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GEOLOGY AND GROUND-WATER RESOURCES OF LOGAN COUNTY, KANSAS

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GEOLOGY AND GROUND-WATER RESOURCES OF LOGAN COUNTY, KANSAS

By Carlton R. Johnson

ABSTRACT

This report describes the geology and ground-water resources of Logan County in the High Plains of northwestern Kansas. The county has an area of 1,073 square miles, divisible into upland plains comprising about 35 percent of the county, flood plains along Smoky Hill River and tributaries, and dissected "pediment" slopes. The streams drain eastward and southeastward at gradients ranging from 14 to 24 feet per mile. Lakes in the county have been formed naturally by subsidence, deflation, and alluviation and artificially by damming small valleys.

The Pierre shale and Niobrara formation of Cretaceous age underlie the county and are exposed along the major valleys. These rocks are intricately faulted. The Ogallala formation, of Pliocene age, which underlies the upland plain, was deposited on the eroded surface of the Cretaceous rocks. The configuration of this surface perhaps was influenced by regional structure. Test drilling indicated distinct pre-Ogallala drainage channels trending generally northeast in the northern upland and southeast in the southern part of the county.

Ground water is one of the most important mineral resources of Logan County. The major aquifer in the northern upland is the Ogallala formation, which yields moderate to abundant amounts of hard calcium magnesium bicarbonate water to livestock, domestic, public-supply, and irrigation wells. Where the formation occupies pre-Ogallala valleys, its saturated thickness is sufficient to permit development of large wells for public supply and irrigation. In the northern upland, ground water moves eastward down a gradient of 10 feet per mile. The direction of movement is primarily dependent on the general configuration of the surface of the pre-Ogallala rocks, which are relatively impervious and confine the ground water to the permeable beds of the Ogallala formation. Ground water is scanty in the Ogallala formation in the southern upland and is very scarce in areas between the edge of the Ogallala formation and the flood plains of the major streams, where wells are supplied chiefly from Pleistocene alluvial deposits in small valleys. Wells drilled into the Dakota formation or the jointed Niobrara formation adjacent to faults probably will yield water of quality suitable for livestock in places to which water now is hauled for this purpose. Pleistocene deposits in flood-plain areas yield moderate to abundant supplies of water to livestock and domestic wells.

The chemical quality of the ground water in the county is related to geologic source. Five distinctive types of water are characteristic of the Ogallala formation, Pierre shale, Niobrara formation, Codell sandstone zone of the Carlile shale, and sandstone of the Dakota formation, respectively. The amount of dissolved solids in water from the Ogallala formation seems inversely related to the thickness of the water-bearing materials. The water in the Ogallala formation is hard but generally suitable for irrigation.

Recharge to the northern upland is estimated at almost 3,000 acre-feet per year. Factors involved in the computation include average gradient through

the estimated cross-sectional area of permeable rocks at the east county line and a value for the permeability of the Ogallala formation, which is based on aquifer tests.

Ground water in Logan County is developed principally for livestock and domestic use. The amount of water developed for irrigation is about 1,000 acre-feet per year and probably will increase in the northern upland area in future years.

INTRODUCTION

Purpose and Scope of Investigation

The investigation upon which this report is based was begun in June 1954 as part of a program of ground-water studies in Kansas by the United States Geological Survey and the State Geological Survey of Kansas in cooperation with the Division of Sanitation of the Kansas State Board of Health and the Division of Water Resources of the Kansas State Board of Agriculture. Many similar investigations have been completed since the program began in 1937, and several are now being made in other areas in Kansas (Fig 1).

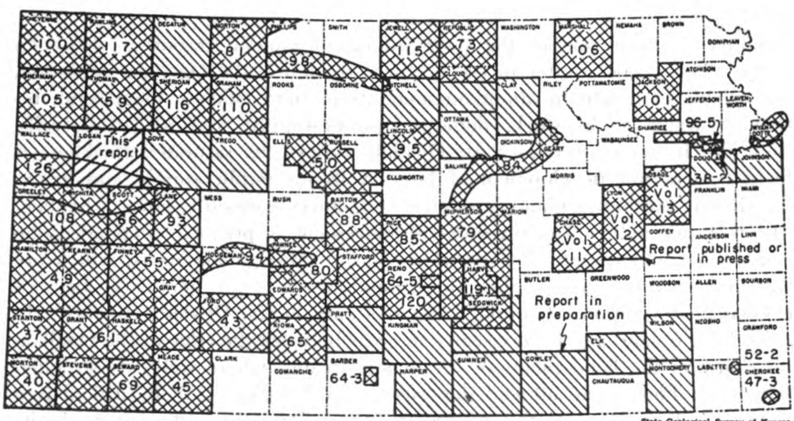


Fig. 1.—Index map of Kansas showing area discussed in this report and other areas for which cooperative ground-water reports have been published or are in preparation.

Ground water is one of the principal mineral resources of Logan County, as well as of most of western Kansas. All public supplies and nearly all domestic and livestock water supplies are obtained from wells. Most of the irrigation wells in the county have been drilled since 1945, and the use of ground water for irrigation, especially in the upland areas, probably will increase. An adequate understanding of the quantity and quality of the available supply, of where additional supplies can be obtained, and of what measures may be necessary to safeguard their continuance is needed.

Location and Extent of Area

Logan County is in the third tier of counties south of the northern border of Kansas and is the second county east of the western border (Fig. 1). It is bounded on the west by Wallace County, on the south by Wichita and Scott Counties, on the east by Gove County, and on the north by Thomas and Sherman Counties. It contains 30 townships from T. 11 S. to T. 15 S. and from R. 32 W. to R. 37 W. and has an area of 1,073 square miles.

Previous Investigations

A detailed study of the areal geology and ground-water resources of Logan County has not been undertaken previously, but specific reference to the area has been made in many earlier geological and hydrological reports.

In 1892 Willard reported barometric fluctuations in a well at Winona. Robert Hay (1895) mentioned the occurrence and moisture absorption of an "agatized mortar bed" at McAllaster (p. 553) and indicated that the Pierre shale extends east to the middle of Logan County (p. 573). Haworth (1897) described the physiography of western Kansas and discussed the origin of the High Plains, described the physical properties of the Tertiary rocks in western Kansas (1897a), and reported on the geology of the underground water in western Kansas (1897b). In his reports on the utilization of the High Plains, Johnson (1901, 1902) referred to the source, availability, and use of ground water in western Kansas. Darton (1905) described the geology and ground-water resources of the central Great Plains, in a report in which he briefly referred to deep test holes and wells drilled in Logan County (p. 306-307), and a report by Parker (1911) contained the analyses of samples of ground water (p. 127) and the analyses of two samples of surface water collected at sites in Logan County (p. 204). In a special report on well waters in Kansas, Haworth (1913) devoted a chapter to the Tertiary area of western Kansas (p. 57-68). Lupton, Lee, and Van Burgh (1922) reported on the Elkader dome, the Hell Creek structure, and the Twin Buttes anticline in Logan County. Russell (1929) studied the rocks of the Niobrara formation in Logan, Gove, and Trego Counties and reported on the usefulness of bentonite layers in interpreting the stratigraphy. Elias (1931), in a bulletin on the geology of Wallace County, made many references to the geology of Logan County and described a geologic section of the

Pierre shale east of McAllaster Buttes (p. 63). Lee (1940, pl. 7) gave a geologic section across Logan County depicting the structure of the rocks of Mississippian age. A report (U. S. Geological Survey, 1944) on water levels and artesian pressures in the United States in 1942 briefly outlined the observation-well program in Logan County (p. 137-138). Similar reports that contain water-level measurements for several wells in Logan County for the years 1943 through 1955 have been published. A cross section by Collins (1947) contains two well logs in Logan County. In 1951 and 1952 a detailed geologic and hydrologic investigation was made of the Ladder Creek area in Kansas, which contains the part of Logan County south of Smoky Hill River (Bradley and Johnson, 1957). Merriam and Frye (1954), reporting on the Cenozoic of western Kansas, presented maps (pl. 1, 2) showing the areal geology, pre-Cenozoic geology, and pre-Cenozoic topography of part of Logan County.

Reports of investigations of the geology and ground-water resources made as part of a program of ground-water investigations in Kansas include, among others, those on Thomas County (Frye, 1945), Scott County (Waite, 1947), Lane County (Prescott, 1951), Sherman County (Prescott, 1953), and Wichita and Greeley Counties (Prescott, Branch, and Wilson, 1954).

Methods of Investigation

Data for this report were collected during the summers of 1954 and 1955. Records were collected on 276 wells; most were measured with a steel tape to determine the depth of the well and the depth to water. Well owners and drillers were interviewed regarding yield and drawdown of wells and the character of the water-bearing materials. Four aquifer tests using public-supply and irrigation wells were made to determine the permeability of the Ogallala formation. Chemical analyses of samples of water from 42 wells and 4 streams were used to relate the chemical character of each water to its geologic source.

The areal geology was mapped and studied in regard to its influence on the occurrence and movement of ground water. The nature of the subsurface materials was determined by the drilling of 28 test holes and by microscopic examination of the drill cuttings. The altitude of the surface at the test holes and wells was determined by plane table and alidade. The altitude of the Tertiary-Cretaceous contact was determined by altimeter at several exposures.

The wells and test holes shown on Plates 1 and 2 were located by automobile odometer and aerial photographs. The base map was prepared from a county map published by the Soil Conservation Service of the U. S. Department of Agriculture.

Well-Numbering System

The well and test-hole numbers used in this report give the location of wells according to General Land Office surveys and in the following sequence: township, range, section, quarter section or 160-acre tract, and quarter-quarter section or 40-acre tract (Fig. 2). The 160-acre and 40-acre tracts are designated a, b, c, or d in a counterclockwise direction starting in the northeast quarter. If two or more wells are within a 40-acre tract, the wells are numbered serially beginning with the first well measured.

Acknowledgments

Many residents of Logan County gave permission to inventory their wells and supplied helpful information. Special thanks are given to Horace Holmes, James Ahrens, and officials of the cities of Winona and Oakley who permitted aquifer tests to be made using

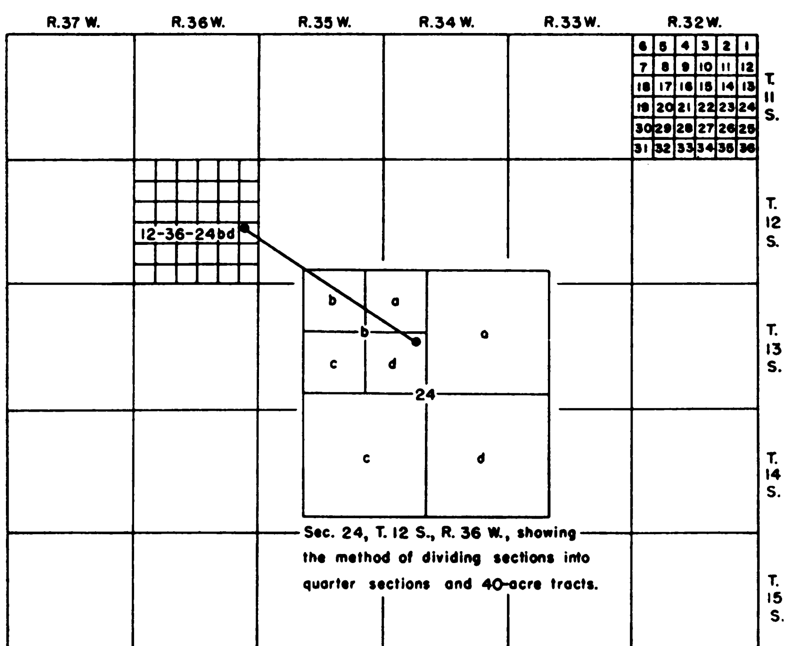


Fig. 2.—Map of Logan County illustrating well-numbering system used in this report.

their wells, and to Marvin Becker who permitted the logging of a deep well to the Dakota formation. The following drillers provided logs of wells and test holes and other information on wells in the county: Struckoff Brothers, Grinnell; C. A. Robbin, Norton; Wesley Weishaar, Scott City; and John Heim, Dorrance. E. Wayne Brenn of the Soil Conservation Service, U. S. Department of Agriculture, and his staff aided in the collection of information and outlined the ground-water needs of residents of the county.

Assistance during field work was given by the following personnel of the U. S. Geological Survey or the State Geological Survey of Kansas: G. J. Stramel, William Gellinger, and E. L. and Carrie Reavis.

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

GEOGRAPHY

Topography and Drainage

Most of Logan County is in the High Plains section of the Great Plains province, but the eastern part falls within the Plains Border section of the same province (Fenneman, 1931, pl. 1). The topography of the county little resembles the flat, almost featureless plains characteristic of the counties adjacent on the north and on the south. Instead, the county consists of gently rolling cultivated lands bisected by an east-west strip of rolling, broken grasslands, dissected "pediments", buttes, and rocky canyons.

The largest streams of the area are Smoky Hill River and its tributaries, Chalk, Twin Butte, Hackberry, and Turtle Creeks, and North Fork of Smoky Hill River, which flow eastward and southeastward. The longer tributary streams enter from the north-northwest, and the shorter tributaries from the south-southwest.

The upland plain, which is underlain by Tertiary rocks, slopes slightly south of east from a maximum altitude in Logan County of 3,550 feet to a minimum of 3,000 feet. It includes an area in the northern part of the county that is about 15 miles wide at the northeastern corner and tapers to only a few miles at the northwestern corner of the county. Smaller segments of the upland plain are present in the southwestern part of the county, along the Twin

Butte Creek-Chalk Creek divide, and in a strip along the southern border.

The upland plain areas constitute about 35 percent of the total area of Logan County and are characterized by well-developed soils, broad gentle swells, shallow narrow drainage channels, and undrained depressions a few acres in extent.

River flood plains occupy but a small area in Logan County, mostly along Smoky Hill River. Much of the flat flood plain is sandy and has no cover except sagebrush, but grasslands are extensive where the soil is stable. The channel of Smoky Hill River is braided locally and has a maximum width of a quarter of a mile.

Intermediate between the flood plain and the upland plain, dissected flat surfaces slope gently toward the main valley. These "flanking pediments", as these features have been called by Frye (1954), are separated from the upland by a break in slope at the edge of the upland plain and from the valley by bluffs along the sides of the valley. The "pediments" are absent over wide areas because of erosion by minor tributaries separated from one another by steep valley slopes and rolling divides forming the large grassland area. This belt of intermediate rolling grasslands and cultivated "pediment" areas is wider on the north side of Smoky Hill River and Chalk and Twin Butte Creeks than on the south side of those streams. Rock exposures, especially of Cretaceous chalk in the Niobrara formation, are present as cliffs and buttes along the valley slopes and in places are dissected into deep, narrow canyons and striking pinnacles, as in sec. 25 and 26, T. 14 S., R. 33 W. In parts of the county, especially in the southeastern corner, deep valleys have been eroded into the Ogallala formation, and the cemented beds of the Ogallala form vertical cliffs.

Streams

The drainage basin of Smoky Hill River above Elkader extends into eastern Colorado and has an area of 3,555 square miles. The width of the floodplain and adjacent low stream terraces is slightly more than a mile. The braided channel is generally a barren area of loose sand and gravel (Pl. 5B). The stream has a west-to-east gradient of approximately 14 feet per mile, dropping from an altitude of 3,150 feet at the west edge of the county to about 2,580 at the east edge. The average discharge at Elkader is 57.3 cubic feet per second for the 13 years of record, 1939 to 1952. Maximum discharge of 19,700 cfs was attained June 11, 1951. During hot, dry periods in the summer, there is often no flow in the channel.

The drainage basin of Twin Butte Creek is elongated and bordered by high divides, and has moderate to steep slopes and no large tributaries. The slope to the floodplain from the apex of the divide on the north side is considerably gentler than that on the south side, where prominent bluffs are common. The stream has a gradient of about 20 feet per mile, dropping from 3,300 feet above sea level at the west border of the area to about 2,700 at its mouth. Average discharge is probably less than 3 cfs, as during the hot,

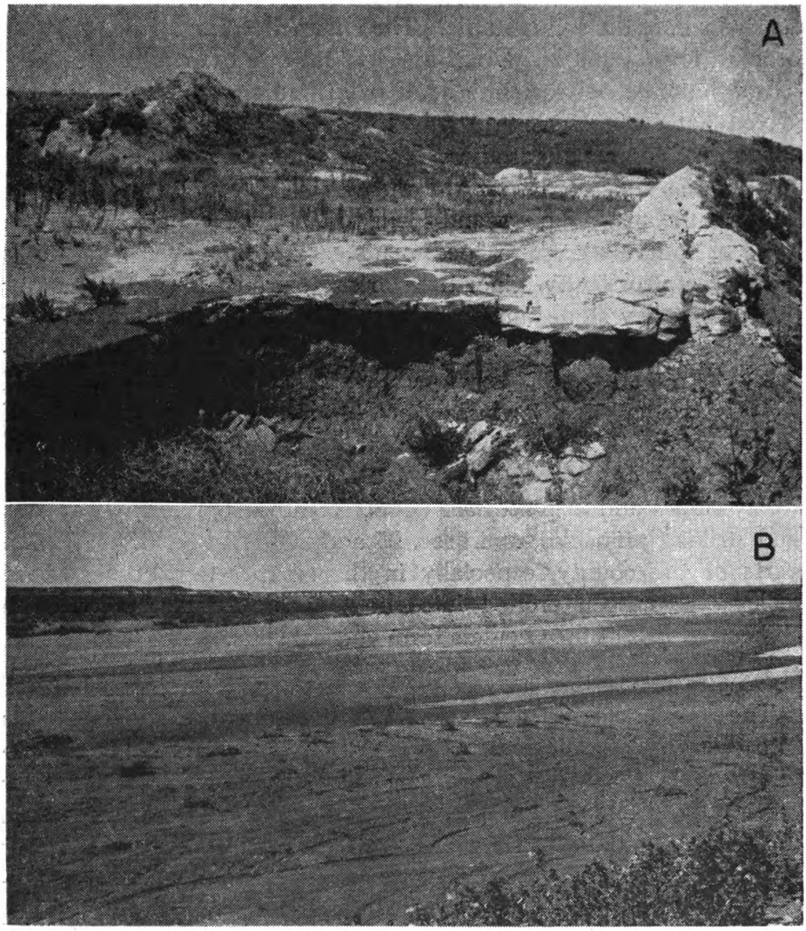


PLATE 5.—A, Abandoned quarry in Pearlette ash bed of Meade Group in sec. 11, T. 13 S., R. 35 W. Underlying the ash, which here reaches a thickness of 8 feet, is dark-gray shale. B, Sand and gravel in channel of Smoky Hill River in sec. 28, T. 14 S., R. 32 W. Light-colored cliffs in background are chalk of Niobrara formation, capped by darker Crete formation of Sanborn Group.

dry part of the summer the stream is dry except for pools of water in low spots in the channel.

Chalk Creek occupies a long narrow drainage basin having a gentle northern slope and a steeper southern slope. The valley is not deep and, except for a small stretch in the western part of the county, is cut into the Niobrara formation. The stream has a gradient of about 24 feet per mile, dropping from an altitude of about 3,400 feet at the west edge of the county to about 2,700 at its mouth. Average discharge is probably less than 6 cfs. The valley is incised below the contact of the Ogallala and Niobrara formations over most of its length, and springs are common in the stretch between sec. 36, T. 15 S., R. 35 W., and sec. 31, T. 15 S., R. 36 W. Running water in the channel farther downstream is infrequent during the hot dry summers, despite the increments in flow from the springs.

Ladder Creek drains an area of approximately 1,460 square miles lying mostly south and west of Logan County. The valley is incised into the Ogallala formation in Scott, Wichita, and Greeley Counties. In those areas, the Ogallala provides a perennial discharge, but the water is consumed completely by evapotranspiration in the summer months, hence the stream is often dry through its extent in Logan County. Maximum discharge, not affected by discharge from the dam at Lake McBride, was 8,650 cfs on June 11, 1951.

Lakes

Intermittent lakes are prevalent throughout Logan County, but only a few are more than a few hundred acres in area. The lakes can be divided into four distinct types: (1) lakes in deep depressions; (2) small, shallow upland ponds; (3) small ponds along watercourses; and (4) artificial stock ponds.

The large, deep depressions are a unique feature of the upland topography. Area of the depressions ranges from a few hundred acres to somewhat more than 3,000 acres. They are in sec. 2, T. 12 S., R. 37 W.; sec. 6, T. 12 S., R. 36 W.; sec. 6, T. 11 S., R. 36 W.; sec. 12, T. 13 S., R. 33 W.; and sec. 13, T. 13 S., R. 33 W. A very well developed depression and a good example of the type is in sec. 29, T. 12 S., R. 33 W. (Pl. 6A). The largest of the depressions is in the south-central part of T. 12 S., R. 37 W. The depression floor is sometimes flooded over an area of several hundred acres after heavy rains, but is commonly dry during hot, dry periods when runoff from precipitation to the lake is small.

