Geology and Ground-Water Resources of the North Fork Solomon River in Mitchell, Osborne, Smith, and Phillips Counties, Kansas

By

ALVIN R. LEONARD

UNIVERSITY OF KANSAS PUBLICATIONS
STATE GEOLOGICAL SURVEY OF KANSAS
BULLETIN 98
1952

STATE GEOLOGICAL SURVEY OF KANSAS
FRANKLIN D. MURPHY, M. D.,
Chancellor of the University, and ex officio Director of the Survey

JOHN C. FRYE, Ph. D.,
Executive Director

RAYMOND C. MOORE, Ph. D., Sc. D.,
State Geologist and Director of Research

Division of Ground Water
V. C. FISHEL, B. S.,
Engineer in Charge

BULLETIN 98

GEOLOGY AND GROUND-WATER RESOURCES OF THE NORTH FORK SOLOMON RIVER IN MITCHELL, OSBORNE, SMITH, AND PHILLIPS COUNTIES, KANSAS

By ALVIN R. LEONARD
(U. S. Geological Survey)

with a chapter on the chemical quality of the ground water

By WALTON H. DURUM
(U. S. Geological Survey)

This report is a joint product of the program of the Interior Department for development of the Missouri River Basin and the co-operative ground-water program of the United States Geological Survey, the State Geological Survey of Kansas, the Division of Sanitation of the Kansas State Board of Health, and the Division of Water Resources of Kansas State Board of Agriculture.

Printed by authority of the State of Kansas
Distributed from Lawrence

NOVEMBER, 1952

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

24-3808

STATE OF KANSAS

Edward F. Arn, *Governor*

STATE BOARD OF REGENTS

Oscar Stauffer, *Chairman*

Walter Fees
Mrs. Leo Haughey
A. W. Hershberger
Willis N. Kelly
Lester McCoy
Drew McLaughlin
Grover Poole
LaVerne B. Spake

MINERAL INDUSTRIES COUNCIL

B. O. Weaver ('53), *Chairman*
Lester McCoy ('52)
J. E. Missimer ('52)
Charles Cook ('52)
K. A. Spencer ('53)
W. L. Stryker ('53)
Brian O'Brian ('55), *Vice-chairman*
M. L. Breidenthal ('54)
Howard Carey ('54)
John L. Garlough ('54)
O. W. Bilharz ('55)
George K. Mackie, Jr. ('55)

STATE GEOLOGICAL SURVEY OF KANSAS

Franklin D. Murphy, M. D., Chancellor of the University of Kansas, and ex officio Director of the Survey

John C. Frye, Ph. D.
Executive Director

BASIC GEOLOGY

Stratigraphy, Areal Geology, and Paleontology
- John M. Jewett, Ph. D., Geologist
- A. B. Leonard, Ph. D., Paleontologist*
- Ruth L. Breazeal, Stenographer

PUBLICATIONS AND RECORDS

- Betty J. Hagerman, Secretary
- Grace Muilenburg, B. S., Journalist
- Alice M. White, B. F. A., Draftsman
- Regina Rodina, Draftsman
- Joan Jaeger, B. F. A., Draftsman
- Phyllis Miskimen, Clerk-Typist
- Phyllis Gibler, Clerk-Typist

MINERAL RESOURCES

- Robert O. Kulstad, M. S., Econ. Geologist
- W. H. Schoewe, Ph. D., Coal Geologist
- Kenneth E. Rose, M. S., Metallurgist*
- Frank Bowdish, S. M., Met. Engineer*
- H. E. Risser, E. M., Mining Engineer

Petrography
- Ada Swineford, M. S., Petrologist
- Carrie B. Thurber, Laboratory Asst.

Raymond C. Moore, Ph. D., Sc. D.
State Geologist and Director of Research

MINERAL RESOURCES

Oil and Gas
- Edwin D. Goebel, M. S., Geologist
- Walter A. Ver Wiebe, Ph. D., Geologist*
- Charles F. Weinaug, Ph. D., Petroleum Engineer*
- J. P. Everett, M. S., Petroleum Engineer*
- Ruby Marcellus, Well Sample Curator
- Lois Rissman, Clerk Typist
- V. O. Cooper, Laboratory Assistant

Wichita Well Sample Library
- Ethelyn McDonald, M. A., Curator
- Della B. Cummings, Clerk

Ceramics
- Norman Plummer, A. B., Ceramist
- William B. Hladik, Asst. Ceramist
- Sheldon Carey, A. M., Ceramist*
- Clarence Edmonds, Laboratory Asst.
- Ethel W. Owen, Laboratory Asst.

Geochemistry
- Russell T. Runnels, B. S., Chemist
- John Schleicher, B. S., Chemist
- H. S. Van Nortwick, B. S., Chemist

Southeast Kansas Field Office
- Allison Hornbaker, M. S., Geologist
- Christine Notari, Stenographer

Co-operative Projects with United States Geological Survey

GROUND-WATER RESOURCES

- V. C. Fishel, B. S., Engineer in Charge
- Alvin R. Leonard, A. B., Geologist
- Delmar W. Berry, A. B., Geologist
- Howard G. O'Connor, B. S., Geologist
- Glenn C. Prescott, M. S., Geologist
- Kenneth Walters, B. S., Geologist
- Charles K. Bayne, A. B., Geologist
- Norman W. Biegler, M. S., Geologist
- Willis D. Waterman, M. S., Geologist
- W. W. Wilson, Scientific Aide
- William Connor, Core Driller
- Betty Henderson, A. B., Stenographer
- Betty J. Mason, Stenographer

MINERAL FUELS RESOURCES

- Wallace Lee, E. M., Geologist in charge
- Holly C. Wagner, M. A., Geologist

TOPOGRAPHIC SURVEYS

- D. L. Kennedy, Division Engineer
- Max J. Gleissner, Section Chief
- J. P. Rydeen, Topographer

Special Consultants: Ray Q. Brewster, Ph. D., Chemistry; Robert M. Dreyer, Ph. D., Geology and Geophysics; Eugene A. Stephenson, Ph. D., Petroleum Engineering; Robert W. Wilson, Ph. D., Vertebrate Paleontology.

Co-operative State Agencies: *State Board of Agriculture, Division of Water Resources,* Robert Smrha, Chief Engineer; *State Board of Health, Division of Sanitation,* Dwight Metzler, Chief Engineer and Director, and Willard O. Hilton, Geologist.

*** Intermittent employment only.**

CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY AND GROUND-WATER RESOURCES OF THE NORTH FORK SOLOMON RIVER IN MITCHELL, OSBORNE, SMITH AND PHILLIPS COUNTIES, KANSAS

By Alvin R. Leonard

ABSTRACT

This report describes the geography, geology, and ground-water resources of the valley of the North Fork of Solomon River in north-central Kansas from the west side of Phillips County to the confluence of the north and south forks in northwestern Mitchell County. The area is from 2 to 3 miles wide, is 84 miles long, and extends across Phillips, Smith, Osborne, and Mitchell Counties. The area has a subhumid climate, average normal precipitation being about 22.5 inches and the mean annual temperature about 54° F. Farming and livestock raising are the principal occupations; wheat and corn are the major crops. A few farms are irrigated with surface water in dry years. Oil and construction materials are produced in the area.

The exposed rocks range in age from Cretaceous to Recent. A map showing the surface geology and cross sections illustrating the relation of the various formations are included in this report. The Pleistocene alluvial deposits, which range in age from Kansas to Recent, are the important aquifers in the area. The shape and slope of the water table are illustrated by a map that shows contours of the water table and depth to the water table in wells. This map shows that ground water moves downstream and toward the river.

Ground-water recharge in the area is largely from local precipitation; ground-water discharge is mainly by seepage into streams and transpiration by plants. All municipal and industrial water supplies and most of the domestic and stock supplies are obtained from wells. In the eastern part of the area some surface water has been used for irrigation.

The principal mineral constituents of the ground water are discussed with relation to its occurrence and use. The water is hard and mineralized and samples from different formations are similar in their content of dissolved solids. Nitrate in excess of 45 parts per million, identified with surface seepage, is found in both the terrace deposits and the Crete member of the Sanborn formation. Base flow in the North Fork Solomon River is nearly free from nitrate and shows a slightly lower mineralization than is found in the ground water. A rating based on the present chemical quality of the ground water is included for use in planning for irrigation in this area. All ground water in the area rated "good to permissible" or better for irrigation purposes.

The hydrologic and geologic field data upon which this report is based include records of 244 wells, chemical analyses of water from 22 wells and 8 municipal supplies, and logs of 122 wells and test holes including 57 test holes drilled as a part of this investigation and 19 drilled along the site of the proposed Kirwin dam by the Bureau of Reclamation and Corps of Engineers.

INTRODUCTION

Purpose and Scope of Investigation

During the fall of 1945, the United States Geological Survey started a series of ground-water investigations as a part of the program of the Department of the Interior for development of the Missouri River basin. The investigations of ground-water resources in the Kansas part of the basin have been co-ordinated with the co-operative ground-water studies that were begun in 1937 by the U. S. Geological Survey, the State Geological Survey of Kansas, the Division of Sanitation of the Kansas State Board of Health, and the Division of Water Resources of the Kansas State Board of Agriculture. The present status of investigations resulting from these programs is shown in Figure 1.

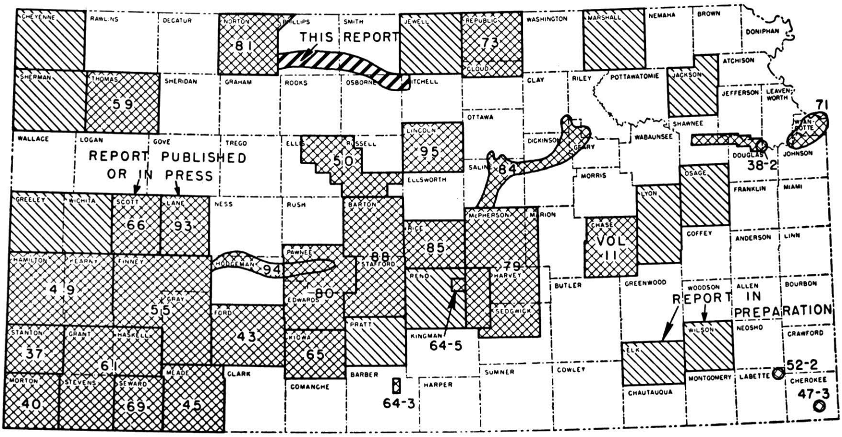

Fig. 1.—Areas in Kansas where ground-water data are being collected and where co-operative ground-water studies have been or are being made.

As a part of the Missouri Basin program, a study of the geology and ground-water resources in the lower part of the valley of North Fork Solomon River was begun in the fall of 1945. During the first half of 1946, measurements of the water level in many wells in the area were made, test holes were drilled to determine the character and thickness of the water-bearing formations, a program of periodic observations of water-level fluctuations was started, and a geologic map of the area was prepared.

Construction of the proposed Kirwin Reservoir on North Fork Solomon River will provide storage capacity for 200,000 acre-feet of surface water, of which 80,000 acre-feet will be used for irrigation.

The purposes of this investigation were: to study the natural ground-water conditions in the area before they were disturbed by the construction of the reservoir or by irrigation developments; to determine the availability and quality of ground water for domestic, stock, municipal, industrial, and irrigation supplies; to learn the geologic factors that are related to and that control the occurrence of ground water; to determine the chemical character of the water and its relation to geologic factors; and to study the relation of surface water in North Fork Solomon River to the ground water in the valley.

Present information on the mineralization of ground water in the North Solomon Valley will be used as reference data for future studies. Such studies should be made to determine the effect of irrigation on the mineralization of the ground water.

This investigation was made under the general supervision of A. N. Sayre, chief of the Ground Water Branch of the U. S. Geological Survey, and G. H. Taylor, regional engineer in charge of ground-water investigations in the Missouri River Basin.

The study of quality of water was under the general direction of S. K. Love, chief of the Quality of Water Branch, and under the supervision of P. C. Benedict, regional engineer in charge of quality-of-water investigations in the Missouri River Basin.

Location and Extent of the Area

The area described by this report is a narrow strip along the valley of North Fork Solomon River (referred to in this report as the North Solomon River); it extends from the western boundary of Phillips County, through southwestern Smith and northeastern Osborne Counties, to the confluence of North and South Forks of Solomon River near Cawker City in northwestern Mitchell County. Throughout this area the rocks bordering the valley consist of Cretaceous shales and chalks, which are relatively impervious and which differ in ground-water characteristics from the alluvial deposits of the valley. For this reason the valley is a distinct ground-water area. North and South Forks of Solomon River are part of the Kansas River system. They join in northwestern Mitchell County to form Solomon River, which flows east and southeast and which joins Smoky Hill River in northeastern Saline County.

The western half of this area, west of the Niobrara and Carlile contact near Cedar (Pl. 1), is in the area described by Adams (1903, p. 113) as the High Plains. The eastern part lies in the Smoky Hills Upland division (Adams, 1903) or in the Blue Hills Upland

(Schoewe, 1949, fig. 22). Fenneman (1931, p. 25; Frye, 1946, p. 76) has suggested that alluviated and terraced valleys are not typical of the High Plains, and therefore, the references to physiographic districts serve only to place this area in its proper regional setting.

PREVIOUS INVESTIGATIONS

A recently published report on Norton and part of Phillips Counties (Frye and Leonard, 1949) describes the geology and ground water along the North Solomon River in Norton County. Field work has been completed and a report is being prepared on the geology and ground-water resources of Jewell County, which lies north of the eastern part of this area. Well inventories and observation-well programs have been started in the Glen Elder and Webster units of the Missouri Basin, which are adjacent to this area (Fig. 1).

Several early reports of the University Geological Survey of Kansas (Haworth, 1897; Logan, 1897; Williston, 1897) discussed the geology of this area. In 1913, Haworth briefly discussed the availability of ground water along the Solomon Valley. Landes (1930) described the geology of Mitchell and Osborne Counties and his report includes a brief discussion of the ground-water resources of the eastern part of this area. The general occurrence of ground water in Kansas and the significance of the Cretaceous rocks as aquifers were discussed by Moore and others (1940). Landes and Keroher (1942) described the mineral resources, including ground water, of Phillips County, and Lohman and others (1942) mentioned the general availability of ground water along the Solomon Valley. Reports on construction materials in Phillips County (Byrne, Beck, and Houston, 1948), in Smith County (Byrne, Houston, and Mudge, 1948) and in Mitchell County (Byrne, Johnson, and Bergman, 1951) have been prepared; a report for Osborne County is in preparation.

METHODS OF INVESTIGATION

During the winter and spring of 1946 I spent 4½ months in the field completing the well inventory and mapping the geology. Many of the water-level measurements that were used in the preparation of the water-table contour map were made by John Sears and Milton Sears in the late fall of 1945. D. W. Berry made most of the water-level measurements since field work was completed. All measurements were made from a fixed measuring point at the top of each well with a steel tape graduated to hundredths of a foot. The altitude of the measuring point for each well was determined with an alidade and a plane table by C. K. Bayne assisted by Norbert Reibel. General information regarding the character and thickness of the water-bearing material, yields of wells, and use and quality of the water was obtained from many farmers in the area. Data on the municipal and industrial wells were obtained from the superintendents of municipal water plants and from the Layne-Western Co., Wilson & Co., the Chicago, Rock Island, & Pacific Railway Co., and the Missouri Pacific Railroad Co.

In April and May 1946, 57 test holes were drilled by J. B. Cooper and W. T. Connor, who used a portable hydraulic-rotary drilling rig owned and operated by the State Geological Survey. Samples of drill cuttings were collected and studied in the field by Cooper and were studied later in the office by me. Many test holes were drilled along the axis of the dam and in the vicinity of the dam site at Kirwin by the Bureau of Reclamation and Corps of Engineers. Cross section C-C′ (Pl. 3) was based on logs of these test holes. Six other cross sections, which were prepared from test-hole data of the State Geological Survey, are also shown in Plate 3. These cross sections indicate the general character and thickness of the water-bearing materials in the valley and adjacent areas. Logs of all the test holes are included in this report.

Field mapping was done on county highway maps and was supplemented by use of aerial photographs of the U. S. Department of Agriculture. These photographs were used also to make highway corrections and to delineate the drainage shown on the geologic map (Pl. 1). Wells and test holes were located on the maps by measuring the distances from section corners and section lines with an odometer.

Samples of water from 18 stock and domestic wells in Mitchell, Osborne, Smith, and Phillips Counties were collected during March 1947 by D. W. Berry and samples from 4 stock and domestic wells in Smith County were collected in May 1950 by W. H. Durum and A. R. Leonard. Four samples of water for analysis were collected from North Solomon River at Kirwin to determine the relation of the mineral content of the ground water to that of the low-flow surface water. Samples of water were collected from each municipal supply by the Kansas State Board of Health and were analyzed by Howard Stoltenberg in the laboratory of the Board of Health in

Lawrence, Kansas. The samples of water collected from the stock and domestic wells and from the river were analyzed by W. M. Barr and J. Bonebright in the laboratory of the Federal Geological Survey at Lincoln, Nebraska.

WELL-NUMBERING SYSTEM

The Federal Geological Survey has adopted a system for numbering wells and test holes in the Missouri Basin which utilizes the General Land Office survey according to the following sequence: township, range, section, quarter section, and 40-acre tract within that quarter section. The numbers used to designate the township, range, and section are those assigned in the General Land Office survey. The quarter-section and 40-acre tracts are lettered a, b, c, or d in a counter-clockwise direction beginning in the northeast quadrant. For example, well 6-11-18ba is located in the NE¼ NW¼ sec. 18, T. 6 S., R. 11 W. (Fig. 2). If two or more wells are located within a 40-acre tract, they are numbered serially according to the order in which they were inventoried.

ACKNOWLEDGMENTS

Appreciation is expressed to the many persons who co-operated and assisted in the collection of field data. Special thanks are extended to the water superintendents and other officials of the Cities of Logan, Speed, Phillipsburg, Kirwin, Gaylord, Smith Center, Portis, and Downs for information concerning their municipal wells, the use of water, and other pertinent data; to the officials of the Chicago, Rock Island, & Pacific Railway Co. for data on their wells near Glade; to D. R. Soder and the other officials of Layne-Western Co. for test-hole and well data on the Phillipsburg and Smith Center wells; and to C. F. Popejoy and other officials of the Missouri Pacific Railroad Co. for data on their wells in this area.

J. C. Frye spent several days in the field with me and gave valuable assistance in interpreting the terrace and loess stratigraphy. Ada Swineford assisted in measuring and identifying outcrops of the Ogallala. W. W. Wilson drafted the maps and other illustrations.

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

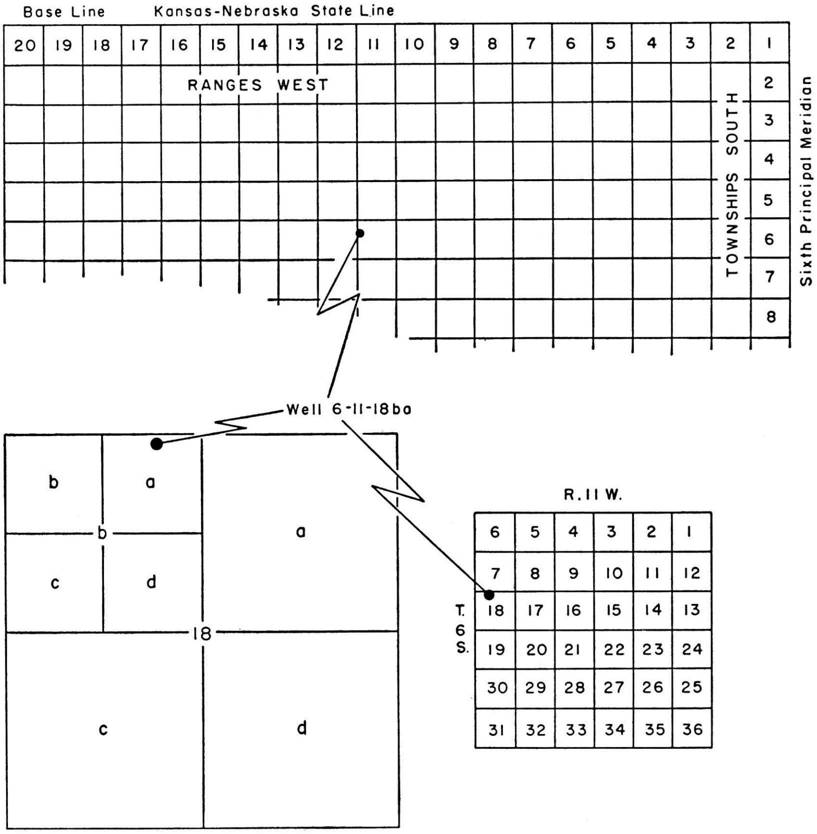

FIG. 2.—Diagram illustrating the well-numbering system used in this report.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

Although the area described in this report lies in two different physiographic provinces according to Adams (1903) and Schoewe (1949), these divisions are regional in nature and are determined principally by the features of the uplands. The valleys, in fact, are not characteristic of either province. Except that it is narrower where it is bordered by the resistant Fort Hays limestone member of the Niobrara formation, the valley of North Solomon River is much the same throughout the area studied. Physiographically the area on Plate 1 might be divided into two parts: (1) the uplands and (2) the valley proper.

In the eastern half of the area the uplands bordering the valley consist of steep-sided flat-topped chalk hills covered with a thin layer of loess. They are well drained and have a fine-textured drainage pattern. From the heel of the flat terrace up a precipitous shale slope and a nearly vertical limestone escarpment to the top of the hills, the relief in many places is more than 200 feet. West of Cedar the uplands consist of hills that are slightly rounded, although in many places they have precipitous slopes similar to those farther east. In western Phillips County rounded hills give way to rounded slopes that rise to relatively flat uplands. In places these uplands form the dissected surface of a Pleistocene high terrace.

The valley proper consists of broad undissected terraces and a narrow flood plain (Pl. 4). Relief within the valley, from the stream channel to the top of the terrace surface, is as much as 40 feet in some places. The terrace is here designated the Kirwin terrace, from the town of that name built upon it. The terrace surface lies above flood level, slopes very gently, and is moderately well drained, although its drainage pattern is noticeably coarser than that of the adjacent uplands (Pl. 5). Many of the small ephemeral streams that drain the uplands do not have channels across the terrace but fan out and disappear on its surface, contributing a large part of their water to the ground-water reservoir in the area (Pl. 1).

The terrace area includes much of the cultivated farm land and at least part of each town shown on the map. The average gradient of the terrace surface in the area studied is 7.3 feet per mile. The terrace slopes from an altitude of 1,975 feet near Logan, in Phillips County, to about 1,460 feet south of Cawker City, in Mitchell County. The average gradient of the river channel is 5.2 feet per mile, but it decreases from 7.1 feet per mile across Phillips County to 2.7 feet per mile below Downs, in Osborne County (Fig. 3).

The lowest point in the area has an altitude of about 1,410 feet and is at the mouth of North Solomon River in Mitchell County. The highest point has an altitude of about 2,100 feet and is on the uplands near the valley in the western part of Phillips County.

Like the other valleys in north-central Kansas, the valleys of North Solomon River and its principal tributaries are asymmetrical. Valleys of this type have been described by Bass (1949, pp. 17-23), Frye (1945, p. 29), and Frye and Leonard (1929, p. 14). Typically developed asymmetrical valleys have precipitous south walls and gently sloping north walls, as illustrated by cross sections B-B′ and D-D′ on Plate 3. These features are accounted for, in part, by local

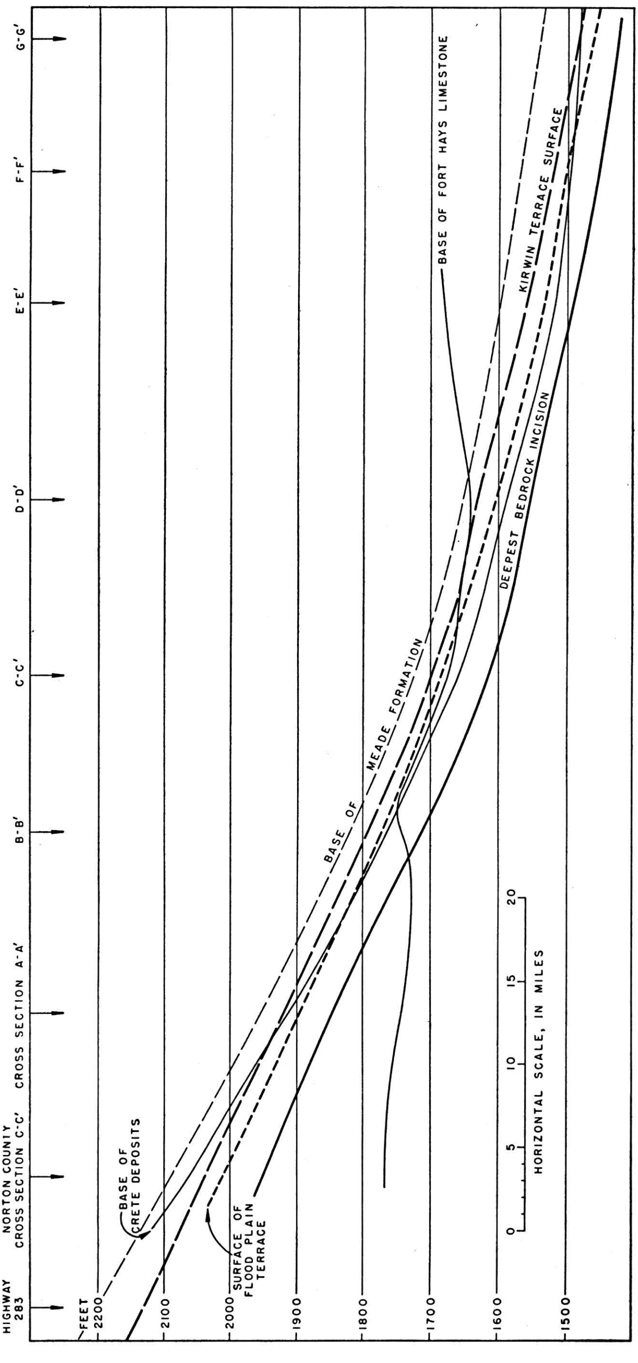

Fig. 3.—Longitudinal profiles of North Solomon Valley. Profiles are shown for the base of the Meade, base of Crete, Kirwin terrace, floodplain terrace, and deepest bedrock incision, at a vertical exaggeration of 210 ×. Profiles are from central Norton County to western Mitchell County and indicate gradient of river at time of deposition of successive alluvial deposits. Based on topographic data of Bureau of Reclamation and subsurface data from test-holes. Locations of test-hole lines shown on Plate 3 are indicated at top of figure.

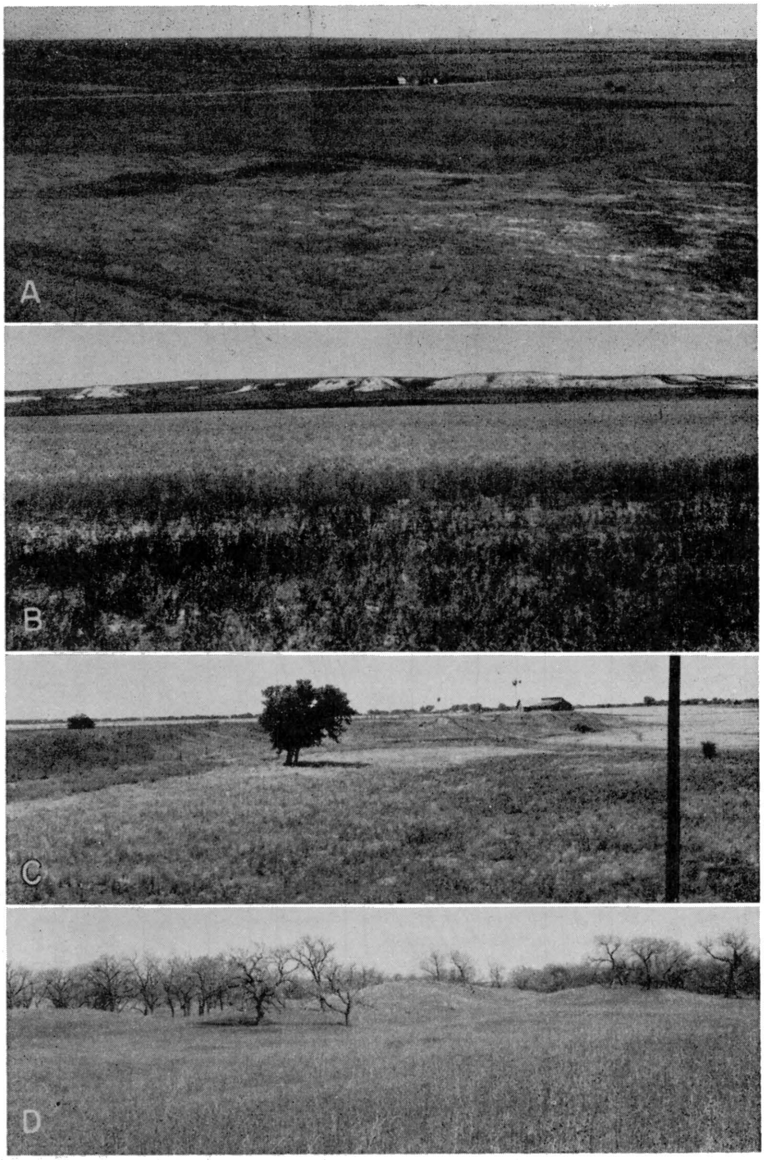

PLATE 4. **A**, North Solomon Valley near Harlan. **B**, Kirwin terrace surface and valley walls of Smoky Hill chalk member of the Niobrara formation, SW¼ sec. 26, T. 4 S., R. 16 W., Phillips County. **C**, Flood plain and scarp of Kirwin terrace near Portis; looking west from U. S. Highway 281, NE¼ sec. 7, T. 6 S., R. 12 W., Osborne County. **D**, Sand dunes on the flood plain of North Solomon River, SW¼ sec. 29, T. 4 S., R. 17 W., Phillips County.

Pleistocene stream deposits and loess in a high terrace position on the north side of the valley. Southeast of Portis, in Osborne County, stream deposits of the Crete member of the Sanborn formation and the Meade formation occur in successively higher terraces on the south side of the valley, and the valley has a pronounced asymmetry with the steep wall on the north. Where the south valley wall is formed by the chalk of the Niobrara formation and the north wall is formed by unconsolidated Pleistocene deposits, the drainage pattern in the chalk hills is very fine-textured, whereas in the areas of Pleistocene deposits it is coarser (Pl. 5).

Most of the streams shown on Plate 1 are ephemeral and flow only after precipitation. Several of the larger tributaries are intermittent, and Bow Creek and North Solomon River are perennial streams.

CLIMATE

Normal conditions.—The part of the North Solomon Valley covered by this report has a subhumid climate. Days are hot during the summer, but the nights are generally cool. Low relative humidity and a good breeze help to relieve the summer heat. Winters are normally moderate, with light snowfall and only occasional short periods of severe cold.

According to records of the U. S. Weather Bureau, the normal annual precipitation in this area averages about 22.57 inches, of which 75 percent falls during the growing season, from April to September. Four weather stations are located only a few miles from the North Solomon Valley but none is in the immediate area. A summary of the climatic data at these four stations is given in Table 1. The relation of the annual precipitation to the normal precipitation at the Weather Bureau stations at Alton, Smith Center, and Phillipsburg are shown graphically in Figures 4, 5, and 6. The Alton and Cawker City stations are in valley areas, and those at Smith Center and Phillipsburg are in the uplands.

The average length of the growing season is about 167 days. July, the hottest month, has a mean temperature of 80.2° F. at Alton and 80° F. at Phillipsburg. The coldest month is January, which has a mean temperature of 27.6° F. at Alton and 27.9° F. at Phillipsburg. The mean annual temperature is 54.4° F. at Alton and 53.7° F. at Phillipsburg.

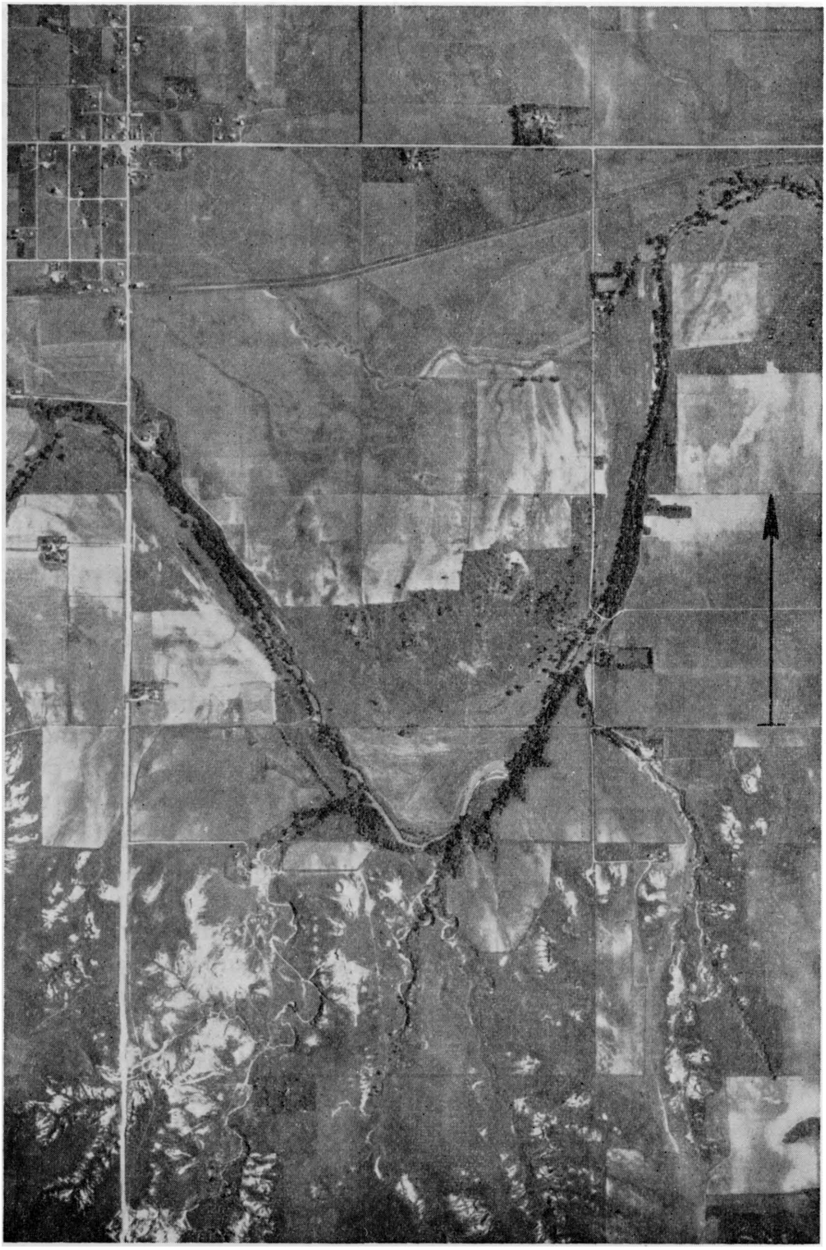

PLATE 5. Aerial photograph of the North Solomon Valley near Glade showing contrast between fine-textured drainage pattern developed in the Niobrara bedrock and coarse-textured pattern in unconsolidated Pleistocene deposits north of the river. Arrow points north and is half a mile long. (Photo by U. S. Department of Agriculture.)

Drought.—The normal climatic classification of this part of Kansas is subhumid, but periodic seasons of deficient precipitation have been recorded since the first permanent settlements about 75 years ago. Hoyt (1936, p. 2) suggests that a drought condition exists when precipitation is less than 85 percent of normal. Accordingly, he lists seven major drought years for Kansas (1890, 1894, 1901, 1910, 1917, 1933, and 1934), from the earliest Weather Bureau records until 1935. These were followed by droughts during 1936, 1937, and 1939; thus 10 droughts occurred during the 60-year period 1890-1949.

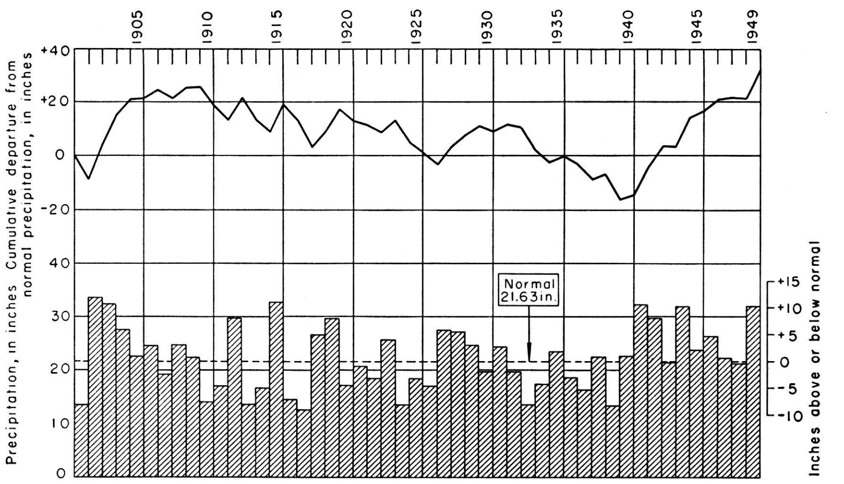

FIG. 4.—Annual precipitation and cumulative departure from normal precipitation near Alton.

Weather stations were established at Phillipsburg in 1892 and at Alton in 1894. Precipitation records show that since then Phillipsburg has had 18 seasons and Alton 15 seasons when precipitation was less than 85 percent of normal. However, during only nine of these seasons were drought conditions experienced at both stations. In fact, such conditions did not prevail at Alton during the statewide droughts of 1894 and 1936, nor at Phillipsburg during the general drought of 1901. Drought conditions prevailed at both stations during 1910, 1914, 1916, 1917, 1924, 1933, 1934, 1937, and 1939. During the 4-year period from 1914 to 1917 this area had three drought seasons, but because of the abnormally high precipitation during 1915, the average annual precipitation for the 4 years was 19.12 inches at Alton and 20.09 inches at Phillipsburg. Probably

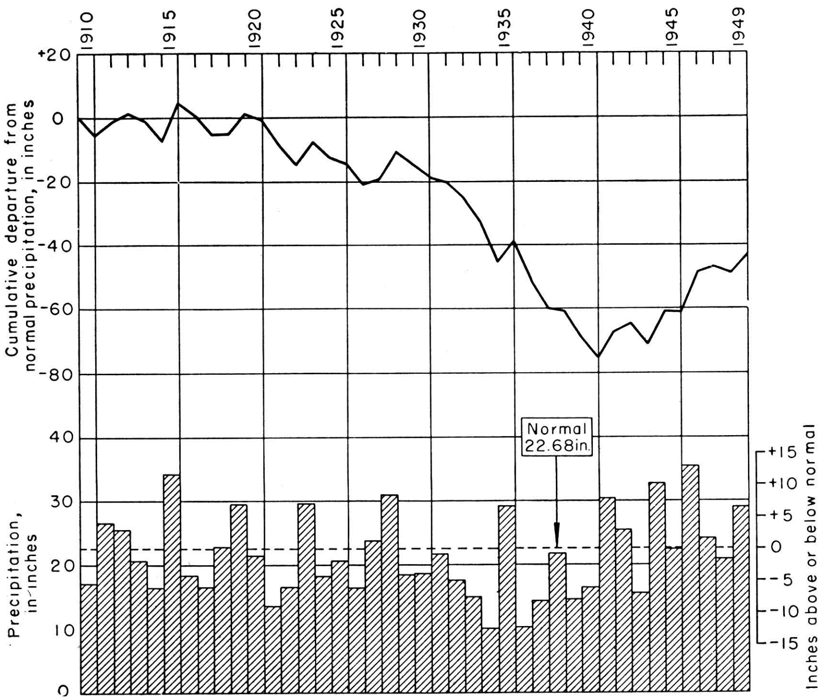

FIG. 5.—Annual precipitation and cumulative departure from normal precipitation at Smith Center.

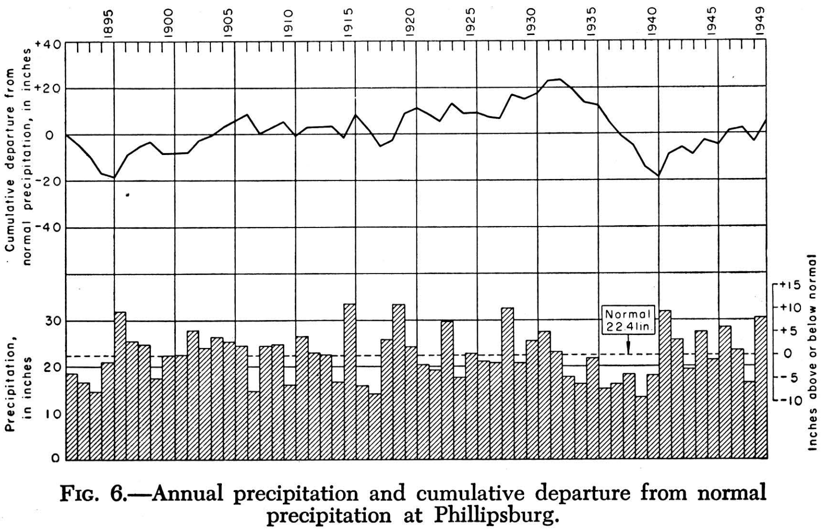

FIG. 6.—Annual precipitation and cumulative departure from normal precipitation at Phillipsburg.

