigation no ground water was being used for irrigation.

DOMESTIC AND STOCK SUPPLIES

Domestic wells supply homes with water for drinking, cooking, and washing, and supply schools not served by municipal wells. Stock wells supply water for livestock, principally cattle. Most water for domestic use is obtained from wells, but in some of the areas of outcrop of Greenhorn limestone and Graneros shale a few cisterns are used. Most of the stock water is obtained from wells, but in recent years there has been an increased construction of dams on dry watercourses in areas where supplies of ground water are difficult to obtain. Although the water from wells penetrating the Dakota formation may have a high chloride content, it generally is satisfactory for stock use.

PUBLIC SUPPLIES

Lincoln, Sylvan Grove, and Barnard are the only cities in Lincoln County that have public water supplies, and they are supplied from wells. Brief descriptions of the water-supply systems of these cities follow, and details of well construction are listed in Table 14.

Lincoln.—The City of Lincoln is supplied from two dug wells penetrating the Dakota formation. These wells are 80 feet deep and are walled with native stone. They are equipped with turbine pumps powered by 15- and 20-horsepower electric motors. The depth to water in each well is reported to be 30 feet.

In 1949 the City of Lincoln consumed an average of about 9 million gallons of water a month and had a storage capacity of 950,000 gallons. The storage space is divided into three units: an elevated tank having a capacity of 750,000 gallons, and two underground reservoirs each having a capacity of 100,000 gallons.

Sylvan Grove.—The water supply for Sylvan Grove is obtained from two drilled wells penetrating a sandstone of the Dakota formation. The wells are on a terrace on the north side of Saline River at the west side of the city. They are 68 and 70 feet deep respectively, and have a static water level of about 45 feet. Both wells are cased with iron and are equipped with turbine pumps powered by 40-horsepower electric motors. The wells are reported to have a drawdown of 8.5 feet after being pumped at the rate of 350 gallons a minute for 4 hours.

The City of Sylvan Grove consumes about 3.5 million gallons of water a month and has a storage capacity of 82,000 gallons. The storage space is divided into two units: an elevated tank, which has a capacity of 50,000 gallons, and an underground reservoir. which has a capacity of 32,000 gallons.

Barnard.—The City of Barnard is supplied with water from a dug well 60 feet deep and 8 feet in diameter. The depth to water was about 9.5 feet in September 1949. Although the well is located on a terrace along Salt Creek, the depth of the well and the character of the water indicate that the aquifer is a sandstone of the Dakota formation. A 5-horsepower electric motor operates the turbine pump on the well.

The city is reported to consume about 300,000 gallons of water a month. Water is stored in an elevated concrete tank having a capacity of 80,000 gallons.

Chemical Quality of Ground Water

By Walton H. Durum

GENERAL CONDITIONS

All ground water contains mineral substances in solution. The major constituents in the ground water in Lincoln County include the cations calcium, magnesium, sodium, and potassium, and the anions bicarbonate, sulfate, chloride, and nitrate. Lesser amounts of fluoride, boron, iron, and silica also are present. The quantities of the various constituents, together with other related physical measurements, are presented in Table 3. For those samples that were analyzed by the U. S. Geological Survey, pH and specific conductance (the reciprocal of the electrical resistivity of the water, a function of ion concentration and mobility) were determined also.

Calcium is the predominant basic ion in most water in the area of shallow wells and, in deeper wells, in water that is in contact with deposits of gypsum, selenite, or limestone. Calcium and magnesium impart hardness to water and are responsible for increased use of soap and for the undesirable curd formed in washing processes. Water that contains less than 50 or 60 parts per million hardness (as $CaCO_3$) is considered to be soft, whereas hardness in excess of 60 parts per million becomes increasingly noticeable to the consumer. In the samples of water from Lincoln County, the contents of calcium and magnesium ranged from 4.0 to 446 parts per million and from 3.2 to 49 parts per million, respectively.

Sodium and potassium, which are common to all natural water, are of particular importance in evaluating water for irrigation. A high percentage of sodium in water for irrigation is undesirable because it may alter the soil structure to such an extent as to inhibit downward movement of the water. There is a wide range in the content of sodium and potassium in water in the county. The

TABLE 3.—*Mineral constituents, in parts per million, and related physical measurements of ground water in Lincoln County*

LOCATION OF WELL OR SPRING	Date of collection	Depth of well (feet)	Temperature (°F)	pH	Specific conductance (micromhos @ 250°C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Percent sodium
Alluvium																					
10 7 11cd	6-15-49	25.0	......	......	......	16	3.6	218	27		196	417	301	170	0.3	230	......	1,360	655	313	39
12 8 6aa	9-15-47	18.9	60	7.5	3,020	20	.80	446	46	544	9.6	521	522	1,060	.0	40	0.17	2,940	1,300	875	47
12 9 16bb	9-16-47	61.0	60	8.6	849	33	1.8	130	16	41	7.5	416	92	36	.1	.5	.19	556	390	50	18
12 10 8bb	9-16-47	29.5	58	7.4	614	28	1.8	41	8.3	91	5.4	283	47	20	.1	40	.26	409	136	0	58
12 10 21dd	9-16-47	31.8	58	7.4	875	27	.28	64	19	114	9.5	402	74	30	.1	60	.26	578	238	0	50
Sanborn formation																					
11 8 35da	9-15-47	25.2	60	8.3	450	20	.44	39	13	37	6.5	157	43	39	.3	12	.20	271	151	22	34
12 6 25bb	9-15-47	20.5	59	7.3	2,120	24	.31	211	48	241	6.4	329	744	130	.4	35	.24	1,600	724	454	42
12 8 11cb	9-15-47	32.0	58	7.3	1,240	38	.53	214	25	29	11	597	137	55	.1	7.0	.21	810	637	148	9
13 10 27dd	6-17-49	80.0	......	......	......	17	.48	120	7.2		11	324	16	31	.2	33	......	395	329	63	7
Dakota formation																					
10 6 16da	6-15-49	34	......	......	......	7.0	12	143	18		84	407	66	47	.2	181	......	746	431	97	30
10 8 17cc	5-31-49	186	......	......	......	21	6.1	50	42		1,060	717	465	1,080	1.7	3.9	......	3,080	298	0	89
10 10 14ca	6-16-49	206.0	......	......	......	9.2	2.4	97	11		38	342	73	8.0	.4	2.1	......	407	287	7	23
11 7 1bc	5-26-49	195	......	......	......	12	6.1	24	15		338	564	333	30	1.0	4.0	......	1,040	122	0	86
11 8 9ba	6- 1-49	260.0	......	......	......	12	1.2	4.0	3.2		450	726	166	160	2.8	1.8	......	1,160	23	0	98
11 8 36aa	11-20-50	200	......	......	......	10	.44	125	48		66	342	265	45	1.0	38	......	766	510	230	22
11 10 17bb	6-17-49	190	......	......	......	10	9.7	4.0	3.8		439	632	212	165	2.4	2.6	......	1,150	26	0	97
11 10 26cb	6-16-49	194.0	......	......	......	5.0	2.5	47	10		160	442	74	44	.9	2.3	......	561	158	0	69
12 6 32aa	9-15-47	30.5	59	7.0	1,650	19	7.2	200	49	39	4.0	195	73	165	.1	408	.19	1,050	700	540	12
12 7 9ad	9-15-47	38.0	59	7.2	422	46	.38	49	7.7	29	3.1	159	50	27	.1	1.5	.08	291	154	24	29
12 7 12aa	9-15-47	130.0	60	7.1	1,710	11	5.2	128	31	228	6.4	330	409	162	.8	30	.50	1,170	447	176	52
12 8 13dd	9-15-47	70.0	59	6.8	716	22	1.7	92	18	31	2.6	234	71	45	.4	55	.10	474	304	112	18
12 9 11dd	9-16-47	16.0	60	7.3	1,020	14	.30	136	25	61	7.0	300	192	75	.4	40	.18	692	442	196	23
12 10 24dd	9-16-47	70.7	60	7.3	2,650	16	2.8	102	40	429	15	366	223	575	1.3	31	0.70	1,610	419	119	68
13 10 15ad	6-17-49	97	......	......	......	13	5.7	108	15		28	272	128	24	.5	1.3	......	452	331	108	16
13 10 25dc	6-17-49	130.0	......	......	......	4.0	9.3	115	26		57	378	154	32	.7	1.8	......	576	394	84	24
Undifferentiated																					
11 8 31ad	6-16-49	34.6	......	......	......	15	1.1	186	22		86	368	125	85	.1	235	......	935	554	252	25
12 6 11ac	9-15-47	37.0	59	7.3	3,010	4.0	3.7	211	44	395	24	341	361	425	.9	420	.41	2,050	708	428	54
12 10 14bc	9-16-47	44.9	59	7.8	660	20	.50	101	10	23	3.8	296	48	34	.1	10	......	416	293	50	14

range in sodium is from 11 parts per million in a dilute water of the Pleistocene silts and sands to 1,060 parts per million in a highly concentrated water in the Dakota formation. The percentages of sodium range from 7 to 98.

Bicarbonate is the principal anion in water in Lincoln County that has a dissolved solids concentration lower than 1,000 parts per million. The bicarbonate content in samples that were analyzed for this report ranged from 157 to 726 parts per million.

The strong acid constituents—sulfate, chloride, and nitrate—in combination with calcium and magnesium cause permanent hardness in water, and chloride and nitrate are also effective corrosive agents in cased wells. High concentrations of sulfate are common in the various stratigraphic units in the area, the range being from 16 to 744 parts per million. Water of high chloride content is obtained from the Dakota formation or from the alluvium and Sanborn formation, whose water is affected by water from the Dakota formation or by surface contamination. Nitrate in concentrations that exceed 45 parts per million is undesirable because of the possible toxic effect on the blood circulatory system of infants. Much of the water sampled, particularly from shallow wells, was high in nitrate (as NO_3), which ranged from 0.4 to 553 parts per million.

Fluoride in small quantities is desirable for the normal development of teeth, but quantities that exceed 1.5 parts per million may cause the pitting and discoloration of teeth of small children. Recently, there has been a trend toward fluoridation of municipal supplies in some areas of the United States where the fluoride content of the water is very low. The fluoride content of water samples collected in Lincoln County ranged from 0.1 to 2.8 parts per million, and one sample from the alluvium had no fluoride. Most of the high-fluoride water was associated with the Dakota formation.

Boron concentrations exceeding 1.0 part per million in water for irrigation may prove harmful to boron-sensitive crops. The amount of boron in 15 samples from Lincoln County that were examined was low, ranging from 0.08 to 0.70 part per million. One sample had no boron.

Iron and manganese in quantities that exceed 0.3 part per million are undesirable, as they stain fabrics and plumbing fixtures and produce an unpleasant coloration in the water. Water in the ground may contain much iron, but upon exposure to air the iron precipitates, only a few tenths of a part of iron remaining in solution. The iron content in untreated water in Lincoln County is a problem to users of domestic supplies; in 26 of 28 samples analyzed it exceeded 0.3 part per million, ranging from 0.28 to 12 parts per million.

Water examined in this study was essentially from three geologic sources: from alluvium (5 wells, 18.9 to 61.0 feet deep); Sanborn formation (4 wells, 20.5 to 80.0 feet deep); and Dakota formation (16 wells, 16.0 to 260 feet deep). The water from three wells could not be correlated with any of the water-bearing formations. A summary of the range in mineral constituents is given in Table 4.

Quality of Water

Alluvium

Of the five water samples that were obtained from wells in the alluvium, three have dissolved solids concentrations of less than 600 parts per million. These are essentially bicarbonate waters of either calcium or sodium, and they are hard. The other two waters are high in dissolved solids (1,360 and 2,940 parts per million) which consist of approximately equal quantities of calcium, sodium, bicarbonate, and sulfate. The water from well 12-8-6aa also contained 1,060 parts per million chloride, which indicates that saline water from the Dakota formation locally may be draining into the alluvium. High concentrations of nitrate are common to water from

Table 4.—*Maximum and minimum content, in parts per million, of mineral constituents in ground water from the alluvium, Sanborn formation, and Dakota formation*

Constituent	Maximum	Minimum
Calcium	446	4.0
Magnesium	49	3.2
Sodium and potassium	1,060	11
Bicarbonate	726	157
Sulfate	744	16
Chloride*	1,410	8.0
Fluoride	2.8	0
Nitrate (as NO_3)*	553	0.4
Dissolved solids	3,080	271
Total hardness	1,300	23
Percent sodium	98	7

* Includes those samples for which only chloride and nitrate were determined.

wells in the alluvium; this problem is discussed later in this report. A summary of mineral constituents of water from the alluvium in Lincoln County is given in Table 5.

As compared with water in the Dakota formation (Tables 3 and 7), that in the alluvium has a greater range in quantities of calcium and nitrate and is harder. This relationship is seen in Figure 7 in

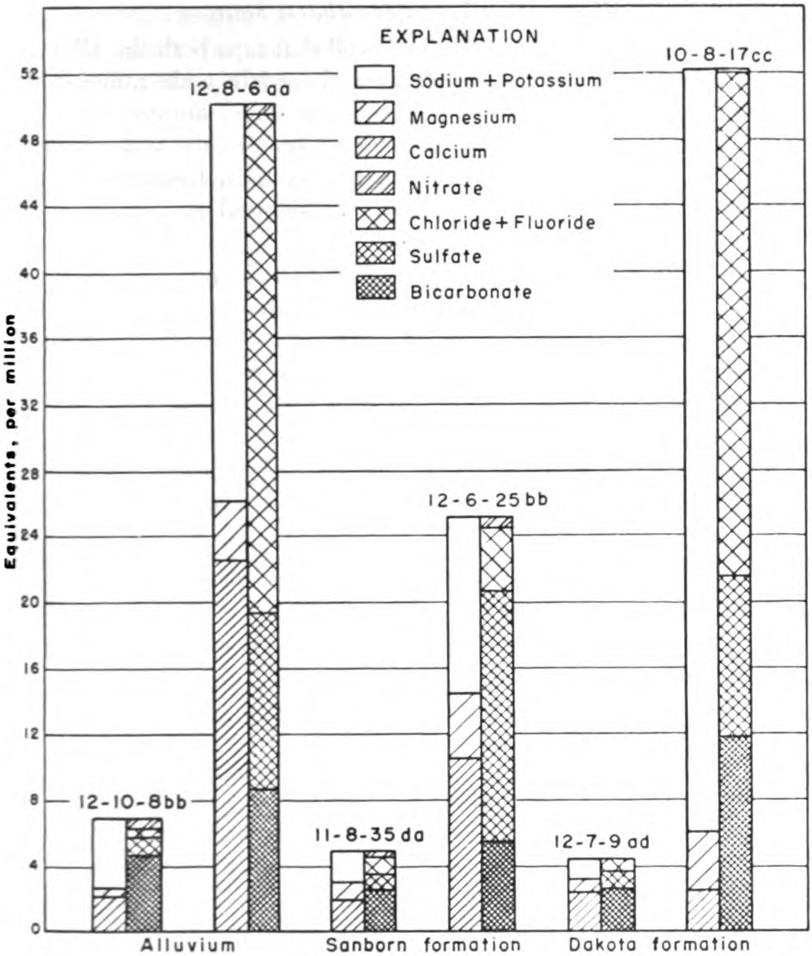


FIG. 7.—Chemical analyses of dilute and concentrated water in the three principal water-bearing formations in Lincoln County.

which the analyses of water from wells 12-8-6aa and 10-8-17cc are shown diagrammatically. The total concentration, as equivalents per million, is similar in water from both aquifers. The ground water from the alluvium contains approximately 4½ times as much calcium and magnesium, together. It is particularly significant that in all determinations made for chloride and nitrate, little difference is noted in the average quantity of chloride in the the two stratigraphic units. The average chloride content of 16 samples from the alluvium was 129 parts per million, whereas the average was 125 parts per million for 80 samples from the Dakota formation.

Water from Undifferentiated Sources

One sample was obtained from a well that taps both the alluvium and the Sanborn formation. Because there is a wide range in the mineral content of the water from both geologic sources, it is difficult to predict the extent of influence of each of the water-bearing sources. Presumably, the water in the Sanborn formation would, on the average, be somewhat lower in mineral content than the water obtained from the alluvium.

The water from well 11-8-31ad, 34.6 feet deep, has a dissolved solids content of 935 parts per million, largely calcium bicarbonate. The water is extremely hard; the hardness as calcium carbonate is 554 parts per million. The possibility of pollution is indicated by a nitrate (as NO_3) content of 235 parts per million. This is further substantiated by a chloride content of 85 parts per million, which is somewhat higher than the chloride content of wells in those unconsolidated deposits that yield water of low nitrate content.

TABLE 5.—*Maximum and minimum content, in parts per million, of mineral constituents in ground water from the alluvium*

CONSTITUENT	Maximum	Minimum	Average
Calcium	446	41	....
Magnesium	46	8.3	....
Sodium and potassium	570	45	....
Bicarbonate	521	283	....
Sulfate	522	47	....
Chloride*	1,060	14	129
Fluoride	0.3	0	....
Nitrate (as NO_3)*	553	0.4	72
Dissolved solids	2,940	409	....
Total hardness	1,300	136	....
Percent sodium	58	18	....

* Includes those samples for which only chloride and nitrate were determined.

One well, 12-10-14bc, 44.9 feet deep, is believed to be drawing water from both the alluvium and the Dakota formation; however, the character of the water is more typical of that associated with the unconsolidated materials in the area. The water contains 416 parts per million dissolved solids and is a calcium bicarbonate type. Accordingly, this supply also is hard.