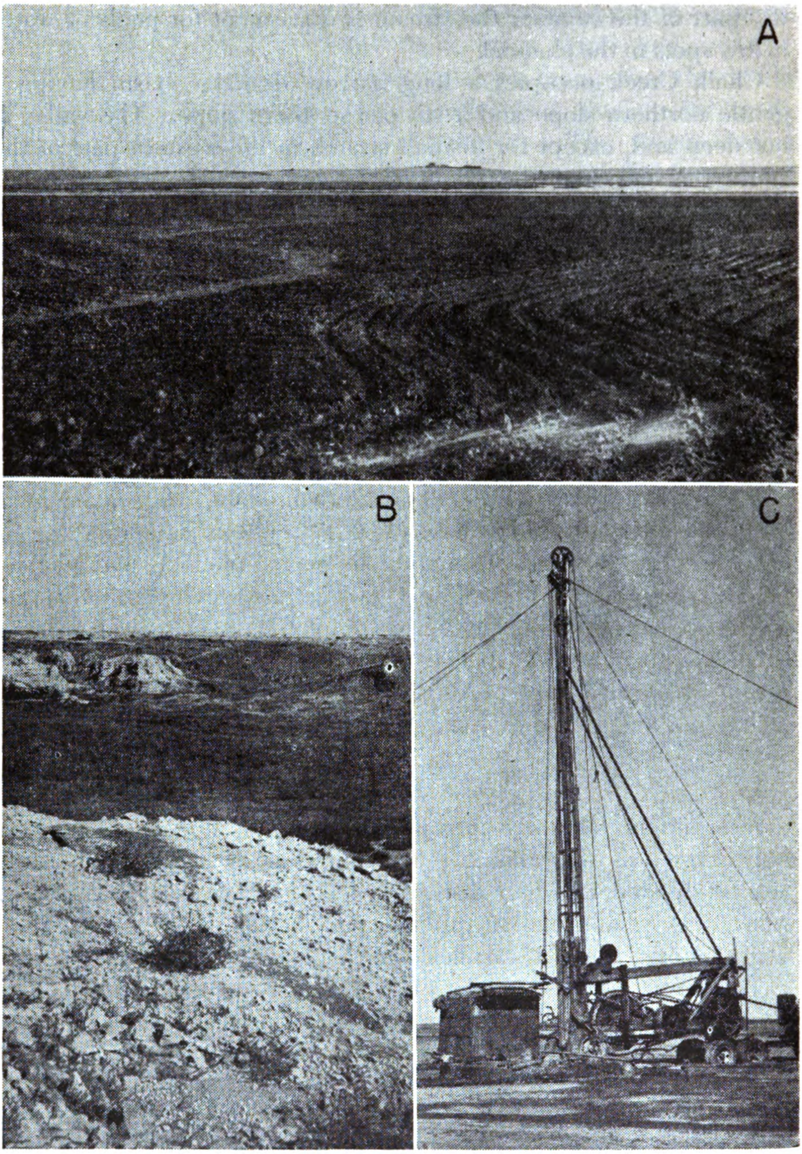


PLATE 6.—A, Large, deep depression in sec. 29, T. 12 S., R. 33 W. The bottom of the depression probably is lower than the base of the sandstone of the Ogallala formation in the surrounding slopes. B, Fault bringing Pierre shale against Niobrara formation in sec. 17, T. 13 S., R. 35 W. Niobrara formation is exposed in foreground and left background; Pierre shale is exposed in right background. Fault strikes nearly due east parallel to jointing along which hammer is laid; fault plane dips to right. C, Churn drill owned by John Heim, Dorrance, at site of first successful well in Dakota formation in Logan County. Well was drilled on S. Dirks farm to depth of 1,230 feet. Water rose under artesian pressure to within 695 feet of surface.

The deep upland depressions probably resulted from subsidence of the underlying Cretaceous rocks. A local subsidence in Wallace County in 1926 and recent subsidences in Sherman and Hamilton Counties support this view. The basins seem too deep in relation to their area to be a result of wind erosion. The differential compaction of Tertiary sediments has been suggested as a causal factor (Johnson, 1901), but cannot be a cause of those depressions directly underlain by Cretaceous rocks or by very thin Tertiary rocks.

Elias (1931, p. 232-233) believed that the subsidences were caused by solution of chalk in the Niobrara formation along existing fault planes and the sudden collapse of the ensuing cavities. Moore (1926) explained the subsidences as resulting from solution of the shaly chalk of the Niobrara formation along its bedding planes. The thickness of Pierre shale beneath many of the depressions is several hundred feet and presumably would increase as one result of slumping. The size of cavern required to accommodate sufficient material to produce an appreciable basin would suggest solution on a scale great enough to be noticeable in exposures of the Niobrara formation. Evidence of large caverns in the extremely shaly Niobrara formation or of extensive solution along the faults where exposed in Logan County is lacking, however.

Russell (1929a) explained the recent subsidences as resulting from collapse of cavities formed by late Pliocene to early Pleistocene faulting. Tensional faulting, which has produced small local grabens in Logan County, may be continuing to the present time. Definite proof of the origin of these unusual topographic features is lacking, but this explanation seems to be the most plausible.

Hundreds of the small undrained shallow basins that are characteristic of the uplands of the High Plains are present in Logan County. The "lagoons" or "buffalo wallows", as they are locally called, are a few acres to several tens of acres in area. After heavy rains, storm runoff collects in these small basins, forming temporary lakes. The water in the ponds is shallow and generally evaporates or seeps into the ground after a few weeks. The larger depressions were mapped from aerial photographs and are shown on Plate 1.

Darton (1905, p. 36-37) explained the origin of these High Plains depressions as resulting from the action of buffalos and wind. Johnson (1901, p. 702-704) attributed them to rainwater accumulation in initial faint unevenness of the plain. The seeping of the water beneath the pond caused a settling of the underlying sediments by mechanical compaction and solution.

In Logan County, the lagoons are wet only for short periods after rains. When dry, the floors of the lagoons are the source of much blowing dust, which buries fences and fills roadside ditches in the vicinity of the ponds. Consequently, eolian erosion of the floor of the basin not protected by vegetation or plowing is not a negligible factor.

Frye (1945, p. 29) observed that some of the depressions are aligned along shallow valleys. These alignments are well developed in Logan County, particularly southeast of Winona and in the northeastern part of T. 12 S., R. 34 W. In stream channels, basins resulting from irregularities in deposition along the length of a stream are well known. In the uppermost reaches of a stream, where the valley is shallow and broad and begins to fade into the upland plain, these same irregularities probably exist. Such local reversals of gradient would cause shallow, broad undrained areas in which some of the stream runoff would accumulate. The turf would be destroyed, and upon drying, the floor of the basin would be subjected to eolian erosion, with perhaps some help from animals, both deepening and somewhat increasing the area of the basin. The basin would thus be able to accumulate more water, the endless circle would continue, and the basin would persist. As depth increased, wind velocity across the bottom would be reduced and periods of inundation would be longer, and both these factors would decrease deflation. None of the shallow depressions exceeds 50 acres in area.

The extremely large depressions in sec. 12, T. 13 S., R. 34 W., and sec. 11 and 12, T. 12 S., R. 37 W., are related to depressions in the Pierre shale, which underlies both.

The small ponds along watercourses are developed in the same way as the original ponds from which the upland shallow depressions evolved. The small depressions are in fairly deep valleys and narrow draws that protect them from the wind, and thus they escape enlargement and deepening by eolian action. The bottoms of the draws in many places support a dense vegetation and stay wet for long periods, and any wind action that otherwise would be effective is minimized. As a result, these depressions are less than an acre in area, arranged in alignment with the channel of the ephemeral or intermittent stream that connects them in many places, steep sided and abrupt owing to abundant vegetation supporting the sides, and generally wet during a greater part of the year than other types of depressions in the area.

Population

According to the U. S. Census, Logan County in 1950 had a population of 4,206 and an average density of 3.9 inhabitants to the square mile, compared to an average of 24.4 for the state. The population had increased from 3,688 in 1940. In 1950 the population of Oakley was 1,915; Winona, 382; Russell Springs, 161; Monument, 141; Page City, 100; McAllaster, 25; and Elkader, 7.

Transportation

Logan County is served by the Union Pacific Railroad, a line of which crosses from east to west through Oakley, Monument, Page City, Winona, and McAllaster. The principal hard-surfaced highways are U. S. Highway 40, which parallels the railroad, and U. S. Highway 83, which crosses the eastern part of the county from north to south through Elkader and Oakley. Kansas Highway 25 extends from U. S. Highway 40 south through Russell Springs then west and south across the county. From a point about 3 miles west of Russell Springs to its junction with U. S. Highway 40, Highway 25 is hard surfaced; the rest is graveled. There are several gravel-surfaced county highways and an extensive system of improved section-line roads. Oakley has a small airport.

Agriculture

Agriculture is the dominant economic activity in Logan County, the prinicipal types being wheat farming, cattle raising, and general farming. The principal crops are wheat and grain sorghums, but smaller acreages commonly are planted to barley, alfalfa, oats, and corn. In 1950 the value of crops sold was 60 percent of the total value of all agricultural products sold to market from Logan County; 37 percent was from the sale of livestock; and less than 2 percent was from dairying.

According to the U. S. Census of 1950, the number of farms in Logan County was 437, the average acreage 1,234, and the average value of both land and buildings $42,278. In 1954, 11 wells were used to irrigate nearly 1,000 acres. Principal crops irrigated were grain sorghum, corn, and alfalfa.

Mineral Resources

Logan County has no known mineral resources of great value other than soil and ground water. Sand and gravel deposits in the alluvium and other Pleistocene units along Smoky Hill River are worked to some extent for road-surfacing material. Chalk from the Smoky Hill chalk member of the Niobrara formation is quarried for use as building stone. The locations of pits and quarries are shown on Plate 1.

The Kansas Geological Survey (1931) described the diatomaceous marl beds in Wallace and Logan Counties and stated that preliminary study showed that the material could be burned for hydraulic lime and used in making slow-setting cement. Samples of rock collected in 1937 from exposures of the Ogallala formation in an escarpment in Scott County State Park just south of the southern border of Logan County contained sufficient calcium carbonate to be classified as wool rock (Plummer, 1937, p. 25-26). Presumably, rock of this quality is present in exposures of the Ogallala formation in Logan County. Five samples of the Bignell formation, Brady soil, and Peoria formation of the Sanborn group collected from the NE¼ sec. 32, T. 12 S., R. 37 W. (Frye, Plummer, Runnels, and Hladik, 1949, p. 83), were found to be suited especially to the production of ceramic slag, which can be used for railroad ballast, riprap, road-surfacing material, and concrete aggregate. Plummer and Hladik (1951, p. 70-71) reported the suitability of a sample of Pierre shale collected in the center of the S½ sec. 8, T. 12 S., R. 36 W., for use in the manufacture of light-weight concrete aggregate. Carey, Frye, Plummer, and Swineford (1952) described six exposures of volcanic ash in Logan County, some of which were mined by the State Highway Department for aggregate.

Prior to 1955, nineteen wildcat wells had been drilled in Logan County (Fig. 3) in attempts to discover oil or gas, but all were unsuccessful. Subsequently four additional dry holes were drilled in 1956. The county has been geophysically surveyed, and the recent successful oil wells in Gove and Scott Counties probably will stimulate further prospecting for oil in Logan County.

Climate

The climate of Logan County is semiarid and is characterized by abundant sunshine, moderate precipitation, considerable wind, a high rate of evaporation, and relatively low humidity. The effects of the summer heat are reduced to some extent by low humidity and brisk winds; the summer days are hot, but the nights are generally cool. The winters are moderate and have little snowfall and only short periods of severely cold weather.

In Logan County the amount of precipitation and its seasonal distribution are the chief factors governing crop growth. According to records of the U. S. Weather Bureau, about 77 percent of the annual precipitation falls during the 6-month growing season from April through September.

The U. S. Weather Bureau maintains precipitation gages at Oakley, Russell Springs, and Winona, and near Elkader. The normal annual precipitation at Oakley (Fig. 4), which has the longest record, is 18.97 inches. The recorded precipitation in Logan County has ranged from a minimum of 8.84 inches at Russell Springs in 1916 to a maximum of 34.63 inches at Oakley in 1941.

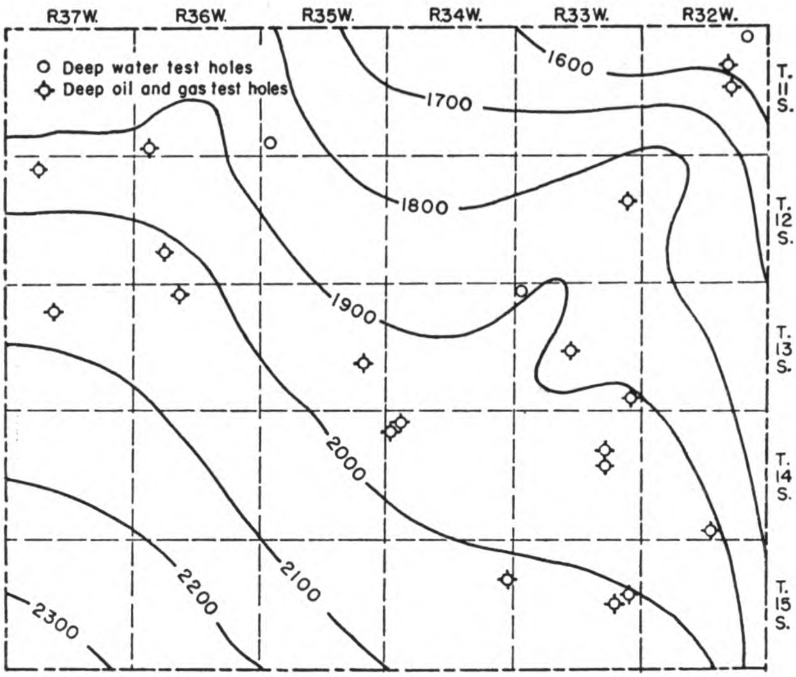


FIG. 3.—Regional structure of Logan County shown by contouring top of Dakota formation.

Foley, Smrha, and Metzler (1955) suggested that there may be cyclic trends in Kansas precipitation; the statewide precipitation trended upward in the periods 1902-09, 1920-31, and 1941-51, and downward in 1910-19, 1932-40, and again beginning in 1952. These trends are demonstrated by a curve of the progressive 10-year average precipitation at Oakley (Fig. 4), which smooths out the large variations of annual precipitation. Each point on the graph represents the average annual precipitation of the previous 10 years.

The annual mean temperature at Oakley is 53.3°F. The lowest recorded temperature at Oakley was -24°F on February 8, 1933, and the highest was 111°F on June 24, 1936.

Evaporation is not recorded in Logan County by an official agency, but evaporation data available from U. S. Weather Bureau stations at Tribune and Colby suggest that the potential annual evaporation in Logan County is probably about 60 inches.

The average date of the last killing frost in the spring is May 2 and the average date of the first killing frost in the fall is October 12. The average length of the growing season is 163 days.

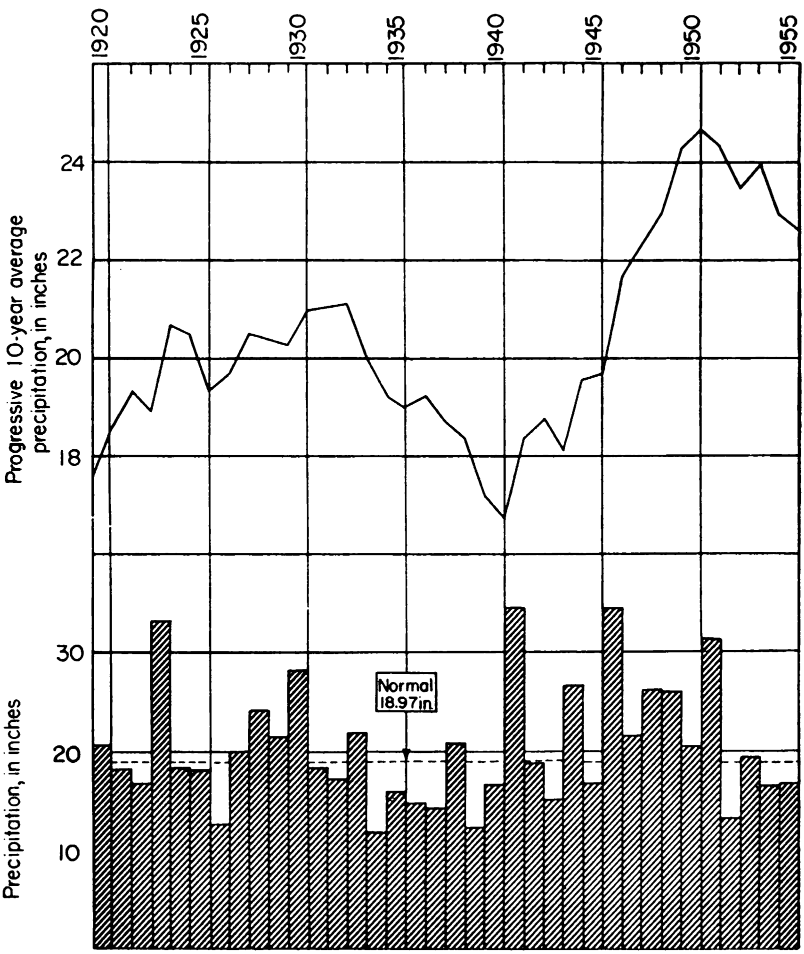


FIG. 4.—Graphs showing normal annual precipitation and progressive 10-year average precipitation at Oakley.

GEOLOGY *

Summary of Stratigraphy

The rocks exposed in Logan County range in age from Late Cretaceous to Recent (Pl. 1). The oldest rocks, which crop out in the eastern and central parts of the county along the Smoky Hill River valley, belong to the Smoky Hill chalk member of the Niobrara formation. The largest area of outcrop of the Pierre shale, which overlies the Niobrara formation, is in the western part of the county.

The Ogallala formation, of Pliocene age, unconformably overlies the Pierre shale and the Niobrara formation except in the Smoky Hill Valley, where it has been entirely eroded away. The Ogallala formation crops out in much of the county and is best exposed along the stream valleys and at the edge of the upland plain. The undissected upland plain is mantled by windblown silt (loess) of the Sanborn Group. Sand and gravel of late Pleistocene age mantles the dissected Pleistocene "pediments". In parts of sec. 18 and 27, T. 14 S., R. 33 W., some of these deposits have been reworked by the wind into active dunes. Colluvial deposits derived chiefly from loess are extensive on the steeper slopes in the Smoky Hill River valley and tributary valleys and are mapped as part of the Sanborn Group. Small areas of dune sand and alluvium in the Turtle Creek and Smoky Hill River valleys are the youngest deposits in the area.

The water-bearing character and lithology of the geologic formations are described briefly in Table 1. The stratigraphic relations of the formations are shown in the geologic cross sections (Pl. 3, 4).

Summary of Geologic History

Although the oldest formation exposed at the surface in Logan County is the Niobrara formation, it is known from the records of deep tests for oil and gas that the exposed rocks are underlain by older sedimentary rocks of Mesozoic and Paleozoic age, which in turn rest upon crystalline rocks of Precambrian age. Logs of test wells for gas and oil indicate that Logan County is underlain by at least 4,500 feet of sedimentary rocks of Paleozoic age. Before the Paleozoic era the crystalline rocks of Precambrian age had been eroded in places to local relief of about 1,000 feet.

During Early and Middle Cambrian time Logan County was above sea level, but in Late Cambrian time an interior sea ad-

* The geologic classification and nomenclature of this report follow the usage of the State Geological Survey of Kansas and differ somewhat from those of the U. S. Geological Survey.

vanced over the area. It persisted through most of the Ordovician period. During this submergence, extensive calcareous sediments were deposited, which are recognized in well cuttings and electric logs as the Arbuckle Group of Cambrian and Ordovician age and the Viola limestone of Ordovician age. In an oil-test well drilled in the center of sec. 13, T. 15 S., R. 33 W., the thickness of the Arbuckle Group is 550 feet, the thickness of the Viola limestone is 125 feet, and the top of the Ordovician rocks was penetrated at a depth of about 5,300 feet.

Rocks of Silurian and Devonian age are not known to underlie Logan County. A shallow sea or a low land mass may have been present, but no evidence of either erosion or deposition has been found.

During Early Mississippian time, marine dolomitic limestone and some shale were deposited. Logs of oil tests indicate that the top of the Mississippian strata is at a depth of about 4,650 feet. Rock types found in formations of this period include oölitic limestone, dolomite, cherty limestone, and cherty dolomite. In later Mississippian time uplift occurred, and during the emergence, lower Mississippian strata were eroded. During the Pennsylvanian period, subsidence and uplift alternated several times, and both marine and continental sedimentary rocks consisting of sandstone, limestone, coal, and shale were deposited. The Pennsylvanian rocks in the subsurface of Logan County are approximately 1,000 feet thick. The top of the Pennsylvanian strata is at a depth of about 3,600 feet.

Alternating submergence and emergence continued during early Permian time, and limestone, dolomite, and shale were deposited. Extensive lenses of salt, anhydrite, and gypsum suggest a climate of rapid evaporation. During middle Permian time, shallow basins and low plains were areas of continental deposition, predominantly of shale and sandstone. Logs of oil tests indicate that Logan County is underlain by at least 1,300 feet of Permian sedimentary rocks.

Part of the Permian rocks and any Triassic rocks deposited in Logan County were removed by erosion prior to the deposition of the Jurassic rocks. During a small part of Jurassic time the area was again under water and deposition of marine sediments resumed. Oil tests have penetrated a shale section 100 to 200 feet thick that has been correlated with the Morrison formation.