TABLE 1. *Summary of climatic data recorded at four Weather Bureau stations near the North Solomon Valley*

	Station			
	Cawker City*	Alton	Smith Center*	Phillipsburg
Length of record, in years	33	46	38	57
Normal annual precipitation, inches	23.55	21.63	22.68	22.41
Normal precipitation from April 1 to September 30, inches	17.77	16.42	17.34	17.30
Minimum annual precipitation, inches	15.98*	12.78	10.02	13.36
Year of minimum annual precipitation	1936	1917	1934	1939
Maximum annual precipitation, inches	39.26	33.68	35.47	33.51
Year of maximum annual precipitation	1919	1902	1946	1919
Average date of last killing frost in spring	....	April 27	....	April 26
Latest recorded spring frost	....	May 29	....	May 29
Average date of first killing frost in fall	....	Oct. 12	....	Oct. 10
Earliest recorded fall frost	....	Sept. 17	....	Sept. 9
Average growing season, in days	....	168	....	167
Mean annual temperature, degrees F	....	54.4	....	53.7
January mean temperature, degrees F	....	27.6	....	27.9
July mean temperature, degrees F	....	80.2	....	80.0

* Incomplete record.

the only drought period that might be classed as severe during the entire period of record is that of 1933-1939, when the average annual precipitation was only 16.97 inches at Phillipsburg and 17.80 inches at Alton.

Droughts have occurred every few years at irregular intervals since precipitation records have been kept in this area. During these periods the combination of deficient precipitation and hot drying winds is generally ruinous to cultivated crops. Fortunately, two or more drought seasons are rarely successive and drought periods are balanced by periods of above-normal precipitation. Weather records also indicate that even during widespread droughts some local areas are not seriously affected.

POPULATION

According to the 1950 census, Osborne, Phillips, and Smith Counties had a combined population of 26,677, a rural population of 13,427, and a rural population density of 5.0 persons per square mile. The population density for the more thickly settled valley area is somewhat greater than the average for the counties. The total population of the approximately 225-square-mile area covered by this report is estimated at 5,000 persons, of which 3,234 live in the cities of Cedar, Downs, Gaylord, Glade, Kirwin, Logan, Portis, and Speed.

TRANSPORTATION

In the North Solomon Valley, the Lenora branch of the Missouri Pacific Railroad runs from Downs to its terminus at Lenora in Norton County. At Downs this branch line connects with the Stockton branch, which connects with a larger branch line of the Missouri Pacific at Jamestown in Cloud County. The Lenora branch is an important carrier in this area, transporting many of the principal grain crops.

An excellent system of hard-surfaced Federal and State highways serves this area (Pl. 1). U. S. Highway 24 traverses the eastern part of the area through Cawker City and Downs. U. S. Highway 281 passes through the eastern part of the area in a north-south direction, following the valley from south of Portis to 3 miles east of Gaylord. Kansas Highway 9 traverses the entire valley area; it follows the same route as U. S. Highway 24 from Cawker City to south of Portis, the route of U. S. Highway 281 to the junction east of Gaylord, and parallels North Solomon River on the north side of the valley until it passes into Norton County, 2 miles west of Logan. Kansas Highway 181 crosses the area from north to south through Downs and U. S. Highway 183 crosses the valley similarly through Glade. A system of improved county roads connects with these main highways.

AGRICULTURE

The soils in the North Solomon Valley are primarily fertile silty clay-loam soils derived from reworked loess which was carried into the valley by tributary streams. Almost all the land in the valley area is cultivated, agriculture being the chief occupation. The most important crops are wheat and corn. In Phillips and Smith Counties the total acreage of corn about equals that of wheat, but in the valley areas corn is the most important crop. Other crops are sorghum, oats, and alfalfa. Surface water pumped from North Solomon River is used to irrigate some tracts in a few areas.

Much of the area bordering the valley is too steep for cultivation or has a rocky soil formed on the chalk and limestone rocks. Much of this area is range land used to pasture cattle. Many farms contain an upland area of range land and a valley area that is cultivated.

Forty percent of the farm land in Smith, Phillips, and Osborne Counties is pasture land.

MINERAL RESOURCES

The principal mineral resources of the North Solomon Valley area, aside from ground water, are petroleum, chalk, ceramic materials, and construction materials.

Oil and gas.—No gas is produced in this area, but oil is produced from the Logan pool, which is just south of Logan in the North Solomon Valley, and from several pools a few miles south of the valley, in southwestern Phillips County. Oil was discovered in this area in the Bow Creek pool in 1939. The Ray pool was discovered in 1940, the Hansen pool in 1943, and the Logan pool in 1945. Production is from the Reagan sandstone, Arbuckle rocks, and Kansas City-Lansing limestones.

The Logan pool was discovered in November 1945 from a well in the NW¼ NW¼ SE¼ sec. 3, T. 5 S., R. 20 W., which produced oil from porous zones in the Arbuckle dolomite at depths of 3,381 to 3,387 and 3,391 to 3,404 feet. The well was plugged back to the Kansas City-Lansing limestone and gave an initial production of 201 barrels of oil a day (Ver Wiebe, 1946, p. 58). Three new oil wells were drilled in this pool in 1946 (Ver Wiebe, 1947, p. 62), five in 1947 (Ver Wiebe and others, 1948, table 51), and one during 1948 (Ver Wiebe, Jewett, Nixon, 1949, p. 124). By the end of 1950 this pool had produced 256,731 barrels of oil (Ver Wiebe and others, 1951, table 62).

Chalk.—Chalk for whiting produced at a small quarry in the SW¼ NW¼ sec. 36, T. 4 S., R. 15 W., is trucked to Cedar, and is shipped via the Missouri Pacific Railroad. Several carloads are produced annually. Before being shipped, the chalk is broken into small boulders and the visible concretions of pyrite are chipped out by hand. This chalk occurs as fine-grained dense massive limestone beds in the Fort Hays limestone member of the Niobrara formation. Chalk from this member is quarried in northern Jewell County for use in the manufacture of Portland cement. It has also been used in this area as building stone and construction material, and it is well suited for use as industrial or agricultural lime. The chalk when processed with the underlying shale has also proved to be a satisfactory source of rock-wool material (Plummer, 1937, pp. 59-60). A chemical analysis of the chalk from the quarry near Cedar was made in the laboratory of the State Geological Survey (Table 2).

TABLE 2.—*Analysis of chalk from quarry near Cedar*

Component	Percent of total
SiO_2	1.09
Al_2O_3	.50
$Fe_2O_3 + TiO_2$	.10
CaO	55.01
MgO	1.08
P_2O_5	trace
Ignition loss 140-1,000° C.	42.96
Total	100.74
$CaCO_3$ calculated 98.09	
$MgCO_3$ calculated 2.26	

Ceramic materials.—Clays suitable for the manufacture of certain ceramic products are found in the Sanborn formation throughout this area. The State Geological Survey has made a study (Frye and others, 1949) of the ceramic uses of these beds in northern Kansas. This study shows (pp. 80-83) that the silts and soil zones of the Sanborn formation are the most suitable for the manufacture of brick, tile, and ceramic aggregate. Ceramic aggregate is used for concrete aggregate, road metal, and ballast. Clay that is usable in the manufacture of aggregate is present in the Loveland silt member of the Sanborn formation at a locality north of Speed (SW¼ SW¼ sec. 24, T. 4 S., R. 19 W.).

Construction materials.—Rocks from three formations, the Greenhorn limestone, the Niobrara formation, and the Ogallala formation, have been used for building and foundation stone in this area. The limestone bed in the Greenhorn that has been used most extensively is the Fencepost bed at the top of the formation. Along its area of outcrop, the limestone is commonly used for building stone, fence posts, and flagstones. The county courthouse in Beloit is built of limestone from this bed.

The Fort Hays limestone member of the Niobrara formation also has been quarried for use as building stone. It is not as durable as the Fencepost limestone and crumbles badly when used for foundations. Several buildings in Kirwin are built of this stone.

The third rock used for building stone is the green "quartzite" of the Ogallala formation; it is quarried just south of North Solomon River in western Phillips County. Tests show that this rock is unsuitable for use as concrete aggregate (Frye and Swineford, 1946) because of the reaction between the opaline cement in the "quartzite" and the alkali in the cement.

Each of the three building stones discussed above has been crushed for use as road metal. The quartzite breaks into sharp jagged fragments which damage tires and the chalk of the Fort Hays limestone member disintegrates rapidly under traffic conditions. The Greenhorn limestone makes a satisfactory road material, and in Mitchell County it is generally crushed together with the underlying shales and thin limestones. The shale aids in packing and the combined material makes a hard serviceable all-weather road.

Sand and gravel deposits are fairly common in the valley area and have been quarried at many pits. The best gravel for most construction purposes contains a minimum amount of limestone pebbles and silt. The gravel in the Meade formation, which is being quarried at a pit in the NW¼ sec. 11, T. 6 S., R. 13 W., and the gravel deposits from the Recent alluvium, which are being mined by hydraulic methods at Speed, are probably most suitable for concrete aggregate, road material, and general construction use. Gravel and sand have been obtained from several small pits in the Crete member of the Sanborn formation in western Phillips County, but these deposits contain a high percentage of fine material. In Osborne County, several pits for obtaining local highway material have been opened in limestone gravel deposits that were derived from the Fort Hays limestone member of the Niobrara formation (Pl. 1). This gravel contains silt and clay from the Sanborn formation and the Carlile shale; these bind the coarser material together to form a hard smooth road surface.

GEOLOGY

SUMMARY OF STRATIGRAPHY*

The rocks that crop out in the area discussed in this report are sedimentary and range in age from Cretaceous (Gulfian) to Recent. A generalized section of the geologic formations is given in Table 3, their areal distribution is shown on Plate 1, and their stratigraphic relationship is shown on Plate 3.

The oldest rocks exposed in this area are marine Cretaceous rocks and are represented by the Greenhorn limestone, the Carlile shale, and the Niobrara formation. Underlying these rocks and cropping out a few miles to the east are the Graneros shale and the Dakota formation (Moore and Landes, 1937). At the extreme western end of this area, the divides north and south of Solomon River are capped by remnants of the Ogallala formation of Pliocene age. The eolian silts that make up the Sanborn formation are widely distributed

---

* The stratigraphic classification used in this report is that of the State Geological Survey of Kansas and differs somewhat from that of the United States Geological Survey.

over the uplands and valley walls of north-central Kansas. Along the major streams, these silts may be underlain by stream-deposited sands which are in a high-terrace position with respect to the valleys and which locally are important sources of ground water. Along North Solomon River and many of its tributaries are terrace deposits laid down by these streams in an earlier aggradational cycle. Narrow belts of alluvium are adjacent to the river channel and its tributaries. Most of the alluvium is of Recent age, and deposition of this material by the streams is still in progress. In local areas on the flood plain of North Solomon River, modern winds have formed dunes from the alluvial sand (Pl. 4D). In other places, sand has drifted and modified the terrace surface (A-A′, Pl. 3).

GEOLOGY IN RELATION TO GROUND WATER

CRETACEOUS SYSTEM (GULFIAN SERIES)

Dakota Formation

The Dakota formation does not crop out in this area and no wells in the North Solomon Valley are known to obtain water from it. This formation, however, contains lenticular sand bodies, which are sources of potable water in parts of central Kansas (Frye and Brazil, 1943; Moore and others, 1951). Several attempts to obtain water from the Dakota formation have been made in this area, but only salt water has been found.

Character.—The Dakota formation was named by Meek and Hayden (1862) from an exposure near Dakota City in northeastern Nebraska. In that area, as along the outcrop in central Kansas, the Dakota consists of clay, sandstone, and lignite. In 1930 Landes (pp. 30, 49-50) described the upper part of the Dakota along the Solomon Valley in eastern Mitchell County and discussed the occurrence of ground water in this formation. A detailed study of the stratigraphy and lithology of the Dakota in its outcrop area was made by Plummer and Romary (1942), and Landes and Keroher (1942, p. 299) discussed the character of the formation in the subsurface of Phillips County.

Plummer and Romary have shown that in Kansas the Dakota consists predominantly of shale, clay, and siltstone 100 to 275 feet in thickness. Lentils of fine-grained sandstone may occur at any horizon in the formation, and lignite, hematite, and siderite are present locally. Many of the sandstone lentils probably are interconnected and some water-bearing sandstone is present at most locations. Along the outcrop in northern Kansas, the Dakota is the

TABLE 3.—*Generalized section of geologic formations and their water-bearing properties*

SYSTEM	Series	Formation	Thickness, feet	Character	Water supply
Quaternary	Pleistocene*	Recent alluvium	0–40	Sand, gravel, silt, and clay; stratified or cross-bedded, and unconsolidated; well-sorted only in major valleys.	Yields abundant supplies of water to wells along North Solomon River, smaller supplies along tributaries.
		Terrace deposits	0–90	Silt and clay, stratified; contains soil zones in upper part. Lower part consists of sand and gravel containing silt lenses.	Yields moderate supplies of water to wells except where lower sand and gravel is absent.
		Sanborn formation*	0–70	Silt, massive, well-sorted, light-gray, tan, and reddish-tan; contains one widespread and one local buried soil zone. Locally, lower part consists of well-sorted sand grading into sand and gravel (Crete member).	Basal sand and gravel yields moderate supplies of water to wells where it occurs below the water table.
		Meade formation*	0–40	Sand, gravel, and silt; cross-bedded and stratified.	Yields moderate supplies of water locally where below water table.
Tertiary	Pliocene	Ogallala formation	0–30 ±	Sand, gravel, and silt; gray and greenish-gray; locally, cemented with opal or calcium carbonate.	Occurs above the water table; yields no water to wells in this area.
Cretaceous	Gulfian*	Niobrara formation	600 ±	Chalk and chalky shale; contains 50 feet of chalky limestone at base (Fort Hays limestone member).	May yield small quantities of water occasionally from fractures or joints.
		Carlile shale	300	Shale, fissile, noncalcareous, lead-gray, and chalky gray shale; contains thin lenses of fine-grained sandstone (Codell) at top, calcareous concretions in upper part, and thin limestone and bentonite beds in base.	Yields little or no water to wells in this area.
		Greenhorn limestone	85	Shale, chalky, gray, alternating with thin chalky limestones in upper part and thin petroliferous limestones in base. Only upper 20 feet exposed in area.	Yields little or no water to wells in this area.
		Graneros shale	30 ±	Shale, fissile, noncalcareous, gray to black; contains selenite crystals, lenticular sandstones, and "ironstones." Not exposed in this area.	Yields little or no water to wells in this area.
		Dakota formation	200 ±	Clay, gray, white, and buff shale, lenticular sandstone, and beds of lime-cemented sand; contains lignite and siderite pellets. Not exposed in this area.	Yields moderate quantities of highly mineralized water under artesian pressure to deep wells.

* Classification of the State Geological Survey of Kansas.

basal unit of the Cretaceous System, lying nonconformably on Permian redbeds, but toward the west, lower Cretaceous (Comanchean) rocks underlie this formation (Landes and Keroher, 1942). It is overlain conformably by the Graneros shale and other upper Cretaceous marine rocks. The top of the Dakota lies at a depth of about 100 feet near Downs, at about 450 feet at Kirwin, and at more than 800 feet near Logan.

Water supply.—Oil and gas test holes that have penetrated the Dakota formation in Phillips County and the few water wells that have been drilled in this area indicate that the sandstones in the Dakota formation contain moderate supplies of water under artesian pressure. The water is so highly mineralized, however, that it is unfit for domestic, stock, or irrigation use. Logan (1897, p. 209) referred to a zone of saliferous shales in the upper part of the Dakota formation, and Darton (1905, pp. 307-311) attributed the salt water in the sandstone lentils to this material. In Ellis and Russell Counties Frye and Brazil (1943) found evidence that water in the Dakota was more mineralized where the rocks were more deeply buried. Landes (1930) stated that water in the Dakota formation in northern Mitchell County and in Osborne County was too highly mineralized for domestic use; this statement seems to be true also for the parts of the North Solomon Valley in Phillips and Smith Counties.

Graneros Shale

Character.—Gilbert (1896) named the Graneros shale from exposures of noncalcareous marine shale along Graneros Creek about 20 miles south of Pueblo, Colorado. In central Kansas, the name Graneros is applied to the noncalcareous shale at the base of the group of beds formerly referred to as "Benton" (Logan, 1897). It consists of about 30 feet of gray to black fissile shale (Landes, 1930, p. 30; Plummer and Romary, 1942, pp. 328-331) and contains selenite crystals, thin bentonite partings, and sandstone lentils. The Graneros shale lies conformably on the Dakota formation and is overlain conformably by the Greenhorn limestone. The shale does not crop out in the area studied.

Water supply.—The Graneros shale is not known to furnish water to any wells in this part of Kansas. In surface exposures near the area the sandstones are similar in character to those in the Dakota and they probably have similar water-bearing properties.

Greenhorn Limestone

Character.—The Greenhorn limestone was named by Gilbert (1896) from exposures of interbedded limestone and calcareous shale near Greenhorn Station, about 15 miles south of Pueblo, Colorado. In Kansas the Greenhorn limestone consists of the series of chalky limestones, calcareous shales, and bentonite between the Carlile shale and the noncalcareous shale of the Graneros. Landes (1930, p. 23) gives the total thickness of the Greenhorn in Mitchell County as 82 feet. Only the upper 20 feet is exposed in the area studied, but the entire section is exposed farther east along Solomon River. In Mitchell County (Landes, 1930, pp. 13, 23-30) the formation has been divided into four members, including the Pfeifer shale at the top, the Jetmore chalk, the Hartland shale, and the Lincoln limestone. The upper layer is the Fencepost limestone bed, which is about 0.8 foot thick and which has been quarried extensively for fence posts and for building stone in north-central Kansas. In Mitchell County the Fencepost bed is massive, contains *Inoceramus* shells, and has an iron-stained band in its center. The remainder of the Pfeifer member consists of calcareous shales separated by thin concretionary limestones.

Section of the Greenhorn limestone and overlying Carlile shale measured along small creek in the SW¼ sec. 32, T. 6 S., R. 10 W., Mitchell County (Measured by A. R. Leonard and J. B. Cooper, 1946)

	Thickness, feet
Cretaceous—Gulfian	
Carlile shale—Fairport chalky shale member	
13. Limestone, crystalline, composed of flat discoidal concretions	0.4
12. Shale, calcareous, light gray-buff	1.4
11. Limestone, thin persistent, crystalline; has limonite stains	0.2
10. Shale, calcareous, tan-buff	1.35
9. Limestone, crystalline, persistent; has limonite stains	0.15
8. Shale, calcareous, buff	0.85
Total Carlile shale exposed	4.35
Greenhorn limestone	
Pfeifer shale member	
7. Limestone (Fencepost), dense; contains shells, iron-stained band in center	0.5–0.65
6. Shale, fossiliferous, light gray-black; weathers whitish; contains calcite crystals. Shale has a 0.3-foot concretionary limestone bed 2 feet above base and a 0.15-foot concretionary bed 1 foot from top	5.0
5. Limestone, crystalline, light gray-pink; weathers yellowish,	0.4
4. Shale, fossiliferous, calcareous, dark-gray; weathers blue-gray; contains several discoidal limestone concretionary beds up to 0.4 foot in thickness	6.0

	Thickness, feet
3. Limestone, dense, hard, persistent; abundantly fossiliferous,	0.2
2. Shale, fissile, calcareous, dark tan-buff to dark-gray; contains several zones of discoidal concretionary limestones with abundant fossils	5.7
Total thickness, Pfeifer member	17.9
Jetmore chalk member	
1. Limestone ("shell bed"), dense, resistant, very fossiliferous; has irregular shale parting in center	1.0
Total section measured	23.3

Water supply.—The shales and chalky limestones that make up the Greenhorn are impervious and do not yield water to wells in this area. Under favorable conditions, the upper chalky part of the formation might weather deeply and store meager quantities of water. In all localities along Solomon Valley where deep weathering might have occurred, the Greenhorn lies above the water table.

Carlile Shale

Character.—The Carlile shale was named by Gilbert (1896) from exposures along Arkansas River near Carlile Station, 21 miles west of Pueblo, Colorado. He described it as a gray argillaceous shale, 175 to 200 feet thick, containing sand and calcareous concretions. Logan (1897, pp. 232-234) compared the upper part of the "Benton" with Gilbert's section and later (1899) made the correlation more definite. Rubey and Bass (1925, pp. 32-45) formally divided the Carlile shale into members, applying Logan's term "Blue Hill" to the upper argillaceous member and naming the lower zone of calcareous shales and thin chalky limestones the Fairport shale member. Bass (1926, p. 28) named and described the Codell sandstone zone, in the upper part of the Blue Hill shale member, from exposures along Saline River in northern Ellis County. Landes (1930, pp. 19-23) recognized the Fairport, Blue Hill, and Codell in Mitchell and Osborne Counties, and Landes and Keroher (1942) noted the upper part of the Carlile shale in the Solomon Valley near Glade, where it arches across the top of the Stockton anticline.

The Carlile shale consists of about 300 feet of argillaceous and chalky shale between the top of the Fencepost bed of the Greenhorn limestone, and the base of the Niobrara formation. The Fairport chalky shale member, at the base of the Carlile shale, consists of alternating light-gray to buff carcareous shale and thin chalky limestones, and contains thin persistent bentonite seams. The limestones are generally white or pink and those in the lower part of the

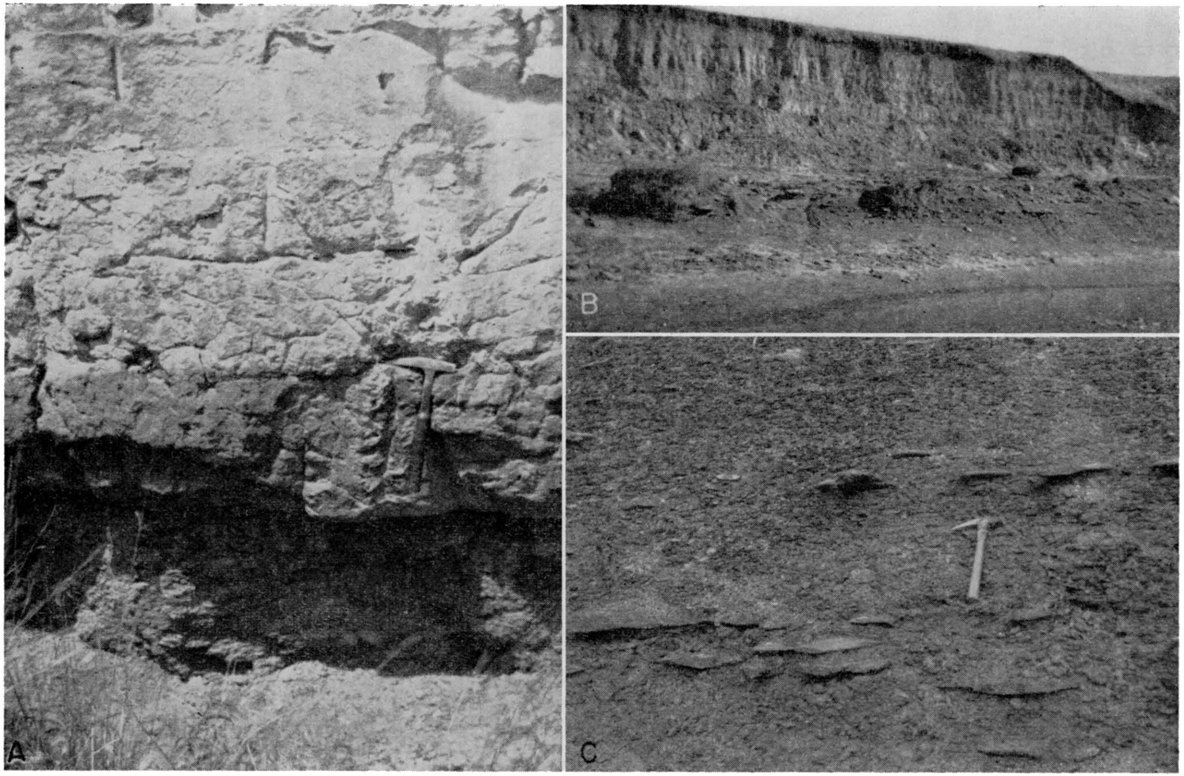

PLATE 6. **A**, Fort Hays limestone member, Codell sandstone zone, and Blue Hill shale member in road cut, NE¼ sec. 17, T. 6 S., R. 13 W., Osborne County. Hammer head marks contact of Codell and Fort Hays. **B**, Crete sand and gravel member overlying thin-bedded Blue Hill shale member in bank of North Solomon River, SW¼ NW¼ sec. 26, T. 5 S., R. 13 W., Smith County. **C**, Close-up of Blue Hill shale member (above) showing flat discoidal concretions.

member are concretionary, like those in the upper part of the Greenhorn limestone. In fresh exposures the shale of the Fairport member is fissile and light gray, flecked with minute particles of white calcite. The shale weathers to form a bright-yellow clay soil. *Ostrea* shells are common in the Fairport member and early geologists referred to these beds as the "Ostrea shales" (Logan, 1897, pp. 217-218). In Osborne County the total thickness of the Fairport shale member is about 100 feet (Landes, 1930, p. 21).

The 200 feet of fissile noncalcareous black to blue-gray shale conformably overlying the Fairport member constitutes the Blue Hill shale member. Sandstone and sandy shale occurring in the upper 30 feet make up the Codell sandstone zone. In southwestern Osborne County (Landes, 1930, p. 30) and southern Rooks County (Bass, 1926, pp. 27-28), the Codell is about 30 feet thick. Northwest of Osborne and along the North Solomon Valley in southwestern Smith County, the Codell is only 1 to 2 feet thick and consists of fine-grained sand loosely cemented with limonite (Pl. 6A). Locally, fossil shark teeth or vertebrae are present in the Codell sandstone zone. Numerous zones of calcareous septarian and ordinary concretions are found in the Blue Hill member (Pl. 7B). The septaria are roughly spherical, discoidal, or lemon-shaped, and contain cross-cutting veins of dark-brown calcite which weather in relief. They range from a few inches to 8 feet in diameter and are found in layers that form slight benches on the steep slopes below the Fort Hays escarpment. Several zones of brown flat discoidal concretions in the lower part of the Blue Hill shale member are exposed in the bank of North Solomon River in the NE¼ sec. 27, T. 5 S., R. 13 W. (Pl. 6B, 6C). Many of these are weathered and reveal the nacreous shells of mollusks. Thin layers of ocher and layers of diamond-shaped selenite crystals also are found in the Blue Hill shale member. The shale erodes easily and is not well exposed except on steep slopes below the Fort Hays escarpment, where it forms small badlands. A typical section of the upper part of the Blue Hill shale member is given below.

Measured section of upper Carlile shale in SE¼ sec. 3, T. 7 S., R. 13 W., Osborne County, Kansas

		Thickness, feet
Cretaceous—Gulfian		
Niobrara formation—Fort Hays limestone member		
	Massive chalky limestone	....
Carlile shale—Blue Hill shale member		
14.	Sandstone (Codell), fine- to very fine-grained, contains limonite	1.0
13.	Shale, massive, silty, noncalcareous, light-gray	3.0
12.	Shale, fissile, dark gray-black; contains layers of selenite crystals and limonite bands	11.0
11.	Shale, light-gray to rusty-buff; less fissile than shale above; contains rusty and sulfur-yellow streaks	15.0
10.	Sandstone, very fine-grained, argillaceous, rusty	0.05
9.	Shale, fissile, dark-gray to black; contains streaks of limonite and ocher	1.0
8.	Sand, very fine-grained, rusty	0.1
7.	Shale, fissile, black	1.5
6.	Sandstone, very fine-grained, hard, dense, calcareous; lenses out in short distance	1.5
5.	Shale, fissile, noncalcareous, black	1.0
4.	Concretionary zone, giant brown sugar-textured calcareous concretions	3.0
3.	Shale, fissile, black; has rusty limonitic streaks	6.0
2.	Concretionary zone, giant brown calcareous concretions	3.0
1.	Shale, fissile, noncalcareous, black; has limonitic streaks	7.0
	Total exposed Carlile shale	54.15 +

Water supply.—The shales of the Carlile are impervious and do not yield water to wells in this area. Adjacent to the North Solomon Valley the Codell sandstone is thin and is not a source of water, but in southeastern Norton County (Frye and Leonard, 1949, p. 27) and in southwestern Osborne County (Landes, 1930, p. 49) it yields water to wells.

Niobrara Formation

Character.—In 1862 Meek and Hayden named the Niobrara formation from exposures of calcareous marl and chalky limestone near the mouth of Niobrara River in northeastern Nebraska. In 1897 Logan (pp. 219-221, 228, 234) described the Niobrara of north-central Kansas and subdivided it into the Fort Hays limestone and Smoky Hill chalk or *Pteranodon* beds. He described a section of the Cretaceous beds along Solomon River from Beloit into Norton County, which shows the interrelation of the Cretaceous units (Logan, 1897, pl. 30, fig. 2). Williston (1897, pp. 235-246) discussed the paleontology and stratigraphy of the Niobrara in western Kansas. Landes (1930, pp. 16-18) described the occurrence and appearance of the lower part of the formation in Osborne County.

Although the Niobrara probably is 650 feet thick in Phillips County (Landes and Keroher, 1942, p. 286), only the lower 300 or 400 feet is exposed in this area. The lower 45 to 50 feet, the Fort Hays limestone member, consists of massive white chalk beds 3 to 5 feet thick separated by thin partings of gray chalky shale. The Fort Hays limestone member is more resistant to erosion than the overlying Smoky Hill chalk member or the underlying Carlile shale, and it commonly forms a prominent escarpment where the beds are well exposed in quarries and road cuts. The following section in a road cut and quarry along Kansas Highway 9 illustrates the character of the member.

Measured section of the Fort Hays limestone member of the Niobrara formation at SW cor. SW¼ NW¼ sec. 36, T. 4 S., R. 15 W., Smith County, Kansas
(Measured by A. R. Leonard and Ira Dubins, April 1947)

	Thickness, feet
Cretaceous—Gulfian	
Niobrara formation	
Smoky Hill chalk member	
35. Limestone, soft, chalky, buff to white	0.5
34. Shale, chalky, yellow	0.25
33. Limestone, soft, chalky, white	0.5
Fort Hays limestone member	
32. Shale, fissile, calcareous, gray with orange streaks	0.3
31. Limestone, massive, chalky; has parting plane 0.8 foot base; increases in thickness to the east	3.4
30. Shale gray	0.05
29. Limestone, chalky; thickness varies; averages	0.8
28. Shale, fissile, calcareous, gray and orange	0.6
27. Limestone, chalky, massive; irregular parting 2.2 feet above base	3.4
26. Shale parting, chalky, gray	0.08
25. Limestone, chalky, massive, white; contains indistinct parting 1.2 feet below top, and pyrite concretions and manganese dioxide stains. Thickens toward east	4.1
24. Shale, chalky, yellow-banded	0.3
23. Limestone, massive, chalky; contains pyrite concretions and a black-stained band 1.3 feet above base	2.1
22. Shale, calcareous, yellowish	0.08
21. Limestone, chalky	1.1
20. Shale, chalky, fissile, yellow	0.12
19. Limestone, chalky, white	0.75
18. Shale, chalky, fissile, yellow	0.04

	Thickness, feet
17. Limestone, chalky, massive, yellow. Lower 0.4 foot more resistant to weathering than upper part	2.4
16. Shale, calcareous	0.1
15. Limestone, chalky	2.3
14. Shale, calcareous	0.06
13. Limestone, chalky	2.2
12. Shale, calcareous, fissile, gray-buff	0.08
11. Limestone, chalky	1.5
10. Shale, calcareous, buff; upper part fissile, lower part chalky,	0.5
9. Limestone, chalky	3.0
8. Shale, chalky	0.4
7. Limestone, chalky, massive, light-colored	1.6
6. Shale, calcareous, buff	0.25
5. Limestone, chalky; indistinct shale parting at base	0.8
4. Limestone, chalky; whiter than bed no. 2	2.0
3. Shale parting	0.15
2. Limestone, massive, chalky, yellowish; surface stained with limonite; contains pyrite concretions	3.6
1. Limestone, massive, chalky, yellowish; contains a little sand in lower part and indistinct shale parting at top	5.4
Carlile shale—Blue Hill shale member	
Total measured section	44.81

The upper part of the Niobrara formation, the Smoky Hill chalk member, consists of chalky shale beds which are blue-gray when fresh and yellowish buff, bright yellow, or orange when weathered. Locally, the member contains massive beds of chalk that resemble the underlying Fort Hays limestone member, and thin bentonite beds occur in many stratigraphic positions. Large fossil shells of *Inoceramus grandis* and small *Ostrea congesta* shells are abundant in the chalk beds, and concretions of pyrite and limonite are present. The Smoky Hill chalk member has eroded into the rounded promontories along North Solomon River in Phillips County and in western Smith County (Pl. 4B) and elsewhere has eroded into badlands or weird erosional features. Many exposures of the member contain nearly vertical fractures that are filled with pure white crystalline calcite. Along some of these fractures, slippage caused by surficial slumping has displaced the chalk beds slightly and has slickensided the calcite fillings.

Water supply.—In general, the chalk and chalky limestone beds of the Niobrara formation are impervious and do not yield water to wells. The Fort Hays limestone member breaks into platy fragments and becomes jointed and fractured upon weathering (Pl. 7A).

These joints and fractures and the fractures in the Smoky Hill chalk member may permit the infiltration and movement of small quantities of water into the formation. In most places, weathering

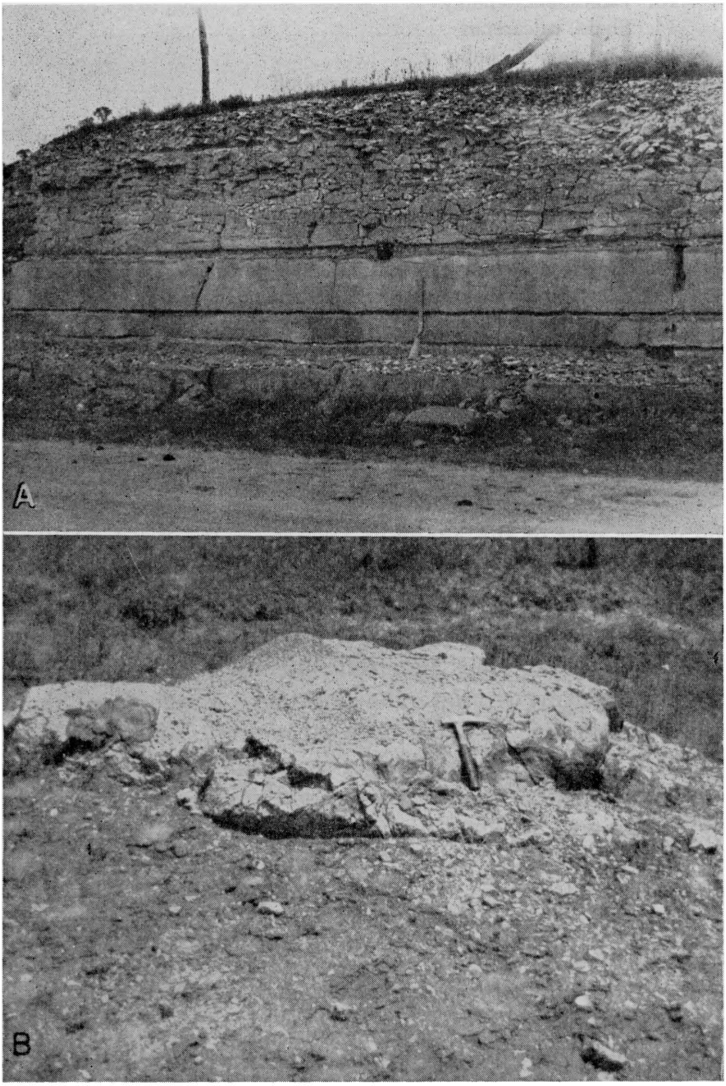

Plate 7. **A,** Fort Hays limestone member of the Niobrara formation showing jointing and typical weathering near surface; NE¼ sec. 3, T. 5 S., R. 13 W., Smith County. **B,** Large septarian concretion weathered from Blue Hill shale; NE¼ sec. 25, T. 5 S., R. 13 W., Smith County.

does not extend below the water table, and only small zones of perched water are found in the Niobrara. Well 5-16-3bc is the only well in this area known to obtain water from the Niobrara formation.

TERTIARY SYSTEM (PLIOCENE SERIES)

Ogallala Formation

Darton named the Ogallala formation in 1899 (pp. 734-742) from a locality in southwestern Nebraska that he later referred to as near Ogallala Station. Elias (1931) made a detailed study of the Ogallala in the western part of Kansas and later (1942) described fossil seeds from the formation. The present usage of the State Geological Survey of Kansas is to classify the Ogallala as a formation composed of the Valentine, Ash Hollow, and Kimball members (Frye and Leonard, 1949, p. 38).

Only the lower 30 feet of the Ogallala formation is present along the sides of the North Solomon Valley in western Phillips County, where it lies above the water table. In this area, the Ogallala formation consists largely of sand, silt, gravel, and clay and is locally cemented with silica or calcium carbonate. The silica-cemented lentils of sand and gravel form resistant ledges of dense green "quartzite," which make prominent benches along the sides of the valley near Logan and cap the hills along the North Solomon-Bow Creek divide as far east as Glade. The following measured section illustrates the formation in this area.

Measured section of Ogallala formation in the SW¼ sec. 13, T. 5 S., R. 19 W., Phillips County (Measured by John C. Frye, Ada Swineford, and Alvin R. Leonard)

	Thickness, feet
Quaternary—Pleistocene	
12. Silt and sand, tan	8.0
Tertiary—Pliocene	
Ogallala formation	
11. Quartzite, fine-grained, dense, green	1.5
10. Sand, massive, green and red; contains fragmentary Mastodon tooth	5.0
9. Quartzite, fine-grained, fairly well cemented, green	1.0
8. Sand and silt, massive, green, spotted and streaked with calcium carbonate	3.0
7. Silt and sand, massive, partly silicified, hard, light-gray	1.5
6. Sand, silty, massive, tightly cemented with calcium carbonate; weathers to a deeply etched surface of vertical columns and horizontal sheets	1.0
5. Sand, fine, and silt, green; speckled with calcium carbonate	2.5
4. Quartzite, fine-grained, lenticular, light-green	1.5

	Thickness, feet
3. Silt and fine sand, partly covered, light greenish-gray, weathers to ash-gray; contains few nodules of calcium carbonate	2.5
2. Sand, fine and silt, indistinct bedding, very light greenish-gray, weathers to platy and nodular surface; loosely cemented throughout with calcium carbonate; forms indistinct bench along near-by canyon side	4.5
1. Silt, sandy, calcareous; contains calcium carbonate in irregular nodules and stringers; upper part more clayey, darker gray, contains less carbonate	6.0
Total section measured	38.0

QUATERNARY SYSTEM (PLEISTOCENE SERIES)

The unconsolidated deposits of Quaternary age are the most important water-bearing rocks in this area. They are the surficial rocks over the greater part of the mapped area (Pl. 1) and are the source of virtually all water supplies of the valley area. Under the classification system used in this report (that of the State Geological Survey of Kansas), the Pleistocene Series includes the entire Quaternary System. The Pleistocene deposits in the area covered by this report are the Meade formation, Sanborn formation, terrace deposits, and alluvium. The Meade does not crop out in this area; the areal distribution of the other formations is shown on Plate 1. The relation of these rocks to each other and to the Cretaceous bedrock formations is shown on Plate 3.

Meade Formation

Character.—Deposits classed as Meade formation are found south of North Solomon River southwest of Portis, north of the river east of Harlan, and north of Cedar Creek in western Smith County. These beds are remnants of stream deposits of an ancestral phase of North Solomon River and have a high terrace relation to the modern valley. Other remnants of stream deposits which cap the hills north and south of Downs have a similar topographic position and relation to younger beds and may also be Meade formation. Some of the high terrace sand and gravel underlying the silts of the Sanborn formation in western Phillips County may belong to the Meade formation instead of to the Crete sand and gravel member of the Sanborn as indicated on Plate 3. The Meade has not been recognized in that area, but it is known to be present along the North Solomon Valley in southern Norton County. In northern Osborne County (Pl. 8) the Meade consists of coarse cross-bedded gravel that grades upward into sand overlain by silt and sandy silt containing fossil snails, which were identified by A. B.

Leonard (personal communication) as diagnostic of the Sappa member of the Meade formation.

Measured section of Pleistocene deposits in a gravel pit in the NW¼ sec. 11, T. 6 S., R. 13 W., Osborne County

	Thickness, feet
Quaternary—Pleistocene	
5. Colluvium; gravel, clay, and silt, intermixed and overlain by red-brown silt to top of vertical cut	6.0
Meade formation	
4. Silt and clay, massive, calcareous, gray; contains snails; upper part leached, blocky clay resembling the lower part of a soil profile. Beveled to the north and overlain uncomfortably to the south by colluvium	1.5
3. Clay, silty, jointed, hard, gray-green; contains abundant snails of Yarmouthian age	3.5
2. Sand, silty, poorly stratified, hard, gray; contains snail and clam shells	1.8
1. Gravel, cross-bedded, coarse at base, grading upward into sand and gravel; contains much local material. To base of gravel pit	16.0
Total section measured	28.8

Frye, Swineford, and Leonard (1948) correlated the Meade formation from the type locality over a wide area in Kansas and the Great Plains and showed the formation to be of Kansan age. Deposits of Pearlette volcanic ash are exposed near Kensington in Smith County and along Bow Creek in southwestern Phillips County. These deposits may be continuous with the Meade deposits along North Solomon River and form an integrated drainage pattern of Kansan age.

