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GEOLOGY AND GROUND-WATER RESOURCES OF NORTON COUNTY AND NORTHWESTERN PHILLIPS COUNTY, KANSAS

By JOHN C. FRYE AND A. R. LEONARD

Prepared by the State Geological Survey of Kansas and the United States Geological Survey, with the coöperation of the Division of Sanitation of the Kansas State Board of Health, the Division of Water Resources of the Kansas State Board of Agriculture, and the Bureau of Reclamation of the United States Department of the Interior.

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CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY AND GROUND-WATER RESOURCES OF NORTON COUNTY AND NORTH-WESTERN PHILLIPS COUNTY, KANSAS

By John C. Frye and A. R. Leonard

ABSTRACT

This report describes the geography, geology, and ground-water resources of Norton County and northwestern Phillips County in north-central Kansas. The hydrologic and geologic information was obtained in the field during the years 1945-48 inclusive. Records for 241 wells in Norton County and 44 wells in northwestern Phillips County were collected, and 64 test holes were drilled to determine the thickness and character of the water-bearing materials. These data were utilized to plot a water-table map of the area. The outcropping rock formations were studied in the field and by aid of test-hole samples, and a geologic map and cross sections were prepared.

The area covered by this report lies in the Plains Border section of the Great Plains physiographic province. It is drained by North Fork Solomon River, a tributary to Smoky Hill River, and Sappa and Prairie Dog Creeks, tributaries to Republican River. For the most part the topography is moderately fine-textured and maturely dissected, with extensive flat areas occurring along the terraces of the major valleys, and at a few places on the upland divides. The climate is subhumid, the average annual precipitation being a little more than 20 inches. In addition to a generally deep fertile soil and the ground-water supplies, the principal mineral resources of the area are oil and gas, volcanic ash, stone, and ceramic raw materials.

The oldest outcropping rock unit is the Smoky Hill chalk member of the Niobrara formation (Cretaceous), which underlies the entire area. Pierre shale (Cretaceous) overlies the Niobrara formation in northwestern Phillips County, where it has been protected from erosion by a structural downwarp. The Ogallala formation (Pliocene) overlies the Cretaceous rocks and, except along the major valleys, underlies nearly the entire area. The Ogallala formation constitutes the most widespread source of adequate well-water supplies in the area. The Sanborn formation (Pleistocene) overlies the Ogallala formation and constitutes the near-surface deposits of most of the area. The basal (Crete) member of the Sanborn occurs adjacent to major valleys and in restricted areas is an adequate source of potable ground water. The deposits underlying the prominent terrace surfaces in the three major valleys yield abundant supplies of water to wells, and alluvium is a source of ground water in many tributary valleys.

North Fork Solomon River and Sappa and Prairie Dog Creeks are permanent streams in this area; nevertheless, wells supply nearly all the water for domestic, irrigation, and municipal uses. Four cities in Norton County (Almena, Clayton, Lenora, and Norton) and one in northwestern Phillips County

(Long Island) obtain their water supplies from the terrace deposits and alluvium of the major valleys. Adequate supplies of ground water are available for additional irrigation wells at many places in the terrace deposits of the major valleys, at some places in the Crete sand and gravel member of the Sanborn formation along the north side of Prairie Dog Creek, and at a few places in the Ogallala formation under the Prairie Dog-Sappa Creek divide area in western Norton County. Most other places in the area do not have adequate ground-water supplies for extensive well-water irrigation.

Analyses of 45 samples of ground water are included in this report, together with a discussion of the principal chemical constituents in relation to the use and geologic occurrence of the water. Most of the ground water in the area is satisfactory for ordinary purposes, but some is sufficiently hard to require softening for special uses.

INTRODUCTION

Purpose and Scope of the Investigation

A program of investigation of the ground-water resources of Kansas was initiated in 1937 by the State Geological Survey at the University of Kansas and the United States Geological Survey, in coöperation with the Division of Sanitation of the Kansas State Board of Health and the Division of Water Resources of the Kansas State Board of Agriculture. It is the purpose of this program to make detailed surveys of county areas and major stream valleys or irrigation districts where ground-water supply problems are acute. The present status of investigations resulting from this program is shown in Figure 1.

As a part of these investigations, a study of the geology and ground-water resources of Norton County was initiated during the summer of 1945. Test drilling to determine the character and thickness of the water-bearing formations and the measurement of water levels in many existing private wells were carried out during 1946. In 1947 the Federal Geological Survey undertook, at the request of the United States Bureau of Reclamation, a detailed investigation of the ground-water supplies in the Prairie Dog Creek Valley of eastern Norton County and northwestern Phillips County. This area comprises the Bureau of Reclamation's Almena project area. As this investigation overlapped a part of Norton County, the two studies are combined in this report.

In Norton County and adjacent northwestern Phillips County, as in much of the western half of Kansas, ground water constitutes one of the most important mineral resources. Although this area is crossed by three perennial streams—the North Fork of Solomon

River, Prairie Dog Creek, and Sappa Creek—nearly all public, railroad, irrigation, and domestic water supplies are obtained from wells. There is therefore, a definite need for an adequate understanding of the quantity and quality of the available supply, where and how additional supplies can be obtained, and what measures may be necessary to safeguard their continuance.

This investigation was made under the general supervision of A. N. Sayre, Geologist in Charge of the Ground-Water Branch of the Federal Geological Survey. That part of the investigation relating to the Almena area was also under the general supervision of George H. Taylor, Regional Engineer, Ground-Water Branch.

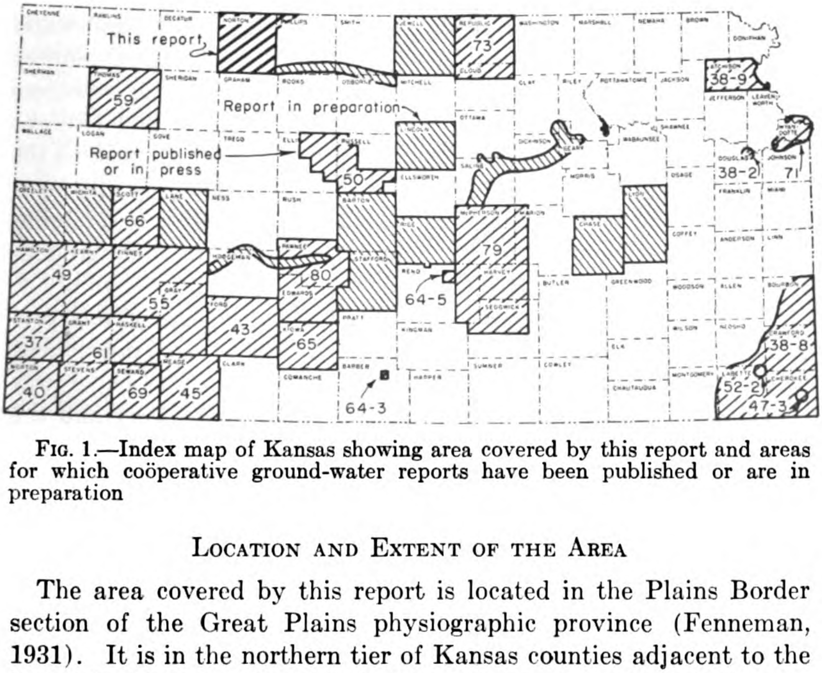

Fig. 1.—Index map of Kansas showing area covered by this report and areas for which coöperative ground-water reports have been published or are in preparation

Location and Extent of the Area

The area covered by this report is located in the Plains Border section of the Great Plains physiographic province (Fenneman, 1931). It is in the northern tier of Kansas counties adjacent to the Nebraska State line, and is bounded on the west by Decatur County, on the south by Graham County, and on the east by adjacent parts of Phillips County. Most of the area lies between 39° 28′ and 40° 00′ north latitude and 99° 21′ and 100° 12′ west longitude. It contains more than 27 townships, from T. 1 S. to T. 5 S., and from R. 18 W. to R. 25 W. It has an area of approximately 1,000 square miles.

Previous Investigations

In the northwestern part of Kansas only Thomas County has been covered by a coöperative county ground-water report (Frye, 1945) published as Bulletin 59 of the State Geological Survey. A comparable report has been published on Scott County, which lies in the fourth tier of counties south from the Nebraska line (Waite, 1947), and a specialized report on the occurrence of ground water in the oil-field areas of Ellis and Russell Counties, which lie to the southeast of Norton County (Frye and Brazil, 1943). A reconnaissance of ground-water resources in Rawlins and Decatur Counties was published as Mineral Resources Circular 7 of the State Geological Survey (Elias, 1937), and a detailed report on the geology of Wallace County, which contains some data on ground-water supplies, was published as Bulletin 18 of the Geological Survey (Elias, 1931). Field investigations of the ground-water resources in the North Solomon Valley across Phillips, Smith, and Osborne Counties have been completed by A. R. Leonard, and a report on the geology and ground-water resources of Jewell County is in preparation. In addition, several regional studies (Haworth, 1897; Johnson, 1901; Darton, 1905) touch upon the geology and underground-water supplies of this area.

The earliest report on the geology of Norton County was prepared by Robert Hay and was published in 1885 in the Transactions of the Kansas Academy of Science (pp. 16-24). The paper was read before the Academy at its Topeka meeting in 1883 and the clarity with which Hay presented the essential features of the geology of Norton County is striking for such an early date. It should be noted that the deposits referred by him to the Miocene are here classed as Pliocene and referred to the Ogallala formation, and the deposits he classed as Pliocene are here classed as the Pleistocene and referred to the Sanborn formation.

Methods of Investigation

The geology of the area was studied and mapped (Pl. 1) during two months of field work in 1945, three weeks each in 1946 and 1947, and a week during the spring of 1948. A partial inventory of existing water wells was made in Norton County during 1946 by John Sears and Milton Sears. Delmar Berry measured the water level in additional wells in the Prairie Dog Valley area of Norton and Phillips Counties during 1947 and has made measurements of observation wells since that time.

The character of the material below the land surface was determined by the drilling of 64 test holes through the entire thickness of water-bearing sand and gravel and into the underlying Cretaceous shales and chalks. These test holes were drilled with the hydraulic rotary drilling machine owned by the State Geological Survey of Kansas and operated by James Cooper and William T. Connor during the season of 1946 and by Connor and Glenn Prescott during the season of 1947. Logs of the test holes were prepared in the field by Cooper and Prescott; these were later supplemented by microscopic examination of the well cuttings. By using a plane table and alidade, level parties headed by Charles K. Bayne and Delmar Berry determined the altitude of the measuring point of wells in which water levels were measured and the altitude of the surface at the test-hole locations.

Wells shown on Plate 2 were located within the sections by use of the odometer. The two figures shown adjacent to well locations on Plate 2 refer to the altitude of the water table and the depth to water below the land surface, the figure above the line being altitude and that below the depth to water. Brackets placed around the bottom figures indicate that a chemical analysis of water from the well is given in the report (Tables 5 and 6).

Samples of water from 45 wells in the county were collected and chemical analyses of them were made by Howard Stoltenberg, chemist in the Water and Sewage laboratory of the Kansas State Board of Health, or by chemists of the Quality of Water Branch of the Federal Geological Survey at Lincoln, Nebraska.

The base map of the county used in Plates 1 and 2 was compiled by Bernita Mansfield and Grace Muilenburg from aerial photographs and county maps of the Soil Conservation Service, and aerial photographs from the Agricultural Adjustment Administration, United States Department of Agriculture, and from county maps prepared by the State Highway Commission of Kansas. Geologic mapping in the field was done on a base map at a scale of one inch to the mile. This field mapping was supplemented by stereoscopic study of aerial photographs along all the major valley areas.

Well-Numbering System

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

If two or more wells are located within a 40-acre tract, the wells are numbered serially according to the order in which they were inventoried. The 160-acre and 40-acre tracts are designated a, b, c, or d in a counter-clockwise direction beginning in the northeast quarter. For example, well 2-24-5da (Fig. 2) is located in the NE¼ SE¼ sec. 5, T. 2 S., R. 24W.

Acknowledgments

Appreciation is expressed to the many residents of Norton County and northwestern Phillips County who supplied information and aided in the collection of field data. Special thanks are extended to the owners of several irrigation wells, who furnished us with information concerning their well-pumping plants; to the city officials of Long Island, Almena, Norton, Lenora, and Clayton for data on municipal water supplies; and to the several water-well drillers operating in the area, who have furnished logs and other pertinent data concerning the installation of water wells. M. K. Elias of the Nebraska Geological Survey spent several days in the field and kindly identified the fossil seeds collected from the Ogallala formation. A. Byron Leonard identified the fossil snails from the Pleistocene deposits of the area, and C. W. Hibbard identified several fragmentary fossil vertebrates.

Frank Byrne and assistants in the section of Engineering Geology, U. S. Geological Survey, spent several days in the field with us and furnished a copy of their geologic map of Phillips County.

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

GEOGRAPHY

Topography and Drainage

Norton and Phillips Counties lie entirely within the area designated by Fenneman (1931) as the Plains Border section of the Great Plains physiographic province. The area consists predominantly of moderately fine textured topography having a local relief of 200 feet or less. Flat upland divide areas are present in western Norton County between North Fork Solomon Valley and Prairie Dog Valley and across central Norton County between Prairie Dog Valley and Sappa Valley. The most extensive areas of flat land occur on the prominent terrace surfaces which are well developed along each of the three major valleys.

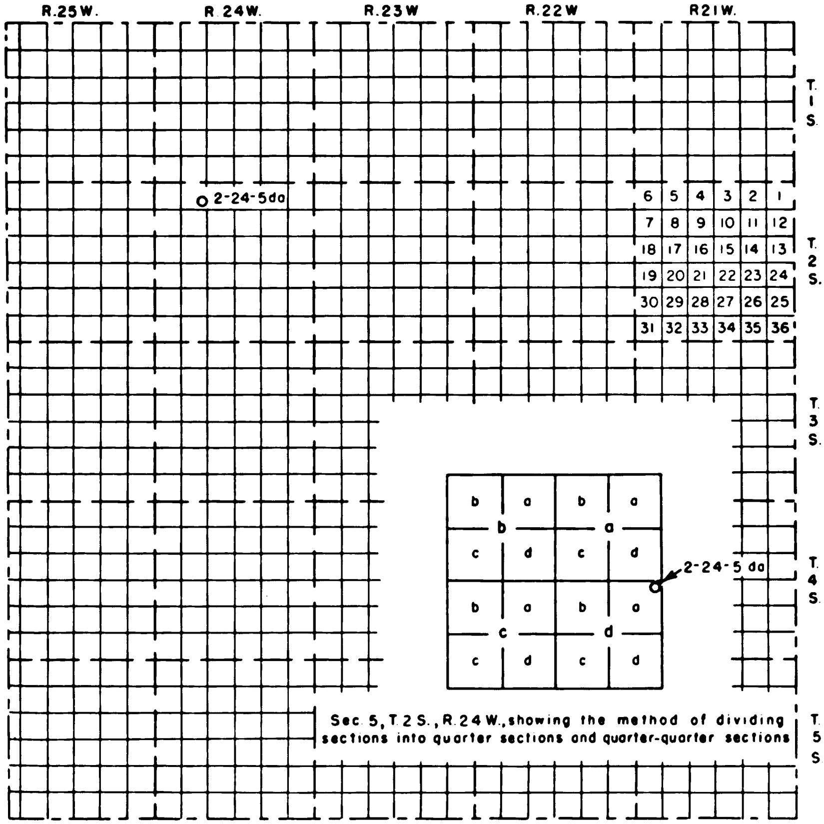

FIG. 2.—Map of Norton County illustrating the well-numbering system used in this report.

On the whole, the area is well drained and sloping ground predominates. The lowest points in the area occur along the Norton-Phillips county line on the flood plain of the North Fork Solomon River, and on the flood plain of Prairie Dog Creek where it crosses into Nebraska in north-central Phillips County. At these localities surface altitudes range from 2,000 to 2,020 feet. The highest points in the area are on the major stream divides along the Norton-Decatur county line, where the surface altitude exceeds 2,550 feet.

The Plains Border section grades westward imperceptibly into the High Plains section and in many respects the topography of the Norton-Phillips County area is more comparable to the High Plains topography farther west than it is to the eastern part of the Plains Border section typically displayed in Jewell, Smith, Mitchell, and Osborne Counties.

One of the most striking topographic features of this part of Kansas is the pronounced asymmetry of the major eastward-trending valleys. In this area, the valleys of both Prairie Dog Creek and North Fork Solomon River have gently sloping north walls and precipitous south walls. In Norton County the asymmetry of the valleys is so well developed that the drainage basin is also asymmetrical. The north-flowing tributaries are shorter and more numerous, and have steeper gradients than those flowing southward (Pl. 1). This particular characteristic seems to be peculiar to valleys in Kansas and it has been noted elsewhere in the state (Frye, 1945, p. 29; Bass, 1926, pp. 17-23). This feature is illustrated on the two north-south geologic cross sections shown in Plate 3.

Prairie Dog Creek and Sappa Creek, which constitute the major drainageways for central and northern Norton County, flow in a general east-northeasterly direction and join Republican River in southern Nebraska. North Fork Solomon River, however, flows in an easterly direction across Norton and western Phillips Counties but trends in a general southeasterly direction from south-central Phillips County to its confluence with Smoky Hill River at the Saline-Dickinson County line. All three of these major streams head on the surface of the High Plains in Thomas and Sherman Counties, Kansas.

Although North Fork Solomon River flows in a slightly different direction from Prairie Dog and Sappa Creeks, the principal tributaries to the three streams exhibit a remarkable parallelism (Pl. 1). Most of the tributaries to the major streams flow either in a south-southeast or north-northwest direction. This alignment causes the north-flowing tributaries to Solomon River and the south-flowing tributaries to Prairie Dog Creek to join the main streams with an acute angle downstream and gives them a somewhat barbed appearance. Another feature that is particularly striking is the difference in texture of the drainage on opposite sides of Prairie Dog Creek. On the south side, where a thin mantle of silt overlies the Ogallala formation, tributary streams are short and closely spaced. This part of the area is well dissected and is used primarily for rangeland. On the north side of Prairie Dog Creek a considerable thickness of silt underlain by the Crete sand and gravel occurs and the drainage pattern is coarse-textured. Slopes are gentle and much of the area is cultivated.

In spite of the well-developed drainage net in Norton and northwestern Phillips Counties the area is not well supplied with surface water. The three major streams are the only perennial streams in the territory, the others carrying water only during and after rains.

Climate

Norton County lies in a region only moderately supplied with rainfall but well supplied with sunshine. The climate is of subhumid type, involving moderate precipitation, moderately high average wind velocity, and rapid evaporation. During the summer the days are hot, but the nights are generally cool. The summer heat is alleviated by good wind movement and low relative humidity. As a rule the winters are moderate, with severe, cold periods of short duration and relatively light snowfall.

According to data presented by the United States Weather Bureau, the normal annual mean temperature for central Norton County is 52.8° F. In general, the hottest month is July, with a normal mean temperature of 78.5° F., and the coldest month is January, with a normal mean of 27.5° F. The average growing season—that is, the interval between the last killing frost in the spring and the first killing frost in the fall—is approximately 160 days. The normal annual precipitation in central Norton County is 20.81 inches and the normal annual precipitation at Long Island in northwestern Phillips County is 21.41 inches. The range in amount of annual precipitation since 1888 in central Norton County is 29.15 inches—from 9.64 inches in 1910 to 38.79 inches in 1891. The bulk of the precipitation occurs during the growing season, when the average precipitation for the 6-month period in this part of Kansas is approximately the same as that in the Dakotas and three-fourths of the average for Illinois, Indiana, and Ohio.

The annual precipitation for the period of record for the station in central Norton County is shown in Figure 3. Charts showing monthly precipitation for the period 1945 through 1947 and the relationship to normal for each month at Norton and at Long Island are presented in Figures 6 and 7.

Population

According to the 1940 Federal census, the population of Norton County was 9,831, and for 1945 the Kansas State Board of Agriculture reports a population of 8,578. Since the census of 1890 the population of Norton County has shown an increase followed by a decline. In 1890 the population of the county was 10,617. By 1900 it had reached 11,325, and in 1910 it had climbed to 11,614. The 1920 census showed a slight decline to 11,423, but the 1930 census showed the maximum of 11,701. The decrease in population be-

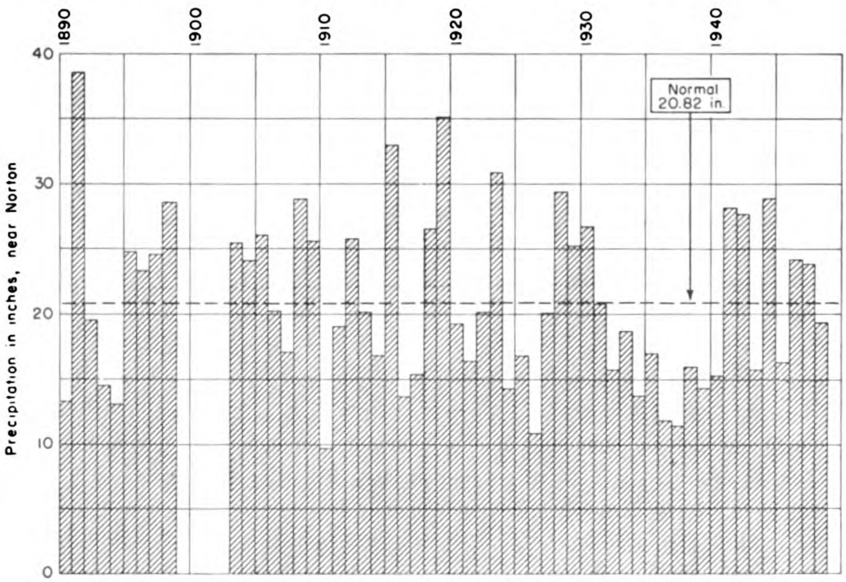

Fig. 3.—Graph showing annual precipitation near Norton for the period of record and normal precipitation at the station. (Records from the U. S. Weather Bureau.)

tween 1930 and 1940 was 16 percent for the county as a whole, but the rural population declined 22 percent. The 1940 Federal census lists population figures for five cities in Norton County. At that time Almena had a population of 543; Clayton, 153; Edmond, 180; Lenora, 537; and Norton, 2,762. Long Island is the only city in the part of Phillips County covered by this report listed in the 1940 census; at that time it had a population of 257. The 1945 Kansas State Board of Agriculture census lists the following population figures for the same cities: Almena, 526; Clayton, 124; Edmond, 119; Lenora, 492; Norton, 2,635; and Long Island, 212.

Transportation

Norton County is crossed by the main line of the Chicago, Rock Island, and Pacific Railroad from Omaha, Neb., to Denver, Colo., which traverses the county east-west along the Prairie Dog Valley, passing through Almena, Norton, and Clayton. A branch line of the Chicago, Burlington, and Quincy from Alma, Neb., to Oberlin, Kan., also traverses the county east-west, along the Prairie Dog Creek Valley through Long Island, Almena, and Norton, and thence northwestward to Norcatur in west-central Decatur County. A branch line of the Missouri Pacific Railroad extends up the North Fork Solomon Valley from Downs to its terminus at Lenora in southwestern Norton County.

Several hard-surfaced Federal and State highways pass through Norton County and northwestern Phillips County. U. S. Highway 36 passes east-west through Norton County through the City of Norton. U. S. Highway 283 traverses Norton County from north to south through the City of Norton, and U. S. Highway 383 traverses the county diagonally from southwest to northeast, extending from Norton northeast along Prairie Dog Valley through Calvert, Almena, Long Island, and Woodruff. State Highway 9 passes east-west through southern Norton County along North Fork Solomon River Valley through New Almelo, Lenora, Edmond, and Densmore. The remainder of the area is served by numerous improved county and township roads (Pl. 1).

Agriculture

Agriculture is the chief occupation in Norton County and northwestern Phillips County. Virtually all the land in this area is in farms. According to the Kansas State Board of Agriculture, 230,240 acres of major crops were harvested in Norton County in 1945. The distribution of major crops for the years 1941 and 1945 are shown in Table 1. Winter wheat, corn, sorghums, barley, and hay were the predominating crops and a sizable percentage of land was used for grazing purposes.

Mineral Resources

Norton County and northwestern Phillips County are endowed with a diversity of mineral raw materials. The more important mineral resources, aside from ground water, are oil and gas, volcanic ash, and construction materials.

Oil and gas.—The first commercial production of petroleum in Norton County was developed by the Phillips Petroleum Company in 1941 when they discovered the Hewitt pool in sec. 11, T. 4 S., R. 21 W. Since that time exploration for petroleum has been active, particularly in the southeastern part of Norton County. It has resulted in the extension of the Ray pool from Phillips County into the extreme southeastern corner of Norton County, and the discovery in 1945 of the Ray West pool in Norton County in sec. 26, T. 5 S., R. 21 W. At the end of 1946 (Ver Wiebe, 1947, p. 58) the

TABLE 1.—*Acreage of principal crops in Norton County in 1941 and 1945*

(Data from Kansas State Board of Agriculture biennial reports)

Crop	1941 Acres	1941 Percentage	1945 Acres	1945 Percentage
Winter wheat	74,800	31.8	95,000	41.3
Corn	70,460	30.0	81,800	35.5
Oats	3,260	1.4	3,050	1.3
Barley	32,880	14.0	6,500	2.8
Sorghum				
For grain	16,560	7.1	13,850	6.0
For forage	32,100	13.7	22,110	9.6
All hay	4,610	2.0	7,930	3.4
Total	234,670		230,240	

cumulative production of the Hewitt pool was 32,050 barrels and that of the Ray West pool was 23,180 barrels. Production is from the Kansas City-Lansing limestone and the Arbuckle dolomite, respectively. Data concerning oil and gas developments and production in the county are listed in the annual reports of the State Geological Survey published as Bulletin 42, covering 1941, and Bulletins 48, 54, 56, 62, 68, and 75 for the succeeding years. All producing oil wells, abandoned oil wells, and dry wildcat test holes drilled to the end of 1947 are shown on Plate 1.

Volcanic ash.—Volcanic ash is another important mineral resource of Norton County. Active mining of volcanic ash was started in the vicinity of Calvert in 1908 and since that time one or more ash mines have been in almost continuous operation. At the present time one large mine is operated at Calvert by the Wyandotte Chemical Co. of Wyandotte, Mich. (Pl. 7A). The ash is mined by the open-cut method, rough-screened in the pit, and hauled by truck less than a quarter of a mile to a screening and storage plant along the rail siding at Calvert. Volcanic ash deposits occur at scattered points throughout the county, and have been mined in several other places. In addition, deposits of commercial thickness were observed at localities where no mining has been undertaken. The location of existing ash mines and unmined deposits of volcanic ash of commercial thickness are shown by symbols on Plate 1. Data on the occurrence and commercial usefulness of volcanic ash are given by Landes (1928) and Jewett and Schoewe (1942). The results of a petrographic and chemical study of the various ash deposits of western Kansas with special emphasis on the Norton County area are given by Swineford and Frye (1946).

Construction materials.—Several varieties of durable stone uncommon in central and western Kansas occur abundantly in Norton County and northwestern Phillips County (Byrne and others, 1948; 1949.)

The silicified sand and gravel zones or "quartzite" that occur in the Ogallala formation represent, perhaps, the most unusual rock type of the region. This "quartzite" was produced by the cementation of sand and gravel by opaline silica into a very hard and durable rock. It occurs in lenticular deposits and crops out at several localities in southeastern Norton County and northwestern Phillips County. Frye and Swineford (1946) made a detailed petrographic study of this rock and evaluated its usefulness for various purposes. In their conclusions they state (pp. 62-64):

> The data presented in this report, supplemented by meager information from local users, indicate that the Ogallala quartzite is far superior to any other deposit in the northwestern part of Kansas and in most cases will probably be suitable for railroad ballast and riprap, and possibly also for a local source of road metal. The unusual coloration and mottled appearance of some deposits should make them desirable for monuments and ornamental stone, and, if economical methods of quarrying and finishing are developed, the quartzite may be useful as a durable building stone. The rock is harder than many others used for such purposes; it is closely comparable in resistance and weathering properties to a good grade of granite. Although it has been reported that Ogallala quartzite has been used locally with success as concrete aggregate, it contains a large amount of opal and caution should be exercised when it is used in concrete or terrazzo, particularly if it is used in conjunction with high-alkali cement, until its suitability for such purposes has been more thoroughly investigated.

Additional data on the occurrence of silicified rocks of the Ogallala formation in Phillips County have been presented by Landes and Keroher (1942, pp. 305-308), and the location of all active and abandoned quarries in the area covered by this report is shown by symbols on Plate 1. The rock has been utilized in the construction of several buildings in Norton and other communities.

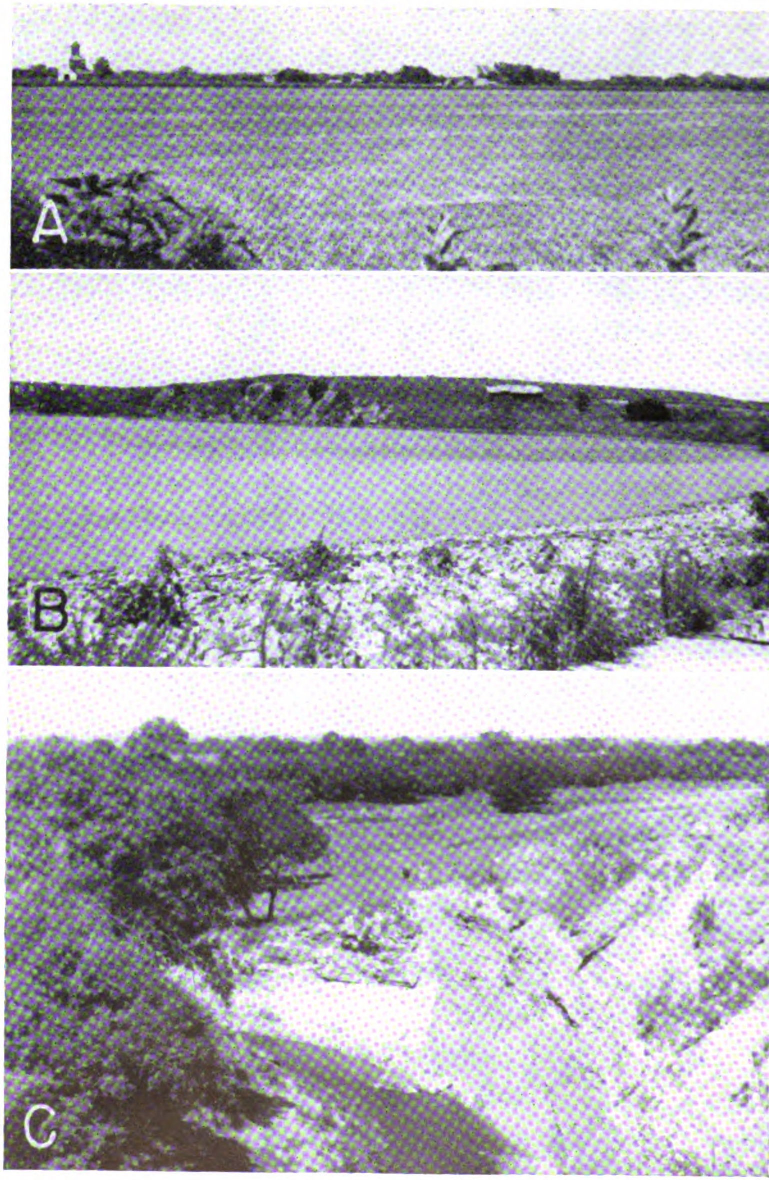

PLATE 4. *A,* Surface of prominent terrace in Prairie Dog Creek Valley at Woodruff, Phillips County. *B,* Lake Lenora, east of Lenora, southwestern Norton County. Bluff of Niobrara chalk exposed on distant side of lake and riprap of Niobrara chalk on back of dam. *C,* Prairie Dog Creek Valley, Phillips County. A fault, Niobrara chalk against Pierre shale, is exposed in the east bank of Prairie Dog Creek.

Still another rock type of commercial usefulness occurs within the Ogallala formation of Norton County. This is a soft light-gray to white limestone produced by calcium carbonate cement, which binds tightly together a sandy silt. The rock as quarried is predominantly calcium carbonate, and in some zones contains abundant molds of fossil snails. The limestone has been quarried east of Almena and south of New Almelo, where it is used as crushed rock and as building stone. A church and adjacent buildings at New Almelo are constructed from this rock. At some localities the bed that has been quarried is more than 10 feet thick, but at other places it is only 2 or 3 feet thick. Soft limestone is known to occur at several stratigraphic positions within the Ash Hollow member of the Ogallala formation. Active and abandoned quarries of limestone of the Ogallala formation are shown by the quarry symbol on Plate 1.

Although deposits of clean sand and gravel are not as abundant in this area as they are at some places in western Kansas, they have been quarried near Lenora and at several other places throughout the two counties. Sand and gravel mixed with silt is common at many stratigraphic positions within the Ogallala formation, and underlies much of the prominent terrace area along North Fork Solomon River, Prairie Dog Creek, and Sappa Creek. Also, the alluvium under the channel and flood plains of these streams consists partly of sand and gravel deposits.

Soft chalks and chalky shales of the Niobrara formation underlie all of Norton County and northwestern Phillips County. They crop out at the surface at many places along the major valleys. For the most part these chalky shales are too soft to be used for construction, but might be utilized as a source of impure calcium carbonate for some purposes. At a few localities the upper part of this chalky shale has been altered by the addition of silica and a hard flinty rock has resulted. This silicified chalk breaks very much like bottle glass when struck with a hammer, and it has been used to some extent as road material and riprap (Pl. 4B). Its occurrence in Phillips County has been described by Landes and Keroher (1942, pp. 305-308) and active and abandoned quarries in Norton County are shown by a symbol on Plate 1 of this report.

Ceramic materials.—Clay of a type usable for certain ceramic products occurs widely in Norton and northwestern Phillips Counties. Deposits of bentonitic clay are known in the basal part of the Ogallala formation in northwestern Phillips County. Data concerning the usefulness of the bentonitic clays have been presented by Kinney (1942). The ceramic character of the widespread loess mantle of the region is described briefly by Norman Plummer in paragraphs immediately below.

Detailed ceramic tests have been made on samples collected from the several members of the Sanborn formation exposed in cuts north of the City of Norton. Data obtained from these tests are presented in Table 2. The firing range was determined to be relatively short (over a range of 5 cones, or approximately 150° F.) but sufficiently great to allow commercial usefulness. Although significant differ-

TABLE 2.—*Ceramic properties of the Sanborn formation, 1 mile north of Norton, central Norton County* (Data furnished by Norman Plummer)

			1	2	3		4
Plastic properties	Water of plasticity, percent.....	..	20.3	23.3	21.7	..	25.6
	Linear drying shrinkage, percent,	..	3.5	4.5	2.1	..	6.1
		At cone				At cone	
Fired properties	Fired color[5]	02	O	O	Lr	01	Lr
		4	Dr	Dr	Dr	3	Dr
	Linear firing shrinkage..........	02	.1	1.3	.4	01	4.8
		4	8.9	9.3	10.7	3	9.5
	Total linear shrinkage..........	02	3.6	5.7	2.5	01	11.0
		4	12.4	13.8	12.9	3	15.6
	Absorption (5 hours in boiling water)	02	20.0	18.0	23.7	01	12.1
		4	1.8	2.1	2.0	3	3.0
	Absorption (24 hours in cold water)	02	16.3	15.5	19.9	01	....
		4	1.2	1.3	1.1	3	....
	Saturation coefficient	02	.81	.86	.84	..	....
		4	.64	.64	.58	..	....
	Apparent porosity	02	34.3	32.0	38.1	01	23.8
		4	4.1	4.8	4.6	3	6.8
	Apparent specific gravity........	02	2.62	2.61	2.60	01	2.57
		4	2.35	2.40	2.38	3	2.45
	Bulk specific gravity............	02	1.72	1.78	1.61	01	1.96
		4	2.25	2.29	2.27	3	2.28
	Hardness, as to steel[6]...........	02	S	S	S	01	Sh
		4	H	H	H	3	H
	Firing range (cones)............	..	02-3	01-3	01-3	..	02-3
	Pyrometric cone equivalent (cone)	..	8	8	6-7	..	10

1. Composite of 4 feet of Bignell silt member.
2. Composite of 2 feet of Brady soil (top of Peoria silt member).
3. Composite of 12 feet of Peoria silt member.
4. Composite of 19 feet of Loveland silt member.
5. O, orange; Lr, light red; Dr, dark red.
6. S, softer than steel; H, harder than steel; Sh, steel hard.

ences among the several members of the Sanborn formation were determined, their characteristics were sufficiently comparable to permit ceramic utilization of the entire thickness of the Sanborn silts at this locality. These clays work well both by hand molding and by stiff mud extrusion, even though they are slightly lean. They are particularly adaptable to stiff mud extrusion. Also, the drying characteristics are good.

These data, given in Table 2, show that the silts of the Sanborn formation are suitable for the manufacture of red brick, hollow tile, and other structural clay products. Their usefulness for the manufacture of artificial aggregate and railroad ballast has been described by Plummer and Hladik (1948). The several silt members of the Sanborn formation present a uniform aspect and it is probable that throughout the area covered by this report their properties as a ceramic raw material are essentially the same.

GEOLOGY IN RELATION TO GROUND WATER

Geologic Setting

The area treated in this report lies in the heart of the Great Plains physiographic province. The Great Plains is a broad region extending several hundred miles eastward from the eastern margin of the Rocky Mountains and from Texas northward into Canada. The Great Plains are typified by relatively flat lying sedimentary rocks of Cretaceous age, or younger. Much of the surface area of the Plains region is mantled by nonmarine deposits of late Tertiary and Quaternary age. It is this mantle of nonresistant gently dipping to flat beds and the relatively low precipitation that typify the region throughout its entire extent. The local relief is moderate, and ranges from the almost flat and undissected High Plains surface to the moderately fine-textured topography illustrated in this area and the cuestas and low scarps that characterize part of the belt of the Cretaceous outcrop farther east.

In the latitude of Norton and Phillips Counties, the eastern margin of the Cretaceous outcrops extends to within a hundred miles of Missouri River, from where the Cretaceous formations extend westward under north-central and northwestern Kansas to reappear again in central Colorado where they are upturned sharply along the eastern flank of the Rocky Mountain Front Range.

Below the thick Cretaceous section, Paleozoic rocks rest on a basement complex of Pre-Cambrian crystalline rocks and exhibit a much more complex structural pattern, recording a history of repeated gentle folding and erosion. The intermittent deposition, folding, and erosion during Paleozoic time has produced conditions suitable for the accumulation of petroleum, as indicated by the numerous oil fields that extend from this area toward the south and east. The major structural feature in the Paleozoic rocks is a broad arch that extends from Phillips County toward the southeast and is generally referred to as the Central Kansas uplift (Moore and Jewett, 1942). The petroleum production of Norton County comes from wells drilled on the west flank of this broad regional structure.