Well 12-6-11ac, 37.0 feet deep, drawing water from the Sanborn and Dakota formations, undifferentiated, yields water containing 2,050 parts per million of dissolved solids and relatively equal amounts of bicarbonate, sulfate, chloride, and nitrate. The hardness is 708 parts per million. The analysis is characteristic of water that has been altered by drainage from the Dakota formation.

Sanborn Formation

Unless it is affected by surface flows from other formations, it is likely that water from the terrace deposits is probably more dilute than other ground water in the area.

Three of four samples from wells in the Sanborn formation are dilute as compared with water from the alluvium. They are predominantly of the calcium bicarbonate type and have 271, 395, 810, and 1,600 parts per million dissolved solids. The water from well 12-6-25bb, 20.5 feet deep, has the highest sulfate content of all water samples analyzed. It is likely that the water has encountered some gypsum or selenite rocks. All the water is hard, the range in hardness (as calcium carbonate) being from 151 to 724 parts per million. Conversely, the percentages of sodium are generally lower than those of water in other formations in the area.

Dakota Formation

Sixteen samples were obtained from wells that penetrate the Dakota formation at depths that range from 16.0 to 260 feet. The range in chemical substances in the water is given in Table 6.

TABLE 6.—*Maximum and minimum content, in parts per million, of mineral constituents in ground water from the Dakota formation*

CONSTITUENT	Maximum	Minimum	Average
Calcium	200	4.0	....
Magnesium	49	3.2	....
Sodium and potassium	1,060	28	....
Bicarbonate	726	159	....
Sulfate	465	50	....
Chloride*	1,410	8.0	125
Fluoride	2.8	0.1	....
Nitrate (as NO_3)*	469	0.9	49
Dissolved solids	3,080	291	....
Total hardness	700	23	....
Percent sodium	98	12	....

* Includes those samples for which only chloride and nitrate were determined.

By comparison with water in the Pleistocene deposits, those samples obtained from the Dakota formation are generally lower in calcium and accordingly are softer, whereas the content of sodium and chloride is higher. The fluoride ion, which ranges from 0.1 to 2.8 parts per million, is generally more prominent in water from the Dakota formation and as a rule the concentration of nitrate is lower.

Water samples from the Dakota formation indicate a slight increase in fluoride with depth of well (Fig. 8). Otherwise, no particular relationship exists between the quantity of mineral constitu-

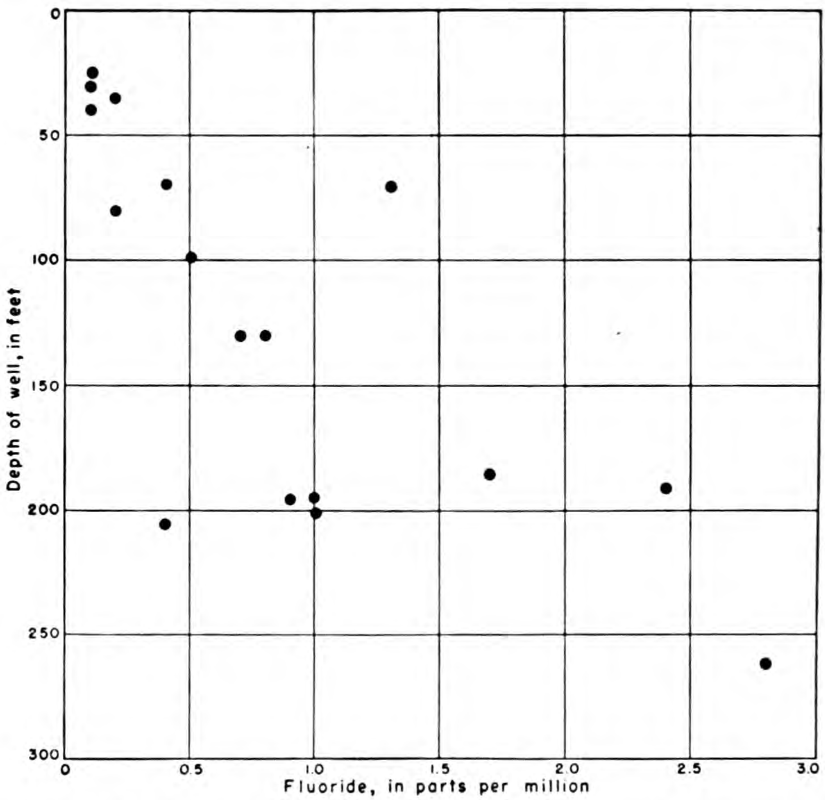


Fig. 8.—Fluoride concentration with relation to depth in the Dakota formation.

ents and depth of well in the Dakota formation. For the most part, shallow and deep wells that enter this formation yield water in which the dissolved solids range from about 400 to 1,200 parts per million. High chloride and hardness may be as prominent at depths of 200 feet as they are at shallow depths; evidence is lacking as to what changes might take place at greater depths in the formation.

CHLORIDE-NITRATE RELATIONS

In addition to 28 complete analyses, a total of 88 partial analyses for chloride and nitrate content were made. The results are given in Table 7.

In correlating the concentration of nitrate with depth of the well, it was observed that the high-nitrate water was generally at depths less than 50 feet. Of 36 samples from wells in the Pleistocene deposits, 11 (about 31 percent) of the samples exceeded 45 parts per million nitrate (as NO_3). Five samples had a nitrate content that exceeded 90 parts per million (Table 8).

Of 80 analyses of water samples from the underlying Dakota formation (Table 9), 20 (about 25 percent) contained nitrate (as NO_3) in excess of 45 parts per million and 12 (about 15 percent) contained more than 90 parts per million. Most of these were collected from depths of less than 50 feet, which indicates a possible relationship to surface drainage (Fig. 9).

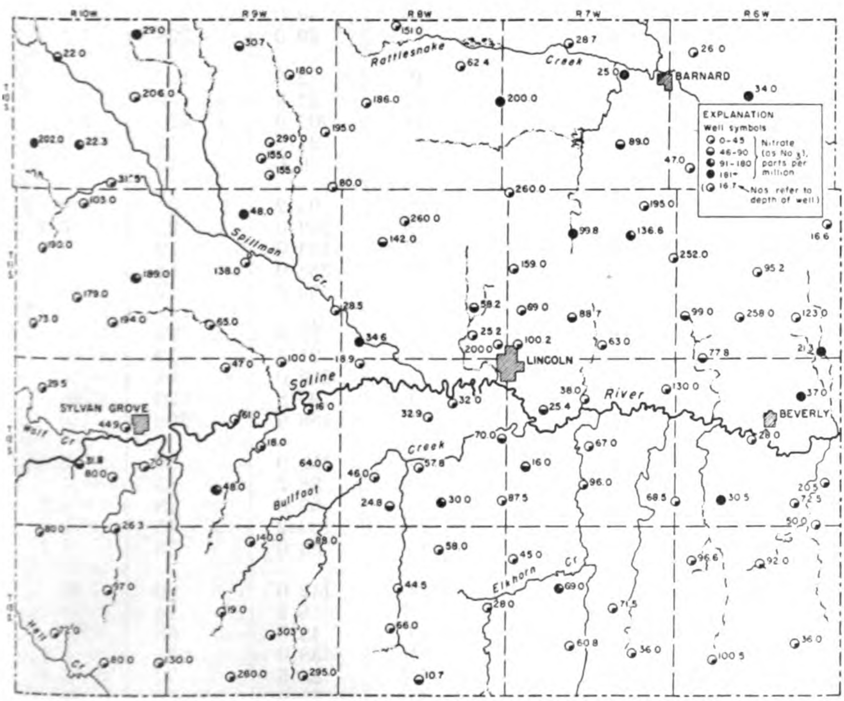


FIG. 9.—Nitrate in ground water in Lincoln County.

TABLE 7.—*Chloride and nitrate in waters from wells in Lincoln County*
(Analyses by Kansas State Board of Health)

Well Location	Source*	Depth of well, feet	Chloride	Nitrate (as NO_3)
			Parts per million	
10-6-7aa	P	26.0	47	2.4
31ad	P	47.0	31	18
10-7-4dd	D	28.7	95	21
26bd	D	89.0	127	66
10-8-4bb	D	151.0	56	1.1
11ba	D	62.4	1,410	7.1
13dd	D	200.0	110	221
10-9-4dc	P	30.7	302	66
11cd	D	180.0	660	1.5
24dc	D	195.0	176	1.8
28ad	D	290.0	25	1.5
28cc	D	155.0	17	0.9
34aa	D	155.0	15	1.9
36dd	D	80.0	12	1.5
10-10-2ad	P	29.0	298	553
9bc	P	22.0	130	62
28ad	P	22.3	79	97
29bc	D	202.0	470	301
36cc	P	31.5	15	2.0
11-6-12da	D	16.6	18	12
15cc	P	95.2	31	19
18bc	D	252.0	25	0.9
26bd	D	123.0	19	2.2
28cc	D	258.0	11	1.0
30cc	D	99.0	12	49
32cc	D	77.8	21	80
36ca	D	21.3	73	469
11-7-6bb	D	260.0	41	19
9aa	D	99.8	130	266
11bd	D	136.6	268	150
18db	D	159.0	26	3.4
28bb	D	88.7	25	71
30aa	P	69.0	38	4.9
31ca	D	100.2	45	8.8
34cc	D	63.0	35	1.7
11-8-8dc	D	142.0	80	80
26aa	D	58.2	24	49
11-9-4dc	D	48.0	68	217
16db	D	138.0	955	8.8
25ad	P	28.5	22	1.9
29cc	D	65.0	29	38
11-10-4da	D	103.0	24	1.5
21dc	D	179.0	116	1.3
23aa	D	189.0	79	106
30dd	D	73.0	33	3.1

TABLE 7.—*Chloride and nitrate in waters from wells in Lincoln County*—Concluded

WELL LOCATION	Source*	Depth of well, feet	Chloride	Nitrate (as NO_3)
			Parts per million	
12-6-16dd	P	28.0	305	0.9
31bb	D	68.5	12	2.2
35ba	D	72.5	156	1.3
36cc	D	50.0	32	3.4
12-7-8dd	P	25.4	20	88
19dd	P	16.0	29	80
22bb	P	67.0	19	1.3
28db	P	96.0	310	0.4
12-8-15bb	D	32.9	127	30
21dd	D	57.8	20	28
29bb	D	46.0	18	8.4
32aa	D	24.8	35	71
34ab	D	30.0	83	137
36aa	D	87.5	60	5.3
12-9-3aa	D	100.0	27	2.4
5ad	D	47.0	17	2.2
22bb	P	18.0	28	5.8
24cd	D	64.0	34	22
29dc	D	48.0	70	124
12-10-26bc	D	80.0	30	2.3
13-6-7ab	D	96.6	45	1.0
10bb	D	92.0	223	1.5
26ba	D	36.0	91	1.3
29ca	D	100.5	17	1.3
13-7-7bb	D	45.0	17	1.1
15dc	D	71.5	21	5.8
17aa	D	69.0	334	168
26ac	P	36.0	15	1.3
28ba	P	60.8	12	1.5
13-8-3dc	D	58.0	18	3.2
13cc	P	28.0	44	3.4
16bb	P	44.5	22	31
20cb	D	66.0	21	39
33ad	P	10.7	40	71
13-9-2da	D	88.0	11	1.3
4ad	D	140.0	22	1.3
20aa	P	19.0	14	3.5
22dc	D	303.0	54	4.9
33bc	D	260.0	15	4.4
35ad	D	295.0	22	0.9
13-10-2bb	P	26.3	70	14
5ac	D	80.0	30	24
20dd	P	72.0	11	23

* P, Pleistocene deposits; D, Dakota formation.

TABLE 8.—*Number of samples from wells in Pleistocene deposits in Lincoln County as classified by nitrate concentrations*

Depth of well, feet	Number samples containing				Total
	0-45 ppm nitrate	46-90 ppm nitrate	91-180 ppm nitrate	181+ppm nitrate	
0–50	17	6	1	4	28
51–100	8	....	....	....	8
Totals	25	6	1	4	36

TABLE 9.—*Number of samples from wells in the Dakota formation in Lincoln County, as classified by nitrate concentrations*

Depth of well, feet	Number samples containing				Total
	0-45 ppm nitrate	46-90 ppm nitrate	91-180 ppm nitrate	181+ppm nitrate	
0–50	10	1	2	4	17
51–100	22	6	1	1	30
101–150	7	1	1	....	9
151–200	12	....	1	1	14
201–250	1	....	....	1	2
251–300	7	....	....	....	7
300+	1	....	....	....	1
Totals	60	8	5	7	80

With relation to the chloride content of the water in the Pleistocene deposits, 23 of the 36 samples (approximately 64 percent) contained less than 50 parts per million (Table 10). Six had chloride that exceeded 250 parts per million; all samples except one that had more than 50 parts per million were obtained at depths less than 50 feet.

Of the 80 chloride determinations on water from the Dakota formation, 48 (60 percent of the total) showed less than 50 parts per million (Table 11). Eight of the samples had chloride contents exceeding 250 parts per million; these were taken at various depths below 250 feet.

In Figure 10, nitrate (as NO_3) is plotted against chloride for all samples. Above 10 parts per million nitrate (as NO_3), which was arbitrarily selected as the threshold for above-normal concentrations of nitrate, a slight trend in increased nitrate with increased chloride can be observed. There is some indication, at least, that the chloride content in water from shallow wells, both in the Pleistocene deposits and in the Dakota formation, may be more closely related to surface pollution than to naturally occurring high-chloride waters that are known to be present in the upper part of the Dakota formation in some areas. The correlation is poor; however, the trend is significant.

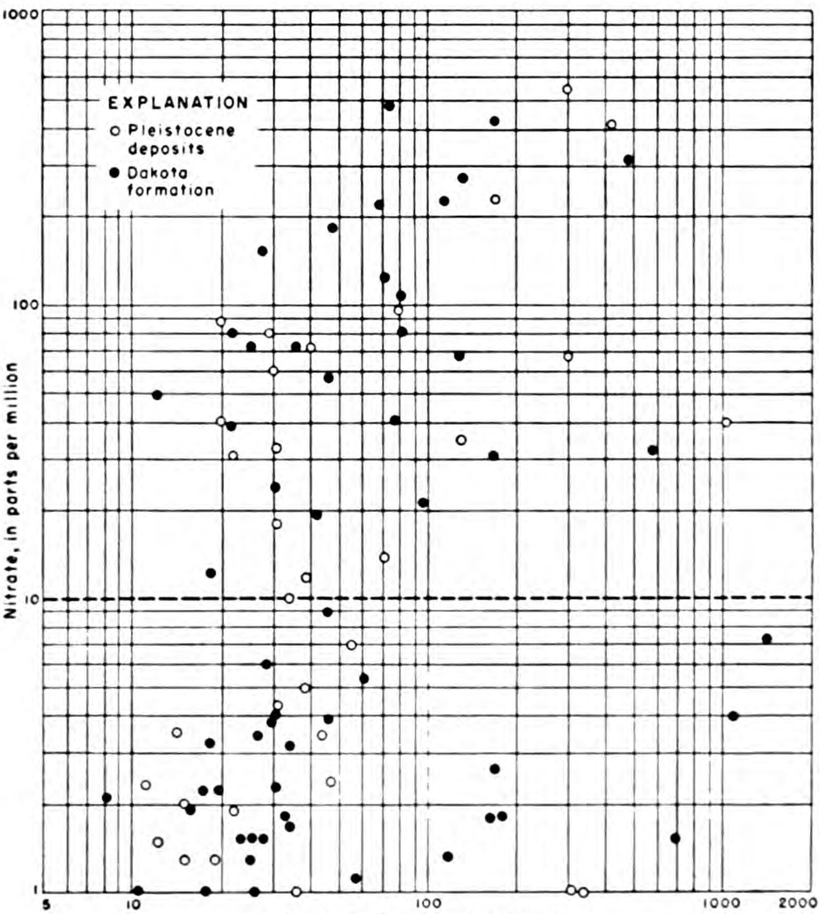


FIG. 10.—Relation of chloride and nitrate in water from Pleistocene deposits and the Dakota formation in Lincoln County.

An examination of the data indicates that no particular diminution of chloride and nitrate occurs to depths of 200 feet. At greater depths, nine samples showed negligible quantities of nitrate, and quantities of chloride in most cases were less than 200 parts per million. Metzler and Stoltenberg (1950) have discussed high-nitrate content of ground water and its relation to construction of wells, water levels in wells, leaching of topsoil, and barnyard pollution. They conclude that a number of factors must be known in order to determine the cause of pollution and to insure safety from cyanosis. Among them are: (1) the effect of vegetation, soil conditions, and ground-water level on the nitrate content; (2) the depth to which a properly constructed well must be extended to assure its freedom from nitrate pollution; and (3) the area of nitrate

TABLE 10.—*Number of samples from wells in Pleistocene deposits in Lincoln County, as classified by chloride concentrations*

Depth of well, feet	Number samples containing				Total
	0-50 ppm chloride	51-100 ppm chloride	101-250 ppm chloride	251+ppm chloride	
0–50	16	4	3	5	28
51–100	7	....	....	1	8
Totals	23	4	3	6	36

TABLE 11.—*Number of samples from wells in the Dakota formation in Lincoln County, as classified by chloride concentrations*

Depth of well, feet	Number samples containing				Total
	0-50 ppm chloride	51-100 ppm chloride	101-250 ppm chloride	251+ppm chloride	
0–50	8	7	2	....	17
51–100	23	1	4	3	31
101–150	4	1	1	2	8
151–200	6	2	4	2	14
201–250	1	....	....	1	2
251–300	6	....	1	....	7
300+	....	1	....	....	1
Totals	48	12	12	8	80

pollution, which is so extensive in some localities that it cannot be explained satisfactorily as by seepage from barnyards and similar places.