Except in artificial cuts for highways and gravel pits, the Meade formation does not crop out in this area, but its character and relation to younger deposits have been determined from several test holes. The Meade has been mapped (Pl. 1) with the overlying Sanborn formation.

Water supply.—Most of the Meade deposits in this area are of small extent and lie above the water table. North of Cedar Creek in Smith County and southwest of Portis in Osborne County, these deposits are of sufficient lateral extent to serve as local acquifers; however, only one well (4-14-28cb) obtaining water from these deposits was inventoried during this investigation. The relation of the Meade formation to the adjacent Crete deposits suggests that water moves from the higher Meade into the Crete, then into and through the terrace deposits, and into the channel of North Solomon River (Pl. 3).

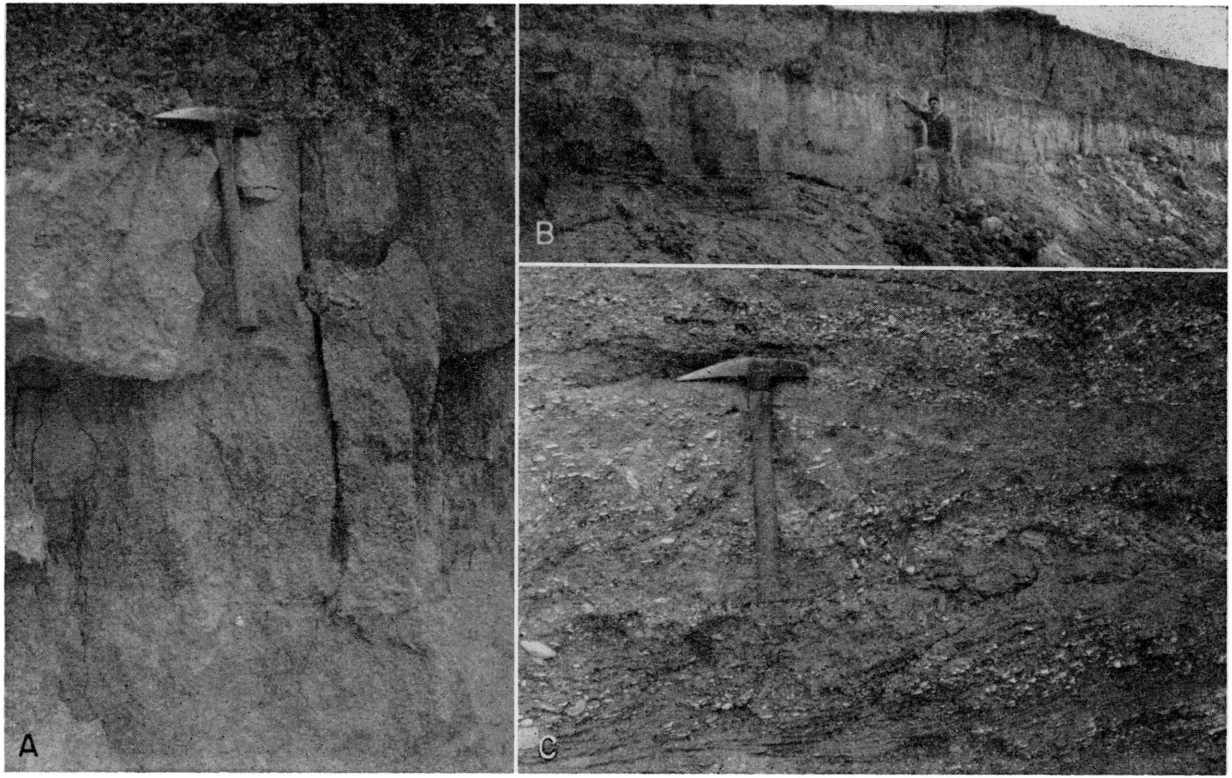

PLATE 8. Meade formation in gravel pit in the NW¼ sec. 11, T. 6 S., R. 13 W. **A**, Close-up of silt in the upper part of the Meade formation overlain by colluvium. Crumby-textured deposit below hammer is pond silt containing snails. **B**, Silt of the Meade formation overlying cross-bedded gravel. Man's hand indicates top of silt beneath colluvium. **C**, Close-up view of cross-bedded gravel in lower part of the Meade formation.

Sanborn Formation

Character.—Elias (1931, pp. 163-180) noted thick deposits of silt and other unconsolidated Pleistocene material in northwestern Kansas and named these deposits the Sanborn formation from a locality in northwestern Cheyenne County, Kansas, south of the town of Sanborn, Nebraska. Later studies by Frye and others have shown that the Sanborn in most of north-central Kansas consists of wind-deposited silt or loess. In 1947, Frye and Fent divided the formation into several members, in ascending order: Loveland silt, Peoria silt, and Bignell silt. This classification was modified in Norton County by Frye and Leonard (1949) who applied the name Crete to the sand and gravel member which underlies the Loveland silt, forms a high terrace in this area, and is overlain by the younger silts. All four subdivisions have been recognized in this area and the fourfold classification will be used in this report.

The oldest deposit of the Sanborn formation in this area is the Crete sand and gravel member, which represents channel fills of Illinoian age (Pl. 9C). During the time when these beds were being formed, the ancestral North Solomon River followed a course parallel to the present valley. Crete deposits consist of stream-deposited coarse sand and fine gravel from 30 to 50 feet thick, which form a high terrace above the present stream. These deposits grade upward into sandy and poorly stratified silt, classed as Loveland silt member, which grades laterally into eolian silt mantling the upland surface.

Measured section of the Crete and Loveland members of the Sanborn formation in the SE¼ sec. 26, T. 4 S., R. 14 W., Smith County

	Thickness, feet
Quarternary—Pleistocene	
Sanborn formation	
Loveland silt member	
6. Silt, sandy, light-gray, weathers whitish gray; contains more sand near base; upper 2 feet is darker "soil zone" which forms "high terrace" surface	15.0
5. Silt and fine sand, reddish-buff	6.0
4. Sand, silty, very fine, light-buff; contains thin lenses of silty clay	7.5
Crete sand and gravel member (?)	
3. Sand, fine, silty, with stringers of clay and fine gravel; contains small snail shells	7.0
2. Clay, silty, buff, lenticular; average thickness	0.7
1. Sand, fine; contains stringers of fine chalk pebbles and silt; base at level of Beaver Creek flood plain	3.5
Total section measured	39.7

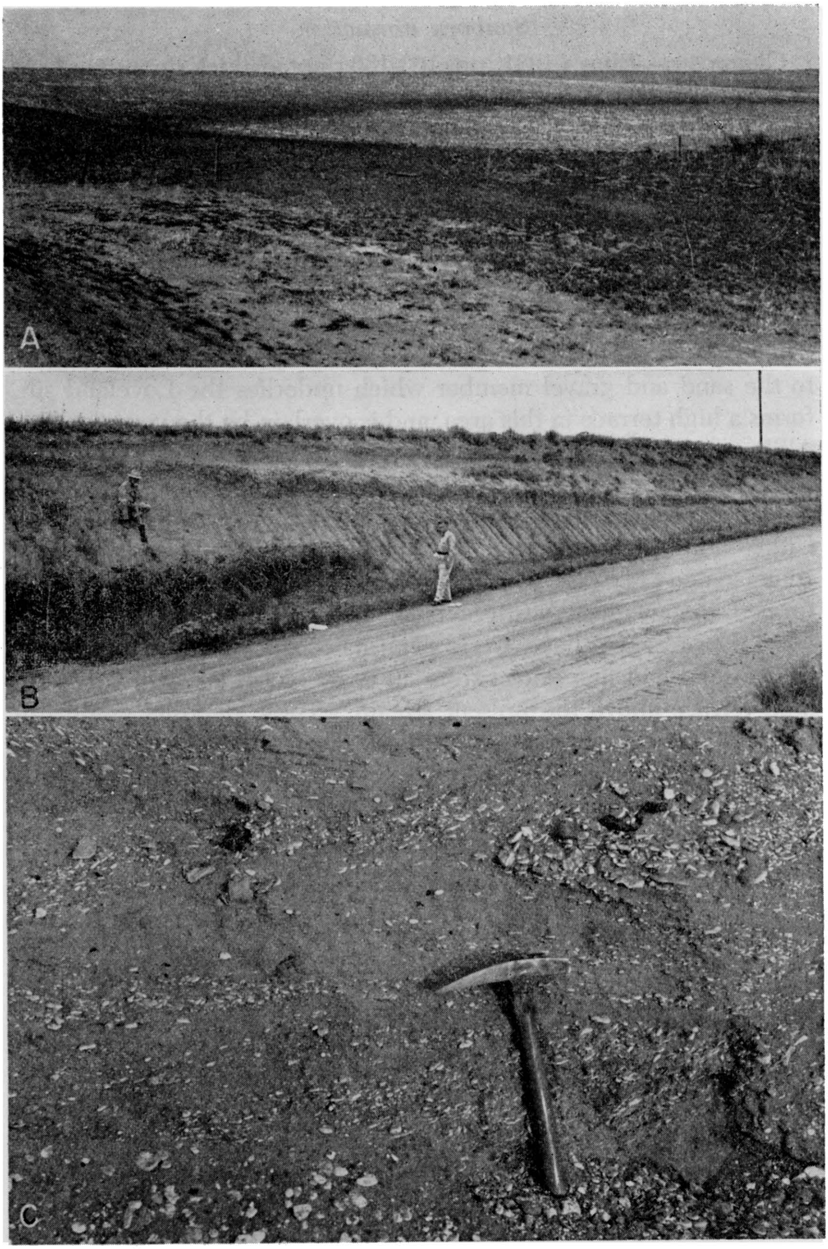

PLATE 9. Deposits of the Sanborn formation. **A**, Soil zone of the Loveland silt member of the Sanborn formation in plowed field in the SW¼ sec. 20, T. 4 S., R. 16 W., Phillips County. **B**, Bignell silt, Brady soil, and Peoria silt in road cut in the SW¼ sec. 24, T. 4 S., R. 19 W., Phillips County. **C**, Cross-bedded sand and gravel of the Crete member in river bank in the SW¼ NW¼ sec. 26, T. 5 S., R. 13 W., Smith County.

The Loveland silt member may be from 10 to 20 feet thick along the valley margins where it overlies the Crete member, but it is generally less than 10 feet thick where it overlies Cretaceous rocks in the upland areas. The Loveland is composed of fine-grained slightly calcareous well-sorted silt, and contains a well-developed fossil soil profile at the top. This soil is well exposed in road cuts and in freshly plowed fields adjacent to the valley (Pl. 9A). It may be as much as 3 feet thick; the upper part contains organic material and is dark brown. The lower part of the soil profile contains an accumulation of clay and has a prominent red color, which may extend all the way through the member. In many places caliche nodules are concentrated below the base of the soil zone.

The upper part of the soil zone grades into the overlying Peoria silt member. This member has been widely correlated in Kansas, Nebraska, and Iowa with deposits of early Wisconsinan (Iowan) age in the glaciated area. Swineford and Frye (1951) have shown that the flood plains of Platte and Republican Rivers are the source areas for the Peoria loess. Large quantities of fine material accumulated on the flood plains of these glacier-fed streams and were carried over a large area of the High Plains by strong northwesterly winds. In the North Solomon Valley area, the Peoria member is represented by about 15 feet of yellowish-gray well-sorted calcareous silt which extends in an almost unbroken blanket over the upland and overlaps the lower-lying terraces developed on Meade and Crete deposits. In many localities along the larger tributary streams, erosion has removed the entire thickness of Peoria silt, has cut through the Loveland soil, and has exposed the underlying Loveland silt member.

In general, the Peoria silt member is the youngest deposit on the upland bordering the North Solomon Valley. At a few localities, the top of the Peoria member is marked by a moderately developed fossil soil (Brady soil) and is overlain by as much as 5 feet of gray silt, the Bignell silt member. The only locality where the Bignell was observed in the mapped area (Pl. 1) is just north of Speed, in Phillips County. At this locality, about 5 feet of light-gray silt overlies a well-developed soil zone at the top of the Peoria silt. The upper part of the following section of Pleistocene deposits is shown in Plate 9B.

Measured section of Pleistocene deposits in the SW¼ SW¼ sec. 24, T. 4 S., R. 19 W., Phillips County

	Thickness, feet
Quaternary—Pleistocene	
Sanborn formation	
Bignell silt member	
4. Silt, light-gray. Fills a shallow depression and thins to north and south; maximum	5.0
Peoria silt member	
3. Silt, fossiliferous, light yellow-buff; contains black clayey, sandy soil zone (Brady fossil soil) at top and slight caliche accumulation 2 feet below top; average	11.0
Loveland silt member	
2. Silt, calcareous, reddish-buff; contains much chalk material in lower part. Upper 4 feet is fossil soil zone, clayey, dark chocolate-buff	8.0
Cretaceous—Gulfian	
Niobrara formation	
Smoky Hill chalk member	
1. Shale, chalky, soft, yellow-buff, deeply weathered	...
Total Pleistocene section	24.0

The topographic position and fine-grained character of these deposits indicate that the Bignell is an eolian silt. The Nebraska Geological Survey (Condra, Reed, and Gordon, 1947) classifies the Bignell loess as of latest Wisconsinan age. In this area it represents the youngest upland eolian deposit and may be in part of Recent age.

Water supply.—Throughout much of this area the Sanborn formation consists of a thin layer of wind-deposited silt, which overlies Cretaceous rocks. The Sanborn is an important source of ground water only where the basal Crete sand and gravel member is present along major valleys. In the upland areas of northeastern Osborne County, east of Harlan and north of Cedar Creek in Smith County, and adjacent to the valley in western Phillips County, many good farm wells derive their water from this formation. At these localities the Crete member forms a high terrace above the present valley and water moves from these deposits into the lower-lying terrace deposits in the main part of the valley. Analyses of water samples from the Crete member are given in Tables 8 and 12, and are shown graphically in Figure 16. Although water in these rocks contains appreciable amounts of most minerals, it is satisfactory for all domestic uses.

Terrace Deposits

Character.—Not only is the broad, low terrace along North Solomon Valley the most prominent physiographic feature in the mapped area (Pl. 4), but the deposits underlying this terrace surface constitute the most important aquifer in the area. The deposits underlying the Kirwin terrace surface represent essentially a single cycle of valley cutting and filling, although minor irregularities in the terrace surface suggest a complex of several partly developed alluvial cycles.

In general, the terrace surface throughout this area is underlain by 30 to 90 feet of unconsolidated deposits, which probably represent a single cycle of stream deposition. Test-hole data show that the Cretaceous bedrock beneath the terrace fill is immediately overlain by moderately sorted gravel, which grades upward into sand and gravel. This material is composed of Rocky Mountain type sand and gravel derived from the Ogallala formation in the headwaters of North Solomon River and intermixed with a small amount of material derived from local rocks of Cretaceous age. The coarser deposits grade upward into sandy silt and stratified silt in the upper part of the terrace fill. Good exposures of the upper 30 feet of the terrace deposits in cut banks along North Solomon River indicate that the silt beds are interstratified with thin lenticular beds of silty clay. The thickness of the finer-grained deposits is from 30 to 40 feet. One or more dark humic bands in the upper 6 feet of the terrace fill probably represent poorly developed soil zones that were buried by younger flood-plain deposits in the closing stages of the terrace cycle.

The terrace deposits are probably of late Wisconsinan age, because they fill a well-developed valley that is incised considerably below the older Crete and Loveland stream deposits along the valley margins. The Peoria silt member of the Sanborn formation is apparently truncated along the valley walls, but its relation to the terrace deposits is not clear. No Peoria silt has been found overlying the terrace, but the upper silts in the terrace fill may correspond to the Bignell silt member of the uplands. The relation of the terrace to the channel of North Solomon River and its principal tributaries indicates the extreme youth of the terrace. The streams do not have fully developed meander belts but have meanders that are incised into the terrace surface. At many places along these streams, narrow peninsulas and islands of terrace deposits project into the meander loops (Pl. 1). These meanders, moving downstream, will eradicate the projections of terrace material and, in a short span of geologic time, will establish a meander belt of uniform width without the present incised character. Probably the present cycle of downcutting represents only a part of Recent time, and the terrace deposits are, in part, of Recent age.

Water supply.—The terrace deposits are the most important water-bearing material in this area. The coarse-textured sand and gravel in the base of the terrace fill is quite permeable and lies below the water table. The broad, nearly flat terrace surface constitutes a large recharge area and additional recharge is furnished by streams that head in the near-by hills of Cretaceous rocks and cross the terrace surface in shallow poorly developed channels. Where saturated deposits of the Crete sand and gravel member are found adjacent to the valley, they form a continuous hydrologic system with the lower-lying terrace deposits and water thus moves from the upland into the valley. Ground water moves laterally through the terrace deposits and into the alluvium or into the channel of North Solomon River. More than half the wells for which records are given in Table 15, including those supplying the cities of Logan, Speed, Kirwin, Smith Center, Gaylord, Portis, and Downs, obtain water from the terrace deposits. Well 5-14-1ca2 had the largest reported yield, 323 gallons per minute when test-pumped for 4 hours in 1940. Hydrologic data for the wells tested are given in Table 4. The chemical character of water from the terrace deposits is given in Tables 7, 8, and 11 and shown graphically in Figure 16.

Recent Alluvium

Character.—The area mapped as alluvium (Pl. 1) consists of the flood plain of North Solomon River and its principal tributaries. It is not possible, with the mapping scale used, to show the alluvium along the smallest streams. Along the North Solomon Valley the flood plain is from one-tenth to one-half a mile wide and lies at an altitude of 15 to 25 feet below the level of the Kirwin terrace and 12 to 16 feet above the water level of the river. Segments of one or two poorly developed terrace levels in the flood plain area suggest partly developed alluvial cycles, although the Recent alluvium probably represents only a single major cycle of cutting and filling. At many places in the North Solomon Valley the alluvium lies in a narrow valley that is cut through the terrace deposits into Cretaceous rocks. In other places the alluvium fills a channel that is cut into these deposits (Pl. 3).

TABLE 4.—*Hydrologic data for wells that have been test-pumped*

WELL NO.	Well owner	Date of pump test	Depth to water, feet	Discharge, gallons a minute	Length of pump test, hours	Drawdown, feet	Specific capacity, gals. per min. per foot of drawdown
4-18-26da4	R. I. R. R. no. 4	1943	21	275	24	23	11.96
4-18-26cc1	Phillipsburg no. 1	1944	17 ±	175	8	35	5.00
4-18-26cc2	Phillipsburg no. 2	1944	17 ±	200	8	38	7.90
4-18-26cc3	Phillipsburg no. 3	1944	15	200	8	36	8.33
5-14-1ca1	Gaylord (new well)	1946	25 ±	150	....	9 ±	16.67
5-14-1ca2	Smith Center no. 3	1940	43	323	4	21	15.38
6-11-28a2	Mo. Pac. R. R.	1937	35	70	3	5	14.00

At several places in the flood plain in Phillips County, the wind has piled up sand from the alluvium into dunes (Pls. 1, 4D). South of the river near Logan, on both sides of the river 3 miles east of Logan, and north of the river 6 miles west of Kirwin, thin layers of wind-drifted sand cover the terrace surface.

Only the upper part of the alluvium is exposed along the river channel, but its thickness and character are known from several test holes that penetrated these deposits. The alluvium consists largely of coarse sand and gravel intermixed with a small amount of silt and in places contains thin layers of clay. The coarse materials at the base of the alluvium grade upward into finer sands and silt near the flood-plain surface. Along the river the alluvium ranges in thickness from 25 to 50 feet, but it may be considerably thinner in the small tributary streams a short distance from the river. The alluvium of these minor streams contains a large percentage of material derived from the Cretaceous rocks into which they are incised; it is generally poorly sorted, and may have a low permeability. Although they are poor aquifers, these deposits are the only water-bearing beds present in local areas.

The North Solomon Valley alluvium is the stream-deposited material that has accumulated since the close of the alluvial cycle during which the broad Kirwin terrace was formed. The alluvium is entirely of Recent age, and represents only a slight reworking of older material. More alluvium is added when floods rework alluvial material and deposit new material on the flood plains.

Water supply.—The water table in the Recent alluvium is continuous with the water table in the terrace deposits and with the water level in the flowing streams in the area. The alluvium lies largely below the water table, and the coarse nature of the alluvial deposits makes them an important potential source of ground water. Along the North Solomon Valley, only a few wells tap these deposits, because the area where the alluvium is at the surface is subject to floods. A few stock wells and, near Glade, the Phillipsburg municipal wells and the Rock Island Railroad wells obtain water from these beds. In the upland adjoining the valley, where the Cretaceous rocks lie near the surface, the only available water supplies are in the alluvium of minor tributary valleys. In these areas even the alluvial wells frequently go dry during prolonged periods of drought. Chemical analyses of water from wells in the Recent alluvium are given in Tables 8 and 10, and are shown graphically in Figure 16.

GEOLOGIC HISTORY AND GEOMORPHOLOGY

PRE-PLEISTOCENE GEOLOGIC HISTORY

The oldest rocks exposed at the surface in the area covered by this report are shales of late Cretaceous age. The history of geologic events that preceded the deposition of these rocks is known partly from the records of deep tests for oil and partly from surface exposures of the deeply buried rocks east of this area. The oldest known rocks beneath this area are the Pre-Cambrian crystalline rocks that have been penetrated at depths of 3,800 to 4,000 feet in western Phillips County. A long period of erosion followed the formation of these rocks. The first rocks deposited after this erosion interval were marine sandstones, then a thick series of other marine rocks. At intervals the area was warped, raised above sea level, subjected to erosion, and later covered again by the sea. The youngest Paleozoic marine sediments beneath this area are the series of alternating shale and limestone of Permian age that is overlain by "redbeds." The redbeds record a late Permian interval of deposition in a great inland sea in which shale, siltstone, and evaporites accumulated.

After the formation of the redbeds, the area was again raised above sea level and subjected to a long period of subaerial erosion, which lasted throughout Triassic, Jurassic, and early Cretaceous time. Near the close of early Cretaceous time, the sea again covered the area, and marine sandstone and shale were deposited on the eroded surface of Permian rocks. At the beginning of late Cretaceous time, the sea withdrew somewhat and the sandstone and clay of the Dakota formation accumulated under near-shore conditions. The sea again covered the land, and the thick section of upper Cretaceous shale, chalk, and limestone that forms the bedrock in this area was deposited. At the close of Cretaceous time the sea withdrew from the plains region, and a continental environment has existed since that time.

During most of Tertiary time, western and central Kansas were subjected to subaerial erosion and great quantities of Cretaceous rocks were stripped off. The effect of this erosion was to bevel the Cretaceous rocks so that their upper surface slopes eastward. More than 1,000 feet of Cretaceous rocks still remain beneath western Phillips County, but only about 400 feet remain in western Mitchell County. By late Tertiary time, north-central Kansas was an area of low relief characterized by smooth gentle divides and broad valleys. During Pliocene time, the streams from the Rocky Mountains that crossed this area spread an apron of alluvial debris on the eroded surface of Cretaceous rocks. The irregularities of the bedrock surface were leveled, and as the streams shifted back and forth across the area, they built up an eastward-sloping alluvial plain, which may have extended from the Rocky Mountains nearly to the Flint Hills. As much as 300 feet of material (the Ogallala formation) was deposited in Norton County and westward, but these deposits thin rapidly eastward and only a few inches of Tertiary sediments cap the upland in Mitchell County. At the close of Tertiary time these sediments formed a nearly featureless eastward-sloping plain that was marked with small water-table lakes in which the fresh-water "Algal limestone" of the Ogallala formation was forming.

PLEISTOCENE GEOLOGIC HISTORY AND GEOMORPHOLOGY

The events that formed the present topographic features began with the close of "Algal limestone" deposition and the beginning of Pleistocene erosion. During early Pleistocene time, streams formed on the plain of the Ogallala formation and began to cut their way into and through this unconsolidated material. No deposits of Nebraskan age have been identified in this area, and the exact events that took place during that interval are unknown. The history of erosion during that time is inferred from the known record of the same interval elsewhere in Kansas. By Kansan time, major streams had been formed and the approximate pattern of modern drainage was established. These streams had intrenched their valleys to a level less than 100 feet above the greatest bedrock incision beneath the present valley. The deposits left by the Kansan streams are remnants of coarse channel deposits (Meade formation) that are found at several localities in this area. Figure 3, which shows generalized profiles of the Pleistocene deposits from localities in southern Norton County to Osborne County, suggests that the stream that deposited the Meade had a gradient across Phillips County equal to the gradient of the younger terrace deposits but that the gradient flattened somewhat in Osborne County. The relation of these beds to younger stream deposits is shown in Plate 3.

A period of pronounced erosion and downcutting followed the deposition of the stream deposits of the Meade formation. During this interval, the ancestral Solomon River intrenched its valley about 50 feet below the base of the Meade deposits. The stream deposits of late Illinoian (Crete) age fill a bedrock channel that has a gradient equal to that of the Meade across Smith County, but which is somewhat steeper upstream and somewhat reduced downstream. Deposits of the Crete sand and gravel member of the Sanborn formation overlie the gravel of the Meade in Norton County and may be channeled into the Meade in western Phillips County, although the older beds have not been identified there. Valley floors that were being aggraded during this interval probably were the source of the loess of the Loveland silt member of the Sanborn which was spread over a wide upland area by the wind. Late Sangamonian time was apparently a period of essential equilibrium when very little erosion took place and which was ideal for the formation of the well-developed soil of the Loveland.

During earliest Wisconsinan time, the older deposits were dissected by erosion and the main valley was lowered. Channel deposits overlying the bedrock have been penetrated by test drilling. In general, the terrace deposits seem to represent a single period of cut and fill, but test holes through these deposits near Glade and west of Downs have penetrated gravel immediately above the bedrock that seems to differ from the overlying gravel deposits. This gravel may represent deposits of early Wisconsinan age that are not present throughout the entire area. The only positively identified deposit of this age is the Peoria loess, which blankets the upland. This silt was picked up by the wind from the flood plains of the Platte and Republican Rivers and spread in a broad sheet across northwestern and north-central Kansas.

The interval following the deposition of the Peoria silt was marked by erosion of the uplands and by cutting of the principal bedrock valley, in which the younger terrace deposits accumulated.

The bedrock surface was cut 30 to 60 feet below the deepest part of the Crete channel. Accumulation of the terrace fill beneath the Kirwin terrace surface was either contemporaneous with the cutting of the bedrock channel or soon after this period of erosion. The top of these deposits is a smooth, relatively undissected surface, which has a gradient across Phillips and western Smith Counties similar to the gradient on the Meade deposits (Fig. 3). The gradient is decreased somewhat near Cedar as if the resistant Fort Hays limestone member had lessened downcutting at that point, but downstream from Cedar the terrace has a steeper gradient than either the Meade or the Crete deposits.

The deposition of the terrace fill sediments beneath the Kirwin terrace surface probably took place in the last part of Wisconsinan time and in part of early Recent time. Evidence for the extreme youth of this terrace is presented in the stratigraphic discussion of the deposits. After this period of deposition, North Solomon River was again rejuvenated and incised its channel 30 feet or more into the terrace deposits. At some places (Pl. 3) the stream overlies a narrow channel cut into bedrock and filled with alluvial material, which is probably of Recent age. In other places the modern channel and flood plain overlie relatively high bedrock ridges which indicates that the stream has cut a channel into the terrace fill only during the latest cycle of downcutting. This cycle is clearly in an early stage of development, and the stream can be expected to broaden its flood plain, establish a meander belt, and probably cut a deeper bedrock channel before the cycle is completed.

GROUND WATER

Principles of Occurrence

The following discussion of the principles governing the occurrence of ground water has been adapted from the excellent discussion by Meinzer (1923), and the reader is referred to his report for a more complete discussion of the subject. A summary of the occurrence of ground water in Kansas has been made by Moore and others (1940).

Nearly all the rocks that immediately underlie the surface of the earth contain open spaces or interstices, which may contain water or other fluids. The number, size, shape, and arrangement of these openings are controlled by the character of the rock so that the occurrence of ground water is determined by the geology of the region. These openings in the rocks may range in size from microscopic pores or interstices to the huge caverns sometimes found in limestone regions. If the open spaces are connected, water can percolate from one to another, but sometimes these open spaces are isolated and there is relatively little movement of water. Some of the more prominent types of open spaces and the relation of rock texture to porosity are shown in Figure 7.

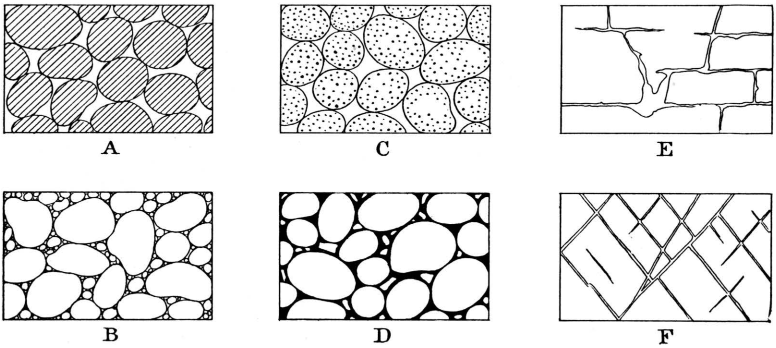

FIG. 7.—Diagram showing several types of rock interstices and the relation of rock texture to porosity. **A**, Well-sorted sedimentary deposit having a high porosity; **B**, poorly sorted sedimentary deposit having low porosity; **C**, well-sorted sedimentary deposit consisting of pebbles that are themselves 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.)

In central Kansas the source of all ground water is precipitation, which falls as rain or snow. A part of the precipitation may percolate downward through the soil and eventually become ground water. The remainder runs off the surface, evaporates, or is transpired by plants. The proportion of the total precipitation that becomes ground water depends upon a large number of factors, such as the type and porosity of the soil, the permeability of the underlying rocks, the rate of evaporation, and the topography and drainage of the area.

The percentage of the volume of open spaces to the total volume of rock is known as the porosity. When all the porous spaces in a rock are filled with water, it is said to be saturated. The permeability of a rock is its ability to transmit water under a hydraulic gradient. A rock made up of very small particles may contain a large volume of openings, but because the openings are small, the rock may have a very low permeability even though the porosity is high. Similarly, larger openings that are not interconnected may result in a high rock porosity and a low permeability. If both the porosity and the permeability are high, water can move freely through the rock and the rock is a good aquifer.

In the North Solomon Valley, the Cretaceous rocks are somewhat porous but are composed predominantly of very fine-grained material and have small openings that are poorly connected. These rocks have a low permeability and are of no importance as aquifers in this area. In contrast the alluvial material comprising the gravels of the Meade formation, the Crete sand and gravel member of the Sanborn formation, the terrace deposits, and the alluvium of the major valleys is composed of relatively coarse, moderately sorted sediments that have both a high porosity and a high percentage of interconnected openings. These rocks have a relatively high permeability compared to the Cretaceous rocks.

THE WATER TABLE AND MOVEMENT OF GROUND WATER

The water table is defined as the upper surface of the zone of saturation in ordinary porous rock (Meinzer, 1923a, p. 32). If the upper surface is formed by a layer of impermeable rock, the water table is absent and artesian conditions exist. Actually, the water table is not a plane surface but is generally a sloping surface, which has irregularities caused by differences in the permeability of water-bearing material, by unequal additions or withdrawals of ground water, or by irregularity of the land surface. The water table does not remain stationary but fluctuates in response to additions to or withdrawals from water in storage.

Plate 2 shows the location of all water wells in which the depth to water was measured, the location of test holes drilled by the State Geological Survey, the altitude of the water surface with respect to sea level at various points along the channels of the major streams; and contours on the water table. Water-table contours are not shown in the areas of Cretaceous rocks because the general water table occurring in the valley area does not extend into those areas.

SHAPE AND SLOPE

The shape and slope of the water table in the area covered by this report is shown on Plate 2 by means of contours. Each point on the water table on a given contour line is at the same altitude. Thus, the water-table contours show the configuration of the water surface in the same way that topographic contours show the shape of the land surface. The direction of ground-water movement is at right angles to the contour lines in the down-slope direction.

Plate 2 indicates that ground water moves down the valley from the west toward the east. Along the valley sides it moves also toward the center of the valley. The map shows, by contours close together, many places along the sides of the valley where the water table slopes more steeply than in the center of the valley. These steeper gradients are probably a reflection of the lower permeability of the rocks along the valley sides where the water-bearing sediments contain more fine-grained material derived from the Cretaceous rocks than is found in the central parts of the valley. It should be noted also that the general downstream movement of the ground water in the valley varies throughout the area. In western Phillips County, the downstream slope of the water table is at the rate of about 11.5 feet per mile, whereas near Kirwin it is about 6.4 feet per mile and near Downs it is a little less than 5 feet per mile.

Wells that draw large quantities of water from the ground-water reservoir may cause local depressions in the water table. As indicated on the water-table contour map (Pl. 2), the city well at Portis is the only one of the larger wells that seems to have created a local depression.

RELATION TO GEOLOGY

In many respects, the rate and direction of ground-water movement are controlled by the geology. It has already been stated that the general water table that lies under the main part of the valley does not extend into the Cretaceous rock that forms the valley walls. Furthermore, where the terrace deposits along the sides of the valley contain a considerable amount of locally derived material and are not well sorted, the gradient of the water table is much greater than in the coarser, better-sorted materials in the central part of the valley. Although it is not apparent on Plate 2, the materials that compose the Crete member of the Sanborn formation generally are finer than the younger terrace deposits; hence the ground-water movement through them is slower, and the gradient is probably steeper than it is in the terrace deposits. In a few localities, the water table may be in the Sanborn loess or in the upper silty part of the terrace deposits, which are still finer-grained and where movement of ground water is still slower. In some places under the main part of the valley, as in sec. 28, T. 4 S., R. 17 W., hills of Cretaceous rocks buried beneath the alluvial materials extend above the water table. Wells in these localities have not yielded ground water.

RELATION TO TOPOGRAPHY AND DRAINAGE

The water table generally reflects the surface topography; thus, the downstream gradient of the water table is approximately equal to the downstream slope of the terrace surface, and where unconsolidated deposits form the walls of the valley, the water table extends into them. The water table near the valley walls generally has a greater slope than in the central part of the valley and reflects in a subdued way, the steepness of the valley walls. The depth to water in each well in the valley area is shown on Plate 2.

The most important features affecting the water table in this area are the streams. The North Solomon River and Bow Creek are the only perennial streams in this area. The major tributaries, Deer Creek, Madison Creek, Cedar Creek, Beaver Creek, Spring Creek, Dry Creek, and Lawrence Creek, are intermittent streams that flow except during prolonged dry seasons. All other streams are ephemeral, that is, they flow only in response to precipitation. Most ephemeral streams lie above the water table, and when they flow, probably contribute some water to the ground-water body. Figure 8, prepared by Latta (1944) to illustrate the Arkansas River, indicates the relation to the water table of both influent and effluent streams. Figure 8A is a longitudinal view of an influent stream that in its downstream course intersects the water table and be-

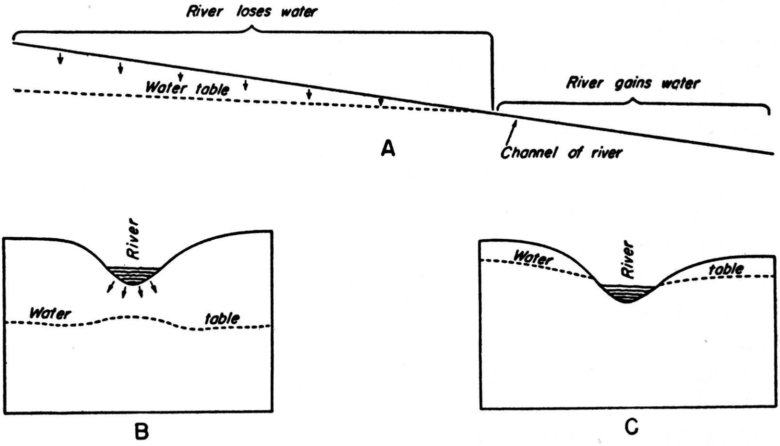

FIG. 8.—Diagrammatic sections showing influent and effluent streams. A, Longitudinal section showing (right) how river gains water and (left) how it loses water. B, Transverse section across influent part of river. C, Transverse section across effluent part of river. (After Latta, 1944, fig. 14.)

comes an effluent stream—that is, a stream that receives water from the ground-water body. Figure 8B is a cross section of a stream that contributes water to the reservoir and shows the mounding effect of the water table beneath such a stream. Most small tributaries probably lose some water to the ground-water body during periods of heavy runoff; however, the resultant mounding effect of the water table is probably small and is not noticeable after the stream stops flowing. Figure 8C is a cross-section of a stream that is gaining water from the water table. The Solomon River and its major tributaries throughout this area are gaining streams; their flow is maintained, in part, by ground water that seeps into them from the channel banks. Consequently the contours on the water-table map (Pl. 2) bend around the streams and each major stream flows in a small ground-water trench. This seepage is the most noticeable feature of the water table in this area and is an important factor in maintaining the flow of North Solomon River.

FLUCTUATIONS OF THE WATER TABLE

The water table does not remain in a stationary position, but fluctuates vertically like the water level of a surface reservoir. The rise or decline of the water table depends upon the amount of recharge into the ground-water reservoir or the amount of discharge from the reservoir. When the inflow exceeds the draft the water table rises and, conversely, when the draft exceeds the inflow the water table declines. If the water-bearing materials have a specific yield of 20 percent, the addition of 1 foot of water to the ground-water reservoir will cause a rise of the water table of 5 feet.

Some of the factors that control the rise of the water table are the amount of precipitation that percolates downward through the soil to the water table, the amount of recharge by seepage from streams that lie above the water table, and the amount of water that moves into the area from upstream. The principal factors controlling the decline of the water table are the amount of water lost from the ground-water reservoir by effluent seepage into the streams, the amount of discharge through transpiration where the water table is within the reach of plants, the amount evaporated directly from the ground-water reservoir where it lies near the surface of the ground, the discharge by pumping within the area, and the amount of water leaving the area through subsurface flow in a downstream direction.

In order to determine the character and magnitude of the water-level fluctuations in this area, 22 wells were selected for observation, and periodic measurements of the depth to water in them were begun in 1945 and 1946. Annual records of these wells are published by the U. S. Geological Survey (Sayre and others, 1949) and fluctuations in some of the wells are illustrated graphically in Figures 9, 10, and 11. Each graph shows the normal precipitation in the area where the wells are located, the monthly precipitation, and the cumulative departure from the normal monthly precipitation.

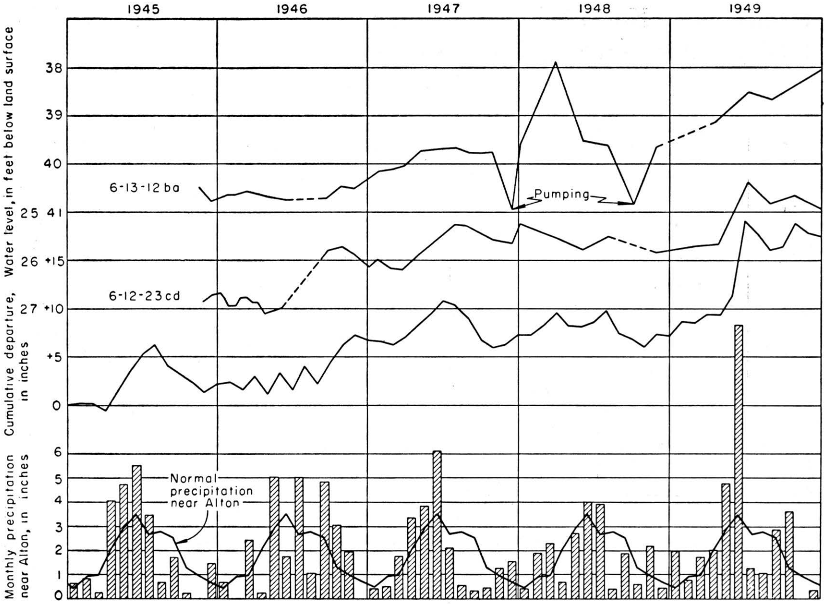

FIG. 9.—Hydrographs showing fluctuations of water levels of two wells in Osborne County and graphs showing monthly precipitation and cumulative departure from normal monthly precipitation near Alton.

RECHARGE

Recharge is the addition of water to the ground-water reservoir, and it takes place in several ways. Ground water that is within a practical drilling depth in the area described in this report is derived from water that falls as rain or snow in this or adjacent area. After the water becomes a part of the ground-water body, it moves down the slope of the water table and is discharged farther downstream.

RECHARGE FROM PRECIPITATION

The normal annual precipitation in this area ranges from about 21.6 to 23.5 inches and averages about 22.5 inches. Probably only a small part of this water reaches the zone of saturation, the remainder being discharged as surface runoff, evaporation and transpiration. The depth to the water table and the character of the material underlying the land surface exert considerable influence on the amount of water that is added to the ground-water reservoir as recharge. Another factor influencing the proportion of precipitation that becomes recharge is the topography of the area. In an area of steep slopes, such as the valley sides, a very small proportion of the precipitation will become recharge. In a flat area, such as the broad terrace along North Solomon River, a much larger proportion of the total precipitation may become recharge.