Although the pre-Cretaceous rocks of north-central Kansas are of great importance to the production of oil and gas, they are not known to contain potable waters; therefore, for the purposes of this report the discussion of stratigraphy will be confined to Cretaceous and younger sediments.

Summary of Stratigraphy*

The age of the outcropping rocks of Norton County and northwestern Phillips County is late Cretaceous (Gulfian), Pliocene, Pleistocene, and Recent. The subdivisions and stratigraphic classification of these strata are shown in Table 3 and in the cross sections on Plate 3. The areal distribution of their outcrops is shown on the geologic map (Pl. 1).

The Niobara formation of Cretaceous age underlies the entire area and crops out at many places along the valleys of North Fork Solomon River, Prairie Dog Creek, and Sappa Creek. It consists predominantly of chalks and chalky shales. Locally in northwestern Phillips County it is overlain by the Pierre shale, which consists of black fissile shale with thin beds of bentonite. The Ogallala formation of Pliocene age underlies most of the area with the exception of the major valleys. Owing to its widespread occurrence and generally porous texture, it is of great importance as a source of ground water. A blanket of eolian silt, classed as the Sanborn formation and divided into the Loveland, Peoria, and Bignell silt members, covers much of the upland areas, and deposits of gravel, sand, and silt underlie the prominent terrace surfaces along the major valleys. Alluvium is present under the channels and flood plains of all the major streams and the lower reaches of all the im-

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

TABLE 3. *Generalized section of the geologic formations of Norton County and northwestern Phillips County, Kansas*

System	Series	Formation	Member	Thickness (feet)	Character	Water supply
Quaternary	Recent	Alluvium		15–40	Sand, gravel, silt, and clay, well sorted along major valleys; poorly sorted in tributary valleys.	Yields abundant supplies of water to wells in major valleys; small supplies in tributary valleys.
	Recent and Pleistocene	Deposits underlying prominent terrace surfaces in the valleys of Sappa Creek, Prairie Dog Creek, and North Fork Solomon River.		35–85	Gravel, sand, and silt, generally coarse and well sorted in lower part, and fine-textured in upper part. Several buried soils in upper part.	Yields abundant supplies of water to wells.
	Pleistocene	Sanborn formation	Bignell silt member	0–20	Massive, well-sorted silt, light yellow gray to light tan. Blankets the uplands in some places.	Above the water table; yields no water to wells.
			Peoria silt member	0–40	Massive, well-sorted silt, light yellow tan to ash gray. Brady soil at top. Underlies most uplands and gentle slopes.	Generally above water table; yields little or no water to wells.
			Loveland silt, and Crete sand and gravel members	0–60	Massive silt, reddish tan to tan. Thick Loveland soil at top. Locally sand and gravel (Crete member) at base.	Basal sand and gravel, where present, yields moderate to large supplies of water to wells.
		Meade(?) formation	Sappa and Grand Island members	20–30	Sand, gravel, and silt in lower part (Grand Island), grading into sandy silt and silt in upper part (Sappa). Crops out at only a few places in south-central Norton County, and northwestern Phillips County.	Where basal sand and gravel are below the water table, probably yields abundant supplies to wells at a few places only.

TABLE 3. *Generalized section of the geologic formations of Norton County and northwestern Phillips County, Kansas—Concluded*

System	Series	Formation	Member	Thickness (feet)	Character	Water supply
Tertiary	Pliocene	Ogallala formation	Kimball member	75 ?	Chert, sand, gravel, silt, in part cemented with calcium carbonate. Occurs at only a few places.	All known occurrences above the water table; yields no water to wells.
			Ash Hollow member	90–150	Silt, gravel, sand, partly cemented with $CaCO_3$, volcanic ash, and impure limestone; tan, reddish tan, and gray.	Yields moderate supplies of water to wells at many places.
			Valentine member	0–100	Sand, gravel, silt (partly cemented by $CaCO_3$), impure limestone, and opal-cemented lentils, gray, gray tan, and greenish gray.	Yields moderate to large supplies of water to wells at many places.
Cretaceous	Gulfian	Pierre shale	Sharon Springs shale member	100 ±	Black to coffee-colored fissile shale, a few beds of chalky shale, and bentonite in lower part.	Yields no water to wells.
		Niobrara formation	Smoky Hill chalk member	600 ±	Chalky shale and chalk, blue gray, gray and yellow tan. A few bentonite beds.	Yields small supplies of mineralized water to wells at some places.

portant tributaries. Remnants of stream deposits classed as the Meade formation occur along the north part of the North Fork Solomon River Valley in south-central Norton County and along the south side of Prairie Dog Creek Valley in northwestern Phillips County. Somewhat younger stream deposits classed as the Crete sand and gravel member of the Sanborn formation occur at a level above the prominent terrace on the north side of Prairie Dog Creek Valley and at some places in the Valleys of North Fork Solomon River and Sappa Creek.

Throughout this area the Carlile shale of Cretaceous age underlies the Niobrara formation. Oil wells drilled in the area have encountered a sequence of pre-Carlile Cretaceous sediments above the Paleozoic rocks comparable to the sequence exposed in the outcrop belt farther east in Kansas.

Cretaceous System (Gulfian Series)

FORMATIONS OF PRE-NIOBRARA AGE

At only a few places in the area covered by this report do wells obtain water from rocks occurring stratigraphically below the Niobrara formation. However, in southeastern Norton County, both north and south of Solomon River, a few wells have been drilled through the Niobrara formation and obtain meager supplies of mineralized water from the underlying formation. A few deep wells have also been drilled in the vicinity of Norton and at a few other localities throughout the area.

The Carlile shale, which is about 300 feet thick, underlies the Niobrara formation. The Carlile has been divided into three members, the lowest of which is composed of calcareous shale with thin chalky beds in the lower part and is called the Fairport chalky shale member. The Blue Hill shale member overlies the Fairport and consists of about 200 feet of dark-colored, platy, noncalcareous shale containing zones of flat discoidal concretions in the lower part and zones of septarian concretions in the upper part. The Codell sandstone member occurs as a lentil above the Blue Hill shale member and immediately below the base of the Niobrara formation. The Codell sandstone member ranges in thickness from a few inches to as much as 20 feet where it is exposed on the outcrops, and consists predominantly of fine to very fine sand and silt. At some places where this part of the section is exposed, the Codell does not consist of a well-developed sandstone bed but of thin lentils of sand in the upper 15 to 20 feet of the Blue Hill shale member. These sand streaks in many places do not exceed 2 or 3 inches in thickness and are thought to be relatively nonpersistent. At a few localities a lentil of sand several feet in thickness and lithologically resembling the Codell occurs as much as 20 to 40 feet below the top of the Blue Hill shale member.

As none of the test holes drilled in this area penetrated the Carlile shale and as samples were not generally collected from the oil tests drilled in this area until a greater depth was attained, little detailed information on the exact nature of the Codell sandstone member in this area is available. Several of the deeper water wells in southeastern Norton County may obtain all or part of their water from the Codell sandstone member of the Carlile shale.

The Greenhorn limestone lies below the Carlile shale. It consists of alternating beds of chalky limestone and chalky shale and probably does not exceed 100 feet in thickness in this area. Next below the Greenhorn limestone is the Graneros shale which is a dark-gray to black, fissile, noncalcareous shale with lentils of sand. The Graneros shale overlies the Dakota formation, which is made up of clay, shale, siltstone, and sandstone. Although in areas farther east and southeast the Dakota formation is an important source of ground water, no water wells drilled to the Dakota were found in the area of this report. Wells drilled into the Dakota toward the east in Smith and Phillips Counties have encountered highly mineralized water in the formation and it is probable that waters of similar quality occur in the formation in this area. Below the Dakota formation are the Kiowa shale and Cheyenne sandstone of the early Cretaceous Comanchean Series.

NIOBRARA FORMATION

The Niobrara formation was named in 1862 by Meek and Hayden from exposures along Missouri River near the mouth of Niobrara River in Nebraska. The first detailed description of this stratigraphic unit in Norton County is included in "The Geology of Norton County" by Hay (1885, pp. 18-20). Hay describes outcrops of Niobrara chalk along the three major valleys of the county. In 1897 Logan (pp. 219-221) described the occurrence of the Niobrara formation in western Kansas. He used a twofold subdivision of the Niobrara consisting of the Fort Hays limestone member as the lower division and the *Pteranodon* beds or Smoky Hill chalk, a name proposed earlier by Cragin, as the upper division. In his description of the Niobrara, Logan mentions chert, which seems to be interstratified with the chalk and is well exposed in the vicinity of Norton and Prairie Dog Creek Valley. In the same year Williston (1897, pp. 237-246) described the stratigraphy of the Niobrara formation of western Kansas and its contained fossils. In 1925 the stratigraphy of the Niobrara formation in Russell County, Kansas, southeast of this area, was described in detail by Rubey and Bass (pp. 25-32), and in the following year Bass (1926, pp. 19-26) described the Niobrara formation in Ellis County immediately west of Russell County. A rough zonation of the Smoky Hill chalk member was proposed by Russell in 1929, and Elias in 1931 (pp. 29-43) described the Niobrara formation in Wallace County, Kansas.

The exposures of Niobrara in Norton County and northwestern Phillips County represent approximately the upper half of the Smoky Hill chalk member. However, the lower part of the Smoky Hill chalk member and the Fort Hays limestone member underlie the entire area covered by this report. Where it is exposed at the surface to the east and south, the Fort Hays consists of massive beds of chalky limestone as much as 4 feet in thickness, separated by thin beds of chalky shale and shaly chalk. The Fort Hays grades upward into chalky shales and shaly chalks composing the Smoky Hill chalk member. Where encountered in fresh exposures or penetrated by the drill, the Smoky Hill chalk member is typically bluish gray in color and contains a large percentage of calcium carbonate. On weathered exposures it is yellow, orange, light gray, or nearly white in color and has a shaly or claylike appearance. In many of the test holes penetrating the Niobrara formation in this area, a similar weathered zone was encountered immediately below the unconformity without regard to stratigraphic position. Although the Smoky Hill chalk member is predominantly shaly in appearance, at some localities thick massive beds of chalk have been observed (Pl. 9C), and thin beds of bentonite occur at many stratigraphic positions. The upper part of the member is particularly characterized by numerous thin bentonite beds, which also occur in the overlying Pierre shale, as shown by the measured stratigraphic section in northwestern Phillips County.

Section measured along creek bank in the SW¼ sec. 6, T. 1 S., R. 19 W., Phillips County

CRETACEOUS—GULFIAN

Pierre shale—Sharon Springs shale member

	Thickness, feet
18. Shale, thin-bedded, dark gray; fine gypsum crystals and limonite along bedding planes	2.0
17. Shale, fissile, dark gray, noncalcareous; ochre on bedding planes	1.3

		Thickness feet
16.	Chalky paper shale, yellow brown	0.05
15.	Shale, fissile, dark gray; noncalcareous; contains bands of ochre, gypsum crystals, and limonite	3.5
14.	Bentonite, impure, with limonite and calcareous shale	0.1
13.	Shale, fissile, dark gray; noncalcareous; bands of ochre, gypsum crystals, and limonite on bedding planes	5.0
12.	Bentonite with gypsum and limonite	0.05
Niobrara Formation		
Smoky Hill chalk member		
11.	Chalky shale, thin-bedded, gray, weathers to yellow tan	1.5
10.	Bentonite, yellow tan	0.3
9.	Chalk, dark gray, massive	0.7
8.	Bentonite, impure, yellow tan	0.05
7.	Chalk, thin-bedded, dark gray, breaks with a conchoidal fracture on exposed surfaces, weathers to light orange	1.5
6.	Bentonite, yellow tan	0.2
5.	Chalk, massive, dark gray, weathers to light orange	0.9
4.	Bentonite	0.05
3.	Chalk, thin-bedded, dark gray	0.8
2.	Bentonite	0.01
1.	Chalk, thick-bedded, dark gray. From low water level in Prairie Dog Creek	2.0
	Total measured	about 20.

For many years silicified zones in the Smoky Hill chalk member were thought to represent definite stratigraphic horizons. These zones have been observed at several localities in north-central Kansas at various stratigraphic positions but always near the eroded upper surface of the member. In a few places, the silicified chalk is cemented to overlying silicified deposits of the Ogallala formation. It is our conclusion that the silicified zones in the chalk were formed by secondary silicification of the uppermost exposed chalk beds probably at the same time as the silicification of zones in the overlying Ogallala formation (Landes and Keroher, 1942, p. 306; Frye and Swineford, 1946, pp. 58-59).

The maximum thickness of the Niobrara formation in Phillips County has been reported by Landes and Keroher (1942, p. 286) as 650 feet. They considered the thickness of the Fort Hays limestone member as about 50 feet and the remaining 600 feet of the formation they assign to the Smoky Hill chalk member.

Although the Niobrara formation yields meager supplies of mineralized water to wells at some places, the relatively impervious character of the formation prevents the movement of large quantities of water and renders it unsatisfactory as a general source of

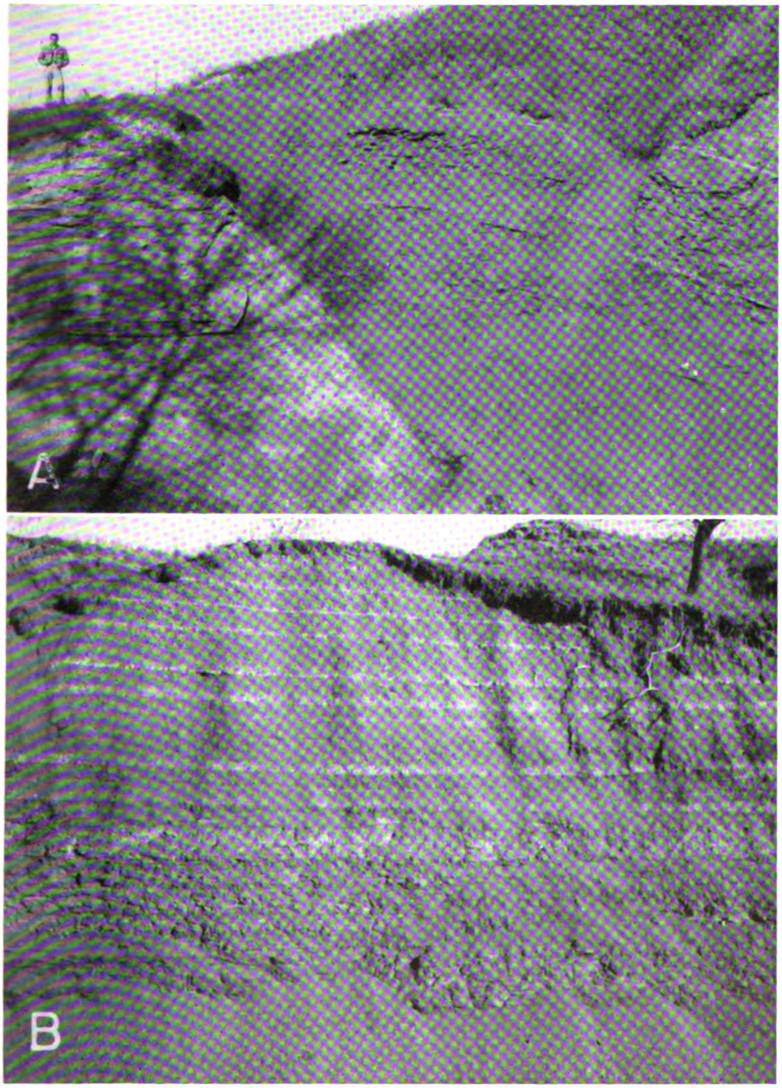

PLATE 5. Cretaceous rocks in northwestern Phillips County. *A,* Niobrara chalk (left) faulted against Pierre shale (right) exposed along east bank of Prairie Dog Creek in the SE¼ sec. 24, T. 1 S., R. 20 W.; *B,* Pierre shale exposed in east bank of Prairie Dog Creek in the SE¼ sec. 24, T. 1 S., R. 20 W.

ground water. At some places, particularly where the chalk has been partially silicified, jointing in the upper part has permitted the entrance of water in sufficient quantities to supply small wells. Old stone well (no. 2-23-33aa) near Norton is an example of a well producing water from silicified chalk of the Niobrara formation. Also, faults occur in the Niobrara in some areas (Pls. 4C and 5A) and some water may move along the porous fracture zones produced by the fault planes. Deep wells drilled into the chalk, particularly in southeastern Norton County, obtain water from depths of 250 to 400 feet. In most cases, although the water level in these wells stands up in the chalk, the source of the water is from the underlying Codell sandstone. Chemical analyses of water from several wells penetrating the Niobrara and Codell are shown in Table 5 and Figure 9.

PIERRE SHALE

The Pierre shale was named by Meek and Hayden in 1862 from exposures at old Fort Pierre in South Dakota. The Pierre shale of Kansas has been studied and described in detail by Elias (1931, pp. 43-131). He described several members in the Pierre shale and discussed their correlation with late Cretaceous units throughout North America. In the area covered by this report only the lowermost of the members described by Elias, the Sharon Springs shale member, is exposed. The occurrence of Pierre shale in northwestern Phillips County was described by Landes and Keroher (1942, pp. 284-286).

In Phillips County the Pierre shale consists of black to dark gray-brown fissile, platy noncalcareous shale with numerous thin beds of bentonite and several zones of chalky shale. The shale typically contains thin veins and isolated crystals of gypsum and scattered nodules of limonite. Large septarian concretions, described by Elias as typical of the upper part of the Sharon Springs shale member, were not observed in the Pierre shale of this area. However, a few small concretionary limestones were observed at scattered localities. The maximum thickness of Pierre shale observed in outcrops was about 30 feet (Pl. 5B), and the maximum thickness encountered in test holes was 46 feet. Probably the total thickness of the Pierre shale in Phillips County is considerably less than 100 feet. Although no fossils were obtained from this formation in Phillips County, close similarity of lithology to that in Wallace and adjacent counties, described by Elias, and the stratigraphic thickness encountered above the top of the Niobrara formation suggest that all the Pierre shale of Phillips County should be classed as the lower part of the Sharon Springs member. The contact between the Niobrara formation and the Pierre shale is described by Elias (1931, pp. 29-31) as difficult to recognize in the field except by the use of acid, because the two units where they are in contact may be of similar color and lithologic appearance. However, he describes the contact as being sharp when checked for calcium carbonate content. In Phillips County, several beds of chalky shale occurring in the lower part of the Pierre attain a maximum thickness of more than 3 feet; as outcrops are generally meager, it is difficult in some places to distinguish with certainty Pierre shale from Niobrara formation. The occurrence of numerous thin bentonite beds in both the upper part of the Niobrara and the lower part of the Pierre shale is shown by the measured section in the SW¼ sec. 6, T. 1 S., R. 19 W., Phillips County. For the purposes of this report the base of the Pierre shale is drawn at the top of the uniformly calcareous chalky shales which are here classed as the upper part of the Niobrara formation.

The occurrence of Pierre shale in northwestern Phillips County and adjacent Nebraska, lying east of widespread Pierre shale deposits of northwestern Kansas and isolated from that area by an extensive region devoid of Pierre shale outcrops, has been explained by downwarping of the Long Island syncline on the west flank of the Stockton anticline (Landes and Keroher, 1942, p. 289. Faults have been observed at many of the outcrops of Pierre shale (Pls. 4C and 5A) and it is possible that this faulting is associated with the structural movements that gave rise to the Long Island syncline.

No wells in this area are known to obtain water from Pierre shale.

Tertiary System (Pliocene Series)

OGALLALA FORMATION

The Ogallala formation was named by Darton in 1899 (pp. 734, 735, 741-742, pl. 84) 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 area of western Kansas and later (Elias, 1937) briefly described the Ogallala in Rawlins and Decatur Counties immediately west of Norton County. In 1942 Elias described Tertiary fossil seeds and other plant remains of the central Great Plains. Lugn (1939) presented a

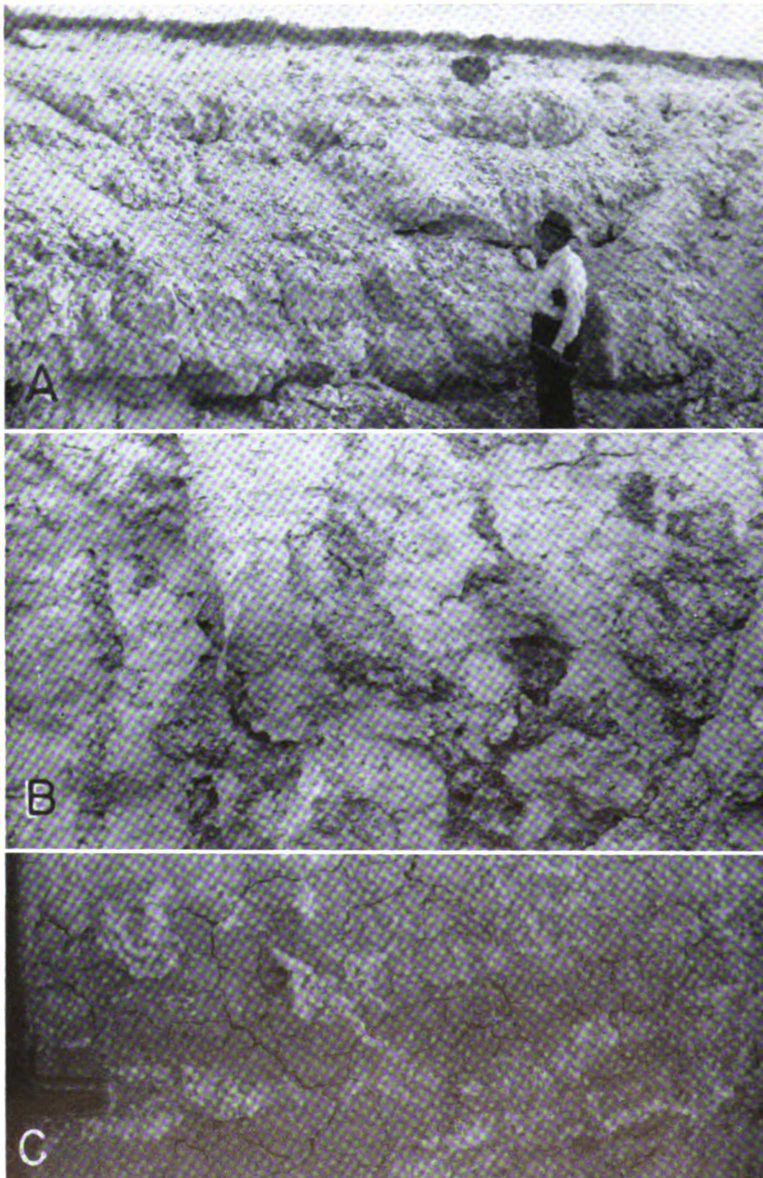

PLATE 6. Ogallala formation south of Almena, Norton County. *A*, Impure limestone of the Ogallala formation in quarry on south side of Prairie Dog Creek Valley. Quarry is one-fourth mile east of measured section in this report and the rock grades laterally into bed 14 of measured section. Limestone contains a few molds of fossil snails. *B*, Detail of middle of bed 12 of measured section south of Almena. *C*, Detailed view of weathered surface of bed 10 of measured section south of Almena.

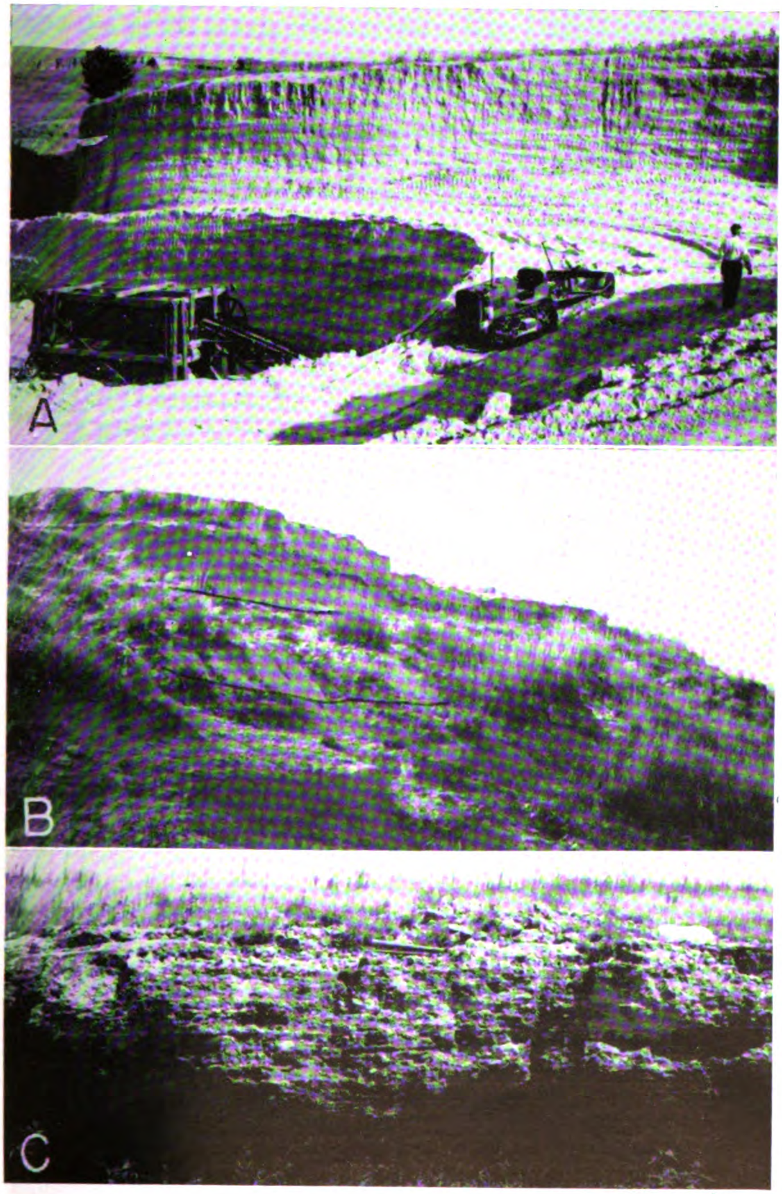

Plate 7. Volcanic ash of the Ogallala formation in Norton County. *A*, Mine of Wyandotte Chemical Corporation at Calvert. *B*, Exposure of Ogallala formation showing volcanic ash below beds from which *Biorbia fossilia* (Berry) was collected, NW¼ NE¼ sec. 36, T. 2 S., R. 25 W. *C*, Cemented upper part of volcanic ash, south of Almena. Bed 17 of measured section in this report.

classification of the Tertiary formations of Nebraska in which he considered the Ogallala as a group containing the following formations in ascending order: Valentine, Ash Hollow, Sydney gravel, and Kimball.

Character and subdivisions.—The Ogallala formation of Norton and Phillips Counties consists of a wide diversity of clastic sediments. It contains sand and gravel, silt, sandy silt, clay, bentonitic clay, and, locally, sandy limestone, silty limestone, volcanic ash, opaline-cemented sands and gravels, and chert (Pls. 6, 7, and 9A). The character of the Ogallala is shown by the logs of test holes and the measured sections included in this report, and by the cross sections in Plate 3. The bluffs on the south side of Prairie Dog Creek Valley in the vicinity of Almena present exceptionally good exposures of the Ogallala formation, and a measured section from that locality is given below.

Section measured south of Almena, W½ sec. 16, T. 2 S., R. 21 W., Norton County, Kansas (Measured by M. K. Elias and John C. Frye)

	Thickness, feet
QUATERNARY—PLEISTOCENE	
Sanborn formation	
24. Silt and fine sand, buff; contains nodules of calcium carbonate	4.0
TERTIARY—PLIOCENE	
Ogallala formation—Ash Hollow member(?)	
23. Limestone, porous, hard, light cream; contains abundant gastropod molds	3.0
22. Covered. Two feet of mortar bed exposed about midway	35.0
21. Sand, silty, fine to medium, loosely cemented with calcium carbonate; contains *Biorbia fossilia* (Berry), *Berryochloa amphoralis*, and *Celtis willistoni* (Cockerell)	6.4
20. Covered. Unconsolidated silt and sand, buff, poorly exposed at a few places	32.0
19. Sand, coarse to fine, and some silt; cemented with calcium carbonate	1.0
18. Sand, fine to medium, buff; contains a small amount of calcium carbonate cement	5.0
17. Volcanic ash, sandy at base (becomes impure to south); upper part locally cemented with calcium carbonate. At Calvert ash mine this bed contains *Krynitzkia coroniformis* Elias, *Stipidium variegatum* var. *dartoni* Elias, *Celtis willistoni* (Cockerell)	6.5
16. Silt and sand cemented with calcium carbonate, roughly bedded; contains *Krynitzkia coroniformis* Elias	6.5
15. Partly covered. Calcareous clay silt, greenish gray at top; buff silt and very fine sand with calcium carbonate concretions in middle; and greenish-gray calcareous clay silt at base	20.0
14. Silt, sand, and calcium carbonate	4.0

	Thickness feet
13. Sandy silt, buff, locally unevenly cemented with calcium carbonate	0.7
12. Silt, sand, and calcium carbonate, massive, light greenish buff,	6.9
Valentine member(?)	
11. Sand, fine to medium, pale greenish tan	3.7
10. Silt, sand, and clay, calcareous, greenish brown	3.0
9. Silt, clay, and sand, greenish brown	1.8
8. Sand and some gravel	3.0
7. Sand, clay, and silt, greenish brown; contains abundant fragments of fossil vertebrates	2.5
6. Sand, medium, poorly sorted, uncemented, brown	3.0
5. Covered	4.0
4. Limestone, porous, hard, white; contains gastropod molds	1.0
3. Sand and silt, highly calcareous, irregularly bedded, gray to pink; upper part more calcareous and contains a few gastropod molds	3.2
2. Silt, with some clay and fine sand, massive, gray to gray green,	5.5
1. Sand, fine, and silt, with some clay and coarse sand, highly calcareous, massive to irregularly bedded, gray. Covered in lower part to level of C. R. I. and P. R. R. tracks	5.3
Total measured	167.0

In spite of the wide diversity of rock types included within the Ogallala formation, the outcrops present a uniformity of aspect which makes the stratigraphic unit easy to identify for mapping purposes. Poorly sorted sandy silts and silty sands and gravels, commonly cemented loosely with calcium carbonate or containing nodules and stringers of calcium carbonate, predominate throughout the formation.

Thin lenticular bodies of well-sorted sand and sand and gravel have been penetrated by several of the test holes as shown by the logs. However, well-sorted sand or sand and gravel is rare in Ogallala outcrops. The general occurrence of sandy silts and silty sand and gravel beds loosely cemented with calcium carbonate gave rise to the widespread application of the term "mortar bed" to the Ogallala formation in northwestern Kansas. Although color differentiation should not be relied upon for correlation purposes, the lower part of the Ogallala section in Norton and Phillips Counties is predominantly gray to gray green in color, whereas the upper part generally is characterized by a pinkish color.

The stratigraphic subdivision of the Ogallala formation is rendered difficult by the occurrence throughout its entire thickness of similar lithologies. In Nebraska the Ogallala has been classed by Lugn (1939) as a group consisting of four formational units. Because these several units are conformable they are recognized with difficulty in field mapping; the State Geological Survey of Kansas classes the Ogallala as a formation and recognizes as members within it three units classed in Nebraska as formations. It is our judgment that in Norton County and northwestern Phillips County nearly an entire section of Ogallala is present, representing the Valentine, Ash Hollow, and Kimball members. The cross sections (Pl. 3) clearly show that the unconformable surface on which the Ogallala deposits were laid down is not flat but has relief of more than 100 feet in this area. The tracing of seed zones and lithologic types suggests that deposits here classed as Valentine member accumulated in the low areas on the pre-Ogallala erosion surface and thus represent fills in the early Pliocene valleys. The Valentine member thus thins toward the Cretaceous highs and probably pinches out entirely under part of the divide area between Prairie Dog Creek and Solomon River in the eastern part of Norton County and south of Sappa Creek Valley in northwestern Norton County. The Ash Hollow member is thought to be represented by many of the outcrops encountered along the major valley areas and to have been deposited over the entire area. Alluviation of this part of the Great Plains during the time of Ash Hollow sedimentation had built the surface of the alluvial plain (Frye, 1945) above the level of the pre-Pliocene major stream divides. Although deposits comprising the Kimball member of the Ogallala are thought to have originally been continuous over this part of Kansas, they are now represented only by isolated erosion remnants projecting above the general upper surface of Ogallala deposits. The crest of Twin Mounds south of Lenora, capped by resistant cherty beds, may represent the approximate stratigraphic position of the Algal limestone and thus mark the top of the Kimball member and of the Ogallala formation.

The recognition of the Valentine, Ash Hollow, and Kimball members is based primarily on plant fossils and a few distinctive lithologic types. Elias (1942) has described the fossil flora of the Ogallala formation and recognized floral zones characterized by three distinctive fossil seeds. He considers the zone of *Stipidium commune* to be roughly coincident with the Valentine member, the zone of *Krynitzkia coroniformis* to occur in the lower Ash Hollow and possibly uppermost Valentine, and the zone of *Biorbia fossilia* to comprise all but the lowermost part of the Ash Hollow. As the seeds occur widely in Ogallala deposits, they are quite useful in aiding the recognition of the several members. Their stratigraphic position in Norton and Phillips Counties is noted in several measured sections included in this report.

Of the special lithologic types included in the Ogallala formation of this area, lenticular deposits of volcanic ash have proved to be the most useful stratigraphically. Detailed petrographic studies (Swineford and Frye, 1946) of volcanic ash from six localities in Norton County have been made. At five of these places the petrographic characteristics indicate that the ash represents the same fall, whereas a higher index of refraction at the sixth locality (NW¼ NE¼ sec. 36, T. 2 S., R. 25 W.) suggests a different ash fall not contemporaneous in age with the other ash deposits. The widespread ash typically exposed in the Calvert mine (Pl. 7) has been placed by Swineford and Frye (1946) in the lower part of the Ash Hollow member.

Another distinctive lithologic type in this area is the silica-cemented lentils of sand and gravel. This rock type has been described in detail by Frye and Swineford (1946) and, although it occurs at several slightly different stratigraphic positions, the lentils for the most part have been placed by them in the zone of *Stipidium commune* and the lower part of the zone of *Krynitzkia coroniformis* and thus probably should be assigned to the lowermost part of the Ash Hollow member or the uppermost part of the Valentine member. Beds of soft limestone typified by molds of fossil snails and the absence of coarse sand or gravel occur at several stratigraphic positions within the formation and are well exposed in the vicinity of Almena and New Almelo.

Bentonitic clay, in places silty or sandy, is another distinctive lithologic type found in the Ogallala formation. Landes and Keroher (1942) have described the occurrence of this clay in Phillips County and Kinney (1942) has made a study of its properties and use. It is typically gray green to olive tan in color and occurs in lenticular bodies in the lower part of the formation. This clay has been assigned to the Cretaceous by some geologists, but its occurrence in some localities interstratified with and overlying typical calcium carbonate-cemented sand and gravel place it definitely within the Ogallala. The occurrence of this clay at the base of the Ogallala overlying Pierre shale at some places and upper Niobrara at other places suggests that it may be related to the erosional surface below the Ogallala formation.

Distribution and thickness.—The ogallala formation underlies all of Norton and northwestern Phillips Counties, except where it has been removed by erosion along the valleys of the major streams and the lower parts of some of their tributaries, and in an area adjacent to North Fork Solomon Valley in southeastern Norton County where the relatively high position of the Niobrara formation has permitted the removal by erosion of the Ogallala formation from the upland areas. Westward from Norton County the Ogallala formation extends in an unbroken sheet to the Colorado State line. The thickness of the formation is shown in the cross sections (Pl. 3) and the logs of test holes in this report. It was penetrated by 28 test holes where its thickness ranged from 5 to more than 250 feet; the average thickness penetrated by test holes is about 115 feet. The original thickness of the Ogallala formation at the close of the time of its deposition in this area probably ranged from a little more than 100 feet to about 300 feet.

Age and correlation.—The beds in the type area of the Ogallala formation near Ogallala, Nebraska, have been studied by Elias (1931) and the fossil vertebrates have been described and discussed (Hibbard, 1933; Hesse, 1935; Stirton, 1936). Although a large collection of vertebrate fossils has been made from quarries in the Ogallala formation south of Long Island in northwestern Phillips County and a few fragmentary fossil vertebrates have been collected from several places in Norton County, detailed correlations on the basis of fossil vertebrates have not been made in this area. However, abundant collections of fossil seeds, made by us and identified by M. K. Elias, aid in the correlation of these deposits with the Ogallala formation of Nebraska and western and southwestern Kansas. The stratigraphic placement of the fossil seeds is shown in the measured sections. A list of fossil plants collected from the Ogallala in Norton and Phillips Counties is given below.

Fossil seeds from the Ogallala formation in Norton and northwestern Phillips Counties, Kansas (Identified by M. K. Elias)

Berryochloa amphoralis
Biorbia fossilia (Berry)
Biorbia minor (Elias)
Celtis willistoni (Cockerell)
Krynitzkia coroniformis Elias
Panicum elegans mut. *nebraskense* Elias
Prolithospermum corrugatus Elias
Stipidium coloradoensis Elias
Stipidium commune Elias
Stipidium cf. *grande* Elias
Stipidium intermedium Elias
Stipidium sp.

The Ogallala formation of Norton and northwestern Phillips Counties is considered to be entirely of Pliocene age, as it has been correlated with deposits elsewhere in the Central Great Plains that have yielded characteristic Pliocene vertebrate faunas.

Water supply.—The sand and gravel of the Ogallala formation is the most widespread source of ground water in Norton County. Most of the wells in the uplands obtain all or part of their water from this formation. The finer materials of the formation and those cemented with calcium carbonate generally are porous and hold considerable water but are not permeable enough to yield water freely. The coarser materials—gravel in particular—commonly yield abundant supplies of water. Although laboratory determinations of coefficients of permeability of samples from the Ogallala formation from Norton County were not made, determinations made on similar materials from Thomas County showed a range from 107 to 609 for uncemented sand and gravels (Frye, 1945, p. 65). Although these permeabilities are probably considerably less than the permeability of materials underlying the prominent terraces of Solomon River and Prairie Dog and Sappa Creeks, they indicate that relatively large supplies of water can be obtained from wells where a considerable thickness of Ogallala sediments is saturated.

The position of the water table in the Ogallala is shown on Plate 2 by contour lines and figures indicating the altitude of the water table and its depth below land surface, and on the cross sections in Plate 3. Details concerning individual wells producing from the Ogallala are given in Table 8. The chemical character of the water from the Ogallala formation is given in Tables 5 and 6, and is shown on Figures 9 and 10.