CHLORIDE AS RELATED TO GROUND- AND SURFACE-WATER DRAINAGE

Some concept of the distribution of chloride in water in the county can be observed in Figure 11, in which chloride content is shown diagrammatically. Seemingly, a greater distribution of high-chloride water occurs in the area north of Saline River that is drained by Spillman Creek and Rattlesnake Creek; however, a large percentage of the samples in this area were obtained from relatively deep wells in the Dakota formation.

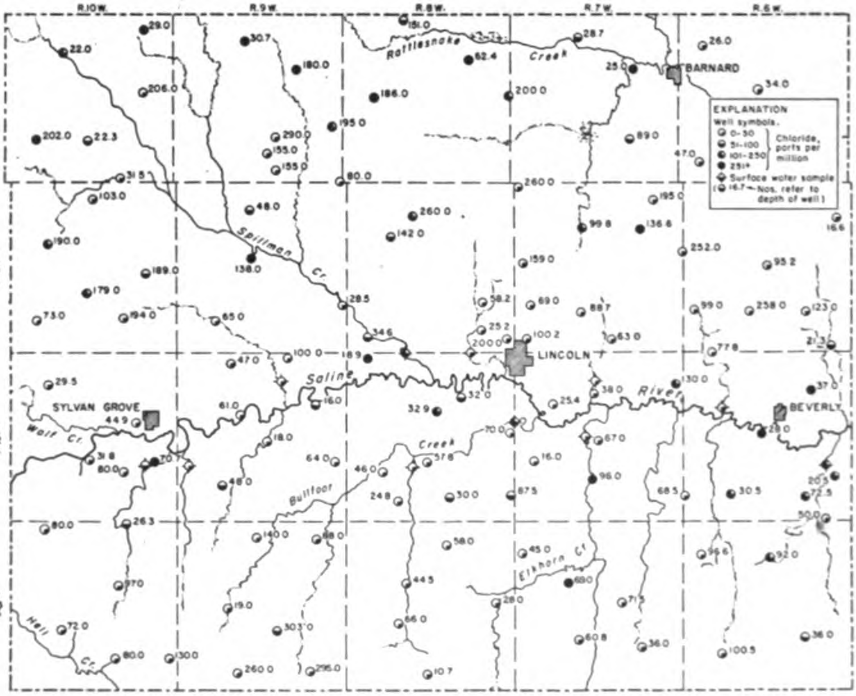


FIG. 11.—Chloride in ground and surface water in Lincoln County.

The chloride content of surface water in Lincoln County correlates well with the particular stratigraphic units that are drained. The water in Saline River, which is the major stream in the area, may have more than 2,500 parts per million of dissolved solids, largely as sodium chloride (Durum, 1950, p. 41) during low flow at Tescott, which is a few miles downstream from Lincoln. Most of this mineralization is believed to be acquired from ground and surface waters upstream from Lincoln County and from Wolf Creek, which flows into Saline River at the western edge of the county. Wolf Creek has a deep-cut channel and receives highly mineralized ground water, probably from the Dakota formation. At a base flow of 0.6 second-foot, the dissolved solids content of the water was 4,630 and the chloride content was 2,000 parts per million. In contrast, base-flow water of intermittent streams tributary to Saline River east of Wolf Creek is generally more dilute, as indicated in Table 12. For example, analysis of base flow of West Twin Creek, which drains Pleistocene deposits south of Saline River, showed a dissolved solids content of 698 parts per million and a chloride content of 66 parts per million.

TABLE 12.—*Analyses of several mineral constituents in streams tributary to Saline River in Lincoln County (in downstream order)*

Creek	Date	Discharge, in sec.-ft.*	Dissolved solids	Chloride	Percent sodium
			Parts per million		
Wolf Creek near Sylvan Grove	Oct. 2, 1948	0.6	4,630	2,000	85
West Twin Creek near Sylvan Grove	May 2, 1950	1.0	698	66	30
East Twin Creek near Sylvan Grove	May 2, 1950	1.0	514	28	29
Unnamed Creek, 1-½ miles west of Vesper	May 5, 1950	1.0	158	0.6	10
Spillman Creek near Lincoln	May 2, 1950	1.0	808	174	52
Lost Creek near Lincoln	May 2, 1950	1.0	548	42	29
Spring Creek near Lincoln	May 2, 1950	1.0	540	37	29
Bullfoot Creek	May 5, 1950	1.5	700	140	53
Beaver Creek, 2-½ miles east of Lincoln	May 5, 1950	1.0	778	39	47
Twelve Mile Creek, ⅘ mile east of Shady Bend	May 5, 1950	1.0	534	21	43
Elkhorn Creek near Lincoln	May 2, 1950	1.0	780	49	31
Table Rock Creek near Beverly	May 2, 1950	1.0	933	142	44

* Estimated, except that of Wolf Creek.

These data indicate that the water is representative of drainage from Pleistocene deposits, and are supported by most results of chloride analysis of water from shallow wells along the main streams and tributaries (Fig. 11). Unusually high concentrations of chloride in water in the Pleistocene deposits, such as are found in the eastern half of T. 12 S., R. 6 E., can probably be attributed to contamination from underlying deposits whose water drains to the stream channel.

RELATION OF QUALITY OF WATER TO USE

Domestic

A tabulation of the 116 samples that were collected from wells in the area establishes the following uses for the various supplies:

Use	Number of wells	Percent
Domestic	18	15.5
Stock	37	31.9
Domestic and stock	55	47.4
None	6	5.2
Total	116	100.0

These data show that about 63 percent of the supplies have some domestic use. This fact is particularly pertinent in that approximately 27 percent of the wells sampled have a nitrate (as NO_3) content that exceeds 45 parts per million. This emphasizes the importance of existing educational programs in Kansas relating to quality of domestic water supplies.

Fourteen water samples (about 12 percent of those analyzed) each had a chloride content that exceeded 250 parts per million, the upper limit recommended by the U. S. Public Health Service. Where more suitable supplies are available, the chemical substances that may be present in natural or treated waters preferably should not exceed the following quantities:

Constituent	Maximum parts per million
Iron and manganese (together)	0.3
Magnesium	125
Sulfate	250
Fluoride	1.5
Chloride	250
Dissolved solids	500 (1,000 permitted)

In addition, limits are placed on the quantities of lead, arsenic, hexavalent chromium, selenium, copper, zinc, and phenol. However, the quantities of these substances usually are not determined in routine analyses by the Geological Survey. With respect to physical requirements, the water must be low in turbidity and should have no objectionable taste or odor.

Of the 25 samples known to be from the two stratigraphic units of which more complete analyses were made in connection with this study, the number in which the chemical substances exceeded the recommended upper limits are as follows:

Constituent	Pleistocene deposits	Dakota formation
Total samples analyzed	9	16
Iron and manganese (together)	8	16
Magnesium	0	0
Sulfate	3	4
Fluoride	0	3
Chloride	1	2
Dissolved solids	3	7

The results given above indicate that troublesome quantities of iron are present in water in both shallow and deep wells. For the water in the Dakota formation, eight of the samples had iron in excess of 5 parts per million. The quantities of magnesium in all samples were relatively low. Excessive amounts of sulfate were found in eight of the samples, most of these being from the eastern half of the county. Samples from three wells in the Dakota formation had 1.7, 2.8, and 2.4 parts per million fluoride, and the concentrations appeared to increase somewhat with depth. Nearly half of the waters from the Dakota formation exceeded 1,000 parts per million dissolved solids.

Municipal

Water supplies from Barnard, Lincoln, and Sylvan Grove were inventoried, and analyses by the Kansas State Board of Health (personal correspondence) indicate that the water at both Lincoln and Sylvan Grove is of moderately low mineral content but is hard. The Lincoln supply is effectively softened from nearly 500 to less than 200 parts per million hardness, and the amounts of iron and manganese in the finished water are negligible.

The Barnard supply, which is obtained from a well 60 feet deep in the alluvium, is of poor quality (Table 13). The water is hard and contains nearly 2,100 parts per million of dissolved solids. Sodium and chloride are predominant constituents, and objectionable amounts of iron and manganese are present.

Irrigation

None of the wells sampled or inventoried is presently used for irrigation other than for lawns or gardens. As discussed previously in this report, the available ground-water supplies are generally adequate only for small irrigation projects. However, because of the variable quality of water in the county, the individual supplies should be carefully evaluated prior to application of the water to the lands. At least three factors should be considered in estimating the water quality (Wilcox, 1948, p. 25): (1) the total concentration of dissolved solids; (2) the percentage of sodium; and (3) the quantity of boron. Each must be considered with respect to other factors, such as soil composition, permeability, drainage, irrigation practices, and crop tolerances.

Continuous use of water high in dissolved solids may increase the salinity of the soil solution, which may ultimately affect the permeability of the soil and disturb plant growth.

Experience has shown that irrigation water containing a high percentage of sodium may cause dispersion of soil particles and may retard water and air movement through the soil. In addition

TABLE 13.—*Analyses of water supplies for the cities of Barnard, Lincoln, and Sylvan Grove*

CONSTITUENT	Barnard[1]	Lincoln[2]		Sylvan Grove[3]
	3-10-51	11-28-49 (raw)	8-21-50 (treated)	11-27-50
Calcium	91	165	57	108
Magnesium	33	15	13	11
Sodium	657	70	112	38
Bicarbonate	744	320	105	337
Sulfate	260	264	262	46
Chloride	640	46	45	40
Nitrate	8.4	27	20	20
Fluoride	0.6	0.3	0.3	0.1
Iron	0.48	2.2	0.10	0.15
Manganese	0.14	0.7	0	0
Hardness	362	473	196	314
Dissolved solids	2,100	791	590	467

1. From well, 60 feet deep, in alluvium.
2. From two wells, both 80 feet deep. One well draws water from the alluvium, the other from the Dakota formation.
3. From two wells. One well, 70 feet deep, draws water from the terrace deposits, the other, 68 feet deep, from the Dakota formation.

to soil and drainage conditions, the amount and type of other constituents in the water and soil, such as calcium carbonate and gypsum, are important in establishing the permissible limits of sodium in the irrigation water. If the concentration of dissolved solids is low, a higher percentage of sodium is tolerable for a soil that is coarse-textured, calcareous, permeable, and well-drained than for a soil that is very tight.

A diagram proposed by Wilcox (1948, p. 26) is used to illustrate the suitability of water in Lincoln County for irrigation (Fig. 12).

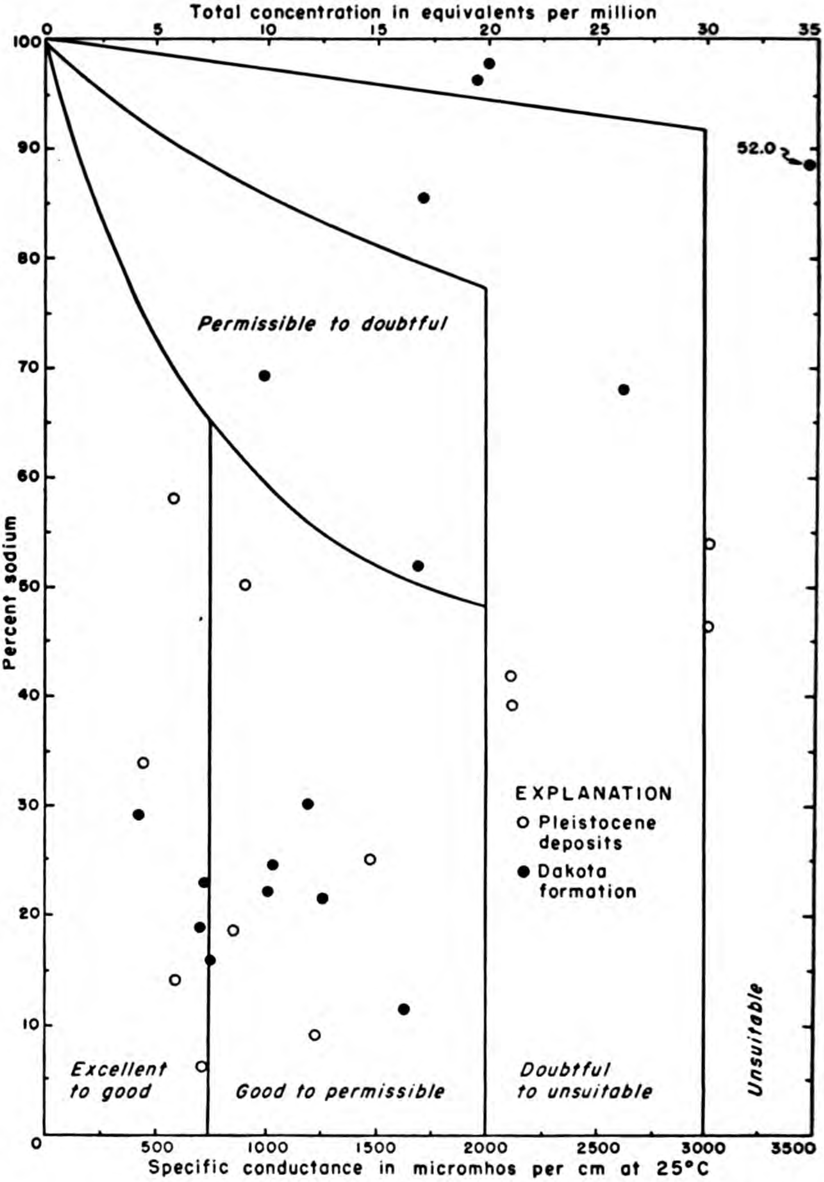


FIG. 12.—Classification of water for irrigation use in Lincoln County (after Wilcox, 1948).

The water classes are determined by the quantity of mineral substances as indicated by the specific conductance (or equivalents per million) and the percentage of sodium. In general, the water takes a progressively lower classification as the mineralization and percentage of sodium increase.

The water in the county varies widely in composition, as shown by representation in all classes. Seventeen samples, however, rate at least "good to permissible." Unsatisfactory water in the Pleistocene deposits is so designated largely by reason of a high content of dissolved solids, whereas water of poor quality in the Dakota formation has a high percentage of sodium.

Summary of Quality of Ground Water

Water examined in this study was essentially from three geologic sources: alluvium, Sanborn formation, and Dakota formation. In the five samples obtained from the alluvium the dissolved solids ranged from 409 to 2,940 parts per million, and the water was hard; the hardness (as $CaCO_3$) ranged from 136 to 1,300 parts per million. Dilute water is the calcium bicarbonate type, whereas the concentrated water is essentially the sodium chloride type. Saline water from the Dakota formation may be draining into the alluvium in some parts of the area; high concentrations of nitrate are common in water from many wells in the alluvium—an indication of surface pollution.

All water samples obtained from the Sanborn formation were hard, the hardness (as $CaCO_3$) ranging from 151 to 724 parts per million. Although only four samples were obtained from wells in the Sanborn formation, they represented on the average, the better-quality water in the area.

By comparison with water in the Pleistocene deposits, those samples obtained from the Dakota formation were generally lower in calcium, and they were softer. Sodium and chloride were frequently more prominent than in water from Pleistocene deposits; however, the dissolved solids in the Dakota formation generally ranged from approximately 400 to 1,200 parts per million. Fluoride is commonly more prominent in water of the Dakota formation, and some evidence is present that fluoride increases with the depth of the well.

Data obtained from chloride and nitrate determinations of 116 samples indicate that in approximately 31 percent of the samples from Pleistocene deposits the nitrate (as NO_3), exceeds 45 parts per million, whereas in approximately 25 percent of the samples from the Dakota formation nitrate exceeds 45 parts per million. The average chloride and nitrate concentrations in Pleistocene deposits and in the Dakota formation are similar. No particular diminution of chloride or nitrate occurs to depths of 200 feet.

The chloride content of streams tributary to Saline River correlates well with the drainage pattern. Wolf Creek, which has a deeply cut channel, discharges highly mineralized water at base flow, at which period the chloride content may exceed 2,000 parts per million. In contrast, base-flow water of most intermittent streams tributary to Saline River east of Wolf Creek is generally more dilute.

RECORDS OF TYPICAL WELLS

Information pertaining to 175 water wells in Lincoln County is tabulated in Table 14. The well-numbering system used in this table is illustrated in Figure 3.

LOGS OF TEST HOLES

Listed in the following pages are logs of 43 test holes in Lincoln County and adjacent Ellsworth County which were drilled by the State Geological Survey during 1948 and 1950. Samples of the material penetrated by the test holes were examined in the field by Kenneth L. Walters, who supervised the drilling and prepared the logs. The samples were subsequently studied microscopically by me.

The test holes are numbered according to the system described on page 11. Locations of the test holes are shown on Plate 3.