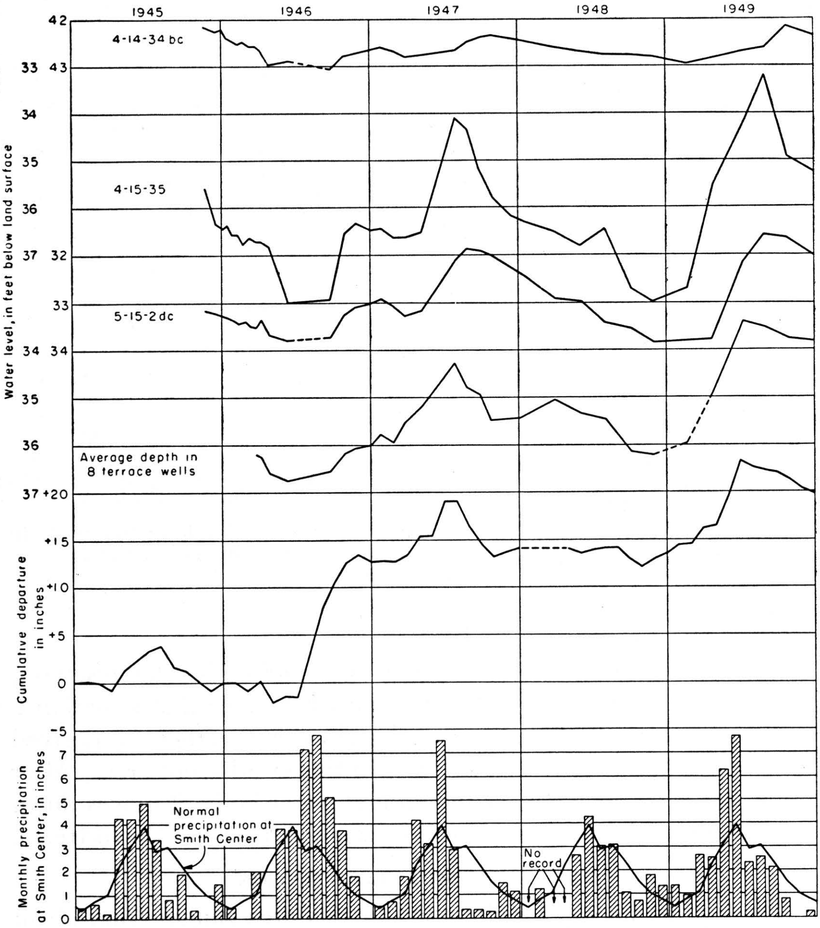

FIG. 10.—Hydrographs showing fluctuations of water levels of several wells in Smith County and graphs showing monthly precipitation and cumulative departure from normal monthly precipitation at Smith Center.

Figure 9 shows the precipitation near Alton, the cumulative departure from the normal near Alton, and the fluctuations of the water level in wells in Osborne County. A direct relation may be seen between fluctuations of the water table and local precipitation. Thus water levels rose during the periods of heavy precipitation in the fall of 1946 and the spring of 1947, whereas they declined during the period of below-normal precipitation in the summer of 1947. The water table rose after the very heavy precipitation of May 1949 and declined during the period of below-normal precipitation during June and July of 1949. Figure 10 shows hydrographs of three wells on the terrace in Smith County, a graph of the

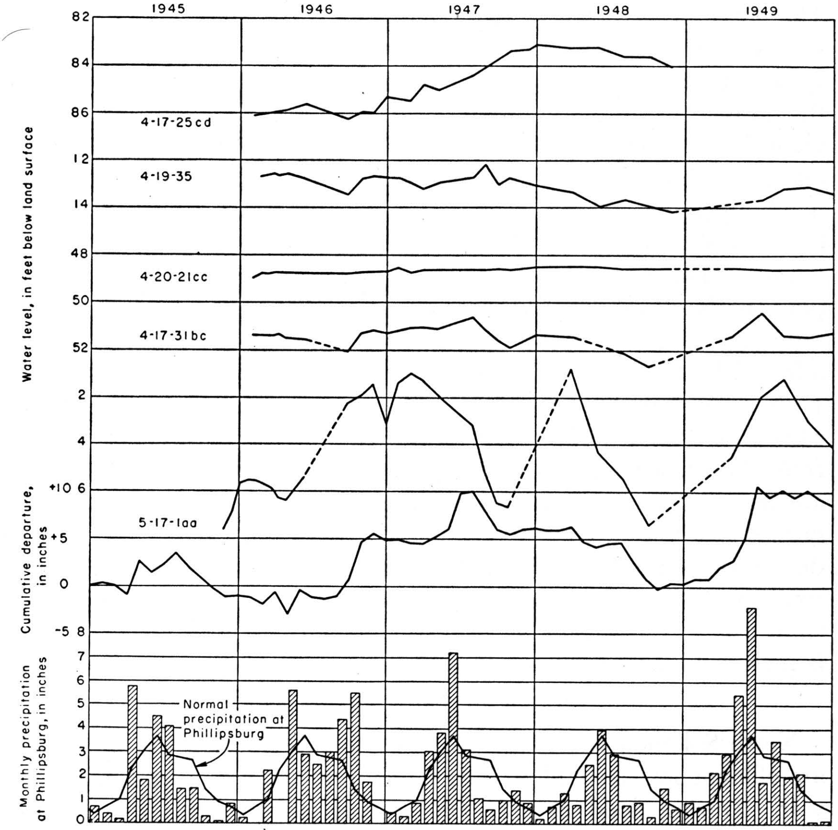

FIG. 11.—Hydrographs showing fluctuations of water levels of five wells in Phillips County and graphs showing monthly precipitation and cumulative departure from normal monthly precipitation at Phillipsburg.

average depth to water in eight terrace wells, precipitation data, and the cumulative departure from normal precipitation at Smith Center. These graphs indicate that the water table rose after heavy precipitation in September and October 1946, in May 1947, and in the late spring of 1949. Water levels declined during the fall of 1947 and the fall of 1948 after periods of below-normal precipitation. The curve of the average depth to water in the eight terrace wells shows a rise in the average water level of nearly 2.5 feet since the spring of 1946. During this period, the cumulative departure from the normal precipitation was nearly 20 inches. Figure 11 shows the water levels in five wells in North Solomon Valley in Phillips County and a graph of the cumulative departure from normal precipitation in Phillipsburg. These wells show effects that are directly related to the precipitation and that are similar to those shown in the other figures. The water level in well 5-17-1aa, which is on the flood plain of North Solomon River, fluctuated considerably more than the water levels in the other wells in the area and is believed to be affected by the water stage in North Solomon River. In November 1946, an automatic water-stage recorder was installed on well 6-11-34aa (Pl. 10C). Small fluctuations of the water level, observed from the records of this well, indicate that part of the fluctuations are due to changes in atmospheric pressure. Several of the hydrographs of different wells indicate that a lowering of the water table during the summer months is probably the result of excessive transpiration. The relation between water levels and precipitation, as shown by the hydographs, suggests that the ground-water reservoir is recharged largely by local precipitation.

RECHARGE FROM STREAMS

North Solomon River and all its principal tributaries in this area are effluent streams and receive water from the ground-water reservoir. During flood periods, the streams may contribute a small amount of water to the ground-water reservoir, but the quantity is small compared to the amount contributed by rainfall. The small tributary streams, which flow only after periods of rainfall, constitute an important source of recharge in this area. Many of these streams head in chalk hills a few miles from the Solomon Valley and carry considerable volumes of water. They have no channels across the terrace surface (Pl. 1) but they discharge water upon it, and a large part of this water percolates downward to the ground-water reservoir.

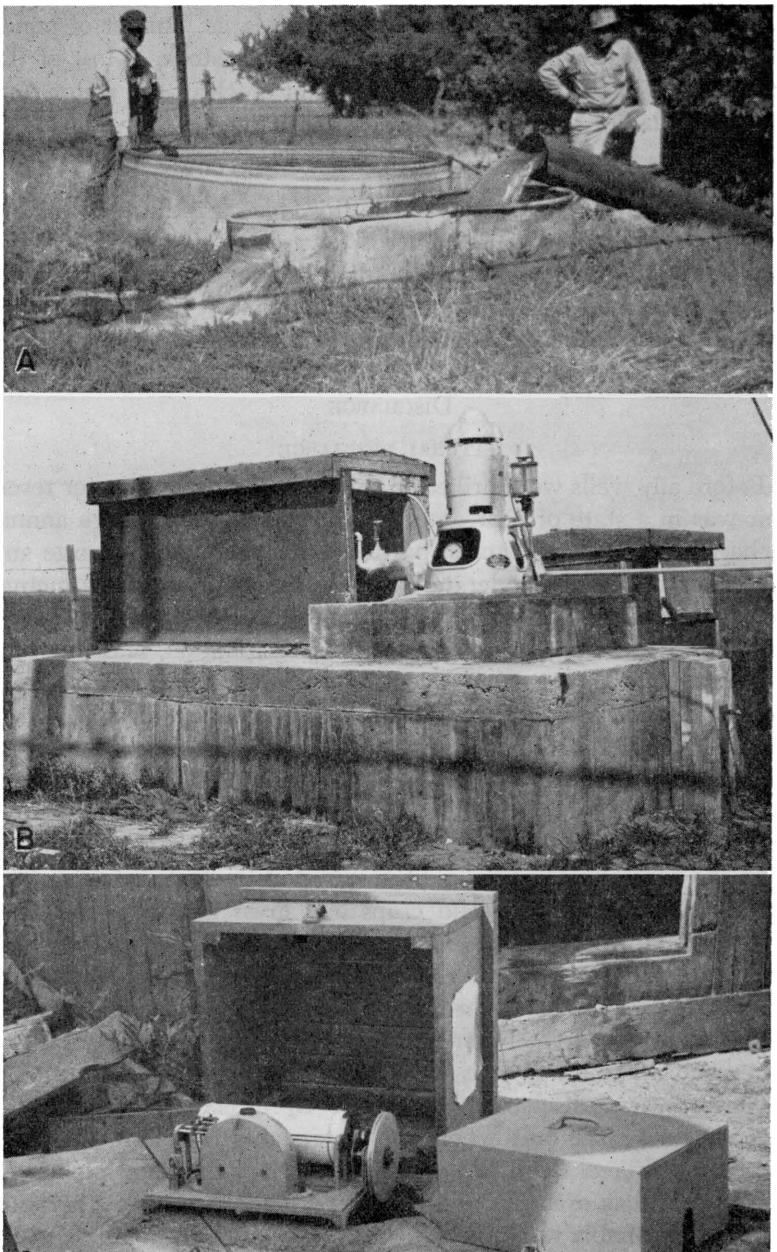

PLATE 10. **A**, Part of Aaron Fink surface-water irrigation plant in operation in the SW¼ sec. 14, T. 6 S., R. 12 W., April 1946. **B**, Phillipsburg municipal well No. 1 in the SW¼ sec. 26, T. 4 S., R. 18 W. **C**, Automatic water-stage recorder on well 6-11-34aa, Osborne County.

In the chalk hills that border the valley a large number of ponds have been constructed to furnish water for livestock. Most of the ponds are located in small tributaries, and much of the water they hold eventually becomes ground-water recharge.

RECHARGE FROM SUBSURFACE INFLOW

The movement of ground water in this area, as indicated on Plate 2 by the slope of the water table, is toward the east and southeast in a downstream direction; hence, a small amount of recharge from the precipitation in parts of the valley to the west moves into western Phillips County and contributes to the available ground-water supply in this area.

DISCHARGE

NATURAL DISCHARGE

Before any wells were drilled in this area, the ground-water reservoir was in a state of near equilibrium; that is, the average annual recharge was nearly balanced by the average annual discharge and the water table was moderately stable except for seasonal fluctuations. Water was added to the ground-water reservoir by movement from the west, by recharge from precipitation, and by seepage from intermittent streams. Ground water was discharged from this area principally by movement to the east, by discharge into North Solomon River and its tributaries, by evaporation, and through transpiration by plants.

One of the principal methods of ground-water discharge in this area is transpiration. Water is taken up through the roots of plants from the zone of saturation and transpired at the leaf surfaces. The limit of lift by ordinary field crops and grass is only a few feet. However, the roots of alfalfa and certain desert plants have been known to penetrate the water table at depths of 60 feet. Alfalfa is a principal farm crop along the terrace in the valley area, and trees line the banks of the major streams; therefore the total discharge of water by transpiration in this area is considerable.

Ground-water discharge occurs also by direct evaporation, but this can take place only where the water table is shallow, as along the banks of creeks and in the narrow parts of the flood plain. As these conditions exist in only a small part of the area, evaporation losses are probably not large.

DISCHARGE FROM WELLS

The pumping of water from wells is now one of the principal means of ground-water discharge. Tables 5 and 6 show that the annual pumpage of ground water for industrial and public supply use amounts to more than 330 million gallons. This pumpage also constitutes ground-water discharge. This is probably several times the total amount pumped from farm wells for domestic and stock use in the valley area, but the total pumpage probably is considerably more than 350 million gallons per year.

RECOVERY

PRINCIPLES OF RECOVERY

When water is standing in a well there is equilibrium between its head and the head of water in the aquifer outside the well. When water is withdrawn from the well, a difference in head is created between the water inside the well and the water in the aquifer for some distance from the well. The water table in the vicinity of the well develops a cone of depression (Fig. 12), which is greatest at the contact with the pumped well and extends some distance around the well. A higher pumping rate in a well produces a greater drawdown (depression of the water table) and the diameter of the cone of influence and the area of influence are increased. Thus, water moves toward the well from a greater distance, under a higher gradient, and at a greater rate. The specific capacity of a well is the rate of yield and is generally stated in gallons a minute per foot of drawdown. It is generally determined

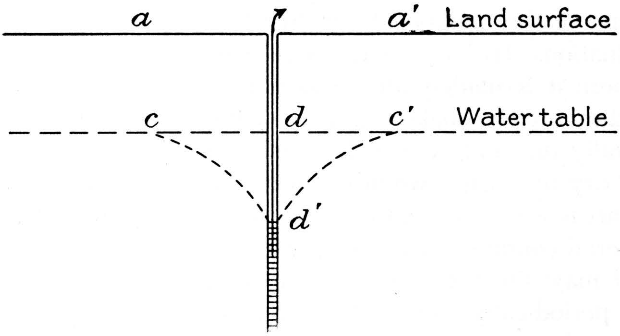

FIG. 12.—Diagrammatic section of a well that is being pumped showing its drawdown (dd'), cone of influence (cc'd'), and area of influence (aa'). (After Meinzer, 1923a, fig. 30.)

after the well has been pumped long enough to stabilize the drawdown. Table 4 gives the specific capacity and other hydrologic data for several of the municipal and industrial wells that have been test-pumped in this area.

The character of the water-bearing material largely controls the yield, drawdown, and specific capacity of a well. If the water-bearing material is coarse and well sorted, it will readily yield large quantities of water with a minimum of drawdown. If the water-bearing material is fine or poorly sorted, it will offer much resistance to the flow of water and thereby decrease the yield and increase the drawdown. All 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, and farm machinery. They range from 2 to 6 feet in diameter, most most of them being less than 4 feet. The dug wells are restricted to the area of terrace deposits or to the alluvium of tributary valleys in the uplands. They are generally walled with stone, brick, or boards, plastered with cement, or cased with large tile. Rock or brick walls are probably the most common. Of the 244 wells listed in the well tables, 95 are dug wells.

Because of the method of construction, a dug well is subject to contamination. Its large diameter permits surface seepage into the well where it is inadequately covered, and its rock or brick wall allows dirt, insects, snakes, and small boring animals to enter. It is generally dug only a few feet below the water table and may become dry in seasons when the water table declines. Unless the lower part is walled up with care, especially where the water-bearing material contains a large proportion of fine sand or silt, the fine material may work its way into the well, which will have to be cleaned periodically. Five of the wells that were visited had been dug some 20 or 30 feet—apparently, when the water table was exceptionally high—and had later been deepened by drilling or driving sand points inside the dug well.

Bored wells.—Wells are bored by augers or post-hole diggers in unconsolidated sediments. Many of the shallow farm wells in the terrace and alluvial areas have been bored and 54 of the wells visited during the course of this investigation were bored wells. Such wells may be left uncased, but in this area most of the bored wells were cased with galvanized iron casing, tile, or boards. To penetrate far below the water table with a hand auger is difficult; therefore, most of the bored wells penetrate the water table only a few feet. Generally they are not more than 8 inches in diameter and most of them are about 6 inches in diameter. A few bored wells are 10 to 12 inches in diameter; one or two of the city wells in Downs have been bored with large auger equipment.

Drilled wells.—A drilled well is excavated by means of a percussion or rotary drilling machine. In this area drilled domestic and stock wells generally are 5 to 10 inches in diameter and are cased with galvanized iron, tile, or wrought iron. Most of the public-supply and industrial wells are drilled. Eighty-eight drilled wells were inventoried in this area.

METHODS OF LIFT AND TYPES OF PUMPS

Most of the domestic and stock wells along North Solomon Valley are equipped with lift or force pumps. The cylinders of both types of pumps are similar and are located below the land surface, either above or below the water table. A lift pump can discharge water only at the pump head, but a force pump can deliver water above this point. Force pumps are used to pump water into elevated storage and stock tanks.

Except for the municipal well at Speed and the well of the Missouri Pacific Railroad at Harlan, the municipal and railroad wells in this area are equipped with turbine pumps that are powered by electric motors. Data concerning these wells are given in the table of well records (Table 15).

UTILIZATION

During this investigation information was obtained for 244 wells in the North Solomon Valley. Most of them supply or have supplied water for domestic and stock use. Of the wells listed in Table 15, 12 were not in use when visited, 28 supplied water for domestic use, 61 supplied water for livestock, 119 supplied water for both domestic and stock use, 18 supplied water for municipalities, and 6 supplied water for railroads. Table 5 gives the industrial use of water, Table 6 the municipal use, and Table 7 the chemical character of municipal water supplies in this area.

DOMESTIC AND STOCK SUPPLIES

Domestic wells supply water to homes for cooking, drinking, and laundry, to schools not supplied from municipal systems, and for the irrigation of lawns and gardens. Stock wells supply drinking water for livestock. On many farms both domestic and stock supplies are obtained from one well, which generally is a dug or drilled well equipped with a cylinder pump and a windmill. Most of the wells are shallow, ranging in depth from about 20 feet to about 50 feet. The water is hard, but is satisfactory for domestic and stock use.

In the upland area that borders the valley, water supplies are difficult to obtain and ponds are used extensively to supply livestock with water. In this part of the area many domestic supplies are obtained from shallow alluvial wells in small tributary valleys and are supplemented with rain water that is stored in cisterns. During periods of extended drought, water is hauled from wells in the valley.

RAILROAD AND INDUSTRIAL SUPPLIES

Several wells in the North Solomon Valley are used for railroad supplies. The wells obtain water from the alluvial sand and gravel that underlie the low terrace and flood plain surfaces.

Missouri Pacific Railroad Co. well at Downs—At Downs the Missouri Pacific Railroad is supplied with water from well 6-11-28a1. This is a gravel-walled well constructed by the Layne-Western Co. in 1938. It is 57 feet deep and had a static water level 36.5 feet below the surface in December 1940. The well is cased with 12-inch metal casing and is equipped with a turbine pump rated at 100 gallons per minute and powered by an electric motor. In 1946, an average of 805,000 gallons of water a month was pumped from this well. The water is treated with lime and soda ash to soften it for boiler use.

Well 6-11-28a2 is a gravel-walled well near well 6-11-28a1. It was constructed by Layne-Western Co. in 1936 and when completed had a drawdown of 5 feet after being test-pumped at 70 gallons per minute for 3 hours. The well was abandoned because it failed to supply the amount of water required by the railroad.

Missouri Pacific Railroad Co. well at Harlan.—A drilled well (5-13-22ad1) supplies the Missouri Pacific Railroad at Harlan. This well was constructed in 1921 and is reported to be 60.5 feet deep and to have a static water level of 47 feet below the land surface. It is cased with 10-inch steel casing and is equipped with a cylinder pump powered by a 7-horsepower gasoline engine. An average of 60,000 gallons of water per month was pumped from this well in 1946. The water is hard but is not treated.

Chicago, Rock Island, and Pacific Railroad Co. wells at Glade.—The Chicago, Rock Island, and Pacific Railroad has four wells (4-18-26da1, -26da2, -26da3, and -26da4) in the North Solomon Valley near Glade in southern Phillips County. Water from these wells is pumped about 6 miles to the railroad yards at Phillipsburg. Prior to the construction of the Phillipsburg municipal wells in the Solomon Valley in 1944, the railroad furnished the city with part of its water supply. The oil refinery of the National Co-operative Re-

TABLE 5.—*Pumpage of ground water in North Solomon Valley for railroad and industrial use*

LOCATION	Number of wells	Railroad	Annual pumpage, million gallons
Downs	1	Missouri Pacific	9.7
Glade	4	Chicago, Rock Island, and Pacific*	120.0
Harlan	1	Missouri Pacific	0.7
Total			130.4

* Sells water to National Co-operative Refinery Association at Phillipsurg.

TABLE 6.—*Pumpage of ground water in North Solomon Valley for municipal use*

CITY	Number of wells	Population (1950 census)	Annual pumpage, million gallons
Downs	4	1,221	42.4
Gaylord	2	231	4.4
Kirwin	1	374	19.1
Logan	3	859	30.0
Phillipsburg	3	2,589	29.7
Portis	1	286	44.0
Smith Center	3	2,026	69.9
Speed	1	70	2.2
Totals	18	7,656	201.7

finery Association at Phillipsburg obtains its water supply from the railroad wells.

Two of the railroad wells are located on the north side of the river and are reported to be 43 feet deep and to have a static water level of 34 feet. They have been in use for several years. The two wells on the south side of the river were constructed in 1940 and 1943. They are gravel-packed, have 18-inch concrete casing, are 53 feet deep, and had a static water level of 22.5 feet in June 1946. Well 4-18-26da4 had a drawdown of 23 feet when pumped for 24 hours at the rate of 275 gallons per minute in June 1943. A log of this well is included among the logs of wells and test holes. All four wells are equipped with turbine pumps powered by electric motors. Water is pumped into an underground reservoir on the north side of the river and then through a 6-inch pipeline to Phillipsburg. Water for steam boilers is softened with lime and soda ash at Phillipsburg. Raw water is furnished by the railroad to the refinery of the National Co-operative Refinery Association, where it is softened before use. The refinery also treats the water for algae and acidulates the water in the cooling pits before recirculating it. The railroad uses water at an average rate of about 3.1 million gallons per month and the refinery, when operating at normal capacity, uses water at the average rate of about 6.8 million gallons per month. The amount of water pumped is the greatest for any installation in the area.

MUNICIPAL SUPPLIES

Eight cities obtain municipal water supplies from sand and gravel in the alluvium and the terrace deposits in the North Solomon Valley. With the exception of Phillipsburg and Smith Center, these cities are situated in the valley. Phillipsburg pumps water 6 miles from wells near Glade and Smith Center pumps water 10 miles from wells near Gaylord. Chemical analyses of water from each municipal supply are given in Table 7.

Logan.—Water for Logan (population 859, 1950 census) is supplied by three shallow wells (4-20-34ca1, -34ca2, -34ca3) in the terrace deposits. A log of well 4-20-34ca3, which was dug in 1932, is included among the well logs. The other two wells were dug in 1937. All the wells are gravel packed with 20-inch copper alloy casing. They are reported to be 65 feet deep, with a static water level 30 feet below land surface. Each is equipped with an electric-powered turbine pump rated at 150 gallons per minute. No data on the yield or drawdown were available. Water is pumped directly into the city mains; any excess goes into an 80,000-gallon elevated steel storage tank.

The average monthly consumption of water is reported to be about 2.5 million gallons, of which the Missouri Pacific Railroad uses about 0.2 million gallons. The water is hard but otherwise is of good quality.

Speed.—Speed (population 70) is supplied by a gravel-packed well (4-19-25cb). The well is reported to be about 30 feet deep and to obtain water from coarse alluvial material. It is equipped with a lift pump powered by an electric motor. Water is pumped directly into the mains. Storage is provided by an elevated steel tank having a capacity of 30,100 gallons. The average monthly consumption of water is about 183,000 gallons. The water is hard but is suitable for most domestic uses.

Phillipsburg.—A large part of the Phillipsburg (population 2,589) water supply is obtained from three wells (4-18-26cc1, -26cc2, -26cc3) in the North Solomon Valley, 1 mile west and three-fourths mile south of Glade. Sixteen test holes were drilled in the alluvium in 1944 to determine the best location for the wells. Figure 13 shows the locations of these test holes and wells, and of the pumping station in the well field. Logs of the wells and test holes are given in the records of logs. The wells were drilled and put into use in the summer of 1944. All are gravel-packed with 12-inch casing and 10 feet of slotted casing set opposite the coarser material. Each is equipped with a turbine pump powered by an electric motor.

Well 4-18-26cc1 (no. 1) is 57 feet deep with a static water level 17 feet below land surface (Pl. 10B). The well is reported to yield 175 gallons per minute with a drawdown of 35 feet after 8 hours of pumping. Well 4-18-26cc2 (no. 2) is 53 feet deep and has a static water level of 14 feet. The yield is reported to be 200 gallons per minute with 38 feet of drawdown after 8 hours of pumping. Well 4-18-26cc3 (no. 3) is 56 feet deep and has a static water level of 15 feet. At the end of an 8-hour pumping test, the drawdown was 36 feet at a pumping rate of 200 gallons per minute.

All wells discharge into a 100,000-gallon underground reservoir in the northwest corner of the well field. Water is pumped from this reservoir through an 8-inch pipeline to the water plant at Phillipsburg. Storage is provided by a 110,000-gallon elevated steel storage tank and at the water plant by a 210,000-gallon underground tank. Total monthly consumption of water by the city of Phillipsburg averages about 4.5 million gallons of which 2.5 million gallons comes from the wells in North Solomon Valley and the remainder from wells in the city. The water is hard, but otherwise is of good quality.

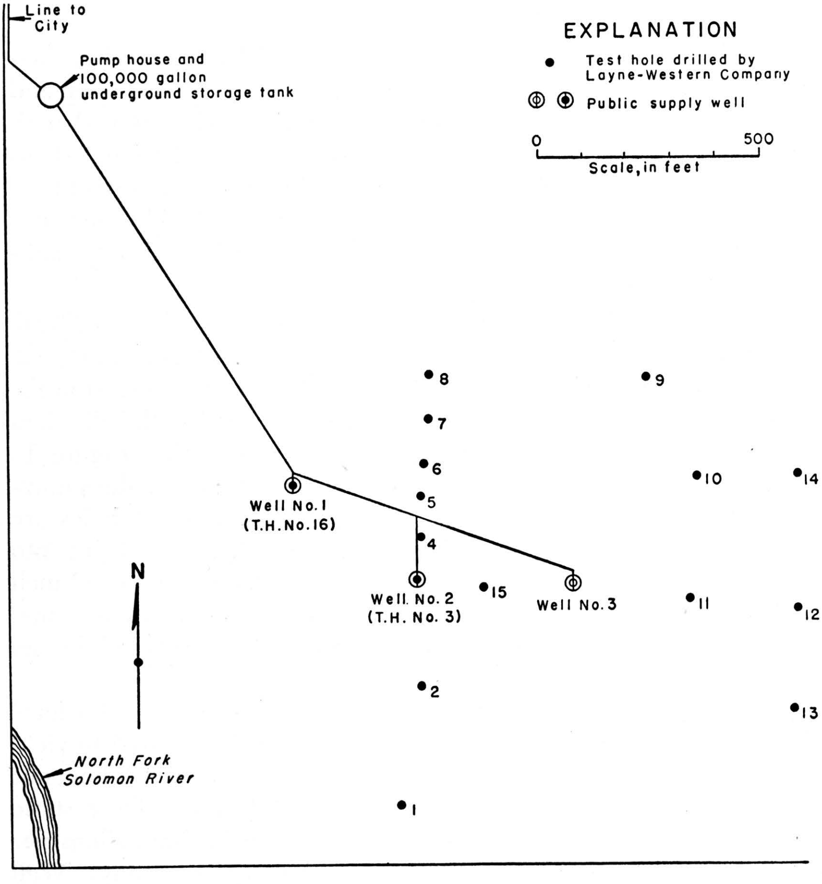

FIG. 13.—Phillipsburg well field showing locations of wells and test holes drilled by Layne-Western Co. (Modified from a map of Wilson and Co.)

Kirwin.—The water supply of Kirwin (population 374) is obtained from a bored well (4-16-27ca) that penetrates the coarse material underlying the low terrace surface. The well is said to be 70 feet deep and is cased with 18-inch concrete casing. It is equipped with a turbine pump powered by an electric motor. Water is pumped directly through the mains into an elevated steel storage tank that has a capacity of 75,000 gallons. The average monthly consumption of water is 1.6 million gallons, of which the railroad uses 124,400 gallons. According to the State Board of Health, the water has a total hardness of 405 parts per million and a chloride content of 50 parts per million.

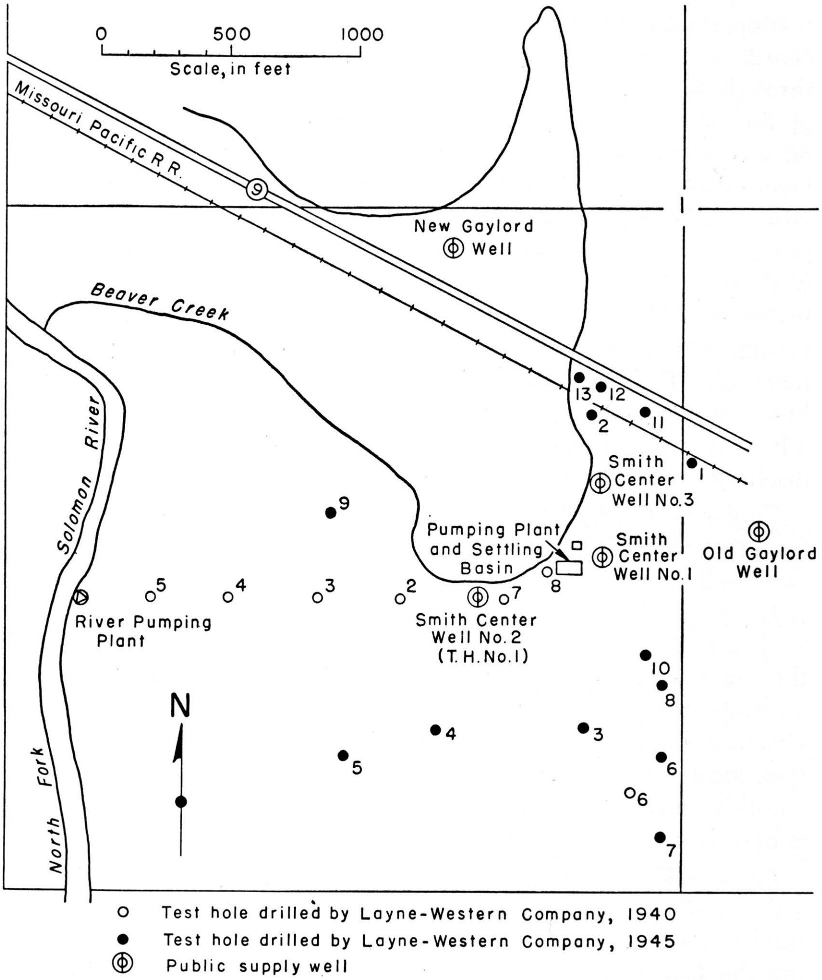

FIG. 14.—Smith Center well field showing locations of wells and test holes.

Smith Center.—Smith Center (population 2,026) is supplied with water from three wells (5-14-1ca2, -1cd1, and -1cd2) near Gaylord, which penetrate terrace sand and gravel in the North Solomon Valley. Figure 14 shows the location of the wells and the test holes that were drilled in 1940 and 1945. Logs of the test holes are given in the records of logs. Water is piped to the city through the pipeline that was laid when a river pumping plant (no longer used) was built on North Solomon River.

Well 5-14-1cd1 (Smith Center well no. 1) is a 12-inch drilled well equipped with a turbine pump powered by an electric motor. Discharge is into a settling basin, from which water is repumped through the pipeline to Smith Center. The well is used only in case of fire or other emergency. Well 5-14-1cd2 (Smith Center well no. 2) is a gravel-packed well 68 feet deep, which had a static water level of 34 feet in 1940. It has a 10-inch casing and is equipped with a turbine pump powered by an electric motor. The water is pumped directly into the pipeline. Well 5-14-1ca2 (Smith Center well no. 3) is a gravel-packed well 70 feet deep, which has a static water level 43 feet below land surface. It has a 10-inch metal casing, with 10 feet of bronze shutter screen opposite the coarser material. The well is equipped with an electrically powered turbine. When pumped at a rate of 323 gallons per minute during a 4-hour pumping test in 1940, the drawdown was 21 feet. The well discharges directly into the pipeline.

Gaylord.—Gaylord (population 231) obtains its water supply from two wells drilled into the low terrace deposits. Well 5-14-1db (old well) is an 8-inch bored well with a reported depth of 70 feet. It is equipped with a turbine pump powered by an electric motor. Well 5-14-1ca1 (new well) is a gravel-walled well drilled during the summer of 1946. It has a 17-inch casing and is equipped with a turbine pump. Water from both wells is pumped directly into the city mains; the excess goes to a 50,000-gallon elevated steel storage tank located on the hill at the north side of the city. The average monthly consumption of water is about 466,000 gallons. The water is hard but is suitable for most domestic uses.

Portis.—The water supply of Portis (population 286) comes from a dug well (6-12-5cb), which taps the sand and gravel underlying the low terrace. The well is 61 feet deep, the lower 8 feet penetrating the Carlile shale. The static water level is 47.51 feet below land surface. The well is equipped with an electrically powered turbine pump, which discharges directly into the city mains; the excess water goes into a 40,000-gallon elevated steel storage tank. Consumption is at an average rate of 417,000 gallons per month. The water is hard but otherwise of good quality.

Downs.—The city of Downs (population 1,221) obtains its water supply from four wells (6-11-27c, -28d1, -28d2, -28d3) which penetrate the coarse terrace material. Well 6-11-27c is a gravel-walled well half a block south and one block east of the city pump house. It is reported to be 62 feet deep; the static water level in May 1946 was 24 feet below land surface. Well 6-11-28d1, at the city pump house, is an old dug well which is reported to be 49 feet deep and to have penetrated 15 feet of coarse sand and gravel. Well 6-11-28d2 is half a block south and one block west, and well 6-11-28d3 is half a block north and one block west of the pump house. Both are gravel-walled and are reported to be 50 feet deep.

All wells are equipped with turbine pumps powered by electric motors. The water is pumped directly into the mains, the excess water going to a 230,000-gallon steel standpipe reservoir at the north edge of the city. An average of about 3.6 million gallons per month was pumped during 1946. The water is hard but is suitable for most purposes.

CHEMICAL CHARACTER OF THE WATER

By Walton H. Durum

INTRODUCTION

Water charged with carbon dioxide from the atmosphere infiltrates the soil and dissolves mineral salts and organic substances. The mineral matter that goes into solution is called the dissolved solids. The relation of the mineral content of ground water to the mineral composition of rocks depends on such factors as the chemical character of the influent water, the chemical character of the geologic formations through which the water passes, and the rate of movement of the water in the aquifer.

The analytical results in Tables 7 and 8 show that the major constituents in ground water in the North Solomon Valley are the cations calcium, magnesium, sodium, and potassium; and the anions bicarbonate, sulfate, chloride, and nitrate. Determinations were also made for carbonate, iron, fluoride, and boron, which are present in smaller quantities.

Calcium, the predominant basic ion in the water, and magnesium cause hardness. Hardness in water is recognized both by the quantity of soap that is required to produce a lather and by an insoluble curd that is formed during washing. Water with a hardness of less than 50 parts per million is soft. A hardness of 50 to 150 parts per million increases the consumption of soap and causes considerable scale in boilers. Hardness above 150 parts per million can be easily detected. Where softening treatment is used for municipal supplies, the hardness is generally reduced to about 100 parts per million. Ground-water samples from the North Solomon Valley had a calcium content of 63 to 235 parts per million and a magnesium content of 9.6 to 31 parts per million. Total hardness, as $CaCO_3$, ranged from 234 to 702 parts per million.

Sodium and potassium receive most attention in water supplies to be used for irrigation. A high percentage of sodium (equivalents per million of sodium divided by equivalents per million of total cations) is undesirable in an irrigation supply. The quantities of sodium and potassium were low in the samples that were analyzed, ranging from 5.0 to 154 parts per million. The percentage of sodium ranged from 4 to 55; in all but two samples it was less than 30.

Bicarbonate, the predominant anion in the ground water in this area, and carbonate cause the alkalinity of the water. The concentration of bicarbonate ranged from 290 to 597 parts per million.

Sulfate, chloride, and nitrate, combined with calcium and magnesium, cause permanent hardness in water. The concentrations in water samples from the North Solomon Valley were: Sulfate, 19 to 359; chloride, 1.5 to 119; and nitrate, 0-3 to 400 parts per million. One sample had no nitrate.

Fluoride in small quantities helps prevent tooth decay but in concentrations that exceed 1.5 parts per million may cause pitting or discoloration of children's teeth. Waters that were analyzed in this area had fluoride contents of 0.1 to 1.4 parts per million; only two samples had more than 0.5 part per million.

Ground water in the North Solomon Valley has a low boron content, ranging from 0.02 to 0.44 part per million in 17 samples; one sample had no boron. Irrigation water that contains more than 2.0 parts per million may adversely affect the growth of certain crops, particularly fruit and nuts.

Although ground water may contain considerable iron, most of the iron is precipitated when exposed to air and causes an unpleasant discoloration of the water. Iron in concentrations that exceed 0.3 part per million causes stains on porcelain fixtures and clothing. The total iron concentration was determined for five water samples from the terrace deposits. Of these, three samples contained more than 0.3 part per million, and the iron content of one sample (from well 6-12-23aa) was 25 parts per million.

TABLE 7.—*Analyses of water from municipal supplies in North Solomon Valley*

Analyzed by Howard Stoltenberg. Dissolved constituents given in parts per million.[a]

MUNICIPAL SUPPLY	Geologic source	Date of collection	Temperature (°F)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$		
															Total	Carbonate	Noncarbonate
Logan	Terrace deposits	Sept. 29, 1947	......	637	22	4.0	133	19	61	422	87	73	0.4	2.4	410	346	64
Speed	do	Sept. 10, 1946	......	545	25	.36	128	13	27	329	121	19	.3	8.9	373	270	103
Phillipsburg	Alluvium	June 10, 1947	......	639	23	.86	125	22	40	349	128	40	.3	16	402	286	116
Kirwin	Terrace deposits	Jan. 22, 1947	......	718	34	0	126	22	86	437	137	50	.1	26	405	358	47
Smith Center	do	June 5, 1947	......	770	31	6.7	131	21	88	497	151	27	.2	1.3	414	407	7
Gaylord	do	Aug. 26, 1947	......	738	38	5.6	120	19	96	486	131	36	.2	1.5	378	378	0
Portis	do	Sept. 5, 1946	......	588	41	2.8	102	17	80	454	72	35	.2	2.0	324	324	0
Downs	do	Nov. 26, 1946	......	442	28	.03	101	11	34	339	42	23	.2	21	297	278	19

[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.