Quaternary System

Although relatively thin in most places, deposits of Quaternary age were found to be the near-surface materials in a very large part of the area shown by the geologic map (Pl. 1). The Quaternary deposits are classed as Meade formation, Sanborn formation, terrace deposits, alluvium, and slope deposits.

MEADE (?) FORMATION (PLEISTOCENE SERIES)

Deposits tentatively classed as Meade formation occur south of Prairie Dog Creek Valley in the vicinity of Long Island and north of Solomon River Valley in south-central Norton County. In the vicinity of Long Island these deposits consist of sand and gravel containing abundant abraded pebbles of several distinctive rock types of the Ogallala formation and overlain by sandy silt. They occupy a topographic position well above that of the sand and gravel classed as the Crete member of the Sanborn formation, which in turn occurs topographically higher than the prominent terrace level along Prairie Dog Creek Valley. Thus at this locality the deposits assigned to the Meade formation constitute a dissected remnant of a high terrace. The topographic position of the sediments judged to be Meade in Solomon Valley is similar to that of the deposits in the Long Island locality. The south-central Norton County deposits, however, consist primarily of fine sand and silt which contains a meager snail fauna. An auger hole revealed the presence of relatively well-sorted sand below the sand and silt.

The Meade formation has been correlated from its type locality in Meade County, Kansas, widely over the western and central parts of the state (Frye, Swineford, and Leonard, 1948). However, the distinctive Pearlette volcanic ash was not found in this area, and a meager collection of fossil snails from the south-central Norton County locality failed to yield diagnostic species which would have permitted definite correlation. Where observed, the Meade (?) formation occurs above the water table and is of small importance as a water-bearing formation. It may, however, underlie several square miles of northwestern Phillips County where the surficial materials consist entirely of the younger Sanborn formation.

Because of their small areal extent, these outcrops of Meade (?) formation are included with the Sanborn formation on the geologic map (Pl. 1).

SANBORN FORMATION (PLEISTOCENE SERIES)

Character and subdivisions.—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 located in Nebraska just north of the type area. In 1944 Hibbard, Frye, and Leonard made a reconnaissance of the Sanborn formation and its contained vertebrate and molluscan faunas in north-central Kansas. This report uses the classification and correlations of the Sanborn formation as described by Frye and Fent (1947) in central Kansas. Four members are recognized within the Sanborn formation in this area—Crete sand and gravel member at the base, grading upward into the Loveland silt member which is capped by the Loveland soil, the Peoria silt member terminated upward by the Brady soil, and the Bignell silt member terminated upward by the modern surface soil.

The formation as a whole consists of three predominant lithologic types which directly reflect three environments of deposition. Stream deposits of sand and gravel representing the major channel fills of earliest Sanborn time occur in a terrace position above the prominent terraces of the major valleys and well below the uplands. The Crete sand and gravel is almost continuous along the north side of Prairie Dog Creek Valley throughout Norton County and northwestern Phillips County. Similar deposits of a local type occupy a tributary position to the major valleys in some places. Deposits of Crete sand and gravel were also observed at scattered localities along North Fork Solomon River and Sappa Creek Valleys. The second lithologic type occurs widely as a surficial material over much of the area mapped, as shown in Plate 1. It consists of eolian silts transported by winds from the flood plains of the major valleys of these counties and adjacent areas during periods of active alluviation and deposited as a nearly continuous mantle over the upland areas. The third lithologic type is minor in areal extent and thickness and consists of colluvial materials on steep slopes derived in part from the underlying bedrock (Pliocene or Cretaceous) and in part from the upland mantle of eolian silts. Two measured sections of the Sanborn formation and underlying Ogallala formation are given below.

Section measured along steep cut bank on W. side of creek in the SE¼ sec. 13, T. 1 S., R. 24 W., Norton County, Kansas. (Measured by Stafford C. Happ and John C. Frye.)

	Thickness, feet
QUATERNARY—PLEISTOCENE	
Sanborn formation	
15. Silt and very fine sand below surface with no soil development, indistinct bedding, light yellow tan (Bignell silt member?). Some fossil snails present	1.5
14. Soil (Brady), dark brown to brown black, blocky; indistinct contacts at top and bottom	1.5
13. Silt, with some very fine sand, massive, yellow tan (Peoria silt member). Snails collected from zone 3-5 feet above base included *Pupilla muscorum* (Linnaeus), *Helicodiscus parallelus* (Say), *Succinea grosvenori* Lea, *Vallonia gracilicosta* Reinhardt	14.0
12. Soil (Loveland), brown to reddish brown, compact sandy silt with a few pebbles, indistinct contacts at top and bottom. Lower 0.5 foot contains fossil vertebrates and the following fossil snails: *Vertigo tridentata* Wolf, *Succinea grosvenori* Lea, *Vallonia gracilicosta* Reinhardt, and *Pupilla muscorum* (Linnaeus)	3.5

	Thickness feet
11. Silt, sandy with occasional small pebbles, compact, irregular vertical structure, pinkish buff (Loveland silt member)	1.5
10. Sand, silt, and some gravel, massive, buff	1.0
9. Silt, sandy, massive, brown	1.0
8. Sand, fine, silty, massive, with some pebbles, tan	1.0
7. Covered	1.5
6. Sand, stratified, tan; contains streaks of uncemented silt and pebbles (dominantly mortar-bed material)	1.5
5. Sand, gravel, and silt, lenticular, irregularly bedded, tan (pebbles of Ogallala type)	2.0
4. Gravel (mostly derived from the Ogallala formation); minor disconformity at base	0.8
3. Silt, with some sand and gravel, irregularly bedded, greenish gray. Distinct unconformity at base	3.2
TERTIARY—PLIOCENE (?)	
Ogallala formation (?)	
2. Silt, sandy, calcareous, greenish	0.8
1. Sand with some silt, massive, green gray. Partly covered in lower part	4.5
Total measured	39.3

3-23-11. *Section measured in road cut in the NW¼ sec. 11, T. 3 S., R. 23 W., Norton County, Kansas.* (Measured by Claude W. Hibbard and John C. Frye [Hibbard, Frye, and Leonard, 1944]).

	Thickness, feet
Sanborn formation	
4. Silt, massive, gray to yellow tan (Peoria silt member). *Citellus richardsonii* (Sabine) 2.5 feet and 21 feet above base. Fossil snails 4 feet above base include *Vallonia gracilicosta* (Müller), *Succinea grosvenori* Lea, and *Pupilla blandi* Morse; 20 feet above base, *Succinea grosvenori* Lea, *Pupilla muscorum* (Linnaeus), *Pupilla blandi* Morse, and *Discus cronkhitei* (Newcomb)	25.0
3. Soil (Loveland). Sand, fine, and silt, blocky to massive; contains nodules of caliche in lower part; *Citellus richardsonii* (Sabine)	3.5
2. Silt and fine sand, a few patches and streaks of caliche, light gray buff (Loveland silt member). *Citellus richardsonii* (Sabine) and *Geomys* sp. Bed 2 pinches out laterally on unconformable surface of the Ogallala formation	4.4
Ogallala formation—Ash Hollow member	
1. Sand, silt, and gravel, cemented loosely throughout with calcium carbonate, gray. Fossil vertebrates 12.5 feet below top	31.0
Total	63.9

On the upland divides, where the Sanborn formation consists predominantly of eolian silts with minor amounts of colluvial materials in the basal part, three stratigraphic units have been recognized on the basis of two distinct unconformities. For the most part these

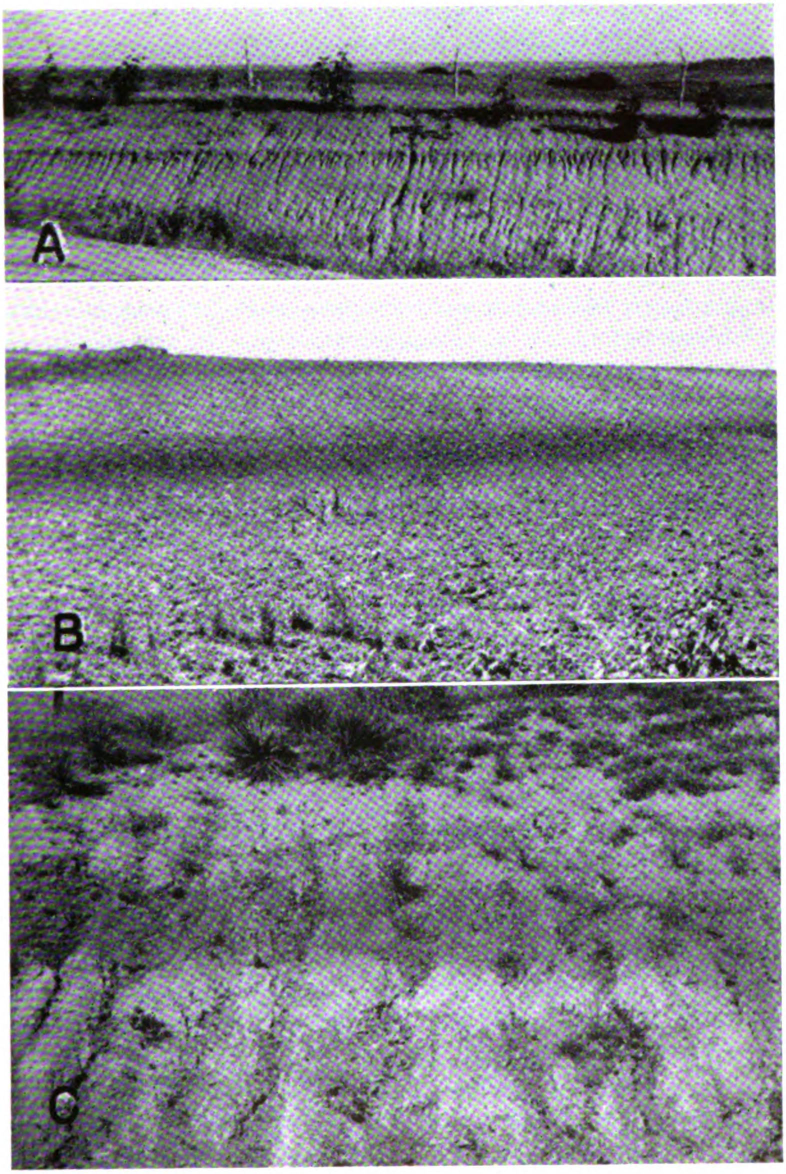

Plate 8. Buried soils in the Sanborn formation. *A*, Brady soil developed on Peoria silt member and overlain by Bignell silt member. Road cut, N. line, NW¼ sec. 26, T. 2 S., R. 23 W., Norton County, Kansas. Fossil snails abundant in Peoria member. *B*, Loveland soil overlain by Peoria silt, truncated by modern sloping surface, exposed in a plowed field in the NW¼ NE¼ sec. 21, T. 3 S., R. 12 W., Smith County, Kansas. *C*, Loveland soil overlain by Peoria silt member, in cut along Kansas Highway 9, sec. 18, T. 5 S., R. 23 W., Norton County, Kansas.

unconformities are not marked by deep erosion or intricate dissection of the area, but rather by episodes of weathering that have given rise to well-developed soil profiles now buried below overlying silts. The most prominent of these soil profiles occurs at the top of the Loveland member on the divide areas, and is several times as thick as the modern soil profile at the surface. It is well exposed in road cuts in the vicinity of Norton and elsewhere throughout the area, and has been encountered in test holes and auger borings. The depth of leaching in all exposures where it was checked exceeds 30 inches and the upper part of the soil is colored dark brown by organic material and oxidation. An accumulation of clay occurs below the dark-brown zone and a prominent red color extends downward into the Loveland silt member for several feet at most places. Concentration of caliche in the form of nodules and stringers has been observed at depths of 4 to 6 feet below the top of the soil. The Loveland silt member on the divides rarely exceeds a thickness of 20 feet.

The Peoria silt member overlies the Loveland and consists predominantly of light yellowish-tan massive uniform calcareous silt. At the base of the Peoria member there is a gradational transition zone which is judged to represent the initial slow accumulation of silt that later culminated in the deposition of the member. This slow initial deposition allowed weathering processes to leach part of the calcium carbonate from the silts as they were deposited. The Peoria silt member is terminated upward by the Brady soil, which is somewhat thicker than the modern top soil which it resembles in road cuts and auger holes.

The uppermost division of the Sanborn formation consists of discontinuous thin deposits of eolian silt resting on the surface of the Brady soil. This uppermost member has been named Bignell from a locality in Nebraska (Schultz and Stout, 1945) and is terminated upward by the modern top soil (Pl. 8). Its occurrence is sporadic and is largely confined to the divide areas.

Colluvial deposits on some slopes are not properly classed as part of the Sanborn formation. However, for the purposes of field mapping, such slope deposits are included with the Sanborn formation on the geologic map (Pl. 1), where they are of sufficient thickness to conceal the underlying rocks in gullies and along road cuts.

Where the Sanborn formation is thick, the topography is generally characterized by rounded slopes and a deep fertile soil. Where road cuts have been made through these silt members, they display in some degree the characteristic of loess in that they stand in steep cuts for long periods of time. On the broad interdivide areas in western Norton County the Sanborn formation underlies flat upland surfaces.

Distribution and thickness.—As shown on Plate 1, the Sanborn formation and minor amounts of associated slope deposits underlie the surface of a very large part of Norton County and northwestern Phillips County. The thickness of this unit is shown by logs of test holes and measured sections included in this report and in the plotted cross sections shown on Plate 3. The uppermost or Bignell silt member is generally 3 to 5 feet in thickness but a total thickness of 20 feet was penetrated in one test hole. The underlying Peoria silt member is as much as 40 feet thick, and is commonly 15 to 25 feet thick. The next older member, the Loveland silt member, in the upland areas ranges in thickness from a featheredge to as much as 15 feet, and the basal or Crete sand and gravel member is commonly more than 30 feet thick.

Age and correlation.—The Sanborn formation includes the deposits referred to in 1885 by Hay (p. 21) as "chalky sandy marl of Pliocene age." Subsequently it was called "Tertiary marl" or "Plains marl" by many of the early workers in the central Great Plains region. When Elias (1931) applied the name Sanborn to these deposits farther west in Kansas, he considered them to be of Pleistocene age. In 1944 a reconnaissance of the Pleistocene deposits of north-central Kansas was made by Hibbard, Frye, and Leonard, and collections of both vertebrate and invertebrate fossils from these deposits were made at many localities. One of the sections studied at that time included the exposures of Loveland and Peoria members of the Sanborn which cap the Ogallala bluffs south of the City of Norton. A measured section from that locality is included in this report and the stratigraphic placement of fossils is shown. The Loveland soil has been traced into Nebraska where it is included within the *Citellus* zone of earlier Nebraska classification. Condra, Reed, and Gordon (1947) have traced the Peorian loess and Loveland loess from western Iowa across Nebraska to the Colorado line. These units have been traced southward from Nebraska as far as central Kansas (Frye and Fent, 1947) but are here classed as members of the Sanborn formation. In the Missouri Valley area these two stratigraphic units occur above and below deposits of glacial till, and the Peoria member of the Sanborn has been established as post-Iowan in age and the Loveland member as pre-Iowan. In fact, a well-developed soil was formed on the top of the Loveland before it was overridden by the Iowan ice, and for that reason it is quite probable that this member may be as old as the Illinoian glacial epoch. The Bignell member is separated from the Peoria by a well-developed profile of weathering, and it is thought to be latest Pleistocene in age.

Fossil snails were collected from the Sanborn formation during the course of field work for this report. They have been identified by A. Byron Leonard and are given in the measured sections. All species obtained from the Loveland and Peoria members are listed below.

Fossil snails from the Loveland silt member of the Sanborn formation in Norton County (Identified by A. Byron Leonard)

Pupilla muscorum (Linnaeus)
Succinea grosvenori Lea
Vallonia gracilicosta Reinhardt
Vertigo tridentata Wolf

Fossil snails from the Peoria silt member of the Sanborn formation in Norton and Phillips Counties (Identified by A. Byron Leonard)

Columella alticola Ingersol
Discus cronkhitei (Newcomb)
Euconulus fulvus (Müller)
Helicodiscus parallelus (Say)
Pupilla blandi Morse
Succinea grosvenori Lea
Vallonia gracilicosta Reinhardt
Vallonia pulchella (Müller)
Vertigo modesta Gould
Vertigo coloradensis Cockerell

Water supply.—On the upland divide areas the Sanborn formation occurs entirely above the water table and therefore does not yield water to wells. The fine-textured composition and low permeability of these silts probably retard the downward percolation of water into the underlying formations. The Crete sand and gravel member, on the other hand, is an important source of ground-water supplies, particularly in a strip averaging about 2 miles in width along the north side of Prairie Dog Creek Valley, and at scattered localities along the margins of Sappa Creek Valley and North Solomon River Valley. Analyses of water from two wells in the Crete member are listed in Table 6 and shown on Figure 11.

TERRACE DEPOSITS OF MAJOR VALLEYS (PLEISTOCENE AND RECENT SERIES)

Character and extent.—Broad smooth terrace surfaces (Pl. 4A) trenched by relatively narrow channels characterize the major valleys of this area. Their extent is shown on the geologic map (Pl. 1) and their thickness and character are given by cross sections in Plate 3 and logs of test holes at the end of this report.

Although the terrace surface along each major valley is in general continuous, there are minor breaks in level which indicate that the broad terraces were developed during several episodes, and thus each should probably be considered as a terrace complex rather than as a single terrace. The more recognizable breaks in the terrace surface—that is, where a generally flat terrace area drops to a slightly lower level—are shown by dashed lines on the geologic map. These variations in surface level, however, are not reflected by variations in the character of the deposits below the terrace surface or in the level of the eroded bedrock valley floor.

For the most part, each terrace is underlain at depths ranging from 40 to 80 feet by deposits of sand and gravel immediately above the Cretaceous bedrock surface. The deposits of sand and gravel grade upward into sand, sandy silt, and well-stratified silts in the upper part of the terrace fill. At many places an alluvial soil band has been observed in the upper part of the terrace deposits (Pl. 9B) and in the cuttings from several of the test holes.

After the major valleys had eroded bedrock below the level of the Crete sand and gravel the basal member of the Sanborn formation, they filled their valleys with alluvium to develop the terraces. The episode of cut and fill that produced terraces in the major valleys also affected the minor tributaries. In many of the more important tributary streams of Norton and northwestern Phillips Counties remnants of terraces which represent an extension of the major terrace levels can be observed (Pl. 10B). However, owing to their small areal extent, discontinuous nature, and small importance as water-bearing material, the remnants of terraces in the tributary valleys have been included with the alluvium on the geologic map (Pl. 1).

Age and correlation.—The terrace deposits along all the major valleys are of late Pleistocene and Recent age. This is attested by their relationship to the Crete and Loveland members of the Sanborn formation. The Crete sand and gravel deposits and the Love-

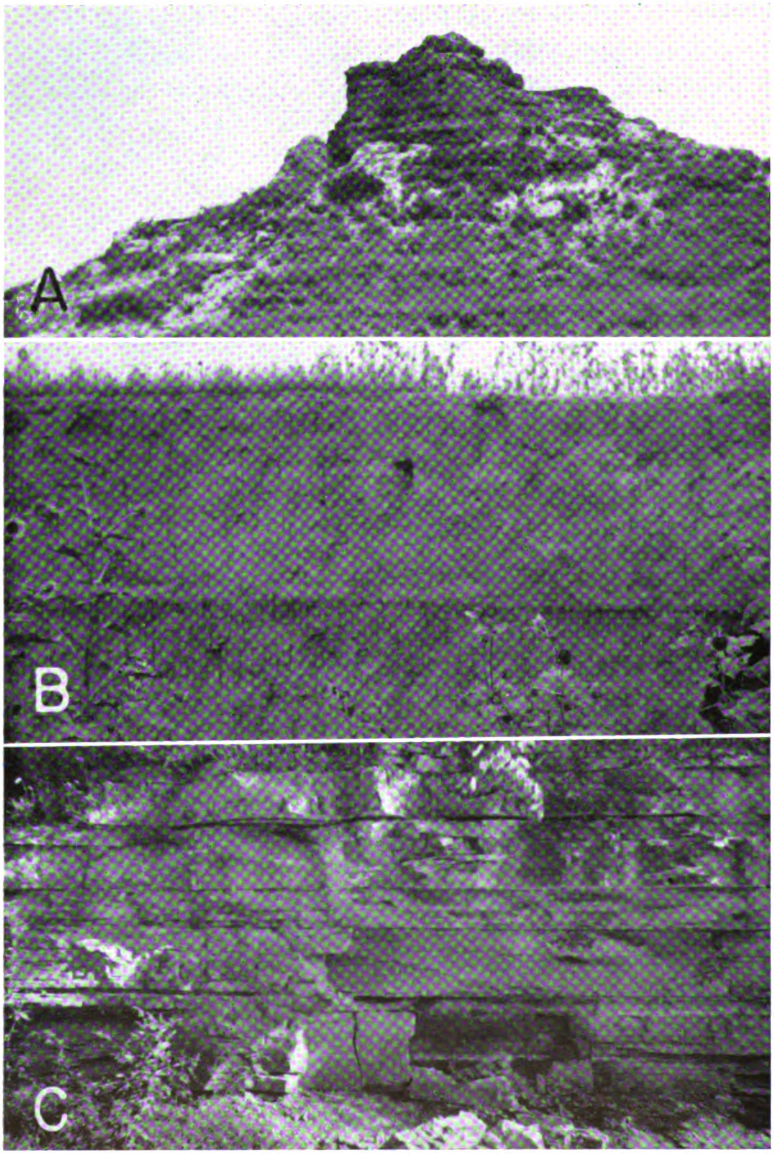

PLATE 9. Rocks of central Norton County. *A*, Ogallala formation exposed along south side of Prairie Dog Creek Valley west of Dellvale. *Biorbia fossilia* (Berry) collected from the sandy silt beds exposed. *B*, Soil band in terrace deposits of Prairie Dog Creek Valley west of Norton. *C*, Niobrara chalk along south bank of Prairie Dog Creek at Norton.

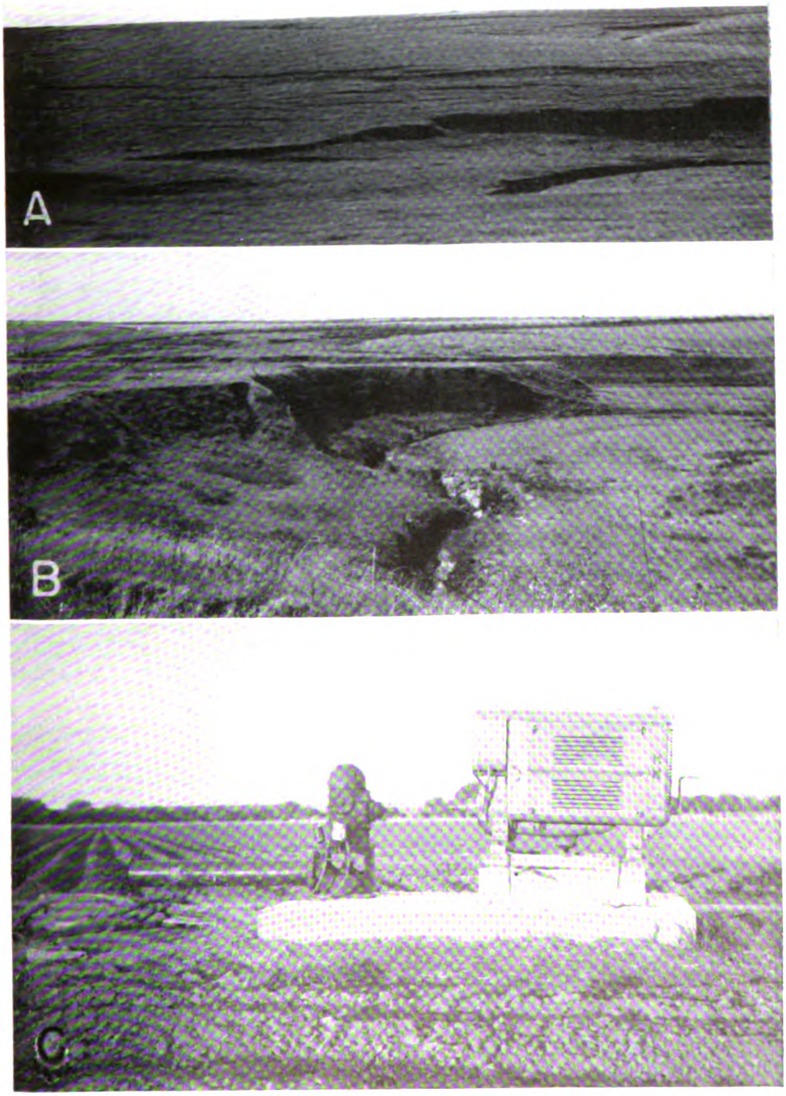

PLATE 10. *A*, Loess topography in the NW¼ sec. 24, T. 1 S., R. 24 W., Norton County. The thin loess mantle over the Ogallala formation has resulted in small slump or creep features referred to as "cat steps." *B*, Terrace remnants and alluvium in a tributary valley, E. of center sec. 29, T. 3 S., R. 24, W., Norton County. *C*, Irrigation pumping plant on terrace level in Prairie Dog Creek Valley in the NE¼ sec. 8, T. 1 S., R. 19 W., Phillips County.

land silt and its contained soil were dissected during the period of erosion that developed the present valley, and therefore the terrace deposits are younger than Crete and Loveland and are probably Wisconsinan in age. The relationship of the Peoria silt member of the Sanborn formation to the terrace deposits is not clear. It is possible, that the prominent soil band in the upper part of the terrace silts corresponds in age to the Brady soil that marks the top of the Peoria silt member of the Sanborn formation and occurs below the Bignell silt member of the Sanborn formation. This relationship, however, is not clearly demonstrated by field observations. Other evidence for the extreme youth of the terraces is their relation to the stream courses. At many places along each of the three major streams narrow promontories and islands of terrace deposits project into meander loops of the streams (Pl. 1). As the meanders move downstream, they will cut off the promontories to form islands and eventually eradicate them. In a short span of geologic time, the streams will have meander belts of uniform width without projections of terraces into them.

Collections of fossil snails were made from the terrace deposits along North Fork Solomon Valley and Prairie Dog Creek Valley and a few fossil snails were collected from alluvium. They have been identified by A. B. Leonard and are listed below.

Fossil snails collected from terrace deposits of late Pleistocene and Recent age and Recent alluvium in Norton County (Identified by A. Byron Leonard)

Discus shimeki (Pilsbry)
Euconulus fulvus (Müller)
Gastrocopta armifera Sterki
Gastrocopta procera
Gyraulus parvus (Say)
Hawaiia miniscula (Binney)
Helisoma trivolvis (Say)
Helicodiscus parallelus (Say)
Physa hawnii Lea
Pupoides marginatus Say
Pupilla blandi Morse
Pupilla muscorum (Linnaeus)
Sphaerium sp.
Succinea grosvenori Lea
Vallonia gracilicosta Reinhardt
Vertigo modesta Gould

Correlation of these terraces with other described terraces toward the east is possible only in the case of the North Fork Solomon River. Here a prominent terrace named Kirwin by A. R. Leonard (Report in preparation) has been traced by him across Osborne, Smith, and

Phillips Counties and found to be continuous with the prominent terrace mapped across southern Norton County. For the purpose of this report the terrace of Prairie Dog Creek Valley is named the Almena terrace from the town of that name built on its surface. The Almena terrace has been traced across Norton and Phillips Counties and into Nebraska, where it is thought to merge with one of the terraces of Republican River Valley. However, as an adequate correlation with a named and described terrace in Nebraska has not yet been made, it is thought preferable to use a local name for this terrace. The terrace of Sappa Creek Valley has not been traced beyond the limits of the area shown in the geologic map (Pl. 1).

Water supply.—The terrace deposits constitute the most important source of ground-water supply for irrigation, municipal, and industrial wells in this area. The relatively coarse-textured sand and gravel that constitutes the lowermost part of the valley fill under much of the terrace surfaces is quite permeable. In most places it lies below the water table and is saturated with water. Along many of the major valley courses ground water moves from the adjacent Ogallala formation and Crete sand and gravel member of the Sanborn formation laterally into the terrace deposits, thus contributing to the replenishment of water in this material. The major stream channels lie below the water table and are fed by ground-water seepage throughout their courses across Norton and Phillips Counties. The relatively shallow depth to the deposits and shallow static level contribute to the availability of ground-water supplies from terrace deposits. The chemical character of water obtained from these materials is shown by the analyses in Tables 5 and 6 and Figures 9 and 10.

ALLUVIUM (RECENT SERIES)

In major valleys.—Deposits of alluvium occur along the valleys and underlie the flood plains of all the major valleys of this area. The alluvium consists predominantly of sand and gravel with some silt and very small amounts of clay. In most cases the valley flat or flood plain that forms the upper surface of the Recent alluvium along Solomon River and Prairie Dog and Sappa Creeks is from 15 to 25 feet below the adjacent terrace surfaces. The flood plains in turn stand pronouncedly above the channel floors. There are indications that these flood plains are being built upward by deposits of sand and silt during each major flood; thus the alluvial deposits of this area are still in the process of accumulating.

The areal extent of alluvium in the major valleys is shown on the geologic map (Pl. 1). Detailed information concerning thickness of Recent alluvium is not generally available as only a few test holes were drilled on the flood-plain surface. The inferred thickness in many places is shown by the cross sections in Plate 3.

The body of ground water contained in the terrace deposits is continuous with the water in the alluvium, and wells drilled into this material should obtain large quantities of water at shallow depths. Their small areal extent, however, renders them a minor source of water in this area.

In tributary valleys.—The character of the alluvium occurring in the valley flats of tributary streams is quite diverse. This is largely because alluvial deposits are representative of the rocks underlying their drainage basins. The source of sediments varies from one tributary valley to another. As a result, where the watershed is underlain by rocks of the Ogallala formation, the alluvial deposits consist predominantly of fragments of Ogallala rocks. Likewise, where the watershed is underlain largely by rocks of Niobrara formation, the alluvium contains an abundance of water-worn pebbles and grains of Niobrara chalk. For this reason it is impossible to generalize concerning all the tributary valleys of the area. For the most part, however, in their lower courses they contain coarse alluvial material saturated in part and serve as a source of moderate supplies of ground water of variable quality to wells. Chemical analyses of water obtained from wells in the alluvium are given in Tables 5 and 6 shown on Figure 10.

Geomorphology

The development of the present topography of Norton County and northwestern Phillips County has been entirely in response to events during Pleistocene and Recent times. During Pliocene time streams flowing east and southeast from the Rocky Mountain region deposited sediments which accumulated in the lower parts of former broad valleys and later, as these valleys were filled, the streams shifted laterally and developed an extensive almost featureless plain of alluvium (Frye, 1945). Early in Pleistocene time the then-existing streams, in response to climatic or structural control, started to cut valleys below the surface of this vast constructional plain. The nature of events in this area during earliest Pleistocene time is not known because deposits of Nebraskan and Aftonian age have not been found. Furthermore, only scattered remnants of deposits of Kansan and Yarmouthian age have been observed in the area. They are adequate, however, to indicate that by Kansan time the major valleys had become entrenched approximately halfway from the surface of the Ogallala alluvial plain to the present maximum depth of bedrock cutting, and that these Kansan-Yarmouthian valleys were later alluviated.

By Illinoian or Sangamonian time, the bedrock floors of the major valleys had been cut to within approximately 30 feet of the present bedrock floors, and the major valleys were again alluviated, as is demonstrated by the deposits of the Crete sand and gravel member of the Sanborn formation. The rapidly aggrading valley floors of this age probably served as a source of eolian silts that were spread over the uplands and on valley slopes and which now constitute the Loveland member of the Sanborn formation. Late Sangamonian time represented a period of essential equilibrium when the topography was more subdued than now and the area was not being actively eroded. Prevalent grasslands of that time aided the development of the deep Loveland soil.

The period of erosion during which the Loveland surface was dissected and valleys were cut below the level of the Crete sand and gravel member of the Sanborn formation must have been followed by rapid alluviation which brought a large quantity of fine sediments into the valleys of this region. This is suggested by the extensive deposits of eolian silt which form a nearly continuous blanket over the upland areas and valley slopes, and which are here classed as the Peoria member of the Sanborn formation. The fact that the Peoria deposits are for the most part eolian in origin is attested by their uniformly fine texture, lack of bedding, molluscan fauna, stratigraphic position above an extensive well-developed soil undisturbed by physical processes, and by the topographic position of these silts which form an almost unbroken blanket over the highest elements of the topography—uplands, parts of the valley slopes, and high terraces alike. No other known process of transportation and deposition can account for these facts.

The Bignell silt member of the Sanborn, which occurs at scattered localities above the Peoria member, attests to minor recurrence of comparable conditions during latest Pleistocene time. That the topography and drainage pattern acquired its present aspect by about mid-Pleistocene time is suggested by the general concordance of the Loveland soil topography with the present topography and the parallelism of the Crete sand and gravel member of the Sanborn with the major terrace deposits and present channel course. These same data, however, demonstrate that the local relief has increased markedly since mid-Pleistocene time, both by the dissection and lowering of the major valley levels and by an increase in height of many of the upland areas by the deposition of several feet of eolian silt. The presence of undistorted fossil rodent burrows, terminating at the top of the Loveland soil, extending downward into the Loveland silt member, and containing fossil *Citellus richardsonii*, strongly suggests that these deposits have not moved down slope by creep except in local areas. Greater relief and steeper slopes existing at the present time, however, are more conducive to creep, and at many places where a thin silt mantle overlies sloping surfaces on the Ogallala formation small slump terraces, sometimes referred to as "catsteps," can be observed (Pl. 10A).

Several physiographic features worthy of note are suggested by the geologic map. At several locations along the major valleys, particularly west of Almena, streams have breached saddles in narrow spurs, leaving isolated remnants of earlier Pleistocene deposits projecting as hills above the prominent terrace surfaces. The sharp hairpin turn in the course of Prairie Dog Creek, which now reverses the direction of flow in the vicinity of Woodruff and passes to the west and northwest around a hill capped by the resistant silicified lentils of the Ogallala formation, is also of interest. The earlier Pleistocene course of Prairie Dog Creek is thought to have been, at least in part, through the saddle south of this resistant hill, and the deposits are now exposed in the cut along the Chicago, Burlington, and Quincy Railroad. This anomalous course of Prairie Dog Creek is thought to have given rise to the long parallel tributary Elk Creek and the development of gentle, almost imperceptible natural levees along the main stem of Prairie Dog Creek.

GROUND WATER

Source

The following discussion on the source and occurrence of ground water has been adapted from Meinzer (1923, pp. 2-102) and the reader is referred to his report for a more complete discussion of the subject. A summary of ground-water conditions in Kansas has been made by Moore (1940).

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

In Norton and northwestern Phillips Counties, as in other parts of the central Great Plains, ground water is derived almost entirely from precipitation in the form 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 part 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. In the southern High Plains the average amount of rainfall entering the ground-water body each year has been determined by two different investigations as about one-fourth inch (Frye, 1942, p. 66) and as about one-half inch (Theis, Burleigh, and Waite, 1935, pp. 1-4). The geologic conditions in this area are somewhat different from those in the two areas farther south, but the average annual rainfall is only a few inches more and the amount of rainfall reaching the ground-water body is probably of the same order of magnitude. Although this is a small percentage of the annual rainfall, it should be noted that one-half inch of water entering the ground-water reservoir under 1 square mile amounts to 8,689,348 gallons, or 26.6 acre-feet.

Ground water moves slowly through the rocks in directions determined by the shape and slope of the water table, which is controlled by topography, local variations in the quantity of recharge or discharge, and the stratigraphy and structure of the rocks. It is eventually discharged through springs or wells, through seeps into streams, or by evaporation or transpiration in bottom lands adjacent to streams. Most of the water obtained from wells in Norton County and northwestern Phillips County comes from precipitation in the general vicinity and adjacent areas to the west.

Occurrence

Nearly all rocks that underlie the surface of the earth at depths shallow enough to be penetrated by drills contain voids or interstices. These range in size from microscopic openings to the large caverns developed in limestone regions. The percentage of the volume of the rock mass consisting of such open spaces is known as the porosity. Although it is desirable when considering problems of ground-water supply to know the porosity of the strata under an area, it is the permeability of the material that influences the amount of ground water which can move through it toward a pumping well. The permeability of a rock is determined by the size, shape, and arrangement of the openings. For instance, a bed of fine silt or clay might 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 very thin layer of water on the surface of each grain, these layers of water (that are not free to move) might fill or almost fill all 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 might 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 texture to porosity are shown in Figure 4.

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). It may also be regarded as the boundary between the zone of saturation and the zone of aeration. The water table is not a level surface but rather is generally a sloping

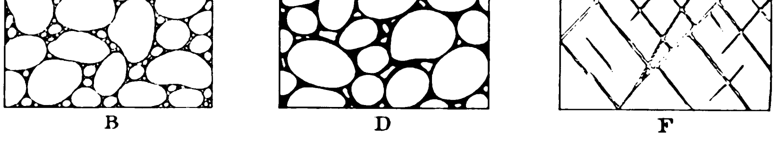

FIG. 4.—Diagram showing several types of rock interstices and the relation of rock texture to porosity. *A*, Well-sorted sedimentary deposit having a high porosity; *B*, Poorly sorted sedimentary deposit having low porosity; *C*, Well-sorted sedimentary deposit consisting of pebbles that are themselves porous so that the deposit as a whole has a very high porosity; *D*, Well-sorted sedimentary deposit 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 O. E. Meinzer)

surface having many irregularities caused by differences in permeability or thickness of the water-bearing materials or by unequal additions to or withdrawals from the ground-water reservoir at different places.

The shape and slope of the water table in Norton and northwestern Phillips Counties are shown on the map (Pl. 2) by means of contour lines drawn on the water table. Each point on the water table along a given contour line has the same altitude. These water-table contours show the configuration of the water surface just as contours on a topographic map show the configuration of the land surface. The direction of movement of the ground water is at right angles to these contour lines—in the direction of the greatest slope.

Plate 2 shows the location of all water wells in which depth to water level was measured, the location of test holes drilled with the State Geological Survey's hydraulic rotary drilling machine, and the sea-level elevation of the water surface at various points along the channels of the main streams. These various data were utilized in the preparation of the water-table contour map, which is generalized because the wells are not close enough to allow detailed control in variable materials such as the Ogallala formation. Also, it was impossible to show minor variations in the water table produced by the deeper parts of many of the tributary valleys. It should be noted that contours have not been drawn for several local areas, particularly in the southeastern corner of Norton County, because in such areas the surficial mantle of Tertiary and Quaternary sediments is thin or absent. This lack of contour lines should not be construed, however, to mean that ground water is not present in the area. In the uncontoured localities of southeastern Norton County some wells obtain water from local alluvial deposits, and deep drilled wells obtain water from Cretaceous rocks.