TABLE 14.—*Records of wells in Lincoln County*

Well number (1)	Owner or tenant	Type of well (2)	Depth of well (feet)	Diameter of well, inches	Type of casing (3)	Principal water-bearing bed: Character of material (4)	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
T. 10 S., R. 6 W.														
*10-6-7aa	School District	B	26.0	6	GI	Sand and gravel	Alluvium	P, H	D	Top of casing	1.0	14.63	6-15-49	
(10-6-16da)	Etta M. Abercrombie	Dr	34.0	6	GI	Sandstone	Dakota	Cy, W	S	do	.8	20.76	6-15-49	
10-6-18bb	City of Barnard	Du	60.0	192	C	Sand and gravel	Alluvium	T, E	P,S	Land surface	0	9.50	9-16-49	
*10-6-31ad	E. Jackson	Dr	47.0	5	GI	do	Sanborn deposits	Cy, W	D,S	Top of concrete platform	.3	31.45	6-24-49	
10-6-36cc	P. L. Shirley	Du	65.0	36	R	Sandstone	Dakota	Cy, H	S	Top of platform	.3	28.86	5-26-49	
T. 10 S., R. 7 W.														
*10-7-4dd	M. Talcum	Dr	28.7	.....	.....	Sandstone	do	Cy, W	S	Top of board platform	.2	13.50	5-27-49	
10-7-7bb	State Highway Commis	B	8.5	2	Sl	Silt and clay	Alluvium	N	N	Land surface	0	1.25	7-16-47	Auger hole drilled to determine depth to water along State highway.
(10-7-11cd)	Sherman Jackson	DD	25.0	5	R,GI	Sand and gravel	do	Cy, W, H	D,S	Top of concrete curb	1.3	12.15	6-15-49	
10-7-21cd	Earl Keeler	Dr	85.0	6	GI	Sandstone	Dakota	Cy, W	D,S	Land surface	0	17.00	5-27-49	
*10-7-26bd	Ivan Adams	Dr	89.0	6	C	do	do	Cy,W,G	D,S	Top of concrete platform	.8	48.74	6-24-49	
T. 10 S., R. 8 W.														
*10-8-4bb	A. E. Eslinger	Dr	151.0	6	GI	do	do	Cy, W	D,S	Land surface	0	115.00	6-21-49	
*10-8-11ba	Mr. Watson	Dr	62.4	7	GI	do	do	Cy, W	S	Base of pump	1.4	25.10	6- 1-49	
*10-8-13dd	Lloyd Ahring	Dr	200.0	6	GI	do	do	Cy, G	D,S	Top of casing	.7	13.49	6-21-49	
10-8-14cd	R. W. Tromble	Dr	186.0	5	GI	do	do	Cy, W	N	Top of casing, north side	.2	153.44	5-31-49	
(10-8-17cc)	Emily Broberg et al.	Dr	186.0	.....	GI	do	do	Cy, W	D,S	Top of plank under pump base	.3	137.62	5-31-49	
10-8-28dd	F. Spear et al	Dr	230.0	5	GI	do	do	N	N	Top of casing	.3	183.8	5-31-49	
T. 10 S., R. 9 W.														
*10-9-4dc	R. L. Vanpelt	Du	30.7	30	R	Limestone and silt	Greenhorn and Sanborn.	N	N	Top of wooden platform	.3	17.34	6-24-49	
*10-9-11cd	E. J. Nitsch	Dr	180.0	6	GI	Sandstone	Dakota	Cy, W	D,S	Land surface	0	175.00	6-21-49	
*10-9-24dc	E. H. Spear	Dr	195.0	6	GI	do	do	Cy, W	D,S	Top of platform	.1	67.60	6-24-49	
*10-9-28ad	Adolph Jepsen	Dr	290.0	6	GI	Sandstone	Cheyenne ? and Dakota	Cy,W,H	D,S	Land surface	0	185.00	6-22-49	
*10-9-28cc	Andrew Nelson	Dr	155.0	6	GI	do	Dakota	Cy,W,H	D	Top of casing	1.3	96.46	6-22-49	
*10-9-34aa	Leonard Wiebke	Dr	155.0	6	GI	do	do	Cy,W,H	D,S	Base of pump	.2	126.70	6- 2-49	
*10-9-36dd	....	Dr	80.0	6	GI	do	do	Cy, W	S	Top of casing	.8	55.76	6- 2-49	

T. 10 S., R. 10 W.													
•10-10-2ad	Grover Parron	Du	29.0	24	R	Sand and gravel	Alluvium	Cy, W	S	Top of wooden platform	2.0	13.12	6-24-49
•10-10-9bc	R. W. Watson	Du	22.0	30	R	do	do	Cy, G	S	Top of rock curb	4.5	8.41	6-23-49
(10-10-14da)	W. A. Berry	Dr	206.0	6	GI	Sandstone	Dakota	Cy,W,H	D,S	Top of casing	.5	152.90	6-16-49
•10-10-28ad	George Brown	Du	22.3	48	R	Sand and gravel	Alluvium	Cy, W	S	Top of wooden platform	1.0	9.55	6-24-49
•10-10-29bc	E. J. Steinle	Dr	202.0	6	GI	Sandstone	Dakota	Cy,W,H	D,S	Land surface	0	63.00	6-23-49
•10-10-36cc	H. V. Williams	Du	31.5	36	R	Sand and gravel	Sanborn deposits	Cy, W	D,S	Base of pump	1.0	17.18	6-22-49
T. 11 S., R. 6 W.													
•11-6-12da	P. L. Shirley	Du	16.6	24	R	Sandstone	Dakota	Cy, W	S	Hole in board platform	.6	10.30	5-26-49
•11-6-15cc	Joseph McBride	Dr	95.2	6	GI	Sandstone and sand and gravel.	Dakota and Sanborn.	Cy,W,H	S	Top of board platform	.5	68.20	6-15-49
•11-6-18bc	H. E. Pautsch	Dr	252.0	6	GI	Sandstone	Dakota	Cy, W	S	Land surface	0	117.00	6-15-49
•11-6-26bd	Donald Bell	Dr	123.0	7	I	do	do	Cy,W,H	D,S	Top of concrete base	0	70.85	5-26-49
•11-6-28cc	Alvin Steinberg	Dr	258.0	5	GI	do	do	Cy,W,H	D,S	Land surface	0	249.00	5-24-49
•11-6-30cc	Elmer Rosebrook	Dr	99.0	5	GI	do	do	Cy,W,H	D,S	Top of concrete platform	2.0	6.00	5-26-49
•11-6-32cc	Leonard Hall	Dr	77.8	6	GI	do	do	Cy,W,H	S	Base of pump	1.7	45.82	5-24-49
•11-6-36ca	Lewis Rathburn	Du	21.3	60	R	do	do	Cy, H	D	Top of manhole, south side	.5	16.39	5-23-49
T. 11 S., R. 7 W.													
(11-7-1bc)	Cozad Bros	Dr	195.0	6	GI	do	do	Cy, W	D,S	Top of casing	1.0	133.44	5-26-49
•11-7-6bb	Russell Bird	Dr	260.0			do	do	Cy,W,H	D,S	Land surface	0	230.00	6-21-49
•11-7-9aa	Lloyd Parson	Dr	99.8	6	GI	Sandstone	Dakota	Cy, H	D	Base of pump	.3	71.10	5-27-49
•11-7-11bd	School District	Dr	136.6	6	GI	do	do	Cy, H	D	Top of casing	.2	33.20	5-24-49
11-7-18ba	Carl Long	Dr	148.0	6	GI	do	do	Cy, W	S	Base of pump, south side	.3	126.69	5-23-49
•11-7-18db	R. K. Crawford	Dr	159.0	5	GI	do	do	Cy, W	S	Top of casing	.8	148.10	6- 2-49
11-7-20ab	James Larsen	Dr	65.0	6	GI	Limestone	Greenhorn	N	N	Top of 2 x 10 over well	0	63.15	4-15-49
•11-7-28bb	A. Sheldon	Dr	88.7	6	GI	Sandstone	Dakota	Cy, W	S	Top of casing	.5	41.80	11- 8-49
•11-7-30aa	T. A. Rhudy & Sons	Dr	69.0	6	GI	Sandstone, sand and gravel.	Dakota and alluvium.	Cy, W	S	do	.5	14.53	6- 2-49
•11-7-31ca	Elmer Howard	Du, Dr	100.2	6	GI	Sandstone	Dakota	J, E	D,S	Top of casing, south side	-6.0	51.80	5-25-49
11-7-32dc	Lincoln Golf Club	Dr	97.5	6	GI	do	do	N	N	Top of native stone surface, base of pump.	.9	75.24	3-14-47
11-7-34ab	C. T. Brown	Du	18.6	24	R	Sand and gravel	Alluvium	Cy, W	N	Base of pump	.5	13.23	6-11-48
•11-7-34cc	H. Jorgesen	Dr	63.0	5	GI	Sandstone	Dakota	Cy, W	S	Top of casing	.8	41.04	5-23-49
T. 11 S., R. 8 W.													
•11-8-8dc	F. E. McMillen	Dr	142.0	5	GI	do	do	Cy,W,H	D,S	do	1.3	23.66	6- 2-49
(11-8-9ba)	Adolph Quade	Dr	260.0	6	GI	do	do	Cy, W	D,S	Land surface	0	248.00	6- 1-49
11-8-22bb	B. J. and H. Strange	Dr	114.0	6	GI	do	do	Cy, W	S	Top of casing	.5	100.35	4-15-48
•11-8-26aa	Crawford Bros	Du	58.2	36	R	do	do	Cy, W	S	Top of rock platform	.7	48.10	2-14-47
11-8-29bc	J. K. Stevenson estate	Dr	39.1	6	GI	do	Dakota	Cy, W	N	Top of stone platform	.8	36.84	2-18-47
(11-8-31ad)	J. Taylor	B	34.6	6	GI	Sand and gravel	Alluvium and Sanborn.	Cy, G	S	Top of casing	.5	15.67	6-16-49
11-8-34cc	School District	B	29.9	6	GI	do	Alluvium	Cy, H	D	Top of board platform	0	5.34	2-18-47
(11-8-35da)	Emil Gabelman	B	25.2	6	GI	do	Sanborn	N	N	Top of casing	0	5.75	4-15-48

TABLE 14.—*Records of wells in Lincoln County*—Continued

Well number (1)	Owner or tenant	Type of well (2)	Depth of well (feet)	Diameter of well, inches	Type of casing (3)	Principal water-bearing bed: Character of material (4)	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
T. 11 S., R. 9 W.														
*11-9-4dc	N. P. Peterson	Dr	48.0	7	I	Sandstone	Dakota	Cy,W,H	D,S	Top of casing	6.0	24.02	6-22-49	
11-9-15bc	W. S. Taylor	Dr	43.7	5	GI	Sand and gravel	Alluvium	Cy, W	D	Top of casing, west side	.9	29.92	2-18-47	
11-9-15dd	E. Traulsen	Du	33.0	48	S	Sand and gravel	Alluvium	N	N	Top of stone platform	1.0	23.63	2-18-47	
*11-9-16db	Ed Larson	Dr	138.0	6	GI	Sandstone	Dakota	Cy, W	S	do	.5	77.60	2-18-47	
*11-9-25ad	H. Larson	B	28.5	6	GI	Sand and gravel	Sanborn	Cy, H	D	Top of board platform	.9	13.87	2-18-47	
*11-9-29cc	Carl Dillon	Dr	65.0	6	GI	Sandstone	Dakota	CyWHG	D,S	Top of board plank	.5	46.35	6-21-49	
11-9-36cd	James Powers	Dr	93.5	6	GI	do	do	Cy, W	S	Top of 2 x 6 at pump base	1.0	27.66	3-19-47	
T. 11 S., R. 10 W.														
*11-10-4da	Floyd Bates	Dr	103.0	6	GI	do	do	Cy, W	D,S	Top of wooden platform	.9	83.15	6-24-49	
(11-10-17bb)	Harold Chegwidden	Dr	190.0	6	GI	do	do	Cy,W,H	D,S	Top of board plank	1.0	166.87	6-17-49	
*11-10-21dc	C. G. Willers	Dr	179.0	6	GI	do	do	Cy, W	D,S	Hole in casing	-4.2	144.07	6-24-49	
*11-10-23aa	L. Herrs	Dr	189.0	6	GI	do	do	Cy,W,H	D,S	Top of casing	.2	125.00	6-22-49	
(11-10-26cb)	Gilbert Ziegenbalg	Dr	194.0	5	GI	do	do	Cy, W	D,S	do	2.5	164.50	6-16-49	
*11-10-30dd	J. A. Watts	Dr	73.0	6	GI	do	do	Cy, W	D,S	Top of stone curb	.5	53.55	6-24-49	
T. 12 S., R. 6 W.														
12-6-3cd	D. T. Skinner	Du	22.4	48	S	do	do	N	N	Top of stone, west side	0	19.14	3-24-47	
(12-6-11ac)	H. Deringer	B	37.0	6	GI	Sand and gravel and sandstone.	Sanborn and Dakota.	Cy, H	D	Top of casing	.3	30.85	11- 8-49	
12-6-12cd	Harry W. Woody	Du	27.0	48	S	Sand and gravel	Alluvium	N	N	Top of board platform, east side.	.2	13.57	3-15-47	
12-6-16cc	O. Anderson	Du	25.5	48	S	do	do	N	N	Top of concrete, southwest corner.	.3	21.48	2-21-47	
*12-6-16dd	W. H. Thomas	Du	28.0	48	S	do	Sanborn	Cy, H	S	Top of board at pump	.8	22.27	2-20-47	
12-6-19ad	A. R. Reitz	B	30.8	6	GI	do	Alluvium	Cy, H	N	Top of casing, north side	0	6.25	2-21-47	
12-6-25aa	L. Earl	Dr	42.0	6	GI	Sandstone	Dakota	Cy, W	S	Top of casing, south side	1.5	25.62	2-20-47	
(12-6-25bb)	School District	B	20.5	6	GI	Sand and gravel	Sanborn	Cy, H	D	Top of casing	.2	8.46	2-28-48	
12-6-27bb	A. E. Skinner et al.	Du	37.0	36	S	Sandstone	Dakota	Cy, W	S	Top of board platform	0	24.06	2-20-47	
*12-6-31bb	H. W. Suelter	Dr	68.5	6	GI	do	do	Cy, W	S	Top of casing	0	32.02	2-21-47	
(12-6-32aa)	J. P. Quinn	Du	30.5	36	S	do	do	Cy, W	D,S	Top of board platform	.9	20.90	2-20-47	
*12-6-35ba	M. Chamberlain	Dr	72.5	6	GI	do	do	Cy, W	S	Top of platform	2.0	64.36	2-20-47	
*12-6-36cc	W. G. Pfeifer	Dr	50.0	6	GI	do	do	Cy, W	S	Top of casing, east side	.8	25.53	2-20-47	