TABLE 8.—*Mineral constituents, in parts per million, and related physical measurements of waters in North Solomon Valley*

Source and well number	Date of collection	Depth of well (feet)	Temperature (°F)	pH	Specific conductance (micromhos at 25°C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)*	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium
																				Total	Noncarbonate	
Recent alluvium:																						
4–19–35ab	Mar. 17, 1947	33.5	60	7.5	1,010	......	......	144	20	35	......	0	313	198	38	0.4	0.6	0.00	653	442	185	15
5–15–2bc	Mar. 18, 1947	22.8	58	8.7	766	......	......	121	16	35	......	0	325	131	16	.2	25	.06	553	368	101	15
Terrace deposits:																						
4–14–29cc	Mar. 18, 1947	37.1	60	7.5	1,210	......	......	201	29	43	......	0	597	107	37	.1	75	.09	895	621	131	13
4–14–34bc	Mar. 18, 1947	46.2	57	7.9	1,470	......	......	213	21	83	......	0	311	50	119	.3	400	....	1,040	618	363	23
4–14–36bd	Mar. 18, 1947	30.3	58	8.1	787	......	......	106	18	52	......	8	325	132	25	.2	6.5	.06	551	338	65	25
4–16–20da	Mar. 17, 1947	55.7	59	7.6	1,050	......	......	104	31	76	......	0	422	166	22	.4	4.0	.08	671	387	41	30
4–18–25ab	Mar. 17, 1947	42.0	58	7.4	620	......	......	83	13	31	......	0	332	42	7.5	.4	.0	.02	385	261	0	20
4–18–30cc	Mar. 17, 1947	33.6	57	7.6	1,240	......	......	212	24	33	......	0	362	359	18	.2	5.0	.02	906	628	331	10
4–20–32db	Mar. 17, 1947	38.5	58	7.5	833	......	......	100	21	43	......	0	332	134	7.0	.2	8.0	.10	530	336	64	22
5–13–4dc	Mar. 18, 1947	42.6	60	7.5	1,490	......	......	235	28	91	......	0	520	233	78	.2	150	....	1,080	702	276	22
5–13–29aa	May 3, 1950	31.3	57	7.3	1,520	28	0.28	187	24	85	19	0	342	156	93	.2	264	.22	1,020	565	285	24
5–13–34aa	May 3, 1950	33.4	57	7.5	897	30	.14	124	12	59	12	0	388	148	15	.2	11	.14	625	359	41	26
5–14–6dc	May 3, 1950	37.3	58	7.7	557	25	.49	78	9.6	27	6.8	0	290	53	8.0	.3	1.5	.20	363	234	0	19
5–14–11da	May 3, 1950	50.0	56	8.4	943	28	.42	132	16	53	7.6	18	302	187	32	.3	18	.20	694	396	118	22
6–12–23aa	Mar. 18, 1947	43.9	60	7.7	988	......	25	139	23	66	......	0	571	33	57	.0	2.0	....	621	441	0	24
6–13–12ba	Mar. 18, 1947	47.7	59	7.6	787	......	......	112	14	52	......	0	373	86	34	.0	5.0	.11	526	337	31	25
Crete member, Sanborn formation:																						
4–16–30cc	Mar. 17, 1947	80.9	60	7.4	791	......	......	113	10	21	......	0	329	67	14	.3	10	.02	460	323	53	12
4–20–26cc	Mar. 17, 1947	51.4	58	7.8	581	......	......	94	12	5.0	......	0	310	20	1.5	.3	10	.02	351	284	30	4
5–13–23dd	Mar. 18, 1947	77.1	61	7.6	988	......	......	166	19	34	......	0	379	144	17	.3	100	.10	706	492	181	13
6–10–20aa	Mar. 18, 1947	36.1	59	7.7	702	......	......	122	10	12	......	0	313	19	41	.1	45	.06	485	346	89	7
6–11–24ad	Mar. 18, 1947	38.3	60	7.6	1,370	......	......	184	24	89	......	0	378	173	113	.2	125	....	917	558	248	26
Niobrara formation:																						
5–16–3bc	Mar. 17, 1947	110.7	59	7.7	1,210	......	......	63	29	154	......	0	464	140	57	1.4	.3	.44	697	276	0	55
Surface water (low flow) at Kirwin:																						
Discharge (sec.-ft.)																						
35	April 25, 1947	....	......	7.9	582	......	.05	86	17	27	......	0	284	90	12	.0	.2	....	393	284	52	13
8.0	Aug. 20, 1948	....	......	7.8	376	......	.02	56	8.5	14	......	0	198	34	4.0	.3	1.7	.00	254	175	13	15
32	May 2, 1949	....	......	7.6	548	......	.01	75	15	24	......	0	274	59	9.4	.4	1.2	....	374	249	24	18
12	Sept. 20, 1949	....	......	8.1	583	......	.02	92	17	16	......	0	276	90	10	.4	.5	....	413	300	74	11

* Includes potassium (K) except where separate potassium analysis is reported.

MINERAL CHARACTER OF THE GROUND WATER

Analyses, in parts per million, of ground-water samples from the North Solomon Valley are given in Tables 7 and 8. In Table 8 the wells sampled are listed under geologic source. Factors for con-

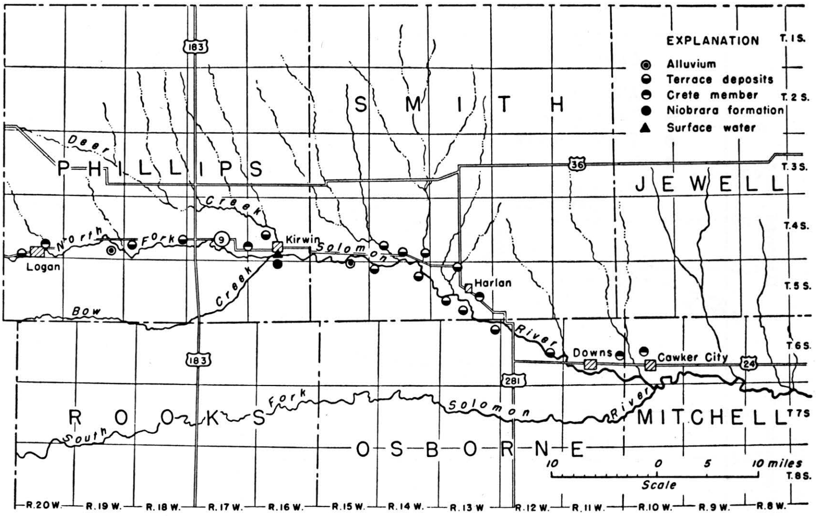

FIG. 15.—Ground- and surface-water sampling points in the North Solomon Valley.

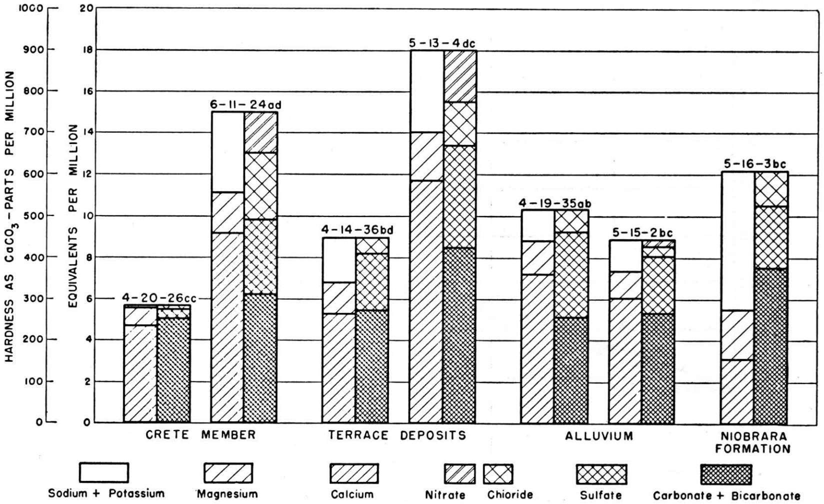

FIG. 16.—Mineral constituents of ground water from representative wells, North Solomon Valley. For hardness, as $CaCO_3$ in parts per million, read from top of magnesium column on hardness scale at left.

verting parts per million of mineral constituents to equivalents per million are given in Table 9. The waters analyzed were from wells that ranged in depth from 22.8 to 110.7 feet. The geologic source of some of the water samples was difficult to determine because the well records were incomplete. If several water-bearing strata

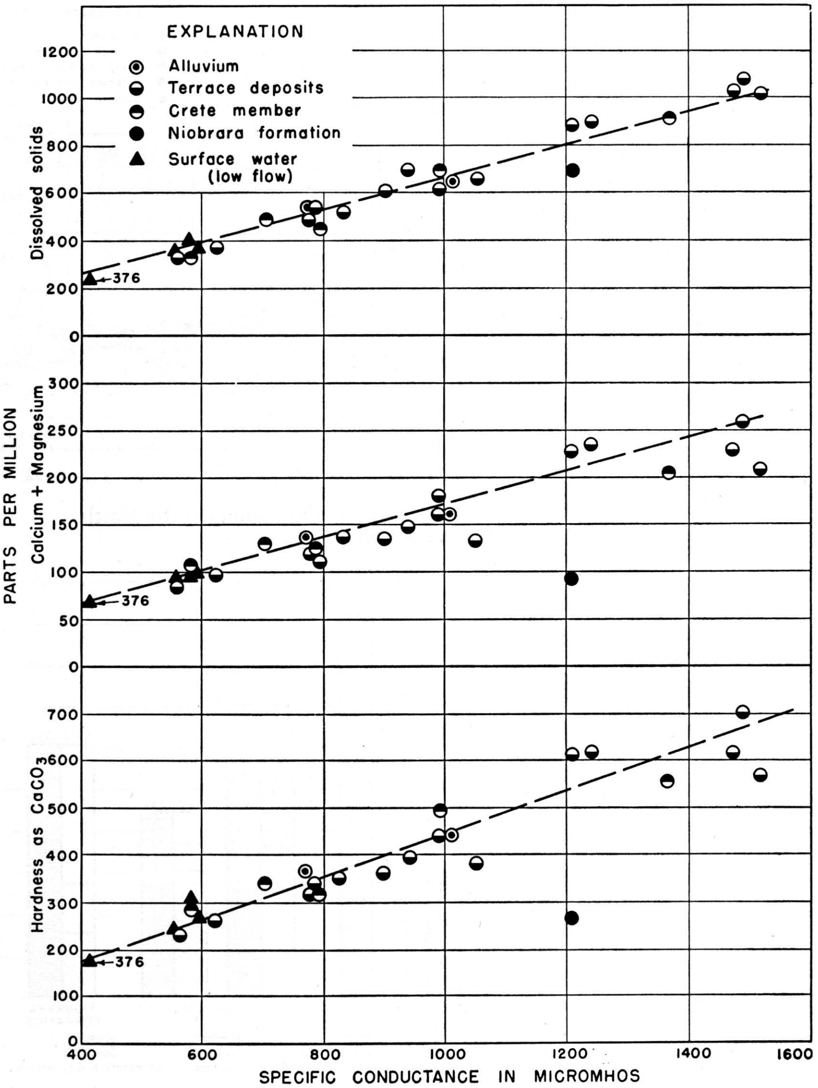

FIG. 17.—Relation of mineral constituents to specific conductance in ground water from North Solomon Valley.

TABLE 9.—*Factors for converting parts per million of mineral constituents to equivalents per million*

Cation	Conversion factor	Anion	Conversion factor
Ca^{++}	0.0499	HCO_3^-	0.0164
Mg^{++}	.0822	SO_4^{--}	.0208
Na^+	.0435	Cl^-	.0282
		NO_3^-	.0161
		F^-	.0526

TABLE 10.—*Analyses, in parts per million, of water from the Recent alluvium*

Well number	Depth of well (feet)	Dissolved solids	Total hardness ($CaCO_3$)	Chloride	Nitrate	Percent sodium
4–19–35ab	33.5	653	442	38	0.6	15
5–15–2bc	22.8	553	368	16	25	15

TABLE 11.—*Summary of chemical characteristics of 14 water samples collected from the terrace deposits*

Parts per million	Number of samples		Parts per million	Number of samples	
	Dissolved solids	Total hardness		Chloride	Nitrate
201–300	0	2	0 – 5.0	0	6
301–400	2	6	5.1– 10	3	2
401–500	0	1	11 – 20	2	2
501–700	7	4	21 – 50	5	0
701–1,000	2	1	51 –100	3	1
More than 1,000	3	0	More than 100	1	3

are penetrated in drilling a well, a sample taken from the well does not represent a particular formation but is probably a mixture of water from two or more sources.

Twenty-two water samples were collected from four geologic sources: the alluvium, the terrace deposits, the Crete member of the Sanborn formation, and the Niobrara formation (Fig. 15). The principal mineral constituents, in equivalents per million, are shown diagrammatically in Figure 16. The total hardness, as $CaCO_3$, in parts per million, is read from the right ordinate at the top of the magnesium column. The relation of several mineral constituents to total mineralization, expressed as specific conductance in micromhos, is shown in Figure 17. Dissolved solids, hardness, and calcium plus magnesium show linear trends when plotted against specific conductance. This relationship is constant for low-sodium waters from the alluvium, terrace deposits, and Crete deposits. The high-sodium water from the Niobrara formation does not follow the same linear trend.

Recent Alluvium.—Table 10 gives the well depth and concentrations of several mineral constituents for two samples that were collected from wells in the Recent alluvium.

The water from the alluvium is hard and moderately high in mineral content. Calcium bicarbonate is the principal dissolved mineral and causes the excessive hardness of the water. The sample from well 5-15-2bc had 25 parts per million nitrate (as NO_3) and was probably contaminated by surface drainage. High nitrate concentrations and correspondingly high chlorides in water may be an indication of pollution from sewage or drainage from barnyards. Another source of nitrate has been discussed by Frye and Leonard (1949, p. 81); wells near fields of alfalfa or other nitrate-producing legumes might receive nitrate from recharge waters percolating through the soil. They concluded that differences in nitrate concentrations in ground water in the area of investigation were not related to geologic formations.

Terrace deposits.—Fourteen water samples were collected from wells that penetrate the terrace deposits. Their chemical characteristics are summarized in Table 11.

Water in the terrace deposits is similar in chemical character to the water in the alluvium, but several samples had a higher mineral concentration. It is difficult to compare the results obtained in the two stratigraphic units because of the limited sampling in the alluvium. Three water samples from the terrace deposits contained more than 1,000 parts per million dissolved solids, and nine samples contained between 501 and 1,000 parts per million. Total hardness ranged from 234 to 702 parts per million and averaged 445 parts per million. The percentage of sodium was low, and all the water was suitable for irrigation (Fig. 18). Four samples contained more than 45 parts per million of nitrate (as NO_3); one of these had 400 parts. Three samples were from shallow dug wells (4-14-29cc,

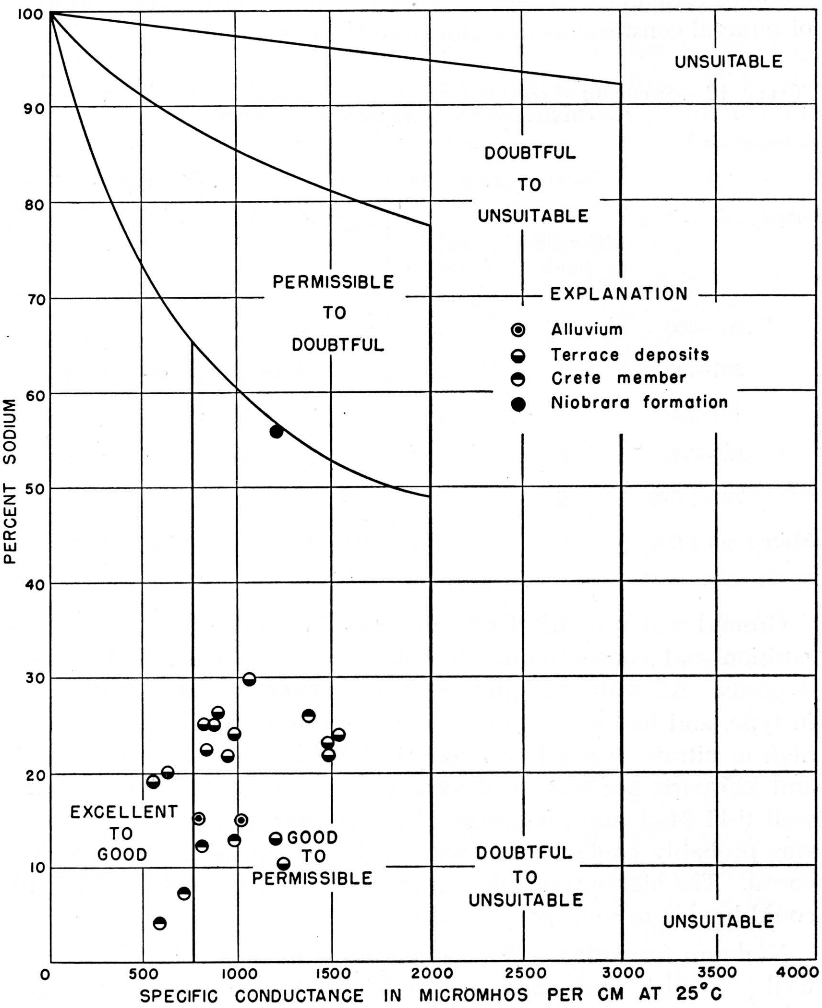

FIG. 18.—Classification as irrigation supplies of ground water from North Solomon Valley. (After Wilcox, 1948.)

4-14-34bc, and 5-13-4dc) of large diameter and porous wall construction. These samples also contained relatively high chloride concentrations, which suggest that the high nitrate content was due to contamination by surface drainage. Corrals near wells 4-14-34bc and 5-13-4dc were possible sources of contamination.

Sanborn formation, Crete member.—Samples of water were collected from five wells that penetrate the Crete member of the Sanborn formation. Table 12 gives a summary of the concentration of mineral constituents in water from these wells.

TABLE 12.—*Summary of chemical data from five water samples collected from the Crete member of the Sanborn formation*

Parts per million	Number of samples		Parts per million	Number of samples	
	Dissolved solids	Total hardness		Chloride	Nitrate
201–300	0	1	0 - 5.0	1	0
301–400	1	2	5.1- 10	0	2
401–500	2	1	11 - 20	2	0
501–700	0	1	21 - 50	1	1
701–1,000	2	0	51 -100	0	0
More than 1,000	0	0	More than 100	1	2

Ground water in the Crete deposits is similar in mineral composition and concentration to water in the alluvium and terrace deposits. All water samples were hard, were calcium bicarbonate in type, and had a low percentage of sodium. Two samples were high in nitrate; water from wells 5-13-23dd and 6-11-24ad had 100 and 125 parts per million of nitrate, respectively. The water from well 6-11-24ad also contained 113 parts per million chloride and was probably contaminated with surface seepage from a near-by corral. The high-nitrate concentration in water from well 5-13-23dd could be due to some other cause.

Niobrara formation.—One sample of water was collected from a well (5-16-3bc) that penetrates the Niobrara formation. This water differed in composition from samples obtained from the unconsolidated deposits, although it is similar in total mineral content. The water was softer than the other water samples analyzed and had a hardness of 276 parts per million. Apparently, this water had been softened by the action of natural zeolites. The fluoride content (1.4 parts per million), boron (0.44 part per million), and the percentage of sodium (55) were the highest for any of the water samples analyzed.

MINERAL CHARACTER OF THE SURFACE WATER

Chemical analyses of four samples of water that were taken during periods of low flow from North Solomon River at Kirwin are given in Table 8. The calcium bicarbonate composition of the river water is similar to that of the ground water that was sampled in the area (Fig. 17). Concentrations of dissolved solids ranged from 254 parts per million for a flow of 8 second-feet to 413 parts per million for a flow of 12 second-feet. The low-nitrate content of the surface-water samples suggests that nitrate in the ground water is not related to the geology of the area. The concentrations of bicarbonate, sulfate, chloride, and calcium were also lower than are generally found in the ground water.

RELATION OF QUALITY TO USE

Water samples were collected for analysis from 22 wells. Thirteen of the 22 furnished water for domestic and stock use, 3 for domestic use only, and 6 for stock use only.

Most of the analyzed water samples had amounts of the chemical constituents that fall within the limits recommended by the U. S. Public Health Service (1946, pp. 371-384) for public water supplies:

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

Limits of nitrate in water for domestic use are not well established. Comly (1945, pp. 112-116) suggests that water containing 45 to 90 parts per million nitrate (as NO_3) is dangerous for use in infant feeding. Water containing more than 90 parts per million nitrate is likely to cause infant cyanosis. Apparently, older children, adults, and domestic animals are not affected by nitrate in drinking water. Six of the water samples that were analyzed contained more than

45 parts per million nitrate, and five samples contained more than 90 parts per million.

The percentage of sodium and the electrical conductivity of the water have been used by Wilcox (1948, p. 27) as a basis for rating water for irrigation. Table 13 gives the permissible limits.

In Figure 18 the percentage of sodium for the water samples from the North Solomon Valley is plotted against electrical conductivity on a reproduction of Wilcox's diagram. The area in which the plotted point falls designates the quality classification of the water. Although none of the wells are presently supplying water for irrigation, all the water samples analyzed fall into the "good to permissible" classification.

SUMMARY OF CHEMICAL CHARACTERISTICS

The samples of ground water from the alluvium, terrace deposits, and Crete sand and gravel member of Sanborn formation were calcium bicarbonate waters of similar composition. They were moderately high in mineral content and were hard. The sample from the Niobrara formation was of sodium bicarbonate type and had a higher content of boron and fluoride than the other samples. Several samples contained excessive amounts of nitrate; this suggests contamination by surface drainage. All samples rated at least "good to permissible" for irrigation use.

TABLE 13.—*Permissible limits for electrical conductivity and percentage of sodium of several classes of irrigation water*

Classes of water		Electrical conductivity (micromhos at 25° C.)	Percent sodium
Rating	Grade		
1	Excellent	Less than 250	Less than 20
2	Good	250– 750	20–40
3	Permissible	750–2,000	40–60
4	Doubtful	2,000–3,000	60–80
5	Unsuitable	More than 3,000	More than 80

Low-flow surface waters had a chemical composition similar to the ground water in the area, but they had lower mineral concentration.

IRRIGATION

Successful agriculture requires that the moisture supply be sufficient to mature growing plants. In any area where the precipitation during the growing season does not supply the amount of moisture needed by crops, some supplementary water must be added if the crops are to mature. In the North Solomon Valley precipitation normally is great enough to supply this demand adequately; however, periods of drought have been recurrent in this area. During such periods, interest in irrigation increases rapidly.

HISTORY OF IRRIGATION

Although the North Solomon Valley is well suited for irrigation, it has been practiced very little. Numerous attempts to locate artesian water in the Dakota formation have produced only salt water. Shallow alluvial wells are used to irrigate small garden tracts, but only one attempt to utilize ground water for irrigation has been reported. Mr. J. A. Ifland of Gaylord reports that in the first part of the century a dug well in Beaver Creek Valley was used to irrigate about 40 acres of alfalfa. This project was abandoned after a few years. More recently, several attempts have been made to utilize surface water from North Solomon River and its principal tributaries (Table 14). The small flow of the river in drought seasons has handicapped these projects. In the summer of 1946, a well for irrigation purposes (5-13-18db) was drilled by Otto Meier. No pumping test has been made on the well and no attempt has been made to use it for irrigation.

SURFACE-WATER IRRIGATION

According to the records of the Kansas State Board of Agriculture, the first use of surface water for irrigation in this area was in 1928 when two pumping plants were established on North Solomon River in Phillips County. Two more were established in Smith County in 1930, but it was the prolonged drought of the 1930's that stimulated interest in irrigation. Several more pumping plants were put into operation, and by 1946, 13 had been established in this area. Table 14 lists these plants and shows the acreage irrigated and the amount of water allotted to each plant annually. The heavy precipitation of the past few years has made supplemental irrigation unnecessary and most plants have not been operated regularly. The crops most frequently grown on irrigated land are alfalfa, corn, and forage crops; wheat is occasionally irrigated.

TABLE 14.—*Surface-water supplemental irrigation plants in North Solomon Valley, 1946*

Date use started	OPERATOR	Point of division	County	Maximum annual use acre-feet	Pumping capacity, gallons per minute	Acreage irrigated	Remarks
1928	Clarence Billings	SE SE sec. 28, T. 4 S., R. 17 W.	Phillips	33	1,100	22	
1928	A. W. Gibbs	SW SE sec. 26, T. 4 S., R. 18 W.	do	8	450	5	
1941	Bartlett & Thompson	SW NW sec. 10, T. 4 S., R. 17 W.	do	40	2,000	30	Water from Deer Creek.
1936	Martin Tanis	N/2 SW sec. 24, T. 5 S., R. 11 W.	Smith	132	500	122	Water from Oak Creek.
1938	Albert Dannenberg	NE NE sec. 19, T. 5 S., R. 13 W.	do	10	350	12	
1930	A. G. Tack	NW SW sec. 20, T. 5 S., R. 13 W.	do	43	350	45	
1930	W. H Weiser	SW NW sec. 21, T. 5 S., R. 13 W.	do	16	250	10	Last used for irrigation in 1942.
1938	J. O. Grisier	NE sec. 2, T. 5 S., R. 14 W.	do	36	350	25	
1940	B. W. Verhage	SW sec. 27, T. 6 S., R. 11 W.	Osborne	86	2,000	100	Owner, J. Rieman.
1937	do	NW SW sec. 33, T. 6 S., R. 11 W.	do	147	2,000	117	Several owners.
1940	Aaron Fink	SW SW sec. 14, T. 6 S., R. 12 W.	do	77	1,250	50	
1939	Ernest McClain	NW NW sec. 1, T. 6 S., R. 13 W.	do	100	2,000	80	Owner, Mary Staalduine.
1945	Linn S. White	NE NW sec. 26, T. 6 S., R. 11 W.	do	95	1,000	50	Under construction 6-28-45.
	Totals			823		668	

Most pumping plants draw water from the river with a centrifugal pump powered with a stationary engine or tractor. Water is forced up to the level of the Kirwin terrace surface, where a series of canals carries it to the field. The amount of water allotted ranges from 0.86 acre-foot to 1.9 acre-feet per acre; the average is about 1.3 acre-feet per acre. If all plants were operated to capacity, 823 acre-feet of water would be withdrawn from North Solomon River and its tributaries to irrigate 668 acres. Plate 10A shows part of Aaron Fink's pumping plant in operation during the spring of 1946.

The use of surface water for irrigation during seasons of subnormal precipitation is apparently a profitable procedure, as the number of pumping plants has increased in the past decade. The greatest disadvantage of using stream water for irrigation is that during periods of drought, when irrigation is most necessary, the stream flow may be too low.

POSSIBILITIES FOR GROUND-WATER IRRIGATION

Fine to coarse alluvial material of moderate thickness underlies the valley of North Solomon River at shallow depth. In many places this material is not well sorted and the transmissibility is not high. Data furnished by the cities that have attempted to get municipal-water supplies along the valley and data from the test-drilling program indicate that the saturated material is not thick enough nor coarse enough for the development of wells with high yields. The greatest yield reported from the wells for which hydrologic data are given in Table 4 is 323 gallons per minute and the highest specific capacity is 16.7 gallons per minute per foot of drawdown. An irrigation well should have a yield of nearly twice that amount. The saturated material becomes less coarse in a downstream direction, where the valley gradient decreases and where the Cretaceous fine-grained chalk and shale replace the conglomeratic Ogallala formation as the bedrock along the valley walls.

The possibility of obtaining artesian water from the underlying Dakota formation for irrigation does not seem feasible, as wells in the area drilled to this formation tapped salt water. The water in the Dakota is judged to be highly mineralized throughout this area.

IRRIGATION PROBLEMS

Irrigation with ground water in this area creates several problems. One is the problem of subsurface drainage for the irrigation water that is not used by plants. If subsurface drainage is inadequate, the soil may become waterlogged and unfit for crops.

Under natural conditions the proposed Kirwin irrigation district, which lies largely on the Kirwin terrace surface, has good subsurface drainage. The water table is in the coarser part of the terrace deposits and lies 30 to 40 feet below the land surface. Some of the precipitation on the terrace percolates downward to the water table, thus indicating that no widespread impervious beds occur above the water table.

In the eastern part of the irrigation area, where steep slopes on the Carlile shale form the valley sides, weathered shale material, in the form of heavy clay, has been deposited on the terrace surface by colluvial processes. This material is impermeable, and as water penetrates very slowly to the lower part of the soil in these local areas, serious drainage problems probably will occur.

The upper part of the terrace deposits consists of silt and sandy silt. Where these deposits are exposed, thin lenses of silty clay are interstratified with the silts. If large quantities of water are added to the land surface during irrigation, much of the colloidal material may be removed from the soil, moved downward through the silty layers, and be concentrated along the clay layers. This may also result in the local development of waterlogged areas.

Although natural drainage conditions are good, the danger of waterlogging is inherent in any irrigation development in this area. A detailed observation-well program is recommended to determine the seasonal fluctuation of the water table and to detect any areas where abnormal changes of the water table occur. If such a program were maintained during the early period of irrigation, any rise in the water table due to this alteration of natural conditions could be noted.

Another problem is a form of inhibited drainage, which may be termed temporary waterlogging. In the more arid regions, where irrigation is practiced extensively, almost no rainfall occurs during the crop-growing season. In the subhumid region, which includes the area discussed in this report, considerable rainfall occurs during the growing season when irrigation would be in progress. Much of this rainfall comes in heavy storms when several inches of rain may fall in a short period of time. If several inches of rain should fall immediately after the soil of an area had been saturated with several inches of irrigation water, the upper soil might be temporarily waterlogged, or water might even stand on the land surface long enough to damage the soil severely and destroy the crops in that area. Thus, temporary waterlogging in this area of moderate rainfall during the growing season is a definite hazard to be considered in the planning of irrigation.

RECORDS OF WELLS

Information pertaining to 244 wells in the North Solomon Valley area is given in Table 15. The well-numbering system in this table utilizes the General Land Office survey as described on page 12.

TABLE 15.—*Records of wells in North Solomon River Valley, Kans.*

WELL NUMBER[1]	Owner or tenant	Type of well[2]	Depth of well (feet)[3]	Diameter of well (in.)	Type of casing[4]	Principal water-bearing bed		Method of lift[5]	Use of water[6]	Measuring point			Depth to water level below measuring point (feet)[7]	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
						Character of material	Geologic source			Description	Distance above land surface (feet)	Height above mean sea level (feet)			
T. 4 S., R. 13 W.															
4-13-27dd	....	Du	30.1	......	......	Sand and gravel	Alluv'm and terrace deposits.	Cy,W	S	Top of wooden curb	0.0	1,667.9	21.60	11-20-45	
4-13-29dd	E. Jacobs	Du	32.5	......	......	do.	Terrace deposits	Cy,W	S	Base of pump	1.8	1,615.9	20.15	11-20-45	
4-13-31cc	Richard Horning	Du	74.0	......	C	do.	Crete member, Sanborn formation.	Cy,W	D,S	Top of wooden curb	.4	1,644.7	72.40	5- 7-46	Reported depth 92 feet. Well caved in.
4-13-33dd	....	Du	23.3	......	R	do.	do.	Cy,W	S	do.	2.0	1,669.7	18.75	11-24-45	Unused stock well.
T. 4 S., R. 14 W.															
4-14-26ad	H. Dohe	Du	34.8	......	......	do.	Terrace deposits	Cy,W	S	do.	1.7	1,616.0	30.90	11-20-45	
4-14-27dd	David Becker	Du	28.3	24	Br	do.	do.	Cy,W	S	Top of wooden curb, south side.	1.1	1,642.9	25.28	5- 7-46	Small yield.
4-14-28cb	E. W. Cole	Du	66.8	48	Br	do.	Meade	Cy,W	D,S	Top of wooden platform, south side.	.6	1,660.8	60.78	2-20-46	Unused farm well.
4-14-28dd	....	Du	62.0	40	Br	do.	Alluvium	Cy,W	S	Top of brick and concrete curb, west side.	1.5	1,642.0	56.91	2-20-46	
*4-14-29cc	....	Du	37.8	36	Br	do.	Terrace deposits	Cy,W	D,S	Top of wooden curb, south side.	.7	1,626.1	30.47	2-19-46	Chemical analysis.
4-14-30cb	Hofer Brothers	Du	68.8	36	C	do.	Terrace deposits, alluvium.	Cy,W	D,S	Top of wooden platform, east side of pump.	.6	1,645.3	38.45	2-20-46	Reported dug through chalk. Farm pond ¼ mile above well.
4-14-31db	L. L. Cole	Dr	41.1	8	T	do.	Terrace deposits	Cy,W	D,S	Base of pump	.8	1,632.7	38.90	11-24-45	
4-14-32bd	Norris Cole	Du	41.8	30	C	do.	do.	Cy,W	D,S	Top of wooden platform, north side.	.4	1,623.7	35.47	2-26-46	
*4-14-34bc	Laura Davis	Du	46.3	32	R	do.	do.	Cy,W	S	Top of wooden platform	.1	1,622.7	42.25	11-21-45	Chemical analysis.
4-14-35cc	R. H. Ritchie	B	53.1	8	T	do.	do.	Cy,G,W	D,S	do.	.3	1,610.5	34.30	4- 2-46	
*4-14-36bd	J. A. Ifland	Du	30.8	36	R	do.	do.	Cy,W	S	do.	.5	1,611.5	26.89	3-13-46	Chemical analysis.
T. 4 S., R. 15 W.															
4-15-27cc	J. H. Curry	Dr	70.7	......	T	do.	do.	Cy,W	S	Top of wooden well curb, north side.	1.5	1,680.3	47.49	11-29-45	
4-15-29bc	J. A. Hagman	Du	41.4	......	R	do.	Alluvium	N	N	Top of wooden curb	2.2	1,715.0	32.57	2-14-46	
4-15-31bb	Wilbur Lala	Dr	43.5	8	T	do.	Terrace deposits	Cy,W	S	Top of wooden platform	1.7	1,678.9	37.6	11-21-45	
4-15-33dd	Phoebe Walker	Du	23.8	36	R	do.	Alluv'm and terrace deposits.	Cy,W	D,S	Top of wooden platform, south side.	0	1,650.4	23.40	2- 4-46	Well reported dug to "blue shale" (Carlile) small yield reported.

4-15-35bc	H. R. Dannenburg....	Du	39.6	......	R	do..........	Terrace deposits	Cy,W	S	Top of wooden platform..	.8	1,650.4	36.40	11-21-46	
4-15-36cb	H. A. Diechens........	B	21.8	8	T	do..........	Alluv'm and terrace deposits.	Cy,H	S	Edge of metal plate covering tile casing.	0	1,628.0	17.94	2-19-46	Unused stock well.
T. 4 S., R. 16 W.															
4-16-16bc	....	Du	54.5	......	Br	Silt, chalk......	Sanborn, Niobrara.	Cy,G,W	D,S	Top of concrete curb, north side.	1.7	1,737.5	53.49	2-12-46	Reported dug 2 feet into Niobrara. Very poor yield.
4-16-17cb	....	B	51.4	8	T	Sand and gravel	Terrace deposits	Cy,W	D,S	Top of concrete curb.....	.7	1,723.6	37.59	2-12-46	
4-16-18cd	....	Dr	64.4	8	T	do..........	do..........	Cy,W	D,S	Top of board platform, north side.	.4	1,725.3	40.78	2-12-46	
*4-16-20da	....	Du	56.5	36	C	do..........	do..........	Cy,W	D,S	Top of concrete curb, south side.	.8	1,712.1	47.68	2-12-46	Chemical analysis.
4-16-21dd	J. B. Wyrill..........	Dr	46.1	6	GI	do..........	do..........	N	D	Top of concrete curb.....	.8	1,701.7	39.05	11-23-45	Unused domestic well.
4-16-22bb	....	Du	70.9	30	Br	....	Sanborn, Niobrara.	Cy,W	D,S	Top of wooden platform, north side.	0	1,752.3	63.69	2-12-46	
4-16-24da	....	Du	67.8	36	Br	....	Niobrara (?)....	Cy,W	D,S	Top of wooden platform, east side.	.6	1,793.3	55.47	2-16-46	Unused farm well.
4-16-26da	W. M. Kilmer........	Du	50.1	......	N	Sand and gravel	Terrace gravels	Cy,W	D,S	Top of wooden platform, east side of pump.	1	1,694.7	45.88	2-12-46	"Quicksand" reported in well.
*4-16-27ca	City of Kirwin........	B	70	18	C	do..........	do..........	T,E	P	....	.....	....	48	....	Reported water level. Chemical analysis.
4-16-29cd	E. E. Gray..........	Dr	60.5	8	GI	....	Sanborn, Niobrara	Cy,W	D,S	Top of wooden platform..	.5	1,729.3	49.6	11-23-45	
*4-16-30cc	W. F. H. Gray........	Dr	80.9	8	GI	Gravel and sand	Crete deposits...	Cy,W	D,S	Pump base, east side.....	0	1,767.1	71.54	12- 5-45	Chemical analysis.
T. 4 S., R. 17 W.															
4-17-19dc	....	Dr	67.0	6	GI	do..........	do..........	Cy,H	D	Top of concrete curb, north side.	.6	1,776.5	36.90	12- 3-45	Abandoned domestic well.
4-17-20da	....	Du	42.4	42	R	do..........	Terrace deposits	Cy,W	S	Top of wooden platform, west side.	.6	1,766.9	36.67	2-19-46	
4-17-22bd	....	Du	71.6	36	R	....	Alluvium, Niobrara.	Cy,W	D,S	Top of casing, west side..	.6	1,791.8	59.91	12- 3-45	
4-17-25cd	John Gray...........	B	91.0	10	GI	Sand..........	Crete..........	Cy,W	D,S	Top of wooden platform, north side.	1.1	1,784.7	87.22	2- 8-46	Observation well.
4-17-27da	Fannie Townley.......	B	47.3	8	T	Sand and gravel	Terrace deposits	Cy,W	D,S	do..................	1.0	1,740.9	33.50	2-18-46	
4-17-28ad	E. M. Kinnick........	Du	43.8	24	C	do..........	do..........	Cy,W	D,S	Top of wooden platform, east side.	.8	1,752.5	39.75	2-18-46	
4-17-28cd	E. W. Pfost..........	B	47.7	8	GI	do..........	do..........	Cy,W	D,S	Top of wooden platform..	.7	1,747.5	34.83	1-30-46	Well reported bored to bedrock (Niobrara).
4-17-29db	Mary Kuiken.........	Du	34.9	......	R	do..........	do..........	Cy,W	D	Top of concrete curb, edge of manhole, east side.	0	1,758.6	29.75	12- 5-45	
4-17-30dd	W. T. Keeton.........	B	42.2	12	GI	do..........	do..........	Cy,W	D,S	Top of concrete curb, north side.	1.1	1,769.7	34.52	2- 4-46	Unused farm well.
4-17-31bc	C. B. Brower.........	B	61.3	8	T	do..........	do..........	Cy,W	D,S	Top of concrete curb, south side of pump.	.8	1,798.2	52.19	2- 4-46	Observation well.
4-17-31dd	Margaret McCall......	Du	30.8	36	R	....	Alluvium, Niobrara.	Cy,W	S	Top of rock curb, north side.	2.0	1,799.8	27.22	11-23-45	Unused stock well.
4-17-34ba	C. A. Johnson........	Dr	23.3	......	......	Sand and gravel	Terrace deposits	Cy,W	S	Top of wooden curb.....	.8	1,720.6	20.46	12- 5-45	
4-17-34cc	do................	Dr	66.5	8	GI	do..........	do..........	Cy,W	S	do..................	0	1,749.5	33.78	1-30-46	
4-17-34db	Omar Ellis...........	Dr	36.5	8	GI	do..........	Terrace deposits, alluvium.	Cy,W,G	D,S	Top of wooden curb, east side.	1.2	1,731.9	23.59	2- 9-46	
4-17-36cb	F. M. Brotemarkle....	B	40.4	8	GI	do..........	Terrace deposits	Cy,G,W	D,S	Top of concrete curb, northeast side.	1.3	1,728.4	31.68	2- 8-46	

TABLE 15.—*Records of wells in North Solomon River Valley—Continued*

WELL NUMBER[1]	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)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)[7]	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
T. 4 S., R. 18 W.															
4-18-21cc		Du	29.9				Alluvium, Niobrara.	Cy,W	S	Top of well curb	2.2	1,851.3	15.76	12- 4-45	Unused stock well.
*4-18-25ab	J. R. Donaldson estate	Du	42.5		R	Sand and gravel	Terrace deposits	Cy,W	D	Top of wooden platform, north side of pump.	.5	1,774.2	26.77	12- 5-45	Chemical analysis.
4-18-25cb		Dr	35.3	8	GI	do.	do.	Cy,W	D,S	Top of concrete curb	.5	1,782.8	25.04	1-29-46	
4-18-26da1	C. R. I. & P. Ry. Co.	Dr	43	17		do.	Alluvium	T,E	R.R.				9	6-12-46	Well constructed by Layne-Western Co.
4-18-26da2	do.	Dr	43	17		do.	do.	T,E	R.R.				9	6-12-46	Do
4-18-26da3	do.	Dr	54	17		do.	do.	T,E	R.R.					6-12-46	Do
4-18-26da4	do.	Dr	52.6	17		do.	do.	T,E	R.R.	Top of concrete curb	0		22.33	6-12-46	Do
4-18-26cc1	City of Phillipsburg	Dr	57			do.	do.	T,E	P				17		Gravel-packed well drilled in August, 1944, by Layne-Western Co.
4-18-26cc2	do.	Dr	53			do.	do.	T,E	P				14		Do
4-18-26cc3	do.	Dr	56			do.	do.	T,E	P				14		Do
4-18-27aa		Du	49.0	16	T	do.	Crete	Cy,W	D,S	Top of wooden curb, east side.	1.2	1,813.4	43.60	1-24-46	Unused farm well.
4-18-28ad		Du	21.2	52	C	do.	Alluvium, terrace deposits.	Cy,W	D,S	Top of wooden curb, west side.	.4	1,795.7	20.41	3-22-46	
4-18-29cb		B	58.8	8	T	do.	Crete	Cy,W	D,S	Top of concrete curb, east side.	.2	1,840.1	39.72	3-14-46	
4-18-30ab		Du	36.5			do.	Alluvium	N	N	Top of wooden curb	.2	1,896.0	19.5	12- 4-45	Abandoned farm well used as observation well.
*4-18-30cc		Du	35.1	36	N	do.	Terrace deposits	Cy,W,T	D,S	Top of wooden platform	1.5	1,844.1	25.96	3-14-46	Chemical analysis.
4-18-32dd		B	22.7	6	GI	do.	Alluvium	Cy,H	D,S	Top of board platform	.8	1,822.0	20.40	3-14-46	Very small yield.
4-18-34ad		DDr	51.7	42	R	do.	Terrace deposits	Cy,W	D,S	Top of wooden platform	1.9	1,805.8	36.62	3-22-46	Bottom 18 feet cased with 8-inch tile.
4-18-34cb		B	53.8	8	T	do.	do.	Cy,H	D,S	Base of pump	.7	1,824.9	41.70	1-29-46	
4-18-36ca	Martha Adams	B	56.7	13	W	do.	do.	Cy,W	D,S	Top of wooden platform, north side.	.5	1,801.5	44.22	2-19-46	Reported depth, 85 feet.