The map shows that ground water moves under the plains in a general easterly direction across this area, and moves out from the major divide areas toward the principal valleys. The direction of flow of ground water toward the major valleys generally makes an oblique angle upstream with them, and some water may move in a direction essentially parallel to the divides for long distances under the interstream areas. Owing to the great variation in direction of ground-water flow, the gradient of the water table varies greatly. Under the major divide crests it has a general easterly slope of as little as 5 feet per mile. However, along the flanks of the major valleys the water table attains a gradient of as much as 50 feet per mile.

All the major streams of Norton and northwestern Phillips Counties exert an important influence on the shape of the water table. In the divide areas ground water moves down slope toward these streams through Ogallala formation, terrace deposits, and alluvium, and is discharged into the channel by seepage along its banks. However, most of the tributary valleys, except in their lower parts, are well above the water table and during periods of flow lose water by seepage rather than gain it. These two relationships of streams to the water table are called influent, for streams that lose water to the water table, and effluent, for streams that gain water from the water table. They have been described by Meinzer and are illustrated in Figure 5.

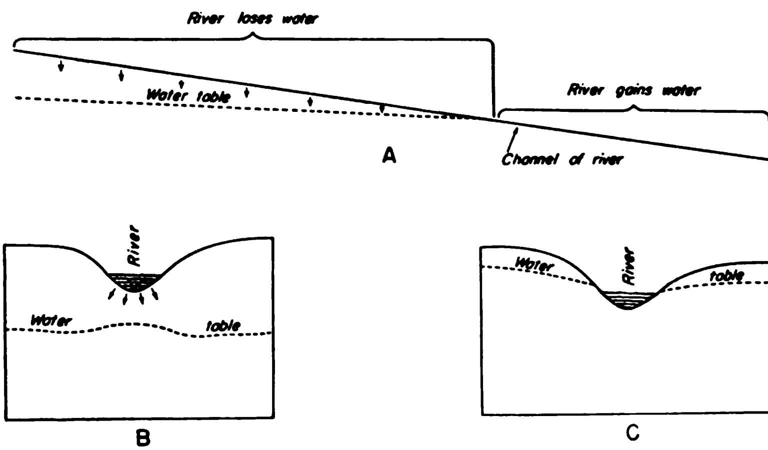

FIG. 5.—Diagrammatic sections showing influent and effluent streams. (From O. E. Meinzer.)

RELATION TO TOPOGRAPHY

In general the shape of the water table conforms to the regional topography, but it is little affected by minor or local features. That is, the water table slopes upward under the major divide areas to a crest about midway between the major streams, but it is at a greater depth under the divide areas than it is in the valley areas. It might be said that the hills on the water table are not as high as the hills on the surface. Plate 2 shows that the depth to water in some wells in the uplands is as much as 175 feet, whereas the depth to water under the prominent terrace surface along the major valleys is generally less than 40 feet, and in some wells dug or drilled into the alluvium it is less than 10 feet. For the most part, minor topographic features such as the headwater areas of tributary valleys have little or no effect on the water table. For this reason a well drilled in a small valley in the uplands will generally encounter water at a shallower depth than a well drilled on a nearby divide, although the water level in the two may be at about the same elevation with reference to sea level.

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 will rise. Conversely, if the draft exceeds the inflow, the water table will decline. Thus the rate and magnitude of fluctuations of the water table depend upon the rate and magnitude at which the underground reservoir is replenished or depleted.

Factors controlling the rise of the water table in this area are the amount of rainfall that descends 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 water entering the county beneath the surface from areas to the west and south. All these factors depend upon precipitation, either in this area or immediately adjacent to the western edge of Norton County.

Factors controlling the decline of the water table are the amount of water pumped from wells, the amount of water absorbed directly from the water table by plants (transpiration), the amount of water lost from the ground-water reservoir by evaporation, the amount of ground water entering surface streams by channel-bank seepage, and the amount of water passing beneath the surface into adjacent areas.

Changes in the water levels in wells record the fluctuations of the water table, which in turn record the recharge and discharge of the ground-water reservoir. In order to determine the character and magnitude of water-level fluctuations in this area, a group of wells was selected for observation and periodic measurement of the water levels in them was begun in 1947. Complete records of these wells are to be published annually by the Federal Geological Survey.

The fluctuations of water level in four observation wells in Norton and Phillips Counties and the monthly precipitation near Norton and at Long Island for the period 1945 through 1947 are given in Figures 6 and 7. The period of observation measurements in these wells is as yet too short to permit definite correlation between precipitation and recharge. Nevertheless, the general concordance between rising water levels and high precipitation is indicated.

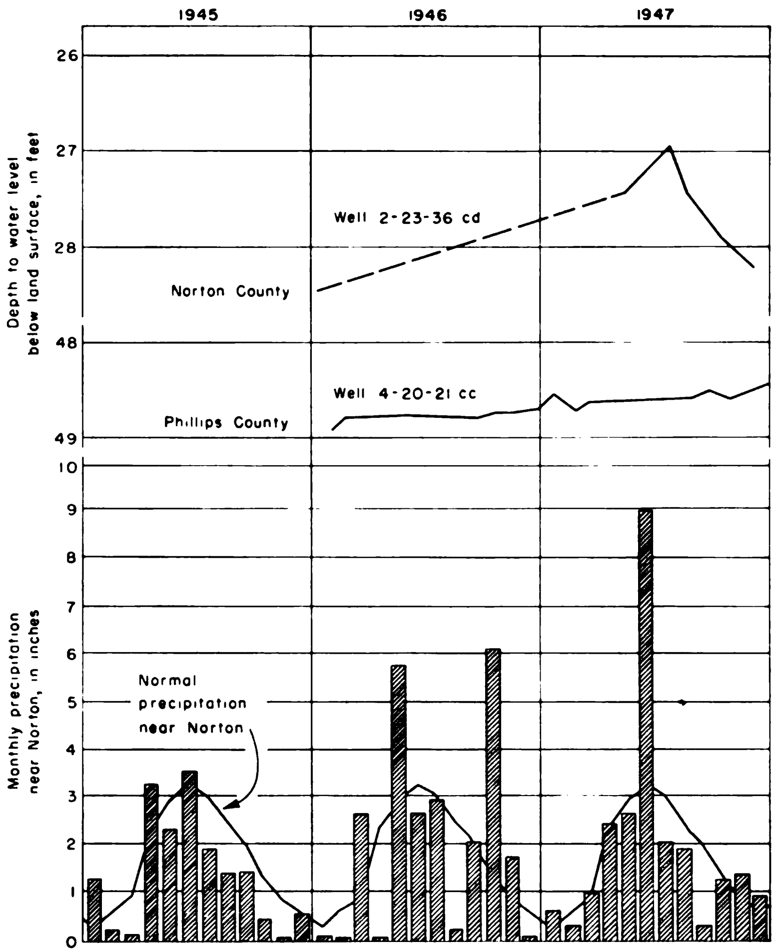

FIG. 6.—Hydrographs of two observation wells and monthly precipitatation (1945-47) near Norton. (Precipitation data from U. S. Weather Bureau.)

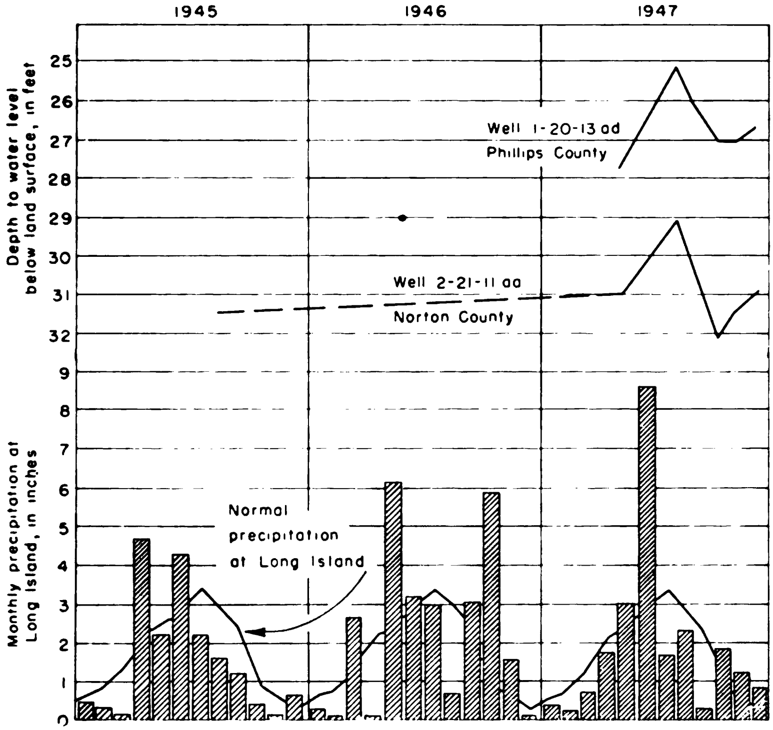

FIG. 7.—Hydrographs of two observation wells and monthly precipitation (1945-47) at Long Island. (Precipitation data from U. S. Weather Bureau.)

RECHARGE

Recharge is the addition of water to the underground reservoir and may be accomplished in several ways. All ground water within a practicable drilling depth in Norton and northwestern Phillips Counties, with the possible exception of that obtained from some of the Cretaceous rocks, as in the southeastern part of Norton County, is derived from water that falls as snow or rain either within the area or on nearby areas to the west. Once the water becomes a part of the ground-water body it moves down the slope of the water table, later to be discharged for the most part into the channels of the major streams of this area or those areas immediately adjacent to the east and northeast, or by transpiration in the shallow water areas.

Recharge from local precipitation.—The normal annual precipitation in this area is about 21 inches, but probably only a small fraction of this amount enters the zone of saturation, thus to recharge the ground-water reservoir. The depth to the water table exerts an important influence on the amount and frequency of recharge, as does the type of material occurring above the water table. That is, the broad flat terrace surfaces and flood plains of North Fork Solomon River and Prairie Dog and Sappa Creeks, where the water table lies relatively near the surface and is overlain by unconsolidated deposits of sand and sandy silt, represent areas of relatively high recharge. On the other hand, maturely dissected divide areas characterized by channels and steep slopes, where the water table lies at considerable depth below the surface and is overlain by the Ogallala formation and massive silts and buried soils of the Sanborn formation, represent areas of relatively small recharge. Recharge into the small areas of outcropping Cretaceous rocks may vary widely, as little water can penetrate the almost impervious chalky shales and black fissile shales which typify these formations. However, in areas where faulting has occurred, where joints are well developed, or where solution has opened up small channelways in the chalk, recharge may be relatively high.

Recharge from streams and ponds.—All three of the major streams crossing this area occur below the water table and are receiving water from the ground-water reservoir. Therefore they do not constitute sources of recharge to the ground-water body, except in rare instances in local areas where heavy pumping from wells may have lowered the water table below channel level. The upper courses of tributary streams, however, occur 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 join the general body of ground water.

A relatively large number of surface ponds have been constructed in Norton County (Moore, 1940, p. 55). Where such ponds contain water, occur above the water table, and are underlain by permeable material, they constitute a source of recharge to the ground-water body. However, where the ponds are well sealed to prevent downward leakage, they have small effect in recharging the ground-water reservoir.

Recharge from subsurface inflow.—As indicated by the slope of the water table (Pl. 2), the movement of ground water under the major divides is in an easterly direction. Hence a small amount of recharge from precipitation that occurs in eastern Decatur County moves into western Norton 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 Norton and Phillips Counties. Water has been thought to enter these rocks along their outcrop belt east and southeast of this area, and to move westward to replenish the supply under these counties. However, the Cretaceous rocks in southeastern Norton County dip eastward toward the outcrop areas, and the wells which penetrate these rocks in that part of the area encounter water that is under artesian pressure, so that at some places the piezometric surface is more than 100 feet above the level at which the water was encountered. These facts, together with the folding and faulting noted in the Cretaceous rocks in many places, suggest that the source of the water in these beds is either in or adjacent to this area or west of it, where the land surface is higher and would contribute to the development of hydrostatic pressure.

DISCHARGE

Natural discharge at the surface.—Before any wells were drilled the ground-water reservoir of Norton and northwestern Phillips Counties was in a state of approximate equilibrium—that is, the average annual recharge was balanced by an approximately equal average annual discharge. The greater part of this discharge occurred by ground-water movement into the major stream channels and eastward under the divide areas out of the counties, and by transpiration by plants in the areas of shallow water. The factors producing discharge by seepage into major stream channels have been changed little, and seepage likely accounts for the major part of the ground-water discharge in the area.

Discharge from wells.—At the present time wells constitute one of the principal means of discharge of ground water. Although the total quantity of water pumped annually from wells is not known, all city supplies and some irrigation supplies have been obtained from wells. Most of the rural residents of these counties obtain their domestic and stock supplies from wells, but the total volume of water pumped for such uses is comparatively small.

Recovery

PRINCIPLES OF RECOVERY

When water is withdrawn from a well there is a difference in head between the water inside the well and the water in the surrounding material for some distance from the well. The water table in the

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vicinity of the well develops a cone of depression (Fig. 8). In any given well a higher pumping rate produces a greater drawdown (depression of the water level, commonly expressed in feet), and the diameters of the cone of influence and of the area of influence will be greater.

The specific capacity of a well is its rate of yield per unit of drawdown, and it is generally stated in gallons a minute per foot of drawdown after a specified period of pumping. When a well is pumped the water level drops rapidly at first and then more slowly, and it may continue to decline until a balance is established between recharge and pumping. In testing the specific capacity of a well,

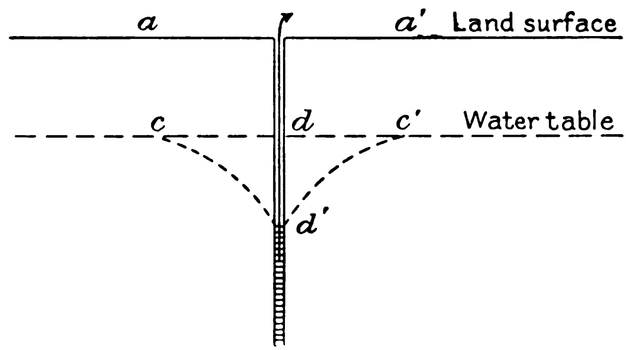

FIG. 8.—Diagrammatic section of a well that is being pumped showing drawdown (dd'), cone of influence (cc'd'), and area of influence (aa'). (From O. E. Meinzer.)

therefore, it is important to continue pumping until the water level remains approximately stationary. When the pump is stopped the water level rises rapidly at first, then more slowly, and may continue to rise long after pumping has ceased (Fig. 9).

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

TYPES OF WELLS

Dug wells.—Dug wells are excavated with picks, shovels, spades, or power machinery. They generally are between 2 and 10 feet in diameter and are quite shallow. Many of the early wells in this area were dug by hand, but many of these have since been replaced

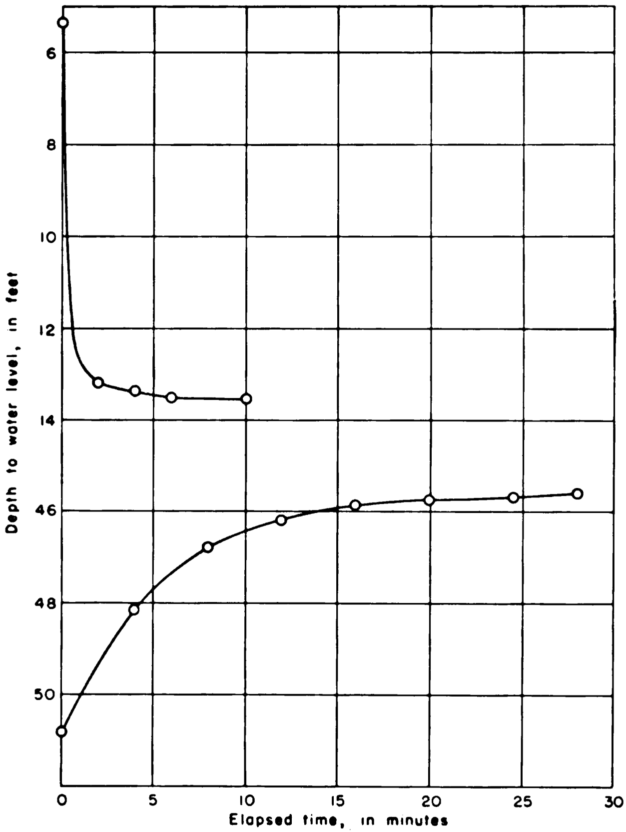

FIG. 9.—Drawdown curve of city well at Lenora, and recovery curve of a city well at Norton. All measurements were made by steel tape during the field season of 1945.

by drilled wells. A few dug wells now are in use in the major valleys. Of the 285 wells listed in Table 8 only 28 are dug wells, 10 are bored wells, and 247 are drilled wells.

Bored and driven wells.—Bored wells are made by augers or post-hole diggers. Some wells are bored to the water-bearing formation, and a well point is then driven into the sand or gravel from which the water is obtained. In some shallow-water areas well points are driven from the surface without recourse to boring. These are called driven wells. Bored and driven wells are in use in the valley areas and at some places on the uplands.

Drilled wells.—A drilled well is one that is excavated by means of a percussion or rotary drill. Many of the wells in Norton County and northwestern Phillips County are drilled wells. The drilled domestic and stock wells generally are 6 inches in diameter and those used for irrigation and public supply purposes generally are 14 to 18 inches in diameter.

All the wells in this area, with the exception of the few deep wells penetrating Cretaceous rocks, obtain water from relatively unconsolidated deposits. Wells in such deposits generally are cased nearly to the bottom of the hole with galvanized or wrought-iron casing. In some wells the water may enter only through the open end of the casing, but to provide greater intake facilities a strainer or well screen may be used or the casing may be perforated below the water table. The size of the perforations is an important factor in the construction of a well and the capacity or even the life of the well may be determined by it. If the perforations are too large the fine material may filter through and fill the well; if the perforations are too small they may become clogged so that water is prevented from entering the well freely.

Some wells in unconsolidated sediments are equipped with well screens. It is good practice to select a slot size that will pass 30 to 60 percent of the water-bearing material, depending on the texture and degree of sorting. The coarser particles that remain around the screen form a natural gravel pack which increases the effective diameter and therefore the capacity of the well.

Gravel-wall wells generally are effective for obtaining large supplies of water from relatively fine-grained unconsolidated deposits and have been used for public supply and irrigation. In such wells a large-diameter hole is first drilled with a rotary drill or excavated by a hoist and orange-peel bucket and temporarily cased with unperforated casing. A well screen or perforated casing is then centered in the hole opposite the water-bearing material and enough blank casing added to reach the surface. The space between the two casings is filled with carefully screened gravel and all but 20 or 30 feet of the outer casing is pulled from the hole. A packing of a well-sorted medium to coarse gravel generally gives the best results, but where the water-bearing material is extremely fine a coarse sand or fine gravel may be preferred. The slots in the screen or casing should be as large as possible without permitting entry of the gravel used for packing the well. If the water-bearing formation consists of well-sorted coarse gravel the capacity of the well probably will not be increased by addition of a gravel pack around the screen.

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

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

A report (Davison, 1939) containing descriptions of different types of pumping plants, the conditions for which each is best suited, construction methods, and a discussion of construction costs is available from the Division of Water Resources, Kansas State Board of Agriculture, Topeka, Kansas, and the reader is referred to this publication for additional details of well construction.

METHODS OF LIFT AND TYPES OF PUMPS

Water from many of the domestic and stock wells in this area is obtained by wind-mill-operated lift or force pumps. The cylinders or working barrels in both lift pumps and force pumps are similar and are located below the land surface, either above or below the water surface, but a lift pump is capable of discharging water only at the pump head, whereas a force pump can raise water above this point—such as to an elevated tank. Pitcher pumps are used on some dug or bored wells in the shallow-water areas of the major valleys. Most of the pitcher pumps and a few of the lift and force pumps are hand-operated.

Several types of power-driven pumps are in use in the irrigation and city wells. For the most part these are turbine pumps and are powered by electric motors, stationary gasoline engines, and tractor engines. Data concerning such wells are given in Table 8.

Utilization

During the course of this investigation data on 241 wells in Norton County and 44 wells in northwestern Phillips County were obtained. All types of wells in all parts of the area were visited. Of the 285 wells listed in Table 8, 86 were used for stock water, 46 for domestic supplies, and 101 for both purposes. Of the remaining wells, 14 were used for public supply and 17 for irrigation; 21 were not in use at the time they were visited. Although Table 8 includes only part of the domestic and stock wells in the area, all the public supply and irrigation wells that could be located during the course of the field work were visited and are listed in the table.

DOMESTIC AND STOCK SUPPLIES

Nearly all the domestic supplies and many of the stock supplies in rural areas are obtained from wells. In parts of Norton County ponds are used to some extent to supply stock water. The domestic use of water generally includes drinking, cooking, washing, and in some cases the disposal of sewage. In this area the ground water generally is satisfactory for all domestic purposes (see Quality of Water), and can be obtained in sufficient quantities for such uses at nearly any locality.

PUBLIC SUPPLIES

Four municipalities in Norton County and one in northwestern Phillips County have public water supplies obtained from wells.

Almena.—The City of Almena, located in the Prairie Dog Creek Valley in northeastern Norton County, obtains its water supply from two wells (2-21-8ca and 2-21-8dc) drilled into sand and gravel deposits underlying the prominent Almena terrace surface. Water is pumped from these wells to a steel standpipe located on the bluffs of Prairie Dog Creek Valley on the south side of the city. The storage tank has a reported capacity of 90,000 gallons. Each of the two wells is pumped with a turbine pump powered by an electric motor; they have rated capacities of 150 and 250 gallons per minute. The reported maximum daily capacity of the system is 72,000 gallons but the average daily consumption is not known. Data on the wells are given in Table 8 and a chemical analysis is given in Table 5. The water is of good quality and is not treated.

Clayton.—The City of Clayton, located at the western edge of Norton County in the Prairie Dog Creek Valley, obtains its water supply from one well (4-25-6ab) drilled into the terrace deposits. Water is pumped from this well into a concrete storage tank on the southeast side of town, which provides capacity for 50,000 gallons. The maximum daily use of water in Clayton is reported to be 9,000 gallons and the annual use is reported to be about 300,000 gallons. Data on the well are given in Table 8 and a chemical analysis of the water is given in Table 5. The water is of good quality and is not treated.

Lenora.—The City of Lenora, located in the valley of North Solomon River in southwestern Norton County, obtains its water supply from one well (5-24-14cb) drilled in the alluvium of North Fork Solomon River. The water is pumped with a 4-inch centrifugal pump powered by an electric motor and a standby pump powered with a gasoline engine is provided in the well house. Water is pumped from the well to an elevated standpipe with a reported storage capacity of 50,000 gallons. Data on the well are given in Table 8 and a chemical analysis of the water is given in Table 5. The water is of good quality and is not treated.

Long Island.—The City of Long Island, located in northwestern Phillips County in the Valley of Prairie Dog Creek, obtains its water supply from two wells (1-20-23da1 and 1-20-23da2) drilled into the deposits underlying the prominent terrace surface. Water is pumped from the wells to an elevated steel storage tank with a reported capacity of 30,000 gallons in the northern part of town. Reported maximum daily use is 26,000 gallons, and 4,900,000 gallons was used from June 1, 1946, to June 1, 1947. Data on the wells are given in Table 8 and a chemical analysis of the water is given in Table 5. The water is of good quality and is not treated.

Norton.—Norton, the county seat of Norton County and largest city in the area covered by this report, obtains its water supply from six wells drilled into the deposits underlying the dominant terrace level along Prairie Dog Creek Valley. Each of the six wells is pumped with a turbine pump powered by electricity and has a rated capacity of 250 gallons per minute. Water is pumped from the wells into a collecting reservoir with a capacity of 360,000 gallons located near the municipal power plant. The water from the collecting reservoir is pumped to the city distribution system by three high-service pumps having a combined capacity of approximately 1,400 gallons per minute. An elevated storage tank with a capacity of 250,000 gallons is located in the northwestern part of the city. The annual pumpage of water by the city generally exceeds 100,000,000 gallons and the largest pumpage recorded is for 1946 when 181,474,600 gallons of water was pumped. Pumpage data for the period 1930 through 1947 are given in Table 4. The rated daily capacity of the system is 1,730,000 gallons. Data on the wells are given in Table 8 and a chemical analysis of the water is given in Table 5. The water is of good quality and is not treated.

IRRIGATION SUPPLIES

A relatively small amount of water has been pumped for irrigation use in Norton County and northwestern Phillips County. The Division of Water Resources of the Kansas State Board of Agriculture lists 575 acres under irrigation in Norton County in 1943. For the most part irrigation has been by well water, but in a few places some water has been pumped from major stream channels for irrigation purposes. At the time field work was in progress for this investigation, irrigation was restricted to the terrace surfaces along three major valleys of the area studied. Seventeen irrigation wells were visited, and data concerning them are given in Table 8. Chemical analyses of the water obtained from several of these wells are given in Tables 5 and 6. The yields of the irrigation wells visited vary widely, but several of them have reported yields well in excess of 1,000 gallons per minute.

TABLE 4.—*Annual pumpage of water by the city of Norton, 1930-47* (Data furnished by Lloyd Johnson, City Engineer).

Year	Water pumped (millions of gallons)
1930	135
1935	131
1940	116
1941	104
1942	89
1943	136
1944	115
1945	121
1946	181
1947	168

The quantity of water available for possible future irrigation supplies varies widely throughout this area. The terrace deposits along the three major valleys present the most adequate source of ground water for irrigation. Also, the water table is relatively near the surface and is uniform in slope under these generally flat terrace surfaces. The water-table contours on Plate 2 show that water is moving from the divide areas into the deposits underlying the terrace surfaces, so that these deposits are supplied with ground water not only from recharge by precipitation on their surfaces but also from recharge that occurs in the broad divide areas. Furthermore, the stream channels of the three major valleys are essentially at water-table level; therefore, in areas where local cones of depression are developed which might lower the level of the water table below the stream channel some additional recharge might be obtained by water entering the ground from the stream channels. Owing to the lenticular nature of the alluvial deposits underlying the major terraces, however, it is advisable to drill test holes to determine the amount of saturated sand and gravel at any locality before an irrigation well is constructed there.

The area underlain by the Crete sand and gravel member of the Sanborn formation, generally along the north side of Prairie Dog Creek Valley, probably represents the second most likely source of irrigation water. Here water generally moves from the divide area on the north and aids in the replenishment of the supply in these sands and gravels. However, the Crete sand and gravel has been dissected by many tributaries, and the bedrock floor below the sand and gravel deposits is somewhat uneven. For these reasons the quantity of water available in this area varies widely, and careful test drilling should be done before any irrigation well is constructed.

A third area in which quantities of water adequate for irrigation purposes might be obtained is the upland divide area between Sappa and Prairie Dog Creeks in northwestern Norton County. The cross sections in Plate 3 show a relatively great thickness of saturated sand and gravel underlying this divide, with the water table generally at a depth of more than 100 feet below the surface. However, only relatively meager subsurface data on this area are available and special caution should be used in planning any irrigation in this area.

It is unlikely that the Ogallala formation, except in northwestern Norton County, will yield adequate supplies of water to wells for extensive irrigation. Future test drilling, however, may reveal other small areas of the Ogallala formation where large supplies of water may be obtained. In the parts of the two counties where saturated deposits of Tertiary and Quaternary age do not generally occur and where the existing water wells draw upon supplies in the Cretaceous rocks, it is quite unlikely that adequate supplies of water for irrigation can be obtained.

For data concerning cost of pumping water for irrigation and construction of irrigation pumping plants the reader is referred to reports prepared by the Kansas State Board of Agriculture (Davison, 1939; McCall and Davison, 1939).

Quality

The chemical character of ground water in Norton County and northwestern Phillips County is indicated by the analyses in Tables 5 and 6, and in Figures 10 and 11. The analyses were made by Howard Stoltenberg in the Water and Sewage Laboratory of the Kansas State Board of Health and by the Quality of Water Branch of the Federal Geological Survey. Samples of water were collected for chemical analysis from 45 representative wells distributed as uniformly as possible within Norton County, but concentrated in the Prairie Dog Creek Valley of Phillips County. The water samples are representative of all the water-bearing formations of the area. Analyses of the water pumped from several municipal wells are also given in Table 5.

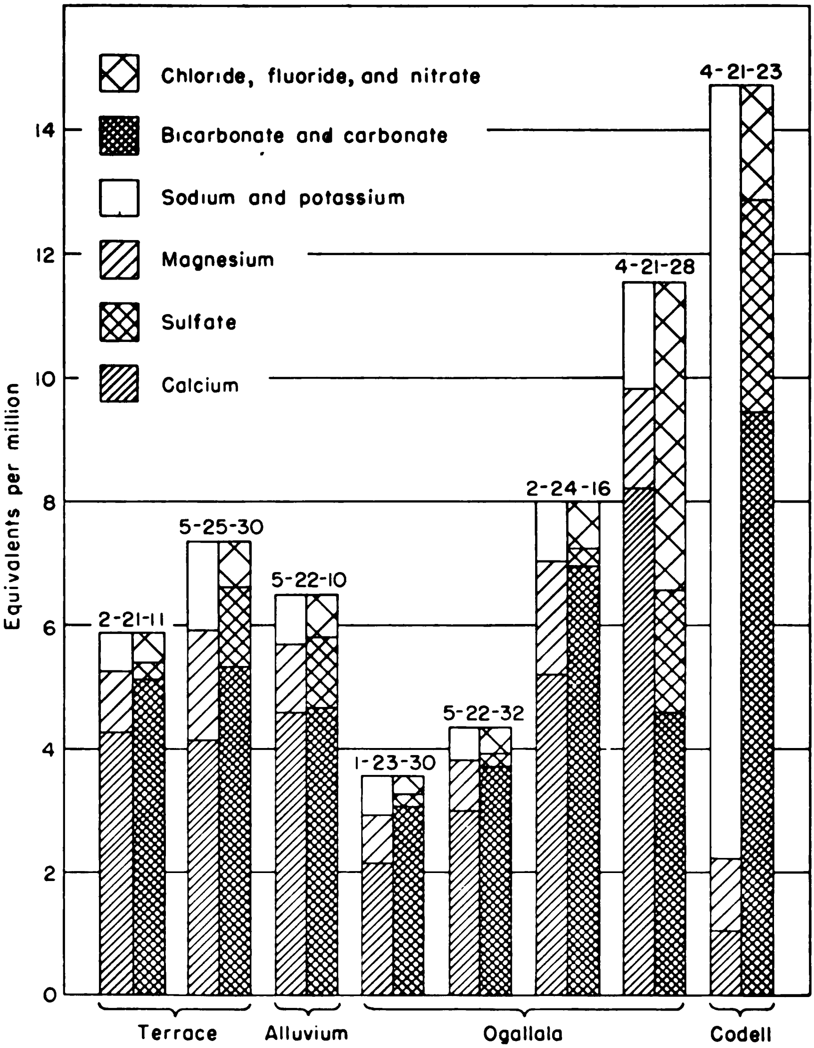

FIG. 10.—Analyses of water from the principal water-bearing formations in Norton County. The various constituents are shown by patterns and the number refers to the number of the well in this report.

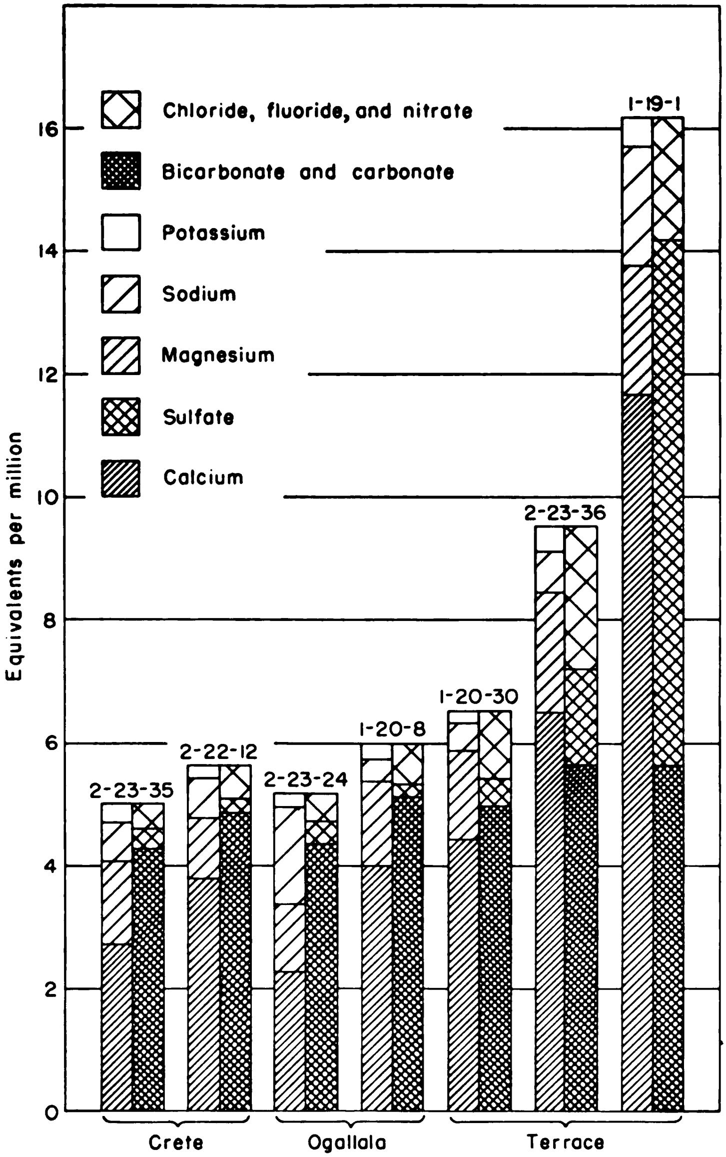

FIG. 11.—Analyses of water from the principal water-bearing formations in eastern Norton County and northwestern Phillips County. The various constituents are shown by patterns, and the number refers to the number of the well in this report.