During late Comanchean (Cretaceous) time, a shallow sea transgressed northward across central and western Kansas. The Chey-

TABLE 1.—*Geologic formations of Logan County and their water-bearing properties**

System	Series	Formation	Thickness (feet)	Character	Water-bearing properties
Quaternary	Pleistocene	Alluvium	0–35	Sand, gravel, silt, and clay deposited in channels and flood plains of the major river valleys.	Where saturated, yields moderate to large quantities of very hard water to wells.
		Dune sand	0–20	Fine sand and silt in dunes and blowouts on high divides.	Lies above the water table and does not yield water to wells.
		Sanborn (Group)	0–100	Silt, yellowish gray, deposited as loess on uplands; locally contains thick deposits of sand and gravel at base beneath "pediments" along major streams.	Commonly lies above the water table, but Crete formation where saturated yields water to wells.
		Meade (Group)	0–50	Silt and fine sand, yellowish gray and orange, and thick lenses of volcanic ash. May contain sand and gravel at base locally.	Commonly lies above the water table, but may supply water to wells in some draws and beneath high "pediments".
Tertiary	Pliocene	Ogallala formation	0–220	Calcareous sandstone containing lenses of reddish-gray clayey silt and persistent shale layers; contains some limestone beds and volcanic ash.	Yields moderate to large quantities of water to wells where sufficient thickness is saturated.
Cretaceous	Gulfian	Pierre shale	0–300	Medium to dark-gray fissile shale containing bentonite seams and abundant gypsum.	Not known to yield water to wells in Logan County.
		Niobrara formation	300–690	Shaly chalk, grayish yellow orange to light gray, containing bentonite seams and abundant gypsum.	Yields water to wells in a few localities where sufficiently faulted and jointed.
		Carlile shale	215	Dark-gray noncalcareous shale containing gypsum and large septarian concretions in the upper part and thick beds of chalky shale alternating with thin beds of chalk or chalky limestone. Upper 10 feet is a shaly sandstone, the Codell sandstone zone.	Yields minor amounts of mineralized water from Codell sandstone zone.
		Greenhorn limestone	125	Thin chalky and crystalline limestones separated by thicker beds of medium-gray chalky shale.	Not known to yield water to wells in Logan County.
		Graneros shale	65	Shale containing thin beds of sandstone and bentonite, dark to medium gray, noncalareous, marine.	Not known to yield water to wells in Logan County.
		Dakota formation	300	Shale and lenticular sandstone beds, variegated.	Yields moderate to abundant amounts of soft water to wells.

* The classification is that of the State Geological Survey of Kansas.

enne sandstone was deposited near the shore of this advancing sea and the Kiowa shale in the deeper water that subsequently covered the area. The part of the geologic history of the region that is pertinent in an account of the occurrence of ground water begins in middle Cretaceous time, when the sandstone and shale of the Dakota formation were deposited in a near-shore area during Gulfian time. After the deposition of the Dakota formation, marine conditions prevailed throughout most of the rest of Cretaceous time, and hundreds of feet of shale, limestone, and chalk were deposited. Thin beds of bentonite in these formations are believed to be altered beds of volcanic ash blown into the sea in which the sediments were being deposited. The Cretaceous and underlying rocks were gently folded before the deposition of the Tertiary rocks.

Since the withdrawal of the Cretaceous sea, Logan County has been continually above sea level, and during the early Tertiary Period much of the Great Plains region was subjected to subaerial erosion. The post-Cretaceous surface was a broad plains area having lower relief than at present and wide, shallow valleys containing streams flowing generally eastward. Extensive uplift occurred in the area of the Rocky Mountains, causing the streams to carry debris eroded from the highlands and to deposit farther downstream a complex sequence of lenticular and sheetlike beds of gravel, sand, silt, and clay. These fluviatile deposits not only filled the shallow valleys but also spread across the divides, so that at the close of the deposition of the Ogallala formation, Logan County and adjacent areas were covered with a veneer of Tertiary sediments forming an aggradational plain. The lateral shifting of the streams that had deposited the clastic material probably caused the formation of many relatively impermanent lakes in abandoned channel segments and provided an environment for the deposition of "Algal limestone" (Frye, 1945), which marks the top of the Ogallala formation in northwestern Kansas.

After the deposition of the "Algal limestone" the streams cut valleys into the Tertiary and Cretaceous rocks. At some time during the incision of the large valleys the shales may have bulged upward, causing local tensional jointing and faulting. The earliest Pleistocene deposits in Logan County consist of silt and sandy clay deposited on "pediments" flanking the valleys of Smoky Hill River and Twin Butte and Chalk Creeks, which occupied valleys about in their present geographical position. These deposits, which probably graded into the flood plains of the streams, can be identified by locally thick accumulations of volcanic ash. Deepening of the channels followed, and new "pediments" formed that were mantled by coarse gravel and sand. These deposits also were left above the present flood plain by a deepening of the channel into the Cretaceous rocks. Late in Pleistocene time a thick mantle of silt was deposited over the county, chiefly by the wind. Contemporaneously with the deposition of alluvium in the major valleys, erosion and creep moved large quantities of colluvial material down the present valley sides. The alluviation of the valleys, the accumulation of colluvial deposits, and some deposition of silt by eolian action probably are continuing at the present time.

Structure

The regional structure of the area (Fig. 3), shown by contouring the top of the Dakota formation, was determined from electric logs and sample logs of oil test holes where available. Data from surface exposures and shallow water wells were used where additional control was needed. As there are no major unconformities in the sequence between the Pierre shale and the Dakota formation, the general structure depicted by the surface of the Dakota is representative also of the structures affecting the younger Cretaceous strata.

The principal structural feature in Logan County is the northeastward dip of the Cretaceous rocks at about 20 feet per mile. The rocks lie on the broad northeastern flank of the Las Animas Arch, a major structural feature extending southwestward into Colorado. The rocks in the extreme eastern part of the county dip eastward into a deep syncline along the margin of the Las Animas Arch. Small folds trending northeastward are superimposed upon the regional dip.

This structure in the Cretaceous rocks may have influenced somewhat the topography that developed upon the pre-Ogallala surface, although the subsurface information is not adequate to do more than suggest a possible relationship. A comparison of the contours on the Dakota (Fig. 3) and the contours drawn at the base of the Ogallala formation (Pl. 1) shows some similarities. The anticline whose axis trends northeastward approximately through Oakley (Pl. 1) corresponds to a nose between Russell Springs and Oakley indicated by a northeastward bulge of the contours (Fig. 3) representing the top of the Dakota. A sag in the contours on the southeastern flank of this bedrock high indicates a slight trough, which corresponds with the flanking syncline in Figure 3. The high divide between the pre-Ogallala channels northwest of Winona seems to be represented in the subsurface structure by a northeastward-trending anticline.

No structural deformation of the Ogallala formation such as was reported in Wallace County by Elias (1931, p. 186-187) was observed in Logan County. The configuration of the persistent shale layers of the Ogallala formation only superficially resembles the structures indicated by the contours on Figure 3, and any folding of the Ogallala probably is of such small magnitude as to be obscured by the initial dip of the rocks.

Joints in the chalk of the Niobrara formation, which are traceable for many miles in the same direction in south-central Logan County, probably are associated with the major structure. The joints are vertical and in two sets about at right angles to each other, but the set trending approximately east is the better developed. Joints dipping less than 85° are relatively short and not persistent in direction of strike and do not seem to be related in origin to the vertical joints. Well-developed jointing parallel and normal to faults probably is the result of local, rather than regional, structural deformation.

The regional structure has influenced the pre-Pliocene topography and, therefore, the thickness and general character of the Tertiary beds deposited on the earlier topography. The most common structural features observed during the surface mapping of Logan County were many small faults (Pl. 7) in the Cretaceous rocks. So far as known, these faults are not related to the regional structure. The faults are normal and dip between 30° and 50° and most commonly at exactly 45°. The strikes of individual faults are not consistent in direction, and some faults were observed that trend in pronounced curves. Commonly, a fault branches into several faults of similar dip and strike. At one locality in sec. 35, T. 13 S., R. 35 W., several faults seemingly radiate from a single point and dip in diverse directions. The plane of many of the faults is distinguished by a slickensided calcite filling; other faults consist of brecciated zones displaying no single fault surface. Because of the difficulty of identification of marker beds within the Niobrara formation and Pierre shale, the exact displacement of faults was not determined, but obviously it exceeds 100 feet in many faults and may exceed 200 feet in some.

No dominant trend of the faults was observed. They are generally short; the longest fault traced was less than 3.5 miles long and even that may be a series of shorter en échelon faults. Many

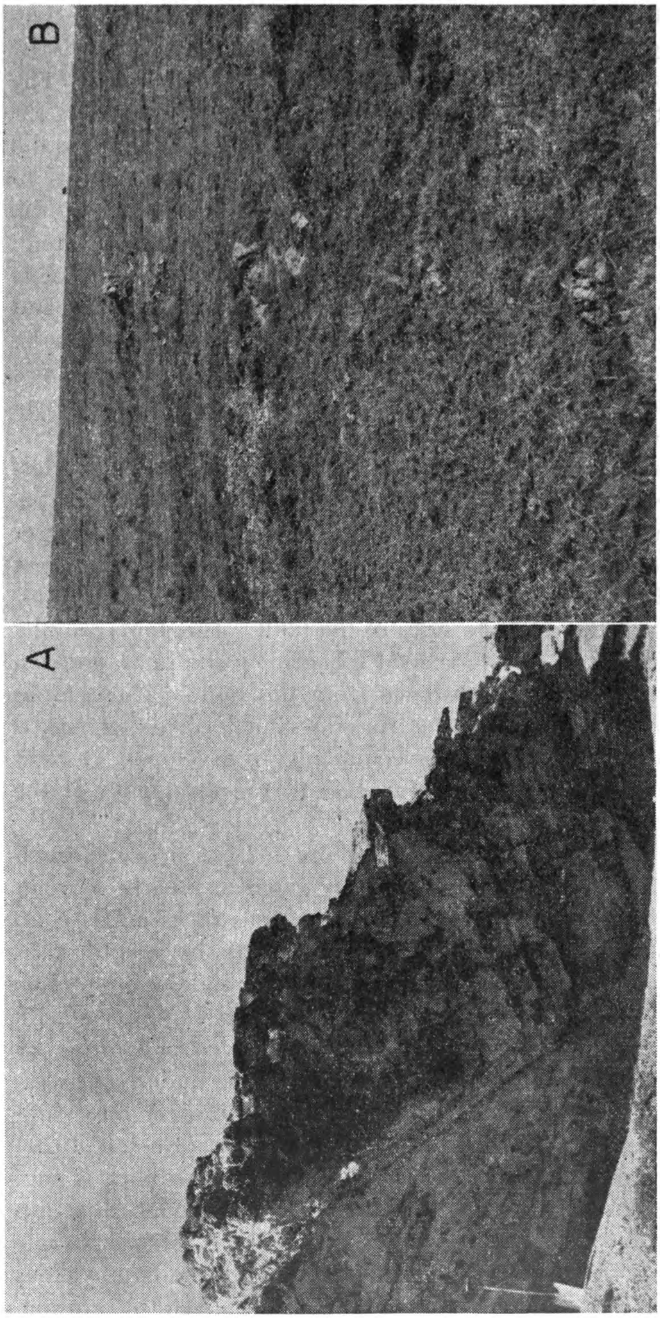


Plate 7.—A, Fault in Niobrara formation in sec. 11, T. 14 S., R. 32 W., showing gentle folding associated with faulting. Folds to right of fault are on downthrown side and have axes trending at a small angle to strike of fault. Fold at left of fault has been caused by drag of downthrown side of fault. **B,** Fault line in Pierre shale in sec. 33 and 34, T. 13 S., R. 35 W. Fault plane dips to right probably at 45°. Difference in nature of shale on opposite sides of fault is reflected in color of soil and in vegetation.

faults are only a few hundred feet long, and almost all are less than a mile in length.

Associated with the faults are folds (Pl. 7A) and joints. The folds are of three distinct types: (1) folds dipping as much as 15° on the flank whose fold axes trend parallel or at small angles to the fault strike; (2) smaller folds whose axes trend at large angles to the strike of the fault plane; and (3) minor folds adjacent to the fault. Jointing is best developed parallel to and, to a lesser extent, at right angles to the fault. The larger folds and the parallel joints are an aid to mapping because they indicate the location, dip, and trend of the fault so that definitive evidence of faulting can be found. In a few places the trace of the fault on the surface could be recognized by differences between the soil and vegetation on one side and those on the opposite side of the fault (Pl. 7B).

The mechanics of the folding and faulting are not clearly understood, but seemingly the faults are tensional and probably are related to the relief of the compressive forces that created the larger folds. The set of folds normal to the fault is probably the result of differential drag along the fault plane. The smaller folds result from the drag of the opposite sides of the fault. The joints parallel to the fault are more closely spaced adjacent to the fault, and the spacing increases with the distance from the fault. These probably are release fractures resulting from the same tension that caused the fault. Another set of joints commonly is developed at right angles to the fault plane; their function in the mechanics of the faulting is not known.

The faulting and associated folding are intense in some small areas where individual faults commonly intersect nearly at right angles. The faulting has broken the Cretaceous rocks into a complex series of tilted blocks, some of which can be identified as typical grabens and intervening horsts. The random orientation of the faults seems to discount the idea of their association with major structural trends, nor was evidence observed of faulting by surficial slumping. Differential compaction of the underlying sediments such as that suggested by Twenhofel (1925) or local subsidence as a result of solution of underlying beds (Russell, 1929) are possible causes of the fracturing. Another possibility is suggested by the greater number of faults in Logan County that dip outward from the major stream valleys; the weak Cretaceous shale and shaly chalk may have bulged upward beneath the large valleys from which great thicknesses of rock were removed by erosion. The anticline caused by the relief of the rocks might produce sufficient tensional force to rupture the Cretaceous beds. Upward bulges of weak shales resulting in anticlines of nontectonic origin have been reported in Great Britain (Hollingsworth, Taylor, and Kellaway, 1944).

The various fractures may permit small accumulations of ground water, especially in areas where it is difficult to obtain supplies for livestock from other sources. For this reason the occurrence of faults and joints in the region is of considerable practical significance.

GEOLOGIC FORMATIONS IN RELATION TO GROUND WATER

Cretaceous System

Gulfian Series

Dakota Formation

Distribution and thickness. — Although not exposed in Logan County, the Dakota formation underlies the area and has been penetrated in test wells drilled for oil and in one water well. It is the oldest formation known to yield water in Logan County. The closest outcrops of the Dakota formation are in southern Hamilton County, where the uppermost 25 or 30 feet is exposed (McLaughlin, 1943, p. 120).

The gradational changes between the Dakota formation and the overlying Graneros shale and the underlying Kiowa shale and Cheyenne sandstone make definition of their exact boundaries difficult. The thickness of the Dakota probably averages about 300 feet. According to Landes and Keroher (1939, p. 24), the combined thickness of the Dakota formation, Kiowa shale, and Cheyenne sandstone ranges from 450 to 550 feet in Logan, Gove, and Trego Counties.

Character.—The Dakota formation is composed mainly of variegated shale and lenticular sandstone beds. The sandstones are crossbedded and interfinger with the shale. McLaughlin (1943) found that in Hamilton County about 40 to 45 percent of the formation consists of clay, but the ratio of sandstone to shale varies from place to place. Only about one-fourth of the formation is sandstone in Ness and Hodgeman Counties (Moss, 1932, p. 32).

Water supply.—The Dakota formation contains saturated sandstone that is a good aquifer. The sandstone penetrated in well 13-33-6bb (Pl. 6C) is about 40 feet thick, and there are other sandstones in the formation at greater depth. The pressure in the aquifer forced the water 500 feet above the top of the producing bed. The pressure is considerably less than normal fluid pressure expected at this depth, a fact suggesting that the artesian aquifer is being recharged at lower altitude or at a distance sufficient to result in a loss of head by friction within the reservoir itself, or both. The altitude of the water level in this well conforms to a piezometric surface based on data from other wells in the Dakota formation. Hydraulic gradient of this surface indicates movement of water to the north from an outcrop area in southern Hamilton County.

No aquifer tests were made on the Dakota formation, and the yield of the well drilled into the formation was not measured, hence the permeability of the formation is not known. Considering the nature of the material, which is fine to medium sand, and the thickness of the sandstone section, wells having moderately large yields probably could be developed in the formation.

Graneros Shale

Distribution and thickness.—The Graneros shale is not exposed in Logan County but was penetrated in oil test holes and probably underlies the entire county. The nearest exposures of the Graneros shale are in the southern part of Hamilton County, where 60 to 65 feet of the formation is exposed (Bass, 1926, p. 72).

Character.—The Graneros shale consists of noncalcareous marine shale ranging from dark gray to medium gray, but contains also a few thin beds or lenses of sandstone and sandy shale and some thin bentonite beds. The conformable contact between the Graneros shale and the underlying Dakota formation is not everywhere distinct, but probably is a transitional zone in which sandstones and shales of the Dakota formation grade upward into sandy shales of the Graneros. The top of the formation is marked by a sharp lithologic break between the noncalcareous Graneros shale and the overlying Greenhorn limestone.

Water supply.—The Graneros shale is not a source of ground water for wells in the county.

Greenhorn Limestone

Distribution and thickness.—The Greenhorn limestone underlies Logan County but does not crop out. The nearest outcrops are in Hamilton County, where the Greenhorn limestone is 132 feet thick, the contact with the Carlile shale being determined on the basis of fossils (Bass, 1926, p. 66). Landes and Keroher (1939, p. 24) reported the thickness of the Greenhorn limestone to be about 100 feet.

Character.—The Greenhorn limestone consists of thin chalky and crystalline medium-gray limestones separated by thicker beds of medium-gray chalky shale that contain thin light-gray beds of bentonite. Limestone concretions are common in the shales in the upper part of the formation. The Greenhorn limestone grades upward into chalky beds of the Carlile shale; hence, there is no distinct lithologic break between the formations.

Water supply.—The Greenhorn limestone is not a source of ground water in Logan County, and no wells are known to have been drilled into it for the purpose of producing water.

Carlile Shale

Distribution and thickness.—The Carlile shale does not crop out in Logan County but underlies the county. The thickness ranges from 150 to 260 feet in Logan, Gove, and Trego Counties (Landes and Keroher, 1939, p. 23). The conformable contact of the shale with the overlying Fort Hays limestone member of the Niobrara formation is distinct.

Character.—The Carlile shale contains two members, the Fairport chalky shale and the Blue Hill shale. The Fairport constitutes about the lower third of the formation and consists of thick beds of chalky shale alternating with thin beds of chalk or chalky limestone. Many hard concretions occur in the lower part of the member and few bentonite beds occur in the shale. The Blue Hill constitutes the upper two-thirds of the Carlile shale and consists of dark-gray noncalcareous shale, containing seams and crystals of gypsum, and in the upper part a zone of large septarian concretions.

The Codell sandstone is a sandy zone at the top of the Blue Hill shale member. In an exposure in southeastern Lane County (Prescott, 1951, p. 72) the Codell sandstone consists of about 2 feet of tan fine-grained sandstone and sandy shale grading downward into the shale of the Blue Hill shale member.

Water supply.—The Carlile shale is a dense shale of low permeability containing the thin Codell sandstone at the top. The Codell may produce small quantities of water that is likely to be too mineralized even for livestock use.

Niobrara Formation

Distribution and thickness.—The Niobrara formation is exposed extensively in Logan County (Pl. 1) where the formation is not mantled by Pleistocene deposits. Along Smoky Hill River and Chalk and Twin Butte Creeks, the Smoky Hill chalk member crops out as steep bluffs having meandering steep-walled canyons and pinnacles cut from the soft chalk by the action of water. Many of the exposures of the chalk cover hundreds of acres of winding canyons, barren rocky ridges, and buttes.

The examination of cuttings from test holes for oil and gas indicates that the maximum thickness of the Niobrara formation is about 690 feet in Logan County. Where Smoky Hill River has cut away much of the Smoky Hill chalk member in the eastern part of the county, the thickness is probably about 300 feet.

Character.—The Niobrara formation consists chiefly of clayey, somewhat fissile chalk containing chalky limestone and bentonite seams. The Niobrara formation is divided into the Fort Hays limestone member below and the Smoky Hill chalk member above.

The Fort Hays limestone member is composed of thick beds of massive chalky limestone separated by thin beds of chalky shale. The member is exposed in Lane County (Prescott, 1951, p. 72). The contact of the Fort Hays limestone member and the underlying Carlile shale is marked by a distinct change from the dark-gray noncalcareous fissile shale of the Carlile to the massive light-colored limestone of the Fort Hays.

Conformably overlying the Fort Hays limestone member is the Smoky Hill chalk member, which consists of soft shaly chalk, massive in the upper part and thin-bedded and somewhat fissile in the lower part. The Smoky Hill chalk member is medium gray and weathers to colorful white, yellow, pink, and orange. Thin bentonite beds are common and can be traced many miles along the outcrop. Pyrite concretions are present throughout the member but are most common in certain persistent zones. Large discoidal soft reddish to yellowish-brown concretions of limonite and pyrite are arranged in indistinct disconnected layers in the upper and middle parts of the member. The upper contact is recognized by the abrupt change from the medium-gray chalk of the Niobrara formation to the dark-gray fissile noncalcareous Pierre shale.