T. 12 S., R. 7 W.													
12 7 6acb	City of Lincoln	Du	80 0	240	R	Sandstone, silt and sand.	Dakota and alluvium.	T, E	P,S	Land surface	0	30.00	9-20-49	200 gallons per minute
12-7-6acc	City of Lincoln	Du	80 0	66	R	do	do	T, E	P,S	do	0	30.00	9-20-49	do
*12 7 8dd	F. R. Goure	Du	25 4	48	S	Sand and gravel	Alluvium	Cy, W	S	Top of board platform	1.4	15.84	2-22-47	
(12 7 9ad)	E. L. Wiebke	Du	38.0		R	Sandstone	Dakota	Cy, W	D,S	Top of platform, west side	.8	34.00	4-23-48	
(12 7 12aa)	R. G. Kerr	Dr	130 0	5	GI	do	do	Cy, W	S	Land surface	0	51.00	4-28-48	
12-7-13ab	M. Cline	Dr	39.5	5	I	Sand and gravel	Alluvium	N	N	Top of casing, north side	.2	17.33	2-21-47	
12-7-14ba	M. Walding	Du	38.0	48	S	do	do	Cy, W	D,S	Top of board platform	1.0	25.60	2-21-47	
12-7-18aa	Rev. Hendrickson	B	49.5	6	GI	do	do	Cy, H	N	Top of platform at pump base.	0	20.62	2-22-47	
*12-7-19dd	H. C. Behrens	Du	16.0	36	S	do	do	Cy, H	S	Top of board platform	0	12.60	3- 7-47	
*12-7-22bb	H. A. Walter	Dr	67.0	6	GI	do	Sanborn	Cy, W	D	Top of concrete curb	.3	21.48	4-23-48	
12-7-23aa	R. E. Ancell	Du	17.9	36	R	do	do	N	N	Top of stone curb	1.0	13.56	9- 8-47	
12-7-23aal	R. E. Ancell	Dr	23.8	5	I	do	do	Cy, H	N	Top of casing	1.3	14.70	2-21-47	
*12-7-28db	Paul Suelter	Dr	96.0	6	GI	Sand and gravel and sandstone.	Sanborn and Dakota.	F	S	Land surface	0	—9.00	4-23-48	10 gallons per minute
12-7-32da	W. C. Weseloh	Du	30.5	30	R	do	Alluvium and Dakota.	N	N	Top of 1 x 10 south side	3.5	28.10	4-21-48	
12-7-34ad	A. Rittman	Du	56.0	48	S	Sandstone	Dakota	Cy, H	N	Top of board platform	1.0	51.84	2-21-47	
12-7-36cd	Paul Suelter	Dr	38.5	6	GI	do	do	N	N	Top of casing	1.2	27.00	2-21-47	
T. 12 S., R. 8 W.														
12-8-4cc	B. Shardon	Du	25.0	48	S	Sand and gravel	Alluvium	N	N	Top of board platform	0	19.69	3-14-47	
(12-8-6aa)	Darrell Dean	B	18.9	6	GI	do	do	Cy, H	N	do	.3	6.54	2-18-47	
12-8-8cd	S. C. Meredith	Du	34.5	48	S	Sandstone	Dakota	Cy	N	do	.6	14.27	3-14-47	
12-8-9cb	H. A. Panzer	Dr	86.0	6	GI	do	do	Cy, W	S	Top of casing	.6	19.89	3-17-47	
(12-8-11cb)	Jas. and Edward Healy	Du	32.0	48	S	Sand and gravel	Alluvium	Cy, W	D,S	Top of concrete surface	0	18.37	2-22-47	
(12-8-13dd)	B. J. Tarning	Dr	70.0			Sandstone	Dakota	Cy, W	D,S	Land surface	0	30.00	4-15-48	
*12-8-15bb	Mrs. M. Bohling	Du	32.9	48	S	do	do	Cy, W	D,S	Top of sheet iron, under pump.	.7	16.60	3-17-47	
12-8-21bb	F. E. Lewick et al	Du	25.0	36	R	Sand and gravel	Sanborn	Cy, W	N	Hole in platform, east side	0	20.72	4-19-48	
*12-8-21dd	School District	Dr	57.8	5	GI	Sandstone	Dakota	Cy, H	N	Top of casing	0	50.07	4-15-48	
*12-8-29bb	Mrs. Henry Bohling	Dr	46.0	6	GI	do	do	Cy, W	S	Land surface	0	22.00	11- 7-49	
*12-8-32aa	Ernest K. Wacker	Du	24.8	48	R	do	do	Cy, W	D,S	Top of 2-inch platform, west side.	.5	21.46	6-24-49	
*12-8-34ab	Herman Zier	Du	30.0	48	R	do	do	Cy, W	D,S	Land surface	0	23.00	11- 9-48	
*12-8-36aa	Henry Steinhaus	Dr	87.5	6	GI	do	do	Cy, W	D,S	Top of concrete platform	.3	16.07	6-24-49	
T. 12 S., R. 9 W.														
12-9-2aa	N. C. Jensen	Dr	74.0	6	GI	do	do	Cy, W	S	Top of casing, west side	0	26.97	3-17-47	
*12-9-3aa	J. E. Cheney	Dr	100.0	6	GI	do	do	Cy, W	D,S	Land surface	0	90.00	11-10-48	
*12-9-5ad	Alice Haley	Dr	47.0	6	GI	Sandstone	do	Cy, W	S	Top of casing	1.9	28.00	6-21-49	
12-9-8cc	Mrs. Boetcher	Dr	55.5	6	GI	do	do	Cy, W	D,S	Base pump	.5	29.54	5-20-47	
12-9-10ad	Harry Cromwell	Dr	30.9	6	GI	Sand and gravel	Alluvium	Cy	N	Top of concrete surface	0	19.61	3-21-47	
12-9-10ca	F. B. Walker et al	Dr	38.0	6	GI	do	do	N	N	Top of board surface	.1	19.70	3-20-47	
(12-9-11dd)	R. E. Ancell	Dr	16.0	6	GI	Sandstone	Dakota	Cy, W	S	Top of casing	1.0	10.03	3-17-47	
(12-9-16bb)	H. E. Gerder	Dr	61.0	6	GI	Sand and gravel	Alluvium	T, E	D,S	Land surface	0	39.00	9-20-49	
12-9-20bd	H. J. Meyer	Dr	32.0	6	GI	Sandstone	Dakota	Cy, W	S	Top of concrete surface	1.5	23.46	3-20-47	
*12-9-22bb	John Sheldon	B	18.0	6	GI	Sand and gravel	Alluvium	Cy,W,H	D,S	Top of stone slab	1.0	16.00	6-23-49	
*12-9-24cd	Louis Felcamp	Dr	64.0	6	GI	Sandstone	Dakota	Cy,W,H	D,S	Land surface	0	40.00	4-19-48	
*12-9-29dc	W. Weidman	Du	48.0		R	do	do	Cy,W,H	D,S	Top of board plank	.2	42.12	6-23-49	
12 9-30aa	C. J. Miller	Du	33.0	48	S	do	do	Cy, W	D,S	Top of board platform	1.0	29.40	3-20-47	

TABLE 14.—*Records of wells in Lincoln County*—Concluded

Well number (1)	Owner or tenant	Type of well (2)	Depth of well (feet)	Diameter of well, inches	Type of casing (3)	Principal water-bearing bed: Character of material (4)	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
T. 12 S., R. 10 W.														
(12-10-8bb)	C. Meitler	B	29.5	6	GI	Sand and gravel	Alluvium	Cy, W	S	Top of casing, north side	1.0	17.20	3-21-47	
12-10-13aa	Saenger estate	Dr	30.2	6	GI	Sand and gravel, and sandstone.	Alluvium and Dakota.	Cy, H	S	Top of casing, south side	1.4	25.48	3-13-47	
12-10-14ac1	City of Sylvan Grove	Dr	70.0	16	I	do	Sanborn and Dakota.	T, E	P,S	Land surface	0	45.00	9-16-49	450 gals. per minute
12-10-14ac2	City of Sylvan Grove	Dr	68.0	16	I	do	do	T, E	P,S	do	0	45.00	9-16-49	350 gals. per minute; 8.5 feet drawdown.
(12-10-14bc)	Clarence Owhler	Dr	44.9	6	GI	do	Alluvium and Dakota.	Cy,W,H	D,S	Pump base	.8	30.85	9- 8-49	
12-10-16db	O. H. Pfaff	Du	32.5	48	S	Sandstone	Dakota	Cy, W	S	Top of board platform	1.0	25.05	3-21-47	
12-10-17ab	School District	Dr	45.0	6	GI	do	do	N	N	Top of casing	.4	26.56	3-18-47	
12-10-20ab	A. Heine	Du	44.0	96	S	Sand and gravel, and sandstone.	Sanborn and Dakota.	Cy, W	D,S	Top of floor of well house	1.0	38.20	3-18-47	
(12-10-21dd)	F. D. Meyer	Du	31.8	48	S	Sand and gravel	Alluvium	Cy, W	D,S	Top of concrete platform	.3	27.17	3-18-47	
(12-10-24dd)	A. R. Buzick estate	Du	70.7	60	R	Sand and gravel, and sandstone.	Sanborn and Dakota.	Cy,W,H	D,S	Top of concrete slab at manhole.	1.3	33.80	9- 8-49	
*12-10-26bc	School District	Dr	80.0	6	GI	Sandstone	Dakota	Cy, H	D	Top of casing	.2	73.23	6-23-49	
12-10-33bb	W. A. Shanlee	Du	14.5	48	S	Sand and gravel	Alluvium	Cy, W	S	Pump base	0	11.85	2-18-47	
T. 13 S., R. 6 W.														
*13-6-7ab	W. A. Trapp	Dr	96.6	6	GI	Sandstone	Dakota	Cy, W	S	Top of casing, east side	1.0	47.32	4-27-48	
*13-6-10bb	Perry Adamson	Dr	92.0	5	I	do	do	Cy, W	D,S	Land surface	0	30.00	4-28-48	
13-6-12cc	Edward Holman	Dr	30.3	6	GI	Sand and gravel	Sanborn	N	N	Top of casing	.8	14.69	4-28-48	
13-6-16cc	S. W. Stone	Du	15.1	24	R	Sandstone	Dakota	N	N	Top of iron bar across center of well.	0	12.46	4-30-48	
*13-6-26ba	School District	Dr	36.0	6	GI	do	do	Cy, H	D	Top break in pump	.9	29.68	5- 5-48	
*13-6-29ca	School District	Dr	100.5	5	GI	do	do	Cy, H	D	Top of casing	.5	85.71	5- 5-48	
13-6-34dc	G. W. Woodworth	Dr	60.3	6	GI	Sand and gravel, and sandstone.	Sanborn and Dakota.	N	N	Top of concrete platform	0	13.25	5- 5-48	

T. 13 S., R. 7 W.													
*13-7-7bb	Loyal Achterberg	Dr	45.0	6	GI	Sandstone	Dakota	Cy, W	D	Pump base	.5	26.45	4-21-48
13-7-10ba	W. J. Meier	Dr	73.0	6	GI	do	do	N	N	Top of casing	.3	45.63	4-27-48
13-7-12cb	M. W. Webb	Du	37.3	24	R	do	do	N	N	Top of iron platform, east side.	.8	32.32	4-30-48
*13-7-15dc	Emma Michael	Dr	71.5	5	GI	do	do	Cy, W	S	Top of casing	1.0	52.55	4-28-48
*13-7-17aa	Mary M. Soldner	Dr	69.0	6	GI	do	do	Cy, W	D,S	Pump base, south side	.8	43.83	4-27-48
13-7-19ab	William Garrity	Du	14.2		R	do	do	Cy, H	N	Top of concrete platform	.7	10.50	4-28-48
13-7-24cd	E. Dodge	Dr	39.1	6	GI	do	do	N	N	Top of casing	.8	12.60	4-30-48
*13-7-26ac	School District	B	36.0	4.5	I	Sand and gravel, and sandstone.	Sanborn and Dakota.	Cy, H	N	do	.3	12.40	5-5-48
*13-7-28ba	School District	Dr	60.8	5	GI	Sandstone	do	Cy, H	D	do	.3	14.27	4-28-48
13-7-33dc	John Shoemaker	Dr	52.3	5.5	GI	Sand and gravel, and sandstone.	do	J, E	D,S	do	—1.0	18.10	5-5-48
T. 13 S., R. 8 W.													
*13-8-3dc	Albert Wachs	Dr	58.0	5	GI	Sandstone	Dakota	Cy, W	D,S	Top of wooden platform	.6	54.02	6-24-49
*13-8-13cc	Edwin Reinert	Du	28.0	36	S	Sand and gravel	Alluvium	C, E	D	Land surface	0	20.00	11-8-48
*13-8-16bb	Harve Kobbeman	B	44.5	6	GI	do	do	Cy,W,H	S	Top of casing	.8	26.17	11-8-48
*13-8-20cb	Rex Mayberry	Dr	66.0	6	GI	Sandstone	Dakota	Cy, W	D	Top of concrete platform	.3	34.26	6-24-49
13-8-25dd	C. J. Panzer	Dr	58.5	5	GI	do	do	Cy, W	S	Pump base, east side	1.0	47.90	4-29-48
*13-8-33ad	C. J. Urbaneck	Du	10.7	24	R	Sand and gravel	Alluvium	Cy, W	S	Top of board platform	.9	3.00	11-8-49
T. 13 S., R. 9 W.													
*13-9-2da	John Weidman	Dr	88.0	5.5	GI	Sandstone	Dakota	Cy,W,H	D,S	Top of concrete slab	1.0	54.58	11-7-49
*13-9-4ad	Harry L. Snyder	Dr	140.0	4.5	GI	do	do	Cy, W	D,S	Land surface	0	80.00	11-7-49
13-9-6bc	Elmer Groth	Dr	83.0	6	GI	do	do	Cy,W,H	D,S	Top of board plank	.7	35.80	6-23-49
13-9-7cd	D. Seagle	Dr	82.0	6	GI	do	do	Cy,W,H	D,S	Pump base	.2	22.13	6-23-49
*13-9-20aa	William Kratky	Du	19.0		R	Sand and gravel	Alluvium	Cy, W	S	Top of board platform	2.1	6.08	11-7-49
*13-9-22dc	Charles Borman	Dr	303.0	6	GI	Sandstone	Dakota	Cy,W,H	D,S	Land surface	0	265.00	11-8-49
*13-9-33bc	Everett Weinhold	Dr	260.0	6	GI	do	do	Cy, W	D,S	do	0	248.00	11-10-48
*13-9-35ad	J. Shaeffer	Dr	295.0	6	GI	do	do	Cy,W,H	S	do	0	240.00	9-15-49
T. 13 S., R. 10 W.													
*13-10-2bb	Albert Holley	Du	26.3	36	R	Sand and gravel	Sanborn	Cy, H	S	Top of board platform, north side of manhole.	1.2	19.48	6-23-49
*13-10-5ac	Fred Brichacek	Dr	80.0	6	GI	Sandstone	Dakota	Cy,W,H	D,S	Top of concrete slab	1.0	67.30	6-23-49
(13-10-15ad)	Charles Prachar	Dr	97.0	6	GI	do	do	Cy,W,E	D,S	Land surface	0	60.00	6-17-49
*13-10-20dd	School District	Dr	72.0	6	GI	Sandstone, and sand and gravel.	Dakota and Meade	Cy, H	D	Top of casing	0	55.94	6-23-49
(13-10-25dc)	Victor Pechacek	Dr	130.0	6	GI	Sandstone	Dakota	Cy, H	D,S	Top of plank under pump base.	.7	89.20	6-17-49
(13-10-27dd)	Ernest Hanzlicek	Dr	80.0	6	GI	Sand and gravel, and sandstone.	Sanborn and Dakota.	Cy, W	S	Top plank under pump	.5	62.83	6-17-49

1. Well number: Well number gives the location of well, as illustrated by Figure 3. Asterisk by well number indicates that chloride and nitrate contents of water are given in table 4. Parentheses around well number indicate complete chemical analysis of water is given in Table 3.

2. B, bored; DD, dug and drilled; Dr, drilled; Du, dug.

3. C, concrete; GI, galvanized sheet iron; I, iron; R, rock; S, stone; Sl, soil.

4. Method of lift: Cy, cylinder; F, natural flow; J, jet; T, turbine. Type of power: E, electric; G, gas engine; H, hand-operated; W, windmill.

5. D, domestic; P, public supply; S, stock.

10-6-8aa. *Sample log of test hole in the NE¼ NE¼ sec. 8, T. 10 S., R. 6 W., 75 feet north and 75 feet west of road intersection, drilled November 1950.*

	Thickness, feet	Depth, feet
Soil and silt, black	2.5	2.5
CRETACEOUS—Gulfian		
Dakota formation		
Sandstone rubble, tan to rusty-brown	2	4.5
Sandstone, rusty-brown to tan	5.5	10
Sandstone, rusty-brown, and gray clay	3	13

10-6-17aa. *Sample log of test hole in the NE¼ NE¼ sec. 17, T. 10 S., R. 6 W., 100 feet south and 15 feet west of road intersection, drilled November 1950. Surface altitude, 1,334.1 feet; depth to water, 10.71 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, gray-brown (soil)	3	3
Sand, fine, tan to yellow	3	6
Sand, fine, orange	5	11
Sand, fine, orange; contains some gravel	7.5	18.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay and shale, varicolored, gray to yellow	4	22.5

10-6-17da. *Sample log of test hole in the NE¼ SE¼ sec. 17, T. 10 S., R. 6 W., 0.5 mile south of road intersection and 10 feet west of center of road, drilled November 1950. Surface altitude, 1,317.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, brown	5	5
Silt, rusty-brown	2	7
Silt, compact, buff; contains some caliche	4	11
Silt, compact, cream to buff	6	17
Silt, slightly sandy, tan	8	25
Silt, compact, buff	3	28
Silt, tan to white	2	30
Gravel and sand, medium to coarse	4.5	34.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay and shale, varicolored, red and gray predominating,	5.5	40

10-6-21bb. *Sample log of test hole in the NW¼ NW¼ sec. 21, T. 10 S., R. 6 W., 150 feet south of bridge and on east shoulder of road, drilled September 1948. Surface altitude, 1,293.7 feet; depth to water, 4.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, black	3	3
Clay and silt, sandy, tan to brown	14	17
Clay, sandy, greenish-gray	19	36
Gravel, limestone, and sandstone; fine- to medium-grained, rounded	2	38

CRETACEOUS—Gulfian

Dakota formation	Thickness, feet	Depth, feet
Clay, sandy, tan and gray	2	40
Clay, sandy, light-tan	10	50

10-6-21cb. *Sample log of test hole in the NW¼ SW¼ sec. 21, T. 10 S., R. 6 W., 0.4 mile north of road intersection and on east shoulder of road, drilled September 1948. Surface altitude, 1,292.8 feet; depth to water, 9.46 feet.*

QUATERNARY—Pleistocene

Alluvium	Thickness, feet	Depth, feet
Silt and clay, black	5	5
Clay, sandy, tan	10	15
Clay, slightly sandy, brownish-tan	8	23
Clay, bluish-black	22	45
Clay, very sandy, fossiliferous, greenish	11	56
Sand, quartz, fine to medium, fossiliferous, greenish	5	61
Gravel, fine to medium; contains rounded limestone	2	63
CRETACEOUS—Gulfian		
Dakota formation		
Clay, tan, gray, and red; contains lignite from 68 to 70 feet	7	70

10-6-28bc. *Sample log of test hole in the SW¼ NW¼ sec. 28, T. 10 S., R. 6 W., 0.3 mile south of road intersection and on east shoulder of road, drilled September 1948. Surface altitude, 1,306.0 feet; depth to water, 15.18 feet.*

QUATERNARY—Pleistocene

Alluvium	Thickness, feet	Depth, feet
Silt, black	4	4
Clay, very sandy, light-tan	4	8
Clay, very sandy, fossiliferous, light-tan	3	11
Gravel, limestone, fine to coarse, angular, rounded; contains clay	4	15
Gravel, limestone, fine to medium; contains thin clay beds	8	23
CRETACEOUS—Gulfian		
Dakota formation		
Clay, gray and red	4	27

10-6-28cb. *Sample log of test hole in the NW¼ SW¼ sec. 28, T. 10 S., R. 6 W., 0.35 mile north of road intersection and on east shoulder of road, drilled September 1948. Surface altitude, 1,313.9 feet; depth to water, 13.80 feet.*

QUATERNARY—Pleistocene

Alluvium	Thickness, feet	Depth, feet
Silt and clay, brown to black; contains some road fill	8.5	8.5
Clay, sandy, light-gray, tan, and buff	9.5	18
Clay, light-tan and red	7	25
Clay, red; contains a trace of gravel	7	32
Sand, fine to medium quartz	1	33