TABLE 5. *Analyses of water from typical wells in Norton County, Kansas*

Analyzed by H. A. Stoltenberg. Dissolved constituents given in parts per million,[a] and in equivalents per million[b] (in italics)

No. on Plate 2	Location	Depth (feet)	Geologic source	Date of collection, 1946	Temperature (°F)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate
1-20-23da	Long Island City well (Phillips County)	46	Terrace	Jan. 18(c)	......	880	40	0.08	173 *8.63*	36 *2.96*	65 *2.81*	515 *8.45*	118 *2.45*	78 *2.20*	0.1 *0.01*	80 *1.29*	580	422	158
1-21-16dd	*T. 1 S., R. 21 W.* SE, SE, sec. 16	55.2	Ogallala	June 27	56	323	32	.57	80 *3.99*	16 *1.32*	12 *.53*	307 *5.03*	9.9 *.21*	19 *.54*	.4 *.02*	2.7 *.04*	266	252	14
1-22-14ba	*T. 1 S., R. 22 W.* NE, NW, sec. 14	67.4	do.	April 3	54	286	39	2.7	67 *3.34*	15 *1.23*	10 *.45*	279 *4.58*	9.5 *.20*	7.0 *.20*	.4 *.02*	1.3 *.02*	228	228	0
1-23-7da	*T. 1 S., R. 23 W.* NE, SE, sec. 7	108.2	do.	April 4	56	311	28	18	84 *4.19*	12 *.99*	12 *.53*	328 *5.38*	3.7 *.08*	8.0 *.22*	.3 *.02*	.88 *.01*	259	259	0
1-23-26aa	NE, NE, sec. 26	143.0	do.	April 3	55.5	285	48	.66	62 *3.09*	15 *1.23*	11 *.49*	270 *4.43*	8.6 *.18*	5.0 *.14*	.5 *.03*	1.8 *.03*	216	216	0
1-23-30aa	NE, NE, sec. 30	109.2	do.	April 4	54	196	18	31	43 *2.14*	9.3 *.76*	15 *.65*	189 *3.10*	9.1 *.19*	8.0 *.22*	.7 *.04*	0.0 *.0*	145	145	0
1-25-19aa	*T. 1 S., R. 25 W.* NE, NE, sec. 19	50.8	do.	June 24	58	296	41	3.4	62 *3.09*	17 *1.40*	15 *.65*	282 *4.62*	10 *.21*	7.0 *.20*	.6 *.03*	4.9 *.08*	224	224	0
1-25-24cc	SW, SW, sec. 24	95.6	do.	June 24	57	282	45	.33	61 *3.04*	16 *1.32*	9.9 *.43*	266 *4.36*	5.3 *.11*	6.0 *.17*	.3 *.02*	8.0 *.13*	218	218	0
2-21-8	*T. 2 S., R. 21 W.* Almena City wells	64	Terrace	Nov. 20	......	456	40	.06	104 *5.19*	19 *1.56*	26 *1.14*	436 *7.15*	15 *.31*	13 *.37*	.3 *.02*	2.2 *.04*	338	338	0
2-21-11aa	NE, NE, sec. 11	82	do.	April 5	56	338	39	.10	86 *4.29*	12 *.99*	14 *.59*	314 *5.15*	12 *.25*	11 *.31*	.3 *.02*	8.4 *.14*	264	258	6
2-22-9dc	*T. 2 S., R. 22 W.* SW, SE, sec. 9	93.3	Ogallala	June 27	58	333	40	.10	78 *3.89*	14 *1.15*	15 *.66*	283 *4.64*	14 *.29*	19 *.54*	.3 *.02*	13 *.21*	252	232	20
2-22-32bd	SE, NW, sec. 32	47.2	Terrace	April 3	55	442	35	7.7	101 *5.04*	22 *1.81*	29 *1.26*	439 *7.20*	26 *.54*	12 *.34*	.3 *.02*	.44 *.01*	342	342	0
2-24-16dc	*T. 2 S., R. 24 W.* SW, SE, sec. 16	148.5	Ogallala	June 24	56	454	42	.03	105 *5.24*	22 *1.81*	22 *.95*	428 *7.02*	12 *.25*	6.0 *.17*	.2 *.01*	34 *.55*	352	351	1
2-25-27ba	*T. 2 S., R. 25 W.* NE, NW, sec. 27	148.0	do.	June 27	57	278	41	.75	53 *2.64*	19 *1.56*	14 *.63*	266 *4.36*	6.2 *.13*	9.0 *.25*	.4 *.02*	4.4 *.07*	210	210	0
3-21-2dd	*T. 3 S., R. 21 W.* SE, SE, sec. 21	96.5	do.	April 4	56	263	31	8.0	64 *3.19*	14 *1.15*	6.7 *.29*	254 *4.16*	9.5 *.20*	5.0 *.14*	.4 *.02*	7.1 *.11*	217	208	9
3-21-27cc	SW, SW, sec. 27	40.1	Alluvium	June 27	56	306	34	1.2	70 *3.49*	17 *1.40*	13 *.55*	295 *4.84*	9.9 *.21*	9.0 *.25*	.5 *.03*	7.1 *.11*	244	242	2

	T. 3 S., R. 22 W.																		
3-22-9bb	NW, NW, sec. 9	70.2	Ogallala	April 4	56	259	27	4.9	69 *3.44*	10 *.82*	8.3 *.36*	259 *4.25*	7.0 *.14*	6.0 *.17*	.2 *.01*	3.3 *.05*	213	212	1
	T. 3 S., R. 23 W.																		
3-23-3	Norton City wells	58–70	Terrace and alluvium	Feb. 11	......	614	31	.48	136 *6.79*	24 *1.97*	30 *1.30*	410 *6.72*	120 *2.50*	27.0 *.76*	.3 *.02*	3.5 *.06*	438	336	102
3-23-27ba	NE, NW, sec. 27	153.3	Ogallala	June 26	57	266	41	1.7	61 *3.04*	10 *.82*	12 *.51*	207 *3.39*	17.0 *.35*	20 *.56*	.5 *.03*	2.7 *.04*	193	170	23
	T. 3 S., R. 25 W.																		
3-25-27ad	SE, NE, sec. 27	34.1	Terrace	June 27	56	395	41	.73	86 *4.29*	19 *1.56*	27.0 *1.16*	371 *6.08*	20 *.42*	16 *.45*	.4 *.02*	2.2 *.04*	292	292	0
	T. 4 S., R. 21 W.																		
4-21-23cd	SE, SW, sec. 23	364.2	Codell	June 27	59	852	12	.88	21 *1.05*	15 *1.23*	289 *12.56*	578 *9.48*	165 *3.43*	58 *1.64*	5.0 *.26*	2.1 *.03*	114	114	0
4-21-28ba	NE, NW, sec. 28	45.3	Ogallala	April 4	54	722	33	.64	165 *8.23*	20 *1.64*	40 *1.73*	277 *4.54*	96 *2.00*	108 *3.04*	.3 *.02*	124 *2.00*	494	227	267
	T. 4 S., R. 22 W.																		
4-22-29da	NE, SE, sec. 29	109.0	Ogallala	April 4	56	284	35	2.1	67 *3.34*	14 *1.15*	12 *.53*	279 *4.58*	9.5 *.20*	6.0 *.17*	0.4 *0.02*	3.0 *.05*	224	224	0
	T. 4 S., R. 23 W.																		
4-23-1ac	SW. NE. sec. 1	74.0	do	April 4	55	338	31	13	94 *4.69*	12 *.99*	6.7 *.29*	315 *5.17*	16 *.33*	8.0 *.22*	.2 *.01*	15 *.24*	284	258	26
4-23-19dc	SW, SE, sec. 19	145.3	do	June 26	57	294	33	4.4	73 *3.64*	15 *1.23*	7.6 *.33*	282 *4.62*	9.9 *.21*	7.5 *.21*	.4 *.02*	8.8 *.14*	244	231	13
	T. 4 S., R. 24 W.																		
4-24-31ac	SE, NE, sec. 31	30.6	Alluvium	June 26	55	266	36	.66	60 *2.99*	15 *1.23*	10 *.45*	261 *4.28*	4.9 *.10*	6.5 *.18*	.5 *.03*	4.9 *.08*	211	211	0
	T. 4 S., R. 25 W.																		
4-25-6ab	Clayton City well	51	Terrace	July 5	......	434	37	.00	90 *4.49*	22 *1.81*	27 *1.16*	377 *6.18*	28 *.58*	21 *.59*	.3 *.02*	5.3 *.09*	315	309	6
4-25-7da	NE, SE, sec. 7	120.0	Ogallala	June 27	57	285	34	1.3	67 *3.34*	15 *1.23*	9.2 *.40*	259 *4.25*	12 *.25*	11 *.31*	.3 *.02*	8.8 *.14*	228	212	16
	T. 5 S., R. 21 W.																		
5-21-16ba	NE, NW, sec. 16	309.5	Niobrara and Codell	June 25	58	384	9.2	4.6	12 *.60*	9.2 *.76*	129 *5.60*	340 *5.58*	40 *.83*	12 *.34*	3.4 *.18*	1.9 *.03*	68	68	0
	T. 5 S., R. 22 W.																		
5-22-10dd	SE, SE, sec. 10	34.9	Alluvium	June 26	58	397	45	.23	92 *4.59*	14 *1.15*	17 *.75*	281 *4.61*	58 *1.21*	11 *.31*	.4 *.02*	21 *.34*	287	230	57
5-22-32da	NE, SE, sec. 32	117.0	Ogallala	June 26	58	260	36	.97	61 *3.04*	10 *.82*	12 *.51*	227 *3.72*	11 *.23*	10 *.28*	.2 *.01*	8.0 *.13*	193	186	7
	T. 5 S., R. 24 W.																		
5-24-14cb	Lenora City well	29	Alluvium	Mar 23	......	719	24	0.0	138 *6.89*	27 *2.22*	44 *1.91*	393 *6.45*	119 *2.48*	51 *1.44*	.4 *.02*	39 *.63*	456	322	134
5-24-20bc	SW, NW, sec. 20	43.1	Terrace	April 4	56	449	45	0.4	124 *6.19*	19 *1.56*	6.7 *.29*	439 *7.20*	14 *.29*	11 *.31*	.5 *.03*	13 *.21*	388	360	28
5-24-24bc	SW, NW, sec. 24	53	do	June 26	55	427	35	0.0	105 *5.24*	22 *1.81*	16 *.71*	409 *6.71*	21 *.44*	14 *.39*	.5 *.03*	12 *.19*	352	336	16
	T. 5 S., R. 25 W.																		
5-25-30dd	SE, SE, sec. 30	33.4	do	June 26	55	420	32	0.0	84 *4.19*	21 *1.73*	33 *1.45*	328 *5.38*	61 *1.27*	22 *.62*	.6 *.03*	4.4 *.07*	296	269	27

a. One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.
b. An equivalent per million is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing the concentration in parts per million by the chemical combining weight of the substance or ion.
c. 1947.

TABLE 6.—*Analyses of water from typical wells in Almena Unit area, Norton and Phillips Counties, Kansas*

[Analyzed] by Quality of Water Branch, Federal Geological Survey, Lincoln, Nebraska. Dissolved constituents given in parts per million,[a] and in equivalents per million[b] (in italics)

No. on Plate 2	Location	Depth (feet)	Geologic source	Date of collection, 1947	Temperature (°F)	Dissolved solids	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)	Percent sodium	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	U.S.G.S. lab. sample No.
	T. 1 S., R. 19 W.																						
1-19-1db	NW, SE, sec. 1	46.7	Terrace	Dec. 18	55	1,020	42	0.1	234 *11.68*	25 *2.06*	44 *1.90*	17 *0.44*	353 *5.78*	402 *8.37*	48 *1.35*	0.3 *0.02*	35 *0.56*	0.07	1	687	289	398	3406
1-19-8cb	NW, SW, sec. 8	53.4	do.	Dec. 19	55	864	53	.05	160 *7.98*	42 *3.45*	46 *2.02*	25 *.64*	497 *8.14*	118 *2.46*	60 *1.69*	.15 *.01*	111 *1.79*	.09	14	572	408	164	3407
1-19-9cb	NW, SW, sec. 9	43	do.	Dec. 18	55	1,030	40	.10	202 *10.08*	39 *3.21*	71 *3.07*	20 *.51*	512 *8.39*	242 *5.04*	70 *1.97*	.3 *.02*	90 *1.45*	.12	18	664	419	245	3409
1-19-20dd	SE, SE, sec. 20	41.8	Alluvium	Dec. 19	56	1,880	25	.1	378 *18.86*	67 *5.51*	41 *1.79*	32 *.82*	269 *4.41*	272 *5.66*	160 *4.51*	.2 *.01*	768 *12.39*	.09	7	1,220	222	998	3411
	T. 1 S., R. 20 W.																						
1-20-8dd	SE, SE, sec. 8	97	Ogallala	Dec. 18	56	342	45	.08	82 *4.09*	16 *1.32*	8.5 *0.37*	8.1 *.21*	317 *5.20*	9.7 *0.20*	12 *0.34*	.2 *.01*	15 *.24*	.0	6	270	260	10	3401
1-20-11dc	SW, SE, sec. 11	70.2	do.	Dec. 18	55	297	43	.04	69 *3.443*	12 *0.987*	12 *.541*	5.7 *.146*	270 *4.430*	14 *.291*	11 *.310*	.4 *.021*	4 *.065*	.02	11	222	222	0	3402
1-20-30dd	SE, SE, sec. 30	45.4	Terrace	Dec. 17	56	393	40	.02	91 *4.54*	17 *1.40*	9.9 *.43*	7.8 *.20*	310 *5.09*	19 *.40*	18 *.51*	.2 *.01*	35 *.56*	.05	6	297	255	42	3412
1-20-32ad	SE, NE, sec. 32	50	do.	Dec. 17	55	682	26	.05	138 *6.89*	45 *3.70*	23 *1.01*	18 *.46*	498 *8.17*	148 *3.08*	28 *.79*	.1 *.0*	1 *.02*	.18	8	530	409	121	3405
	T. 2 S., R. 20 W.																						
2-20-1ab	NW, NE, sec. 1	32	Ogallala	Dec. 18	55	298	51	.02	71 *3.543*	12 *.987*	8.3 *.360*	5.5 *.141*	265 *4.343*	9 *.187*	16 *.451*	.5 *.026*	1.5 *.024*	.0	7	226	216.6	9.4	3413
2-20-5da	NE, SE, sec. 5	46	do.	Dec. 17	55	500	40	.05	123 *6.14*	16 *1.32*	12 *.50*	8.7 *.22*	328 *5.38*	50 *1.04*	45 *1.27*	.15 *.01*	30 *.48*	.0	6	373	269	104	3403
	T. 2 S., R. 21 W.																						
2-21-30cb	NW, SW, sec. 30	71.7	Terrace	Dec. 17	56	309	55	.12	75 *3.743*	13 *1.069*	13 *.559*	4.8 *.123*	302 *4.949*	8 *.167*	12 *.338*	.3 *.016*	1.5 *.024*	.0	10	241	241	0	3400
	T. 2 S., R. 22 W.																						
2-22-12ab	NW, NE, sec. 12	110	Crete	Dec. 17	55	327	44	.02	76 *3.792*	12 *.987*	16 *.685*	6.6 *.169*	298 *4.897*	11 *.229*	13 *.367*	.2 *.011*	8 *.129*	.06	12	239	239	0	3410
	T. 2 S., R. 23 W.																						
2-23-24da	NE, SE, sec. 24	66.5	Ogallala	Dec. 15	56	302	54	.04	47 *2.345*	13 *1.069*	35 *1.536*	8.6 *.220*	273 *4.474*	15 *.312*	10 *.282*	.4 *.021*	5 *.081*	.0	30	171	171	0	3408
2-23-35bb	NW, NW, sec. 35	113	Crete	Dec. 15	60	274	42	.08	55 *2.745*	16 *1.316*	14 *.630*	11 *.281*	262 *4.294*	14 *.291*	11 *.310*	.7 *.037*	2.5 *.040*	.0	13	203	203	0	3404
2-23-36cc	SW, SW, sec. 36	60	Terrace	Dec. 19	55	586	36	.02	131 *6.54*	23 *1.89*	15 *.66*	16 *.41*	349 *5.72*	72 *1.50*	47 *1.33*	.2 *.01*	60 *.94*	.0	7	422	286	136	3414

a. One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.
b. An equivalent per million is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing the concentration in parts per million by the chemical combining weight of the substance or ion.

CHEMICAL CONSTITUENTS IN RELATION TO USE

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

Dissolved solids.—The residue left after a natural water has evaporated consists of mineral matter, with which may be included some organic materials and a small amount of water of crystallization. Water containing less than 500 parts per million of dissolved solids generally is entirely satisfactory for domestic use, except for difficulties resulting from its hardness, and, in some areas, its excessive iron content. Water having more than 1,000 parts per million of dissolved solids is likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable in other respects.

The dissolved solids in samples of water collected from private wells in this area ranged from 196 to 1,880 parts per million. Water from 3 of the 45 wells sampled contained more than 1,000 parts per million of dissolved solids, and that from 8 other wells, between 500 and 1,000 parts per million. The average content for all waters analyzed is 440 parts per million, and only one sample showed less than 250 parts per million.

Hardness.—The hardness of water, which is the property that generally recieves the most attention, is commonly recognized by its effect when soap is used with the water; it produces a curdlike scum. Calcium and magnesium cause nearly all the hardness in most water. These constituents are also the active agents in the formation of the greater part of all the scale found in steam boilers and in other vessels in which water is heated or evaporated.

In addition to total hardness, the analyses indicate the carbonate hardness and the noncarbonate hardness of water. The carbonate hardness is that due to the presence of calcium and magnesium bicarbonate, and it is largely removed by boiling. In some reports this type of hardness has been called temporary hardness. The noncarbonate hardness is due to the presence of sulfates or chlorides of calcium and magnesium, which cannot be removed by boiling, and has sometimes been called permanent hardness. With reference to use with soap, there is no difference between the carbonate and noncarbonate hardness. In general, the noncarbonate hardness forms a harder adhering scale in steam boilers.

Water having hardness of less than 50 parts per million is generally rated as soft, and its treatment for removal of hardness under ordinary circumstances is not necessary. Hardness between 50 and 150 parts per million does not seriously interfere with the use of water for most purposes, but it does slightly increase the consumption of soap; its removal by a softening process is profitable for laundries or other industries using large quantities of soap. Water in the upper part of this range of hardness will cause considerable scale in steam boilers. Hardness exceeding 150 parts per million can be noticed by anyone; if the hardness is 200 or 300 parts per million it is common practice to soften water for household use or to install a cistern to collect soft rain water. Where municipal water supplies are softened, an attempt is generally made to reduce the hardness to about 60 parts per million. The additional improvement from further softening of an entire public supply is deemed not worth the increase in cost.

The hardness of water samples collected from wells in this area ranged from 68 to 1,220 parts per million and averaged 308 parts per million. Of the 45 samples, 3 have a hardness of less than 150 parts per million, 30 between 150 and 300 parts per million, and 12 more than 300 parts per million.

Iron.—Next to hardness, iron is the constituent of natural waters that receives the most attention. The quantity of iron in ground waters may differ greatly from place to place, even though the waters are from the same formation. If a water contains much more than 0.3 part per million of iron, the excess may separate out as a reddish sediment. Iron, which may be present in sufficient quantity to give a disagreeable taste and to stain clothing, porcelain-ware, and cooking utensils, may be removed from most waters by simple aeration and filtration, but a few waters require the addition of lime or some other substance.

The analyses given in Tables 5 and 6 show the range in iron content of waters in the area studied to be from 0 to 31.0 parts per million and the average iron content of 45 samples to be 2.8 parts per million. Twenty-five analyses show 0.3 part per million or less, and 18 show an iron content between 0.3 and 5.0 parts per million.

Fluoride.—Although quantities of fluoride are relatively small as compared with other common constituents of natural waters, it is desirable to know the amount of fluoride present in water that is likely to be used by children. Fluoride in water has been associated with the dental defect known as mottled enamel, which may appear on the teeth of children who drink water containing excessive quantities of fluoride during the period of formation of their permanent teeth. Water containing 1.5 parts per million or more of fluoride is likely to produce mottled enamel. If the water contains as much as 4 parts per million of fluoride, 90 percent of the children exposed are likely to have mottled tooth enamel, and 35 percent or more of the cases will be classed as moderate or worse (Dean, 1936). Small quantities of fluoride, not sufficient to cause mottled enamel, are likely to be beneficial by decreasing dental caries (Dean, Jay, Arnold, and Elvove, 1941).

Two samples of water collected from this area contained more than 1 part per million fluoride and 43 samples contained less than 1 part per million. The average fluoride content of the 45 samples of water analyzed is 0.53 part per million.

Nitrate.—Considerable interest has been shown recently in the amout of nitrate in ground waters. A discovery was made a few years ago that an unusally large amount of nitrate in well water may cause cyanosis when the water is used in the preparation of a baby's formula. The range and average nitrate content for waters analyzed from each formation in the area covered by this report are shown in Table 7. The difference in nitrate content for the waters is great and seemingly is not related to any geologic formation. High nitrate content probably is due to the inflow of surface water around the well or to the movement of water through soil that contains more than a normal amount of nitrate. Wells near fields of alfalfa or other legumes might receive some of the nitrate which these plants have added to the soil. Shallow and poorly sealed wells allow more infiltration of surface seepage than do deeper, more tightly cased wells. Thus shallow wells in alluvium or terrace deposits and dug wells of large diameter are more likely to have water of high nitrate content.

Although nearly all the water samples analyzed contained some nitrate, 40 samples had less than 45 parts per million. Water that contains more than 90 parts of nitrate is considered, by the Kansas State Board of Health, likely to cause infant cyanosis. Water containing less than 10 parts of nitrogen, or 45 parts of nitrate, is generally condisered safe. Four water samples had nitrate contents ranging from 90 to 768 parts per million. It should be noted also that water from two city supplies had considerable nitrate. The water from the Long Island supply had 80 parts per million of nitrate and that from Lenora had 39 parts per million.

TABLE 7. *Range in concentration of constituents, in parts per million, in water from several stratigraphic units in Norton County and northwestern Phillips County, Kansas*

STRATIGRAPHIC UNIT	No. of analyses	Total hardness (as $CaCO_3$)			Fluoride (F)			Iron (Fe)			Nitrate (NO_3)			Dissolved solids		
		Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
Alluvium	4	1,220	211	490	.50	.20	.40	1.20	0.10	.55	768	4.9	200.3*	1,880	266	712
Terraces	13	687	241	411	.60	.10	.32	9.4	0.0	1.77	111	0.44	28.76	1,030	338	566
Crete	2	239	203	221	.70	.20	.45	.08	.02	.05	8.0	2.5	5.25	327	274	300
Ogallala	24	494	145	247	.70	.15	.37	31.0	.02	3.95	124	0.0	12.8	722	196	323
Niobrara and Codell	2	114	68	91	5.0	3.4	4.2	4.6	.88	2.74	2.1	1.9	2.0	852	384	618

* Average of three samples, 21.6.

SANITARY CONSIDERATIONS

The analyses of water (Tables 5 and 6) show only the amount of dissolved mineral matter in the water and do not indicate the sanitary quality of the water. An abnormal amount of certain mineral constituents, such as nitrate or chloride, however, may indicate pollution of the water.

The entire population of Norton County and northwestern Phillips County and nearly all the livestock are dependent on well-water supplies. Although the area has five municipal water plants that are safeguarded against pollution, a large percentage of the population is dependent upon private wells, and every precaution should be taken to protect these supplies from pollution. Deep drilled wells on the uplands that penetrate relatively impervious silt above the water table are less subject to pollution than are shallow dug or driven wells in the valleys, where pervious sandy material extends from the surface down to the shallow water table. A well should not be located close to or below possible sources of pollution, such as barnyards, privies, and cesspools, and every well should be tightly sealed down to a level several feet below the land surface. It is generally advisable to locate a well on a site slightly higher than the surrounding area, or bank earth around the top of the well so that surface drainage will run away from rather than into the well. If a well must be located near a source of possible pollution it should be up slope from such pollution so that rain water will run toward the source of pollution rather than toward the well. Drilled wells are generally satisfactorily protected by the casing, although some are poorly sealed at the top.

QUALITY IN RELATION TO STRATIGRAPHY

The quantity of various dissolved mineral constituents in the ground waters of this area differs greatly from one formation to another. A sufficient number of chemical analyses are available to permit general conclusions concerning waters pumped from the Ogallala formation and the terrace deposits, but the few analyses of water collected from the alluvium, the Crete member of the Sanborn formation, the Niobrara formation, and the Codell sandstone member of the Carlile shale give less reliable indication of the quality of water in those stratigraphic units.

The maximum, minimum, and average concentrations of several constituents in parts per million from five water-bearing formations are given in Table 7, and typical analyses from each are plotted in graphic form in Figures 10 and 11. Twenty-four analyses show the water in the Ogallala formation to be of generally good quality and the range in dissolved constituents to be relatively low. The highest total hardness of Ogallala waters is less than 500 parts per million, and the average hardness of the 24 samples is 247 parts per million. The range in iron content is high—from 0.02 to 31.0 parts per million—with an average of 3.95 parts per million.

Two samples of water from Crete sand and gravel were analyzed and all constituents fall within the range of the Ogallala waters. As the water table is continuous from the Ogallala deposits into the Crete there is seemingly no significant difference between the waters of the two formations (Fig. 10).

Thirteen analyses of water pumped from terrace deposits indicate that the water from this source is significantly higher in total hardness than water in the Ogallala formation. The average hardness of waters from the terrace deposits is 411 parts per million as contrasted with an average of 247 parts per million for the Ogallala. The average iron content is much lower than for the Ogallala water but the range of 0.0 to 9.4 parts per million indicates that this may have little significance. Dissolved solids in waters from the terrace deposits have a range of 338 to 1,030 parts per million and the average is nearly 250 parts per million more than the average for water in the Ogallala.

As the water table at many places is continuous from the Ogallala into the terrace deposits the contrast in quality between the two probably is the result of the addition of dissolved mineral matter to the water from the terrace deposits themselves, or from the Cretaceous bedrock adjacent to the terrace deposits. Part of the water occurring under the prominent terraces is derived from the adjacent Ogallala formation and Crete sand and gravel and part from recharge from the terrace surface.

Although only four samples of water from alluvium in this area were analyzed, the ranges in total hardness and total dissolved solids are greater than for all other waters analyzed, and the average in each case is higher than the average for water from any other formation. The fluoride and iron content, on the other hand, are relatively low. Because only four analyses are available and the range in concentration of various constituents is extremely large, comparison with waters from other formations is apt to be misleading. The differences in composition of the water may be caused by the range in materials constituting the alluvium and by the fact that part of the recharge to these deposits is derived from surface-water infiltration at times of overflow of the stream channels.

Only two analyses of water from the Niobrara formation and Codell sandstone are available. However, the contrast in quality of these waters to the other waters of the area is so striking that they deserve special notice. The fluoride contents shown by these analyses are 5.0 and 3.4 parts per million, whereas the highest fluoride among the other 43 analyses is 0.7 part per million. The total hardnesses are 68 and 91 parts per million, whereas the lowest hardness among the other 43 analyses is 145 parts per million and only 4 samples have a hardness of less than 200 parts per million. The range of iron content and dissolved solids is no greater than in water from the other formations. The calcium and magnesium content of water from the Codell is low and the sodium content is quite high (129 and 289 parts per million). The lowest sodium content is significantly greater than the highest reported from the other formations. Probably the chemical characteristics peculiar to waters from the Codell sandstone are the result of a natural softening process. Water which percolates into the Codell from the overlying formations probably has a high content of calcium and magnesium and would be quite hard. The water in the Codell probably is softened by a natural base exchange in which calcium and magnesium ions in the water are exchanged for sodium ions in the rocks.

SUMMARY OF GROUND-WATER CONDITIONS IN THE ALMENA UNIT AREA

The Almena Unit is a proposed project in the U. S. Bureau of Reclamation's Missouri Basin development program. The area is now being investigated and if approved for construction, a dam would be built on Prairie Dog Creek a few miles west of Norton to form a storage reservoir. Water from this reservoir would be brought downstream through a series of canals to an irrigation district comprising much of the terrace area between Almena and the point where Prairie Dog Creek flows into Nebraska. At present, irrigation in this area is limited to five well plants, four of which are in Norton County, and to several surface-water pumping plants which have not been used for several years.

Like the main part of the area covered by this report, ground water in the Almena Unit area is derived ultimately from precipitation in or near the area in the form of rain or snow. Some of the water is carried away by surface drainage, some is evaporated into the atmosphere, and a part is transpired by vegetation. A small part percolates downward through the soil to join the body of ground water in the zone of saturation.

The rocks which immediately underlie the terrace surface along Prairie Dog Creek Valley consist of silt and sandy silt from 30 to 40 feet in thickness, underlain by sand and gravel. This material is described in detail in the test-hole logs at the end of this report. These unconsolidated deposits fill the trough which Prairie Dog Creek has cut into the Cretaceous bedrock (Pl. 3). The deposits of sand and gravel have large interconnected openings which allow the storage of a considerable amount of water and permit it to move freely through the rocks. Plate 2 shows that the ground water moves generally toward the northeast, but also moves from the upland areas toward the valley. Within the valley, there is a general downstream movement of the water with subordinate movement toward the stream channel. Prairie Dog Creek gains water from the water table and it is therefore an effluent stream throughout this area. It is in equilibrium with respect to the water table for a distance of several miles in the vicinity of Long Island. The stream seems to gain water by seepage from the uplands south of the valley, and to lose water into the terrace deposits north of the stream. The ground-water trench seems to correspond, in part at least, with the position of the deep channel in the Cretaceous bedrock beneath the terrace deposits.

The average gradient of the water table in the terrace deposits in the Almena Unit is about 8 feet per mile. The gradient in eastern Norton County is about 7½ feet per mile and increases to about 9 feet per mile near Long Island. Just southwest of the hairpin loop of Prairie Dog Creek 4 miles west of Woodruff the gradient decreases to only 7 feet per mile. After the stream resumes its eastward course the gradient steepens slightly so that it is about 8 feet per mile near Woodruff.

The water table fluctuates in response to additions to or withdrawals from the ground-water reservoir. In general, the water table declines during dry periods and rises during times of heavy precipitation. There is a lag between the time of the rainfall and the rise in the water table, representing the time required for water to percolate downward to the water table. Figure 7 illustrates the changes in the level of the water table due to variations in precipitation. The hydrographs for wells 1-20-13ad and 2-21-11aa show a rise of nearly 2 feet in the water table following the period of heavy rainfall in June 1947. The hydrographs also show a sharp decline in the water table during September 1947, when rainfall was only a fraction of normal.

The addition of water to the ground-water body is called recharge. The source of much of the recharge in the terrace area along Prairie Dog Valley is local precipitation. Part of the water which falls in the valley as rain or snow percolates down to the water table and moves downstream through the porous material that comprises the lower part of the terrace deposits. Recharge in the terrace areas is relatively high compared to the more dissected, steeply sloping areas bordering the valley because runoff from the flat terrace areas is small and the surficial materials are somewhat more permeable than the loess which blankets the upland areas. In addition to the recharge directly from precipitation, some recharge comes from small tributary streams whose channels lie above the water table. Many of these tributaries do not have definite channels across the terrace area, but empty their drainage onto the terrace surface where much of it seeps into the ground and recharges the water table.

In order that the ground-water reservoir shall remain in equilibrium, the amount of discharge in the area must be equal to the amount of recharge. The water table beneath the Almena terrace is neither rising steadily nor declining continually; therefore the ground-water system must be in equilibrium and the amount of discharge over a period of time must be equal to the recharge. During dry seasons, of course, the recharge may be considerably less than the discharge, but during periods of heavy precipitation recharge will be greater than discharge, so that over a long period of time the system remains in equilibrium.

The principal methods of discharge are evaporation from the ground-water reservoir, transpiration by plants, natural discharge into streams, and pumping from wells. Evaporation from the water table can occur only where the water table surface is within a few feet of the land surface. This condition occurs only along the flood plain of Prairie Dog Creek and its principal tributarities. The flood-plain areas are narrow and represent a very minor part of the valley area. The amount of ground water discharged by evaporation in Prairie Dog Creek Valley is relatively small.

A more important method of natural discharge is through transpiration by trees and other plants whose roots reach the water table. Transpiration probably accounts for a considerable amount of the discharge from the reservoir underlying the Almena terrace. The water table lies from 25 to 40 feet below the land surface, within easy reach of the roots of trees and plants such as alfalfa, which is a common crop in this area.

Another important method of discharge is by seepage from the ground-water reservoir into the permanent streams. Prairie Dog Creek is an effluent stream and gains water from the water table throughout its course in Norton and Phillips Counties. This type of discharge serves to keep the ground-water system in equilibrium. When the ground-water level is high the gradient toward the stream is greater, allowing more seepage into the stream. This lowers the water table and reduces the gradient and the amount of discharge.

Wells that pump water from the ground-water reservoir constitute an important means of discharge. Individual domestic and stock wells pump only small quantities of water, but the total volume pumped by them must be quite large. Wells such as irrigation and municipal supply wells which discharge large amount of water frequently lower the water table for a considerable area about the pumped wells. This lowering of the water table is called a cone of depression, and it may extend for some distance if the wells are not allowed to recover fully before being pumped again. The Almena city wells seem to have developed a cone of depression about that area (Pl. 2). After a period of prolonged pumping the irrigation wells also probably have cones of depression. Because these wells are pumped only a short time each year they have ample time to recover before the next season and the cone of depression soon disappears.

Wells for stock and domestic use in the Almena unit area are generally drilled or bored and cased with 5- or 6-inch galvanized casing, slotted opposite the water-bearing sand and gravel. A few are dug wells of large diameter, walled with stone. Most of the wells are equipped with a cylinder pump and windmill. Many are drilled only a few feet below the water table and no attempt is made to penetrate all the water-bearing material. The irrigation wells in the area, however, are constructed somewhat more scientifically. Sites for these wells are generally determined by test drilling or boring and they penetrate all the water-bearing gravel. Commonly they are constructed with either natural or artificial gravel walls, and they are usually equipped with turbine pumps powered with gasoline engines. All the irrigation wells in this area at the time of the field investigation are listed and described in Table 8.

Irrigation.—As already stated, only five irrigation wells are now in use in the Almena Unit area. All these wells obtain water supplies from the gravel deposits underlying the Almena terrace. Test drilling in the valley in the vicinity of Long Island has revealed that in Phillips County the bedrock floor beneath the terrace is not flat but has a deep, narrow notch or channel which was cut by the stream in an earlier erosion cycle. This channel contains about three times as much coarse saturated material as occurs elsewhere beneath the terrace. Wells that penetrate this channel have much higher yields than those penetrating only the thinner gravel deposits. Well 1-19-8ad (Table 8, Pl. 10C) seemingly is drilled into this channel. This well penetrated 56 feet of saturated material and was reported to yield 700 gallons per minute when test pumped in 1948. Unfortunately there is no surface indication of this buried channel; it can be located only by test drilling.

Irrigation wells might be located in favorable places in the Crete deposits along the north side of the valley. Test hole 1-20-14ad penetrated 32 feet of these deposits, including nearly 20 feet of saturated sand and gravel. In general, the Crete deposits are not so likely to furnish large supplies of water as the terrace deposits because they are thinner, contain a smaller percentage of coarse material, and the water table is deeper beneath the surface so that the pumping lift is greater. In addition, the area underlain by Crete is not satisfactory as an irrigation area because it is so dissected that only small areas are flat enough to be irrigated, and it is traversed by numerous deep gullies which make the construction of irrigation ditches very difficult.

Several ground-water problems occur in connection with irrigation which are not encountered under other conditions. One is the problem of subsurface drainage of the irrigation water in excess of that used readily by plants. Poor subsurface drainage will cause the soil to become waterlogged and will drown out the vegetation. Throughout the terrace area in Prairie Dog Creek Valley subsurface drainage is good. The surficial deposits consist of sandy silt which seems to allow surface water to seep readily into the soil. After the water has moved through the silty layers it reaches a layer of sand and gravel, which is thick enough and permeable enough to provide good subsurface drainage. None of the irrigation plants now in operation has experienced drainage difficulties. However, should a large area, such as the irrigation district proposed in the Almena Unit plans, be irrigated, the water table might be raised high enough to saturate the near-surface silty material. This can be foreseen and corrective measures designed before serious damage occurs if an observation well program is begun and maintained to note any abnormal rises in the water table. In order for such a program to be a success, it is essential that normal ground-water conditions in the area be known. The determination of the normal ground-water conditions in the area of the Almena Unit has been one of the primary purposes of this investigation.

Another problem affecting irrigation is the chemical character of the water used for that purpose. Water that has a concentration of sodium ions equal to 50 percent or more of the total bases (percent sodium) may cause an alkaline condition when used to irrigate certain types of soil. Table 6 shows that the percentage of sodium in 15 samples of water analyzed ranges from 1 to 30. The average for nine samples of water from the terrace and Crete deposits is 10 percent.

Chloride is another chemical constituent which may render water unfit for irrigation use. Water that has a high concentration of chloride is too salty for irrigation. Boron is also one of the dissolved constitutents which might also affect the use of water for irrigation. Although the samples of ground water analyzed from this area contain relatively large amounts of some constituents, they are well within the limits for irrigation use. Surface water is generally somewhat less mineralized than ground water, so that the chemical character of the water in this area should present no problems, unless prolonged irrigation should alter the character of the soil.

RECORDS OF TYPICAL WELLS

Information pertaining to 241 water wells in Norton County, 44 wells in northwestern Phillips County, and 9 wells in adjacent areas is tabulated in the following pages (Table 8). The well-numbering system used in this table is described on page 11.

TABLE 8.—*Records of wells in Norton and northwestern Phillips Counties, Kansas, and adjacent areas*

No. on Plate 2 (1)	LOCATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet) (7)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet) (8)	Date of measurement	Remarks
	T. 1 S., R. 18 W.															
1-18-5bc	SW¼ NW¼ sec. 5	Henry Danielson	Dr	52.0	6	GI	Sand and gravel	Terrace	CY,H	D	Top of casing	0.7	2,002.8	44.55	10-14-47	Not in use.
1-18-8bc	SW¼ NW¼ sec. 8	School District	Dr	57.0	6	GI	do	do	CY,H	D	Top of concrete platform	.2	2,019.4	33.68	10-14-47	Do
	T. 1 S., R. 19 W.															
1-19-1db	NW¼ SE¼ sec. 1	Elick Hunter	Dr	46.7	6	GI	do	do	CY,W	D,S	Top of casing in bottom of pit 3.5 feet deep	3.5	2,006.8	37.53	10-14-47	Pit 3.5 feet beneath platform. Chemical analysis.
1-19-3aa	NE¼ NE¼ sec. 3	....	B	44.5	6	GI	do	do	CY,W	D,S	Top of casing	1.3	2,006.8	28.28	10-13-47	Not in use.
1-19-4bd	SE¼ NW¼ sec. 4	....	Dr	71.7	5	GI	do	do	CY,W	S	do	1.0	2,026.2	38.22	9-24-47	
1-19-5db	NW¼ SE¼ sec. 5	Hardy Estate	DD	66.3	5	GI	Sand	Crete	CY,W	D,S	Base of pump	.8	2,076.4	63.37	9-25-47	
1-19-6bb	NW¼NW¼ sec. 6	Mrs. Brash	Dr	44.2	4½	GI	Sand and gravel	Alluvium	CY,W	D,S	Top of casing	.2	2,032.9	20.02	9-25-47	
1-19-8ad	SE¼ NE¼ sec. 8	L. M. Wilson	Dr	81	30	......	do	Terrace	T,G	I	Land surface	.0	......	24.90	6-14-48	Completed June 1948.
1-19-8cb	NW¼ SW¼ sec. 8	H. S. Kats	B	53.4	......		do	do	CY,W	D,S	Base of pump	.2	2,050.6	26.50	9-25-47	Chemical analysis.
1-19-9cb	NW¼ SW¼ sec. 9	Raymond Caswell	Dr	43±	5	GI	do	do	CY,W	S	Top of concrete platform	1.7	2,053.7	33.72	9-24-47	Do
1-19-10cb	NW¼SW¼ sec. 10	....	Du	17.2	48	R	do	Pleistocene	CY,W	S	Base of pump	.5	2,088.2	14.73	10-14-47	Not in use.
1-19-12bc	SW¼ NW¼ sec. 12	John Steenis	Du	55.0	36	......	do	Ogallala	CY,W	D,S	Top of board platform	.3	2,013.7	49.68	10-14-47	
1-19-15cc	SW¼ SW¼ sec. 15	....	DD	70.0	24, 48	......	do	do	N	N	do	0	2,173.8	67.36	10-13-47	Do
1-19-18dd	SE¼ SE¼ sec. 18	....	B	26.5	5	GI	do	Terrace	N	N	Top of casing	.5	2,055.7	24.84	10-13-47	Do
1-19-19cc	SW¼ SW¼ sec. 19	Al Skelton	Du	33.0	96, 120	C,GI	do	Alluvium	CY,W	S	Top of board platform	4.0	2,088.9	21.5	10-10-47	Used as observation well.