The following measured sections indicate the character of the Niobrara formation in southern Logan County:

Section of Smoky Hill chalk member of Niobrara formation on north side of cliff in SE¼ sec. 16, T. 15 S., R. 34 W., measured September 10, 1954.

	Thickness, feet
CRETACEOUS—Gulfian	
Niobrara formation	
Chalk, thick bedded, pale yellowish orange; contains many bentonite partings. Upper 10 feet is poorly exposed and littered with quartzose gravel	66.0
Bentonite	0.2
Chalk, thick bedded, pale yellowish orange	18.5
Bentonite	0.5
Chalk, fissile, grayish orange to reddish orange; contains some gray chalk	18.0
Bentonite	0.1
Chalk, gray	0.5
Bentonite	0.1
Chalk, fissile, gray; some ferruginous and pyrite concretions	6.5
Bentonite	0.2
Chalk, fissile, gray; contains abundant pyrite concretions superficially resembling walnuts. *Ostrea* are found in lower part	28.5
Bentonite	0.1
Chalk, fissile, gray; contains many discoidal ferruginous concretions and pyrite concretions in upper part. *Ostrea* very abundant in persistent beds; contains a more resistant bed 7.5 feet above base	12.0
Bentonite	0.1
Chalk, fissile, gray	0.6
Bentonite	0.1
Chalk, fissile, light gray; contains many large discoidal ferruginous concretions	6.0
Chalk, thick bedded, fissile, gray; contains many ferruginous concretions and some small pyrite concretions. Fish scales and *Ostrea* are abundant	4.5
Total thickness measured	162.5

Section of Smoky Hill chalk member of Niobrara formation exposed in ravines and buttes in SW¼ sec. 25, T. 14 S., R. 33 W., measured September 10, 1954.

	Thickness, feet
CRETACEOUS—Gulfian	
Niobrara formation	
Chalk, fissile, gray	2.0
Bentonite	0.1
Chalk, fissile, gray; contains *Ostrea* in upper part	8.5
Bentonite	0.1
Chalk, fissile, gray; contains abundant *Ostrea*	8.5
Bentonite	0.1
Chalk, fissile, gray; contains *Ostrea*	2.0
Bentonite	0.1
Chalk, fissile, gray; contains very abundant *Ostrea*	5.0
Bentonite	0.1

	Thickness, feet
Chalk, fissile, gray; contains very abundant *Ostrea*	10.0
Bentonite	0.1
Chalk, massive, containing a few partings, pale orange to white; weathers into tall pinnacles and buttes. *Ostrea* are fairly abundant and concentrated in layers	27.5
Total thickness measured	64.1

Section of Smoky Hill chalk member of Niobrara formation in ravine and on west side of cliff in SW¼ sec. 17, T. 15 S., R. 34 W., measured September 6, 1954.

Cretaceous—Gulfian

Niobrara formation

	Thickness, feet
Chalk, poorly exposed on slope, containing some chalk fragments, silicified chalk and quartz, and quartz pebbles	5.5
Chalk, thin bedded, fairly dense, pale to medium yellowish orange, layered	11.0
Chalk, massive, pale yellowish to reddish orange; weathers to rounded knobs and hollows	6.0
Chalk, blocky, friable, white	0.3
Chalk, thin bedded, fissile, layered white, pale yellow, and yellowish orange; some beds weather into miniature masonry-like blocky surfaces	6.5
Chalk, massive except for very thin shale partings, pale yellowish orange to grayish pink; contains a thin bentonite parting 2 feet above base	3.0
Bentonite, blocky, white and dark reddish brown	0.3
Chalk, massive, pale yellowish orange to grayish pink; contains *Ostrea* and fish teeth and scales; weathers to rough, rounded surfaces and forms a bench	6.2
Chalk, massive, white to pale yellowish orange; contains some fish teeth and scales	4.0
Chalk, fissile, layered white to orange; weathers to a recess between adjacent units	0.2
Chalk, massive, white to pale yellowish orange; contains abundant fish teeth and scales	2.5
Chalk, thick bedded, layered white to pale orange; contains bentonite partings at 1.5, 3.0, 4.5, and 7.0 feet above base	7.0
Chalk, thick bedded but locally weathering into fissile chalk, grayish pink to pale orange; contains thin bentonite seams. *Ostrea* are common	20.5
Chalk, thick bedded, fissile, layered pale orange to light gray; contains much coarsely crystalline gypsum as veins and seams. *Ostrea* are abundant	17.0
Chalk, fissile, medium gray; some ferruginous concretions and gypsiferous seams and veins	4.5
Bentonite, pale gray to brown	0.2
Chalk, fissile, light medium gray; contains thin bentonite seams	4.3

	Thickness, feet
Chalk, fissile, medium light gray; gypsum and ferruginous concretions are common. Thin bentonite seams 5.5 and 6.0 feet above base	20.0
Chalk, fissile, medium light gray; contains some ferruginous concretions, prominent jointing, and a persistent bentonite seam 13 feet above base	13.0
Chalk, fissile, medium light gray; contains large discoidal ferruginous concretions and gypsum veins. *Ostrea* and fish teeth and scales are abundant	11.5
Chalk, fissile, medium light gray; contains abundant shark teeth, *Ostrea* in persistent layers, and seams of calcite and gypsum; top marked by persistent layer of pyrite concretions	11.0
Total thickness measured	154.5

Section of Smoky Hill chalk member of Niobrara formation exposed in ravine in NW¼ sec. 13, T. 15 S., R. 35 W., measured September 9, 1954.

	Thickness, feet
CRETACEOUS—Gulfian	
Niobrara formation	
Chalk, massive, pale yellowish orange	4.0
Bentonite	0.2
Chalk, thick bedded, containing thin shale partings, layered white to pale yellowish orange	17.5
Bentonite	0.1
Chalk, massive, layered white to pale yellowish orange	4.0
Bentonite	0.1
Chalk, massive, pale yellowish orange	2.0
Bentonite, light gray to dark brown	0.3
Chalk, fissile, pale yellowish orange; contains veins and seams of gypsum	2.0
Bentonite, light gray	0.1
Chalk, yellowish orange to grayish orange pink; contains many gypsum veins and seams. *Ostrea* are abundant	5.0
Bentonite	0.1
Chalk, thick bedded, pale yellowish orange; contains many gypsum veins. *Ostrea* are abundant	5.5
Chalk, gray; contains many relatively thick bentonite seams and gypsum veins	15.0
Bentonite	0.1
Chalk, gray	0.3
Bentonite	0.2
Chalk, gray	1.0
Bentonite	0.1
Chalk, fissile, light medium gray	10.0
Bentonite	0.1
Chalk, fissile, light medium gray	3.0
Bentonite	0.1
Chalk, fissile, light medium gray	1.5
Bentonite	0.1

	Thickness, feet
Chalk, fissile, light medium gray	0.6
Bentonite	0.2
Chalk, fissile, light medium gray	7.5
Bentonite	0.2
Chalk, fissile, light medium gray	1.5
Bentonite	0.1
Chalk, fissile, light medium gray	6.0
Total thickness measured	88.5

Insoluble residues, which were prepared from several samples of the chalk, constituted 40 to 60 percent of most samples. The large clay content of the chalk probably accounts for its fissile character upon weathering.

The Smoky Hill chalk member in Logan County has long been famous for the many vertebrate and invertebrate fossils it contains. Vertebrate fossils include bones of reptiles and dinosaurs and teeth and scales of fish. Sharks' teeth are especially abundant. The most abundant invertebrate fossils are *Inoceramus grandis,* a large clam, and *Ostrea congesta,* a small oyster, which commonly occur as thick crusts and layers traceable over small distances. Foraminifera, chiefly *Globigerina* and *Gumbelina,* make up more than half the calcareous material of the chalk (Moss, 1932, p. 19). Fossil wood has been found in the formation. Williston (1897, p. 243) reported a fossil tree about 30 feet long discovered near Elkader. Prescott (1951, p. 74) reported a fossil tree trunk in Lane County about 6 feet long that had been altered to lignite. Waite (1947, p. 174) reported that a 3-inch coal bed was penetrated in a test hole drilled into the Niobrara formation in Scott County.

The chalk of the Niobrara formation formerly was used extensively as building stone, especially the massive layers of the upper part. The quarry industry is waning in Logan County, but a few quarries are still active. Much of the chalk is used as road fill where washouts are frequent.

Water supply.—The Niobrara formation is relatively unimportant as a water-bearing formation in Logan County, but several wells in the county derive water from the Niobrara formation where other ground-water supplies are unavailable. The water contains much sulfate and other dissolved solids and is unfit for domestic use and irrigation, but can be used to water livestock.

The beds of shaly chalk are relatively impervious, and water is transmitted chiefly through fractures. A large dam was built in sec. 8, T. 13 S., R. 35 W., across a narrow draw between two bluffs of chalk of the Niobrara formation. A study of the rock on the downstream side of the dam showed much leakage of water through the joints. The Niobrara formation at this locality is dissected by joints associated with a fault about 150 feet downstream that trends approximately parallel to the dam (Pl. 6B).

The rapid movement of water through the joints indicates that the Niobrara formation where faulted could be utilized as a source of water for livestock use, particularly in draws cut into the Niobrara formation where ground-water supplies generally are thought to be insufficient. Study of the jointing and dip of the chalk may disclose a fault that, if intersected 20 or 30 feet below the bottom of a draw by a drilled well, will supply sufficient water for livestock use. Most of the faults mapped on Plate 1 are in areas to which livestock water is being hauled from Winona or Oakley.

Pierre Shale

Distribution and thickness.—The Pierre shale conformably overlies the Niobrara formation, from which it can be readily distinguished by the noncalcareous nature and dark-gray color of the Pierre. The formation is unconformably overlain by Tertiary and Pleistocene strata. The contact is obscured in some localities by the fact that the Tertiary and Pleistocene clay and shale directly overlying the Pierre shale were derived principally from the clayey material of the older formation. The Pierre shale in Wallace County was studied by Elias (1931), who divided it into six members, of which only the Sharon Springs, Weskan, and Lake Creek are exposed in Logan County.

The Pierre shale underlies much of the northern and western parts of Logan County, but has been eroded away along the valleys of Smoky Hill River, Twin Butte Creek, and Chalk Creek. The formation is absent also in the northeastern corner of the county south of Chalk Creek, where the Ogallala formation, of Tertiary age, directly overlies the Niobrara formation. In Logan County the Pierre shale probably attains a maximum thickness of 300 feet in the northwestern part.

Character.—The Pierre shale is a dark-gray fissile noncalcareous shale that occurs in massive beds between which are intercalated seams of bentonite, limonite, and crystalline gypsum. The shale contains many different types of concretions arranged in definite stratigraphic zones that can be used locally as key beds (Elias, 1931). The bentonite beds also have been used to correlate exposures of the Pierre shale in Wallace County (Elias, 1931) and in eastern Colorado (Dorrel, 1938). The Pierre shale is mapped as a single unit on Plate 1 because of the uniform hydrologic characteristics of the formation.

A part of the following stratigraphic section a few miles south of Wallace in Wallace County was studied and measured with the help of N. W. Biegler (Bradley and Johnson, 1957).

Measured section of Pierre shale in sec. 7, T. 14 S., R. 38 W., Wallace County.

	Thickness, feet
CRETACEOUS—Gulfian	
Pierre shale (in contact with overlying Ogallala formation)	
Shale, yellow and brown, mottled; limestone concretions near contact with overlying Ogallala formation; contains fish scales	10.5
Shale, gray, fissile, containing white powdery material in fractures; weathers light gray	11.6
Shale, gray and brown, fissile, containing lenticular silty limestone concretions having maximum diameter of about 7 inches	1.0
Shale, fissile, blue gray	6.5
Bentonite, yellow; contains limonitic shale partings	0.5
Shale, blue gray, containing lenticular limestone bodies as much as 0.5 foot thick and 3 to 6 feet across	3.5
Shale, blue gray, fissile, containing abundant bentonite stringers and, at the base, a persistent hard limonitic bed 0.5 inch thick,	10.2
Shale, brown, limonitic, containing numerous limy concretions as much as 3 inches in diameter	0.6
Shale, blue gray, weathering yellow brown and earthy, fissile; bentonite stringers as much as 0.5 inch thick are common; contains fish scales and many gypsum crystals in platy aggregates	29.0
Total thickness measured	73.4

The above section is comparable to the middle part of the Pierre shale described by Elias (1931). The following stratigraphic section including the Niobrara, Pierre, and Ogallala formations was measured in an exposure on Lone Butte south of Russell Springs (Pl. 8A).

Section of Gulfian Series on east side of Lone Butte in SE¼ sec. 33, T. 14 S., R. 35 W., measured September 9-10, 1954.

	Thickness, feet
TERTIARY—Pliocene	
Ogallala formation	
Limestone, silty, fine grained, calcareous, white; contains much siliceous material	16.5
Sandstone, conglomeratic, calcareous, white to grayish orange pink	11.0

	Thickness, feet
CRETACEOUS—Gulfian	
Pierre shale	
Shale, clayey, fissile, noncalcareous, dark gray; contains some olive-green layers	35.0
Niobrara formation—Smoky Hill chalk member	
Chalk, thin bedded to fissile, calcareous, white to reddish orange; contains some bentonite seams	27.5
Chalk, thick bedded to massive, resistant, white to pale orange; weathers to a blocky, masonry-like ledge	11.5

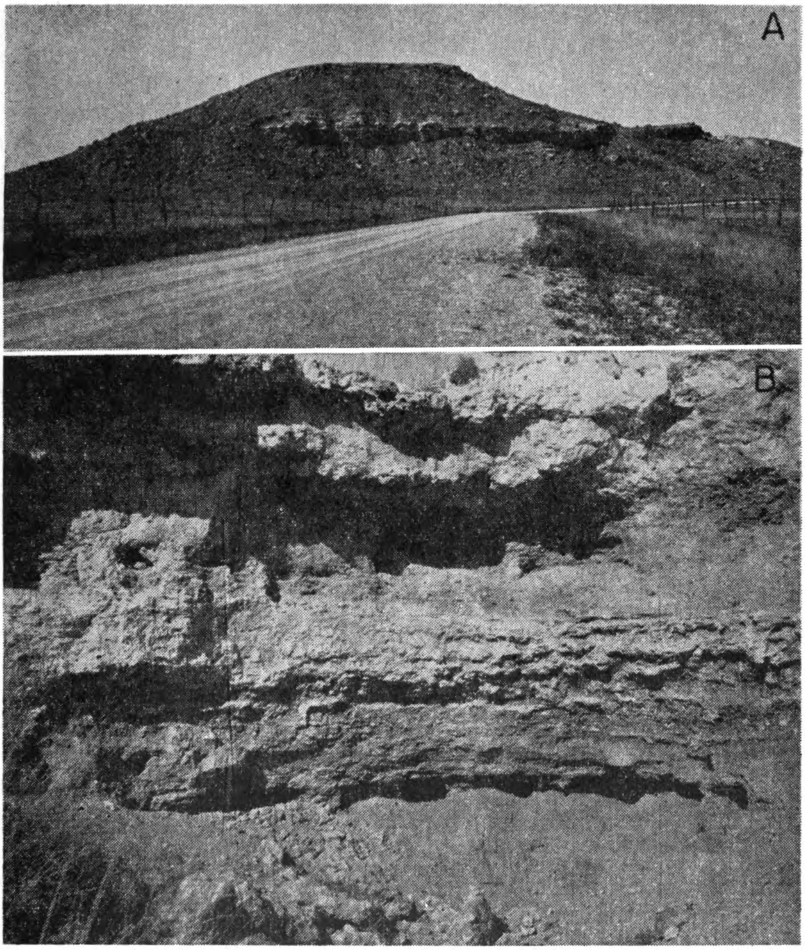


PLATE 8.—A, Lone Butte in sec. 4, T. 15 S., R. 35 W., and sec. 33, T. 14 S., R. 35 W. Niobrara formation is exposed from foot of hill to top of prominent cliff. Gentle slope above cliff is developed on Pierre shale. Butte is capped by sandstone of Ogallala formation. B, Exposure of Ogallala formation in sec. 31, T. 15 S., R. 32 W., showing reddish fine-grained sandstone facies.

	Thickness, feet
Bentonite, pale gray	0.2
Chalk, thick bedded to massive, gypsiferous, pale gray to orange; weathers to a rough, rounded surface; contains *Inoceramus*, *Ostrea*, fish scales, and some acicular unidentified fossils	17.8
Chalk, soft, pale orange; contains two thin bentonite seams	0.5
Chalk, thick bedded, pale orange; contains much gypsum in veins and seams. Where weathered the chalk resembles a fissile shale	2.0
Bentonite, pale gray and reddish brown	0.7
Chalk, pale orange, contains much gypsum and sparse *Ostrea*	1.5
Bentonite	0.2
Chalk, thick bedded, somewhat fissile when weathered, pale gray to pale orange; contains many gypsum veins and abundant *Ostrea*	15.0
Bentonite	0.1
Chalk, gray	1.5
Bentonite	0.1
Chalk, gray	1.5
Bentonite	0.1
Chalk, pink	0.6
Bentonite	0.1
Chalk, soft, fissile, grayish pink to gray; contains much gypsum in veins	5.5
Total thickness measured	148.9

Water supply.—No wells in Logan County derive water from the Pierre shale. Some water probably moves along joints and bedding planes, but the quantity is insufficient to supply wells.

Tertiary System

Pliocene Series

Ogallala Formation

Pre-Ogallala buried valleys.—A mature drainage system was developed upon the Cretaceous rocks before deposition of the Ogallala formation. Determination of the width and depth of the principal valleys of that system is important in delineation of the areas of greatest saturated thickness of the Ogallala formation; consequently, the trend of the channels was explored by test drilling and by measurement of altitude of the Tertiary-Cretaceous contact where exposed at the edge of the upland plain.

The exploration revealed several channels in the northern upland, one of which is 100 to 150 feet deep and is particularly important in that it provides a medium for storage and transmission of ground water. This channel (Pl. 1) trends northeastward across the county from a point about 4 miles south of Winona and crosses the northern boundary of the county at Oakley. The width of the valley between the axes of the contiguous divides is 12 to 15 miles. The channel has been traced through Thomas County (Frye, 1945) and southern Sheridan County (Bayne, 1956) and eastward to the edge of the Tertiary beds through northern Trego County. The channel, if formerly present, has been eroded away in the western part of Logan County, but probably was once continuous with a pre-Ogallala channel 3 miles south of Sharon Springs in Wallace County. The channel forks, the two branches crossing the Colorado-Kansas line 8 and 14 miles respectively north of the Greeley-Wallace County line (Bradley and Johnson, 1957). The flow of the main drainage in pre-Ogallala time was northeastward in the northern part of Logan county and southeastward in the southern part of the county.

Distribution and thickness.—The Ogallala formation is exposed along the valleys of Smoky Hill River and its tributaries and of Chalk and Twin Butte Creeks. In the southeastern corner of the county the Ogallala formation crops out along Hell Creek, which flows into Smoky Hill River farther east in Gove County.

The tapered area of upland plain in the northern part of Logan County is underlain by the Ogallala formation. Areas between Smoky Hill River and Twin Butte Creek and between Twin Butte and Chalk Creeks in the central and western part of the county also are underlain by the Ogallala formation. The Ogallala overlies the Niobrara formation under the upland south of Chalk Creek. Over most of the upland area the Ogallala formation is mantled by loess and by basal sand and gravel of the Sanborn Group of Pleistocene age, but it is exposed in a few places in the interior of the upland where streams have dissected the Pleistocene mantle, especially along Hackberry Creek in the eastern part of the county. The Ogallala formation caps isolated buttes in sec. 13 and 26, T. 12 S., R. 37 W., and in sec. 4, T. 15 S., R. 35 W. (Pl. 8A).

Where present, the Ogallala formation is thickest in the pre-Ogallala valleys and thinnest on the divides. A maximum thickness of 226 feet of Ogallala was penetrated in well 11-32-3bd1. The thickness of the Ogallala formation is nearly 200 feet in several other areas in Logan County.

Character.—The Ogallala formation is composed chiefly of calcareous sandstone containing clay, silt, gravel, cobbles, and boulders. It is cemented by calcium carbonate to various degrees in different places.

The sandstone shows two distinct lithologic facies. One consists of coarse, poorly sorted sandstone or conglomerate, which is locally somewhat crossbedded and contains unevenly cemented beds that weather to rough benches and cliffs. Some beds are loosely cemented, but others are densely cemented with silica. Where not tightly cemented, the coarse conglomerate and conglomeratic sandstone of this facies are the most permeable water-bearing units in the county. The other facies (Pl. 8B) consists of a reddish fine-grained sandstone containing much clay and silt, calcareous nodules, and rootlike concretions. The red color of this facies seems to be derived from red clay that is intermixed with the silt and fine sand. Both sandstones are dominantly quartzose but contain feldspar and igneous rock fragments that are subangular to subrounded. The calcareous cement is white.