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Dakota formation		
Sandstone, yellowish-brown	7	40

10-10-35ad. *Sample log of test hole in the SE¼ NE¼ sec. 35, T. 10 S., R. 10 W., 0.1 mile north of half-section line, drilled August 1948. Surface altitude, 1,481.5 feet, depth to water, 24.30 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt and clay; contains fine tannish-brown sand	5	5
Silt, sandy, tannish-brown	4.5	9.5
Clay, sandy, light-brown	8.5	18
Clay and very fine sand, light-brown	6.5	24.5
Clay, dark-gray	6.5	31
Gravel, fine to medium, "ironstone," and limestone, reddish, and fine sand	6	37
Gravel, fine to medium, "ironstone," and limestone, reddish	7	44
Gravel, coarse, and clay	3	47
Silt and clay, black; contains coarse gravel	7.5	54.5
Silt, soft, gray	3	57.5
Silt, sandy, gray	1.5	59
Gravel, fine to coarse, and limestone fragments	4	63
CRETACEOUS—Gulfian		
Dakota formation		
Shale, very sandy, noncalcareous, gray	10	73

11-6-10ad. *Sample log of test hole in the SE¼ NE¼ sec. 10, T. 11 S., R. 6 W., 0.25 mile south of road intersection and 30 feet west of center of road, drilled November 1950.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, gray to dark-brown soil	2.5	2.5
Silt, compact, brown	3.5	6
Silt, slightly sandy, red-brown	5	11
Gravel, fine to coarse; contains lenses of buff silt and some coarse sand	8	19
Silt, tan to buff	7	26
CRETACEOUS—Gulfian		
Dakota formation		
Sandstone, yellow-brown	3	29
Clay, compact, gray	1	30

11-8-27aa. *Sample log of test hole in the NE¼ NE¼ sec. 27, T. 11 S., R. 8 W., 25 feet south of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,437 feet; depth to water, 8.80 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt and clay, sandy, tan	5	5
Silt and clay, brown	2	7
Clay, sandy, reddish-tan; contains fine limestone gravel,	3	10
Clay, light-tan, and fine limestone gravel	8	18
Gravel, limestone, and clay	2	20
CRETACEOUS—Gulfian		
Dakota formation		
Clay, reddish-tan; contains light-gray clay	19	39
Clay, light-gray and reddish-tan (reddish-tan clay may be lag)	11	50

11-8-27ad. *Sample log of test hole in the SE¼ NE¼ sec. 27, T. 11 S., R. 8 W., 0.3 mile south of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,420.6 feet; depth to water, 12.10 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, black to dark-brown	3.5	3.5
Clay, sandy, tan	3	6.5
Clay, silty, sandy, tan and brown	10.5	17
Gravel, limestone, fine to medium, angular; contains clay	7	24
CRETACEOUS—Gulfian		
Dakota formation		
Clay, tan and gray	6	30

11-8-36aa. *Sample log of test hole in the NE¼ NE¼ sec. 36, T. 11 S., R. 8 W., 65 feet south and 35 feet west of road intersection, drilled November 1950.*

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Dakota formation		
Clay, yellow-orange	4	4
Clay and sandstone, orange to yellow	3	7
Clay and shale, varicolored, predominantly gray	23	30
Clay and shale, varicolored, predominantly rusty-brown,	10	40
Clay and shale, varicolored, predominantly gray; contains sandstone lens from 44 to 45 feet	10	50
Clay, light-gray; contains pyrite	4	54
Clay and sandstone, gray to brown	6	60
Sandstone, solid, compact	17	77
Sandstone; contains clay lenses	23	100
Sandstone and clay; contains pyrite and lignite	10	110
Clay, gray; contains sandstone lenses	30	140
Clay, slightly silty, varicolored, red and gray predominating	20	160

CRETACEOUS—Comanchean	Thickness, feet	Depth, feet
Kiowa shale		
Clay and shale, sandy, blue-gray; contains pyrite	30	190
Clay and shale, blue-gray; contains pyrite and gypsum crystals	10	200

12-6-16aa. *Sample log of test hole in the NE¼ NE¼ sec. 16, T. 12 S., R. 6 W., 200 feet north of railroad and on west shoulder of road, drilled September 1948. Surface altitude, 1,322.2 feet; depth to water, 19.60 feet.*

QUATERNARY—Pleistocene	Thickness, feet	Depth, feet
Alluvium		
Silt, black	4	4
Clay, blocky, tan	9	13
Clay, light-tan	9	22
Clay, compact, light-tan	5	27
Clay, very sandy, tan	3	30
Sand, quartz, very fine; contains clay	17	47
Gravel, fine to medium, rounded; contains medium sand,	3.5	50.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay, very compact, light-gray	3.5	54

12-6-16da. *Sample log of test hole in the NE¼ SE¼ sec. 16, T. 12 S., R. 6 W., 200 feet south of half-section line and on west shoulder of road, drilled August 1948. Surface altitude, 1,324.8 feet; depth to water, 21.14 feet.*

QUATERNARY—Pleistocene	Thickness, feet	Depth, feet
Alluvium		
Silt and clay, black	3	3
Clay, dark-greenish-gray	4.5	7.5
Clay, light-gray	6	13.5
Clay, very sandy, tan	10.5	24
Gravel, fine to medium, and coarse quartz sand	6	30
Sand and fine gravel, mostly quartz	10	40
Sand, coarse, and fine gravel, quartz (6-inch bed of black clay at 48 feet)	10	50
Gravel and gray clay	4.5	54.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay, greenish-black; contains pyrite and lignite	4.5	59

12-6-21aa. *Sample log of test hole in the NE¼ NE¼ sec. 21, T. 12 S., R. 6 W., 30 feet west of center of road and 60 feet south of road intersection, drilled September 1948. Surface altitude, 1,317.9 feet; depth to water, 18.12 feet.*

QUATERNARY—Pleistocene	Thickness, feet	Depth, feet
Alluvium		
Silt and clay, brown to black	4.5	4.5
Clay, silty, tan	9.5	14
Clay, sandy, tan	9	23
Clay and sand, tan	12	35
Gravel, fine to coarse; contains sand	10	45

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Dakota formation		
Clay, bluish-gray and yellow	2	47
Clay, slightly sandy, light-gray	2	49
Sandstone and quartzite, light-gray; contains lignite	5.5	54.5
Clay, very sandy, light bluish-gray, and gray sandstone,	15.5	70
Clay, light-bluish-gray	14.5	84.5
Clay, gray and greenish-gray; contains lignite and pyrite; sandy in thin zone	5.5	90
Clay, sandy, gray to bluish-gray	28	118
Clay, light-green and reddish-brown	8	126
Sandstone, fine, light-tan to gray	34.5	160.5
Shale, very fissile, noncalcareous, bluish-black; contains lignite and sandstone	19.5	180
CRETACEOUS—Comanchean		
Kiowa shale		
Sandstone, medium coarse, calcite-cemented; contains some cemented calcite in thin hard zones	17	197
Shale, noncalcareous, black and blue-green; contains shell fragments and hard beds	13	210
Shale, noncalcareous, thin, black, and tan limestone	14	224
Shale, noncalcareous, black, and tan limestone; contains white crystal fragments	23	247
Shale, black, greenish-gray, and red	12	259
PERMIAN—Guadalupian		
Shale, red; contains black and greenish-gray shale which may be lag	21	280

12-6-21da. *Sample log of test hole in the NE¼ SE¼ sec. 21, T. 12 S., R. 6 W., 125 feet south of concrete bridge and on west shoulder of road, drilled August 1948. Surface altitude, 1,317.8 feet; depth to water, 14.66 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, dark-gray to black; contains sand and gravel	4	4
Clay, sandy, tan; contains limestone gravel	2.5	6.5
Clay, sandy, tan; contains silt and gravel	3.5	10
Silt and clay, sandy, reddish-brown	10	20
Clay, sandy, tan; contains limestone gravel	3	23
Gravel, fine to medium, limestone; contains medium quartz sand	14	37
Gravel, medium, and rounded limestone; fragments contain quartz sand	12	49
CRETACEOUS—Gulfian		
Dakota formation		
Clay, blue-black and yellow; contains quartzitic sandstone	5	54

12-6-21dd. *Sample log of test hole in the SE¼ SE¼ sec. 21 T. 12. S., R. 6 W., 0.1 mile north of road intersection and 8 feet west of center of road, drilled August 1948. Surface altitude, 1,328.2 feet; depth to water, 24.95 feet.*

	Thickness, feet	Depth, feet
Road fill, gravel and silt, dark-brown and gray	2.5	2.5
QUATERNARY—Pleistocene		
Alluvium		
Silt, sticky, compact, gray	3.5	6
Silt, fairly compact, slightly sandy, tan	1.5	7.5
Silt, sandy, medium compact, rusty-brown	1	8.5
Gravel, sandstone	5	13.5
Silt, very sandy, compact, buff to rusty-brown	6.5	20
Sand, fine to coarse, tan to buff	11	31
Gravel, fine to coarse; contains coarse sand and silt lag	9	40
Gravel, fine to coarse, sandstone and limestone	5.5	45.5
CRETACEOUS—Gulfian		
Dakota formation		
Shale and clay, sandy, blue-gray	1	46.5
Sandstone, very solid, blue-gray; contains lag	1	47.5

12-7-34cd. *Sample log of test hole in the SE¼ SW¼ sec. 34, T. 12 S., R. 7 W., 0.4 mile east of road intersection and 5 feet north of center of road, drilled August 1948. Surface altitude, 1,431.1 feet; depth to water, 26.73 feet.*

	Thickness, feet	Depth, feet
Road fill, brown, medium-compact silt	2	2
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, slightly sandy, buff to brown	3	5
Silt, fairly loose, slightly sandy, rusty-brown	5	10
Silt, sandy, light-tan to buff; contains caliche	6	16
Gravel, fine to coarse, limestone, and sandstone	8.5	24.5
CRETACEOUS—Gulfian		
Dakota formation		
Sandstone, compact, yellow-brown	2.5	27
Sandstone, compact, tan	1.5	28.5
Sandstone and sandy clay, fairly compact, white	1.5	30

12-8-2bc. *Sample log of test hole in the SW¼ NW¼ sec. 2, T. 12 S., R. 8 W., 100 feet north of railroad and on east shoulder of road, drilled August 1948. Surface altitude, 1,372.5 feet; depth to water, 3.40 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, black; contains clay	4	4
Clay, light-tan to gray	2	6
Clay, light-tan	6	12
Clay, tan	8	20
Sand, quartz, medium	10	30
Sand and fine gravel	20	50

	Thickness, feet	Depth, feet
Sand and rounded medium limestone gravel; contains a trace of clay at 53½ feet	10	60
Sand, fine, and rounded medium limestone gravel; contains a trace of lignite at 63½ feet	4.5	64.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay, light-gray	5.5	70

12-8-3aa. *Sample log of test hole in the NE¼ NE¼ sec. 3, T. 12 S., R. 8 W., 20 feet south of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,371.6 feet; depth to water, 7.05 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt and clay, black	5	5
Clay, gray and tan, mottled	7	12
Clay, sandy, dark-gray to brown	3.5	15.5
Clay, sandy, light-tan and gray	1.5	17
Sand, very fine, tan	20	37
Sandstone, soft, reddish-tan	7	44
CRETACEOUS—Gulfian		
Dakota formation		
Sandstone, "ironstone," reddish-brown	5.5	49.5

12-8-10aa. *Sample log of test hole in the NE¼ NE¼ sec. 10, T. 12 S., R. 8 W., 0.1 mile south of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,373.4 feet; depth to water, 15.07 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, slightly sandy, black	8.5	8.5
Clay, slightly sandy, tan	8	16.5
Sand, very fine, silty	9	25.5
Sand, quartz, medium to fine	4.5	30
Sand, gravel, and thin beds of clay	14	44
Gravel and fine sand	3	47
Gravel, limestone, medium to coarse, rounded, stained brown; contains sand	6.5	53.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay, light-gray	6.5	60

12-8-10da. *Sample log of test hole in the NE¼ SE¼ sec. 10, T. 12 S., R. 8 W., 0.45 mile north of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,374.6 feet; depth to water, 13.80 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, black; contains clay	4	4
Clay, tan to brown	11	15
Clay and silt, black	5	20
Clay, greenish-gray	11	31
Gravel, fine to coarse; contains coarse sand	8	39
Gravel and sand, medium to coarse	4	43

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Dakota formation		
Clay, light-gray	4	47

12-8-22cb. *Sample log of test hole in the NW¼ SW¼ sec. 22, T. 12 S., R. 8 W., 0.1 mile north of bridge and east of road in field, drilled August 1948. Surface altitude, 1,404.9; depth to water, 16.95 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, black	4	4
Clay, buff-tan; contains fine gravel	10	14
Clay, sandy, buff-tan	6	20
Clay, sandy, tan to buff	6	26
Silt, sandy, fossiliferous, black	3	29
Clay, greenish-gray	5	34
Gravel, coarse to medium, rounded, and limestone	5	39
Gravel, fine to medium, sandy; contains black silty clay,	2.5	41.5
CRETACEOUS—Gulfian		
Dakota formation		
Gravel and clay, gray	1.5	43
Clay, light-gray; contains gray sandstone	2	45

12-10-4cc. *Sample log of test hole in the SW¼ SW¼ sec. 4, T. 12 S., R. 10 W., 50 feet east of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,422.0 feet; depth to water, 11.90 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, dark-brown; contains road fill	3.5	3.5
Clay, sandy, tan	3.5	7
Clay, silty; contains gravel	7	14
Clay, sandy, gray; contains coarse gravel	3.5	17.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay, buff, tan, gray, and some red; contains "ironstone" gravel	2.5	20

12-10-14dd. *Sample log of test hole in the SE¼ SE¼ sec. 14, T. 12 S., R. 10 W., southwest corner of Sylvan Grove fair grounds and on west side of road, drilled August 1948. Surface altitude, 1,429.7 feet; depth to water, 30.30 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, black	3	3
Clay, tannish-brown; contains coarse sand	5.5	8.5
Sand, fine, and coarse limestone gravel	3	11.5
Clay, silty, light-brown	8	19.5
Clay and some very fine sand	1.5	21
Clay, sandy, tan	8	29
Clay, reddish-tan; contains coarse red sand	6	35
Sand, quartz, medium to coarse, rounded	6	41
Gravel, fine to medium, limestone, and quartz	1	42

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Dakota formation		
Clay shale, gray, buff, and reddish-brown	2	44

12-10-16cb. *Sample log of test hole in the NW¼ SW¼ sec. 16, T. 12 S., R. 10 W., 20 feet south of half-mile line and 25 feet east of center of road, drilled August 1948. Surface altitude, 1,439.0 feet; depth to water, 18.20 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, black	4	4
Silt, brown	4	8
Clay, silty, tan	8	16
Clay, sandy, light-tan	9	25
Clay, slightly sandy, grayish-tan	5	30
Clay, dark-gray	10	40
Clay, dark bluish-gray	4	44
Clay, greenish-gray	3	47
Gravel and fine to medium rounded limestone	3	50
Sandstone, fine	4	54
Sand, fine to medium, rounded, quartz	2	56
CRETACEOUS—Gulfian		
Dakota formation		
Clay, soapy, light-gray	4	60

12-10-17aa. *Sample log of test hole in the NE¼ NE¼ sec. 17, T. 12 S., R. 10 W., 25 feet south of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,448.8 feet; depth to water, 26.60 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Clay, silty, buff to brown	6.5	6.5
Clay, silty, tan	6.5	13
Gravel, fine to medium; contains sand and clay	7	20
Gravel, iron-stained limestone, fine to medium	10	30
Gravel, limestone, medium to coarse	6	36
CRETACEOUS—Gulfian		
Dakota formation		
Clay, slightly sandy, gray	4	40

12-10-20aa. *Sample log of test hole in the NE¼ NE¼ sec. 20, T. 12 S., R. 10 W., 20 feet south of road intersection, drilled August 1948. Surface altitude, 1,445.9 feet; depth to water, 22.16 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, very sandy, brown	6	6
Sand, medium to fine, quartz, and feldspar	2	8
Clay, tan, mottled with buff and black	8	16
Clay, sandy, tan, and fine limestone gravel	7	23
Gravel, limestone, and "ironstone"; contains clay	2	25
CRETACEOUS—Gulfian		
Dakota formation		
Clay, gray, buff, tan; contains red sand	4.5	29.5

12-10-20ad. *Sample log of test hole in the SE¼ NE¼ sec. 20, T. 12 S., R. 10 W., 0.4 mile south of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,446.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, fine, sandy, black to dark-brown	8	8
Clay, sandy, tan	8	16
Clay and silt, sandy, brown	4	20
Sand, quartz, medium to coarse, and feldspar	8	28
CRETACEOUS—Gulfian		
Dakota formation		
Clay, red and light-tan	2	30

12-10-20da. *Sample log of test hole in the NE¼ SE¼ sec. 20, T. 12 S., R. 10 W., 300 feet south of the Saline River bridge and on west shoulder of road, drilled August 1948. Surface altitude, 1,437.2 feet; depth to water, 13.35 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt and clay, very sandy, light-tan	6	6
Sand, fine, limestone, and quartz	2	8
Clay, gray	4	12
Gravel, limestone, fine to medium, and dark-gray clay and sand	8	20
Sand, fine to coarse, quartz, and fine gravel	8	28
Clay, dark-gray, and sand	7	35
Gravel, fine to medium; contains quartz sand	15	50
Gravel, fine to coarse; contains quartz sand	13.5	63.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay, red and gray	6.5	70