-20dd	SE¼ SE¼ sec. 20	L. B. Richardson	Du	41.8			do	do	CY,W	D,S	Top of concrete curb	.4	2,104.1	39.60	10-10-47	Chemical analysis.
-31db	NW¼ SE¼ sec. 31	W. A. Kats	Dr	62	5	GI	do	Ogallala	CY,W	S	Top of casing	.5	2,193.2	58.18	10-13-47	
	T. 1 S., R. 20 W.															
-1dc	SW¼ SE¼ sec. 1	Joe S. Young	Dr	39.8	5	GI	do	Alluvium	N	N	Top of GI casing	1.0	2,075.1	29.98	9-24-47	Not in use.
-2ba	NE¼ NW¼ sec. 2	Leon Utter	Dr	89.0	5		do	Ogallala	CY,W	D,S	Top of casing	.3	2,146.7	64.14	9-22-47	
-3dd	SE¼ SE¼ sec. 3		Dr	96.0	6	GI	do	do	CY,W	S	Top of concrete mound	.7	2,184.1	88.40	9-23-47	
-5ad	SE¼ NE¼ sec. 5		Dr	122	5		do	do	CY,W	D,S	Top of casing	0.4	2,231.6	109.96	9-22-47	Not in use.
-7cc	SW¼ SW¼ sec. 7		Dr	92.5	5		do	do	CY,H	D	do	1.3	2,195.0	50.90	9-22-47	
-8bb	NW¼ NW¼ sec. 8		Dr	89.5	6		do	do	CY,W	D,S	do	1.2	2,216.9	77.87	9-22-47	Do
-8dd	SE¼ SE¼ sec. 8	Ernest Halderman	Dr	97	5		do	do	CY,W	D,S	do	.7	2,204.5	88.87	9-22-47	Chemical analysis.
-11dc	SW¼ SE¼ sec. 11	Gale Halderman	Dr	70.2	6	GI	do	do	CY,W	D,S	Top of concrete platform	.2	2,441.1	64.58	9-24-47	Do
-13ad	SE¼ NE¼ sec. 13		Dr	62.8	6		do	Terrace	N	N	Top of casing	.8	2,059.4	28.46	5-7-47	Not in use.
-14cc	SW¼ SW¼ sec. 14	do	Dr	54.5	6	GI	Sand	Crete	CY,W	S	Top of GI casing (platform level)	.3	2,092.7	42.81	9-23-47	Used as observation well
-16dc	SW¼ SE¼ sec. 16		Dr	76.0			Sand and gravel	Ogallala	CY,W	D,S	Top of casing	.5	2,163.0	70.85	4-9-48	Not in use.
-17cc	SW¼ SW¼ sec. 17		Dr	45	6		do	do	CY,W	S	do	.5	2,163.8	40.50	8-6-47	
-22dd	SE¼ SE¼ sec. 22		Dr	38.0	3, 6	GI	do	Terrace	N	D	do	.5	2,081.0	34.13	9-23-47	Do
-23aa	NE¼ NE¼ sec. 23	John Graham	Dr	63.2	8	GI	do	do	N	D	Top edge of hole, board platform	.3	2,069.7	31.96	9-23-47	Do
-23da	NE¼ NS¼ sec. 23	City of Long Island	B	46	10	GI	do	do	T,E	P	At surface	.0	2,068.9	31	9-22-47	Long Island Municipal well. Chemical analysis.
-25cb	NW¼ SW¼ sec. 25		Dr	66.2			do	do	CY,W	S	Top of concrete platform	.2	2,095.2	47.73	9-24-47	
-28ad	SE¼ NE¼ sec. 28	School	Dr	54.5			do	do	CY,H	D	Top of casing	.4	2,084.8	28.66	9-23-47	Not in use.
-29aa	NE¼ NE¼ sec. 29		Dr	76.5	6		Sand	Crete	CY,W	D,S	do	.7	2,153.7	71.11	8-6-47	Do
-30cc	SW¼ SW¼ sec. 30		Dr	85.0	5		do	do	CY,W	D,S	Base of pump	1.0	2,183.0	78.87	8-6-47	Observation well; not in use.
-30dd	SE¼ SE¼ sec. 30		B	45.4	5		Sand and gravel	Terrace	CY,W	S	Top of casing	1.0	2,121.6	37.00	5-7-47	Observation well; Chemical analysis.
-32ad	SE¼ NE¼ sec. 32	L. C. Vanderlynn	Dr	50	5	GI	do	do	CY,W	S	do	1.3	2,105.0	29.15	10-9-47	Do

TABLE 8.—*Records of wells in Norton and northwestern Phillips Counties, Kansas, and adjacent areas*—Continued

No. on Plate 2 (1)	Location	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet) (7)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet) (8)	Date of measurement	Remarks
20-33dd	SE¼ SE¼ sec. 33	Glen Graff	Dr	59.0	6	GI	Sand and gravel	Terrace	N	.....	Top of casing	.7	2,101.2	32.00	10- 9-47	Not in use.
20-34ba	NE¼ NW¼ sec. 34	Harold Parker	Dr	44.8	6	GI	do	do	N	N	do	.5	2,090.8	28.55	10-10-47	Used as observation w
20-35cb	NW¼ SW¼ sec. 35.		Du	40.7	36	.....	do	do	N	N	Top of board platform	0	2,106.3	36.30	10-10-47	Not in use.
	T. 1 S., R. 21 W.															
21-1dc	SW¼ SE¼ sec. 1	C. P. Cox	Dr	46.4	6	GI	do	Ogallala	CY,W	S	Top edge of casing	1.0	2,185.6	30.63	5-20-46	
21-5dd	SE¼ SE¼ sec. 5	R. E. Wendel	Dr	104.7	6	GI	do	do	CY,W	S	do	.3	2,304.1	99.8	1- 7-46	
21-10ba	NE¼ NW¼ sec. 10	C. Baird	Dr	156.6	6	GI	do	do	CY,W	D,S	do	.9	2,318.5	135	5-20-46	
21-16dd	SE¼ SE¼ sec. 16	School District	Dr	55.2	6	GI	do	do	CY,H	D	do	.6	2,229.8	41.6	5-20-46	Chemical analysis.
21-24bb	NW¼ NW¼ sec. 24	N. Delimont	Dr	96.4	6	GI	do	do	CY,W	S	At base of pump	0	2,244.0	75.13	12- 8-45	
21-26ad	SE¼ NE¼ sec. 26	M. G. and N. T. Dale	Dr	61.8	6	GI	do	do	CY,W	D,S	Top of cement at pump base	1.5	2,191.7	53	12- 8-45	Not in use.
21-27cb	NW¼ SW¼ sec. 27.	H. T. Dale	Dr	64.6	6	GI	do	do	CY,W	D,S	Hole in base	.5	2,220.1	59.1	5-20-46	
21-33cc	SW¼ SW¼ sec. 33	W. H. Kemble	Dr	110	6	GI	Sand	Crete	CY,W	S	Top edge of casing	.6	2,233.2	93	6- 6-46	
21-35dc	SW¼ SE¼ sec. 35	H. S. Whitaker	Du	48	34	I	Sand and gravel	Terrace	T,G	I	do	......	2,133.8	33.24	5- 3-46	Used as an observa well.
	T. 1 S., R. 22 W.															
22-5dc	SW¼ SE¼ sec. 5	D. M. Veneman, et al.	Dr	65	6	GI	do	Ogallala	CY,W	D,S	do	.9	2,318.9	53.75	1- 9-46	Not in use.
22-9dd	SE¼ SE¼ sec. 9	C. P. Rumsey	Dr	153.5	6	GI	do	do	CY,W	D,S	do	.3	2,399.9	143.1	1- 9-46	Do
22-14ba	NE¼ NW¼ sec. 14.	W. A. Wilmot	Dr	67.4	6	GI	do	do	CY,W	S	do	.7	2,308.2	62.12	1- 7-46	Chemical analysis.

-18bc	SW¼ NW¼ sec. 18	H. Darling	Dr	117.7	6	GI	do	do	CY,W	S	do	2.0	2,397.6	109.37	1- 9-46	Not in use.
-24ab	NW¼ NE¼ sec. 24	A. G. Leuszler	Dr	32.6	6	GI	do	do	CY,W	S	do	1.0	2,267.8	25.63	1- 7-46	
-28ab	NW¼ NE¼ sec. 28	J. S. Thacker	Dr	109.6	6	GI	do	do	CY,H	D,S	do	.2	2,367.2	94.84	1- 7-46	Do
-30da	NE¼ SE¼ sec. 30	L. H. Donovan	Dr	132.3	6	GI	do	do	CY,W	S	do	.6	2,043.1	101.64	1- 9-46	
-31cc	SW¼ SW¼ sec. 31	K. H. Cohrs, et al	Dr	69.3	6	GI	do	do	CY,W	D,S	At base of pump	1.9	2,351.3	52.63	12-11-45	Do
-35cd	SE¼ SW¼ sec. 35		Dr	68.3	6	GI	do	do	CY,H	D,S	Top edge of casing	0	2,299.0	58.76	5- 8-46	Do
	T. 1 S., R. 23 W.															
-2bd	SE¼ NW¼ sec. 2	A. Fredde	Dr	134.4	6	GI	do	do	CY,W	S	Top of casing	.5	2,387.0	117.17	1- 9-46	
-4da	NE¼ SE¼ sec. 4	Alma Lofgreen	Dr	87.9	6	GI	do	do	CY,W	S	Top edge of casing	0.7	2,360.3	85.99	1- 8-46	Not in use.
-6aa	NE¼ NE¼ sec. 6	H. Collins	Dr	70.4	6	GI	do	do	CY,W	D,S	do	1.7	2,356.2	67.73	1- 8-46	
-7da	NE¼ SE¼ sec. 7	School District	Dr	108.2	6	GI	do	do	CY,H	D	do	.2	2,391.3	102.2	1- 8-46	Chemical analysis.
-16dd	SE¼ SE¼ sec. 16	W. C. Marvin	Dr	94.4	6	GI	do	do	CY,W	S	do	.5	2,379.5	69.2	1- 8-46	
-26aa	NE¼ NE¼ sec. 26	V. Chase	Dr	143	6	GI	do	do	CY,W	D,S	Top of curb	1.1	2,410.3	126	12-11-45	Do
-26dd	SE¼ SE¼ sec. 26	Ross Severi s	Du	113.7			do	do	CY,W	S	Board platform by pump base	.3	2,416.5	104.45	1- 2-46	
-30aa	NE¼ NE¼ sec. 30		Dr	109.2	6	GI	do	do	CY,W	S	Top of casing	.8	2,420.7	90.87	1- 8-46	Do
-34bb	NW¼ NW¼ sec. 34	P. Fox	Dr	148	6	GI	do	do	CY,W	D,S	do	.5	2,452.1	132.2	12- 2-46	
	T. 1 S., R. 24 W.															
-5ad	SE¼ NE¼ sec. 5	L. L. Pywell	Dr	59	6	GI	Sand	Crete	CY,W	D,S	do	.9	2,328.0	57	5- 8-46	
-11aa	NE¼ NE¼ sec. 11	McKinley Ranch	Dr	42.6	6	GI	Sand and gravel	Alluvium	CY,W	D,S	Edge of board platform	.4	2,320.1	33.33	5-21-46	
-13cc	SW¼ SW¼ sec. 13	L. S. Rothschild	Dr	105.6	6	GI	do	Ogallala	CY,W	S	Top edge of casing	1.0	2,436.6	101.2	5-21-46	
-17aa	NE¼ NE¼ sec. 17	C. W. Smiley	Dr	113	6	GI	do	do	CY	D,S	do	.8	2,435.3	100.7	5- 8-46	Not in use.
-32aa	NE¼ NE¼ sec. 32	J. Tweed	Dr	114.5	6	GI	do	do	CY,H	D,S	do	.7	2,465.3	107.62	5- 8-46	Do
-35bc	SW¼ NW¼ sec. 35	J. F. Bryant	Dr	68.7	6	GI	do	do	CY,W	S	do	1.0	2,394.4	48.6	5- 6-46	Used in summer only.

TABLE 8.—*Records of wells in Norton and northwestern Phillips Counties, Kansas, and adjacent areas*—*Continued*

No. on Plate 2 (1)	LOCATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet) (7)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet) (8)	Date of measurement	Remarks
	T. 1 S., R. 25 W.															
25-1aa	NE¼ NE¼ sec. 1	P. Van Cleave	Dr	41.0	6	GI	Sand and gravel	Terrace	CY,W	D,S	Top of casing	.2	2,339.0	34.23	6- 5-46	Not in use.
25-3cb	NW¼ SW¼ sec. 3	D. Fawcett	Dr	85.3	6	GI	Sand	Crete	CY,W	D,S	do	.2	2,442.6	81.60	6- 5-46	Do
25-5cb	NW¼ SW¼ sec. 5		Dr	124.3	6	GI	Sand and gravel	Ogallala	CY,W	D,S	do	.7	2,481.7	106.77	6- 5-46	
25-13ab	NW¼ NE¼ sec. 13	Lola Dey	Dr	35.8	6	GI	do	Alluvium	CY	S	do	.7	2,361.9	16.58	6- 5-46	Do
25-16dc	SW¼ SE¼ sec. 16	Robt. Sumner	Dr	71.4	6	GI	do	do	CY,W	D,S	Edge of old wheel at hole	1.0	2,380.2	30.9	5-21-46	Do
25-19aa	NE¼ NE¼ sec. 19	Robt. Sumner	Dr	50.8	6	GI	do	Ogallala	CY,W	S	Top edge of casing	.5	2,397.6	39.36	6- 5-	Chemical analysis.
25-24cc	SW¼ SW¼ sec. 24	Celia Albin	Dr	95.6	6	GI	do	do	CY,W	D,S	Top of casing	0.8	2,424.6	64.65	6- 1-46	Do
25-32da	NE¼ SE¼ sec. 32	A. Kane	Du	39.6	36	R	do	do	CY,W	D,S	Edge of manhole in concrete platform	.8	2,442.6	38.28	5-21-46	
25-34dd	SE¼ SE¼ sec. 34	Orley Goss	Dr	157	6	GI	do	do	CY,W	D,S	Top edge of casing	.7	2,526.1	146.85	6- 1-46	
	T. 2 S., R. 21 W.															
21-1aa	NE¼ NE¼ sec. 1	W. M. Sorrick	Dr	43	5, 6	GI	do	Terrace	CY,W	D,S	Base of pump	1.0	2,117.2	25.46	8- 6-47	
21-1bb	NW¼ NW¼ sec. 1	Verner Ross	Dr	70.3	24	GI	do	do	T,G	I	Top of pump base	1.3	2,125.35	27.14	6-24-46	Used as observation w
21-2bd	SE¼ NW¼ sec. 2	Vernon J. Hamilton	B	57.5	24	GI	do	do	T,T	I	Top of casing	0	2,127.70	25.76	6-27-46	Do
21-3cc	SW¼ SW¼ sec. 3	Shaw	Dr	64	6	I	do	do	CY,W	S	do	.3	2,138.4	27.33	8- 6-47	
21-6bb	NW¼ NW¼ sec. 6	Fern Donaldson	Du	44.2			do	Ogallala	CY,W	S	Edge of platform at pipe	.8	2,342.8	40.13	5- 8-46	
21-8ca	NE¼ SW¼ sec. 8	City of Almena	Dr		18	I	do	Terrace	T,E	P	Hole in pump base	.7	2,253.1	36.32	8-28-45	Almena municipal well
21-8dc	SW¼ SE¼ sec. 8	do	Dr		18	I	do	do	T,E	P	Land surface		2,142.5	35	8-28-45	Do
21-11aa	NE¼ NE¼ sec. 11	W. B. Woods	Dr		18	I	do	do	T,G	I	Hole in pump base	1.0	2,132.40	32.44	8-29-45	Chemical analysis.

2-21-18aa	NE¼ NE¼ sec. 18	Haypkema	Du	57.5			do	do	N	I	Top of 5-inch plank	.4	2,171.20	43.45	8- 7-47	Used as observation well.
2-21-19dd	SE¼ SE¼ sec. 19	E. Du Boig	Dr	78.1	6	GI	do	Ogallala	CY,W	D,S	Top edge of casing	.9	2,226.50	64.86	5-27-46	Do
2-21-22cc	SW¼ SW¼ sec. 22		Dr	119.5	6	GI	do	do	CY,W	D,S	do	1.5	2,299.1	116.72	5-27-46	
2-21-30cb	NW¼ SW¼ sec. 30	Bessie Bebe	Dr	71.7	5	GI	do	Terrace	CY,W	D,S	Base of pump	1.5	2,201.3	34.05	8- 5-47	Chemical analysis.
2-21-32cc	SW¼ SW¼ sec. 32	J. S. Wiles	Du	78.2	6	GI	do	Ogallala	CY,W	S	Top of casing	5	2,263.7	61.78	5-27-46	Not in use.
2-21-36aa	NE¼ NE¼ sec. 36		Dr	96.6	5	GI	do	do	CY,W	D,S	do	.8	2,267.9	94.86	5-29-46	Do
2-22-4bc	*T. 2 S., R. 22 W.* SW¼ NW¼ sec. 4	Nora Sevier	Dr	116.7	6	GI	do	do	CY,W	D,S	do	0	2,380.8	107.5	1- 7-46	Do
2-22-6dd	SE¼ SE¼ sec. 6	E. Schilling	Dr	106.8	6	GI	do	do	CY,W	S	do	.6	2,373.9	87.04	1- 9-46	
2-22-9dc	SW¼ SE¼ sec. 9	Drommer	Dr	98.3	6	GI	do	do	CY,W	D,S	do	.4	2,324.3	69.52	6- 6-46	Chemical analysis.
2-20-1ab	*T. 2 S., R. 20 W.* NW¼ NE¼ sec. 1	John Hogan	B	32.0	5	GI	do	do	CY,W	D	do	0.7	2,156.0	27.16	10- 9-47	Do
2-20-5da	NE¼ SE¼ sec. 5	Frank Nelson	Dr	46.0	5	GI	do	do	CY,W	D,S	do	.5	2,123.5	30.84	10- 9-47	Do
2-20-7cb	NW¼ SW¼ sec. 7		Du	22.3	24		do	do	CY,H	D	Top of cement platform	.5	2,155.1	21.43	10- 9-47	Not in use.
2-22-11dc	SW¼ SE¼ sec. 11	W. A. Wilmot	Dr	78.8	6	GI	do	do	CY,H	D	Top edge of casing	0	2,280.8	67.17	1- 7-46	Water unfit for human consumption. Well has since been destroyed.
2-22-12ab	NW¼ NE¼ sec. 12	M. G. Hawks	Dr	110	6	GI	Sand	Crete	CY,W	D,S	do	3.7	2,272.2	89.65	8- 6-47	Chemical analysis
2-22-13ab	NW¼ NE¼ sec. 13	Lloyd Hahn	Dr	80	5	GI	do	do	CY,W	D,S	Base of pump	1.5	2,247.8	78.76	8- 5-47	Not in use.
2-22-21dd	SE¼ SE¼ sec. 21	H. E. Fisher	Dr	82.2	6	GI	do	do	CY,W	S	Top edge of casing	9	2,276.3	76	5- 8-46	
2-22-26ac	SW¼ NE¼ sec. 26	Percy G. Whitaker	B	53.1	6	GI	Sand and gravel	Terrace	J,E	D	Top edge of pit	.1	2,193.10	29.41	4-29-46	Observation well.
2-22-28aa	NE¼ NE¼ sec. 28	H. E. Fisher	Dr	50.9	5	GI	Sand	Crete	N	N	Top of casing	.0	2,243.9	49.17	5- 7-47	Used as observation well
2-22-29dd1	SE¼ SE¼ sec. 29	State TB Sanitorium	Dr	72.0	16		Sand and gravel	Terrace	C,E	P	Land surface			35.0	10-14-47	240 gpm with 20-foot drawdown reported.
2-22-29dd2	SE¼ SE¼ sec. 29	do	Dr	63	16		do	do	C,E	P	do			35	10-14-47	
2-22-29dd3	SE¼ SE¼ sec. 29	do	Dr	70	16		do	do	C,E	P	do			35	10-14-47	
2-22-32bd	SE¼ NW¼ sec. 32	School District	Dr	47.2	6	GI	do	do	CY,H	D	Top of casing	.4	2,221.10	36.02	1-12-46	Chemical analysis.
2-22-34bb	NW¼ NW¼ sec. 34	H. A. Fredde *et al*	Dr	70.7	6	GI	do	do	CY,W	S	do	1.2	2,219.1	44.60	1-12-46	Not in use.

TABLE 8.—*Records of wells in Norton and northwestern Phillips Counties, Kansas, and adjacent areas—Continued*

No. on Plate 2 (1)	LOCATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet) (7)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet) (8)	Date of measurement	Remarks
	T. 2 S., R. 23 W.															
-23-1ab.	NW¼ NE¼ sec. 1	Anna Caskey	Dr	96.6	6	GI	Sand and gravel	Ogallala	CY,W	D,S	Pump base	1.0	2,397.9	92.15	12-11-45	Not in use.
-23-2ad	SE¼ NE¼ sec. 2	M. C. Gleason	Dr	95.4	6	GI	do	do	CY,W	S	Top edge of casing	.5	2,394.9	83.0	1- 2-46	
-23-4cd	SE¼ SW¼ sec. 4	Arthur E. Brown	Dr	101.5	6	GI	do	do	CY,W	D,S	do	.0	2,426.6	99.2	1- 7-46	
-23-6aa	NE¼ NE¼ sec. 6	A. Marvin	Dr	155	6	GI	do	do	CY,W	D,S	do	.8	2,472.8	138.48	5- 6-46	
-23-12ba	NE¼ NW¼ sec. 12	J. Donnelly	Dr	63.7	6	....	do	do	CY,W	D,S	Top edge of casing	.0	2,363.1	60.2	12-11-45	Do
-23-13ba	NE¼ NW¼ sec. 13	J. C. Martin	Dr	57.4	6	GI	do	Alluvium	CY,W	D,S	At base of pump	.2	2,300.8	34.52	12-11-45	Do
-23-16aa	NE¼ NE¼ sec. 16	J. A. Wherman	Dr	109	6	GI	do	Ogallala	CY,W	D	Top of casing	.2	2,425.3	102.64	12-21-45	Do
-23-17cc	SW¼ SW¼ sec. 17	C. A. Fitzsimons	Dr	38.2	6	GI	do	Alluvium	CY,W	S	do	1.2	2,367.9	31.25	5- 4-46	
-23-21dd	SE¼ SE¼ sec. 21	School district	Dr	60.3	6	GI	do	Ogallala	CY,W	D,S	do	.6	2,349.5	46.34	5- 4-46	
-23-24da	NE¼ SE¼ sec. 24	Trust's Dartm'th Col.	Dr	66.5	6	GI	do	do	CY,W	D,S	Northeast corner of manhole.	1.0	2,297.2	48.8	12-11-45	Chemical analysis. N... use.
-23-26dd	SE¼ SE¼ sec. 26	A. E. Williams	Dr	62	6	GI	do	Terrace	CY,H	D,S	Top of casing	1.1	2,253.3	39.96	5- 8-46	Not in use.
-23-30dd	SE¼ SE¼ sec. 30	G. Murphy	Dr	27.2	6	GI	do	Alluvium	CY,W	S	Top edge of casing	.5	2,340.1	17.05	5- 4-46	
-23-35bb	NW¼ NW¼ sec. 35	C. H. Bryant	Dr	113	5	GI	Sand	Crete	CY,W	D	Base of pump	.9	2,335.8	76.83	8- 4-47	Chemical analysis.
-23-36cc	SW¼ SW¼ sec. 36	Donnley Estate	Du	60	24	....	Sand and gravel	Terrace	CY,W,G	D,S	Top of 3-inch plant	.9	2,265.9	55.30	5- 5-47	Do
-23-36cd	SE¼ SW¼ sec. 36	R. L. Brooks	Dr	69.1	18	GI	do	do	T,E	I	Lower edge of inspection hole	1.7	2,238.4	30.15	7- 1-46	Used as observation ...

	T. 2 S., R. 24 W.															
4-24-4cd	SE¼ SW¼ sec. 4	A. C. Blickenstaff	Dr	80.5	6	GI	do	Ogallala	CY,W	S	Top of casing	1.3	2,442.0	74	5- 7-46	
2-24-10aa	NE¼ NE¼ sec. 10	School District	Dr	154.5	6	GI	do	do	CY,H	D	do	1.0	2,466.3	128.3	5- 6-46	
2-24-16dc	SW¼ SE¼ sec. 16	G. Wegener	Dr	148.5	6	GI	do	do	CY,W	S	do	.7	2,498.6	127.64	5- 6-46	Chemical analysis.
2-24-24ab	NW¼ NE¼ sec. 24	G. M. Schultz	Dr	104.5	6	GI	do	do	CY,W	S	do	1.5	2,439.6	90.18	5- 6-46	
2-24-28aa	NE¼ NE¼ sec. 28	School District	Dr	122.7	6	GI	do	do	CY,H	D	do	.3	2,471.3	100.87	5- 8-46	
2-24-30ab	NW¼ NE¼ sec. 30	T. Duensing	Dr	114.5	6	GI	do	do	CY,W	S	do	.5	2,495.7	99.73	5- 7-46	
	T. 2 S., R. 25 W.															
2-25-10dc	SW¼ SE¼ sec. 10	H. M. Rallsback	Dr	142	6	GI	do	do	CY,W	S	do	3.0	2,537.0	136.84	5- 7-46	
2-25-12aa	NE¼ NE¼ sec. 12	N. Strayer Estate	Dr	114.5	6	GI	do	do	CY,W	S	do	.7	2,477.9	92.9	5- 7-46	
2-25-16cb	NW¼ SW¼ sec. 16		Dr	137.1	6	GI	do	do	CY	D,S	do	1.0	2,547.6	128.57	5-21-46	Abandoned.
2-25-20cd	SE¼ SW¼ sec. 20	Merl Erwin	Dr	140.5	6	GI	do	do	CY,W	S	do	1.3	2,559.8	126.25	5- 7-46	
2-25-26aa	NE¼ NE¼ sec. 26	D. M. Conway Estate	Dr	84.7	6	GI	do	do	CY,W	S	do	1.0	2,483.4	76.4	5- 6-46	
2-25-27ba	NE¼ NW¼ sec. 27	Hobart Garrison	Dr	148	6	GI	do	do	CY,W	D,S	do		2,548.3	134.13	5- 7-46	Chemical analysis.
2-25-36dd	SE¼ SE¼ sec. 36	L. B. McCabe	Dr	55.1	6	GI	do	do	CY,W	S	do	1.0	2,429.7	43.83	5- 4-46	
	T. 3 S., R. 21 W.															
3-21-2dd	SE¼ SE¼ sec. 2	J. Bogart	Dr	96.5	6	GI	do	do	CY,W	S	do	0.4	2,271.0	88.20	1-12-46	Do
3-21-3bb	NW¼ NW¼ sec. 3	F. Hays	Dr	142.1	6	GI	do	do	CY,W	D,S	do	.3	2,329.7	137.45	5-27-46	
3-21-8dc	SW¼ SE¼ sec. 8	A. Roeder	Dr	166.0	6	GI	do	do	CY,W	S	do	.3	2,370.6	162.54	1-12-46	
3-21-14dd	SE¼ SE¼ sec. 14	F. Hays	Dr	58.3	6	GI	do	Alluvium	CY,W	D,S	do	.2	2,210.1	33.38	1-12-46	Not in use.
3-21-18bb	NW¼ NW¼ sec. 18	L. W. Fellwork Estate	Dr	152.2	6	GI	do	Ogallala	CY,W	D	do	.9	2,362.7	140.42	1-12-46	Do
3-21-21aa	NE¼ NE¼ sec. 21	Federal Land Bank	Dr	81.5	6	GI	do	do	CY,W	D,S	do	.3	2,259.1	60.36	1-14-46	
3-21-25cb	NW¼ SW¼ sec. 25	J. M. Stewart, Jr.	Dr	76.3	6	GI	do	do	CY,W	D,S	do	.5	2,225.3	57.25	1-12-46	
3-21-27cc	SW¼ SW¼ sec. 27	W. F. Bennett	Dr	40.1	6	GI	do	Alluvium	CY,W	S	do	.3	2,207.7	20.20	6-17-46	Chemical analysis.
3-21-32bb	NW¼ NW¼ sec. 32	D. G. Hansen	Dr	72.2	6	GI	do	Ogallala	CY,W	D	do	.5	2,280.2	68.40	1- 9-46	Not in use.

TABLE 8.—*Records of wells in Norton and northwestern Phillips Counties, Kansas, and adjacent areas*—Continued

No. on Plate 2 (1)	Location	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet) (7)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet) (8)	Date of measurement	Remarks
	T. 3 S., R. 22 W.															
22-2dc	SW¼ SE¼ sec. 2	R. B. Wynn	Dr	123.1	6	GI	Sand and gravel	Ogallala	CY	D	Top of casing	1.2	2,327.2	103.9	1-12-46	
22-5cc	SW¼ SW¼ sec. 5	L. P. Reincke	Dr	114.3	6	GI	do	do	CY	S	Top of iron disc		2,361.3	97.97	12-10-45	
22-7cc	SW¼ SW¼ sec. 7	S. E. Jeffers	Dr	111.8	6	GI	do	do	CY	D,S	Top of casing	1.8	2,358.0	99.24	12-10-45	
22-9bb	NW¼ NW¼ sec. 9	J. E. Curry	Du	70.2	6	GI	do	do	CY	S	do	3.2	2,308.8	62.3	12-10-45	Chemical analysis.
22-9dd	SE¼ SE¼ sec. 9	K. M. Casey	Dr	174	6	GI	do	do	CY	S	do	1.2	2,407.6	163.05	12-10-45	
22-18dd	SE¼ SE¼ sec. 18	Fed. Farm Mtg. Corp.	Dr	79.8	6	GI	do	do	CY,W	S	do	1.0	2,338.7	76.66	12-11-45	
22-21bb	NW¼ NW¼ sec. 21	Ida Lawson	Dr	148.2	6	GI	do	do	CY,W	S	do	.6	2,386.4	127.15	12-11-45	Not in use.
22-24dc	SW¼ SE¼ sec. 24	C. Wachtel	Dr	172.7	6	GI	do	do	CY,W	D,S	do	1.0	2,385.2	163.1	1- 9-46	
22-33cd	SE¼ SW¼ sec. 33	Fed. Farm Mtg. Corp.	Dr	102.4	8	GI	do	do	CY,W	D	do	.3	2,352.7	83.76	1-12-46	Do
	T. 3 S., R. 23 W.															
23-1aa	NE¼ NE¼ sec. 1		Dr	45.6	6	GI	do	Terrace	CY	S	do	1.0	2,238.3	30.64	12-10-45	
23-3ac	SW¼ NE¼ sec. 3	City of Norton	Du	67.5	72	S	do	do	T,E	P	Level of pump house floor	1.0	2,258.5	45.59	8-27-45	Norton city well No. 7.
23-3ad1	SE¼ NE¼ sec. 3	do	Dr	60	18	C	do	do	T,E	P	Land surface		2,255.9	45	8-27-45	Norton city well No. 6.
23-3ad2	SE¼ NE¼ sec. 3	do	Dr	58	18	C	do	do	T,E	P	do		2,247.4	45	8-27-45	Norton city well No. 5.
23-3ad3	SE¼ NE¼ sec. 3	do	Du	60	48	S	do	Alluvium	T,E	P	do		2,254.7	38	8-27-45	Norton city well No. 10.
23-3bd1	SE¼ NW¼ sec. 3	do	Du	70	96	B	do	do	T,E	P	do		2,259.3	45	8-27-45	Norton city well No. 8.

23-3bd2	SE¼ NW¼ sec. 3	do	Dr	70	18	I	do	do	T,E	P	do		2,257.4	45	8-27-45	Norton city well No. 9.
23-6dd	SE¼ SE¼ sec. 6	Mrs. Sarah Woolsey	Dr	32.0			Sand	Crete	CY,W	S	Top of casing	.5	2,314.4	29.79	9-25-45	Not in use.
23-8aa	NE¼ NE¼ sec. 8	N. Stapleton	Dr	58.8	6		Sand and gravel	Terrace	CY		do	.3	2,279.3	38.10	5- 7-47	
23-8dc	SW¼ SE¼ sec. 8	Ivan Bryant	Dr	126	5		do	do	CY,W	D,S	Base of pump	.5	2,294.5	37.52	8- 4-47	
23-17aa	NE¼ NE¼ sec. 17	Campbell Estate	B	75.1	5	GI	do	Ogallala	CY,W	S	do	.3	2,313.8	66.32	8- 4-47	
23-23ab	NW¼ NE¼ sec. 23	T. M. Heaton	Dr	66.2	6	GI	do	do	CY,W	S	Top of casing	1.0	2,323.1	52.36	1-18-46	
23-24dd	SE¼ SE¼ sec. 24	do	Dr	160.8	6	GI	do	do	CY,W	S	Top of pump base	1.0	2,423.3	152.60	12-12-45	Do
23-27ba	NE¼ NW¼ sec. 27	J. E. McKee	Dr	153.3	6	GI	do	do	CY,W	S	Top of casing	.9	2,425.6	147.27	12-10-45	Chemical analysis.
23-29bb	NW¼ NW¼ sec. 29	L. O. Cope	Dr	159.7	6	GI	do	do	CY,W	S	Top edge of pump body	1.2	2,441.6	158.45	6- 8-46	Not in use.
23-33dd	SE¼ SE¼ sec. 33	D. G. Hamilton	Dr	182.8	6	GI	do	do	CY,W	D,S	Top of casing	.6	2,472.7	178.81	1-18-46	Do
	T. 3 S., R. 24 W.															
24-1bb	NW¼ NW¼ sec. 1	School District	Dr	87.7	6	GI	do	do	CY,H	D	do	0.1	2,392.7	68.78	9-24-45	Do
24-4dd	SE¼ SE¼ sec. 4	Julia Thompson *et al.*	Dr	51.6	6	GI	do	do	CY,N	D,S	Top edge of casing	1.2	2,363.6	45.28	5-22-46	
24-7aa	NE¼ NE¼ sec. 7	School District	Dr	79.2	6	GI	do	do	CY,H	D	do	.3	2,417.6	66.46	5-25-46	
24-12dd	SE¼ SE¼ sec. 12	Ed Temple	Dr	52.0	5	GI	do	Terrace	CY,W	D,S	Base of pump	.3	2,303.5	34.8	8- 4-47	
24-14aa	NE¼ NE¼ sec. 14	John B. Lawn	B	43.0	6	GI	do	do	CY,H	D,S	Top of wooden platform	.2	2,305.5	31.02	5-31-46	
24-16db	NW¼ SE¼ sec. 16	Will Collins	Dr	54.8	6	GI	Sand	Crete	N,W	N	Top of casing	.0	2,345.0	44.83	9-24-45	Do
24-17aa	NE¼ NE¼ sec. 17	C. H. Camp	Dr	77.4	6	GI	do	do	CY,W	D,S	Base of pump	1.3	2,385.9	63.59	8- 4-47	
24-18dd	SE¼ SE¼ sec. 18	J. Van Meter	Dr	51.6	6	GI	do	do	CY,N	D,S	Top edge of casing	.0	2,363.7	44.27	5-22-46	Do
24-20cc	SW¼ SW¼ sec. 20	School District	Dr	39.3	6	GI	Sand and gravel	Terrace	CY,H	D	Top of concrete curb	.0	2,340.2	29.04	6-20-46	
24-21db	NW¼ SE¼ sec. 21	Carl Roe	Dr	51.8	6	GI	do	Ogallala	N	S	Top of casing	2.1	2,343.8	47.15	9-24-45	Do
24-27aa	NE¼ NE¼ sec. 27	Federal Land Bank	Dr	128	6	GI	do	do	CY,W	S	Top edge of casing	.0	2,405.8	99.32	5-31-46	

TABLE 8.—*Records of wells in Norton and northwestern Phillips Counties, Kansas, and adjacent areas*—Continued

No. on Plate 2 (1)	Location	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.) (4)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet) (7)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet) (8)	Date of measurement	Remarks
	T. 3 S., R. 25 W.															
5-2dd	SE¼ SE¼ sec. 2	School District	Dr	94.6	6	GI	Sand and gravel	Ogallala	CY,H	D	Top of edge casing	.6	2,479.0	91.54	5-22-46	Do
5-5ca	NE¼ SE¼ sec. 5	N. B. Nelson	Dr	76.7	6	GI	do	do	CY,W	S	do	.7	2,483.3	65.97	5-22-46	
5-17dc	SW¼ SE¼ sec. 17	F. H. Brooks	Dr	85.9	6	GI	do	do	CY,W	D	do	.7	2,473.2	68.99	6- 7-46	
5-20cd	SE¼ SW¼ sec. 20	H. K. Brooks	Dr	90	5	GI	do	do	CY,W	D,S	Base of pump	.8	2,474.7	77.07	8- 5-47	
5-21dd	SE¼ SE¼ sec. 21	W. K. Goodman	Dr	79.2	5	GI	do	do	CY,W	D,S	do	.4	2,442.5	78.15	8- 4-47	
5-23ba	NE¼ NW¼ sec. 23	A. Schoen	Dr	132.8	6	GI	do	do	CY,W	S	Top edge of casing	1.0	2,424.0	87.15	5-22-46	
5-25bc	SW¼ NW¼ sec. 25	J. N. Van Meter *et al.*	Dr	52.8	5	GI	do	Terrace	CY,W	S	do	1.0	2,374.2	42.75	6-13-46	Do
5-27ad	SE¼ NE¼ sec. 27	Mrs. T. A. Mizell	Dr	34.1	6	GI	do	do	CY,W	D,S	Top casing	.0	2,372.6	27.89	6-27-46	Chemical analysis.
5-33bc	SW¼ NW¼ sec. 33	L. R. Collins	Dr	59.1	6	GI	do	do	CY,W	S	Top edge of casing	1.0	2,407.8	38.8	6- 7-46	
	T. 4 S., R. 21 W.															
1-1dd	SE¼ SE¼ sec. 1	C. Nelson	Du	54.5	40	R	do	Ogallala	CY,H	D	At manhole on concrete platform	1.1	2,188.2	52.6	1-22-46	Not in use.
1-2bb	NW¼ NW¼ sec. 2	R. Sides	Dr	21.5	10	GI	do	Alluvium	N	S	Top of casing	1.2	2,168.7	10.70	1-22-45	Do
1-3bb	NW¼ NW¼ sec. 3	J. W. Baird	Du	105.5	20	R	do	Ogallala	CY,W	D	Top of board platform	1.4	2,249.9	64.87	1-12-46	Do
1-7dc	SW¼ SE¼ sec. 7	E. E. Stephenson	Dr	75.6	6	GI	do	do	CY,H	D	Top of casing	.7	2,229.6	44.00	1- 9-46	Do
1-23cd	SE¼ SW¼ sec. 23	S. L. Atkinson Estate	Dr	364.2	6	GI	Sand	Codell	CY,W	D,S	Top of concrete base	.6	2,135.8	194.38	6-21-46	Chemical analysis.
1-24bb	NW¼ NW¼ sec. 24	Federal Land Bank	Dr	401.7	6	GI	do	do	CY,W	D,S	do	.5	....	98.14	6-21-46	Not in use.