In some places the Ogallala formation is capped by a limestone referred to as the capping limestone by Smith (1940, p. 44-45). It is commonly massive and weathers to a knobby irregular surface. Elias (1931, p. 136-141) described similar rock in Wallace County and referred to it as algal limestone because of its concentrically "banded" structure. Waite (1947, p. 120-121) described this limestone in outcrops in Scott County where it is as much as 5 feet thick. The capping limestone is exposed on the south side of Chalk Creek in the southern part of Logan County and along Twin Butte Creek in the western part.

Thin beds of yellow or pale-red shale were penetrated in test holes and recognized in exposures. The shale beds are good marker beds, whereas the sandstones are extremely lenticular and show little lateral continuity.

Olive-green bentonitic shale exposed in sec. 7 and 13, T. 11 S., R. 37 W., probably is equivalent to the Woodhouse clay of Wallace County (Elias, 1931, p. 155-158). Whether this bentonitic shale is continuous with the persistent thin clay shales penetrated in test holes drilled in the Ogallala formation farther east is not known. The shale, however, is present also in the basal part of the Ogallala in Scott County (Waite, 1947, p. 119). In Logan County the shale overlies the Pierre shale, from which it can be distinguished readily by its green color.

The Ogallala formation is the chief aquifer of Logan County and is a source of sand and gravel used as road metal on many of the roads. Because the opal-cemented beds used for building stone in other counties in Kansas are not well developed in Logan County, none of the rock is quarried.

The following section of the Ogallala formation was measured and studied at an exposure in the southern part of Logan County.

Section of Ogallala formation exposed on bluff east of Ladder Creek in SW¼ SE¼ sec. 31, T. 15 S., R. 32 W.

	Thickness, feet
Interval at top of bluff covered by much Ogallala "float"	
TERTIARY—Pliocene	
Ogallala formation	
Sandstone, silty, fine grained, thick bedded, calcareous, grayish orange pink; contains lenticular beds of firmly cemented sandstone and loose sand	11.0
Sandstone, silty, fine to medium grained, calcareous, grayish orange pink; contains firmly cemented nodular zones. Poorly exposed	16.5
Sandstone, silty, fine to medium grained, calcareous, grayish orange pink; contains beds of firmly cemented sandstone and some siliceous nodules. Poorly exposed	5.2
Siltstone, calcareous, grayish orange pink; contains considerable sand, firmly cemented in places; weathers to typical knobby light-gray "mortar bed" covered with lichens	7.5
Siltstone, poorly sorted, calcareous, reddish orange; contains much sand and some gravel, and a weakly developed columnar structure	5.5
Siltstone, weakly cemented, calcareous, reddish orange; contains much sand and gravel, rootlike calcareous concretions, and large calcareous nodules	7.9
Siltstone, reddish orange; contains considerable fine sand and some concretions	3.0
Sandstone, fine to coarse grained, having pebbles more than 1 inch in diameter, and much silt, massive, unsorted, weakly cemented, calcareous, grayish orange pink; weathers to rounded knobs and hollows conspicuously without lichen growth. *Celtis willistoni* are common	8.6
Sandstone, medium to coarse grained, containing some silt and gravel, massive, vaguely crossbedded, moderately cemented except for firmly cemented bed at top, calcareous, grayish orange pink; contains balls of finely laminated red silty sand; *Celtis willistoni* are common	8.7
Sandstone, medium to coarse grained, containing considerable silt, firmly cemented, grayish orange pink; contains much siliceous material as cement and nodules	1.2
Shale, containing some silt, weakly cemented, reddish orange; contains shards of volcanic ash and rootlike concretions	1.5
Sandstone, medium to coarse grained, containing some gravel, moderately cemented, calcareous, pale grayish red; contains balls of red silt and clay	1.0

	Thickness, feet
Siltstone, sandy, grayish red; contains specks of calcareous material	0.5
Sandstone, medium to coarse grained, calcareous, grayish orange pink; contains pale-yellow calcareous clay nodules having a maximum diameter of 1 foot	1.6
Sandstone, medium to coarse grained, containing some fine to medium gravel, moderately cemented, poorly sorted, calcareous, grayish orange pink; contains rootlike concretions and rugose nodules. This zone also contains pale-yellow calcareous clay nodules especially abundant in the upper part and commonly less than 2 inches in diameter	6.1
Sandstone, very conglomeratic, medium to coarse grained, unsorted, moderately cemented, calcareous, grayish orange pink	14.7
Covered interval of reddish sand, silt, and talus of the Ogallala	21.8
CRETACEOUS—Gulfian	
Niobrara formation	
Chalk, thick bedded, pale yellowish orange; weathers to a fissile chalk	7.2
Chalk, thick bedded, somewhat fissile, light medium gray	3.8
Chalk, massive, grayish pink to pale orange; contains a bentonite seam	1.0
Chalk, massive, fissile, light medium gray; contains prominent joints dipping about 60° S	3.0
Bentonite, light gray to brown	0.3
Chalk, fissile, light medium gray to pale orange	3.0
Total thickness measured	140.6

Water supply.—The Ogallala formation is the most important water-bearing formation in Logan County. All wells in the upland plain derive water from the Ogallala formation, and there is no difficulty in obtaining water for livestock and domestic use in the north upland area. The saturated thickness of the formation is as much as 142 feet and averages about 30 feet (Fig. 5). The thickest water-bearing materials are in the pre-Ogallala valleys.

The aquifer tests using wells in the Ogallala formation in Logan County indicated coefficients of permeability ranging from about 230 to 1,000 gpd per square foot. The average coefficent of transmissibility divided by the average saturated thickness of the tested aquifer produced an average coefficient of permeability of 440 gpd per square foot, which is similar to the results of aquifer tests of the Ogallala formation in the Ladder Creek area (Bradley and Johnson, 1957).

Water-level fluctuations in wells measured periodically indicate that the water level in the Ogallala formation beneath the upland plain is not influenced by seasonal variations in precipitation or even by extreme differences between consecutive years. The long-term trends in precipitation seem to be reflected in the water levels after about a 3½-year lag, although the length of record is too short to confirm this. Barometric effects in wells in the Ogallala formation have been observed throughout western Kansas where automatic water-level recorders are installed. A barometric effect indicates that the aquifer is confined by relatively less permeable beds and, hence, that the water is under artesian pressure. The artesian effect was confirmed in the aquifer tests.

Wells drilled in the Ogallala formation in Logan County yield as much as 630 gpm. In areas of thickest water-bearing materials, properly constructed wells probably could produce 1,000 gpm.

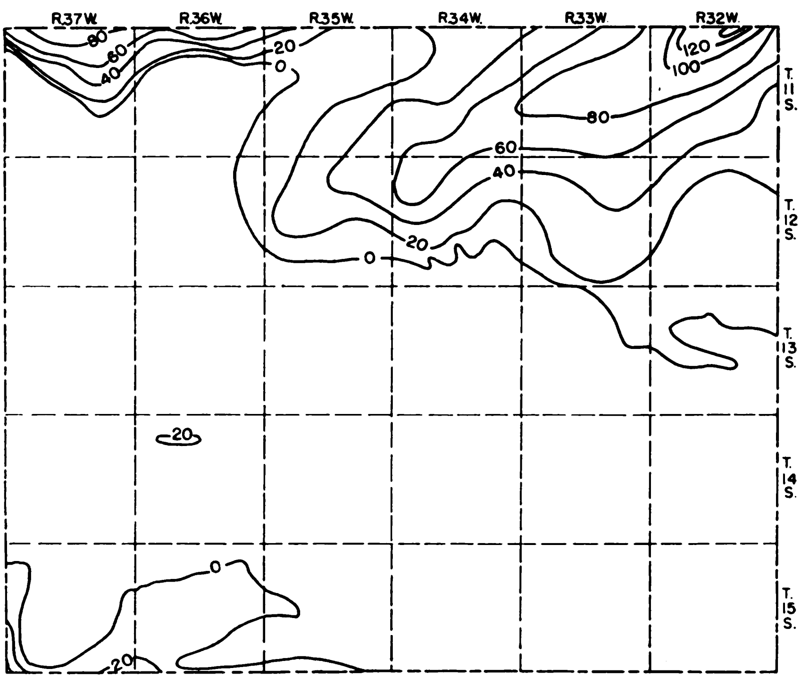


FIG. 5.—Map of Logan County shownig saturated thickness of Ogallala formation.

Quaternary System

Pleistocene Series

Meade Group

The name Meade formation has been applied by different authors to two different sequences of rocks. To preserve the name Meade it has been raised to group rank, the Meade Group including both the formations to which the name Meade has been applied. The deposits in Logan County are classified in the upper of the two formations, as they are believed to be of Kansan age.

Distribution and thickness.—The known exposures of the Meade Group in Logan County are on the north side of the tributaries of Smoky Hill River, where the southward-flowing streams have cut through a "pediment" veneer. The exposures are higher in elevation than the later Pleistocene "pediments" but considerably lower than the edge of the upland plain. The Meade Group generally is mantled, and difficult to distinguish from deposits of the Sanborn Group. Some of the extensive sandy areas close to the river may be equivalent to the Meade Group.

The maximum thickness of the Meade Group observed in Logan County is 32 feet, measured in the NW cor. sec. 13, T. 13 S., R. 35 W., but greater thicknesses probably occur. A test hole drilled in the NW¼ sec. 6, T. 13 S., R. 33 W., penetrated 60 feet of yellow clay, which may represent the Meade at that place. Prescott (1951, p. 81) reported a thickness of 120 feet for the Meade in Lane County.

Character.—The Meade Group consists mainly of clay, sandy silt, and fine sand, but the lower part is chiefly sand and gravel that was deposited as valley fill. Many of the pebbles were derived from the Niobrara formation. The upper formation of the Meade Group in Kansas is separated into two members, the lower Grand Island member, which consists mainly of sand and gravel, and the upper Sappa member, which consists of clay, fine sand, silt, and in some places the Pearlette volcanic ash (Frye, Swineford, and Leonard, 1948, p. 518-523). The ash is light gray to white, medium to fine grained, and friable (Pl. 5A). In exposures where the ash is missing, the Meade is difficult to distinguish from the slope deposits of the Sanborn Group, which have a similar origin. As the Meade is of minor significance hydrologically, no effort was made to correlate exposures of materials probably of the Meade Group by paleontological means. Unless the ash was present to identify it, the Meade was mapped on Plate 1 with the Sanborn Group. Much of the sand and gravel at a lower elevation mapped with the Sanborn Group may be equivalent to or derived from the Grand Island member.

In the following measured sections the Meade could be identified by the ash in or near the exposure.

Section of Meade Group on east side of draw on Briggs Ranch in SW¼ sec. 35, T. 13 S., R. 33 W., measured June 24, 1954.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn Group (?)	
Silt, somewhat sandy, reddish brown; grades from sand at base to light-gray silt above	6.5
Sand and gravel, silty, reddish brown; contains large quartz cobbles but few chalk fragments	4.5
Meade Group	
Sand and gravel, containing considerable silt, pale yellowish orange; contains chalk pebbles of Niobrara formation	5.5
Ash, massive, friable, white; contains siliceous nodules; underlain by a thinly laminated pinkish-gray siliceous layer 2 inches thick,	5.5
Clay, silty, thick bedded, dense, not fissile, pale yellowish orange	12.0
Sand and gravel, massive, calcareous, pale yellowish orange; composed of chalk pebbles and cobbles of Niobrara formation. Weathers to form a protruding ledge	2.0
Covered interval	
Total thickness measured	36.0

Section of Meade Group on east side of draw at NW cor. sec. 13, T. 13 S., R. 35 W., measured July 29, 1955.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn Group (?)	
Sand and gravel, loose, reddish brown	4.0
Meade Group	
Clay and silt, very sandy, calcareous, grayish orange pink	5.5
Clay, calcareous, grayish red; contains white calcareous nodules	5.5
Clay, noncalcareous, light to medium gray	4.5
Clay, moderately compact, grayish orange pink; contains much coarse sand and silt	4.0
Sand and gravel, loosely cemented; contains much yellow silt	16.5
Covered interval	
Total thickness measured	40.0

Water supply.—The Meade Group in Logan County is not an important aquifer. A few wells obtain domestic and livestock supplies from this formation on the higher "pediments". Some parts of this sequence may underlie the alluvium or late Wisconsinan terrace deposits along the major valleys and may produce water to a few wells.

Sanborn Group

Distribution and thickness.—The Sanborn Group is composed chiefly of sand and gravel derived from the Ogallala formation and spread over that formation as a thin veneer over ridges, but thickening toward the major streams. The sand and gravel were mantled by loess probably blown from the north during early Wisconsinan time (Swineford and Frye, 1951). Because it mantles the older formations and has been only slightly dissected since it was deposited, the Sanborn Group is the most widely exposed geologic unit in Logan County.

The greatest thickness observed in the county is 82.5 feet in test hole 13-36-12aa (Pl. 4), which may include some sand and gravel of the Meade Group. The average thickness of the Sanborn Group on the uplands is about 20 feet.

Character.—The Sanborn Group in Logan County consists chiefly of pale yellowish-gray silt of eolian origin and coarse colluvial sand and gravel at the base. The Sanborn Group has been divided into the following formations in ascending order: (1) Crete formation (2) Loveland formation, commonly containing the buried Sangamon soil at the top; (3) early Wisconsinan terrace deposits; (4) Peoria formation, commonly containing the buried Brady soil at the top; (5) late Wisconsinan terrace deposits; and (6) the Bignell formation. The Loveland formation was not positively identified in Logan County, although it may be represented by some thin sandy red silts overlying the Crete formation.

Deposits of the Crete formation are widespread throughout the county and occur at the edges of "pediment" slopes along the major streams. In places the Crete is exposed in vertical bluffs where it is overlain by loess or slope deposits. The formation generally is mantled by various thicknesses of silt and either does not crop out or consists of poorly exposed sand and gravel at the base of a steep slope composed principally of loess. Outcrops of the Crete formation shown on Plate 1 do not represent its maximum extent.

The Peoria and Bignell formations form a mantle over most of Logan County. The silt is pale yellowish-gray calcareous clayey loess containing some fine sand and abundant fossil snails.

Terrace deposits of supposed Wisconsinan age flank the floodplains of the major streams and can be traced up even the smaller tributaries. The deposits closely resemble the silt of the Peoria loess but are laminated in part.

Soil and rock affected by creep and sheetwash mantle the slopes. They consist chiefly of loess mixed with materials derived by erosion of the Tertiary and Cretaceous rocks. The slope deposits are continuous with the various formations of the Sanborn Group, are poorly exposed, and difficult to distinguish from the Sanborn Group. For these reasons the slope deposits, and perhaps some exposures of the Meade Group as well, have been mapped with the Sanborn Group on Plate 1.

The sand and gravel of the Crete formation have been used extensively as road metal and concrete aggregate; hence, this member was differentiated from the rest of the Sanborn Group. Most of the upland soils in Logan County were formed from the silts of the Sanborn Group.

Water supply.—The Sanborn Group generally lies above the water table in the uplands, but probably yields water to the many wells on the dissected "pediment" flats. The alluvium in small draws may be underlain in part by the Sanborn Group, which may yield water to some of the wells in the draws. The Peoria formation is nearly everywhere above the water table and does not yield water to wells.

Dune Sand

Distribution and thickness.—Dune sand is present on the high divides where the wind has stripped the loess cover and exposed the sandy layers. The sand and associated silt are drifted by the prevailing south winds into low mounds and ridges in the lee of low hills or escarpments on the north flanks of the ridges. Accumulations of sand blown from Pleistocene deposits are present in sec. 32, T. 14 S., R. 32 W., and sec. 7, 8, and 27, T. 14 S., R. 33 W. The largest dune-sand area in the county is in sec. 18, T. 14 S., R. 33 W.

Sand from the Ogallala formation has been deposited as a north-trending elongate dune in sec. 30 and 31, T. 11 S., R. 37 W. This is the only dune accumulation of sand derived from the Ogallala formation that was observed in Logan County. It probably resulted because the Ogallala formation is loosely cemented in the northwestern part of the county, the local relief is pronounced, and the area is exposed to the south winds. The thickness of the material in Logan County has not been determined, but it probably does not exceed 20 feet.

Character.—The dune sand in Logan County is composed chiefly of medium to fine quartz sand and silt. The soil zone is thin or absent, and attempts at cultivation have stripped the protective vegetative cover, allowing the upper surface to be subjected to renewed wind action.

Water supply.—The deposits of dune sand in Logan County lie above the water table and are not known to yield water to wells. They readily absorb water from precipitation, however, and transmit a part of it downward to underlying strata.

Alluvium

Distribution and thickness.—Alluvium was deposited in narrow belts along the streams. The alluvium attains its greatest width and thickness in the valley of Smoky Hill River, where in some places it is about a mile wide and about 35 feet thick in the deeper part of the valley.

Character.—The alluvium in Logan County ranges from clay to coarse sand and gravel. The youngest deposits consist chiefly of sand, gravel, and silt deposited over the floodplain or in the channel of the stream (Pl. 5B). Beneath the surficial deposits are slightly older layers of sand and gravel of similar origin. The character of the alluvium in small tributaries is dependent upon the character of the rock into which particular valleys have been incised. The thick coarse alluvial deposits are confined to the major stream valleys.

Water supply.—Alluvium is the chief aquifer beneath the flood plains and yields moderate to abundant supplies of water to wells. Although water from the alluvium is pumped chiefly by domestic and livestock wells, many irrigation wells have been developed in the alluvium of the Smoky Hill River valley.

Water levels in wells in the alluvium generally are within 20 feet of the surface and are affected by individual storms. In the smaller valleys many of the wells producing from these deposits become dry during periods of scanty rainfall. Much of the water in the alluvium is transpired by deep-rooted plants, causing a seasonal low level during the summer, when water used by plants is greatest. Water levels in these wells in wet years may be 15 to 20 feet higher than in dry years.

GROUND WATER

A general discussion of the principles of ground-water occurrence with special reference to Kansas has been presented by Moore and others (1940) and the reader is referred to that report for a more detailed discussion.

Ground water in Logan County is derived from precipitation that falls locally or on adjacent areas to the west. Part of the water that falls as rain or snow runs off directly over the land surface to streams; most of it percolates downward into the soil where it is stored and whence it is later transpired by plants or evaporated. A small amount of water that escapes surface runoff, transpiration, and evaporation percolates downward through the soil and underlying strata until it reaches the water table, where it joins the body of ground water in the zone of saturation.

The water table is the upper surface of the zone of saturation in ordinary porous rock. The water table is not a plane surface, but slopes from areas of recharge to areas of discharge. The water table does not remain stationary, but fluctuates in response to additions to or withdrawals from water in storage.

The specific yield of a rock or soil, with respect to water, is the ratio of (1) the volume of water it will yield by gravity after being saturated to (2) its own volume. This ratio may be stated as either a percentage or a decimal fraction. The specific retention of a rock is the ratio of (1) the volume of water the rock will retain against the pull of gravity after being saturated to (2) its own volume. Specific retention and specific yield together equal porosity.

The permeability of a rock is its capacity for transmitting water under pressure and is measured by the rate at which the rock will transmit water through a given cross section under a given difference of head per unit of distance. The permeability of the water-bearing materials in Logan County was determined by aquifer tests.

Aquifer Tests

The permeability of water-bearing materials can be determined by laboratory methods (summarized by V. C. Fishel in Wenzel, 1942, p. 56-58) or in the field by discharging-well methods (Wenzel, 1942, p. 94-96).

The transmissibility of the Ogallala formation was determined by aquifer tests using the following recovery formula developed by Theis (1935, p. 522):

$$T = \frac{264\ Q \log_{10} t/t'}{s}$$

in which T is the coefficient of transmissibility, in gallons per day through a section of aquifer 1 foot wide having a height equal to the saturated thickness under a unit hydraulic gradient, at the prevailing temperature of the water; Q is the pumping rate, in gallons per minute; t is the time since pumping began, in minutes; t′ is the time since pumping stopped, in minutes; and s is the residual drawdown at the pumped well, in feet, at time t′.

From the Theis equation, Cooper and Jacob (1946) developed the following formula:

$$T = \frac{264\ Q}{\Delta s} \log_{10} \frac{t_2}{t_1}$$

in which T is the coefficient of transmissibility in gallons per day per foot; Q is the discharge of the well, in gallons per minute; Δs is the change in drawdown or recovery, in feet, from time t_1 to t_2, expressed in minutes since pumping began. The coefficient of transmissibility, T, is equal to the field coefficient of permeability, P_f (at the prevailing water temperature) multiplied by the saturated thickness, m, in feet. The laboratory coefficient of permeability is the rate of flow, in gallons a day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at a temperature of 60° F. The solution of the formula for T is facilitated by plotting on semilogarithmic paper the drawdown measurements collected from the observation well. The time of measurement is plotted on the logarithmic co-ordinate and the drawdown on the linear co-ordinate. The curve theoretically should plot as a straight line for all except extremely small values of t. If $\log_{10} \frac{t_1}{t_2}$ is taken over one log cycle of t, the value of the logarithm becomes unity and the value of Δs will be the difference in drawdown over one log cycle of t. In determining P from T, adjustment for temperature was unnecessary, as the temperature of the ground water was only slightly less than 60° F. The type-curve solution devised by Theis (Wenzel, 1942, p. 88-89), the Theis recovery formula (1935), and the Cooper-Jacob formula (1946) were used to check the results obtained by the above method, but only the values of T determined by the recovery method are summarized in Table 6.