T. 4 S., R. 19 W														
4-19-21dd	Fred Kinter	Du	20.5			do	Alluvium	Cy,W	S	Top of well curb	4.0	1,915.4	14.88	12- 4-45	Observation well in draw in chalk hills.
4-19-23ad		Du	37.7	60	Br,C	do	do	N	D	Top of concrete curb, south side.	.5	1,901.3	26.78	2-21-46	Water reported very hard.
*4-19-25cb	City of Speed	Du	30			do	do	Cy,E	P						Chemical analysis.
4-19-26bb		Du	12.7	30	C	do	do	Cy,W	N	Top of wooden platform, south side.	.8	1,853.6	10.67	2-21-46	Abandoned farm well.
4-19-29da	School district	B	22.8	6	GI	do	Alluvium, terrace deposits.	Cy,H	D	Top of concrete curb, east side.	.4	1,886.2	15.69	3- 6-46	Unused school well.
4-19-30cc		B	48.1	12	GI	do	Terrace deposits	Cy,W	S	Top of wooden platform, north side.	.2	1,936.9	44.78	2- 1-46	Abandoned farm well.
4-19-33ad	E. G. Cole	B	32.8	8	T	do	do	Cy,H	D	Top of tile casing, north side.	0	1,887.8	25.88	2-21-46	
4-19-34ab		B	41.1	15	GI	do	do	Cy,W	D,S	Base of pump, west side	0	1,884.3	29.15	2-21-46	
4-19-34dc		Du	35.7	6	GI		Niobrara, Sanborn.	Cy,W	D,S	Top of concrete curb, north side.	.9	1,900.3	30.24	2-21-46	
*4-19-35ab		B	35.0	10	GI	Sand and gravel	Terrace deposits, alluvium.	Cy,W	D,S	Base of pump, north side	1.5	1,849.8	14.16	2-21-46	Observation well. Chemical analysis.
4-19-36cb	C. A. Green	B	19.8	6	GI	do	Alluvium	Cy,W	D,S	Top of concrete curb, east side.	.3	1,840.0	11.02	2-21-46	
T. 4 S., R. 20 W.														
4-20-21cc	Fred Albrecht	Dr	152.0	8	GI		Crete (sand and gravel mem. of Sanborn fm.), Niobrara fm.	N	N	Top of casing, north side	1.0	2,043.0	49.92	2- 6-46	Unused farm well used as observation well.
*4-20-26cc		B	51.9	10	GI	Sand and gravel	Crete, sand and gravel mem. of Sanborn fm.	Cy,W	D,S	Top of wooden platform, north side.	.5	1,967.6	47.82	3-18-46	Chemical analysis.
4-20-26da		Du	40.9	54	W	do	Alluvium	Cy,W	D,S	Top of board platform, south side.	.3	1,958.4	36.55	3- 6-46	Large farm pond reported in draw above well.
4-20-27ca		B	47.6	10	GI	do	Terrace deposits	Cy,W	D,S	Top of wooden curb, north side.	.5	1,960.4	39.04	3-12-46	Unused farm well.
4-20-29bc		B	37.3	12	GI	do	Alluvium, terrace deposits	Cy,W	S	Top of wooden platform, north side.	.9	2,003.1	28.90	2- 6-46	Do.
4-20-31da		Du	17.1	66	N	do	Alluvium, Niobrara.	Cy,G,W	S	Top of wooden platform, west side.	0	1,998.1	13.03	2- 6-46	Well located in draw.
*4-20-32db		B	38.9	10	GI	do	Terrace deposits	Cy,W	S	Top of concrete curb	.4	1,968.0	30.62	3-12-46	Chemical analysis.
4-20-33ca	E. Snyder	Dr	30.8			do	do	Cy,W	D,S	Top of well curb	1.1	1,960.8	25.57	12- 4-45	
4-20-34ca1	City of Logan	Du	65	20	S	do	do	T,E	P				35		36-inch, gravel-packed, with 20-inch copper alloy casing.
4-20-34ca2	do	Du	65	20	S	do	do	T,E	P				35		Do.
4-20-34ca3	do	Du		20	S	do	do	T,E	P				35		Do.
4-20-36cb		B	32.3	6	GI	do	do	Cy,W	S	Top of wooden curb	.9	1,926.4	23.90	3-12-46	
T. 5 S., R. 12 W.														
5-12-28cc	G. Lerew	Du	16.3			do	Alluvium and terrace depos.	Cy,W	S	Base of pump	.6	1,576.5	10.67	11-19-45	Well located in creek valley.
5-12-31ad	D. J. Lerew	Dr	41.5	12	T	do	Terrace deposits	Cy,W	D,S	Top of wooden curb	.2	1,549.2	37.97	11-24-45	

TABLE 15.—*Records of wells in North Solomon River Valley—Continued*

WELL NUMBER[1]	Owner or tenant	Type of well[2]	Depth of well (feet)[2]	Diameter of well (in.)	Type of casing[4]	Principal water-bearing bed		Method of lift[5]	Use of water[6]	Measuring point			Depth to water level below measuring point (feet)[7]	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
						Character of material	Geologic source			Description	Distance above land surface (feet)	Height above mean sea level (feet)			
T. 5 S., R. 13 W.															
*5-13-4dc	Roy Eller	Du	43.0	24	R	Sand and gravel	Alluvium and terrace depos.	Cy,W	D,S	Top of concrete curb	.4	1,612.7	35.5	11-20-45	Observation well in Dry Creek valley. Chemical analysis.
5-13-7aa	J. Martin	Dr	39.8	......	......	do	Terrace deposits	Cy,E,W	D,S	Top of wooden platform	.2	1,597.9	34.05	11-20-45	
5-13-7cc	Ida Koch	Du	39.2	......	......	do	do	Cy,W	D,S	do	1.5	1,589.9	36.0	11-24-45	
5-13-16ba	J. H. Shambaugh	Du	40.4	30	BS	do	Crete	Cy,W	D,S	Top of wooden curb, east side.	.7	1,605.1	35.18	3-28-46	Unused farm well.
5-13-16cd	R. Kellog	Dr	31.2	8	GI	do	Terrace deposits	Cy,W	D,S	Top of casing, west side	.9	1,570.9	28.15	11-27-45	
5-13-17ba	Ella D. Smith	Dr	44.4	8	T	do	do	Cy,H	D	do	1.2	1,589.0	41.76	11-27-45	Unused farm well.
5-13-18db	Otto Meier	Dr	51.5	15	GP	do	do	......	N	Top of casing	2.8	1,588.1	37.66	6- 6-46	New well drilled for irrigation use.
5-13-19db	Ollie Conrad	B	57.9	6	T	do	do	Cy,W	D,S	Top of wooden platform	.9	1,582.7	37.89	3-29-46	
5-13-20bb	A. Bechtold, Jr.	......	40.1	8	GI	do	do	Cy,W	D,S	Top of plank over well pit, south side.	......	1,581.1	36.15	11-27-45	
5-13-22ad1	Lena Renken	B	48.2	8	T	do	do	Cy,W	D	Top of metal plate over wooden curb.	.6	1,578.0	39.25	3-29-46	
5-13-22ad2	Mo. Pac. R. R.	Du	60	10	S	do	do	Cy,G	RR	......	......	......	47	3-29-46	12 feet of good gravel.
*5-13-23dd	L. E. St. Clair	B	77.1	6	GI	Sand	Crete	N	D	Top of casing	1.8	1,607.5	65.03	4- 2-46	Chemical analysis.
5-13-25cc	Zelma Carter	Dr	51.1	10	T	Sand and gravel	do	Cy,W	D	Base of pump	.2	1,567.9	45.5	11-19-45	Observation well.
5-13-25dd	G. A. Kalbfleisch	B	58.0	12	T	do	Terrace deposits	Cy,W	D	Top of board platform, south side.	1.2	1,567.9	50.74	3-19-46	
5-13-28ac	Leonard Brown	B	39.5	12	T	do	do	Cy,W	D,S	Top of wooden platform	1.4	1,561.9	32.05	4- 1-46	
*5-13-29aa	E. J. Shanley et al.	Dr	31.7	8	GI	do	do	Cy,W	D	Top of concrete curb, north side.	.4	1,572.8	31.3	11-27-45	Unused farm well. Chemical analysis.
5-13-29ba	do	Du	41.1	30	R	do	do	Cy,W	S	Top of concrete curb, east side.	1.0	1,585.4	31.86	3-29-46	
5-13-33ba	W. L. Gearhart et al.	Dr	38.7	......	T	do	do	Cy,H	D	Top of wooden platform, west side.	0	1,559.8	26.8	11-27-45	Observation well.
*5-13-34aa	Wilbur Stewart	Dr	34.1	12	T	do	do	Cy,W	D,S	Top of pump base	.7	1,548.1	28.36	11-27-45	Chemical analysis.

T. 5 S., R. 14 W.													
5-14-1ca1	City of Gaylord	Dr	56	17	......	Sand and gravel	do.	T,E	P	Land surface	.0	1,592.6	32	5-27-46	New city well; drilled in 1946.
5-14-1ca2	City of Smith Center	Dr	70	10	......	do.	do.	T,E	P	do.			43	10- 6-40	City well no. 3.
5-14-1cd1	do.	Dr	......	12	......	do.	do.	T,E	P						City well no. 1.
5-14-1cd2	do.	Dr	68	10	......	do.	do.	T,E	P				34	8- 2-40	City well no. 2.
5-14-1db	City of Gaylord	B	70	8	......	do.	do.	T,E	P					3-20-46	
5-14-2bd	Ed Henning	B	32.2	8	GI	do.	do.	Cy,H	D	Top of wooden platform, north side.	.2	1,599.8	27.69	3-13-46	Unused farm well.
5-14-3bc	Walter Felsburg	B	48.8	12	T	do.	do.	Cy,W,T	D,S	Top of casing	.6	1,615.3	36.21	3-29-46	Observation well.
5-14-3db	W. M. Felsburg	DD	50.9	30	GP,Br	do.	do.	Cy,H	D	Top of wooden platform	.4	1,611.3	38.83	3-28-46	Dug 35 feet; 3-inch pipe driven below 35 feet.
5-14-4ba	D. F. Kirchhoff	Dr	25.8	8	GI	do.	Alluvium, terrace deposits.	Cy,W	S	Top of concrete curb	1.0	1,606.0	18.87	11-27-45	
5-14-4cb	E. W. Cole	Du	34.4	48	C	do.	Terrace deposits	Cy,W	D,S	do.	.5	1,615.3	31.60	3-29-46	Well caved in. Has sand point driven below dug part.
5-14-5ab	Elmer Frutiger	Du	36.8	30	C	do.	do.	Cy,W	D,S	Top of wooden platform	.5	1,622.6	33.51	2-26-46	
*5-14-6dc	A. A. Endsley	B	44.1	8	T	do.	do.	Cy,W	D,S	Top of wooden platform, east side.	3	1,633.6	35.93	2- 4-46	Chemical analysis.
5-14-7bc	T. L. Young and Son	......	51.8	10	T	do.	do.	Cy,W	D,S	Top of concrete curb, south side.	—.1	1,636.9	31.02	11-20-45	M. P. 0.1 foot below land surface.
5-14-10bc	E Wilson	Dr	51.3	10	T	do.	do.	Cy,W	D,S	Top of wooden platform, east side.	0	1,628.8	38.22	11-20-45	Well in creek valley.
5-14-11bd	F. J. Henry	B	61.6	8	T	do.	Terrace deposits, slope deposits.	Cy,W	D,S	Top of wooden curb	.8	1,624.9	56.53	3-28-46	Good yield reported.
*5-14-11da	Fred and Vera Horning	Dr	50.0	6	GI	do.	Terrace deposits	Cy,W	D,S	Top of well curb, north side of manhole.	.5	1,609.4	44.97	11-27-45	Chemical analysis 1950.
5-14-12ba	Ira Meadows	Dr	34.7	8	T	do.	do.	Cy,H	D	Top of casing	.2	1,589.0	30.24	11-27-45	Unused farm well.
5-14-13ac	Carl Engelke	Du	38.0	......	R	do.	do.	Cy,W	S	Top of wooden platform, west side.	1.5	1,580.4	34.56	11-19-45	
T. 5 S., R. 15 W.													
5-15-1aa	Annie McGinnis	Dr	34.0	10	T	do.	do.	Cy,H	D,S	Top of wooden platform	3.2	1,633.2	31.07	11-27-45	
*5-15-2bc	W. W. Bose et al.	Dr	24.6	8	T	do.	Alluvium	Cy,W	S	Top of concrete curb, south side.	1.8	1,632.6	17.76	11-30-45	Chemical analysis.
5-15-2dc	G. K. Wamhoff	Dr	42.2	10	T	do.	Terrace deposits	Cy,W	S	Top of wooden platform, west side.	1.2	1,652.2	34.35	11-20-45	Unused stock well used as observation well.
5-15-4bb	A. L. Reynolds	Du	36.3	36	C	do.	do.	Cy,W	D,S	Top of concrete curb	.8	1,651.9	28.57	2- 2-46	
5-15-6da	A. M. Scott	Du	47.1	30	R	do.	do.	Cy,W	D	Top of wooden platform, east side.	.1	1,676.9	44.73	11-30-45	
5-15-7da	Burian	Du	19.1	30	R	do.	Alluvium	Cy,W	D,S	Top of wooden platform, north side.	.8	1,722.4	16.10	2- 2-46	Pond in draw above well.
5-15-8ac	James Burian	Du	35.4	43	N	do.	do.	Cy,W	D,S	Top of wooden platform	1.4	1,674.0	15.91	2-18-46	Well in valley, 40 feet from Madison Creek.
5-15-9bb	P. L. Sweat	Dr	19.5	10	T	do.	Alluvium and ter. deposits.	Cy,W	S	Top of casing, west side	.1	1,669.2	13.90	11-20-45	
5-15-12ba	Ross Eller	B	45.9	8	GI	do.	Terrace deposits	Cy,W	S	Top of concrete curb, west side.	.3	1,650.7	39.54	2- 7-46	
5-15-18bb		Du	17.1	40	C,R	do.	Alluvium	Cy,H	S	do.	.3	1,766.8	12.08	2-18-46	Unused stock well, in upland draw.

Table 15.—*Records of wells in North Solomon River Valley—Continued*

Well Number[1]	Owner or tenant	Type of well[2]	Depth of well (feet)[3]	Diameter of well (in.)	Type of casing[4]	Principal water-bearing bed		Method of lift[5]	Use of water[6]	Measuring point			Depth to water level below measuring point (feet)[7]	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
						Character of material	Geologic source			Description	Distance above land surface (feet)	Height above mean sea level (feet)			
T. 5 S., R. 16 W.															
5-16-1aa	Andrew Scott	Du	43.2	30	C	Sand and gravel	Terrace deposits	Cy,W	D,S	Top of concrete curb, northwest corner.	.2	1,679.5	39.94	11-20-45	Unused farm well.
5-16-2ab	Charlotte E. Werner	Du	47.4	36	C	do	do	Cy,W	D,S	Top of concrete curb	.3	1,694.0	43.86	2-11-46	Do.
5-16-3aa	M. W. Hardman	Du	49.5	30	R	do	do	N,W	S	Top of wooden curb	.6	1,703.7	44.64	11-20-45	Unused stock well. Used as observation well.
*5-16-3bc	J. S. Wyrill	Du	112.3	42	Br		Niobrara, Sanborn.	Cy,W	D,S	Top of concrete curb, north side.	1.6	1,779.4	66.56	2-14-46	Chemical analysis.
5-16-4ba	L. I. Rader	Du	33.7	24	R	Sand and gravel	Terrace deposits	Cy,W	D,S	Top of concrete curb, west side.	.4	1,702.9	31.69	2-14-46	
5-16-5ca	G. T. Perkins	Du	44.1	48	C	do	do	Cy,W	D,S	Top of concrete curb, north side.	.5	1,720.6	25.82	2- 8-46	Unused farm well.
5-16-6aa	L. W. Lemon	DD	29.3	24	I	do	do	Cy,W	D,S	Top of iron casing	0	1,720.4	26.21	2-13-46	"Quicksand" reported in well.
5-16-6dd	School District	Dr	38.2	12	T	do	do	Cy,H	N	Top of wooden platform, west side.	.2	1,727.5	26.07	2- 8-46	Unused school well.
5-16-8ca	E. C. Wickwar	Dr	49.7	10	T	do	do	Cy,W	D,S	Edge of board cover, north side.	.4	1,734.0	27.59	11-21-45	
5-16-18ad	Vernon Townley	DD	33.4	30	Br	do	do	Cy,W	D,S	Top of concrete curb, north side.	.8	1,740.6	29.33	2-14-46	Pipe driven 20 feet below bottom of dug well.
T. 5 S., R. 17 W.															
5-17-1aa	Public road	Dr	33.8	4	I	do	Alluvium	N	N	Top of pipe	0	1,697.1	7.60	11-21-45	Abandoned test hole used as observation well.
5-17-1cb	E. R. Downing et al	Du	64.4	48	C	do	Terrace deposits	Cy,W	S	Top of wooden curb, east side.	.3	1,756.6	64.27	2- 9-46	Unused stock well.
5-17-2ab	Federal Land Bank	B	61.4	12	T	do	do	Cy,W	S	Top of metal plate over wooden platform.	1.3	1,733.3	36.32	2- 9-46	
5-17-3cd		Du	65.6	60	R	do	Alluvium	N	N	Top of rock curb	1.0	1,812.7	12.74	11-23-45	Observation well.
5-17-12aa	E. R. Downing et al	Du	55.0	36	C		Niobrara, Sanborn.	Cy,W	D,S	Top of wooden platform	1.0	1,807.3	53.89	2-13-46	Do.
5-17-12dd	F. R. Ewing	Du	28.5	27	Br	Sand and gravel	Terrace deposits	Cy,W	D,S	Top of concrete curb, west side.	.8	1,741.2	27.99	2-16-46	

T. 5 S., R. 18 W.													
5-18-6aa	A. D. Nay	Du	14.6	......	......	do	Alluvium	Cy,W	D,S	Top of board platform	.2	1,821.6	11.9	12- 5-46	
5-18-6bd	......	Dr	50.5	8	GI	do	Terrace deposits	Cy,W,G	S	Top of concrete curb	.4	1,839.6	25.49	3-22-46	Unused stock well.
5-18-6cd	......	Du	46.1	45	C	do	do	Cy,W	D,S	Top of wooden platform, west side.	.5	1,863.8	27.13	1-29-46	
T. 5 S., R. 19 W.													
5-19-2da	......	Du	31.6	......	R	do	Alluvium	Cy,W	S	Top of wooden curb, south side.	3.7	1,868.5	16.7	11-21-45	Well located in draw.
5-19-4ab	......	Du	26.7	36	R	do	do	Cy,W	S	Top of wooden platform	1.2	1,914.8	20.88	3-22-46	Unused stock well, located in upland draw.
5-19-5ab	......	B	15.5	6	GI	do	do	Cy,H	S	Top of casing, north side	0	1,909.2	9.76	12- 4-45	Do.
5-19-6ba	Becker	Du	48.0	48	W	do	Terrace deposits	Cy,W	D,S	Base of pump, north side	1.1	1,930.8	41.04	3-12-46	
T. 5 S., R. 20 W.													
5-20-2bd	......	Dr	55.3	12	GI	do	do	Cy,W	D,S	Top of wooden platform, north side.	.3	1,964.9	50.88	2- 1-46	
5-20-3bc	......	Dr	42.7	8	GI	do	do	Cy,G,W	S	do	.5	1,962.8	36.22	12- 4-45	
5-20-4ca	......	Dr	57.0	6	GI	do	do	Cy,W	D,S	do	1.4	1,976.1	43.30	2- 1-46	
5-20-5db	O. H. Miller	B	37.2	12	GI	do	do	Cy,W	S	Top of wooden platform, west side.	1.5	1,970.9	31.42	2- 1-46	
5-20-6ad	D. G. Hansen	Dr	39.3	10	T	do	do	Cy,W	D,S	Top of casing, south side	1.1	1,979.1	28.8	12- 4-45	
5-20-7ab	......	B	12.5	6	GI	do	Alluvium	Cy,W	S	Top of wooden curb	0	1,987.4	7.12	1-25-46	Well in draw near spring-fed creek.
5-20-10aa	A. Woltman	Du	22.8	52	Br	do	Alluvium, slope deposits.	Cy,W	D,S	Top of wooden curb, north side.	.8	1,998.4	18.22	1-25-46	Observation well.
T. 6 S., R. 10 W.													
6-10-5dd	Elmer Bock	Dr	37.6	12	T	do	Crete	Cy,W	D	Pump base, west side	.5	1,530.2	25.38	5- 6-46	Unused farm well.
6-10-6dd	Charles Vasterling	Du	22.6	......	R	do	do	Cy,W	D,S	Top of wooden platform	.2	1,511.6	18.93	5- 6-46	Do.
6-10-18bb	John Schoen	Dr	39.9	12	T	do	Terrace deposits	Cy,W	D,S	do	.7	1,483.5	25.35	5- 6-46	
*6-10-20aa	Clifton Helvey	Du	36.7	36	R	do	Crete	Cy,W	D,S	do	.6	1,508.0	33.40	5- 6-46	Chemical analysis.
6-10-30bb	F. S. Klechner	Du	50.0	36	R	do	do	N	N	Top of concrete curb, west side.	.5	1,491.4	47.70	5- 6-46	Abandoned farm well.
6-10-33bb	J. K. Marcheiter	Du	43.8	36	R	do	Terrace deposits	Cy,W	D,S	Top of wooden platform	.6	1,460.5	39.54	5- 7-46	
T. 6 S., R. 11 W.													
6-11-1bb	Vandergiesen	Dr	34.4	12	T	do	do	J,E	S	Top of casing	.8	1,504.6	25.0	11-23-45	Test hole 200 feet south of well reported shale at 34 feet, no gravel.
6-11-5bc	Boyd Lytle	Dr	16.6	10	T	do	Alluvium	Cy,W	S	do	2.5	1,571.5	13.5	11-17-45	Unused stock well located along draw.
6-11-5dd	A. W. Hefly	Du	21.15	27	R	do	do	Cy,W	D,S	Top of stone curb, west side.	1.5	1,599.2	12.02	3-26-46	Unused farm well.
6-11-9cc	J. G. McClum	Du	19.9	33	R	do	do	Cy,W	D,S	Top of wooden platform, south side.	.3	1,544.0	10.43	3-13-46	Do.
6-11-10ba	Henry Mansholt	Du	33.7	48	R	do	do	Cy,W	S	Top of wooden platform, east side.	0	1,557.2	10.57	3-13-46	

TABLE 15.—*Records of wells in North Solomon River Valley—Continued*

WELL NUMBER[1]	Owner or tenant	Type of well[2]	Depth of well (feet)[3]	Diameter of well (in.)	Type of casing[4]	Principal water-bearing bed		Method of lift[5]	Use of water[6]	Measuring point			Depth to water level below measuring point (feet)[7]	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
						Character of material	Geologic source			Description	Distance above land surface (feet)	Height above mean sea level (feet)			
6-11-11dd	C. J. Foreaker	Du	29.0	42	R	Sand and gravel	Alluvium	Cy,W	S	Top of wooden platform, west side.	.3	1,540.0	25.45	3-13-46	
6-11-14dd	E. D. Frizell	B	55.4	12	T	do.	Crete	Cy,W	D,S	Top of wooden curb, north side.	.8	1,526.6	51.48	3-26-46	
6-11-15aa	W. Hofmeister et al.	B	23.5	8	GI	do.	Alluvium	Cy,H	D	Top of wooden curb, north side of pump.	.7	1,529.0	18.08	3-26-46	Unused farm well in draw.
6-11-16da	E. Stoltenberg	Dr	35.9	12	GI	do.	Crete	Cy,W	S	Top of casing, east side	.8	1,524.3	33.7	11-23-45	Unused stock well at head of small draw.
6-11-17cc	Charles E. Wiese	Dr	34.2	10	T	do.	do.	Cy,W	D,S	Top of wooden platform	1.0	1,530.5	29.49	11-17-45	
6-11-18ba	G. J. Vanderiet	Dr	57.1	12	T	do.	Alluvium, Crete	Cy,W	D,S	Top of wooden platform, north side at pump.	.2	1,537.6		2-22-46	Located in small upland draw.
6-11-19dd	H. D. Hampton	Dr	48.3	6	GI	do.	Terrace deposits	Cy,W	S	Top of wooden platform, north side.	.2	1,496.6	34.25	3-26-46	
6-11-20aa	J. H. Poppen	B	35.0	12	T	do.	Alluvium	Cy,W	D,S	Pump base, south side	.5	1,514.5	22.60	3-20-46	
6-11-20dc	F. W. Heiser	B	52.1	8	T	do.	Terrace deposits	Cy,H	D	Top of wooden platform	.5	1,495.5	30.18	3-26-46	
6-11-22aa	W. H. Getty	B	49.5	12	T	do.	Crete	Cy,W	D,S	do.	.6	1,520.0	42.38	3-13-46	Unused farm well.
*6-11-24ad	H. A. Fink	Dr	38.8	6	GI	do.	do.	Cy,W	S	Top of wooden curb, south side.	.5	1,505.2	35.85	11-15-45	Chemical analysis.
6-11-26aa	W. Fletcher	Dr	30.1	12	T	do.	Terrace deposits	Cy,W	D,S	Top of wooden platform, west side.	.5	1,487.7	22.23	3-26-46	Unused farm well.
6-11-27c	City of Downs	Dr	62			do.	do.	T,E	P				24	5-21-46	15 feet of water-bearing material reported.
6-11-27db	B. Getty	Dr	38.2	8		do.	do.	Cy,W	D,S	Top of wooden platform	.7	1,479.3	31.85	11-26-45	
6-11-28a1	Mo. Pac. R. R.	Dr	57	12		do.	do.	T,E	R.R.					6-14-46	Gravel-walled well. Reported pumpage 17,600 gpd.
6-11-28a2	do.	Dr	41	12		do.	do.	N	N				35	2-21-36	Abandoned R. R. supply well.
6-11-28d1	City of Downs	Du	49			do.	do.	T,E	P				24	5-21-46	Original city well at pump house.
6-11-28d2	do.	Dr	50			do.	do.	T,E	P				24	5-21-46	Gravel-packed well southwest of pump house.

6–11–28d3	do	Dr	50	......	......	do	do	T,E	P	......	......	......	24	5–21–46	Gravel-packed well northwest of pump house.
6–11–29dd	E. Richardson	Du	41.3	30	R	do	do	Cy,W	D,S	Top of wooden platform, east side of pump.	1.3	1,493.7	37.33	3–26–46	
6–11–30bc	G. E. Dick	Dr	40.9	12	T	do	do	Cy,W	D	Top of casing, north side	3.1	1,499.2	30.08	11–26–45	
6–11–32cc	J. R. Riemann	B	45.5	6	GI	do	do	Cy,W	D,S	Top of concrete curb, north side of pump.	1.1	1,503.8	38.39	2–22–46	
6–11–33aa	Lyle Warner	DD	48.7	36	R,GP	do	do	Cy,W	D,S	Top of concrete curb	.5	1,490.1	39.41	3–27–46	Dug 35 feet; 3-inch pipe driven below 35 feet.
6–11–34aa	William Lowdon	Du	40.8	......	R	do	do	N	N	Top of stone curb	0	1,482.1	36.48	11–26–45	Unused farm well used as observation well.
6–11–36aa	John M. Irey	Dr	35.5	8	T	do	do	Cy,H	D	Top of tile casing, north side.	0	1,468.3	32.8	11–15–45	Do.
6–11–36bc	Carrie Goheen et al.	Du	38.1	......	R	do	do	Cy,W	S	Top of stone curb, east side.	.8	1,480.1	36.8	11–26–45	
T. 6 S., R. 12 W.															
*6–12–5cb	City of Portis	Du	60.8	72	......	do	do	T,E	P	Top of pump-house foundation.	.6	1,529.0	47.51	3–23–46	Chemical analysis.
6–12–5dd	W. L. and A. M. Lemon	Du	40.1	30	R	do	do	Cy,W	D,S	Top of board platform	.5	1,530.0	36.77	3–19–46	
6–12–6bb	C. W. Angell estate	Dr	43.8	12	T	do	do	Cy,W	D,S	Top of wooden platform	.8	1,538.8	35.08	3–19–46	
6–12–7ab	J. G. Rube	Dr	48.3	8	GI	do	do	Cy,W	D,S	Top of concrete curb, north side.	.5	1,518.6	34.67	3–15–46	Unused farm well.
6–12–7cc	H. Bihlmaier	Dr	50.3	8	T	do	do	Cy,H	D	do	.2	1,543.9	45.64	11–23–45	
6–12–9ab	G. P. Nixon	B	45.7	6	GI	do	Alluvium, terrace deposits.	Cy,W	D,S	Pump base, north side	.6	1,510.5	23.34	3–23–46	
6–12–9dd	B. J. Hutchinson	B	50.75	12	T	do	Terrace deposits	Cy,W,G	D,S	Top of wooden platform, west side.	.9	1,518.5	33.50	2– 7–46	
6–12–10aa	J. Yost	Du	16.2	......	......	do	Alluvium	Cy,H	S	Top of wooden platform	1.7	1,581.0	14.5	11–19–45	Unused stock well.
6–12–12da	C. E. Hofer	Du	38.7	......	C	do	do	Cy,W	S	Top of wooden curb	1.6	1,524.9	33.34	11–26–45	
6–12–14ad	J. P. Solner	Dr	45.0	12	T	do	Terrace deposits	Cy,H	D,S	Top of concrete curb, west side.	.8	1,512.9	37.50	3–23–46	Unused farm well.
6–12–14bb	S. Bomhuer	Dr	50.8	12	T	do	do	Cy,H	D	Top of casing, west side	.7	1,512.9	33.74	3–19–46	Do.
6–12–16bc	Louise Boomer	Dr	49.0	12	T	do	do	Cy,W	D,S	Top of concrete curb, south side.	.3	1,526.9	35.24	1–31–46	
6–12–16dd	do	Dr	31.3	12	T	do	do	Cy,W	D	do	.6	1,514.0	29.1	11–26–45	
6–12–18aa	I. L. Chase	B	40.0	12	T	do	do	Cy,W	D,S	Top of wooden platform	0	1,526.6	29.55	3–19–46	
6–12–20bb	C. M. Storer	Dr	55.4	12	T	do	Crete, alluvium	Cy,W	S	Top of casing, west side	1.5	1,556.2	37.8	11–17–45	Unused stock well used as observation well.
6–12–21ca	E. E. Hall	Du	53.4	......	R	do	Crete	Cy,W	S	Top of wooden platform, north side.	0	1,559.3	43.35	11–26–45	
*6–12–23aa	F. D. Kimble	Dr	44.2	12	T	do	Terrace deposits	Cy,W	D,S	Top of concrete frame for trap door.	.3	1,507.3	33.15	3–26–46	Chemical analysis.
6–12–23bb	Aaron Fink	Dr	56.1	12	T	do	do	Cy,G,W	D,S	Top of wooden platform, east side.	.4	1,509.7	33.20	3–19–46	GI casing inside tile.

TABLE 15.—*Records of wells in North Solomon River Valley—Concluded*

WELL NUMBER[1]	Owner or tenant	Type of well[2]	Depth of well (feet)[3]	Diameter of well (in.)	Type of casing[4]	Principal water-bearing bed		Method of lift[5]	Use of water[6]	Measuring point			Depth to water level below measuring point (feet)[7]	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
						Character of material	Geologic source			Description	Distance above land surface (feet)	Height above mean sea level (feet)			
6-12-23cd	C. Fink	Du	31.8	36	R	Sand and gravel	Terrace deposits	Cy,W	D	Top of wooden platform, south side.	.8	1,505.8	27.59	11-26-45	Observation well.
6-12-24aa	L. J. Konzem	Dr	49.3	......	T	do	do	Cy,W	S	Top of wooden platform	1.0	1,507.6	38	11-23-45	Do.
6-12-26cb	E. E. Easterly	Dr	69.8	12	T	do	Crete	Cy,W	D,S	Top of wooden platform, south side.	.3	1,542.1	63.50	3-27-46	
6-12-26dd	B. F. Otte	Du	38.0	......	R	do	Alluvium	Cy,W	S	Top of concrete curb, north side.	1.0	1,513.6	28.72	11-26-45	Well located in draw.
6-12-27ba	E. E. Fink	Dr	73.4	12	T	do	Crete	Cy,W	D,S	do	.4	1,542.9	61.37	3-27-46	
6-12-28dc	Lloyd Coop	Du	26.0	48	R	do	Alluvium	Cy,W	D,S	Top of board platform	1.7	1,581.2	9.33	3-27-46	Located in upland draw.
6-12-36ad	Fed. Land Bk., Wichita	Dr	54.7	12	T	do	Crete	Cy,W	D	Edge of wooden platform, south side.	.1	1,518.2	48.27	11-17-45	Unused farm well.
T. 6 S., R. 13 W.															
6-13-1aa	M. W. Hardman	B	48.1	12	T	do	Terrace deposits	Cy,W	D,S	Top of concrete curb	1.0	1,538.8	38.47	1-31-46	
6-13-2aa	Roy McComas	B	61.5	12	T	do	do	Cy,W	D,S	Top of wooden curb	1.1	1,543.6	41.74	1-31-46	
6-13-3bb	Morty Watkins	B	37.0	12	T	do	do	Cy,H	D,S	Top of wooden platform at base of pump.	1.5	1,555.6	32.86	4- 1-46	
6-13-4bb	W. S. Lee	B	40.4	8	GI	do	Crete, alluvium	Cy,W	D,S	Top of wooden platform	.6	1,583.9	28.00	1-31-46	Owner reports well not drilled to bedrock (Carlile shale).
6-13-4da	E. F. Bradskey	Dr	29.9	......	......	do	Crete	Cy,W	S	Top of pump base, west side.	1.0	1,597.5	26.64	11-19-45	
6-13-9da	Charles Knoll	B	42.6	8	GI	do	Alluvium	Cy,W	D,S	Top of wooden platform	1.3	1,599.4	11.78	1-31-46	Located in Lawrence Creek valley; quicksand reported in well.
6-13-10aa	Charles Booz	Dr	44.8	12	T	do	Crete	Cy,W	D,S	Top of wooden curb, south side.	0	1,592.5	42.47	1-31-46	
*6-13-12ba	F. L. Smith	Dr	47.9	......	......	do	Terrace deposits	Cy,W	D,S	Top of wooden platform, east side.	.2	1,545.4	40.7	11-14-45	Chemical analysis. Observation well.
6-13-12cc	Pearl McMillan	Dr	48.8	12	T	do	Alluvium, terrace deposits.	Cy,W	S	Top of concrete curb, south side.	0	1,556.5	28.29	3-15-46	Located along small creek.

T. 7 S., R. 10 W.															
7-10-5ad	Leo Walter	Du	20.9	36	R	do	Terrace deposits	Cy,W	D,S	Top of wooden platform	.9	1,465.9	19.25	5- 6-46	
T. 7 S., R. 11 W.															
7-11-1ba	C. P. Simmons	Du	16.5	......	R	do	Alluvium	Cy,W	S	Top of pump base, west side.	0	1,479.5	10.36	11-26-45	Well located in draw.
7-11-2ab	C. C. Carswell	Du	21.9	30	R	do	do	Cy,W	S	Top of concrete curb, west side.	0	1,489.0	11.38	11-16-45	Do.
7-11-3bb	J. D. Cox	Dr	38.6	6	GI	do	Terrace deposits	Cy,W	S	Top of casing, north side	.3	1,493.2	32.63	11-16-45	
7-11-4bb	Onna Socken	Dr	36.1	12	T	do	do	N	N	Top of brick curb, east side.	0	1,491.5	31.99	2-22-46	Abandoned stock well.

1. Well number indicates, in the following order, township, range, section, quarter section, and quarter-quarter section.
2. B, bored well; DD, dug and driven well; Dr, drilled well; Du, dug well; DDr, dug and drilled well.
3. Reported depths below the land surface are given in feet; measured depths are given in feet and tenths below measuring points.
4. Br, brick; C, concrete; GI, galvanized sheet iron; GP, galvanized-iron pipe; I, iron; N, none; R, rock; S, steel; T, tile; W, wood.
5. Method of lift: Cy, cylinder; N, none; T, turbine.
   Type of power: E, electric; G, gas engine; H, hand operated; J, jet; T, tractor; W, windmill.
6. D, domestic; N, not being used; O, observation; P, public supply; RR, railroad; S, stock.
7. Measured depths to water are given in feet, tenths, and hundredths; reported depths are given in feet.

* Chemical analysis given in table 7 or 8.

LOGS OF TEST HOLES AND WELLS

The logs of 117 test holes and water wells in the North Solomon Valley are given on the following pages. Fifty-five of these are sample logs of test holes drilled by the State Geological Survey in May 1946, 19 are of test holes drilled by the U. S. Bureau of Reclamation and Corps of Engineers along the axis of the proposed Kirwin dam, and 43 are of test holes and wells drilled by private drillers. The samples of test holes drilled by the Geological Survey were collected and studied in the field by J. B. Cooper and were studied in the office by me. Water-level measurements are in feet below land-surface datum.