21-28bb	NE¼ NW¼ sec. 28	Henrietta Veeh *et al.*	Du	45.3	18	R	Sand and gravel	Ogallala	CY,W	S	Top of board platform	.0	2,144.0	41.90	1-22-46	Chemical analysis.
21-30dc	SW¼ SE¼ sec. 30	Chester Beach	Du	26.7			do	Alluvium	CY,W	D	do	.0	2,063.4	17.62	1-22-46	
21-35bb	NW¼ NW¼ sec. 35	Henrietta K. Wiltrout	Dr	155			Chalk, sand, and gravel	Niobrara and alluvium	CY,W	D	Top of stone curb	.9	2,062.4	24.20	1-22-46	Not in use.
	T. 4 S., R. 22 W.															
22-1ba	NE¼ NW¼ sec. 1	First State Bank of Norton, Kansas	Dr	69.8	6	GI	Sand and gravel	Ogallala	CY,W	D	Top of casing	.5	2,286.3	60.7	1-12-46	Do
22-2bb	NW¼ NW¼ sec. 2	W. T. Green	Dr	47.1	6	GI	do	do	CY,W	S	do	.2	2,269.7	36.80	1-12-46	
22-6ad	SE¼ NE¼ sec. 6	C. A. Sleffel	Dr	125.5	6	GI	do	do	CY,W	S	do	.4	2,381.5	110.30	1-7-46	Not in use.
22-9cc	SW¼ SW¼ sec. 9	C. Wachtel	Dr	151.3	6	GI	do	do	CY,W	D,S	do	.6	2,287.3	129.43	1-9-46	Do
22-15aa	NE¼ NE¼ sec. 15	Federal Land Bank	Dr	70.0	6	GI	do	do	CY,W	D,S	do	.5	2,283.3	58.11	1-9-46	Do
22-15cd	SE¼ SW¼ sec. 15	E. E. Thompson	Dr	50.3	6	GI	do	do	CY,W	S	do	.1	2,269.1	45.28	1-9-46	
22-17cc	SW¼ SW¼ sec. 17	J. M. Scott Estate	Dr	97.6	6	GI	do	do	CY,W	D	do	.0	2,299.9	71.48	1-18-46	
22-26bb	NW¼ NW¼ sec. 26	School District	Dr	73.3	5	GI	do	do	N	N	do	.3	2,230.0	64.33	8-13-47	Do
22-29da	NE¼ SE¼ sec. 29	School District 95	Dr	109.0	6	GI	do	do	CY,H	D	Top of concrete platform	.3	2,283.0	96.70	1-18-46	Chemical analysis.
	T. 4 S., R. 23 W.															
23-1ac	SW¼ NE¼ sec. 1	Trena Veth	Dr	74.0	6	GI	do	do	CY,W	S	Top of casing	.7	2,335.1	60.24	12-12-45	Chemical analysis.
23-2dc	SW¼ SE¼ sec. 2	J. E. Toole	Dr	127.8	6	GI	do	do	CY,W	D	do	0.5	2,404.2	122.67	1-18-46	Not in use.
23-5dc	SW¼ SE¼ sec. 5	School District	Dr	177.6	6	GI	do	do	CY,H	D	Top edge of casing	1.9	2,467.9	159.60	6-10-46	
23-14ad	SE¼ NE¼ sec. 14	W. H. Bretton	Dr	91.7	6	GI	do	do	CY,W	S	Top of casing	1.5	2,324.7	67.58	1-18-46	
23-19dc	SW¼ SE¼ sec. 19	School District	Dr	145.3	6	GI	do	do	CY,H	D	Top edge of casing	.5	2,424.5	121.05	6-10-46	Not in use. Chemical analysis.
23-25da	NE¼ SE¼ sec. 25	School District	Dr	122.0	6	GI	do	do	CY,H	D	Top of concrete	.2	2,298.8	87.19	1-18-46	Not in use.
23-26ba	NE¼ NW¼ sec. 26	W. W. Bales	Dr	159.0	6	GI	do	do	CY,H	D	do	.5	2,406.4	154.44	1-18-46	Do
23-34cd	SE¼ SW¼ sec. 34	Federal Land Bank	Dr	71.0	6	GI	do	do	CY,W	D,S	Top of casing	.5	2,284.7	58.33	6-4-46	

Table 8.—*Records of wells in Norton and northwestern Phillips Counties, Kansas, and adjacent areas—Continued*

No. on Plate 2 (1)	Location	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet) (7)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet) (8)	Date of measurement	Remarks
	T. 4 S., R. 24 W.															
24-8bb	NW¼ NW¼ sec. 8	R. L. Bullock	Dr	171.5	5	GI	Sand and gravel	Ogallala	N	N	Top of casing	.5	2,518.3	148.00	8-5-47	Not in use.
24-10bb	NW¼ NW¼ sec. 10	E. C. Larson	Dr	190.5	5	GI	do	do	N	N	Top edge of casing	1.0	2,511.6	176.06	5-31-46	Do
24-23bb	NW¼ NW¼ sec. 23	T. M. Wright	Dr	151.2	6	GI	do	do	CY,N	D,S	do	1.0	2,478.8	143.16	5-31-46	Do
24-31ad	SE¼ NE¼ sec. 31	D. C. Neikers	Dr	30.6	6	GI	do	Alluvium	CY,W	D,S	do	.3	2,382.8	22.85	6-14-46	Not in use. Chemical analysis.
24-32cc	SW¼ SW¼ sec. 32	Theodore Fought	Du	37.2	144+	C, GI	do	do	C,G	I	Top of cement curb	10.6	2,360.8	13.80	8-15-47	
24-35cc	SW¼ SW¼ sec. 35	A. A. Schreiber	Dr	110.5	6	GI	do	Ogallala	N	N	Top edge of casing	.2	2,426.3	107.53	5-31-46	Not in use.
	T. 4 S., R. 25 W.															
25-2dd	SE¼ SE¼ sec. 2	Lester Haget	Dr	164.8	6	GI	do	do	CY,W	D,S	Top surface of platform	.8	2,520.8	137.57	6-13-46	
25-5aa	NE¼ NE¼ sec. 5	Bradley Brooks	Dr	113	6	GI	do	do	CY,W	D,S	Base of pump	.9	2,490.0	109.58	8-5-47	
25-6ab	NW¼ NE¼ sec. 6	City of Clayton	Dr	51	12	S	do	Terrace	T,E	D	Top of floor	.5	2,417.6	31	8-15-47	Clayton municipal well.
25-7da	NE¼ SE¼ sec. 7	W. E. Griffith	Dr	120+	6	GI	do	Ogallala	CY,W	S	Top surface concrete platform	.5	2,516.7	117.88	6-7-46	Chemical analysis.
25-16dd	SE¼ SE¼ sec. 16	E. A. Wolf	Dr	180.0	....	GI	do	do	CY,W	D,S	Top of pump bowl	3.4	2,551.3	178.37	8-5-47	Not in use.
25-19da	NE¼ SE¼ sec. 19	D. R. Wonderlich	Dr	182.3	6	GI	do	do	CY,H	D,S	Top edge of casing	.8	2,575.9	179.47	6-7-46	Do
25-24ba	NE¼ NW¼ sec. 24	Eliz. Mindrup	Dr	138.1	6	GI	do	do	CY,W	D,S	Top of concrete platform	.8	2,510.9	134.23	6-13-46	Do
25-26dd	SE¼ SE¼ sec. 26	H. L. Vahling	Dr	121.3	6	GI	do	do	CY,W	D,S	Top edge of casing	0.8	2,446.6	68.35	6-13-46	Not in use.
	T. 5 S., R. 21 W.															
21-1dd	SE¼ SE¼ sec. 1	A. G. Clark	Dr	43.5	8	T	do	Terrace	CY,W	D,S	Top of casing	1.1	2,000.1	34.77	11-28-45	Do
21-3ad	SE¼ NE¼ sec. 3	C. H. Elliott	Dr	43.9	6	GI	do	do	CY,H	D	do	.9	2,008.8	21.86	6-22-46	Do

21-5aa	NE¼ NE¼ sec. 5	Louis Reimann	Dr	50.7	6	.....	do	do	N	D	do	1.6	2,031.4	22.95	8-13-47	New well constructed August 1947.
21-9ba	NE¼ NW¼ sec. 9	W. Archer	Dr	22.4	6	GI	Chalk	Niobrara	CY,W	D,S	do	5.2	2,061.2	134.70	8-13-47	
21-14dd	SE¼ SE¼ sec. 14	J. W. Baird	Dr	54.0	6	GI	Sand and gravel	Ogallala	CY,W	D,S	Top edge of casing	.8	2,163.3	49.46	6- 3-46	
21-15bc	SW¼ NW¼ sec. 15	George Glennemier	Dr	383.0	7	I	Chalk and sand	Niobrara and Codell	N,W	S	Top of platform	.2	2,159.3	59.76	6-21-46	Not in use.
21-16ba	NE¼ NW¼ sec. 16	Joseph Archer	Dr	309.5	8	GI	do	do	CY,W	D,S	Top board of platform	1.0	2,125.7	40.25	6-22-46	Chemical analysis.
21-19cd	SE¼ SW¼ sec. 19	Louis Voss	Dr	86.6	6	GI	Sand and gravel	Ogallala	CY,W	D,S	Top of concrete base	1.8	2,253.2	75.32	6-21-46	
21-26dd	SE¼ SE¼ sec. 26	F. M. Dedrick	Dr	89.0	6	GI	do	do	CY,W	S	Top edge of casing	.8	2,215.4	84.65	6- 3-46	
21-33dc	SW¼ SE¼ sec. 33	E. J. Seely	Dr	105.8	6	GI	do	do	N	N	Top edge of board cover	.0	2,265.6	96.66	6- 3-46	Not in use.
	T. 5 S., R. 22 W.															
22-1dc	SW¼ SE¼ sec. 1	Martin Jacobson	Dr	39.0	6	GI	do	Terrace	CY,H	D	Top of casing	.2	2,065.0	24.80	6-22-46	
22-7dd	SE¼ SE¼ sec. 7	J. W. Heins	Dr	91.6	6	GI	Chalk(?)	Niobrara(?)	CY,W	D	Top of concrete curb	1.6	2,193.1	86.73	1- 7-45	Do
22-10cb	NW¼ SW¼ sec. 10	Frank Schulte	Dr	99.3	6	GI	Chalk	Niobrara	CY,H	D	Top edge of casing	.4	2,117.6	45.89	6-22-46	
22-10dd	SE¼ SE¼ sec. 10	Frank Stenger	Dr	34.9	6	GI	Sand and gravel	Alluvium	CY,W	D,S	Top of casing	.9	2,085.9	20.95	6-22-46	Chemical analysis.
22-21db	NW¼ SE¼ sec. 21	W. Hunter	Dr	29.1	.....	.....	do	do	CY,W	S	Top of casing	1.2	2,163.3	15.26	8-13-47	Depth to water 12.24 feet, April 10, 1948.
22-30ba	NE¼ NW¼ sec. 30	Harry Brooks	Du	7.9	36	GI	do	do	P,H	I	Top of casing	2.3	2,262.7	4.73	8-13-47	
22-32da	NE¼ SE¼ sec. 32	R. A. Billips	Dr	117.0	6	GI	do	Ogallala	CY,W	S	Top edge of casing	1.0	2,317.5	88.25	6- 3-46	Chemical analysis.
22-36dd	SE¼ SE¼ sec. 36	Leland Stewart	Dr	109.0	6	.....	do	do	CY,W	D,S	Pump base	.7	2,304.9	101.00	3-25-48	
	T. 5 S., R. 23 W.															
23-1da	NE¼ SE¼ sec. 1	A. B. Conkey	Dr	74.8	6	GI	do	do	CY,W	S	Top of concrete platform	0.3	2,253.2	63.42	1-18-46	
23-5cc	SW¼ SW¼ sec. 5	School District	Dr	97.8	6	GI	do	do	CY,H	D	Top edge casing	.0	2,343.5	86.25	6-11-46	
23-14bc	SW¼ NW¼ sec. 14	G. A. Sanborn	Dr	44.5	6	GI	do	Terrace	CY,H	D,S	Top of wooden platform	.2	2,169.4	24.18	6- 4-46	Not in use.
23-14da	SW¼ NE¼ SE¼ sec. 14	H. A. Delp	Du	31	24	..	do	Alluvium	C,G	I	Floor surface at engine	1.0	2,148.9	10	8-14-47	
23-17dc	SW¼ SE¼ sec. 17	School District	Dr	50.7	6	GI	do	Terrace	CY,H	D	Top edge of casing	.1	2,223.1	31.05	6-11-46	
23-19bb	NW¼ NW¼ sec. 19	Herbert Fought	Du	39.6	16	GI	do	do	C,G	I	Top of floor	1.3	2,225.4	10.18	8-15-47	

TABLE 8.—*Records of wells in Norton and northwestern Phillips Counties, Kansas, and adjacent areas*—*Concluded*

No. on Plate 2 (1)	LOCATION	Owner or tenant	Type of well (2)	Depth of well (feet) (3)	Diameter of well (in.)	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface (feet) (7)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet) (8)	Date of measurement	Remarks
23-28cd	SE¼ SW¼ sec. 28	J. Williams	Dr	83.0	6	GI	Sand and gravel	Ogallala	CY,W	D,S	Top edge of casing	1.0	2,320.7	65.48	6- 4-46	
23-29bc	SW¼ NW¼ sec. 29	R. V. Bennett	Dr	106.5	5	GI	do	do	N	S	Top of 5-inch casing	1.9	2,334.9	46.44	9-22-45	Do
23-31cc	SW¼ SW¼ sec. 31	O. I. Simons	Dr	43.6	6	GI	do	do	CY,W	D,S	Top edge of casing	.8	2,368.3	33.8	6-11-46	Do
23-35cb	NW¼ SW¼ sec. 35	A. E. Flowers	Dr	157.0	6	GI	do	do	CY,W	D,S	Top of casing	1.0	2,405.8	150.16	6- 4-46	
	T. 5 S., R. 24 W.															
24-7dd	SE¼ SE¼ sec. 7	Anna Zierlein	Dr	83.3	6	GI	do	do	CY,W	D,S	Top edge of casing	.6	2,403.5	66.0	6-14-46	
24-10ba	NE¼ NW¼ sec. 10	Dave Greig	Dr	37	6	GI	do	Terrace	N	N	Top of casing	.5	2,298.2	31.15	8-12-47	Not in use.
24-10da	NE¼ SE¼ sec. 10	F. H. Belden	Du	21.1	24	C,GI	do	do	C,G	I	do	—7.0	2,255.1	1.35	8-15-47	Centrifugal pump in 7-fo[ot] pit.
24-13ca	NE¼ SW¼ sec. 13	L. N. Moore	Dr	62.3	6	GI	do	do	CY,W	S	do	.6	2,255.7	37.09	6-20-46	
24-13dc	SW¼ SE¼ sec. 13	Steve T. Kaufman	Du	34.3	12, 36	T,GI	do	Alluvium	C,G	I	Top of tile casing	2.5	2,235.3	16.38	8-15-47	
24-14cb	NW¼ SW¼ sec. 14	City of Lenora	Dr	29.0	18	C	do	do	C,E	P	Top of concrete casing	—11.5	2,239.3	5.34	8-30-45	Lenora city well.
24-20bc	SW¼ NW¼ sec. 20	School District 62	Dr	43.1	5	GI	do	Terrace	CY,H	D	Top of casing	.3	2,328.1	35.49	9-25-45	Chemical analysis.
24-21ab	NW¼ NE¼ sec. 21	Erma B. Finley	DD	35.8	16	I	do	do	C,G	I	At edge of well house	1.0	2,271.6	14.34	6-20-46	
24-22ba	NE¼ NW¼ sec. 22	E. Goodman Estate	Du	44.5			do	do	N	D	Top of casing	0	2,276.9	35.48	6-20-46	Not in use.
24-24ba	NE¼ NW¼ sec. 24	E. A. Snider	Du	37	48	C	do	do	T,N	I	Top of platform	1.0	2,248.9	28.33	7- 1-46	Do
24-24bc	SW¼ NW¼ sec. 24	T. H. Van Diest	Dr	53	24	I	do	do	C,G	I	Hole in pump base	1.2	2,252.0	24.16	8-30-45	Chemical analysis.
24-32ad	SE¼ NE¼ sec. 32	J. W. Hickert	Dr	140+	6	GI	do	Ogallala	CY,W	S	Base of pump	1.0	2,483.8	137.50	3-24-48	

	T. 5 S., R. 25 W.														
-4ab	NW¼ NE¼ sec. 4	L. P. Moore	Dr	53.8	6	GI	do	do	CY,W	S	Top edge of casing	.6	2,466.2	47.14	6-14-46	Not in use.
-12cc	SW¼ SW¼ sec. 12	A. L. Mindrup	Dr	141	6	GI	do	do	CY,W	S	do	.7	2,490.6	124.94	6-13-46	
-15cc	SW¼SW¼ sec. 15	J. T. Dellere	Dr	82.3	6	GI	do	do	CY,W	S	do	1.0	2,457.5	62.08	6-20-46	
-25bc	SW¼ NW¼ sec. 25	John Hickert	Dr	71.2	6	GI	do	do	CY,W	D,S	do	.0	2,403.7	60.98	6-13-46	
-26aa	NE¼ NE¼ sec. 26	do	DD	55.5			do	Terrace	T,G	I	Top of concrete curb	5.8	2,358.3	17.92	6-20-46	Not used for several years.
-29dd	SE¼ SE¼ sec. 29	School District	Dr	40.8	6	GI	do	do	CY,H	D	Top of casing	.8	2,405.6	21.78	6-20-46	
-30dd	SE¼ SE¼ sec. 30	T. A. Costello	Dr	33.4	6	GI	do	do	CY,W	S	Top edge of casing	1.0	2,416.0	20.38	6-20-46	Chemical analysis.
-32ba	NE¼ NW¼ sec. 32	F. A. Vahling	Dr	56.3	24	GI	do	do	T,G	I	Base of pump	.7	2,419.5	25.67	10-15-47	
-34cb	NW¼ SW¼ sec. 34	Paul Dellere	Dr	152.4	6	GI	do	Ogallala	CY,W	D,S	Top edge of casing	.5	2,523.2	130.3	6-14-46	
	T. 5 S., R. 26 W.															
-12da	NE¼ SE¼ sec. 12	Leo Mindrup	Dr	171	5	GI	do	Terrace	CY,W	D,S	Top of casing	—5.5	2,585.3	144.8	8- 5-47	6-foot pit beneath well platform.
	T. 1 N., R. 18 W.															
18-31da	NE¼ SE¼ sec. 31		B	27.6	4	GI	do	Alluvium	CY,W	D	Top of concrete platform at manhole	1.3	1,975.6	20.87	10-14-47	Not in use.
18-33bc	SW¼ NW¼ sec. 33	J. S. Stone	Dr	50.9	5	GI	do	Terrace	CY,W	D	Top of concrete platform	.5	1,983.7	34.20	10-16-47	
	T. 1 N., R. 19 W.															
19-25ac	SW¼ NW¼ sec. 25	J. R. Starr	Dr	60.0	5, 6	GI			CY,W	D,S	Top of casing in 6-foot pit	—5.5	2,065.0	50.32	10-16-47	6-foot pit under platform.
19-28dc	SW¼ SE¼ sec. 28	C. Abbot	Du	40.0	24				CY,W	S	Top concrete curb	2.3	2,067.5	38.58	10-16-47	
19-32cc	SW¼ SW¼ sec. 32		Dr	73.5		I	Sand and gravel	Terrace	T,G	I	Edge of inspection well	1.7	2,029.9	27.70	9-24-47	
19-33cc	SW¼ SW¼ sec. 33		Dr	42.6	6	GI	do	do	CY,W	D,S	Base of pump	1.0	2,019.0	31.57	9-24-47	Not in use.
19-35bc	SW¼ NW¼ sec. 35	Phillip Rogers	Dr	68.2	4	GI	do	do	N	N	Top of casing	.7	2,004.3	30.75	10-16-47	Do
19-36ca	NE¼ SW¼ sec. 36	Fred Howsden	B	49.9	5	GI	do	do	CY,W	D,S	Top of casing in 4-foot pit	—4.0	1,988.1	17.99	10-14-47	4-foot pit under platform.

1. Well number indicates location of the well as described in the introduction.
2. B, bored well; DD, dug and drilled well; Dr, drilled well; Du, dug well.
3. Reported depths below the land surface are given in feet; measured depths are given in feet and tenths below measuring points.
4. B, brick; C, concrete; GI, galvanized sheet iron; I, iron; R, rock; S, steel; T, tile.
5. Method of lift: C, horizontal centrifugal; CY, cylinder; J, jet pump; N, none; P, pitcher pump; T, turbine.
Type of power: E, electric; G, gas engine; H, hand operated; T, tractor; W, windmill.
6. D, domestic; I, irrigation; N, not being used; P, public supply; S, stock.
7. Minus sign preceding figure indicates measuring point below land surface.
8. Measured depths to water level are given in feet, tenths, and hundredths; reported depths to water level are given in feet.

LOGS OF TEST HOLES AND MEASURED STRATIGRAPHIC SECTIONS

Listed in the following pages are logs of 64 test holes and 8 measred stratigraphic sections in Norton County and northwestern Phillips County. The logs and stratigraphic sections are grouped separately and arranged by townships from north to south and ranges from east to west. Within a township they are arranged by section number. The test holes were drilled by the State Geological Survey during 1946, 1947, and 1948. Samples of the material penetrated by the test holes were examined in the field by James Cooper (1946) and Glenn Prescott (1947 and 1948), who supervised the drilling and prepared logs of the holes. The samples were subsequently studied microscopically by O. S. Fent, John C. Frye, or A. R. Leonard. General location of the test holes is shown on the index map in Plates 2 and 3.

Stratigraphic sections were measured in the field during the seasons of 1945 and 1947. Where credit is not given in the heading, the sections were measured by us. Four additional sections are included in the text. Fossil seeds listed with the sections were identified by M. K. Elias of the Nebraska Geological Survey and fossil snails were identified by A. Byron Leonard of the University of Kansas.

LOGS OF TEST HOLES

1-18-8aa. *Sample log of test hole at the NE cor. sec. 8, T. 1 S., R. 18 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,108.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, tan	23	23
TERTIARY—Pliocene		
Ogallala formation		
Silt, sandy, yellow brown	12	34
Silt and fine sand, white; loosely cemented with calcium carbonate	10	45
Silt and fine sand, pale green, becoming more sandy in lower part	13	58
Clay, silty, bentonitic, olive green	16	74
CRETACEOUS—Gulfian		
Pierre shale		
Shale, noncalcareous, blue gray	7	81
Niobrara formation		
Shale, calcareous, gray	13	94

1-19-9ab. *Sample log of test hole in the NW¼ NE¼ sec. 9, T. 1 S., R. 19 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,110.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Loveland and Crete members		
Silt, sandy, brown	7	7
Sand, medium to coarse, and fine gravel; contains silt and clay in middle part	25	32
Sand, fine to medium, and fine gravel; contains small chalk pebbles	3	35
Silt and very fine sand, light tan	3	38
CRETACEOUS—Gulfian		
Pierre shale		
Shale, clayey and silty, calcareous, yellow	2	40
Shale, light gray and yellow; contains calcareous zones	11	51
Shale, noncalcareous, olive, gray, and mottled red and yellow	6	57
Shale, noncalcareous, black	15	72
Shale, noncalcareous, black; contains calcareous zones	9	81
Niobrara formation		
Shale, calcareous, gray	3	84
Sand, medium to coarse (probably a fault zone)	0.5	84.5
Shale, calcareous, gray	1.5	86

1-20-2aa. *Sample log of test hole at the NE cor. sec. 2, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,093.5 feet; water level, 21 feet below land surface.*

	Thickness, feet	Depth, feet
QUATERNARY—Recent		
Alluvium		
Silt, sandy, dark brown	11	11
Silt, sandy, tan	11	22
CRETACEOUS—Gufian		
Pierre shale		
Shale, noncalcareous, olive green to light gray	8	30
Shale, noncalcareous, gray; contains bentonitic white olive-green clay	12	42
Niobrara formation		
Shale, calcareous, gray	13	55

1-20-12bb. *Sample log of test hole at the NW cor. sec. 12, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,097.3 feet.*

	Thickness, feet	Depth, feet
Road fill, silty, dark brown	4	4
QUATERNARY—Recent		
Alluvium		
Silt, sandy, tan; contains gravel	10	14
Gravel, fine to coarse, and sand	1	15
Silt, white	4	19
Sand, coarse, and fine to coarse gravel; contains chalk fragments	8	27

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Pierre shale		
Shale, noncalcareous, olive green	1	28
Shale, noncalcareous, black; contains zones of calcareous shale	30	58
Niobrara formation		
Shale, calcareous, gray	2	60

1-20-13bb. *Sample log of test hole in the NW¼ NW¼ sec. 13, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude 2,092.1 feet.*

	Thickness, feet	Depth, feet
Road fill, silty, brown	4	4
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, black and dark brown	4	8
Silt, sandy, tan	12	20
Loveland member		
Silt, sandy, tan to brown	10	30
Silt, sandy, brown; contains gravel and snail shells	14	44
Silt, sandy, gray and yellow brown	4	48
CRETACEOUS—Gulfian		
Pierre shale		
Shale, noncalcareous, black; contains calcareous zones	7	55
Niobrara formation		
Shale, calcareous, hard, gray	5	60

1-20-14ad. *Sample log of test hole in the SE¼ NE¼ sec. 14, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,082.6 feet.*

	Thickness, feet	Depth, feet
Road fill, sandy silt, dark brown	4	4
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, sandy, light tan	7	11
Loveland member		
Silt, sandy, light brown with upper part dark brown (Loveland soil)	16	27
Crete member		
Sand and gravel, fine to coarse; contains caliche and snail shells in upper part	20	47
Silt, sandy, brown and green	5	52
Sand and gravel, fine to coarse; contains pebbles up to half an inch in diameter	7	59
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, yellow	2	61
Shale, calcareous, gray	9	70

1-20-14dd. *Sample log of test hole in the SE¼ SE¼ sec. 14, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,063.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, dark brown (fill)	4	4
Silt, tan	21	25
Silt and sand, brown	14	39
Silt and clay, sandy in some zones and calcareous in some zones, gray, greenish gray, to black	29	68
Gravel, fine to coarse	2	70
Gravel, coarse	4	74
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, dark gray	6	80

1-20-20bc. *Sample log of test hole in the SW¼ NW¼ sec. 20, T. 1, S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,129.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Recent		
Alluvium		
Silt (soil), dark brown	1	1
Silt with some sand, light brown	19	20
Sand, medium to coarse, with some brown silt and fine gravel	10	30
Gravel and coarse sand	3	33
CRETACEOUS—Gulfian		
Pierre shale		
Shale, noncalcareous, black to brown	2	35
Shale, noncalcareous, dark gray to black; contains a few bentonite streaks	33	68
Niobrara formation		
Shale, calcareous, dark gray	32	100

1-20-24cb. *Sample log of test hole in the NW¼ SW¼ sec. 24, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,069.3 feet; water level, 29 feet.*

	Thickness, feet	Depth, feet
Road fill, sandy silt, dark brown	2	2
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, sandy, light tan; contains caliche	2	4
Silt, dark brown and tan	6	10
Silt, sandy, yellow tan	21	31
Sand and gravel, fine to coarse	12	43
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, yellow	2	45
Shale, calcareous, light gray	5	50

1-20 25bb. *Sample log of test hole in the NW¼ NW¼ sec. 25, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,073.1 feet; water level, 29 feet.*

	Thickness, feet	Depth, feet
Road fill, dark brown silt	2	2
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, sandy, tan; contains two thin dark brown "soil" bands at 6 and 15 feet below top	34	36
Silt and clay, green	7	43
Sand and gravel, green	3	46
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, yellow brown	1	47
Shale, calcareous, dark gray	13	60

1-20-25bc. *Sample log test hole in the SW¼ NW¼ sec. 25, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1947. Surface altitude, 2,078.4 feet; water level, 28 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, black (soil)	3	3
Silt, light tan; contains abundant snails in lower part	29	32
Silt, sandy, tan	9	41
Sand and gravel, fine to coarse; contains chalk fragments	13	54
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, chalky, yellow	1	55
Shale, calcareous, gray	15	70

1-20-27cb. *Sample log test hole in the NW¼ SW¼ sec. 27, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1947. Surface altitude, 2,081.7 feet; water level, 22 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, dark brown (soil)	1	1
Silt, sandy, tan	9	10
Silt, tan; contains caliche	18	28
Silt, sandy, greenish gray	8	36
Sand and gravel, fine to coarse; contains chalk pebbles	7	43
Silt and clay, sandy; black	14	57
Sand and gravel	11	68
Gravel, medium to coarse	11	79
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, gray	11	90

1-20-27dc. *Sample log of test hole in the SW¼ SE¼ sec. 27, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,089.8 feet.*

	Thickness, feet	Depth, feet
Road fill, black silt	2	2
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, blocky, dark brown	8	10
Silt, light brown; contains caliche	15	25
Silt and sand, very fine	21	46
Sand and gravel, green; contains caliche and chalk fragments	7	53
Sand and gravel, greenish	19	72
Sand and gravel, fine to coarse	6	78
Silt and clay, gray	8	86
CRETACEOUS—Gulfian		
Niobrara formation		
Shale and clay, hard, calcareous, dark gray	17	103
Shale, calcareous, gray	2	105

1-20-28ad. *Sample log of test hole in the SE¼ NE¼ sec. 28, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1947. Surface altitude, 2,084.3 feet; water level, 26 feet.*

	Thickness, feet	Depth, feet
Road fill, dark brown silt	2	2
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, tan	28	30
Silt and sand, very fine, brown	8	38
Silt, dark gray	20	58
Silt, greenish gray; contains snail shells	9	67
Sand and gravel, fine to coarse; contains green and white clay and silt	13	80
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, gray	20	100

1-20-34ad. *Sample log of test hole in the SE¼ NE¼ sec. 34, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1948. Surface altitude, 2,092.7 feet.*

	Thickness, feet	Depth, feet
Road fill, black sandy silt	2	2
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, sandy, tan; contains caliche	17	19
Silt, tan; upper part dark brown	16	35
Silt and sand, very fine, tan	5	40

	Thickness, feet	Depth, feet
Clay, silt and caliche, light green and tan; contains sand 46 to 50 feet	22	62
Silt and sand, very fine to coarse, tan	8	70
Sand and gravel, fine to coarse; contains chalk pebbles	14	84
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, gray	11	95

1-20-36cc. *Sample log of test hole at the SW cor. sec. 36, T. 1 S., R. 20 W., Phillips County, Kansas; drilled in 1947. Surface altitude, 2,199.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, sandy, light tan	7	7
TERTIARY—Pliocene		
Ogallala formation		
Sand, fine to medium, with some silt	2	9
Sand and gravel, cemented with calcium carbonate	9	18
Silt, fine sand, and caliche, green	7	25
Silt and clay, hard, brown	5	30
Silt and sand, cemented with calcium carbonate in some zones	50	80
Clay, bentonitic, noncalcareous, olive green and gray	28	108
Silt and fine sand, tightly cemented with calcium carbonate	10	118
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, pink and yellow	7	125
Shale, calcareous, gray and brown	15	140

1-21-5aa. *Sample log of test hole in the NE cor. sec. 5, T. 1 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,325.9 feet; water level, 96 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, medium compact, gray; contains nodules of caliche	4	4
Silt, soft, tan; contains snail shells	12	16
Loveland member		
Silt, compact, tan to chocolate brown (Loveland soil)	4	20
Silt, tan; contains some fine sand	42	62
TERTIARY—Pliocene		
Ogallala formation		
Silt with some sand, cemented with calcium carbonate in some zones	60	122
Silt and fine sand, tightly cemented with calcium carbonate	8	130
Sand, fine to coarse, with some fine gravel and caliche	6	136
Silt and some fine sand, medium compact, calcareous, light gray	28	164

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, chalky, pink to light yellow	2	166
Chalk, hard, white to light yellow	0.5	166.5
Shale, chalky, light yellow, pink, and buff	3.5	170

1-21-28bb. *Sample log of test hole in the NW cor. sec. 28, T. 1 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,242.9 feet; water level, 41 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, medium, compact, gray	6	6
Loveland member		
Silt, compact, tan (Loveland soil)	3	9
Silt, with some fine sand, tan	14	23
TERTIARY—Pliocene		
Ogallala formation		
Silt, gray to tan; contains some fine sand and caliche	8	31
Sand and gravel, fine to coarse	6	37
Sand, tightly cemented with calcium carbonate	2	39
Silt, compact, gray	1	40
Sand and gravel, fine to coarse, partly cemented	9	49
Silt, light gray; contains some sand; cemented with calcium carbonate	11	60
Silt, sand, and gravel, medium compact, yellow tan to gray	25	85
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, hard, white, interbedded with chalky shale	2	87
Shale, chalky, soft, yellow buff; contains some thin bentonite beds	13	100

1-21-29dd. *Sample log test hole in the SE cor. sec. 29, T. 1 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,249.5 feet; water level, 56 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, loose, tan; contains abundant snail shells	14	14
Loveland member		
Silt, dark gray brown, compact (Loveland soil)	4	18
Silt, medium compact, tan and light gray	7	25
Silt, light gray; contains some sand and fine gravel	5	30
TERTIARY—Pliocene		
Ogallala formation		
Sand and gravel, coarse to fine; contains some caliche	10	40
Silt and some fine sand and gravel, loose	4	44
Silt and some fine sand, loosely cemented in some zones with calcium carbonate	35	79

	Thickness, feet	Depth, feet
Sand, fine to coarse; contains some gravel and silt	14	93
Silt, light gray to white; contains some fragments of chalk and sand	12	105
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, soft, yellow to white	3	108
Chalk, hard, yellow buff	0.2	108.2

1-22-28ad. *Sample log of test hole in the SE¼ NE¼ sec. 28, T. 1 S., R. 22 W., Norton County, Kansas; drilled in 1948. Surface altitude, 2,354.4 feet; water level, 48 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt (soil), dark brown	2	2
Silt, tan	13	15
Loveland member		
Silt, compact, noncalcareous, brown (Loveland soil)	7	22
Silt, light tan	18	40
TERTIARY—Pliocene		
Ogallala formation		
Silt and fine sand, calcareous, light tan to light brown	43	83
Silt, sand, and some gravel, tightly cemented with calcium carbonate, light gray to white	28	111
Sand and silt, partly cemented with calcium carbonate, greenish gray to light brown	9	120
Sand and silt, some gravel, tightly cemented with calcium carbonate, greenish gray to brown. (Unable to drill deeper with existing equipment.)	5	125

1-23-35bb. *Sample log of test hole in the NW cor. sec. 35, T. 1 S., R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,428.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, compact, dark gray to tan	5	5
Silt, loose, tan; contains many snail shells	14	19
Loveland member		
Silt, compact to loose, tan to gray	31	50
TERTIARY—Pliocene		
Ogallala formation		
Sand and silt, cemented in some zones, tan to white	47	97
Silt and fine sand, loose, gray	25	122
Silt and fine sand, cemented in some zones, gray to tan	32	154
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, hard, gray to white	1	155

1-24-34da. *Sample log of test hole in the NE¼ SE¼ sec. 34, T. 1 S., R. 24 W., Norton County, Kansas; drilled in 1948. Surface altitude, 2,474.4 feet; water level, 127 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt (soil), dark brown	1	1
Silt, tan; contains snail shells	22	23
Loveland member		
Silt, noncalcareous, compact, brown (Loveland soil)	3	26
Silt, light tan	16	42
TERTIARY—Pliocene		
Ogallala formation		
Silt and fine sand, calcareous, with some clay and gravel, light tan	38	80
Silt, sand, and caliche, tightly cemented, white	11	91
Silt, dark brown to tan	5	96
Sand, fine, and silt, brown and greenish	15	111
Silt and clay, light tan to light gray green	11	122
Silt and sand, tan to light brown	17	139
Silt and sand, cemented with calcium carbonate, light gray,	11	150
Sand and gravel, with a few streaks of silt, white to light brown	23	173
Silt, brown	6	179
Sand and gravel, brown, with thin beds of silt	27	206
Clay, bentonitic, noncalcareous; contains scattered sand grains and some light greenish-gray to yellow-tan silt	21	227
Sand, fine to medium	1	228
Clay, slightly calcareous, bentonitic, light gray green	2	230
Clay, bentonitic, noncalcareous, light gray green, yellow, brown, and gray	10	240
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, blue gray	10	250

1-25-1bb1. *Sample log of test hole in the NW¼ NW¼ sec. 1, T. 1 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,339.8 feet; water level, 28 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, dark gray to black	3	3
Silt, loose, gray to tan; contains some caliche	6	9
Silt, gray, compact; contains some sand and gravel	29	38
Sand, fine; contains some fine gravel and silt	13	51
Gravel, fine to coarse; contains some sand and gray-blue silt	3	54
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, fissile, dark gray to black; contains a few bentonite streaks	6	60

1-25-1bb2. *Sample log of test hole in the SW cor. NW¼ NW¼ sec. 11, T. 1 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,329.3 feet; water level, 16 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Recent		
Alluvium		
Silt, compact, brown and tan	7	7
Sand, very fine to fine	2	9
Silt, loose, gray	7	16
Gravel, fine to very coarse; contains large pebbles of chalk and some sand	11	27
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, silty, yellow brown and gray	6	33
Shale, calcareous, fissile, dark gray	7	40

1-25-1bc. *Sample log of test hole in the cen. W. line sec. 1, T. 1 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,352.2 feet; water level, 40 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, compact, black	4	4
Silt, brown; few nodules of caliche	3	7
Silt, loose, tan; contains snail shells	21	28
Silt and sand, loose, brown	8	36
Gravel, fine, and sand; contains pebbles of chalk and some silt	7	43
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, calcareous, yellow, silty	2	45
Shale, calcareous, dark gray flecked with light gray	5	50

1-25-1cc. *Sample log of test hole in the SW cor. sec. 1, T. 1 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,358.7 feet; water level, 41 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, compact, black; contains some sand	6	6
Silt, brown; contains nodules of caliche and snail shells	5	11
Silt, tan; contains abundant snail shells	22	33
Gravel, fine, and fine to coarse sand; contains fragments of chalk	4.5	37.5
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, hard, dense, yellow brown	0.5	38
Shale, calcareous, yellow brown	4	42
Shale, calcareous, fissile, brown	4	46
Shale, calcareous, compact, blue gray	4	50

1-25-11dd. *Sample log of test hole in the SE cor. sec. 11, T. 1 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,429.9 feet; water level, 65 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, loose, brown	2	2
Silt, tan to brown and gray; snail shells abundant throughout	29	31
Loveland member		
Silt, gray; contains small amount of sand and fine gravel	6	37
Sand, fine to coarse; contains silt, gravel, and fragments of caliche	9	46
TERTIARY—Pliocene		
Ogallala formation		
Sand, tightly cemented with calcium carbonate, gray	15	61
Sand, fine to medium, partly cemented, gray	5	66
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, hard dense, gray to yellow brown	4	70

1-25-35dd. *Sample log of test hole in the SE cor. sec. 35, T. 1 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,499.2 feet; water level, 122 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Road fill of silt soil, brown	3	3
Silt, loose, brown; contains many snail shells	8	11
Silt, compact, tan	9	20
Loveland member		
Silt, compact, brown	5	25
Silt, gray; contains some fine sand and nodules of caliche,	11	36
TERTIARY—Pliocene		
Ogallala formation		
Sand, fine, gray; cemented with calcium carbonate	3	39
Sand, fine; contains some coarse sand and fine gravel; locally cemented with calcium carbonate	107	146
Sand and gravel, clean, loose	35	181
Sand and silt, plastic, yellow tan	5	186
Sand and some gravel, caliche, and silt	18	204
Sand with some tan and gray silt	12	216
Sand; contains some gravel and silt; cemented with calcium carbonate locally	70	286

2-21-4cc. *Sample log of test hole in the SW cor. sec. 4, T. 2 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,155.6 feet; water level, 36 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, compact, dark brown; contains some gravel	8	8
Silt, compact, light gray tan	8	16
Silt, loose, tan; contains snail shells	28	44
Silt and fine sand, gray to tan; contains caliche	5	49
Sand, fine to coarse, and some gravel; contains fragments of chalk	15	64
Gravel and sand; contains chalk fragments	2	66
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, yellow buff	2	68
Silicified chalk, very hard, yellow buff to white	0.5	68.5