In the five aquifer tests described below, water levels were measured by an electrical device or a chalked steel tape, and discharge was measured by Collins flow meter. All the wells pumped for the aquifer tests obtain water from the Ogallala formation.

Well 11-32-3bd1, a public-supply well owned by the city of Oakley, was pumped for 41 hours beginning on August 27, 1954.

Drawdown and recovery were measured in observation well 11-32-3bd2 installed 180 feet west of the pumped well (Table 2). The specific capacity of the well was about 33 gpm per foot of drawdown. An average pumping rate of 595 gpm was used to compute the coefficients of transmissibility and permeability from the drawn-down and recovery graph (Fig. 6).

From the drawdown curve:

$$T = \frac{(264)\ (595)}{4.70 - 1.00} = 42{,}500 \text{ gpd/ft.}$$

$$P = \frac{42{,}500}{142} = 300 \text{ gpd/ft.}^2$$

From the recovery curve:

$$T = \frac{(264)\ (595)}{5.00 - 1.83} = 49{,}500 \text{ gpd/ft.}$$

$$P = \frac{49{,}500}{142} = 350 \text{ gpd/ft.}^2$$

In this and other tests, the value for T computed from the drawdown curve was used as a check of the result obtained from the recovery curve, which is believed to be a closer approximation of T and which is tabulated in Table 6.

Well 11-33-14bc1, an irrigation well on the James Ahrens farm, was pumped for 89 hours beginning on August 25, 1954. Drawdown was measured in observation well 11-33-14bc2 installed 178 feet south of the pumped well. Recovery was measured in this well for 24 hours after pumping ceased (Table 3). The specific capacity was about 11 gpm per foot of drawdown. An average pumping rate of 440 gpm was used to compute the coefficients of transmissibility and permeability from the drawdown and recovery graph (Fig. 7).

TABLE 2.—*Data on aquifer test using well 11-32-3bd1, Aug. 27-30, 1954*

Time since pumping started (minutes)	Time since pumping stopped (minutes)	Depth to water in observation well (feet)	Drawdown in observation well (feet)	Yield of pumped well (gpm)
0	...	103.24	...	0
0.42	...	103.48	0.24	...
0.58	...	103.68	0.44	...
0.75	...	103.95	0.71	...
0.92	...	104.13	0.89	...
1.17	...	104.48	1.24	...
1.33	...	104.68	1.44	...
1.5	...	104.93	1.69	...
1.75	...	105.13	1.89	...
2	...	105.37	2.13	...
2.25	...	105.52	2.28	...
2.5	...	105.72	2.48	...
2.83	...	105.92	2.68	...
3.17	...	106.10	2.86	...
3.5	...	106.27	3.02	...
4	...	106.46	3.22	...
4.5	...	106.63	3.39	...
5.25	...	106.83	3.59	...
6.5	...	107.62	4.38	...
8	...	107.64	4.40	...
9	...	107.76	4.52	...
11	...	107.93	4.69	...
13	...	108.05	4.81	...
15	...	108.14	4.90	631
17	...	108.20	4.96	...
20	...	108.26	5.02	...
28	...	108.39	5.15	...
35	...	108.45	5.21	...
45	...	108.51	5.27	622
60	...	108.55	5.31	...
75	...	108.59	5.35	...
80	...	...	...	612
105	...	108.62	5.38	...
233	...	108.79	5.55	612
285	...	108.85	5.61	607
375	...	108.87	5.63	600
510	...	108.94	5.70	612
699	...	109.14	5.90	603
855	...	109.11	5.87	594
1,102	...	108.94	5.60	563
1,335	...	109.13	5.89	...
1,395	...	109.29	6.05	594
1,468	...	109.34	6.10	...
1,515	...	109.31	6.07	...
1,584	...	109.35	6.11	603

TABLE 2.—*Data on aquifer test using well 11-32-3bd1, Aug. 27-30, 1954—Concluded*

Time since pumping started (minutes)	Time since pumping stopped (minutes)	Depth to water in observation well (feet)	Drawdown in observation well (feet)	Yield of pumped well (gpm)
1,877	....	109.34	6.10	578
2,057	....	109.44	6.20	589
2,222	....	109.58	6.34	....
2,475	....	109.25	6.01	580
2,768	....	109.40	6.16	574
2,895	....	109.60	6.36	....
2,945	....	....	....	596
3,191	....	109.57	6.33	....
3,282	....	109.48	6.24	....
3,402	....	109.44	6.20	580
3,520	....	....	....	585
3,524	....	109.53	6.29	....
3,525	(Pumping	stopped)		
3,525	0.17	109.53	6.29	0
3,525	0.75	108.62	5.38	....
3,526	1.08	108.12	4.88	....
3,526	1.33	107.82	4.58	....
3,526	1.53	107.62	4.38	....
3,526	1.75	107.42	4.18	....
3,527	2.08	107.22	3.98	....
3,527	2.42	107.02	3.78	....
3,527	2.75	106.82	3.58	....
3,528	3.17	106.62	3.38	....
3,528	3.42	106.52	3.28	....
3,528	3.67	106.42	3.18	....
3,529	4.25	106.22	2.98	....
3,530	5.00	106.02	2.78	....
3,530	5.83	105.82	2.58	....
3,532	7	105.65	2.41	....
3,533	8	105.53	2.29	....
3,534	9	105.42	2.18	....
3,535	10	105.32	2.08	....
3,537	12	105.20	1.96	....
3,539	14	105.11	1.87	....
3,542	17	105.01	1.77	....
3,550	25	104.78	1.54	....
3,555	30	104.78	1.54	....
3,557	32	104.76	1.52	....
3,560	35	104.74	1.50	....
3,565	40	104.68	1.44	....
3,575	50	104.60	1.36	....
3,585	60	104.54	1.30	....
3,605	80	104.48	1.24	....
3,635	110	104.40	1.16	....
3,778	253	104.10	.86	....

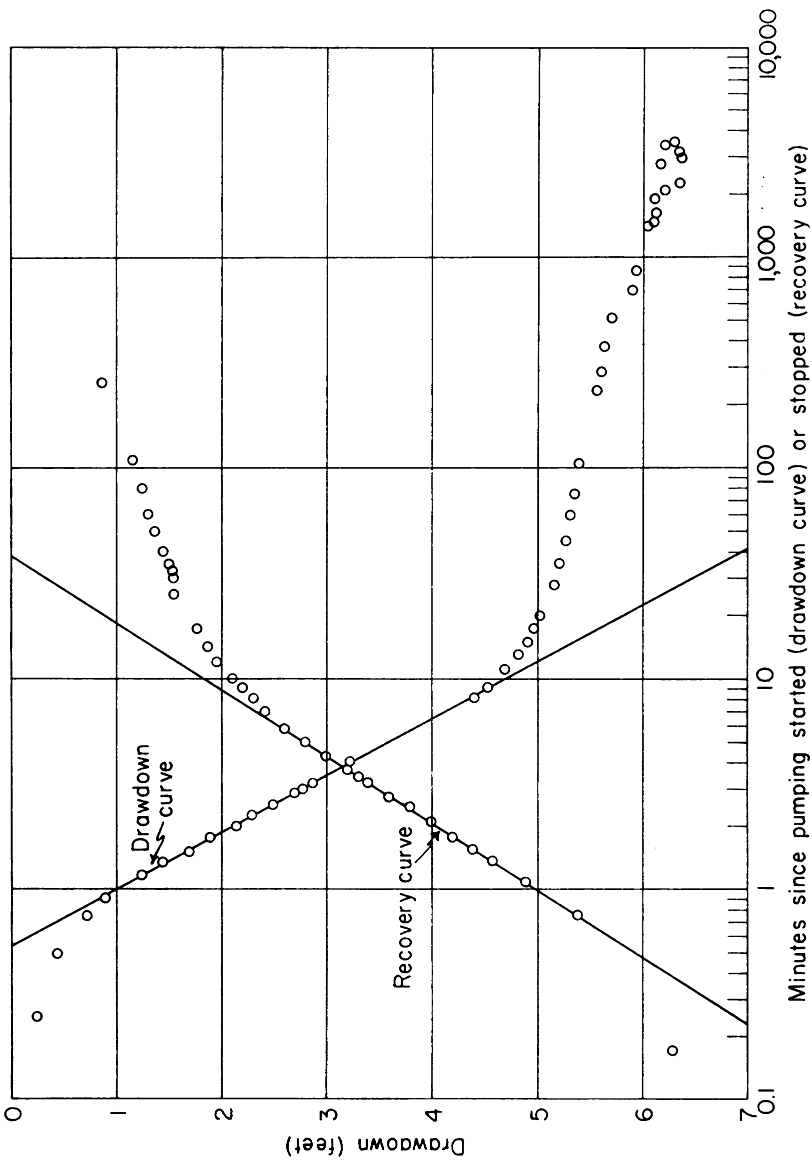


Fig. 6.—Drawdown and recovery of water level in observation well 11-32-3bd2 during aquifer test using public-supply well 11-32-3bd1.

TABLE 3.—*Data on aquifer test using well 11-33-14bc1, Aug. 25-29, 1954*

Time since pumping started (minutes)	Time since pumping stopped (minutes)	Depth to water in observation well (feet)	Drawdown in observation well (feet)	Yield of pumped well (gpm)
0	....	134.54	0	0
1	....	134.54	0	....
2	....	134.54	0	....
3	....	134.56	0.02	....
4	....	134.59	0.05	....
5	....	134.63	0.09	....
6	....	134.68	0.14	....
7	....	134.74	0.20	....
8	....	134.80	0.26	....
9	....	134.86	0.32	....
10	....	134.93	0.39	....
12	....	135.05	0.51	....
14	....	135.16	0.62	....
16	....	135.28	0.74	....
18	....	135.42	0.88	....
20	....	135.53	0.99	....
23	....	135.70	1.16	....
26	....	135.86	1.32	....
32	....	136.12	1.58	....
36	....	136.28	1.74	....
40	....	136.44	1.90	....
45	....	136.65	2.11	....
51	....	136.81	2.27	....
57	....	136.98	2.44	....
63	....	137.13	2.59	....
71	....	137.34	2.80	....
80	....	137.54	3.00	....
90	....	137.73	3.19	....
98	....	137.83	3.29	....
116	....	138.13	3.59	....
120	....	....	....	472
136	....	138.44	3.90	467
150	....	138.57	4.03	472
180	....	138.84	4.30	....
210	....	139.03	4.49	....
230	....	....	....	451
270	....	139.30	4.76	....
277	....	139.35	4.81	452
280	....	139.35	4.81	....
300	....	139.40	4.86	....
330	....	139.49	4.95	....
347	....	....	....	447
365	....	139.55	5.01	....
390	....	139.60	5.06	....
435	....	....	....	421

Table 3.—*Data on aquifer test using well 11-33-14bc1, Aug. 25-29, 1954—Concluded*

Time since pumping started (minutes)	Time since pumping stopped (minutes)	Depth to water in observation well (feet)	Drawdown in observation well (feet)	Yield of pumped well (gpm)
450	....	139.71	5.17	....
540	....	139.82	5.28	425
610	....	139.90	5.36	425
690	....	139.98	5.44	425
810	....	140.05	5.51	436
930	....	140.09	5.55	425
1,060	....	140.14	5.60	421
1,180	....	140.15	5.61	425
1,253	....	140.18	5.64	421
1,268	....	140.19	5.65	....
1,270	(Pumping	stopped)		
1,271	1	140.19	5.65	0
1,272	2	140.19	5.65	....
1,273	3	140.18	5.64	....
1,274	4	140.15	5.61	....
1,275	5	140.12	5.58	....
1,276	6	140.08	5.54	....
1,277	7	140.05	5.51	....
1,278	8	140.02	5.48	....
1,279	9	139.99	5.45	....
1,280	10	139.88	5.34	....
1,282	12	139.88	5.34	....
1,284	14	139.80	5.26	....
1,286	16	139.73	5.19	....
1,288	18	139.64	5.10	....
1,290	20	139.58	5.04	....
1,293	23	139.48	4.94	....
1,296	26	139.40	4.86	....
1,300	30	139.28	4.74	....
1,305	35	139.15	4.61	....
1,310	40	139.05	4.51	....
1,316	46	138.90	4.36	....
1,332	62	138.64	4.10	....
1,339	69	138.53	3.99	....
1,348	78	138.40	3.86	....
1,361	91	138.25	3.71	....
1,377	107	138.07	3.53	....
1,392	122	137.91	3.37	....
1,406	136	137.80	3.26	....
1,429	159	137.62	3.08	....
1,471	201	137.35	2.81	....
1,495	225	137.22	2.68	....
1,496	(Pumping	started)		
3,100	....	140.50	5.96	....
3,520	....	140.38	5.84	....
4,265	....	140.78	6.24	....
4,805	....	140.55	6.01	....
5,334	....	140.78	6.24	....

From the drawdown curve:

$$T = \frac{(264)\ (440)}{6.90 - 3.30} = 32{,}500 \text{ gpd/ft.}$$

$$P = \frac{32{,}500}{84} = 300 \text{ gpd/ft.}^2$$

From the recovery curve:

$$T = \frac{(264)\ (440)}{6.30 - 3.62} = 43{,}500 \text{ gpd/ft.}$$

$$P = \frac{43{,}500}{84} = 520 \text{ gpd/ft.}^2$$

Well 11-34-24ca1, an irrigation well on the farm of Horace Holmes, was pumped 8 hours on August 23, 1954. Drawdown measurements were made in observation well 11-34-24ca2 installed 172 feet north of the pumped well, and recovery measurements were made in this well for 22 hours after pumping ceased (Table 4). The specific capacity was approximately 5 gpm per foot of drawdown, and the pumping rate was 228 gpm.

The observation well was partly plugged during the pumping period, thus invalidating most of the drawdown measurements, but sufficient valid measurements made prior to the cessation of pumping indicated that the drawdown in the observation well was proceeding at a very low rate.

From the recovery curve of the observation well (Fig. 8):

$$T = \frac{(264)\ (228)}{5.07 - 1.97} = 19{,}500 \text{ gpd/ft.}$$

$$P = \frac{19{,}500}{83} = 235 \text{ gpd/ft.}^2$$

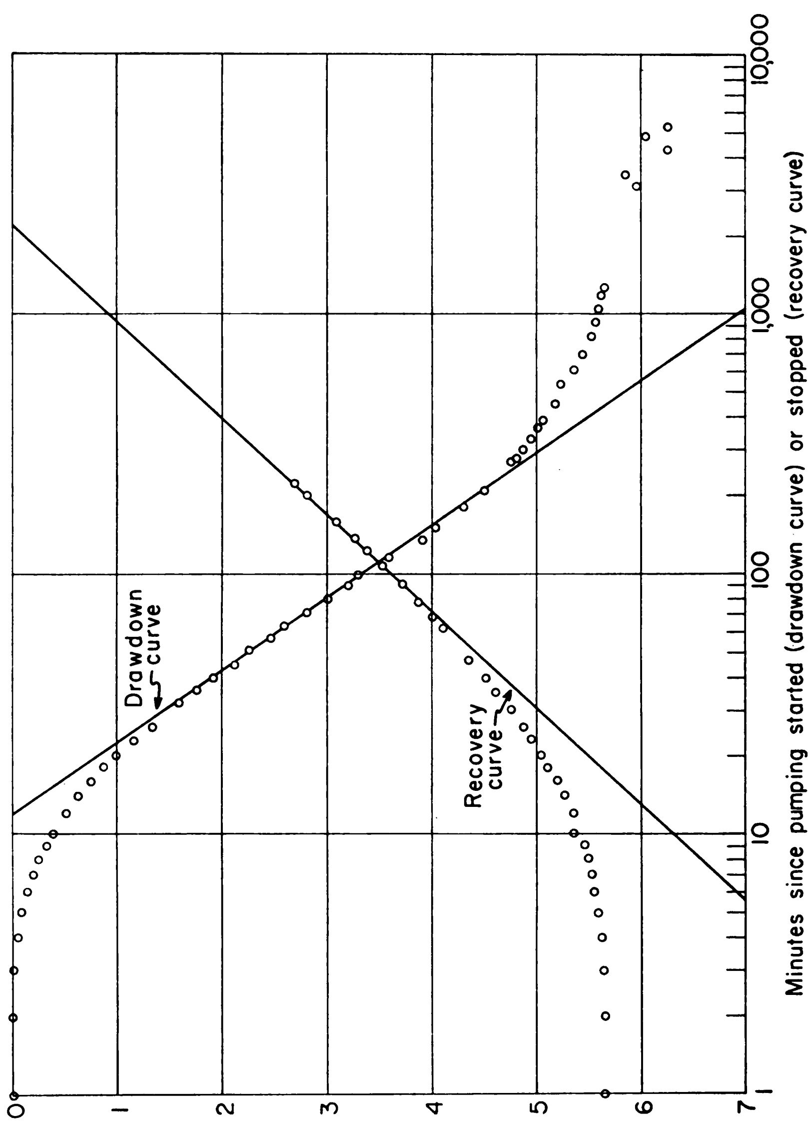


FIG. 7.—Drawdown and recovery of water level in observation well 11-33-14bc2 during aquifer test using irrigation well 11-33-14bc1.

TABLE 4.—*Data on aquifer test using well 11-34-24ca1, Aug. 23-24, 1954*

Time since pumping started (minutes)	Time since pumping stopped (minutes)	Depth to water in observation well (feet)	Drawdown in observation well (feet)	Yield of pumped well (gpm)
0	....	....	....	....
460	....	....	....	228
470	....	54.20	....	....
475	....	54.21	....	....
480	....	54.22	....	....
485	....	54.22	....	....
493	....	54.23	....	....
494.3	(Pumping	stopped)	....	....
494.8	0.5	54.24	4.83*	0
495.8	1.5	54.24	4.83	....
497.3	3	54.22	4.81	....
498.3	4	54.21	4.80	....
499.3	5	54.18	4.77	....
500.3	6	54.14	4.73	....
501.3	7	54.10	4.69	....
502.3	8	54.06	4.65	....
503.3	9	54.03	4.62	....
504.3	10	53.98	4.57	....
505.3	11	53.94	4.53	....
506.3	12	53.87	4.46	....
507.3	13	53.82	4.41	....
508.3	14	53.78	4.37	....
509	14.7	53.75	4.34	....
510	15.7	53.69	4.28	....
511	16.7	53.64	4.23	....
512	17.7	53.59	4.18	....
513	18.7	53.53	4.12	....
514	19.7	53.49	4.08	....
515	20.7	53.44	4.03	....
517	22.7	53.34	3.93	....
519	24.7	53.25	3.84	....
521	26.7	53.15	3.74	....
523	28.7	53.06	3.85	....
525	30.7	52.97	3.56	....
528	33.7	52.84	3.43	....
531	36.7	52.72	3.31	....
534	39.7	52.62	3.21	....
538	43.7	52.48	3.07	....
542	47.7	52.36	2.95	....
547	52.7	52.24	2.83	....

TABLE 4.—*Data on aquifer test using well 11-34-24ca1, Aug. 23-24, 1954—Concluded*

Time since pumping started (minutes)	Time since pumping stopped (minutes)	Depth to water in observation well (feet)	Drawdown in observation well (feet)	Yield of pumped well (gpm)
554	59.7	52.07	2.66	....
562	67.7	51.89	2.48	....
566	71.7	51.82	2.41	....
577	82.7	51.64	2.23	....
591	96.7	51.43	2.02	....
615	120.7	51.10	1.69	....
625	130.7	50.99	1.58	....
652	157.7	50.77	1.36	....
685	190.7	50.55	1.14	....
1,794	1,299.3	49.41	0	....

*Assumed maximum drawdown.