12-10-23aa. *Sample log of test hole in the NE¼ NE¼ sec. 23, T. 12 S., R. 10 W., 150 feet south of Saline River bridge and on west shoulder of road, drilled August 1948. Surface altitude, 1,429.4 feet; depth to water, 26.55 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt and clay; grayish-brown	10	10
Clay and very fine sand	5	15
Clay, tan	7	22
Sand, medium, quartz, rounded	7	29
Gravel, medium, rounded, limestone	4	33
Gravel, fine, quartz, rounded	3.5	36.5
Shale, clay, sandy, dark-gray	3.5	40
CRETACEOUS—Gulfian		
Dakota formation		
Shale, clay, sandy, bluish-gray streaked with red	4.5	44.5

12-10-23da. *Sample log of test hole in the NE¼ SE¼ sec. 23, T. 12 S., R. 10 W., 0.25 mile north of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,434.0 feet; depth to water, 28.50 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Silt, brown to black	4	4
Silt and clay, light-brown	6	10
Clay, sandy, light-brown	4	14
Gravel and clay; contains limestone and quartz gravel	4.5	18.5
Clay, very sandy, tan to buff	2.5	21
Sand, fine to medium, rounded, quartz	4	25
Sand, medium to coarse, rounded, quartz	9	34
Gravel, fine to medium, limestone	2	36
Gravel, medium to coarse, limestone, and gray and red clay shale	1	37
CRETACEOUS—Gulfian		
Dakota formation		
Clay shale, noncalcareous, sandy, gray	0.5	37.5

12-10-26aa. *Sample log of test hole in the NE¼ NE¼ sec. 26, T. 12 S., R. 10 W., 550 feet south of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,472.4 feet; depth to water, 15.09 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, black	4	4
Silt and clay, tan	1.5	5.5
Clay; contains reddish-brown silt	5.5	11
Clay, light-tan grading to light-gray; becomes sandy	4.5	15.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay, sandy, buff, gray, and red	3.5	19
Clay, light-gray, red at 21 feet	4	23
Clay, buff	1	24

12-10-29aa. *Sample log of test hole in the NE¼ NE¼ sec. 29, T. 12 S., R. 10 W., 0.2 mile south of road intersection and on west shoulder of road, drilled August 1948. Surface altitude, 1,449.6 feet; depth to water, 26.95 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium		
Clay, silty, tan	4	4
Silt and clay, buff to tan	6	10
Clay, silty, tan; contains fine gravel	8	18
Sand, medium to coarse, quartz, and fine to medium limestone gravel	10	28
CRETACEOUS—Gulfian		
Dakota formation		
Clay, red and gray	2	30

12-10-29da. *Sample log of test hole in the NE¼ SE¼ sec. 29, T. 12 S., R. 10 W., 0.65 mile south of road intersection and on crest of high terrace, drilled August 1948. Surface altitude, 1,496.9 feet; depth to water, 19.15 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Clay, tan; contains sand, limestone, and caliche	5	5
Clay, tan, sand, limestone gravel, and caliche	3.5	8.5
Sand, fine to medium, quartz	10.5	19
CRETACEOUS—Gulfian		
Dakota formation		
Clay, gray, tan, yellow, and red	3	22

12-10-32ad. *Sample log of test hole in the SE¼ NE¼ sec. 32, T. 12 S., R. 10 W., 100 yards north of concrete bridge and on west shoulder of road, drilled August 1948. Surface altitude, 1,492.0 feet; depth to water, 18.70 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Clay, tan; contains much caliche	3	3
Gravel, limestone, rounded, and caliche	4	7
Gravel, fine, limestone, and fine sand	10	17
Gravel, fine to coarse, limestone, and coarse sand	9	26
Gravel, medium, angular limestone and "ironstone"; contains gray clay	5	31
CRETACEOUS—Gulfian		
Dakota formation		
Clay, gray	6	37

13-9-31cc. *Sample log of test hole in the SW¼ SW¼ sec. 31, T. 13 S., R. 9 W., 20 feet north of road intersection and on east shoulder of road, drilled September 1948. Surface altitude, 1,674.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, sandy, light-brown	4.5	4.5
Meade formation		
Silt and clay, tan to brown	10	14.5
Clay, silty, buff to tan; contains caliche pebbles	15.5	30
Clay, light-tan; contains very fine sand	27	57
Sand, medium to coarse, quartz; contains fine quartz gravel	6.5	63.5
CRETACEOUS—Gulfian		
Dakota formation		
Clay, yellow, fine-grained sandstone; noncalcareous	9.5	73

13-10-33dd. *Sample log of test hole in the SE¼ SE¼ sec. 33, T. 13 S., R. 10 W., on section line and 0.15 mile west of road intersection, drilled September 1948. Surface altitude, 1,667.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations undifferentiated		
Clay and silt, sandy, tan, and gravel	3	3
Clay and coarse sand, tan; contains fine gravel	5	8
Clay, tan, and caliche; contains coarse sand and fine gravel	3	11
Clay, light-tan	6	17
Clay and silt, tan; contains loose sand	3	20
Clay, tan	5	25
Clay, compact, sandy, light-tan	5	30
Clay, sandy, light-tan	5	35
Sand, medium to coarse, rounded, quartz and feldspar,	9	44
Sand and gravel, rounded, quartz, and feldspar	5	49
CRETACEOUS—Gulfian		
Dakota formation		
Sandstone, fine-grained, light-gray	11	60

13-10-34cc. *Sample log of test hole in the SW¼ SW¼ sec. 34, T. 13 S., R. 10 W., 0.2 mile east of road intersection and on section line, drilled September 1948. Surface altitude, 1,669.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations undifferentiated		
Clay and silt, tan	10	10
Clay, light-tan	10	20
Clay, reddish-tan, and caliche	6.5	26.5
Clay, sandy, tan	3.5	30
Clay, sandy, light-tan to gray	7	37
Sand, medium, quartz, rounded	10	47
Gravel, fine to medium, and coarse sand	10	57
Gravel, sandstone, reddish-brown	2	59
CRETACEOUS—Gulfian		
Dakota formation		
Clay, gray and yellow	1	60

13-10-34dd. *Sample log of test hole in the SE¼ SE¼ sec. 34, T. 13 S., R. 10 W., 15 feet west of road intersection, drilled September 1948. Surface altitude, 1,670.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations undifferentiated		
Silt and clay, sandy, brown	10	10
Clay and silt, tan; contains caliche	10	20
Clay and silt, sandy, light-tan; contains caliche	12	32
Clay, greenish-tan	8	40
Clay, compact, greenish-tan	7	47
Sand, medium to coarse, and fine gravel, quartz	3	50
Sand, medium to coarse, and fine gravel (slightly coarser than above sample)	12	62
Gravel, sandstone, and reddish-brown sand	4	66
CRETACEOUS—Gulfian		
Dakota formation		
Clay, light-gray and yellow	3	69

14-9-4bb. *Sample log of test hole in the NW¼ NW¼ sec. 4, T. 14 S., R. 9 W., 0.2 mile east of section line and on south shoulder of road, drilled September 1948. Surface altitude, 1,788.9 feet.*

	Thickness, feet	Depth, feet
Silt, brown	2.5	2.5
TERTIARY—Pliocene		
Ogallala formation		
Limestone, white, algal	1	3.5
CRETACEOUS—Gulfian		
Greenhorn limestone		
Clay shale, calcareous, red	4	7.5
Clay shale, calcareous, tan and red	5	12.5
Limestone, soft, white to tan	1.5	14
Clay shale, calcareous, tan and buff	6	20
Clay shale and limestone in alternating thin layers	10	30
Limestone, light-gray; contains calcareous shale	10	40
Clay and shale, calcareous, tan and buff	1.5	41.5
Shale, calcareous, black	5.5	47

14-9-5bb. *Sample log of test hole in the NW¼ NW¼ sec. 5, T. 14 S., R. 9 W., 40 feet east of section corner and on south shoulder of road, drilled September 1948. Surface altitude, 1,691.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations undifferentiated		
Silt, fine, sandy, brown	3	3
Silt and clay, tan to gray; contains sand	6	9
Clay, sandy, reddish-brown	10	19
Clay, sandy, compact, greenish-gray	4	23
Gravel and yellow clay (gravel is composed mostly of rounded quartz)	6	29
CRETACEOUS—Gulfian		
Greenhorn limestone		
Clay shale, yellow	1	30

14-10-2aa. *Sample log of test hole in the NE¼ NE¼ sec. 2, T. 14 S., R. 10 W., 30 feet south of section corner and on west shoulder of road, drilled September 1948. Surface altitude, 1,667.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations undifferentiated		
Silt, sandy, tan; contains clay	5	5
Clay and silt, tan	4	9
Clay, sandy, reddish-tan	8	17
Clay, sandy, compact, reddish-tan	7.5	24.5
Clay, compact, tan	10.5	35
Clay and caliche, sandy	8	43
Clay, very plastic, light-greenish-gray	5	48
Sand and gravel, fine to medium, quartz	10	58
Gravel, fine to medium, quartz, and fine to medium quartz sand	3	61
CRETACEOUS—Gulfian		
Dakota formation		
Clay, gray and red	8	69

REFERENCES

ADAMS, G. I. (1903) Physiographic divisions of Kansas: Kansas Acad. Sci. Trans., vol. 18, pp. 109-123.

BASS, N. W. (1926) Geologic investigations in western Kansas, with special reference to oil and gas possibilities: Kansas Geol. Survey, Bull. 11, pp. 1-95, figs. 1-27, pls. 1-9.

CAREY, J. S., and others (1952) Kansas volcanic ash resources: Kansas Geol. Survey, Bull. 96, pt. 1, pp. 1-68, figs. 1-4, pls. 1-7.

CONDRA, G. E., AND REED, E. C. (1943) The geological section of Nebraska: Nebraska Geol. Survey, Bull. 14, I-VII, pp. 1-82, correl. chart, 24 figs., 1 pl.

CRAGIN, F. W. (1889) Contributions to the Paleontology of the Plains, No. 1: Washburn Coll. Lab. Nat. History Bull., vol. 2, no. 10, pp. 65-68.

——— (1894) Descriptions of invertebrate fossils from the Comanche Series in Texas, Kansas, and Indian Territory: Colorado Coll. Studies, 5th Ann. Pub., pp. 49-68.

DARTON, N. H. (1899) Preliminary report on the geology and water resources of Nebraska west of the 103d meridian: U. S. Geol. Survey 19th Ann. Rept., pt. 4, pp. 719-785.

——— (1920) Description of the Syracuse and Lakin quadrangles, Kansas: U. S. Geol. Survey, Geol. Atlas 212, pp. 1-85, figs. 1-7, pls. 1-6.

DURUM, W. H. (1950) Progress report, chemical quality of the surface waters in the Saline River basin: U. S. Geol. Survey Mimeographed Rept., 54 pp., 6 pls.

ELIAS, M. K. (1931) Geology of Wallace County, Kansas: Kansas Geol. Survey Bull. 18, pp. 1-254, figs. 1-7, pls. 1-42.

——— (1937) Geology of Rawlins and Decatur Counties, with special reference to water resources: Kansas Geol. Survey, Min. Resources Circ. 7, pp. 1-25, figs. 1-4.

——— (1942) Teritary prairie grasses and other herbs from the High Plains: Geol. Soc. America, Special Paper 41, pp. 1-176, fig. 1, pls. 1-17.

FRYE, J. C., LEONARD, A. B., AND HIBBARD, C. W. (1943) Westward extension of the Kansas "Equus beds": Jour. Geology, vol. 51, no. 1, pp. 33-47, 3 figs., incl. index map.

FRYE, J. C., SWINEFORD, ADA, AND LEONARD, A. B. (1948) Correlation of central Great Plains Pleistocene with the glacial section: Jour. Geology, vol. 56, no. 6, pp. 501-525, figs. 1-3, pls. 1-2.

GILBERT, G. K. (1896) The underground water of the Arkansas valley in eastern Colorado: U. S. Geol. Survey 17th Ann. Rept., pt. 2, pp. 551-601, figs. 45-49, pls. 56-68.

LATTA, B. F. (1941) Geology and ground-water resources of Stanton County, Kansas: Kansas Geol. Survey, Bull. 37, pp. 1-119, figs. 1-6, pls. 1-9.

——— (1946) Cretaceous stratigraphy of the Belvidere area, Kiowa County, Kansas: Kansas Geol. Survey, Bull. 64, pt. 6, pp. 217-260, figs. 1-4, pls. 1-3.

LOGAN, W. N. (1897) The upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. 2, pp. 195-234, figs. 10-11, pls. 28-34.

MEEK, F. B., AND HAYDEN, F. V. (1862) Descriptions of new Cretaceous fossils from Nebraska Territory: Philadelphia Acad. Nat. Sci. Proc., vol. 13, pp. 21-28.

MEINZER, O. E. (1923) The occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey, Water-Supply Paper 489, pp. 1-321, figs. 1-110, pls. 1-31.

——— (1923a) Outline of ground-water hydrology, with definitions: U. S. Geol. Survey, Water-Supply Paper 494, pp. 1-71, figs. 1-35.

METZLER, D. F., AND STOLTENBERG, H. A. (1950) The public health significance of high nitrate waters as a cause of infant cyanosis and methods of control: Kansas Acad. Sci. Trans., vol. 53, no. 2, pp. 194-211, figs. 1-4.

MOORE, R. C., and others (1940) Ground-water resources of Kansas: Kansas Geol. Survey, Bull. 27, pp. 1-112, figs. 1-28, pls. 1-34.

——— (1951) The Kansas rock column: Kansas Geol. Survey, Bull. 89, pp. 1-132, figs. 1-52.

PLUMMER, NORMAN, AND ROMARY, J. F. (1942) Stratigraphy of the pre-Greenhorn Cretaceous beds of Kansas: Kansas Geol. Survey, Bull. 41, pt. 9, pp. 313-348, figs. 1-4, pls. 1-2.

——— (1947) Kansas clay, Dakota formation: Kansas Geol. Survey, Bull. 67, pp. 1-241, figs. 1-17, pls. 1-7.

PROSSER, C. S. (1897) The upper Permian and the lower Cretaceous: Kansas Univ. Geol. Survey, vol. 2, pp. 51-194, figs. 6-9, pls. 9-24.

RUBEY, W. W., AND BASS, N. W. (1925) Geology of Russell County, Kansas: Kansas Geol. Survey, Bull. 10, pp. 1-86, figs. 1-11, pls. 1-7.

SAYRE, A. N., and others (1948) Water levels and artesian pressure in observation wells in the United States in 1948: U. S. Geol. Survey, Water-Supply Paper 1128, pt. 3, pp. 1-325, figs. 1-11.

SWINEFORD, ADA (1947) Cemented sandstones of the Dakota and Kiowa formations in Kansas: Kansas Geol. Survey, Bull. 70, pt. 4, pp. 53-104, figs. 1-3, pls. 1-7.

——— (1949) Source area of Great Plains Pleistocene volcanic ash: Jour. Geology, vol. 57, no. 3, pp. 307-311, fig. 1.

SWINEFORD, ADA, AND FRYE, J. C. (1951) Petrography of the Peoria loess in Kansas: Jour. Geology, vol. 59, no. 4, pp. 306-322, figs. 1-5, pls. 1-3.

SWINEFORD, ADA, AND WILLIAMS, H. L. (1945) The Cheyenne sandstone and adjacent formations of a part of Russell County, Kansas: Kansas Geol. Survey, Bull. 60, pt. 4, pp. 101-168, figs. 1-2, pls. 1-9.

TWENHOFEL, W. H. (1924) Geology and invertebrate paleontology of Comanchean and "Dakota" formations of Kansas: Kansas Geol. Survey, Bull. 9, pp. 1-135, pls. 1-23.

WILCOX, L. V. (1948) The quality of water for irrigation use: U. S. Dept. Agri., Tech. Bull. 962, pp. 1-40.