4-14-18dc. *Sample log of test hole in SW¼ SE¼ sec. 18, T. 4 S., R. 14 W., Smith County, 6 feet north of center of road and 0.3 mile west of road intersection. Surface altitude, 1,701.0 feet. Water level, 56.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations		
Silt, loose, brown (soil)	2	2
Silt, very loose, sandy, tan	5	7
Silt, medium-grained, compact, sandy, dark-brown and reddish	6	13
Silt, sandy, light-gray	3	16
Silt, fairly compact, brown to yellow-brown, and very fine to fine sand	11	27
Silt, medium soft, light-gray to cream, and very fine sand	5	32
Silt, soft, cream, gray, and yellow, and fine to medium quartz sand; contains many chalk pebbles	6	38
Sand, fine to coarse, quartz; contains much white silt, gravel, and chalk pebbles	14	52
CRETACEOUS—Gulfian		
Niobrara formation—Fort Hays limestone member		
Clay, chalky-white to yellowish; contains chalk fragments	3	55
Chalk, white and yellow-brown	2	57
Chalk, hard, white	3	60

4-14-19bc. *Sample log of test hole at the SW cor. NW¼ sec. 19, T. 4 S., R. 14 W., Smith County, 10 feet east of center of road at 0.5 mile line. Surface altitude, 1,666.2 feet. Water level, 29.8 feet.*

	Thickness, feet	Depth, feet
Road fill, silt and limestone pebbles	4	4
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, compact, calcareous, sandy, gray-buff; contains snail shells	7	11
Silt, soft, tan; fine to coarse quartz sand; gravel; and chalk pebbles	5	16
Silt, compact, sandy, red-tan	10	26
Silt, soft, sandy, buff	4	30
Silt, sandy, tan; limestone gravel and pebbles	6	36
Silt, sandy, dark-chocolate brown and gray-brown (Loveland soil ?)	4	40
Silt, sandy, light-gray, iron-stained; contains loose gravel and snail shells	9	49
Sand, very fine to coarse, quartz and gravel; contains silt and 1-inch chalk pebbles	8	57
Sand and gravel, very fine sand to 2-inch chalk pebbles, iron-stained and yellow	2	59
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, plastic, noncalcareous, dark gray-black	1	60

4-14-29bb. *Sample log of test hole in the NW¼ NW¼ sec. 29, T. 4 S., R. 14 W., Smith County, 10 feet east of center of road and 0.1 mile south of road intersection. Surface altitude 1,654.1 feet. Water level, 38.1 feet.*

	Thickness, feet	Depth, feet
Road fill, silt, sandy, and limestone pebbles	6	6
QUATERNARY—Pleistocene		
Terrace (?) deposits		
Silt, calcareous, sandy, light gray-buff	6.5	12.5
Silt, calcareous, sandy, medium-gray	2.5	15
Silt, light-buff; contains white caliche and fine quartz sand	20	35
Sand, very fine to medium, quartz; contains silt and small chalk pebbles	2	37
Sand, fine to coarse, quartz; chalk; and fine to coarse gravel; contains silt and silicified chalk pebbles	11	48
Gravel, coarse, chalk pebbles, and fine to coarse quartz sand	6.5	54.5
Gravel, coarse, chalk, silicified chalk pebbles, and fine to coarse quartz sand	15.5	70
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, dark gray-black	6.5	76.5

4-14-30dd. *Sample log of test hole in the SE¼ SE¼ sec. 30, T. 4 S., R. 14 W., Smith County, 10 feet west of center of road, 140 feet north of bridge over Cedar Creek, and 0.1 mile north of road intersection. Surface altitude, 1,616.9 feet. Water level, 20.2 feet.*

	Thickness, feet	Depth, feet
Road fill, silt and chalk boulders	6	6
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Sand, fine to coarse, quartz; brown silt, and angular chalk fragments	22	28
Sand, very fine to medium, quartz; contains coarse sand and a few limestone pebbles	8	36
Sand, fine to coarse, quartz, and fine to coarse gravel; contains chalk pebbles up to ½ inch in diameter and shale fragments	4	40
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale concretion, very hard, calcareous, dark-gray to gray, shale fragments	1	41

4-14-31ad. *Sample log of test hole in SE¼ NE¼ sec. 31, T. 4 S., R. 14 W., Smith County, 10 feet west of center of road and 0.4 mile south of road intersection. Surface altitude, 1,630.3 feet. Water level, 39.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt; contains limestone fragments (soil)	4	4
Silt, soft, tan	7	11
Silt, soft, noncalcareous, light-tan	7	18
Silt, fairly soft, sandy, dark gray-buff	3	21
Silt, soft, sandy, light-gray; contains snail shells	2	23
Sand, very fine to coarse; contains granitic gravel and chalk pebbles	15	38
Sand, fine to coarse, quartz and granitic, and fine to coarse gravel; contains chalk pebbles	10	48
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member	feet Thickness,	feet Depth,
Shale concretion, very hard, calcareous, dark-gray to brown	1.5	49.5
Shale, clayey, noncalcareous, dark-gray	5.5	55

4-14-31dd. *Sample log of test hole in the SE¼ SE¼ sec. 31, T. 4 S., R. 14 W., Smith County, 36 feet west of center of road, 120 feet south of railroad crossing at Cedar. Surface altitude, 1,627.3 feet. Water level, 31.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, compact, dark-brown (soil)	4	4
Silt, soft, sandy, light gray-tan	14	18
Sand, very fine to coarse; contains sand, fine gravel, and limestone pebbles	22	40
Gravel, fine to coarse, granitic and chalk; contains sand,	4	44

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, plastic, noncalcareous, dark gray-black	6	50

4-16-28ca1. *Log of core hole DH-104, in the NE¼ SW¼ sec. 28, T. 4 S., R. 16 W., Phillips County, 140 feet north and 600 feet west of center of street intersection near Kirwin water tower; drilled by U. S. Bureau of Reclamation, February 1946. Surface altitude, 1,760.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Sand, fine, compact, silty, gray	38.6	38.6
CRETACEOUS—Gulfian		
Niobrara formation—Fort Hays limestone member		
Chalk, firm, gray	10	48.6

4-16-28ca2. *Log of core hole DH-105, in the NE¼ SW¼ sec. 28, T. 4 S., R. 16 W., Phillips County, 475 feet north and 970 feet west of center of street intersection near Kirwin water tower; drilled by the U. S. Bureau of Reclamation, February 1946. Surface altitude, 1,760.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, compact, brown	37	37
Sand, fine, silty, compact, gray	5.6	42.6
CRETACEOUS—Gulfian		
Niobrara formation—Fort Hays limestone member		
Chalk, firm, hard, gray	11	53.6

4-16-28cd. *Log of core hole DH-107 in the SE¼ SW¼ sec. 28, T. 4 S., R. 16 W., Phillips County, 210 feet south and 170 feet west of center of street intersection near Kirwin water tower; drilled by U. S. Bureau of Reclamation, February 1946. Surface altitude, 1,752.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, compact, brown	35	35
Sand, compact, silty, gray	3	38
CRETACEOUS—Gulfian		
Niobrara formation—Fort Hays limestone member		
Chalk, firm, gray	10.7	48.7

4-16-28dc1. *Log of core hole DH-128 in the SW¼ SE¼ sec. 28, T. 4 S., R. 16 W., Phillips County, 10 feet east and 560 feet south of center of street intersection near Kirwin water tower; drilled by U. S. Bureau of Reclamation, March 1946. Surface altitude, 1,731.5 feet. Water level, 33 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Clay-loam, stiff to plastic, silty, brown	18.6	18.6
Sand, medium-grained, compact, clean, gray; contains chalk fragments	13.4	32

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Niobrara chalk—Fort Hays limestone member		
Chalk, weathered, gray; contains soft seams	6	38
Chalk, firm, gray; contains soft broken seams	19.5	57.5
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, firm, blue	10	67.5

4-16-28dc2. *Log of core hole DH-129, in the SW¼ SE¼ sec. 28, T. 4 S., R. 16 W., Phillips County, 920 feet south and 190 feet east of center of street intersection near Kirwin water tower; drilled by U. S. Bureau of Reclamation, March 1946. Surface altitude, 1,707.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Loam, fine, compact, brown	19.5	19.5
Sand, compact, silty, brown	6.5	26
Loam, compact, brown	12.6	38.6
Sand, fine, compact, silty, brown	2.4	41
Sand, fine, compact, clean, gray	6	47
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, weathered, stiff, brown	0.6	47.6
Shale, firm, blue	10.2	57.8

4-16-28dc3. *Log of drive-sample hole TH-9, in the SW¼ SE¼ sec. 28, T. 4 S., R. 16 W., 40 feet north and 2,275 feet west of SE cor. sec. 28; drilled by U. S. Bureau of Reclamation, November 1945. Surface altitude, 1,695.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Clay, silty, tight, brown	15.5	15.5
Sand, fine, compact, silty, buff	14.5	30
Sand, medium, compact, clean, gray	6	36
Sand, coarse, compact, brown	3	39
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, tight, noncalcareous; top slighty weathered and brown, base, firm, blue	3	42

4-16-33ab1. *Log of drive-sample hole TH-6, in the NW¼ NE¼ sec. 33, T. 4 S., R. 16 W., Phillips County, 1,250 feet south and 1,520 feet west of NE cor. sec. 33; drilled by U. S. Bureau of Reclamation, January 1946. Surface altitude, 1,695.9 feet. Water level, 36 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Loam, sandy, brown	3	3
Sand, fine, compact, silty, buff	37	40
Clay, lean, stiff, silty, buff	6	46
Sand, medium, silty, buff	6	52
Sand, coarse, compact, gray; contains chalk fragments	16	68
Silt, stiff, compact	6	74

	Thickness, feet	Depth, feet
Sand, coarse, compact, gray; contains chalk fragments	1	75
Sand, coarse, compact, gravelly, gray; contains chalk fragments	7	82
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, firm, blue	1.5	83.5

4-16-33ab2. *Log of drive-sample TH-7, in the NW¼ NE¼ sec. 33, T. 4 S., R. 16 W., Phillips County, 820 feet south and 1,770 feet west of NE cor. sec. 33; drilled by U. S. Bureau of Reclamation, 1945. Surface altitude, 1,695.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, compact, sandy, brown	5	5
Loam, compact, sandy, brown	4	9
Clay, lean, compact, brown	3	12
Silt, fine, compact, sandy, brown	6	18
Clay, lean, stiff, brown	3	21
Sand, fine, firm, silty, buff	5	26
Clay, lean, stiff, buff	9	35
Silt, buff	3	38
Sand, fine, compact, silty, gray	1	39
Sand, medium, gray; contains silt	9	48
Sand, fine, compact, silty, gray	3	51
Silt, stiff, compact, dark-gray	3	54
Sand, medium-grained, compact, gray	3	57
Sand, coarse, compact, gravelly, clean, gray; contains chalk fragments	3	60
Sand, medium-grained, clean, gray	3	63
Sand, coarse, clean, compact, gray	3	66
Sand, coarse, gravelly	2.5	68.5
Talus, chalk; gravel to 1½ inches, broken chalk to 1¼ inches, colors uneven	5	73.5
Clay, lean, stiff, silty, brown	2.5	76
Silt, soft, brown	3	79
Sand, medium, compact, clean, gray; contains gravel	5.3	84.3
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, firm, blue	0.7	85

4-16-33ab3. *Log of drive-sample hole TH-8 in the NW¼ NE¼ sec. 33, T. 4 S., R. 16 W., Phillips County, 390 feet south and 2,020 feet west of NE cor. sec. 33; drilled by U. S. Bureau of Reclamation, January 1946. Surface altitude, 1,695.5 feet. Water level, 60 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Loam, sandy, brown	3	3
Silt, fine, compact, buff	21	24
Silt, fine, compact, sandy, buff	6	30

	Thickness, feet	Depth, feet
Silt, soft, compact, buff	3	33
Sand, fine, compact, gray	3	36
Silt, soft, brown	18	54
Clay, firm, stiff, silty, blue	27	81
Sand and silt, compact, gray; contains chalk fragments	3	84
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, firm, blue	2	86

4-16-33ad1. *Log of drive-sample hole TH-3, in the SE¼ NE¼ sec. 33, T. 4 S., R. 16 W., Phillips County, 460 feet north of north end of bridge over Solomon River and 820 feet west of section line road; drilled by U. S. Bureau of Reclamation, December 1945. Surface altitude, 1,674.1 feet. Water level, 20 feet.*

QUATERNARY—Pleistocene Alluvium (Recent)	Thickness, feet	Depth, feet
Sand, fine, compact, silty, brown	7.5	7.5
Sand, fine, compact, clean, gray	4.5	12
Clay, lean, stiff, silty, brown	15.5	27.5
Clay, very stiff, blue	11.5	39
Clay, lean, stiff, compact, brown	3	42
Sand, fine, compact, silty, gray	3	45
Sand, fine, compact, clean, gray	3	48
Sand, medium-grained, compact, clean, gray; contains broken chalk fragments	6	54
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, firm, blue	1	55

4-16-33ad2. *Log of drive-sample hole TH-4, in the SE¼ NE¼ sec. 33, T. 4 S., R. 16 W., Phillips County, 790 feet north and 1,010 feet west of north end of North Solomon River bridge; drilled by the U. S. Bureau of Reclamation, December 1945. Surface altitude, 1,698.1 feet. Water level, 38 feet.*

QUATERNARY—Pleistocene Terrace deposits	Thickness, feet	Depth, feet
Sand, fine, compact, silty, brown	33	33
Clay, lean, compact, stiff, buff	18	51
Clay, firm, stiff, silty, blue	32	83
Sand, coarse, compact, gray	6	89
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, firm, blue	...	...

4-16-33ad3. *Log of drive-sample hole TH-5, in the SE¼ NE¼ sec. 33, T. 4 S., R. 16 W., Phillips County, 1,680 feet south and 1,260 feet west of NE cor. sec. 33; drilled by U. S. Bureau of Reclamation, November 1945. Surface altitude, 1,696.7 feet. Water level, 40 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Sand, fine, silty, brown	2.5	2.5
Silt, firm, brown	14.5	17
Clay, lean, firm, brown	3	20
Silt, firm, light-brown	7.5	27.5
Clay, lean, firm, brown	12.5	40
Sand, fine, compact, brown	6	46
Silt, gray	9	55
Sand, very fine, gray	7	62
Silt, compact, dark-gray	9	71
Clay, lean, firm, dark-gray	3	74
Clay, stiff, blue	5.5	79.5
Gravel, coarse, compact, gray; contains clay	3.5	83
Sand, coarse, compact	1.5	84.5
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, firm, blue	2.5	87

4-16-33da1. *Log of drive-sample hole TH-1, in the NE¼ SE¼ sec. 33, T. 4 S., R. 16 W., Phillips County, 390 feet south and 270 feet west of south end of North Solomon River bridge; drilled by U. S. Bureau of Reclamation, December 1945. Surface altitude, 1,673 feet. Water level, 11.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Sand, fine, compact, gray	13	13
Sand, medium-grained, compact, clean, gray	15	28
Sand, medium-grained, clean, gray; contains gravel and chalk fragments	10	38
Sand, coarse, gray; contains chalk fragments	2.5	40.5
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, firm, blue; upper part weathered	2.5	43

4-16-33da2. *Log of drive-sample hole TH-2, in the NE¼ SE¼ sec. 33, T. 4 S., R. 16 W., Phillips County, 510 feet west of south end of North Solomon River bridge; drilled by U. S. Bureau of Reclamation, December 1945. Surface altitude, 1,672.8 feet. Water level, 11 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Sand, fine, compact, gray	3	3
Sand, medium-grained, compact, clean, gray	7	10
Sand, coarse, compact, clean, gray; contains chalk fragments	9	19
Sand, fine, compact, silty, gray	3	22
Sand, medium-grained, compact, gray; contains many chalk fragments	9	31
Sand, coarse, compact, gravelly, clean, gray	3	34

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, firm, blue-gray; upper 0.5 foot weathered	3	37

4-16-34cb. *Log of core hole DH-127, in the NW¼ SW¼ sec. 34, T. 4 S., R. 16 W., Phillips County, 1,370 feet north and 60 feet east of SW cor. sec. 34; drilled by U. S. Bureau of Reclamation, 1946. Surface altitude, 1,698.4 feet. Water level, 27 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Clay loam to silty loam, stiff to plastic; upper 12 feet black, remainder brown	48.8	48.8
Sand, silty, fine, compact	5.2	54
Sand, medium-grained, clean, compact	1	55
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, firm, blue	13	68

4-16-34cc1. *Log of core hole ECH-6, in the SW¼ SW¼ sec. 34, T. 4 S., R. 16 W., Phillips County, 1,060 feet north and 250 feet east of SW cor. sec. 34; drilled by Corps of Engineers, 1943. Surface altitude, 1,712.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Clay-loam, firm, silty, brown	3	3
Silt, jointed, sandy, buff	7	10
Sand, fine, firm, silty, brown-red	7	17
Sand, fine, compact, clean, tan	6	23
CRETACEOUS—Gulfian		
Niobrara formation—Fort Hays limestone member		
Limestone, weathered	1	24
Limestone, hard, chalky, light-yellow	6.5	30.5
Shale, firm, dark-gray	0.4	30.9
Chalk, hard, light-blue	3.3	34.2
Chalk, hard, light-yellow	1.7	35.9
Limestone, chalky, light-blue to dark-gray	3.6	39.5
Shale, soft, dark-gray	0.2	39.7
Limestone, hard, chalky, light-blue and yellow	10	49.7
Carlile shale—Blue Hill shale member		
Shale, subfirm, dark-gray	3.1	52.8

4-16-34cc2. *Log of core hole DH-108, in the SW¼ SW¼ sec. 34, T. 4 S., R. 16 W., Phillips County, 700 feet north and 480 feet east of SW cor. sec. 34; drilled by U. S. Bureau of Reclamation, December 1945. Surface altitude, 1,723.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Loam, silty, brown	19	19
Sand, fine, clean, gray	5	24
Sand, fine, silty, brown; contains lumps of chalk	9	33

	Thickness, feet	Depth, feet
Cretaceous—Gulfian		
Niobrara formation—Fort Hays limestone member		
Chalk, weathered and broken, soft	1.5	34.5
Chalk, firm, gray	23	57.5
Carlile shale—Blue Hill shale member		
Shale, firm, blue	9.1	66.6

4-16-34cc3. *Log of core hole DH-109, in the SW¼ SW¼ sec. 34, T. 4 S., R. 16 W., Phillips County, 390 feet north and 680 feet east of SW cor. sec. 34; drilled by U. S. Bureau of Reclamation, December 1945. Surface altitude, 1,732.5 feet. Water level, 36 feet.*

	Thickness, feet	Depth, feet
Quaternary—Pleistocene		
Sanborn formation		
Loam, compact, sandy, brown	8	8
Cretaceous—Gulfian		
Niobrara formation		
Chalk, weathered, soft, gray	1.5	9.5
Chalk, gray; contains hard and soft streaks	19.5	29
Chalk, firm, gray	37.5	66.5
Carlile shale—Blue Hill shale member		
Shale, firm, blue	6.8	73.3

4-18-23aa. *Sample log of test hole in the NE¼ NE¼ sec. 23, T. 4 S., R. 18 W., Phillips County, 18 feet west of center of U. S. Highway 183 and 0.2 mile south of road intersection. Surface altitude, 1,866.9 feet.*

	Thickness, feet	Depth, feet
Quaternary—Pleistocene		
Sanborn formation		
Silt, fairly loose, brown and tan (soil)	2	2
Silt, loose, sandy, tan; contains small snail shells	9	11
Silt, medium-grained, compact, sandy, dark-brown	3	14
Cretaceous—Gulfian		
Niobrara formation—Smoky Hill shale member		
Chalk, hard, white, limestone, and white to buff shale	2	16
Chalk, consolidated, gray-white, and soft white to gray shale	4	20

4-18-24cb. *Sample log of test hole in the NW¼ SW¼ sec. 24, T. 4 S., R. 18 W., Phillips County, in ditch 35 feet east of center of U. S. Highway 183, 0.3 mile north of highway intersection at Glade. Surface altitude, 1,817.1 feet.*

	Thickness, feet	Depth, feet
Quaternary—Pleistocene		
Sanborn formation		
Silt, fairly loose, sandy, brown and gray-brown (soil)	4	4
Silt, soft, sandy, light-buff-tan	14	18
Silt, light-cream-tan, and fine to coarse sand; contains limestone pebbles	7	25
Sand, fine to coarse, fine to coarse gravel and chalk pebbles	23	48
Cretaceous—Gulfian		
Niobrara formation—Fort Hays limestone member		
Chalk, hard, white and buff shale	2	50

4-18-25bc. *Sample log of test hole in the SW¼ NW¼ sec. 25, T. 4 S., R. 18 W., Phillips County, 20 feet east of center of U. S. Highway 183 and 0.35 mile south of highway intersection at Glade. Surface altitude, 1,800.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, sandy, dark-brown (soil)	5	5
Silt, compact, sandy, light-tan to gray-tan	13	18
Sand, very fine to coarse, tan, and tan silt; contains pebbles	6	24
Sand, fine to coarse, and fine to medium quartz gravel	9	33
Sand, very fine to coarse, quartz, and gravel; contains chalk pebbles and small amount gray silt	10	43
Sand, fine to coarse, quartz, gravel, and chalk pebbles, partly cemented	5	48
CRETACEOUS—Gulfian		
Niobrara formation—Fort Hays limestone member		
Chalk, fairly hard, white, and soft light-blue shale	2	50
Shale, chalky, light-gray and light-blue-gray	5	55
Carlile shale—Blue Hill shale member		
Shale, medium consolidated, gray and dark-gray, fine sandy shale, and hard, dark-gray-black sandstone (Codell sandstone zone)	4	59
Shale, plastic, noncalcareous, dark-bluish-gray	6	65

4-18-25cc. *Sample log of test hole in the SW¼ SW¼ sec. 25, T. 4 S., R. 18 W., Phillips County, 36 feet east of center of U. S. Highway 183, about 0.1 mile south of bridge over North Solomon River. Surface altitude, 1,777.8 feet. Water level, 19.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Sand and silt, very fine to fine, loose, brown (soil)	1	1
Sand, very fine to coarse, fine gravel, and chalk pebbles,	24	25
Sand, very fine to coarse, and fine to coarse greenish gravel; contains few chalk pebbles and shale fragments	15	40
Sand and gravel, fine to coarse; contains chalk pebbles	11	51
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, compact, plastic, noncalcareous, dark-gray	4	55

4-18-26aa. *Sample log of test hole in the NE¼ NE¼ sec. 26, T. 4 S., R. 18 W., 60 feet west of center of U. S. Highway 183 and 0.1 mile south of highway intersection at Glade. Surface altitude, 1,812.5 feet. Water level, 29.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, sandy, dark-brown (soil)	1	1
Silt, loose, sandy, tan; contains small snail shells	15	16
Sand, very fine to medium; contains fine gravel	12	28

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Niobrara formation—Fort Hays limestone member		
Shale, soft, chalky, buff and cream	3	31
Shale, fissile, chalky, dark-gray and light blue-gray; contains bentonite	9	40

4-18-26cc1. *Driller's log of Phillipsburg well 1 and test hole 16 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co., 1944. Surface altitude, 1,782 feet. Water level, 15.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Soil, sandy	5	5
Sand, fine, dirty, and mud	10	15
Sand, fine to medium	5	20
Sand, fine to medium; contains gravel	5	25
Sand, fine to medium, and blue clay	7.5	32.5
Sand, medium, gray	2.5	35
Sand, medium; contains clay	5	40
Sand, coarse, and fine gravel	5	45
Sand, coarse	11	56
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cc2. *Driller's log of Phillipsburg well 2 and test hole 3 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co., 1944. Surface altitude, 1,780 feet. Water level, 14 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Sand soil	5	5
Sand, fine, dirty	8	13
Sand, fine to medium	2	15
Sand, fine to medium, sharp	3	18
Sand, fine, clean	2	20
Sand, fine	5	25
Sand, gravel, and clay	3	28
Clay and gravel	2	30
Gravel, fine, and clay	5	35
Sand and gravel	3	38
Sand, coarse, and clay	2	40
Sand, coarse	3	43
Sand, medium to coarse	8	51
CRETACEOUS—Gulfian		
Carlile shale		
Shale	2	53

4-18-26cc3. *Driller's log of Phillipsburg well 3 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co., 1944. Water level, 15 feet.*

	Thickness, feet	Depth, feet
Quaternary—Pleistocene		
Alluvium (Recent)		
Sand, silty, and earth	2	2
Clay, sandy, light-yellow	12	14
Sandy, fine	5	19
Sand, gravel, clay, and mud	5	24
Sand, fine	14	38
Sand, gravel, clay, and large pebbles	8	46
Sand, fine	1	47
Sand, gravel, clay; contains boulders	5	52
Sand and gravel	4	56
Cretaceous—Gulfian		
Carlile shale		
Shale, blue	...	...

4-18-26cc4. *Driller's log of test hole 4 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,782 feet. Water level, 16.3 feet.*

	Thickness, feet	Depth, feet
Quaternary—Pleistocene		
Alluvium (Recent)		
Sand soil	5	5
Sand, dirty	5	10
Sand, fine to medium, clay, and gravel	5	15
Sand, fine to medium; contains clay	2.5	17.5
Sand, fine to coarse; contains gravel	7.5	25
Sand, medium to coarse, and gravel	5	30
Sand, fine to medium; contains gravel	5	35
Sand, fine; contains a small amount of gravel	2.5	37.5
Sand, medium to coarse; contains gravel	2.5	40
Sand, fine to medium; contains a small amount of gravel,	5	45
Sand, fine	2.5	47.5
Sand, coarse, and gravel	7	54.5
Cretaceous—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cc5. *Driller's log of test hole 5 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W.; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,781 feet. Water level, 15.4 feet.*

	Thickness, feet	Depth, feet
Quaternary—Pleistocene		
Alluvium (Recent)		
Topsoil, sandy	5	5
Soil, sandy	7.5	12.5
Sand, fine, and clay	2.5	15
Sand, medium, and clay	2.5	17.5
Sand, fine to medium	2.5	20

	Thickness, feet	Depth, feet
Sand, fine to medium, clean	5	25
Sand, medium, clay, and small flat gravel	5	30
Sand, fine to medium, and flat gravel	2.5	32.5
Sand, fine to medium, and gravel	2.5	35
Sand, fine to medium, clay, and gravel	5	40
Sand, fine, and clay; contains gravel	2.5	42.5
Sand, fine to medium, gravelly	2.5	45
Sand, medium, and gravel	5	50
Sand, coarse, and gravel	7	57
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cc6. *Driller's log of test hole 6 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,780.5 feet. Water level, 15 feet.*

QUATERNARY—Pleistocene Alluvium (Recent)	Thickness, feet	Depth, feet
Soil, sandy	10	10
Sand, fine to medium, and silt	5	15
Sand, fine to medium	2.5	17.5
Sand, medium to coarse, and gravel	2.5	20
Sand, medium, clay, and gravel	2.5	22.5
Sand, medium, and clay	5	27.5
Sand, fine to medium; contains clay	5	32.5
Sand, fine to medium	2.5	35
Sand, medium	2.5	37.5
Sand, medium, and fine gravel	5	42.5
Gravel, medium to coarse	5	47.5
Sand, coarse, and gravel	6.5	54
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cc7. *Driller's log of test hole 7 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,780.8 feet. Water level, 15.8 feet.*

QUATERNARY—Pleistocene Alluvium (Recent)	Thickness, feet	Depth, feet
Soil, sandy	5	5
Sand, fine, dirty	10	15
Sand, fine to medium	2.5	17.5
Sand, medium to coarse, and fine gravel	5	22.5
Sand, coarse, and medium gravel	2.5	25
Sand, fine to medium; and blue clay	2.5	27.5
Sand, fine to medium, fine gravel, and blue clay	5	32.5
Clay, blue	2.5	35

	Thickness, feet	Depth, feet
Sand, fine to coarse, and fine gravel	2.5	37.5
Sand, medium to coarse, and medium gravel	2.5	40
Sand, coarse, and medium gravel	5	45
Gravel and shale	6	51
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cc8. *Driller's log of test hole 8 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,783 feet. Water level, 15.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Soil, sandy	5	5
Sand, fine, and clay	20	25
Sand, fine, clean	7.5	32.5
Sand, fine to coarse, and fine gravel	5	37.5
Sand, medium to coarse, and clay	2.5	40
Sand, coarse, fine gravel, and clay	3.5	43.5
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cc9. *Driller's log of test hole 15 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,780.8 feet. Water level, 14 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Soil, sandy	5	5
Sand, fine, and soil	10	15
Sand, fine, dirty, and small gravel	2.5	17.5
Sand, fine to medium, and fine gravel	5	22.5
Sand, fine to medium; contains gravel	5	27.5
Sand, fine to medium	2.5	30
Sand, medium to coarse; contains blue clay	2.5	32.5
Sand, medium to coarse; contains fine gravel	5	37.5
Sand, coarse; contains medium gravel	5	42.5
Sand, coarse, and fine to medium gravel	5	47.5
Sand, medium to coarse	2.5	50
Sand, coarse	4	54
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cc10. *Driller's log of test hole 2 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,778 feet. Water level, 13 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Sand, gravel, and clay	5	5
Sand, fine; contains mud	7.5	12.5
Sand, fine	2.5	15
Sand, fine to medium	5	20
Gravel, fine, and shale	2.5	22.5
Sand, medium to coarse, and fine to medium gravel	2.5	25
Shale and gravel	2.5	27.5
Sand and gravel, shaly	2.5	30
Shale, sandy, and gravel	3	33
Sand, coarse, and fine to medium gravel	5	38
Sand, coarse	5	43
Sand, medium to coarse	5	48
Sand and shale	3	51
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cc11. *Driller's log of test hole 1 (Fig. 13) in the SW¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,779 feet. Water level, 14 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Sand, fine	3	3
Sand, fine; contains medium sand	8	11
Sand, fine to medium	3	14
Sand, fine	5	19
Sand, fine to medium; contains gravel	5	24
Sand, fine to medium; contains coarse sand and gravel	5	29
Sand, fine; contains gravel	3	32
Sand, fine, and fine gravel	3	35
Sand, fine to medium	2.5	37.5
Sand, fine	2.5	40
Sand, fine to medium; contains coarse sand	5	45
Sand, coarse, and gravel	5	50
Sand, medium to coarse	2.5	52.5
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cd1. *Driller's log of test hole 9 (Fig. 13) in the SE¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,779 feet. Water level, 12.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Soil, sandy	5	5
Sand, fine, and clay	10	15
Sand, fine, dirty, and fine gravel	2.5	17.5
Sand, fine, and clay	2.5	20
Sand, fine to medium; contains fine gravel	7.5	27.5
Sand, fine to medium, and gravel	2.5	30
Sand, medium to coarse, and fine to medium gravel	7	37
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cd2. *Driller's log of test hole 10 (Fig. 13) in the SE¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg, 1944. Surface altitude, 1,779.3 feet. Water level, 14.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Soil, sandy	5	5
Sand, fine, dirty	7.5	12.5
Sand, fine, yellow	5	17.5
Sand, fine to medium, yellow; contains gravel	5	22.5
Sand, fine to medium, yellow-gray; contains gravel	5	27.5
Sand, fine to medium, gray, and fine gravel	5	32.5
Sand, fine to medium, gray	5	37.5
Sand, medium to coarse, and medium gravel	14.5	52
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cd3. *Driller's log of test hole 11 (Fig. 13) in the SE¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg. Surface altitude, 1,780.3 feet. Water level, 15.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Soil, sandy	5	5
Sand and soil	5	10
Sand, fine to medium; contains fine gravel	7.5	17.5
Sand, fine; contains clay	2.5	20
Sand, medium, yellowish	5	25
Sand, fine to medium, yellowish-gray	2.5	27.5
Sand, medium to coarse, gray; contains gravel	7.5	35
Sand, medium to coarse, and fine gravel	10	45
Sand, fine to medium; contains clay	2.5	47.5

	Thickness, feet	Depth, feet
Sand, fine to coarse, and fine gravel	2.5	50
Sand, coarse, and fine to medium gravel	5	55
Gravel	1	56
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cd4. *Driller's log of test hole 12 (Fig. 13) in the SE¼ SW¼ sec. 30, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg. Surface altitude, 1,780 feet. Water level, 12.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Soil, sandy	5	5
Sand, fine, dirty	5	10
Sand, fine, and silt	5	15
Sand, fine	2.5	17.5
Sand, fine to medium	7.5	25
Sand, fine to coarse	2.5	27.5
Sand, fine, and blue clay	20	47.5
Sand, fine to medium, and blue clay	2.5	50
Sand, fine to coarse; contains gravel	5	55
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-26cd5. *Driller's log of test hole 13 (Fig. 13) in the SE¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg. Surface altitude, 1,780 feet. Water level 15.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Soil, sandy	5	5
Sand, dirty	7.5	12.5
Sand, fine, yellowish	5	17.5
Sand, fine, gray	2.5	20
Sand, fine to medium, gray, and blue mud	5	25
CRETACEOUS—Gulfian		
Niobrara formation		
Shale	...	...

4-18-26cd6. *Driller's log of test hole 14 (Fig. 13) in the SE¼ SW¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co. for the city of Phillipsburg. Surface altitude, 1,779.5 feet. Water level, 15.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Soil, sandy	5	5
Sand, fine, dirty	10	15
Sand, fine	2.5	17.5
Sand, fine, and clay	2.5	20

	Thickness, feet	Depth, feet
Sand, medium, and gravel	5	25
Sand, medium to coarse, and gravel	5	30
Sand, coarse, and gravel; contains clay	5	35
Sand, coarse	5	40
Sand, coarse, and gravel	5	45

4-18-26da4. *Driller's log of Chicago, Rock Island & Pacific Railway Co. well 4 in the NE¼ SE¼ sec. 26, T. 4 S., R. 18 W., Phillips County; drilled by Layne-Western Co., 1943. Water level, 21 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Clay, sandy	2	2
Sand, fine	18	20
Clay, sandy	2	22
Clay, blue	22	44
Sand, coarse, and gravel	9	53
CRETACEOUS—Gulfian		
Carlile shale		
Shale	...	...

4-18-36bb. *Sample log of test hole in NW¼ NW¼ sec. 36, T. 4 S., R. 18 W., Phillips County, 15 feet east of center of U. S. Highway 183, 0.15 mile south of north line of section. Surface altitude, 1,805.1 feet. Water level, 48.6 feet.*

	Thickness, feet	Depth, feet
Road fill	4	4
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, soft, tan; contains chalk pebbles and quartz sand	21	25
Gravel, chalk, and sandy silt, tan	18	43
Silt, soft, tan; contains small amount of fine sand, chalk pebbles, and gravel	10	53
Silt, soft, gray; contains small amount of chalk gravel and very fine sand	9	62
Silt, sandy, medium, soft, slightly plastic, dark blue-gray,	8	70
Silt, soft, plastic, dark blue-gray; contains fine quartz sand and fine chalk gravel	5	75
Sand, very fine to medium; contains some coarse sand and fine to coarse gravel; greenish	5	80
Sand and gravel, fine to coarse; contains broken shale fragments	8	88
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Clay shale, plastic, noncalcareous, dark-gray	2	90

4-19-30cc. *Sample log of test hole in the SW¼ SW¼ sec. 30, T. 4 S., R. 19 W., Phillips County, 20 feet north and 50 feet east of center of road intersection. Surface altitude, 1,931.5 feet. Water level, 35.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Sand, fine to coarse, and loose tan silt	4	4
Silt, medium compact, slightly sandy, dark-gray	3	7
Silt, medium compact, gray-tan; contains small amount of sand and a few snail shells	10	17
Sand, fine to coarse, and brown silt; contains fine gravel,	11	28
Sand, fine to coarse; contains gravel and chalk pebbles,	10	38
Sand, fine to coarse, and gravel; contains chalk pebbles, and broken chalky shale	1	39
CRETACEOUS—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale, chalky, light blue-gray	11	50

4-20-25da. *Sample log of test hole in the NE¼ SE¼ sec. 25, T. 4 S., R. 20 W., Phillips County, 10 feet west of center of road and 0.35 mile north of road intersection. Surface altitude, 1,965.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, loose, sandy, dark-brown (soil)	0.5	0.5
Silt, soft, tan to brown; contains small snail shells	10.5	11
Silt, soft, slightly sandy, dark-brown (Loveland soil?)	3	14
Silt, slightly plastic, medium compact, buff and tan	5	19
Sand, very fine to medium; contains some buff silt	5	24
Sand, very fine to fine; contains silt, some coarse sand, and a small amount of gravel	16	40
Sand, very fine to coarse; contains chalk and igneous gravel and chalky shale fragments	7	47
CRETACEOUS—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale, clayey and chalky, broken, gray to buff	2	49
Shale, hard, chalky, light blue-gray	1	50

4-20-34ca3. *Driller's log of Logan city well 3 in the NE¼ SW¼ sec. 34, T. 4 S., R. 20 W., Phillips County, drilled 1932.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	3	3
Soil, brown	32	35
Clay, green, and fine sand	8	43
Sand	4	47
Muck, greenish	4	51
Sand; contains pebbles	6.5	57.5
Gravel, coarse, sand rock, and soft cofferdam fragments	8	65.5
CRETACEOUS—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale	5	70.5

4-20-36ad. *Sample log of test hole in SE¼ NE¼ sec. 36, T. 4 S., R. 20 W., Phillips County, 12 feet west of center of road and 0.35 mile south of road intersection. Surface altitude, 1,922.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, sandy, gray-brown (soil)	2	2
Silt, tan and brown; contains small amount very fine to medium sand and a few small shells	14	16
Silt, soft, medium brown, fine to coarse sand; contains pebbles	4	20
Sand and gravel, fine to coarse; contains small amount silt, chalk pebbles, and igneous gravel	13	33
Sand and gravel, fine to coarse; contains small amount broken chalky white to gray shale	5	38
CRETACEOUS—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale, fissile, chalky, light-blue-gray	2	40

4-20-36da. *Sample log of test hole in NE¼ SE¼ sec. 36, T. 4 S., R. 20 W., Phillips County, 13 feet west of center of road, 135 feet north of Solomon River bridge, and 0.37 mile north of road intersection. Surface altitude, 1,897.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Sand and silt, loose, brown; contains some shale fragments and gravel (soil)	4	4
Sand, fine to coarse; contains some fine to coarse gravel and scattered pebbles of chalk and chalky shale	11	15
Sand, very fine to coarse, grayish; contains a small amount of igneous gravel	11	26
Sand, fine to coarse, gray-green; contains small amount rounded chalk pebbles and igneous gravel	21	47
CRETACEOUS—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale, fissile, very chalky, light- to dark-gray	3	50

5-13-25bb. *Sample log of test hole in NW¼ NW¼ sec. 25, T. 5 S., R. 13 W., Smith County, 12 feet east and 50 feet south of center of crossroads. Surface altitude, 1,611.3 feet. Water level, 19.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, sandy, black (soil)	2	2
Silt, compact, sandy, noncalcareous, gray to tan	3	5
Silt, fairly soft, noncalcareous, brown and tan	3	8
Silt, compact, cream to buff; contains caliche and chalk gravel	3	11
Gravel, fine to coarse, chalk	5	16
Silt, fairly soft, sandy, brown	3	19

	Thickness, feet	Depth, feet
Silt, fairly soft, tan to gray; contains small amount of sand and chalk gravel	2	21
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, light gray-blue, small amount is cream-colored and iron-stained	5	26
Shale, plastic, noncalcareous, gray-blue and iron-stained,	4	30

5-13-25bc. *Sample log of test hole in SW¼ NW¼ sec. 25, T. 5 S., R. 13 W., Smith County, 12 feet east of middle of road, and 0.3 mile north of intersection of section road with Kansas Highway 9. Surface altitude, 1,588.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, soft, slightly sandy, brown (soil)	2	2
Silt, soft, tan; contains small amount sand and caliche,	3	5
Silt, very loose, calcareous, sandy, light-buff	9	14
Silt, medium compact, plastic, calcareous, buff to tan	9	23
Silt, soft, light-buff; contains much very fine to medium sand	7	30
Sand, very fine to medium; contains some soft tan-buff silt, and a few small snail shells	14	44
Sand, very fine to coarse, and tan-buff silt; contains chalk and quartz gravel	10	54
Sand, fine to coarse, and some fine to medium chalk and igneous gravel	5	59
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, dark gray-blue, some iron-stained,	1	60

5-13-25cc. *Sample log of test hole in the SW¼ SW¼ sec. 25, T. 5 S., R. 13 W., Smith County, 25 feet east of center of road, and 0.1 mile north of road intersection. Surface altitude, 1,570.1 feet. Water level, 32.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, soft, dark gray-brown (soil)	5	5
Silt, very loose, tan and brown; contains a small amount of chalk sand	14	19
Silt, soft, tan; contains caliche	9	28
Sand and gravel, worn chalk fragments, from fine sand to medium gravel; contains small amount of tan silt,	16	44
Sand, very fine to coarse, quartz and coarse chalk, and fine to medium chalk gravel; contains shale fragments	4	48
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, plastic, noncalcareous, dark-gray	2	50

5-13-36bc. *Sample log of test hole in the SW¼ NW¼ sec. 36, T. 5 S., R. 13 W., Smith County, 10 feet east of center of road and 0.3 mile south of road intersection. Surface altitude, 1,550.4 feet. Water level 26.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, compact, slightly sandy, dark-brown (soil)	3	3
Silt, slightly coarse, tan; contains sand	8	11
Silt, medium loose, light gray-tan; contains small amount of sand	4	15
Silt, compact, slightly sandy, dark-tan	3	18
Silt, loose, tan, and very fine to coarse sand; contains fine gravel	8	26
Sand, very fine to coarse; contains small amount of silt and fine to coarse chalk gravel	11.5	37.5
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, clayey, noncalcareous, light- to dark-gray, some iron-stained	2.5	40

5-13-36cc. *Sample log of test hole in the SW¼ SW¼ sec. 36, T. 5 S., R. 13 W., Smith County, 6 feet east of center of farm road, 0.8 mile south of road intersection. Surface altitude, 1,525.0 feet. Water level, 13.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Silt, loose, brown, and very fine to medium sand	5	5
Sand, very fine to coarse, tan; contains small amount of fine to medium gravel	10	15
Sand, very fine to coarse; contains small amount of fine to coarse quartz, feldspar, and angular chalk gravel and shale fragments	5	20
Sand, very fine to medium, gray-green; contains small amount of coarse sand, fine gravel and wood fragments	25	45
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Shale, plastic to silty, calcareous, dark gray-black	5	50

5-14-1ca2. *Driller's log of Smith Center well 3 (Fig. 14) in the NE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled by Layne-Western Co., 1940. Water level, 43 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil, sandy, light	3	3
Soil, black	6	9
Silt, fine, yellow, and sand	7	16
Sand, fine; contains silt	17	33
Clay, sandy	22	55
Sand and gravel	10	65
Sand, coarse, and gravel	4	69
Clay and small boulders	1	70
CRETACEOUS—Gulfian		
Carlile shale		
Shale, black	...	...