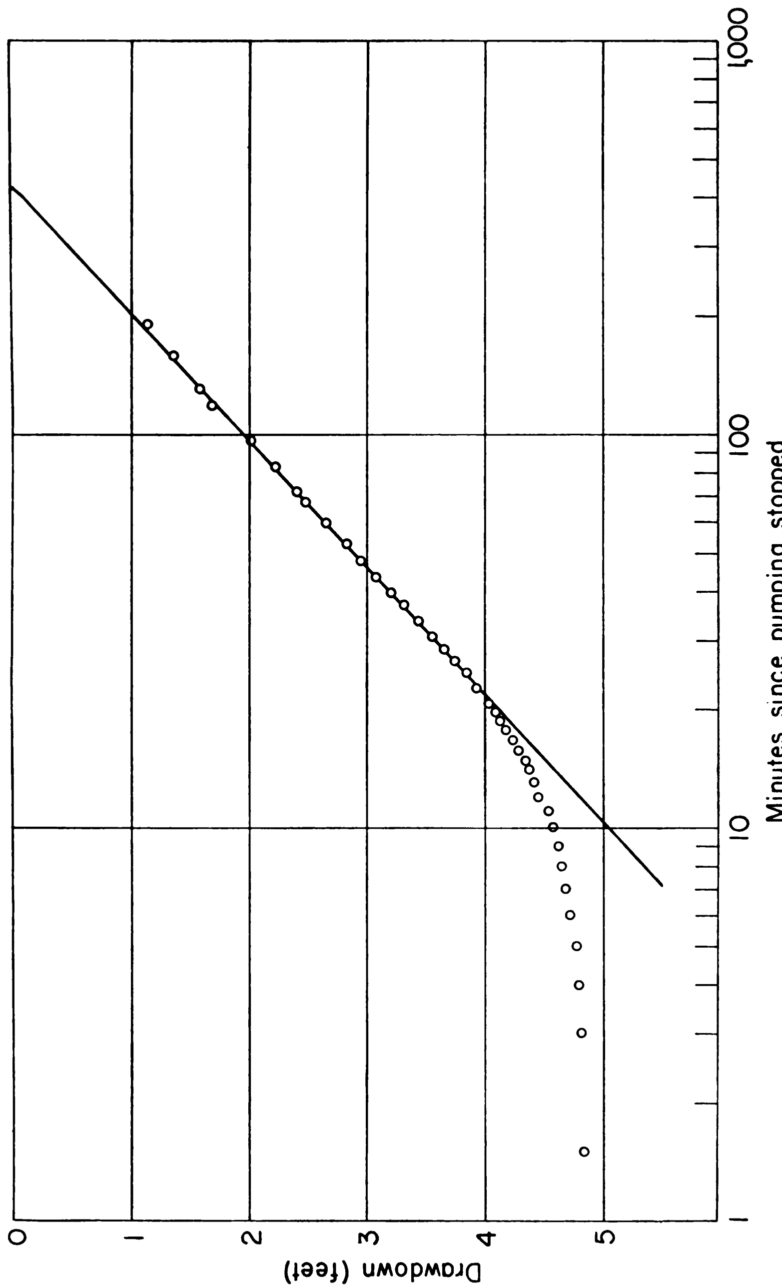


FIG. 8.—Recovery of water level in observation well 11-34-24ca2 during aquifer test using irrigation well 11-34-24ca1.

Well 11-35-5bb1, a public-supply well owned by the city of Winona, was pumped for a period of 270¼ hours beginning on August 24, 1954. Drawdown and recovery were measured in well 11-35-5bb2, which is 440 feet west of the pumped well (Table 5). The specific capacity was about 22 gpm per foot of drawdown, and the average pumping rate was 310 gpm.

The drawdown and recovery measurements were plotted against the time (Fig. 9), and the computations for T and P are as follows:

From the drawdown curve:

$$T = \frac{(264)\ (310)}{3.45 - 1.52} = 42{,}000 \text{ gpd/ft.}$$

$$P = \frac{42{,}000}{41} = 1{,}020 \text{ gpd/ft.}^2$$

From the recovery curve:

$$T = \frac{(264)\ (310)}{3.50 - 1.77} = 47{,}000 \text{ gpd/ft.}$$

$$P = \frac{47{,}000}{41} = 1{,}150 \text{ gpd/ft.}^2$$

In all the aquifer tests the plotted drawdown approximated the theoretical straight-line plot very soon after pumping started. The water level in the observation wells declined immediately after pumping began, despite the distances of 172 to 440 feet between the observation wells and the pumped wells. This effect suggests that the aquifer is artesian, at least during the early part of the pumping period. A similar artesian effect is shown in the recovery curves during the latter part of the recovery period. After pumping periods ranging from 10 to 200 minutes the slope of the time-drawdown curves decreases and departs from the theoretical straight-line curves. A lessening of the artesian effect present in the early part of the pumping period caused by leakage through the confining bed could have produced this effect. After a long period of pumping, the artesian pressure should disappear and water-table conditions should be established in the vicinity of the well. At this time the time-drawdown curve should again plot as a straight line parallel to the curve representing artesian conditions.

TABLE 5.—*Data on aquifer test using well 11-35-5bb1, Aug. 24-Sept. 4, 1954*

Time since pumping started (minutes)	Time since pumping stopped (minutes)	Depth to water in observation well (feet)	Drawdown in observation well (feet)	Yield of pumped well (gpm)
0	....	173.91	0	....
1	....	174.03	0.12	....
2	....	174.29	0.38	....
2½	....	174.41	0.50	....
3	....	174.51	0.60	....
3¾	....	174.65	0.74	....
4½	....	174.78	0.87	....
5	....	174.86	0.95	....
6	....	175.01	1.10	....
7	....	175.13	1.22	....
8½	....	175.30	1.39	....
10	....	175.45	1.54	....
12	....	175.61	1.70	....
14	....	175.75	1.84	....
16	....	175.86	1.95	....
19	....	176.01	2.10	....
22	....	176.12	2.21	....
26	....	176.25	2.34	....
31	....	176.38	2.47	318
37	....	176.50	2.59	....
44	....	176.61	2.70	....
52	....	176.71	2.80	....
60	....	176.78	2.87	....
70	....	176.85	2.94	....
82	....	176.90	2.99	316
95	....	176.94	3.03	....
115	....	176.97	3.06	....
145	....	177.01	3.10	314
200	....	177.02	3.11	312
1,430	....	176.65	2.74	....
4,510	....	177.14	3.23	....
5,940	....	177.20	3.29	....
7,335	....	177.16	3.25	....
9,895	....	176.86	2.95	293
9,905	....	176.86	2.95	....
10,305	....	176.94	3.03	299
11,760	....	177.24	3.33	....
13,250	....	177.04	3.13	311
15,980	....	177.20	3.29	318
16,230	....	177.21	3.30	....
16,230	(Pumping	stopped)		
16,231	1	176.81	2.90	0
16,232	2	176.59	2.68	....
16,233	3	176.46	2.55	....
16,234	4	176.31	2.40	....
16,235	5	176.18	2.27	....

TABLE 5.—*Data on aquifer test using well 11-35-5bb1, Aug. 24-Sept. 4, 1954—Concluded*

Time since pumping started (minutes)	Time since pumping stopped (minutes)	Depth to water in observation well (feet)	Drawdown in observation well (feet)	Yield of pumped well (gpm)
16,236	6	176.07	2.16	....
16,237	7	175.97	2.06	....
16,238	8	175.86	1.95	....
16,239	9	175.80	1.89	....
16,240	10	175.72	1.81	....
16,242	12	175.58	1.67	....
16,244	14	175.45	1.54	....
16,246	16	175.34	1.43	....
16,249	19	175.20	1.29	....
16,252	22	175.09	1.18	....
16,256	26	174.95	1.04	....
16,260	30	174.85	.94	....
16,266	36	174.73	.82	....
16,275	45	174.59	.68	....
16,285	55	174.48	.57	....
16,300	70	174.36	.45	....
16,320	90	174.27	.36	....
16,340	110	174.23	.32	....
16,365	135	174.19	.28	....
16,415	185	174.13	.22	....
16,545	315	174.04	.13	....
16,655	425	173.99	.08	....
16,775	545	173.97	.06	....
16,890	660	173.96	.05	....
17,010	780	173.94	.03	....
17,080	850	173.91	0	....

A nearby recharging well or a nearby stream or pond might cause a similar decrease in slope of the time-drawdown curve; however, no such recharging source was near the sites of the aquifer tests. A lateral increase in any direction in the thickness or permeability of the aquifer also could cause such an effect; no specific information on this possibility is available, however.

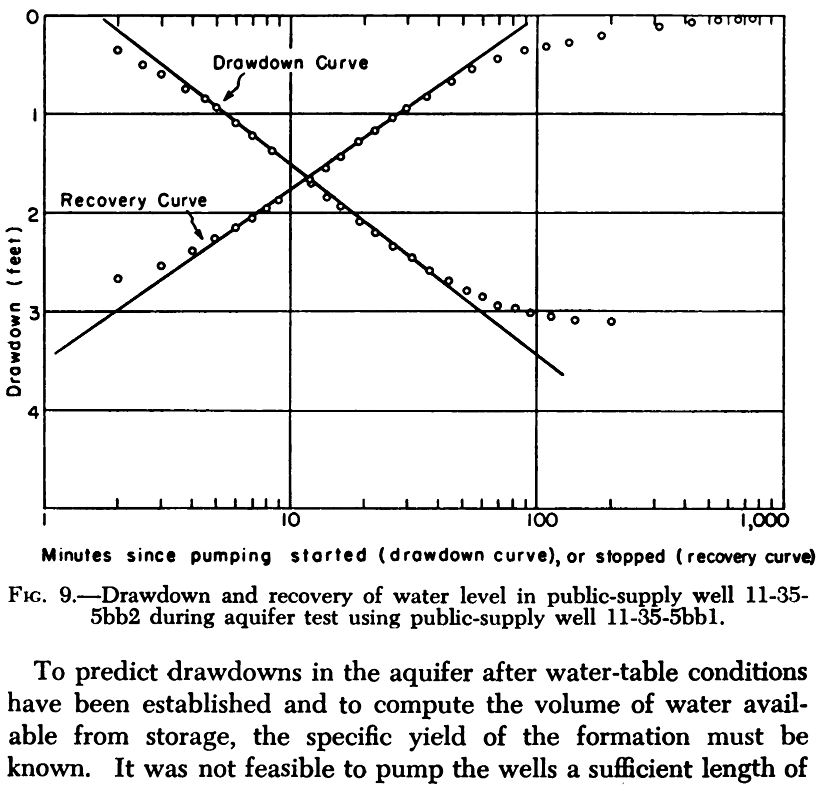


FIG. 9.—Drawdown and recovery of water level in public-supply well 11-35-5bb2 during aquifer test using public-supply well 11-35-5bb1.

To predict drawdowns in the aquifer after water-table conditions have been established and to compute the volume of water available from storage, the specific yield of the formation must be known. It was not feasible to pump the wells a sufficient length of time to obtain the data necessary for the computation of the specific yield.

The results of the aquifer tests are given in Table 6. Because under the conditions of these tests the values of T and P computed from the recovery data are likely to be nearer the true value, these will be used in this report in preference to those computed from the drawdown data.

Movement of Ground Water

Shape and Slope of the Water Table

Plate 1 was compiled from measurements of depth to water made in the summer of 1954 in wells and test holes whose surface altitudes were later determined by plane table and alidade. Table 7 contains the water-level measurements and altitudes of the wells and test holes. The water-table contours connect points of equal altitude of water level in wells and show the configuration of the water table just as topographic maps show the shape of the land surface.

Table 6.—*Results of aquifer tests*

Pumped well	11-32-3bd1	11-33-14bc1	11-34-24ca1	11-35-5bb1
Average discharge, gpm	595	440	228	310
Drawdown, ft.	18	40	40	14
Duration of pumping, minutes	2,475	5,334	494.3	16,230
Specific capacity, gpm/ft.	33	11	5	22
Saturated thickness, ft.	142	84	83	41
Observation well	**11-32-3bd2**	**11-33-14bc2**	**11-34-24ca2**	**11-35-5bb2**
Drawdown, ft.	6.34	6.24	4.83	3.79
Distance from pumped well, ft.	180	178	172	440
*Coefficient of transmissibility, gpd/ft.	49,500	43,500	19,500	47,000
*Coefficient of permeability, gpd/ft.^{2}	350	520	230	1,150

* Computed from the recovery curve.

Ground water moves in a direction at right angles to the contours. The gradient may be determined by inspection of the spacing of the contours. Ground water is moving through Logan County in a generally eastward direction at an average gradient of 10 feet per mile. The gradient is controlled in part by the slope of the surface of the Cretaceous rocks, which also is shown on Plate 1. Comparison of the two sets of contours shows that local irregularities in the (shale and chalk) floor are not reflected in the water table. The local configuration of the water table is caused mainly by local differences in recharge or discharge. These local influences include undrained depressions, pumping wells, streams, and areas differing in porosity, permeability, or thickness of the water-bearing materials.

Local differences in permeability and thickness of the water-bearing beds probably cause the principal irregularities in the water table. In general, the slope of the water table is least in areas underlain by thick, permeable rocks and is steepest in areas underlain by thin, relatively impermeable rocks. Thus, the gradient of the water table steepens in rocks of low transmissibility and flattens in rocks of relatively high transmissibility.

The depth to water, based on measurements made in 1954, is shown in Plate 2. The deepest water level measured in Logan County is in well 13-33-6bb, where the depth to water in the Dakota formation was 695 feet. The maximum depth to water in the Pleistocene deposits and Ogallala formation is 173 feet below the land surface, along the northern edge of the area. The depth to water is least in the alluvium in the stream valleys.

Fluctuations of the Water Table

The factors tending to raise the water table in Logan County are precipitation that penetrates the ground and reaches the zone of saturation, seepage from streams and undrained depressions, and ground water that enters the area by underground movement from the west and north. The factors tending to lower the water table are pumping from wells, discharge from springs, ground-water discharge into streams, evaporation and transpiration, and movement of ground water eastward and southward out of the area.

Five wells in Logan County were selected as observation wells from which to obtain information concerning fluctuations of the water table. Periodic measurement of the water level in these wells has been made chiefly by Howard Corrigan of the Division of Water Resources of the Kansas State Board of Agriculture. These water-level measurements (Table 7) have been published in U. S. Geological Survey Water-Supply Papers 946 (1944, pt. 3, p. 137-138), 988 (1946, pt. 3, p. 126-127), 1018 (1947, pt. 3, p. 103-104), 1025 (1948, pt. 3, p. 105-106), 1073 (1949, pt. 3, p. 99), 1098 (1951, pt. 3, p. 110), 1128 (1951a, pt. 3, p. 101), 1158 (1952, pt. 3, p. 101), 1167 (1952a, pt. 3, p. 68), 1193 (1954, pt. 3, p. 75), 1223 (1954a, pt. 3, p. 41), 1267 (1955, pt. 3, p. 50), 1323 (1956, pt. 3, p. 39), and 1406 (1957, pt. 3, p. 37).

A graph showing the changes of water level during the period 1945 to 1955 in well 11-32-2cc, which is near the city limits of Oakley, is shown in Figure 10. A progressive 30-month average was plotted to smooth out minor variations in individual measurements. The curve indicates that the changes in water level in the Ogallala formation are very small. The water level had a downward trend until 1948, an upward trend until mid-1954, and then a downward trend after 1954.

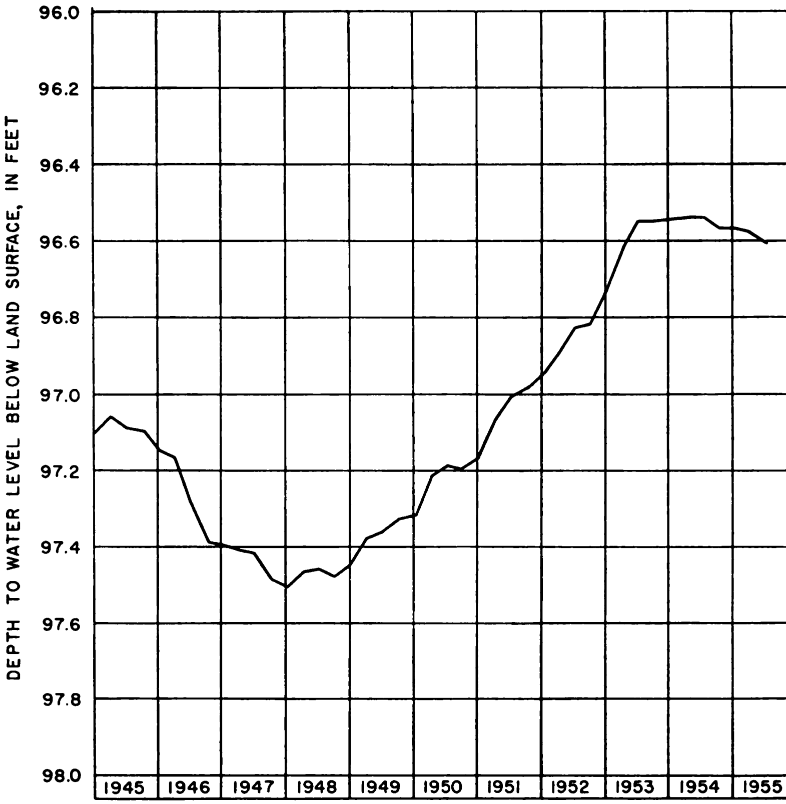


FIG. 10.—Graph showing progressive 30-month average water level in well 11-32-2cc.

The observations made in well 11-32-2cc show that the water level responds to precipitation only after a considerable lapse of time. The lowest point of the hydrograph is near the end of 1947 (Fig. 4). The significant rise of the water level ends in mid-1953. The length of record of well measurements is too short, however, to confirm what seems to be a cyclic trend in water-level fluctuations lagging more than 2 years behind that of precipitation.

TABLE 7.—*Records of water levels in selected wells*

Date	Depth to water level, feet	Date	Depth to water level, feet
Well 11–32–2cc		Well 11–32–2cc—Conc.	
Sept. 17, 1942	97.62	Apr. 14, 1949	97.12
Oct. 7	97.58	July 19	97.10
Nov. 27	97.46	Oct. 10	97.17
Dec. 14	97.50	Jan. 24, 1950	97.21
Jan. 11, 1943	97.08	Apr. 25	96.92
Feb. 11	97.07	July 25	97.34
Mar. 19	97.06	Oct. 9	97.40
Apr. 12	96.56	Jan. 8, 1951	97.20
May 5	96.69	Apr. 23	96.85
June 8	96.98	July 18	96.77
July 3	97.11	Oct. 17	96.95
Aug. 6	97.25	Jan. 16, 1952	96.72
Sept. 16	97.41	Apr. 9	96.65
Oct. 21	97.43	July 14	96.52
Nov. 11	97.38	Oct. 14	96.75
Nov. 23	97.29	Jan. 21, 1953	96.49
Jan. 22, 1944	96.42	Apr. 21	96.25
Feb. 27	97.23	July 8	96.50
Mar. 18	97.08	Oct. 13	96.86
Apr. 24	96.98	Apr. 28, 1954	96.71
May 24	97.09	July 20	96.93
June 12	97.10	July 28	96.71
July 20	97.15	Oct. 25	97.01
Aug. 10	97.24	Jan. 24, 1955	96.65
Sept. 5	96.93	Apr. 13	96.66
Oct. 19	97.43	July 13	97.05
Nov. 28	97.36	Sept. 23	97.38
Dec. 18	97.37	Oct. 11	96.86
Jan. 16, 1945	97.23		
Apr. 24	97.22		
		Well 11–32–24dd	
July 10	97.42	Sept. 17, 1942	60.77
Oct. 23	97.67	Oct. 7	60.74
Jan. 16, 1946	97.61	Nov. 27	60.79
Apr. 25	97.64	Dec. 14	60.82
July 8	97.69	Jan. 11, 1943	59.89
Oct. 4	97.93	Feb. 11	59.86
Jan. 6, 1947	99.29	Mar. 19	59.66
Apr. 4	97.49	Apr. 12	69.88
July 9	97.33	May 5	59.85
Oct. 14	97.91	June 8	59.92
Jan. 14, 1948	97.66	July 3	59.98
Apr. 13	97.28	Aug. 6	Pumping
July 13	97.50	Sept. 16	60.11
Oct. 13	97.79	Oct. 21	60.10
Jan. 5, 1949	97.41	Nov. 11	60.14

TABLE 7.—*Records of water levels in selected wells—Continued*

Date	Depth to water level, feet
Well 11-32-24dd—Conc.	
Nov. 23, 1943	Pumping
Jan. 22, 1944	60.17
Feb. 27	65.21
Apr. 24	60.26
May 24	59.94
July 20	59.87
Aug. 10	59.87
Sept. 5	59.88
Oct. 19	59.96
Nov. 28	60.02
Dec. 18	60.04
Jan. 16, 1945	60.39
Apr. 24	60.19
July 10	60.22
Jan. 16, 1946	60.25
Apr. 25	60.32
July 8	60.16
Oct. 4	60.21
Jan. 6, 1947	60.03
Apr. 4	59.86
July 9	59.80
Oct. 14	59.88
Jan. 14, 1948	59.97
Apr. 13	59.98
July 13	59.89
Oct. 13	59.59
Jan. 5, 1949	59.85
Apr. 14	59.80
Oct. 12	59.67
Apr. 25, 1950	62.49
Discontinued	....
Well 11-34-16cc	
Aug. 11, 1952	126.21
Jan. 6, 1953	126.63
May 12	126.51
Aug. 18	126.46
Nov. 24	126.42
Feb. 9, 1954	126.19
Mar. 4	126.16
July 1	126.15
July 28	126.20
Aug. 10	126.24
Well 11-34-16cc—Conc.	
Nov. 23, 1954	126.45
Feb. 22, 1955	126.19
May 4	126.21
Aug. 30	126.08
Sept. 23	126.18
Well 12-32-27ba	
Oct. 7, 1942	80.75
Nov. 27	80.61
Dec. 14	80.66
Jan. 11, 1943	80.65
Feb. 11	80.63
Mar. 19	80.58
Apr. 12	80.54
May 5	80.49
June 8	80.55
June 23, 1954	79.03
Well 12-37-27aa	
Aug. 11, 1952	43.56
Jan. 6, 1953	43.53
May 12	43.61
Aug. 18	43.76
Nov. 24	43.83
Feb. 9, 1954	43.89
Mar. 4	43.95
July 9	43.95
July 28	43.99
Aug. 10	44.60
Nov. 23	44.34
Feb. 22, 1955	44.00
May 4	43.94
Aug. 30	43.77
Sept. 27	43.73
Well 13-32-10dd	
Oct. 7, 1942	33.59
Nov. 27	33.56
Dec. 14	33.64
Jan. 11, 1943	33.65
Feb. 11	33.64
Mar. 19	33.63
Apr. 12	33.62
May 5	33.59
June 8	33.57
July 3	33.58

TABLE 7.—*Records of water levels in selected wells—Concluded*

Date	Depth to water level, feet	Date	Depth to water level, feet
Well 13-32-10dd—Cont.		Well-13-32-10dd—Conc.	
Aug. 6, 1943	34.85	Jan. 16, 1946	33.50
Sept. 16	33.68	Apr. 25	33.50
Oct. 21	33.61	July 8	33.51
Nov. 11	33.59	Oct. 3	33.43
Nov. 23	33.48	Jan. 6, 1947	33.23
Jan. 22, 1944	33.64	Apr. 4	33.23
Feb. 27	33.62	July 9	33.25
Mar. 18	33.63	Oct. 14	33.27
Apr. 24	11.93	Jan. 14, 1948	33.39
June 12	33.60	Apr. 13	33.30
July 19	33.58	July 13	33.28
Aug. 18	33.71	Oct. 13	32.32
Sept. 5	33.47	Destroyed in 1949	
Oct. 19	33.48		
Nov. 28	33.45		
Dec. 18	33.45		
Jan. 16, 1945	33.41		
Apr. 24	33.47		
July 10	33.50		
Oct. 23	33.45		

RECHARGE OF GROUND WATER

Recharge from Precipitation

Very little of the 18 to 19 inches of annual precipitation in Logan County reaches the water table in an average year. This recharge limits the amount of ground water that can be pumped without steadily lowering the water table. For this reason, an estimate is made of the probable recharge that can be utilized by wells in the northern upland area in Logan County, which may be extensively developed for irrigation.