INDEX

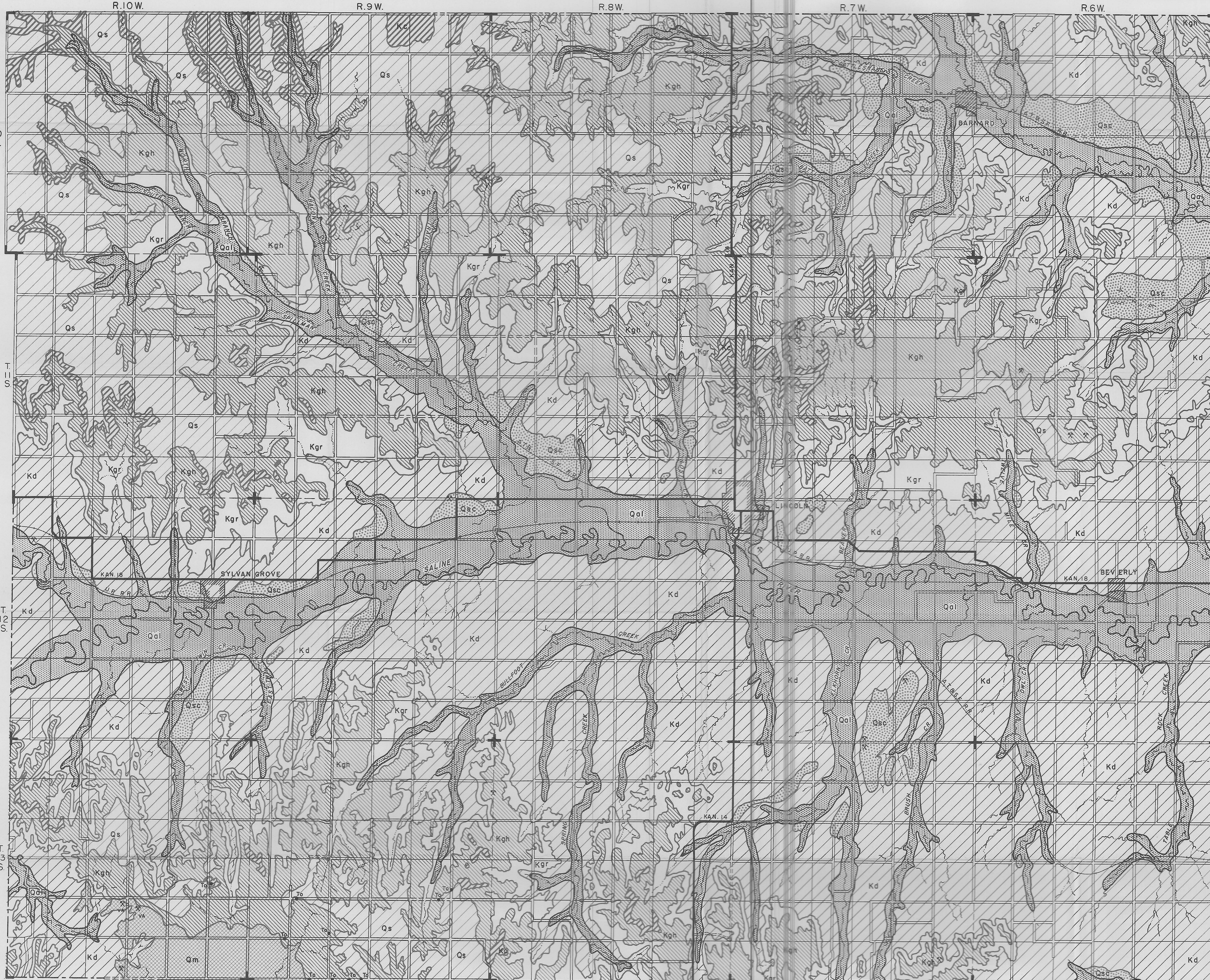
☐
24-3081

AREAL GEOLOGY OF LINCOLN COUNTY, KANSAS

State Geological Survey of Kansas

by Delmar W. Berry
1949

Bulletin 95
Plate 1



EXPLANATION

QUATERNARY

PLEISTOCENE

Qal — Alluvium
Sand, gravel, clay, and silt, comprising stream deposits in the major and tributary valleys. Yields water for domestic and stock supplies. Quantities are limited.

Qs — Sanborn formation
Loess, sand, and, locally, colluvium at the base; tan to gray-buff. Yields little or no water to wells in this area.

Qsc — Crete member of Sanborn formation
Sand, gravel, clay, and silt, locally derived; uppermost stream deposits of the area. Generally lies above the water table. Yields water for domestic and stock uses in small areas.

Qm — Meade formation
Gravel, sand, silt, clay, volcanic ash, and caliche; gray, tan, and buff. Yields meager supplies of water to wells in this area.

TERTIARY

PLIOCENE

•To — Ogallala formation
"Algal limestone", pink, gray, and tan. Fresh-water limestone and caliche. Yields no water to wells in this area.

CRETACEOUS

GULFIAN

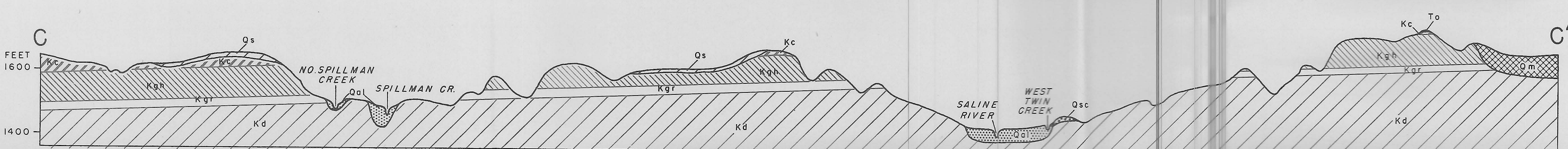
Kc — Carlile shale
Fairport chalky shale member
Shale, chalky to black, fissile; contains some limestone interbedded. Yields no water to wells in this area.

Kgh — Greenhorn limestone
Shale and limestone interbedded. Shale is calcareous, tan to blue-gray; limestone is thin-bedded, fossiliferous, gray. Weathered limestone yields some potable water to shallow wells in the uplands.

Kgr — Graneros shale
Noncalcareous shale, blue-gray; locally contains clay, siltstone, and sandstone. Contains selenite and pyrite. Yields little or no water to wells in this area.

Kd — Dakota formation
Varicolored clay, shale, siltstone, and fine- to coarse-grained sandstone occurring in alternating beds and lenses; contains thin beds of ironstone and lignite. Sandstones of the Dakota formation are the chief source of ground water in the upland areas of Lincoln County and supply water to many domestic and stock wells and to the city supply wells of Lincoln and Sylvan Grove. Yields range from a few gallons to a few hundred gallons a minute. Some wells yield water of good quality, but others yield water too highly mineralized for ordinary uses.

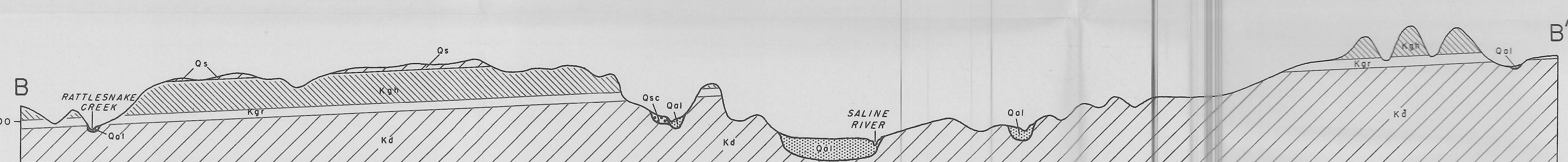
Federal or State Highway
Graded road
Ungraded road
Section line (no road)
Township line (no road)
County line (no road)
Railroad
Perennial stream
Intermittent stream
Gravel pit or stone quarry
Meade volcanic ash location
Quarry in Meade volcanic ash

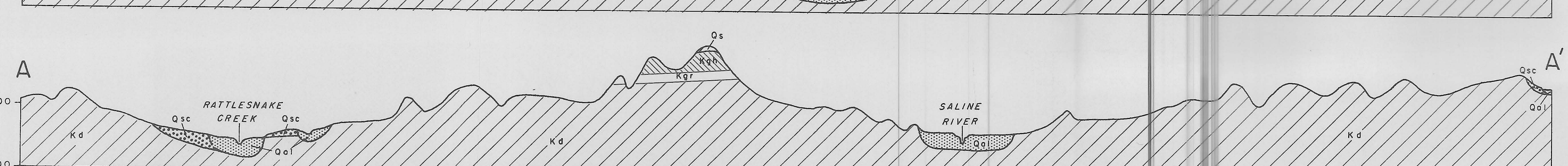


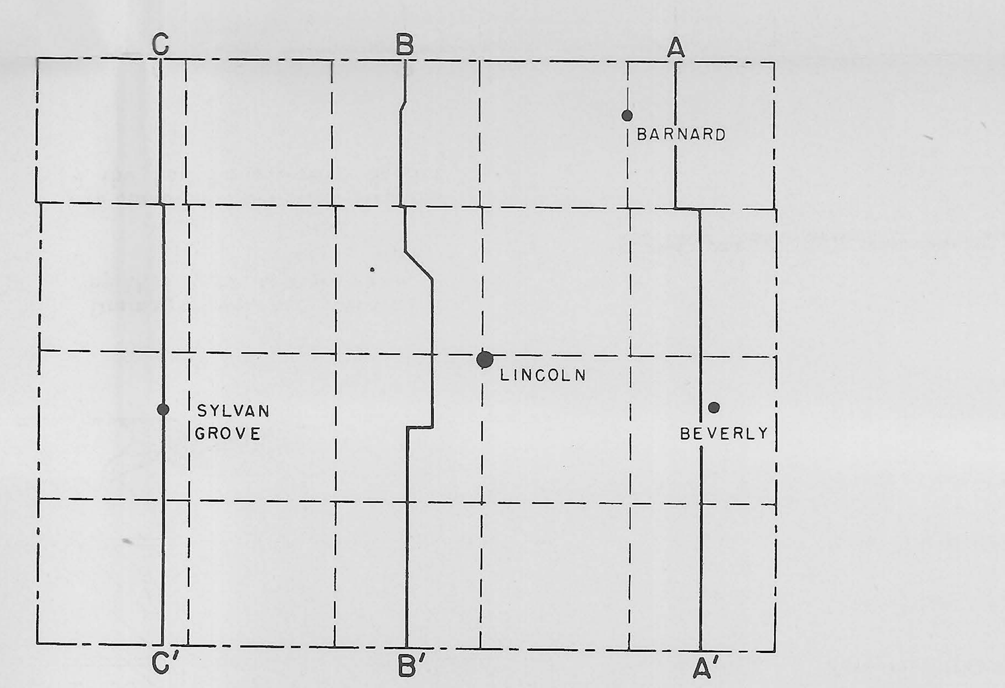
Drainage from map prepared by U. S. Dept. of Agriculture

Base compiled from maps prepared by the Soil Conservation Service

0 1 2 3 4
SCALE IN MILES







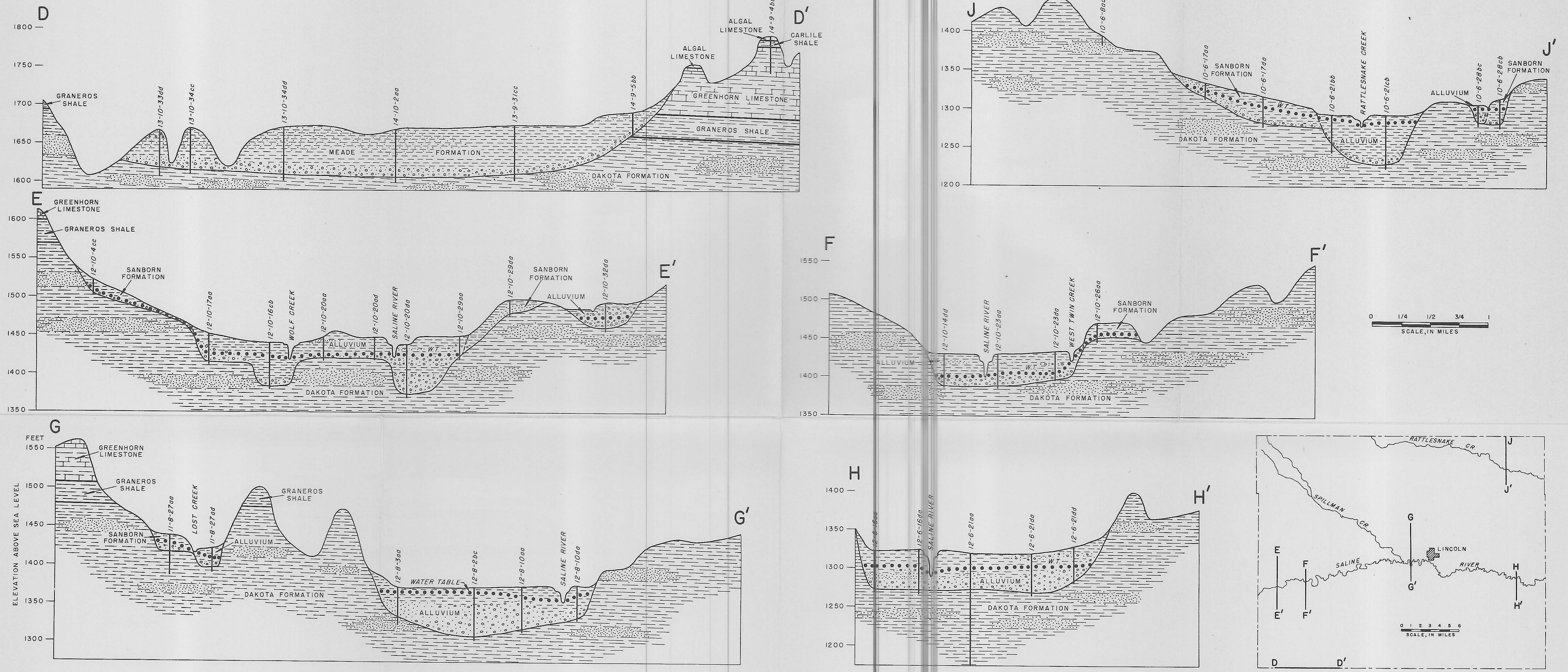
GEOLOGIC CROSS SECTIONS IN LINCOLN COUNTY, KANSAS

by Delmar W. Berry

1949

State Geological Survey of Kansas

Bulletin 95, Plate 3



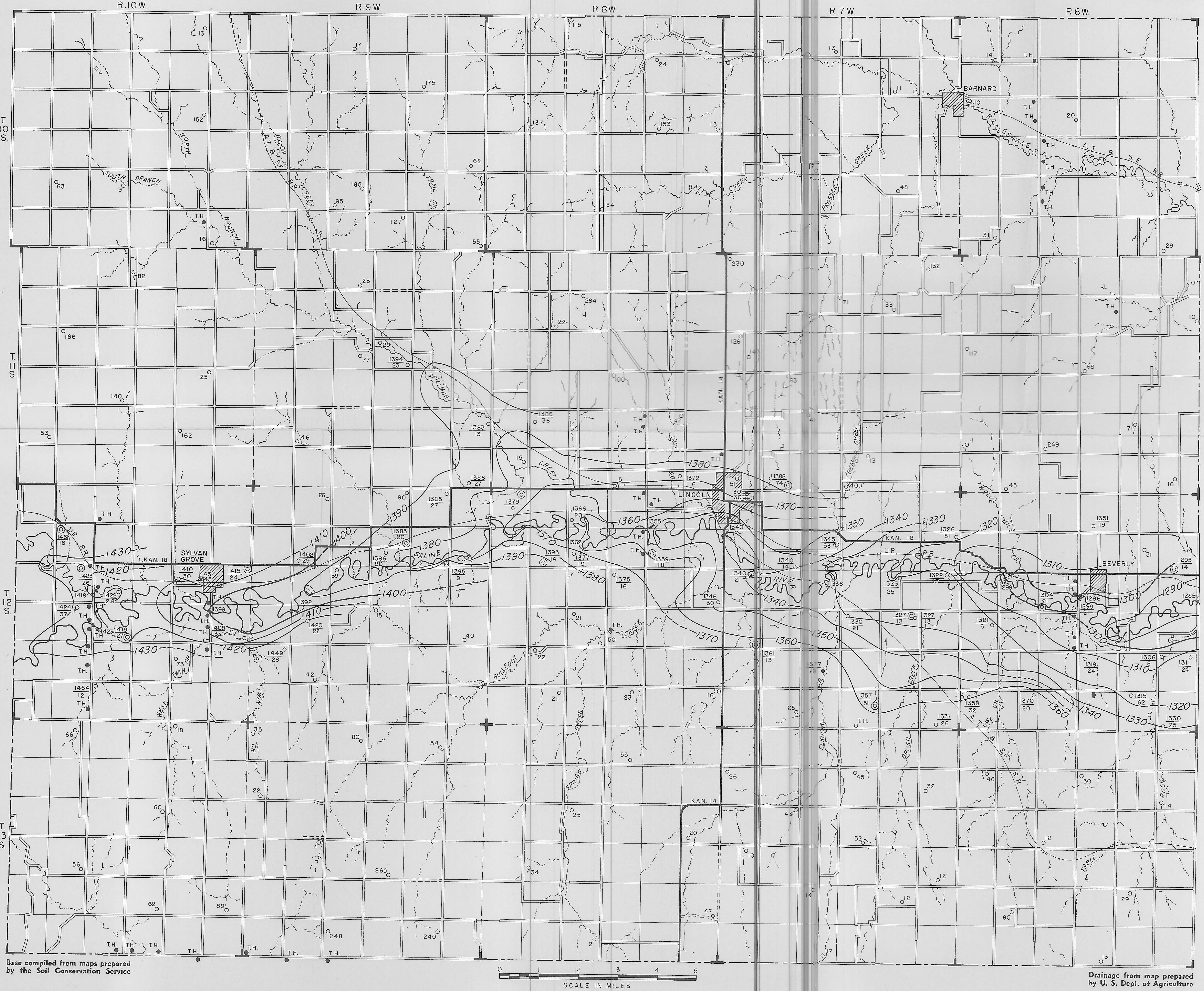
MAP OF LINCOLN COUNTY, KANSAS

Showing the Location of Wells and Test Holes; and Water-Table Contours in the Saline River Valley

State Geological Survey of Kansas

by Delmar W. Berry
1949

Bulletin 95
Plate 2



EXPLANATION

- Domestic and stock wells
- Public supply well
- Flowing well
- Observation well
- Test hole (T.H.)
- Federal or State Highway
- Graded road
- Ungraded road
- Section line (no road)
- Township line (no road)
- County line (no road)
- Railroad
- Perennial stream
- Intermittent stream

1345 / 33

Upper number is the altitude of the water table; lower number is the depth to water level below land surface, in feet. If only one number is given it indicates the depth to water level.

—1380—

Generalized contour of the water table where it occurs in Quaternary deposits.

1362

Altitude of water level in flowing stream.

Contour interval 10 feet