2-21-5aa. *Sample log of test hole in the NE cor. sec. 5, T. 2 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,244.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, compact, dark brown	3	3
Silt, compact, gray to tan; contains snail shells	12	15
Loveland member		
Silt, compact, dark brown (Loveland soil)	4	19
Silt, compact, tan; contains snail shells	70	89
Silt, compact, light green; contains snail shells	7	96
Crete member		
Sand, fine to coarse, and some gravel	7	103
Silt and fine sand, gray to tan	5	108
Silt and sand, fine to coarse, gray	22	130
Gravel of chalk fragments and some sand and silt	4	134
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, chalky, yellow buff	6	140

2-21-8ad. *Sample log of test hole in the SE¼ NE¼ sec. 8, T. 2 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,149.9 feet; water level, 26 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene and Recent		
Terrace deposits		
Silt, compact, dark brown	6	6
Silt, gray to tan; contains some fine sand and a few snail shells	26	32
Silt, dark gray	12	44
Silt and sand, dark gray; contains snail shells and some gravel	5	49

	Thickness, feet	Depth, feet
Sand and gravel, fine to coarse	9	58
Gravel; contains broken fragments of chalk	3.5	61.5
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, gray to buff brown	8.5	70

2-21-9cc. *Sample log of test hole in the SW cor. sec. 9, T. 2 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,155.3 feet; water level, 31 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, brown; contains nodules of caliche	11	11
Silt, loose, tan; contains some sand	7	18
Silt, compact, dark tan; contains snail shells	8	26
Silt, tan to gray; contains some sand and fragments of shells	16	42
Silt and sand, compact, greenish gray	11	53
Sand, fine, with some gravel and silt	14	67
Gravel; contains some pebbles of chalk and silicified chalk	5.5	72.5
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, fissile, dark gray; contains a few streaks of bentonite	7.5	80

2-21-20aa. *Sample log of test hole in the NE¼ NE¼ sec. 20, T. 2 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,294.2 feet; water level, 142 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, tan to tan brown; contains snail shells	18	18
Loveland member		
Silt, medium compact, dark brown (Loveland soil)	7	25
TERTIARY—Pliocene		
Ogallala formation		
Sand, fine to very fine, and silt, partly cemented with calcium carbonate	3	28
Clay, blocky, compact, gray green to tan	3	31
Sand, fine to medium; contains some gray-green silt and calcium carbonate cement	33	64
Clay, gray green, compact; contains some silt	7	71
Sand, fine to coarse, gray to tan; interbedded cemented and uncemented zones and gravel occur in some places	122	193
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, yellow buff, soft	13	206
Shale, dark brown to black, soft, chalky	4	210

2-24-36cb. *Sample log of test hole in the NW¼ SW¼ sec. 36, T. 2 S., R. 24 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,392.0 feet; water level, 57 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, dark brown	3	3
Silt, medium compact, gray	1	4
Silt, loose, tan; contains snail shells	16	20
Loveland member		
Silt, compact, tan to light gray; contains a few nodules of caliche	9	29
TERTIARY—Pliocene		
Ogallala formation		
Silt and sand with some gravel; cemented with calcium carbonate, gray	14	43
Silt, fine sand, and gravel, tan and gray	12	55
Sand and gravel, with some silt	4	59
Silt, with some sand, fine gravel, and caliche, tan and gray,	41	100
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, calcareous, white and yellow	2	102
Limestone, hard, white and yellow brown	0.1	102.1

2-25-36cc. *Sample log of test hole in the SW cor. sec. 36, T. 2 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,518.0 feet; water level, 121 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Bignell member		
Silt, dark gray to brown	1	1
Silt, loose, brown; contains many snail shells	13	14
Peoria member		
Silt, loose, brown; contains many snail shells	8	22
Silt, loose, tan to white	31	53
Loveland member		
Silt, compact; contains nodules of caliche and some sand in lower part	12	65
TERTIARY—Pliocene		
Ogallala formation		
Sand, fine, silt, and gravel, tan to gray green	6	71
Caliche, white to gray	4	75
Sand and silt, gray; contains some gravel	9	84
Silt and sand, white to gray; contains caliche	34	118
Sand with some gravel and silt	16	134
Sand, fine to very fine, and silt, gray	111	245
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, calcareous, yellow orange	5	250
Shale, calcareous, dark gray	20	270

3-21-9bb. ***Sample log of test hole in the NW cor, sec. 9, T. 3 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,314.8 feet; water level, 110 feet.***

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, compact, dark brown and red tan	7	7
Silt, compact, tan	5	12
Loveland member		
Sand, fine, some coarse, tan	5	17
TERTIARY—Pliocene		
Ogallala formation		
Sand and silt with some clay and a small amount of gravel; cemented with calcium carbonate	14	31
Silt, red tan	5	36
Sand, fine, cemented with calcium carbonate	3	39
Sand, very fine to fine, tan	4	43
Silt, clay, and sandy silt, interbedded, compact, gray green to tan, cemented with calcium carbonate	56	99
Sand and gravel, fine to coarse	14	113
Silt and sand, with some gravel and caliche	34	147
Sand and some gravel	27	174
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, white, and chalky shale	2	176

3-23-8cb. *Sample log of test hole in the NW¼ SW¼ sec. 8, T. 3 S., R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,347.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, loose, tan; contains snail shells	15	15
Loveland member		
Silt, loose, tan to gray; contains nodules of caliche	36	51
Crete member		
Gravel and sand, with some silt	4	55
Silt and sand, with some gray gravel	15	70
Sand and gravel	5	75
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, yellow, white, and pink	15	90

3-23-8cc. *Sample log of test hole in the NE¼ SW¼ SW¼ sec. 8, T. 3 S., R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,290.9 feet; water level, 25 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, dark gray; contains some sand and fragments of chalk	12	12
Silt, sand, and gravel, compact, gray	15	27
Sand and gravel, with some silt	6	33

	Thickness, feet	Depth, feet
Sand with some gravel, gray-green silt, and snail shells	16	49
Gravel and sand; contains some clay	2	51
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, yellow and white	4	55
Shale, calcareous, brown	6	61
Shale, calcareous, dark gray; contains some bentonite	3	64

3-23-8cd. *Sample log of test hole in the SE¼ SE¼ SW¼ sec. 8, T. 3 S., R. R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,303.8 feet; water level, 44 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, dark gray	3	3
Silt, loose, tan; contains a few snail shells and a small amount of sand	20	23
Silt, compact, light gray tan; contains some gravel and sand	8.5	31.5
Sand, with some gravel and fragments of chalk	9.5	41
Gravel and clay; contains some silt and sand	6	47
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, yellow and white	13	60

3-23-9cb. *Sample log of test hole in the NW¼ SW¼ sec. 9, T. 3 S., R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude 2,285.6 feet; water level, 34 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, gray, tan, and brown	20	20
Silt, loose, tan; contains snail shells	11	31
Silt and sand, tan; contains a few pebbles, nodules of caliche, and snail shells	9	40
Sand, with some gravel, caliche, and silt	11	51
Gravel and sand	6	57
Silt, yellow tan; contains some sand, gravel, and pebbles of chalk	2	59
Sand; contains some silt and pebbles	3	62
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, light yellow	5	67
Shale, calcareous, gray brown	3	70

3-23-17ad. *Sample log of test hole in the cen. E. line sec. 17, T. 3, S., R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,390.4 feet; water level, 116 feet.*

	Thickness, feet	Depth, feet
TERTIARY—Pliocene		
Ogallala formation		
Silt, compact, dark brown	3	3
Silt and sand, tightly cemented with calcium carbonate, light gray; contains fragments of fossil *Biorbia* seeds,	10	13
Silt, compact, light gray; contains some sand and caliche,	13	26
Silt and sand, tightly cemented with calcium carbonate,	19	45
Sand with some tan silt	9	54
Silt and sand, light gray to gray green, cemented with calcium carbonate; contains some clay	19	73
Sand, partly cemented, gray and tan	29	102
Silt and sand, partly cemented, gray	8	110
Sand, partly cemented; contains some light-gray silt	26	136
Silt and sand, gray and yellow; contains some caliche and fragments of chalk	25	161
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, yellow, white, and pink	9	170

3-23-17ba. *Sample log of test hole in the NE¼ NW¼ sec. 17, T. 3 S., R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,301.8 feet; water level, 34 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, dark brown	3	3
Silt, loose, tan; contains snail shells	26	29
Sand, with some fine gravel and a few pebbles of limestone	5	34
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, hard, yellow brown	6	40

3-23-18ad. *Sample log of test hole at the cen. E. line, sec. 18, T. 3 S., R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,292.3 feet; water level, 26 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, compact, dark gray; contains some sand and snail shells	22	22
Silt, loose, tan	12	34
Sand and silt, gray	6	40
Sand, with some gravel and silt	20	60
Gravel and sand; contains some pebbles of chalk and silt,	10	70

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, hard, yellow brown	0.5	70.5
Shale, calcareous, yellow and brown	8.5	79
Shale, calcareous, gray	1	80

3-23-27aa. *Sample log of test hole in the NE cor. sec. 27, T. 3 S., R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,426.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, compact, dark brown and gray	6	6
Silt, loose, tan	6	12
TERTIARY—Pliocene		
Ogallala formation		
Sand, fine, with some gray silt	9	21
Silt, compact, tan; contains some fine sand	9	30
Sand, fine; contains some silt and nodules of caliche	16	46
Sand, fine, and silt, tightly cemented with calcium carbonate, light gray	28	74
Sand, fine; contains some silt	15	89
Silt, gray; contains some fine sand, partly cemented	22	111
Sand, fine, and gray silt	10	121
Sand, fine, and silt, tightly cemented with calcium carbonate, light gray	11	132
Silt, compact, light gray; contains some fine sand	10	142
Sand, fine; contains some tan silt	11	153
Silt, compact, tan and gray; contains some fine sand	33	186
Sand, fine; contains some white silt	9	195
Silt, gray; contains some fine sand and caliche	4	199
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, calcareous, very hard, silicified, yellow brown,		199

3-24-1ad. *Sample log of test hole in the SE¼ NE¼ sec. 1, T. 3 S., R. 24 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,404.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, compact, dark brown	3	3
Silt, loose, tan; contains a few snail shells	21	24
Loveland member		
Silt, loose, gray tan; contains nodules of caliche	37	61
Crete member		
Sand and silt, tan	9	70
Silt with some fine sand and gravel, gray tan	7	77
Sand, fine, well sorted, compact	14	91
TERTIARY—Pliocene		
Ogallala formation		
Silt and fine sand, light gray and yellow tan	10	101
Sand, fine	7	108

	Thickness, feet	Depth, feet
Silt and fine sand, tan and gray	3	111
Sand with some fine gravel	9	120
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, hard, and shale, calcareous, yellow and white	2	122

3-25-23aa. *Sample log of test hole in the NE cor. sec. 23, T. 3, S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,396.4 feet; water level, 54 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Loveland member		
Silt, compact, tan	4	4
Silt, compact, tan; contains a few nodules of caliche	11	15
Silt, tan; contains some very fine sand	3	18
Crete member		
Gravel and sand; contains some caliche	11	29
Silt, compact, tan	4	33
Sand, fine to very fine, and tan silt	7	40
Gravel, tan; contains some sand and silt	21	61
TERTIARY—Pliocene		
Ogallala formation		
Sand and silt, tightly cemented with calcium carbonate	8	69
Sand, fine to very fine, partly cemented, light gray	11	80
Silt, gray; contains some sand and gravel	9	89
Silt, tan; contains a few nodules of caliche, sand, and gravel	6	95
Gravel and sand; contains some gray and tan silt	5	100
Gravel and sand, yellow; contains fragments of chalk and some silt	12	112
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, hard, yellow	1	113

3-25-23da. *Sample log of test hole in the NE¼ SE¼ sec. 23, T. 3 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,414.7 feet; water level, 74 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Bignell member		
Silt, loose, tan; contains a few snail shells	10	10
Silt, compact, yellow tan; contains some fine sand and snail shells	11	21
Peoria member		
Silt, dark gray, compact (Brady soil)	4	25
Silt, gray to tan	41	66
Loveland member		
Silt, compact, gray to dark brown ((Loveland soil)	7	73
Crete member		
Sand and some gravel	10	83

	Thickness, feet	Depth, feet
TERTIARY—Pliocene		
Ogallala formation		
Silt and fine sand, cemented with calcium carbonate in upper part, gray	15	98
Silt, compact, gray; contains some sand	15	113
Sand and gravel	3	116
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, hard yellow	1	117

3-25-24cb. *Sample log of test hole in the NW¼ SW¼ sec. 24, T. 3 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,362.7 feet; water level, 23 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, dark gray to black	13	13
Silt, compact, tan to light gray	6	19
Sand, fine, and a little gravel, partly cemented, red brown,	4	23
Sand, gravel, and silt, gray	24	47
TERTIARY—Pliocene		
Ogallala formation		
Silt and sand, locally cemented; contains some fragmnets of chalk	15	62
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, hard, yellow	8	70

3-25-25bc. *Sample log of test hole in the cen. W. line sec. 25, T. 3 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,362.3 feet; water level, 26 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, black	4	4
Silt, compact, light gray; contains some fine sand	3	7
Silt, compact, gray and brown	4	11
Silt, compact, tan; contains some sand	8	19
Silt, partly cemented, light gray; contains some sand	5	24
Silt, compact, tan; contains a few snail shells	4	28
Silt and sand, loose, gray; contains many snail shells	7	35
Sand with some gravel, streaked with blue-gray silt near the base	11	46
TERTIARY—Pliocene		
Ogallala formation		
Silt and sand, compact, cemented, white	4	50
Sand, white; contains some fine gravel and silt	1	51
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, calcareous, compact, white to buff	2	53
Limestone, hard, yellow	0.1	53.1

3-25-36ac. *Sample log of test hole in the SW¼ NE¼ sec. 26, T. 3 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,349.8 feet; water level, 12 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Recent		
Alluvium		
Silt and sand, dark gray	6	6
Silt, loose, gray, with some fine sand	9	15
Sand and some gravel, locally silt, tan, gray, and brown,	30	45
CRETACEOUS—Gulfian		
Niobrara formation		
Limestone, silicified, yellow and white	0.5	45.5

4-21-29aa. *Sample log of test hole in the NE cor. sec. 29, T. 4 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,188.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, loose, dark brown	1	1
Silt, loose, tan; contains some very fine sand	13	14
Loveland member		
Silt, compact, brown (Loveland soil)	4	18
Silt, compact, tan and light gray	2	20
Sand, fine to very fine, brown	3	23
Silt and fine sand, light gray	2	25
Silt, chalky, dark brown; contains some sand	1	26
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, yellow, pink, red, and white	4	30

4-23-22dd. *Sample log of test hole at the SE cor. sec. 22, T. 4 S., R. 22 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,360.3 feet; water level, 99 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, tan and buff	3	3
Silt, gray and dark brown	5	8
TERTIARY—Pliocene		
Ogallala formation		
Silt, white; contains sand, gravel, and caliche; some cemented material	18	26
Sand and gravel, fine to coarse; contains some brown and yellow clay	29	55
Silt, pink, buff, and gray; contains fine sand and some tan clay	39	94
Sand; contains some gravel, caliche, and cemented zones,	29	123
Silt, gray; contains sand and zones cemented with calcium carbonate	28	151
Silt, buff, gray, and tan	19	170

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, soft, chalky, yellow and white	10	180

4-25-1bb. *Sample log of test hole in the NW cor. sec. 1, T. 4 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,525.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, dark brown	2	2
Silt, tan; contains some fine sand and many snail shells	16	18
Loveland member		
Silt, tan to light gray; contains some sand and fine gravel, partly cemented	11	29
TERTIARY—Pliocene		
Ogallala formation		
Silt and fine sand, partly cemented with calcium carbonate, gray	12	41
Silt and fine sand, cemented, gray green	11	52
Silt and very fine sand, partly cemented, light gray	31	83
Silt and clay, compact, blocky, gray green	11	94
Silt and fine sand, partly cemented, gray	39	133
Silt, sand, and caliche, yellow buff	28	161
Silt, sand, and fine gravel, tan to light gray	36	197
Sand and gravel, yellow to light gray; contains some silt and clay	7	204
CRETACEOUS—Gulfian		
Pierre shale		
Clay, bentonitic, compact, blocky, yellow, buff, and gray	10	214
Shale, silty, noncalcareous, tough, dark gray to black	8	222

5-21-4bb. *Sample log of test hole in the NW¼ NW¼ sec. 4, T. 5 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,036.6 feet; water level, 30 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, dark brown	7	7
Silt, compact, gray	6	13
Silt, tan to light gray, with some sand; contains soil zone	9	22
Sand, fine to coarse; contains some gravel	20	42
Silt, dark gray; contains some sand and a few pebbles of chalk	26	68
Sand and gravel, fine to coarse	5	73
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, gray, soft	7	80

5-21-5ad. *Sample log of test hole in the cen. E. line sec. 5, T. 5 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,012.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Recent		
Alluvium		
Silt and sand, brown	3	3
Sand, fine to coarse, light tan	3	6
Sand, fine to coarse, light tan; contains some gravel	7.5	13.5
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, soft, dark gray	6.5	20

5-21-8aa. *Sample log of test hole in the NE cor. sec. 8, T. 5 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,045.4 feet; water level, 39 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Sand, fine to very fine	1	1
Silt, gray tan to brown; contains some sand	12	13
Silt, dark brown, medium compact (soil zone)	2	15
Silt, gray tan	2	17
Silt, gray; contains some sand	21	38
Silt, gray tan; contains sand and gravel	2	40
Sand and gravel, fine to coarse	13	53
Silt, gray to black; contains some sand	7	60
Sand and gravel, fine to coarse; contains fragments of chalk	5	65
CRETACEOUS—Gulfian		
Niobrara formation		
Shale, calcareous, dark gray	5	70

5-21-33cc. *Sample log of test hole in the SW¼ SW¼ sec. 33, T. 5 S., R. 21 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,306.3 feet; water level, 101 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation—Peoria member		
Silt, loose, dark gray brown	3	3
Silt, loose, tan; contains snail shells	10	13
Loveland member		
Silt, loose, tan	14	27
Sand, fine to very fine, and tan silt	7	34
TERTIARY—Pliocene		
Ogallala formation		
Sand, fine, light tan to gray; contains gravel and silt	17	51
Sand, well cemented with calcium carbonate	1	52
Sand and silt, light gray to green gray, and caliche	24	76
Silt, compact; contains some dull-red sand	21	97
Sand, fine, and dull-red silt; contains caliche	26	123
Sand, fine to very fine, and silt and some gray and brown clay	55	178

Cretaceous—Gulfian	Thickness, feet	Depth, feet
Niobrara formation		
Shale, calcareous, gray, fissile; contains a few thin bentonite zones	12	190

5-23-34dd. *Sample log of test hole at the SE cor. sec. 34, T. 5 S., R. 23 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,397.3 feet.*

Quaternary—Pleistocene	Thickness, feet	Depth, feet
Sanborn formation		
Silt, brown	2	2
Silt, tan; contains snail shells	5	7
Tertiary—Pliocene		
Ogallala formation		
Sand, fine and very fine, silty, white	12	19
Sand and silt, cemented with calcium carbonate; contains fossil seeds	17	36
Sand, fine to coarse; contains silt, gravel, and caliche	49	85
Sand, with some silt; contains zones cemented with calcium carbonate	40	125
Sand, very fine to coarse, and silt	17	142
Silt, sand, and caliche; contains cemented zones	17	159
Sand and gravel, fine to coarse	24	183
Silt, soft, brown and gray	8	191
Cretaceous—Gulfian		
Niobrara formation		
Shale, chalky, fissile, brown, yellow, and gray; contains bentonite	9	200

5-24-33bb. *Sample log of test hole in NW¼ NW¼ sec. 33, T. 5 S., R. 24 W., Norton County, Kansas; drilled in 1946. Water level, 197 feet.*

Tertiary—Pliocene	Thickness, feet	Depth, feet
Ogallala formation		
Silt, sand, and caliche	2	2
Sand and gravel, fine to coarse; contains caliche	2	4
Limestone, hard, white	5	9
Sand and gravel; contains zones loosely cemented with calcium carbonate	17	26
Sand, fine to coarse, silt, and caliche	12	38
Sand, fine to coarse; contains some gravel; some zones cemented with calcium carbonate	27	65
Sand, fine to coarse, and silt; contains caliche and cemented zones	58	123
Sand and gravel, fine to coarse	22	145
Sand, fine to coarse; contains brown clay	30	175
Sand, fine to coarse; contains silt and some gravel; cemented in some zones	32	207
Sand, silt, and caliche, white (at the bottom of this interval the drill encountered a bed too hard to penetrate)	30	237

5-25-1bb. *Sample log of test hole in the NW cor. sec. 1, T. 5 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,423.9 feet; water level, 42 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Recent		
Alluvium		
Silt, dark brown and tan	2	2
Silt; contains nodules of caliche, gravel, and snail shells	11	13
Silt, sand, and fine gravel, tan to brown	6	19
Gravel and sand; contains some tan silt	2.5	21.5
Silt, sand, and gravel, gray tan	4.5	26
Gravel, sand, and silt, tan	9.5	35.5
TERTIARY—Pliocene		
Ogallala formation		
Silt, sand, and some gravel, gray white to tan; cemented with calcium carbonate	6.5	42
Silt; contains some fine sand and white caliche	5	47
Silt, partly cemented, gray green	8.5	55.5
Sand, light gray; contains some gravel and silt	2	57.5
Sand, tightly cemented with calcium carbonate, light gray,	2.5	60
Gravel, sand, silt, and caliche, gray	25	85
Slit, sand, gravel, and caliche, light gray	9	94
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, calcareous, plastic, white to yellow	2.5	96.5
Limestone, hard, brown yellow	0.3	96.8

5-25-2ad. *Sample log of test hole in the cen. E. line sec. 2, T. 5 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,475.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Recent		
Colluvium		
Silt, sand, and fine gravel, brown and gray	2	2
Silt, sand, gravel, and caliche, tan	5	7
TERTIARY—Pliocene		
Ogallala formation		
Silt, gray; contains some sand and gravel; cemented with calcium carbonate	3	10
Silt, gray, cemented; contains some gravel	10	20
Caliche, white	4	24
Silt, fine sand, and caliche, loose, light gray green	7	31
Silt, sand, and fine gravel, loose, light gray	23	54
Gravel, sand, and silt, tan	21	75
Silt, sand, and gravel, gray and tan	51	126
Sand; contains some fine gravel	6	132
Silt, fine sand, and clay, light gray	10	142
Silt, compact, blocky, tan and gray; contains silty bentonitic clay	7	149
CRETACEOUS—Gulfiian		
Niobrara formation		
Clay, calcareous, yellow and white	3	152
Clay, plastic, brown	2	154
Shale, calcareous, dark gray	6	160

5-25-14ad. *Sample log of test hole in the SE¼ NE¼ sec. 14, T. 5 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,427.0 feet; water level, 61 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt (road fill)	4	4
Silt, compact, dark gray brown	5	9
Silt, tan; contains some gravel	4	13
TERTIARY—Pliocene		
Ogallala formation		
Silt, calcareous; contains some gravel and sand	20	33
Silt, sand, and gravel, calcareous, tan	15	48
Silt, gray; contains some sand and gravel	17	65
Gravel and coarse sand	11	76
Silt and sand, tan to yellow	15	91
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, calcareous, yellow and white	2	93
Limestone, hard, white and brown	0.2	93.2

5-25-26aa. *Sample log of test hole in the NE¼ NE¼ sec. 26, T. 5 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,356.6 feet; water level, 18 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, dark brown and gray, with a few pebbles	7	7
Silt, tan to gray, with some gravel, sand, and nodules of caliche	8	15
Silt, brown, sand, and gravel; contains snail shells	4	19
Gravel, sand, silt, and clay balls	11	30
Gravel and sand; contains pebbles of chalk	13	43
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, calcareous, yellow white	2	45
Shale, calcareous, gray	5	50

5-25-35aa. *Sample log of test hole in the NE cor. sec. 35, T. 5 S., R. 25 W., Norton County, Kansas; drilled in 1946. Surface altitude, 2,507.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, brown	3	3
Silt, loose, tan; contains a small amount of gravel and many snail shells	22	25
Silt, plastic, light gray; contains a small amount of gravel,	13	38
TERTIARY—Pliocene		
Ogallala formation		
Silt and fine sand, tightly cemented with calcium carbonate (Algal limestone? at top)	38	76

	Thickness, feet	Depth, feet
Sand, compact	29	105
Gravel and sand, yellow, with some silt and clay	10	115
Gravel, sand, and silt, partly cemented, gray	40	155
Silt and sand, tan and gray	7	162
Sand, with some gravel	6	168
Sand and gravel, tightly cemented with calcium carbonate	0.3	168.3
Sand, yellow, with small amount of gravel, caliche, and clay (at the bottom of this interval the drill encountered a bed too hard to penetrate)	17.7	186

MEASURED STRATIGRAPHIC SECTIONS

1-19-31. *Section measured along valley and tributary gullies, NW¼ SW¼ sec. 31, T. 1 S., R. 19 W., Phillips County, Kansas.* (Measured by M. K. Elias and John C. Frye)

TERTIARY—Pliocene

Ogallala formation—Ash Hollow member	Thickness, feet
11. Sand and silt, cemented with calcium carbonate	1.5
10. Clay, silt, and fine sand, partly cemented, light gray green; contains nodules and stringers of calcium carbonate	12.0
9. Sand, loosely cemented with calcium carbonate, gray; contains fossil seeds of *Biorbia fossilia* (Berry)	3.0
8. Clay, silt, fine sand, and calcium carbonate, gray	2.0
7. Sand, medium to fine, cemented in upper part, greenish gray; contains fragments of fossil vertebrates	4.0
6. Sand, coarse to fine, and some silt; massive to irregular bedding; weathers to irregular, pitted surface; greenish gray; the following fossil seeds occur in this interval and upper part of bed 5: *Krynitzkia coroniformis* Elias, *Biorbia minor* Elias, *Prolithospermum corrugatus* Elias, *Panicum elegans* mut. *nebraskanse* Elias, *Stipidium intermedian* Elias, *Stipidium* cf. *grande* Elias	6.0
5. Sand, coarse to fine, and some silt; massive to irregularly bedded; cemented more firmly toward top	4.0
4. Partly covered. Silt, clay, and fine sand, tan to greenish gray	15.0
3. Partly covered. Sand, fine to medium, loose, pink tan; contains concretions and nodules of calcium carbonate	12.9
2. Sand and silt, massive to irregularly bedded, loosely and unevenly cemented with calcium carbonate, pale pinkish tan to gray	14.8
1. Clay, silt, and sand with some calcium carbonate, gray to green gray. From bottom of creek	1.8
Total	77.0

1-21-29. *Section measured along cut bank on east side of creek in the SW¼ SW¼ sec. 29, T. 1 S., R. 21 W., Norton County, Kansas.* (Measured by Stafford C. Happ and John C. Frye)

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
13. Silt and fine sand, verticle jointed, light brown to gray (Bignell silt member)	1.8
12. Soil (Brady). sandy silt, blocky, dark brown to brown	1.0
11. Silt, blocky to vertically jointed, tan to light brown (Peoria silt member)	4.0
10. Soil (Loveland). Silt and some sand, blocky, compact, brown	1.0
9. Silt, sandy, massive to indistinctly bedded, pale greenish tan to light buff, darker upward (Loveland silt member)	5.5
8. Sand and gravel; contains pebbles of Ogallala "mortar-bed" type, interbedded with reddish-brown sand and silt. Sand and gravel commonly at base (Crete?)	3.0
TERTIARY—Pliocene	
Ogallala formation	
7. Rubble of sand with fragments of calcium carbonate-cemented sand and silt and concretionary masses of lime rock. Probably weathering residue at top of Ogallala representing unconformable surface	0.5
6. Sand, with some silt and calcium carbonate, irregularly bedded to platy	1.0
5. Clay, blocky, green to pale greenish gray	3.5
4. Sand, fine, and silt; irregularly laminated, gray to pale greenish gray	2.0
3. Clay, silty, blocky, greenish gray streaked with brown	1.0
2. Sand, fine, sandy clayey silt, and silt, irregularly interbedded, gray to pale greenish gray	2.0
1. Silt, sandy, clayey, calcareous, compact, irregularly bedded, light greenish gray. A "mortar bed" at top	3.5
Total measured	29.8

1-24-16. *Section measured along cut bank of creek in the NE¼ SW¼ sec. 16, T. 1 S., R. 24 W., Norton County, Kansas.* (Measured by Stafford C. Happ and John C. Frye)

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
7. Silt, massive, yellow tan; contains fossil snails (Peoria silt member)	14.0
6. Soil (Loveland), brown to reddish brown, compact, sandy silt with a few pebbles	3.0
5. Silt, massive, indistinct verticle jointing, tan to pink buff; contains some sand and a few pebbles (Loveland silt member). Gradational with unit below	6.0

	Thickness feet
4. Sand and silt, with lenses of gravel, stratified, tan; zone of cross-bedded sand and gravel at base; some pebbles of Ogallala "mortar bed" material as large as 6 inches in diameter; snails in upper part	13.0
3. Partly covered. Gray to buff sandy silt	4.0
2. Sand, bedded, loose, brown	3.0
TERTIARY—Pliocene	
Ogallala formation	
1. Sand and silt with some gravel, compact, partly cemented with calcium carbonate, tan to green gray	5.0
Total	48.0

2-25-36. *Section measured along creek bank in the NW¼ NE¼ sec. 36, T. 2 S., R. 25 W., Norton County, Kansas.*

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation (Ash Hollow member)	
6. Sand and fine gravel, cemented, thin lenses of loose sand and silt in lower part. Fossil seeds of *Biorbia fossilia* (Berry) from lower 0.3 foot	3.5
5. Sand, compact but uncemented, blocky, irregularly bedded, greenish tan; contains some silt	5.0
4. Volcanic ash, compact, impure in lower part, gray	3.0
3. Sand with some silt, massive to thick-bedded, compact but not cemented, pale greenish gray	6.2
2. Sand and silt, tightly cemented with calcium carbonate	2.0
1. Covered from bottom of creek channel	6.0
Total	25.7

3-23-8. *Section measured in abandoned sand pit and along road ditch in the NW¼ sec. 8, T. 3 S., R. 23 W., Norton County, Kansas.*

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
6. Silt, massive to blocky, yellow tan, partly covered. Contains fossil snails in several zones	28.0
5. Clay, silt, and sand, thin-bedded, blocky in upper part, brown,	3.0
4. Silt and fine sand, blocky, tan	1.5
3. Sand, fine, silt, and clay, thin-bedded to laminated, light tan,	9.0
2. Sand and gravel, cross-bedded, generally well sorted	5.5
1. Silt and clay, partly covered, gray; contains fossil snails	1.0
Total	48.0

4-23-27. *Section measured in road cut and creek bank in the SE¼ sec. 27, T. 4 S., R. 23 W., Norton County, Kansas.* (Measured by Claude W. Hibbard and John C. Frye, corrected from Hibbard, Frye, and Leonard, 1944)

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
7. Silt, massive, gray to light tan (Peoria silt member). Fossil snails 2 to 8 feet above base: *Vallonia gracilicosta* (Müller), *Succinea grosvenori* Lea, *Pupilla muscorum* (Linnaeus), *Pupilla blandi* Morse, and *Euconulus fulvus* (Müller)	32.0
6. Soil (Loveland). Sandy silt, massive to blocky; contains caliche nodules and is dark gray to gray brown	3.0
5. Sand and silt, lenticular, locally medium to coarse, well sorted, tan (Loveland silt member?)	10.8
4. Sand and gravel; contains igneous pebbles and abraded pebbles of Ogallala "mortar bed." Locally even-bedded fine to coarse sand. Thickness changes laterally above unconformity at top of Ogallala. (Crete?)	8.8
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
3. Volcanic ash, thin-bedded, coarse-textured, bluish gray	0.6
2. Clay, silt, and sand, greenish gray	0.6
1. Sand and silt with a few pebbles, loosely cemented with calcium carbonate; weathers to gray and ash gray	6.2
Total	62.0

4-24-2. *Section measured along creek bank and road cut in the NE¼ sec. 2, T. 4 S., R. 24 W., Norton County, Kansas.*

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
11. Silt, massive to blocky, light tan to yellow tan; contains some fine sand in thin lenses. Fossil snails abundant in middle part	45.0
10. Silt and very fine sand with a small amount of medium to coarse sand, blocky, light brown	7.0
9. Sand with some gravel grading upward into sandy silt, calcareous, gray-buff. (Section offset along road cut)	2.0
Thickness of exposed Sanborn	54.0
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
8. Partly covered. Sand and silt with some clay, pale greenish gray. A cemented zone occurs at top or middle of interval	10.0
7. Volcanic ash, thin-bedded and massive in lower part to irregularly bedded and massive in upper part. Passes laterally into interbedded volvanic ash and sand, partly cemented with calcium carbonate	4.0
6. Sand, pale greenish gray; contains a few bone fragments and lime nodules. *Celtis willistoni* abundant near top	1.5

	Thickness feet
5. Clay, silt, and sand, blocky, calcareous, gray	1.6
4. Sand and silt, massive, pale green; contains bone fragments and angular cemented fragments	0.8
3. Clay, silt, and sand, calcareous, irregularly bedded to massive, pale greenish gray to gray	2.2
2. Sand, loosely cemented with calcium carbonate at base, grading upward into well cemented bed that produces bench, greenish gray. Fossil seeds of *Biorbia fossilia* (Berry) abundant in upper 1 foot	4.0
1. Sand with some silt and clay, irregularly cemented with calcium carbonate and a well-cemented zone at top, greenish gray to pale green. Fossil seeds of *Biorbia fossilia* (Berry) 2 feet below top of interval	6.5
Thickness of exposed Ogallala formation	30.6
Total thickness measured	84.6

5-24-33. *Section measured along creek valley in sec. 33, T. 5 S., R. 24 W., Norton County, Kansas.* (Measured by Ada Swineford, John C. Frye, and A. R. Leonard).

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation—Kimbal member	
10. Limestone, cherty, dense, light gray; contains some silt, sand, and gravel	2.0
9. Covered	5.0
8. Sand, silt, and gravel, loosely cemented with calcium carbonate, gray to pale buff	3.0
Ash Hollow member	
7. Covered slope (note log of adjacent test hole)	96.0
6. Silt, sand, and gravel, irregularly cemented with calcium carbonate, gray to pinkish buff. Weathers to irregular nodular surface	6.0
5. Silt and sand, loosely cemented with calcium carbonate, massive to platy	8.0
4. Sand and silt, with some gravel, well cemented with calcium carbonate, light gray to pale pink, weathers to irregular nodular surface; contains *Biorbia fossilia* (Berry)	3.0
3. Silt, sandy, irregularly cemented with calcium carbonate, greenish gray to gray with spots of brick red, massive. Contains concretions of calcium carbonate and *Biorbia fossilia* (Berry)	6.0
2. Sand and silt, irregularly cemented with calcium carbonate, forms bench along valley side; contains *Biorbia fossilia* (Berry)	6.0
1. Sand and silt, loose, partly covered, forms slope to valley floor	18.0
Total	153.0

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INDEX

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State Geological Survey of Kansas
Bulletin 81, Plate 1

Geologic Map
Norton County and Northwestern Phillips County, Kansas

by John C. Frye and A. R. Leonard

1948

Explanation

Alluvium (Qal)
Gravel, sand, silt. Yields abundant supplies of water in major valleys and moderate supplies in tributary valleys. Includes terraces in tributary valleys.

Terraces (Qt)
Gravel, sand, silt, underlying prominent terrace surface in major valleys. Yields abundant supplies of water to wells.

Intermediate terrace scarps (Qt)
Line of topographic break between major differences of level of terrace surface.

Sanborn formation and slope deposits (Qss)
Silt, soil, and some sand and gravel. Includes Loveland, Peoria, and Bignell silt members. Yields little water to wells except locally where sand and gravel are present. At a few places includes Meade formation.

Sanborn formation (where basal Crete sand and gravel are present along Prairie Dog Creek Valley) (Qss)
Yields moderate to abundant supplies of water where Crete sand and gravel are saturated.

RECENT / PLEISTOCENE — QUATERNARY

Ogallala formation (To)
Sand, silt, gravel, limestone, volcanic ash, and silicified rock. Yields moderate supplies of water to wells at many places. Includes Valentine, Ash Hollow, and Kimball members.

PLIOCENE — TERTIARY

Pierre shale (Kp)
Dark-colored, noncalcareous shale, with some bentonite and thin chalky shale beds. Yields little or no water to wells. Sharon Springs shale member.

Niobrara formation
Chalk and chalky shale. Yields small supplies of mineralized water to deep drilled wells at some places. Smoky Hill chalk member.

GULFIAN — CRETACEOUS

- VA Quarry in Ogallala volcanic ash
- VA Outcrop of Ogallala volcanic ash
- L Quarry in soft Ogallala limestone
- O Quarry in silicified Ogallala
- SC Quarry in silicfied Niobrara
- Oil well
- Dry hole
- Plugged oil well
- Federal or State highway
- Graded road
- Ungraded road
- Section line (no road)
- Township line (no road)
- Perennial stream
- Intermittent stream

0 1 2 3 4
Scale in miles

Drainage from aerial photographs of the U.S. Dept. of Agriculture
Base modified from maps by State Highway Commission of Kansas


State Geological Survey of Kansas
Bulletin 81, Plate 2
Map of
Norton County and Northwestern Phillips County, Kansas
GENERALIZED CONTOURS ON THE WATER TABLE
LOCATION OF WATER WELLS AND TEST HOLES
1947
by John C. Frye and A. R. Leonard
Explanation
Generalized contour on the water table where it occurs in Tertiary or Quaternary deposits; contour interval, 20 feet
Domestic or stock well
Irrigation well
Public supply well
Observation wells
Altitude of water level in flowing stream
Upper number refers to altitude of water table
Lower number is the depth to water level in the well
Brackets indicate water analysis
Location of test hole, log for which is given in this report
Scale in miles
Drainage from aerial photographs of the U.S. Dept. of Agriculture
Base modified from maps by State Highway Commission of Kansas
R. 25 W.
R. 24 W.
R. 23 W.
R. 22 W.
R. 21 W.
R. 20 W.
T. 1 S.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
DECATUR COUNTY
PHILLIPS COUNTY
GRAHAM COUNTY
NORTON
ALMENA
CALVERT
LONG ISLAND
WOODRUFF
REAGER
ORONOQUE
DELLVALE
LENORA
EDMOND
DENSMORE
NEW ALMELO
U.S. 36
U.S. 283
U.S. 383
Kan. 9
Sappa Creek
Prairie Dog Creek
Solomon River
Chicago, Burlington and Quincy Railroad
Chicago, Rock Island and Pacific Railroad
Missouri Pacific Railroad

State Geological Survey
of Kansas

GEOLOGIC CROSS SECTIONS

NORTON COUNTY AND NORTHWESTERN PHILLIPS COUNTY, KANSAS

By John C. Frye and A. R. Leonard, 1948

Bulletin 81
Plate 3