5-14-1ca3. *Driller's log of test hole 2 (Fig. 14) in the NE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt and soil	10	10
Clay	20	30

5-14-1ca4. *Driller's log of test hole 11 (Fig. 14) in the NE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945. Water level, 44 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay	42	43
Sand, fine; contains clay streaks	5	48
Sand, fine, mucky, blue	5	53
Sand, fine; contains clay streaks	10	63
Sand, coarse to medium, gravel; contains clay balls throughout	9	72
CRETACEOUS—Gulfian		
Carlile shale		
Shale	1	73

5-14-1ca5. *Driller's log of test hole 12 (Fig. 14) in the NE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay	34	35
Clay, blue	11	46
Sand, fine	3	49
Sand, medium to coarse	2	51
Clay, blue	4	55
Sand, coarse, gravel, and small fragments of hard shale,	5	60
Sand, coarse; contains gravel	6	66
CRETACEOUS—Gulfian		
Carlile shale		
Shale	2	68

5-14-1ca6. *Driller's log of test hole 13 (Fig. 14) in the NE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Clay	25	25
Sand, fine; contains many clay streaks	8	33
Clay, sandy, blue	6	39
Sand, fine	6	45
Clay, soft, blue	10	55

	Thickness, feet	Depth, feet
Clay; contains sand and gravel	3	58
Sand and gravel	4	62
CRETACEOUS—Gulfian		
Carlile shale		
Shale	3	65

5-14-1cb. *Driller's log of test hole 9 (Fig. 14) in the NW¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay	10	11
Sand, fine, brown, contains clay streaks	16	27
Sand, fine, mucky, blue	8	35
Clay, blue	12	47
Sand, medium to coarse; contains clay streaks	3	50
Sand, medium to coarse, and gravel	5	55
Clay, soft, blue	2	57
Sand, gravel, and clay balls	2	59
CRETACEOUS—Gulfian		
Carlile shale		
Shale	4	63

5-14-1cc1. *Driller's log of test hole 3 (Fig. 14) in the SW¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1940. Water level, 26 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Clay	8	8
Clay, sandy	7	15
Sand, medium to coarse	8	23
Sand and gravel	2	25
Clay, sandy	28	53
Sand, coarse	2	55
Clay, sandy	4	59
CRETACEOUS—Gulfian		
Carlile shale		
Shale	1	60

5-14-1cc2. *Driller's log of test hole 4 (Fig. 14) in the SW¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1940. Water level, 13 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	8	8
Sand, fine	5	13
Clay	2	15
Sand and gravel	11	26

	Thickness, feet	Depth, feet
Clay	20	46
CRETACEOUS—Gulfian		
Carlile shale		
Shale	2	48

5-14-1cc3. *Driller's log of test hole 5 (Fig. 14) in the SW¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1940. Water level, 15 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	4	4
Clay, sandy	6	10
Sand, very fine, dirty	18	28
Sand, coarse; contains gravel	4	32
Clay	3	35
Sand, coarse; contains gravel	5	40
CRETACEOUS—Gulfian		
Carlile shale		
Shale	3	43

5-14-1cd2. *Driller's log of test hole 1 and Smith Center well 2 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled by Layne-Western Co., 1940. Water level, 33.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil, sandy	10	10
Sandy, fine, silty	10	20
Sand, fine, sharp	9	29
Clay	14	43
Sand, coarse	2	45
Sand, fine	3	48
Sand, coarse; contains gravel	5	53
Sand and gravel	10	63
CRETACEOUS—Gulfian		
Carlile shale		
Shale	5	68

5-14-1cd3. *Driller's log of test hole 2 (Fig. 14) in the SE¼ SW¼ sec 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1940. Water level, 30 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil, sandy	8	8
Sand, fine	15	23
Clay, sandy	5	28
Clay, blue	5	33
Clay, sandy	26	59
CRETACEOUS—Gulfian		
Carlile shale		
Shale	1	60

5-14-1cd4. *Driller's log of test hole 6 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1940. Water level, 37 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	6	6
Clay	14	20
Sand, fine	13	33
Clay	12	45
Sand, fine, dirty	8	53
Sand, coarse	2	55
Sand and gravel	12	67
CRETACEOUS—Gulfian		
Carlile shale		
Shale	1	68

5-14-1cd5. *Driller's log of test hole 7 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1940. Water level, 38 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	4	4
Clay	11	15
Sand, fine	18	33
Clay	15	48
Sand, fine, dirty	5	53
Sand, coarse	2	55
Sand, medium to coarse; contains clay balls	3	58
Sand and gravel	7	65
CRETACEOUS—Gulfian		
Carlile shale		
Shale	3	68

5-15-1cd6. *Driller's log of test hole 8 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1940.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Clay	8	8
Clay, sandy	10	18
Sand, fine	18	36
Clay, sandy, blue	20	56
Sand, coarse	2	58
Sand and gravel	9	67
CRETACEOUS—Gulfian		
Carlile shale		
Shale	1	68

5-14-1cd7. *Driller's log of test hole 3 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945. Water level, 31 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay	20	21
Sand, fine, mucky	3	24
Sand, fine, brown	7	31
Clay, blue	10	41
Clay, soft, mucky, blue	13	54
Sand, fine, blue	6	60
Sand, medium to coarse; contains gravel	4	64
CRETACEOUS—Gulfian		
Carlile shale		
Shale, blue	4	68

5-14-1cd8. *Driller's log of test hole 4 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay	15	16
Clay, soft, sandy	13	29
Sand, fine, brown	5	34
Clay, soft, blue	20	54
Sand, fine, dirty	1	55
Sand, medium to coarse, loose, clean	3	58
Sand, medium to coarse	2	60
Sand and gravel	5	65
CRETACEOUS—Gulfian		
Carlile shale		
Shale	2	67

5-14-1cd9. *Driller's log of test hole 5 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945. Water level, 33 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay, black	10	11
Clay, brown	17	28
Sand, fine, dirty; contains clay streaks	7	35
Clay, blue	25	60
Sand, fine to medium, and gravel	6	66
CRETACEOUS—Gulfian		
Carlile shale	2	68

5-14-1cd10. *Driller's log of test hole 6 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945. Water level, 31 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay, black	12	13
Clay, brown	15	28
Sand, fine, brown	4	32
Clay, blue	13	45
Clay, sandy, soft	8	53
Sand, fine; contains clay streaks	5	58
Sand, coarse, and loose gravel	5	63
Sand, boulders, and clay	2	65
CRETACEOUS—Gulfian		
Carlile shale		
Shale	3	68

5-14-1cd11. *Driller's log of test hole 7 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay	19	20
Sand, fine, dirty; contains clay streaks	14	34
Clay, soft, blue	16	50
Sand, fine; contains clay	3	53
Sand, medium to coarse, loose	2	55
Sand, coarse, and gravel, loose	5	60
Sand, medium to coarse; contains clay balls	4	64
CRETACEOUS—Gulfian		
Carlile shale		
Shale	2	66

5-14-1cd12. *Driller's log of test hole 8 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945. Water level, 41 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay, soft, brown	39	40
Clay, blue	8	48
Clay, soft, mucky, blue	3	51
Clay, soft, blue	16	67
Sand, fine, gray	6	73
Sand, coarse, and gravel	2	75
Gravel, boulders, and clay balls	1	76
CRETACEOUS—Gulfian		
Carlile shale		
Shale	2	78

5-14-1cd13. *Driller's log of test hole 10 (Fig. 14) in the SE¼ SW¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945. Water level, 36.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay	29	30
Sand, fine, mucky; contains soft streaks of clay	8	38
Clay, soft, blue	15	53
Clay and sand	5	58
Sand, medium to coarse	2	60
Sand, gravel, and small flat boulders	6	66
Sand and gravel; contains shale streaks	2	68
CRETACEOUS—Gulfian		
Carlile shale		
Shale	5	73

5-14-1db. *Driller's log of test hole 1 (Fig. 14) in the NW¼ SE¼ sec. 1, T. 5 S., R. 14 W., Smith County; drilled for the city of Smith Center by Layne-Western Co., 1945. Water level, 44 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	1	1
Clay	27	28
Clay; contains soft white rock	2	30
Clay, soft, yellow	8	38
Clay, soft, sandy	7	45
Muck, blue	4	49
Sand, very fine, dirty, blue	2	51
Clay, blue	7	58
Sand, medium to coarse; contains clay streaks	2	60
Sand and gravel; contains fine sand and a few small flat boulders	8	68
Sand and gravel	4	72
CRETACEOUS—Gulfian		
Carlile shale		
Shale, blue	6	78

5-14-6aa. *Sample log of test hole in NE¼ NE¼ sec. 6, T. 5 S., R. 14 W., Smith County, 12 feet west of center of road and 0.15 mile south of crossroads at southeast corner of Cedar. Surface altitude, 1,625.7 feet. Water level, 15.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, sandy, dark-brown (soil)	5	5
Silt, compact, slightly sandy, gray	3	8
Silt, slightly sandy, light-tan, slightly iron-stained	12	20

	Thickness, feet	Depth, feet
Silt, fairly soft, gray, fine to coarse quartz sand (fossil soil)	5	25
Sand, fine to coarse, quartz, tan; contains small amount fine to coarse gravel	3	28
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, plastic, dark blue-gray	2	30

5-14-6ad. *Sample log of test hole at SE cor. NE¼ sec. 6, T. 5 S., R. 14 W., Smith County, 10 feet west of center of road and 0.5 mile south of road intersection at Cedar. Surface altitude, 1,627.7 feet. Water level, 25.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, soft, sandy, gray-tan (soil)	5	5
Silt, soft, light-tan; contains a very small amount of sand,	16	21
Sand, very fine to fine; contains small amount medium to coarse sand and chalk, quartz, and granitic gravel	10	31
Silt, rusty brown to brown; contains fine to coarse sand, angular fragments of hard, calcareous gray shale	1	32
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, plastic, noncalcareous, dark gray-black	8	40

5-14-6dd. *Sample log of test hole in the SE¼ SE¼ sec. 6, T. 5 S., R. 14 W., Smith County, 10 feet west of center of road and 0.05 mile north of Solomon River bridge. Surface altitude, 1,603.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Sand, fine to medium, and loose brown silt	5	5
Sand, very fine to fine, tan; contains small amount loose gray silt and a few small snail shells	12	17
Sand, very fine to coarse, and fine to coarse quartz, granitic, and chalk gravel; contains gray clay balls,	6	23
Sand, very fine to coarse, gravelly, gray; contains some soft dark-gray silt	7	30
Silt, compact, soft, dark-gray; contains small amount of sand and fine gravel	5	35
Sand, fine to coarse; contains fine to coarse gravel and shale fragments	15	50
Gravel, fine to medium, quartz and granitic, and fine to coarse sand; contains many greenish gray-white chalk pebbles	3	53
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, plastic, dark gray-black	7	60

5-16-3bb. *Log of core hole DH-110 in the NW¼ NW¼ sec. 3, T. 5 S., R. 18 W., Phillips County, 50 feet south and 950 feet east of NW cor. sec. 3; drilled by the U. S. Bureau of Reclamation, January 1946. Surface altitude 1,745.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Loam, sandy, brown	7	7
CRETACEOUS—Gulfian		
Niobrara formation—Fort Hays limestone member		
Chalk, weathered, soft, gray	3	10
Chalk, weathered, soft, yellow	2	12
Chalk, weathered, firm, gray	3	15
Chalk, weathered, soft, yellow	6	21
Chalk, firm, gray	11.2	32.2

5-19-6bb. *Sample log of test hole in the NW¼ NW¼ sec. 6, T. 5 S., R. 19 W., Phillips County, 9 feet south and 50 feet east of center of crossroads. Surface altitude, 1,931.6 feet. Water level, 41.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Eolian sand, fine to medium, silty, brown	5	5
Terrace deposits		
Silt, medium compact, sandy, gray-tan	5	10
Silt, fairly soft, dark gray-black; contains small amount of fine sand and gravel	5	15
Silt, brown; contains fine to coarse sand and fine to coarse chalk and granitic gravel	5	20
Silt, brown to light-buff; contains sand, gravel, broken shale fragments, and snail shells near base	15	35
Sand, fine to coarse, tan; contains fine to medium gravel and chalky shale fragments	15	50
Sand, fine to coarse, and fine to medium gravel; contains small amount coarse gravel and shale fragments	12	62
Sand, gravel, and broken chalky shale	18	80
CRETACEOUS—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale, soft, fissile, chalky, light- to dark-gray	10	90

5-19-6cc. *Sample log of test hole in the SW¼ SW¼ sec. 6, T. 5 S., R. 19 W., Phillips County, 12 feet north of center of road and 0.05 mile east of road intersection. Surface altitude, 1,996.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, loose, sandy, brown (soil)	2	2
Silt, fairly loose, slightly sandy, tan and gray-brown	8	10
Silt, soft, slightly sandy, gray-brown; contains snail shells	8	18

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale, medium compact, chalky, gray, creamy	2	20
Shale, fissile, light-gray to buff, and soft chalky light-gray shale	4	24
Shale, soft, medium plastic, chalky, light-gray with small amount of buff	3.5	27.5
Shale, soft, plastic, chalky; contains fragments of shells and selenite crystals	.5	28
Shale, fissile, soft, dark gray-black; contains few selenite crystals and shells	2	30

5-20-1aa. *Sample log of test hole in the NE¼ NE¼ sec. 1, T. 5 S., R. 20 W., Phillips County, 12 feet west of center of road and 0.05 mile south of road intersection. Surface altitude, 1,931.6 feet. Water level, 21.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, sandy, brown (soil)	4	4
Silt, medium compact, sandy, gray-tan	2	6
Silt, soft, dark-brown; contains sand and chalk fragments,	3	9
Silt, fairly compact, slightly sandy, tan and dark-brown,	8	17
Sand, fine to coarse; contains small amount of fine to coarse gravel and chalk fragments	12	29
Silt, soft, dark-brown and tan, and fine to coarse sand; contains gravel and chalk pebbles	11	40
Sand, fine to coarse; contains small amount fine to coarse gravel and gray silt	20	60
Sand, fine to coarse; contains small amount of fine to coarse chalk, quartz, and granitic gravel, gray-green at base	19.5	79.5
CRETACEOUS—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale, fissile, chalky, light-gray to dark	.5	80

5-20-1ad. *Sample log of test hole in the SE¼ NE¼ sec. 1, T. 5 S., R. 20 W., Phillips County, 10 feet west of center of road and 0.37 mile south of road intersection. Surface altitude, 1,949.2 feet. Water level, 38.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, dark-gray, and fine to coarse sand	1	1
Silt, soft, dark-gray, and very fine to coarse quartz sand; contains gravel and few small chalk fragments	6	7
Silt, soft, gray-tan, and very fine to coarse quartz sand; contains gravel and fragments of chalk and shale	6	13
Sand, fine to coarse; contains fine to medium limestone, quartz, and granitic gravel	3	16
Sand, fine to coarse; contains soft tan silt and gravel	12	28
Sand, very fine to coarse; contains small amount granitic gravel, and some gray silt	14	42
Silt, medium plastic, soft, light to dark blue-gray, and fine to coarse gray sand	4	46

	Thickness, feet	Depth, feet
Sand, very fine to coarse, gravelly, gray-green; contains small amount gray silt	5.5	51.5
Cretaceous—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale, hard, fissile, chalky, dark-gray; contains bentonite,	3.5	55

5-20-1da. *Sample log of test hole in the NE¼ SE¼ sec. 1, T. 5 S., R. 20 W., Phillips County, 10 feet west of center of road and 0.7 mile south of road intersection. Surface altitude, 1,989.6 feet.*

	Thickness, feet	Depth, feet
Quaternary—Pleistocene		
Sanborn formation		
Silt, loose, sandy, brown to tan (soil)	2	2
Silt, fine, sandy, gray-tan; contains limestone fragments,	9	11
Sand, very fine to coarse, gravelly, light-tan	4	15
Cretaceous—Gulfian		
Niobrara formation—Smoky Hill chalk member		
Shale, fissile, soft to medium compact, chalky, light-gray to light-yellow	5	20

6-10-5cd. *Sample log of test hole in the SE¼ SW¼ sec. 5, T. 6 S., R. 10 W., Mitchell County, 6 feet north of center of road, 0.3 mile east of road intersection. Surface altitude, 1,541.1 feet. Water level, 34.1 feet.*

	Thickness, feet	Depth, feet
Quaternary—Pleistocene		
Sanborn formation		
Silt, dark-gray, loose (soil)	3	3
Silt, medium compact, brown	9	12
Silt, compact, sandy, light gray-tan	25	37
Sand and gravel, very fine to coarse	12	49
Silt, medium compact, sandy, gray	7	56
Sand and limestone gravel, very fine to coarse	3	59
Cretaceous—Gulfian		
Carlile shale—Fairport chalky shale member		
Shale, medium, hard, silty, black	1	60

6-10-8cc. *Sample log of test hole in the SW¼ SW¼ sec. 8, T. 6 S., R. 10 W., Mitchell County, 10 feet east of center of road and 0.21 mile north of road intersection. Surface altitude, 1,508.1 feet. Water level, 30.4 feet.*

	Thickness, feet	Depth, feet
Quaternary—Pleistocene		
Sanborn formation		
Silt, loose, dark-brown (soil)	2	2
Silt, medium compact, light-gray	2	4
Silt, fairly compact, brown	13	17
Silt, compact, yellow-tan to gray	4	21
Silt, soft, sandy, light-tan	6	27
Silt, light-tan, and very fine to fine quartz sand	3	30
Sand, very fine to medium, and small amount coarse sand and fine to coarse gravel; contains a little gray silt	7.5	37.5
Cretaceous—Gulfian		
Greenhorn limestone		
Shale, medium hard, calcareous, black	2.5	40

6-10-17bc. *Sample log of test hole in the SW¼ NW¼ sec. 17, T. 6 S., R. 10 W., Mitchell County, 7 feet east of center of road and 36 feet north of ½-mile line fence. Surface altitude, 1,473.9 feet. Water level 15.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, medium loose, black and gray (soil)	5	5
Silt, medium compact, gray to tan	13	18
Silt, soft, sandy, light green-gray and dark-gray	12	30
Sand, very fine to medium quartz, and fine to coarse limestone gravel; contains small amount gray-green silt and shale fragments	6.5	36.5
CRETACEOUS—Gulfian		
Greenhorn limestone		
Shale, fairly hard, calcareous, black and gray	3.5	40

6-10-20bb. *Sample log of test hole in the NW¼ NW¼ sec. 20, T. 6 S., R. 10 W., Mitchell County, 10 feet east of center of road and 0.15 mile south of road intersection. Surface altitude, 1,469.9 feet. Water level, 22.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, dark gray-black	2	2
Silt, medium soft, friable, tan and light-gray	3	5
Silt, compact, plastic, dark-gray	4	9
Silt, soft, light gray-tan	9	18
Silt, gray, and sand, very fine to fine; contains small amount fine to coarse limestone gravel	11	29
Silt, soft, sandy, gravelly, dark gray-blue	7.5	36.5
Sand, fine to coarse, and fine to coarse limestone and quartz gravel	2.5	39
CRETACEOUS—Gulfian		
Greenhorn limestone		
Shale, medium hard, calcareous, black	1	40

6-10-20cc. *Sample log of test hole in the SW¼ SW¼ sec. 20, T. 6 S., R. 10 W., Mitchell County, 10 feet east of center of road and 0.21 mile north of intersection of road with U. S. Highway 24. Surface altitude, 1,464.7 feet. Water level, 30.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, dark-gray to black	3	3
Silt, medium compact, brown and gray	16	19
Silt, soft, tan, and very fine to fine quartz sand	8	27
Sand, very fine to medium, quartz; contains small amount coarse sand and fine limestone gravel	6	33
Sand, fine to coarse, quartz, and a small amount of fine to medium limestone gravel	6	39
CRETACEOUS—Gulfian		
Greenhorn limestone		
Limestone, very hard, light-gray	0.3	39.3
Shale, hard, fissile, calcareous, black	0.7	40

6-10-29ba. *Sample log of test hole in the NE¼ NW¼ sec. 29, T. 6 S., R. 10 W., Mitchell County, 12 feet west of center of ½-mile road and 0.09 mile south of intersection of road with U. S. Highway 24. Surface altitude, 1,464.2 feet. Water level, 30.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, plastic, medium compact, silty, gray	6	6
Silt, sandy, light-gray to tan	9	15
Silt, dark-tan to tan; contains fine quartz sand	3	18
Sand, very fine to medium, and tan silt; contains chalk gravel	5	23
Sand, very fine to medium and fine to medium limestone gravel	9	32
Sand, very fine to coarse, and much fine to very coarse limestone and granitic gravel; contains small amount of white to yellow clay	22	54
CRETACEOUS—Gulfian		
Greenhorn limestone		
Shale, fissile, medium hard, silty, gray, and soft silty, gray-blue shale; contains light-blue soft bentonite	4	58

6-10-29ca. *Sample log of test hole in the NE¼ SW¼ sec. 29, T. 6 S., R. 10 W., Mitchell County, 11 feet west of center of ½-mile road, and just south of ½-mile fence. Surface altitude, 1,462.8 feet. Water level, 29.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, compact, sandy, black and dark-gray (soil)	3	3
Silt, medium compact, coarse, sandy, gray to brown	8	11
Silt, sandy, tan	7	18
Silt, blocky, sandy, dark-brown	7	25
Silt, light-gray, slightly iron-stained; contains very fine to medium sand and a few small snail shells	2	27
Sand, very fine to fine, quartz and feldspar, and a small amount of medium to coarse sand and fine to medium limestone gravel	3	30
Sand and gravel, very fine to coarse chalk, quartz, granitic, and black igneous rock fragments	6	36
CRETACEOUS—Gulfian		
Greenhorn limestone		
Shale, fissile, hard, dark-gray black, and soft calcareous shale	4	40

6-10-29cc. *Sample log of test hole in the SW¼ SW¼ sec. 29, T. 6 S., R. 10 W., Mitchell County, 12 feet north of center of road and 0.2 mile east of road intersection. Surface altitude, 1,467.1 feet. Water level, 37.6 feet*

	Thickness, feet	Depth feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, soft, brown and tan; contains a few small snail shells	10	10
Silt, soft, sandy, gray to brown	21	31
Silt, sandy, gray	9	40

	Thickness, feet	Depth, feet
Silt, soft, light-gray; contains small amount of very fine to fine sand and a few small snail shells	3	43
Sand, very fine to coarse, quartz and chalk; contains gray silt	7	50
Sand, very fine to coarse; contains a small amount of fine to medium limestone gravel and shale fragments,	2.5	52.5
CRETACEOUS—Gulfian		
Greenhorn limestone		
Shale, hard, fissile, gray-black	2.5	55

6-10-31ad. *Sample log of test hole in SE¼ NE¼ sec. 31, T. 6 S., R. 10 W., Mitchell County, 10 feet west of center of road, 200 feet south of approach to Solomon River bridge. Surface altitude, 1,450.4 feet. Water level, 20.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Alluvium (Recent)		
Silt, soft, sandy, dark-brown	5	5
Silt, soft, slightly sandy, gray and brown; contains small snail shells	11	16
Sand, very fine to fine; contains small amount of medium to coarse sand, fine gravel, and gray silt	5	21
Sand and gravel, fine to coarse, poorly sorted; contains limestone and shale pebbles, and a small amount of gray clay	8	29
Silt, soft, sandy, gray-blue; contains fine gravel and many small snail and clam shells	3	32
Sand, fine to coarse, and fine to coarse quartz and limestone gravel	7	39
CRETACEOUS—Gulfian		
Greenhorn limestone		
Shale, hard, silty, dark gray-black	1	40

6-10-31dd. *Sample log of test hole in the SE¼ SE¼ sec. 31, T. 6 S., R. 10 W., Mitchell County, 11 feet west of center of road and 0.2 mile north of road intersection. Surface altitude, 1,485.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation (?)		
Silt, sandy, dark-brown	2	2
Silt, medium compact, slightly sandy, tan and brown	3	5
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Clay shale, weathered, calcareous, gray-yellow; contains fragments of *Ostrea* shells	2	7
Clay shale, calcareous, light-gray to tan; contains thin medium soft gray limestone	1	8
Clay-shale, calcareous, light-gray; contains shell and chalk fragments	2	10

6-11-28a1. *Driller's log of Missouri Pacific Railroad Co. well 1 in the NE¼ sec. 28, T. 6 S., R. 11 W., Osborne County; drilled by Layne-Western Co., February 1936. Water level, 35 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Soil	2	2
Clay	25	27
Sand and gravel	14	41
CRETACEOUS—Gulfian		
Carlile shale		
Shale	1	42

6-11-28a2. *Driller's log of Missouri Pacific Railroad Co. well 2 in the NE¼ sec. 28, T. 6 S., R. 11 W., Osborne County; drilled by Layne-Western Co., 1938.*

	Thickness, feet	Depth, feet
Cinder fill	5	5
QUATERNARY—Pleistocene		
Terrace deposits		
Clay, black	8	13
Clay, yellow	19	32
Sand, fine	1	33
Sand, coarse, and gravel	15	48
Sand, fine	2	50
Sand, coarse, and gravel	5	55
CRETACEOUS—Gulfian		
Carlile shale		
Shale	2	57

6-12-12cc. *Sample log of test hole in the SW¼ SW¼ sec. 12, T. 6 S., R. 12 W., Osborne County, 12 feet north of center of road and 0.25 mile east of road intersection. Surface altitude, 1,552.3 feet. Water level, 9.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation and alluvium		
Silt, compact, sandy, dark-gray	3	3
Silt, compact, slightly sandy and gravelly, light-gray	5	8
Silt, tan, and fine to medium, yellow-white chalk gravel,	7	15
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, light- to dark-gray, and some tan to yellow	5	20

6-12-13bc. *Sample log of test hole at SW cor. NW¼ sec. 13, T. 6 S., R. 12 W., Osborne County, 7 feet east of center of road and 0.5 mile north of road intersection. Surface altitude, 1,512.9 feet. Water level, 36.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, sandy, dark-gray	4	4
Silt, compact, plastic, dark-gray	4	8
Silt, medium compact, light-gray to tan	4	12

	Thickness, feet	Depth, feet
Silt, very loose, tan and gray	6	18
Silt, medium compact, slightly sandy, light-gray	11	29
Sand, fine to coarse; contains small amount fine quartz, feldspar, and limestone gravel	11	40
Sand and gravel, fine to coarse; contains yellow, red, and brown clay	8	48
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Shale, plastic, calcareous, dark gray-black	2	50

6-12-13cc. *Sample log of test hole in SW¼ SW¼ sec. 13, T. 6 S., R. 12 W., Osborne County, 5 feet east of center of road, 0.2 mile north of road intersection. Surface altitude, 1,507.1 feet. Water level, 32.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, compact, dark-gray	5	5
Silt, medium compact, light-gray to gray	11	16
Silt, fairly loose, light-tan	12	28
Sand, very fine to coarse; contains small amount fine to medium gravel	7	35
Sand, very fine to coarse, and fine limestone gravel, contains gray silt, fragments of gray shale, and gypsum fragments	4	39
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, plastic, noncalcareous, dark-gray	1	40

6-12-24bb. *Sample log of test hole in the NW¼ NW¼ sec. 24, T. 6 S., R. 12 W., Osborne County, 20 feet east of center of trail road and 0.1 mile south of road intersection. Surface altitude, 1,505.0 feet. Water level, 31.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, brown	13	13
Silt, compact, slightly sandy, dark-gray	5	18
Silt, very sandy, tan and gray	12	30
Sand, very fine to medium; contains small amount coarse sand, fine to very coarse limestone gravel, and very small amount green and gray clay	14	44
Silt, soft, sandy and gravelly, dark-gray	6	50
Sand, fine to coarse, greenish; contains fine gravel and dark gray-green clay and silt	9	59
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Shale, silty to plastic, calcareous, dark gray-black	11	70

6-12-24bc. *Sample log of test hole in the SW¼ NW¼ sec. 24, T. 6 S., R. 12 W., Osborne County, 42 feet east of center of trail road and 0.4 mile south of road intersection. Surface altitude, 1,505.5 feet. Water level, 33.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, soft, brown to gray; contains small snail shells	14	14
Silt, medium compact, sandy, gray	6	20
Silt, soft, interbedded, brown and gray; contains small snail shells and very small amount of sand	17	37
Sand, very fine to medium quartz, greenish	13	50
Sand, very fine to coarse, greenish; contains some fine gravel, and gray shale fragments	10	60
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Shale, calcareous, dark gray-black	5	65

6-12-24cc. *Sample log of test hole in the SW¼ SW¼ sec. 24, T. 6 S., R. 12 W., Osborne County, 5 feet east of center of road and 0.2 mile north of intersection of road with U. S. Highway 24. Surface altitude, 1,504.0 feet. Water level, 33.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, soft, gray-brown	3	3
Silt, compact, interbedded, brown and gray	10	13
Silt, fairly soft, grayish-tan; contains a few small snail shells	12	25
Silt, soft, sandy, grayish-tan; contains small snail shells,	9	34
Silt, soft, sandy, gray	7	41
Silt, compact, plastic, dark-gray and soft green; contains very fine sand, and few small snail shells	12	53
Sand, very fine to coarse, quartz, feldspar, and granite; greenish; contains fine limestone gravel, green silt, and gray shale fragments	7	60
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Shale, plastic to silty, calcareous, black	5	65

6-12-26aa. *Sample log of test hole in the NE¼ NE¼ sec. 26, T. 6 S., R. 12 W., Osborne County, 8 feet west of center of road and 0.05 mile south of intersection of road with U. S. Highway 24. Surface altitude, 1,501.8 feet. Water level, 26.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, soft, sandy, dark-brown	4	4
Silt, medium compact, gray	5	9
Silt, medium compact, tan	5	14
Silt, medium compact, sandy, yellow-tan	12	26

	Thickness, feet	Depth, feet
Sand, very fine to coarse, and tan silt; contains fine limestone gravel	4	30
Sand, very fine to coarse, quartz; contains fine limestone gravels, partly iron-stained	10	40
Sand, very fine to very coarse, and fine to coarse quartz gravel, subangular limestone gravel, and shale fragments	5	45
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Shale, plastic to silty, calcareous, black	5	50

6-12-26ad. *Sample log of test hole in the SE¼ NE¼ sec. 26, T. 6 S., R. 12 W., Osborne County, 8 feet west of center of road, 180 feet north of ½-mile fence. Surface altitude, 1,509.2 feet. Water level, 35.1 feet.*

QUATERNARY—Pleistocene Terrace deposits	Thickness, feet	Depth, feet
Silt, soft, slightly sandy, brown	4	4
Silt, medium compact, slightly sandy, gray and tan	12	16
Silt, medium compact, sandy, light-gray and iron-stained	9	25
Silt, sandy, gray, tan, and iron-stained	3	28
Sand, very fine to medium, iron-stained; contains small amount coarse sand and fine quartz gravel	2	30
Sand, very fine to coarse; contains some fine quartz, limestone, and granitic gravel	14	44
Sand, fine to coarse, and fine to medium limestone, quartz, and granitic gravel	8	52
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Shale, plastic to silty, calcareous, black	8	60

6-12-36bb. *Sample log of test hole in the NW¼ NW¼ sec. 36, T. 6 S., R. 12 W., Osborne County, 6 feet south of center of road, 350 feet west of ¼-mile fence. Surface altitude, 1,545.7 feet. Water level, 10.2 feet.*

QUATERNARY—Pleistocene Sanborn formation	Thickness, feet	Depth, feet
Silt, medium compact, brownish-tan; contains much limestone gravel	8	8
Silt, compact, sandy, gray-tan; contains limestone gravel	18	26
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, clayey, light-gray, partly iron-stained	6	32
Shale, clayey, dark-gray	8	40

6-13-2cb. *Sample log of test hole in the NW¼ SW¼ sec. 2, T. 6 S., R. 13 W., Osborne County, 10 feet east of center of section line road, 0.4 mile north of road intersection. Surface altitude, 1,565.0 feet. Water level, 18.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, loose, sandy, dark-brown	5	5
Silt, medium compact, sandy, dark-gray	3	8
Silt, fairly soft, gray-tan	4	12
Silt, soft, sandy, light-tan; contains small snail shells	4	16
Silt, soft, sandy, tan and rusty-brown	4	20
Gravel, fine to medium, chalk, white; contains fine to coarse sand and gray silt	7	27
Silt, sandy, soft, gray-tan, and fine to coarse chalk gravel,	3	30
Sand, very fine to medium, quartz and chalk, gravelly	5	35
Silt, sandy, fairly soft, plastic, dark blue-gray and tan; contains shale fragments	4	39
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, plastic, noncalcareous, dark blue-gray; contains red-brown lignite (?)	6	45

6-13-3aa. *Sample log of test hole in the NE¼ NE¼ sec. 3, T. 6 S., R. 13 W., Osborne County, edge of field near east line of section and 0.3 mile north of intersection of half-section road with section-line road. Surface altitude, 1,655.1 feet. Water level, 24.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Terrace deposits		
Silt, loose, sandy, brown	16	16
Silt, sandy, tan and light gray-white	3	19
Sanborn formation		
Sand, very fine to coarse; contains small amount of fine limestone and quartz gravels	11	30
Sand, very fine to very coarse; contains fine to medium limestone, quartz, and granitic gravel	6	36
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Clay-shale, plastic to silty, blue-gray	4	40

6-13-10aa. *Sample log of test hole in the NE¼ NE¼ sec. 10, T. 6 S., R. 13 W., Osborne County, 20 feet south of center of road and 48 feet west of road intersection. Surface altitude, 1,568.0 feet. Water level, 20.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, loose, sandy, dark-brown	3	3
Silt, soft, sandy, gray-tan	8	11
Silt, soft, gray	5	16
Silt, sandy, soft, gray; contains many small snail shells	5	21

	Thickness, feet	Depth, feet
Silt, soft, gray; contains very fine to coarse sand and fragments of shale and limestone	8	29
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Clay-shale, plastic, dark-gray	6	35

6-13-10dd. *Sample log of test hole at SE cor. sec. 10, T. 6 S., R. 13 W., Osborne County, 9 feet west and 30 feet north of center of crossroads. Surface altitude, 1,643.0 feet. Water level, 35.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn and Meade formations		
Silt, loose, soft, sandy, dark-tan	9	9
Silt, sandy, soft, tan; contains fine to medium limestone gravel	12	21
Silt, soft, tan; contains small amount of limestone gravel and caliche	8	29
Silt, sandy, gray; contains fine limestone gravel	5	34
Gravel, very fine to medium, limestone; contains small amount of tan silt	4	38
Silt, sandy, tan; contains fine to coarse limestone gravel,	2	40
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, noncalcareous, light blue-gray to dark-gray and yellow-brown; contains iron-stained shale and selenite	10	50

6-13-11bc. *Sample log of test hole at SW cor. NW¼ sec. 11, T. 6 S., R. 13 W., Osborne County, 12 feet east of center of road and 0.5 mile north of road intersection. Surface altitude, 1,583.5 feet. Water level, 25.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, soft, sandy, tan	2	2
Silt, medium compact, sandy, black	3	5
Silt, medium compact, gray to gray-tan	7	12
Silt, fairly soft, buff	8	20
Silt, soft, dark-gray	4	24
Silt, light gray-green; contains very fine sand	5	29
Gravel, very fine to coarse, white and iron-stained, limestone; contains fine to coarse sand and some silt	7.5	36.5
CRETACEOUS—Gulfian		
Carlile shale—Blue Hill shale member		
Shale, plastic, noncalcareous, dark-gray	3.5	40

7-10-6aa. *Sample log of test hole in the NE¼ NE¼ sec. 6, T. 7 S., R. 10 W., Mitchell County, 10 feet west of center of road and 0.15 mile south of road intersection. Surface altitude, 1,499.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, soft, dark-brown to black	3	3
Silt, plastic, medium compact, gray and tan	2	5
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Shale, soft, plastic, light-gray, tan, and reddish; contains a few fragments of *Ostrea* shells	5	10

7-10-6da. *Sample log of test hole in the NE¼ SE¼ sec. 6, T. 7 S., R. 10 W., Mitchell County, 13 feet west of center of road and 0.35 mile north of road intersection. Surface altitude, 1,493.2 feet. Water level, 6.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn formation		
Silt, soft, sandy, dark-brown	1	1
Silt, medium compact, sandy, tan and gray	4	5
CRETACEOUS—Gulfian		
Carlile shale—Fairport chalky shale member		
Clay shale, soft, silty, tan; contains shell fragments	1	6
Clay shale, tan and light-gray; contains shell fragments,	1	7
Clay shale, soft, chalky, light-gray	3	10

REFERENCES

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

BASS, N. W. (1926) Geologic investigations in western Kansas, part 1, Geology of Ellis County: Kansas Geol. Survey, Bull. 11, pp. 1-52, figs. 1-12, pls. 1-4.

——— (1929) The geology of Cowley County, Kansas, with special reference to the occurrence of oil and gas: Kansas Geol. Survey, Bull. 12, pp. 1-203, figs. 1-23, pls. 1-12.

BYRNE, F. E., BECK, H. V., and HOUSTON, M. S. (1948) Construction materials in Phillips County, Kansas: U. S. Geol. Survey, Circ. 21, pp. 1-12, figs. 1-3, pl. 1.

BYRNE, F. E., HOUSTON, M. S., and MUDGE, M. R. (1948) Construction materials in Smith County, Kansas: U. S. Geol. Surv., Circ. 25, pp. 1-17, figs. 1-3, pl. 1.

BYRNE, F. E., JOHNSON, W. B., and BERGMAN, D. W. (1951) Geologic construction-material resources in Mitchell County, Kansas: U. S. Geol. Survey, Circ. 106, pp. 1-21, figs. 1-4, pl. 1.

COMLY, H. H. (1945) Cyanosis in infants caused by nitrates in well waters: Am. Med. Assoc. Jour., vol. 129, pp. 112-116.

CONDRA, G. E., REED, E. C., and GORDON, E. D. (1947) Correlation of the Pleistocene deposits of Nebraska: Nebraska Geol. Survey, Bull. 15, pp. 1-73, figs. 1-15.

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

——— (1905) Preliminary report on the geology and underground water resources of the central Great Plains: U. S. Geol. Survey, Prof. Paper 32, pp. 1-433, figs. 1-18, pls. 1-72.

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

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

FENNEMAN, N. M. (1931) Physiography of western United States: pp. 1-534, figs. 1-173, New York, McGraw-Hill Book Co.

FRYE, J. C. (1945) Geology and ground-water resources of Thomas County, Kansas: Kansas Geol. Survey, Bull. 59, pp. 1-110, figs. 1-13, pls. 1-6.

——— (1946) The High Plains surface in Kansas: Kansas Acad. Sci. Trans., vol. 49, pp. 71-86, fig. 1, pls. I-III.

FRYE, J. C., and BRAZIL, J. J. (1943) Ground water in the oil-field areas of Ellis and Russell Counties, Kansas: Kansas Geol. Survey, Bull. 50, pp. 1-104, figs. 1-9, pls. 1-2.

FRYE, J. C., and FENT, O. S. (1947) The late Pleistocene loesses of central Kansas: Kansas Geol. Survey, Bull. 70, pt. 3, pp. 29-52, figs. 1-3, pls. 1-8.

FRYE, J. C., and LEONARD, A. R. (1949) Geology and ground-water resources of Norton County and northwestern Phillips County, Kansas: Kansas Geol. Survey, Bull. 81, pp. 1-144, figs. 1-11, pls. 1-10.

FRYE, J. C., and others (1949) Ceramic utilization of northern Kansas Pleistocene loesses and fossil soils: Kansas Geol. Survey, Bull. 82, pt. 3, pp. 49-124, figs. 1-10, pls. 1-3.

FRYE, J. C., and SWINEFORD, ADA (1946) Silicified rock in the Ogallala formation: Kansas Geol. Survey, Bull. 64, pt. 2, pp. 33-76, fig. 1, pls. 1-8.

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

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

HAWORTH, ERASMUS (1897) Physiography of western Kansas: Kansas Univ. Geol. Survey, vol. 2, pp. 11-49, fig. 1, pls. 1-8.

——— (1913) Special report on well waters in Kansas: Kansas Univ. Geol. Survey, Bull. 1, pp. 1-110, figs. 1-9, pls. 1-6.

HOYT, J. C. (1936) Droughts of 1930-34: U. S. Geol. Survey, Water-Supply Paper 680, pp. 1-106, figs. 1-69, pl. 1.

LANDES, K. K. (1930) Geology of Mitchell and Osborne Counties, Kansas: Kansas Geol. Survey, Bull. 16, pp. 1-55, fig. 1, pls. 1-15.

LANDES, K. K., and KEROHER, R. P. (1942) Mineral resources of Phillips County, Kansas: Kansas Geol. Survey, Bull. 41, pt. 8, pp. 227-312, figs. 1-5, pls. 1-4.

LATTA, B. F. (1944) Geology and ground-water resources of Finney and Gray Counties, Kansas: Kansas Geol. Survey, Bull. 55, pp. 1-272, figs. 1-21, pls. 1-12.

LOGAN, W. N. (1897) Upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. 2, pp. 195-234, figs. 10-11, pls. 28-30.

——— (1899) A discussion and correlation of certain subdivisions of the Colorado formation: Jour. Geology, vol. 7, pp. 88-99.

LOHMAN, S. W., and others (1942) Ground-water supplies available in Kansas for national defense industries: Kansas Geol. Survey, Bull. 41, pt. 2, pp. 21-68, figs. 1-3, pls. 1-4.

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

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

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

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

MOORE, R. C., and others (1951) The Kansas rock column: Kansas Geol. Survey, Bull. 89, pp. 1-132, figs. 1-52.

MOORE, R. C., and LANDES, K. K. (1937) Geologic map of Kansas: Kansas Geol. Survey, scale 1: 500,000.

PLUMMER, NORMAN (1937) Rock wool resources of Kansas: Kansas Geol. Survey, Min. Resources Circ. 5, pp. 1-74, figs. 1-28.

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

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

SAYRE, A. N., and others (1949) Water levels and artesian pressure in observation wells in the United States in 1946: U. S. Geol. Survey, Water-Supply Paper 1073, pp. 1-366.

SCHOEWE, W. H. (1949) The geography of Kansas, part II, Physical geography: Kansas Acad. Sci. Trans., vol. 52, pp. 261-333, figs. 12-55.

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

U. S. PUBLIC HEALTH SERVICE (1946) Drinking water standards: Public Health Reports, vol. 61, no. 11, pp. 371-384.

VER WIEBE, W. A. (1946) Exploration for oil and gas in western Kansas during 1945: Kansas Geol. Survey, Bull. 62, pp. 1-112, figs. 1-31.

——— (1947) Exploration for oil and gas in western Kansas during 1946: Kansas Geol. Survey, Bull. 68, pp. 1-111, figs. 1-30.

VER WIEBE, W. A., and others (1948) Oil and gas developments in Kansas during 1947: Kansas Geol. Survey, Bull. 75, pp. 1-230, figs. 1-51.

VER WIEBE, W. A., JEWETT, J. M., and NIXON, E. K. (1949) Oil and gas developments in Kansas during 1948: Kansas Geol. Survey, Bull. 78, pp. 1-186, figs. 1-53.

VER WIEBE, W. A., and others (1951) Oil and gas developments in Kansas during 1950: Kansas Geol. Survey, Bull. 92, pp. 1-187, figs. 1-12, pls. 1-2.

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

WILLISTON, S. W. (1897) Kansas Niobrara Cretaceous: Kansas Univ. Geol. Survey, vol. 2, pp. 237-246, pls. 35.

INDEX

24-3808

□