The ground water that accumulates from recharge of the aquifer by precipitation moves eastward (Pl. 1) at a slope of approximately 10 feet per mile—in other words, at a hydraulic gradient of 0.0019—and flows through the aquifer shown on the geologic section A-A′ (Pl. 3). The movement through each square foot of the cross section is estimated by assuming a coefficient of permeability of 440 gpd per foot, as determined from the aquifer tests. The total area of saturated material in the cross section is about 2,750,000 square feet. Thus, the ground-water movement through this section is:

$$(440)\ (0.0019)\ (2{,}750{,}000) = 2{,}300{,}000 \text{ gpd},$$

or 2,600 acre-feet per year.

On Plate 1 it can be seen that contours on the water table are generally at right angles to the north county line, hence no appreciable amount of ground water moves across the northern border of this upland. Therefore, the water moving through materials illustrated by geologic cross section A-A′ (Pl. 3) must be derived from recharge from precipitation over this northern upland area.

The total amount of precipitation falling on the 300 square miles of the northern upland area is approximately 19 inches per year and amounts to a total of 304,000 acre-feet per year. Calculations show that only 0.85 percent of the precipitation, approximately 1/6 inch, becomes ground-water recharge. This computation was checked by using geologic cross sections B-B′, C-C′, and D-D′ and computing the recharge in these smaller parts of the area. It should be emphasized that this 1/6 inch of recharge does not represent the actual total recharge to the ground-water reservoir from precipitation in the area, but represents only that amount of recharge that moves as ground water across the area illustrated by section A-A′. An additional quantity of recharge from precipitation is discharged from springs and seeps at the contact of the Tertiary rock and the underlying Cretaceous rock floor where this contact crops out at the southern boundary of the upland area; some of the ground water that sinks into crevices in the Cretaceous rocks may leave the county underground; and some ground water is discharged by wells. The ground-water movement through A-A′ represents the additional amount that could be pumped by wells instead of discharging from the area by ground-water movement into Gove County. The total recharge to the northern upland area cannot be determined accurately because of the difficulty of estimating the discharge of ground water at the exposed contact of the Ogallala formation and the underlying Cretaceous rocks.

Recharge from Streams and Lakes

In the upland areas, during periods of flow in streams such as Hackberry, Chalk, and Twin Butte Creeks, some water leaves the channels and percolates into the underlying Ogallala formation. This percolation contributes recharge to the aquifers. Most of the water from such streams represents water that fell as precipitation within the county.

Shallow depressions or "lagoons" are common in Logan County and are shown on Plate 1 as intermittent ponds. The fact that these depressions, some of which may be 150 feet above the water table, are occupied by shallow ponds for weeks after a heavy rain indicates that most of the water evaporates. Latta (1944, p. 73-74) presented evidence that rapid recharge from storm water took place in a similar depression in Finney County, however. Even though the water level in a well in the depression was 112 feet below the surface, a rapid response to precipitation was noted, and a temporary mound on the water table developed. Latta concluded from this evidence that other depressions in the uplands probably act as catchment areas for recharge and that the water table beneath them fluctuates similarly. In Logan County probably a small part of the water in the depressions recharges the water table, but certainly most of the water evaporates.

Recharge from Irrigated Lands

In the Safford Basin in Arizona (Turner and others, 1941), recharge from irrigation is estimated to approach 25 percent of the applied water. In that locality the irrigation water is distributed in relatively long ditches over alluvial soils that are very permeable. The upland plain in Logan County is heavily mantled by loess, has a dense soil, and is irrigated from water-distribution systems that lose less water; hence, the recharge probably does not exceed 10 percent of the water applied. On the irrigated lands on the flood plain, where the soils are sandy and flooding of hay crops is practiced, the percentage of applied water that recharges the ground-water reservoir is probably somewhat greater.

Recharge by Ground-Water Movement from Adjacent Areas

Plate 1 indicates movement of ground water from Wallace County eastward into the southern upland-plain area of Logan County. The saturated thickness is small, and the recharge probably amounts to less than 25 acre-feet per year.

In the northern uplands of Logan County the ground-water contours are approximately normal to the Thomas County line, indicating that movement across this boundary is negligible. Some ground water moves from Thomas and Wallace Counties into Logan County through the alluvial fill of Smoky Hill River and Turtle Creek. The cross-sectional area of the saturated valley fill is small, and the quantity of water moving through these materials probably is negligible.

Discharge of Ground Water

Ground water is discharged from the zone of saturation in Logan County in the following ways: evaporation from the water table where it is close to the land surface, transpiration by vegetation, discharge by springs, discharge into surface streams, withdrawal from wells, and movement underground to adjacent areas. The measurements of water level in observation wells (Table 7) show that the water table in the upland area has not fluctuated significantly in recent years; thus, the ground-water discharge is in approximate equilibrium with recharge to the ground-water reservoir.

Discharge by Evaporation and Transpiration

Where the water table is within a few feet of the land surface, ground water may evaporate directly from the capillary fringe overlying the ground-water reservoir. If the water table is within a few inches of the land surface, evaporation may occur directly from the zone of saturation. Much of Logan County is an upland area in which the depth to the water table exceeds 40 feet, so that the total amount of ground water discharged by this means probably is not large. In the stream valleys, where the water table is approximately at the level of the stream bed, some ground water is discharged in this manner.

Water may be taken into the roots of plants directly from the zone of saturation and discharged from the plants by transpiration. The depth to which the roots of plants go for water varies with different kinds of plants and types of soil. Plants and grasses commonly do not draw water from depths of more than a few feet, but certain plants, such as alfalfa and cottonwood, may obtain water 20 to 30 feet below the surface. In most of Logan County the water level is considerably below the root tips of plants. In certain areas in the main river valleys and even in upland draws, however, the water table is not far below the land surface, and alfalfa, cottonwood, and hackberry transpire water directly from the water table.

Discharge by Springs

The amount of ground water discharged from springs in Logan County probably is large. There are many springs in the area, most of which discharge at the contact of the Cretaceous formations and the overlying more permeable Pliocene or Pleistocene rocks. Springs at the contact of the Ogallala formation and the underlying Pierre shale or Niobrara formation provide much of the recharge to the ground-water reservoirs in the alluvial fill along the draws in the rolling grassland area intermediate between the upland plain and the flood plain of the main valleys. Springs at the contact of these formations are used as sources of ground-water supplies in the southeastern part of the county.

Springs at the base of the Sanborn Group, of Pleistocene age, generally are larger than those issuing from other formations and are those most commonly developed for livestock and domestic use. The largest spring in the county is believed to be the Hinshaw spring in the NW cor. sec. 23, T. 13 S., R. 37 W., which discharges 60 to 65 gpm at the base of gravel of the Sanborn Group overlying the Niobrara formation. Springs near Russell Springs supply ground water to residents in that vicinity. In the NE¼ sec. 10, T. 13 S., R 36 W., the surface flow derived from springs at the base of Pleistocene sand and gravel is impounded by a small dam and used to water livestock.

The contact of the Ogallala formation and the underlying Cretaceous rocks represents a hydrologic boundary of the upland-plain areas along which the ground water is discharged by springs in areas where the contact crops out. Because the surface of the underlying Cretaceous rocks slopes toward points of outcrop, the flow cannot be stopped unless the ground-water reservoir is drained entirely; thus, the flow is not greatly affected by lowering of the water table in areas miles from the outcrop. For this reason, in computing the quantity of water in such upland areas that can be utilized, the quantity of ground water discharged by these contact springs was ignored.

Discharge by Wells

Most rural residents obtain water for domestic and livestock supplies from small drilled wells equipped with cylinder pumps powered by windmills. The yields of most of these wells are not more than 5 gpm, and they probably average only about 1 gpm. Because of their great number and relatively long pumping periods, however, such wells represent an important withdrawal from the ground-water reservoir. Pumpage for these purposes over the entire area probably is in the magnitude of 1,000 acre-feet per year. A total of approximately 100 acre-feet per year is pumped from public-supply wells at Oakley and Winona. A total of about 1,000 acre-feet per year is pumped from irrigation wells on the upland and the flood plain.

In 1955 the total discharge from wells in the area was estimated to be in excess of 2,000 acre-feet. If the county follows the trend of others in western Kansas toward putting increased acreages under deep-well irrigation, the annual pumpage of ground water in Logan County will show a marked increase in future years.

Discharge to Adjacent Areas

Some ground water is discharged from Logan County by underground movement to adjacent areas. In the northern upland area the discharge eastward into Gove County is estimated to be about 2,600 acre-feet per year. In the southern upland area some ground water moves southeastward into Wichita County, but because the surface of the relatively impermeable Cretaceous rocks slopes to the southeast away from the Pliocene-Cretaceous contact, the amount is believed to be relatively small. Some water, but probably a negligible amount, leaves the county in the Cretaceous rocks; it may be balanced by similar inflow in those rocks.

The movement of ground water out of the county through the alluvial fill of the Smoky Hill River valley is negligible because of the small cross-sectional area of the fill.

Utilization of Ground Water

Ground water in Logan County is used for domestic and livestock supplies, public supplies, and for irrigation. The few industries and railroads in Logan County obtain water from the municipal water systems in Oakley and Winona.

Domestic Supplies

Domestic supplies in the towns and rural areas are obtained from wells and from a few springs. Most domestic wells are equipped with cylinder pumps powered by windmills, are cased with 5½-inch galvanized casing, and are finished with concrete curbs.

In areas where the water-bearing formations are extremely thin, absent, or uneconomically deep, or where the water is unpalatable, water is hauled from the towns by truck and kept in barrels or cisterns for domestic use. Hauling of water is inconvenient and expensive, and finding local supplies of ground water of suitable quality for domestic use constitutes a major problem in the county. Drilling wells into the Dakota formation would provide water within a few hundred feet of the surface. The depth to the Dakota formation can be estimated by determining from Figure 3 the approximate altitude of the Dakota formation at the proposed well site and subtracting it from the altitude of the land surface. The chemical quality of water from the Dakota formation may vary locally, but the effort to find suitable domestic water from this formation probably would be warranted for those farmsteads at considerable distance from public supplies or which use large quantities of water. The high fluoride content of this water may cause mottling of the enamel of the teeth of children, however, if the water is used extensively during the period of formation of the permanent teeth.

Livestock Supplies

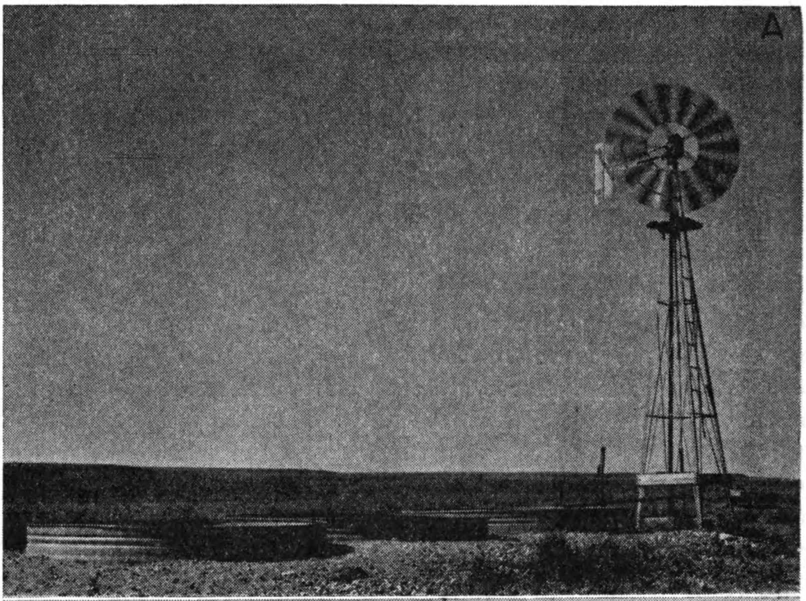
Livestock supplies in the county generally are obtained from wells and springs. Plate 9A shows a typical livestock well. In certain areas in the stream valleys, surface water is sufficient to supply livestock needs except during periods of severe drought. Some ponds that store surface runoff supplement livestock supplies from other sources. In many areas water must be hauled from public supplies or neighboring wells to supply livestock. The resulting expense and inconvenience reduce considerably the number of animals that otherwise would be raised in Logan County. Where ground water can be obtained from the Niobrara formation, however, it can be utilized to water livestock without detrimental effects, although it is unsatisfactory for human use because of excessive sulfate.

Public Supplies

Oakley and Winona are the only towns in Logan County that have municipal water systems. Monument, Page City, Russell Springs, McAllaster, and Elkader are supplied from private wells similar to those used in rural areas.

Oakley.—Oakley is supplied from five drilled wells obtaining water from the Ogallala formation. Three of the wells, 11-32-2bb1, 11-32-2bb2, and 11-32-2bb3, are near the municipal power plant in the northeast corner of the city. Well 11-32-3bd1 is 8 blocks west, on the west edge of the city. The wells have steel casings fitted with brass screens through the coarse water-bearing material and are pumped by electrically powered deep-well turbines.

The water from the wells is pumped directly into the city mains, the excess entering an elevated tank of 70,000-gallon capacity, which maintains in the system a water pressure of about 40 pounds per square inch. The wells are not metered, but the city engineer has estimated the daily average consumption of water throughout the year to be approximately 70,000 gallons. For short periods on hot summer days consumption exceeds the maximum pumping rate of about 1,000 gpm. The Oakley water system has expanded to meet the steady increase in water consumption in the last few years, and present plans call for another increase in capacity to keep pace with the growth of the city and a probable increase in per capita consumption. An analysis of a sample of water (11-32-2bb1) from the



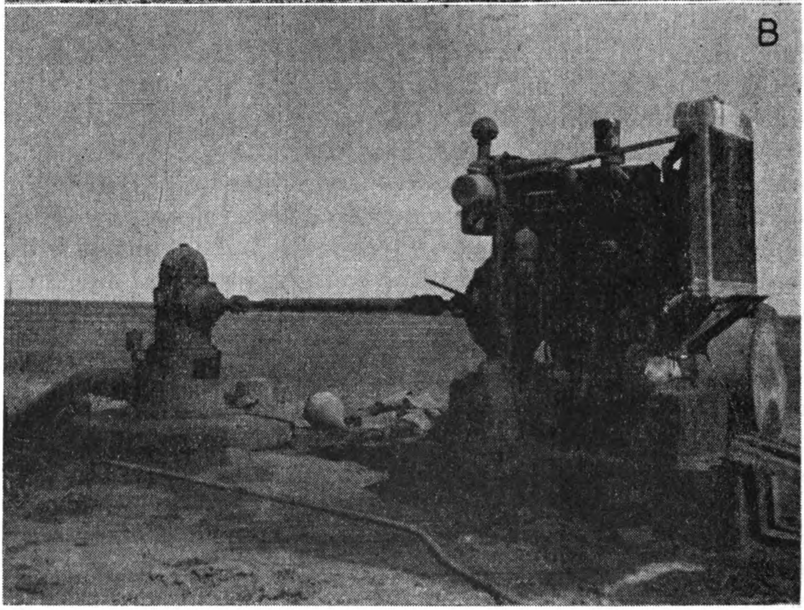


Plate 9.—**A,** Livestock well in sec. 27, T. 14 S., R. 32 W. Well is pumped most of the year; overflow from tank nearest well drains into next tank in sequence. This well is typical of many hundreds of livestock wells in Logan County. **B,** Irrigation well in sec. 28, T. 11 S., R. 33 W., owned by Duttlinger Bros.; reportedly yields 500 gpm. Turbine pump is powered by diesel motor.

water system is given in Table 9. The water, although hard, is not softened.

Winona.—Winona is supplied from wells 11-35-5bb1 and 11-35-5bb2 drilled into the Ogallala formation 5 miles north of the city, on the Thomas County line. A well field 2 miles south of Winona having three wells in the Ogallala formation was abandoned in 1948 because of the lack of capacity to supply the growing water needs of the town. One of these is a dug well having a masonry casing 10 feet in diameter and a reported depth of 100 feet.

The new wells have 12-inch steel casings fitted with brass screens through the permeable water-bearing material and are pumped with electrically powered submersible deep-well turbines. The water is pumped through a pipeline under a pressure at the well-head of 100 pounds per square inch directly into the city mains. The excess enters an elevated tank of 50,000-gallon capacity, which serves to maintain a pressure of about 40 pounds per square inch in the distribution system. The wells are not metered and no figures for average daily consumption are available. The maximum pumping rate exceeds 400,000 gallons per day and is more than sufficient for the water needs of the city even on hot summer days.

The analysis of a water sample collected from well 11-35-5bb1 is given in Table 9. The water, although hard, is not softened.

Irrigation Supplies

Only a small amount of water has been pumped for irrigation in Logan County, compared to that pumped in Scott and Wichita counties, adjacent to Logan county on the south. At the end of 1955 there were eight shallow irrigation wells in valley bottoms and five deeper irrigation wells in upland localities in operation in the county. A few domestic and livestock wells are sometimes used for watering small garden plots, but the quantity of water used for this purpose is small.

Data on pumping and irrigation practices for the upland wells are given in Table 8. Plate 9B shows a typical upland irrigation well.

The irrigation season generally lasts for about 60 days, beginning the first week in July and extending to about the first week in September, but some irrigation is practiced both earlier and later. In years when the rainfall is abundant in July and August, pumping is reduced considerably. Conversely, in comparatively dry summers irrigation begins early and may last about 100 days. Grain sorghum is the crop most commonly irrigated on the upland, but some corn and wheat also are irrigated. On the flood plains alfalfa is the crop most commonly irrigated, and the irrigation season generally is much shorter than that of the upland.

On the uplands the length of the irrigation season and the relatively high lift in irrigation wells necessitate the use of a cheap source of power, such as propane, butane, or diesel fuel. The irrigation wells on the flood plains are powered by gasoline or tractor-fuel engines or by electric motors. Irrigation water most commonly is distributed in open ditches, from which it is conducted into the rows by means of siphon tubes. Pipe having adjustable openings is used to some extent; its initial high cost is offset by eliminating the need to restart siphons whenever the pump is shut off for short periods. Alfalfa is irrigated by flooding or sprinkling.

An area of about 1,000 acres is irrigated annually in Logan County. The quantity of ground water pumped for irrigation probably averages less than 1,000 acre-feet per year.

Aquifer tests were made using two upland irrigation wells to determine the hydraulic characteristics of the Ogallala formation. The results of these tests are discussed in a previous section of the report and are given in Table 6.

Development of ground water for irrigation in Logan County was first started on the flood plain of the Smoky Hill River valley. In 1955, eight wells irrigated crops on the flood plain compared to five in the northern upland area. Because of the small irrigable acreage on the flood plain, future development will be more extensive on the upland plain, where there is much irrigable land and a suitable aquifer. At least 60,000 acres of upland plain is underlain by at least 40 feet of saturated Ogallala formation (Fig. 5). Where this formation has a suitable permeability, this amount of saturated material is sufficient to yield abundant supplies of water to irrigation wells. The major part of this acreage has soil and topography suitable for irrigation.

Records from the upland wells for which irrigation practices were reported suggest that the average annual pumpage for irrigation on the upland plain exceeds 100 acre-feet per well (Table 8). Well 11-34-24ca1 pumps considerably less, but the owner plans to increase this pumpage by modification of his well and expansion of the distribution system so as to bring more land under irrigation.

The annual recharge to the ground-water reservoir beneath the upland plain is less than half an inch, and an estimated $1/6$ inch is

TABLE 8.—*Reported use of five upland irrigation wells*

Well number		11–33–14bc1	11–33–19ca	11–33–28ab	11–33–30ba	11–34–24ca1
Date drilled		1947	1947	1947	1941	1945
Depth (feet)		220	– – – –	185	160	147
Lift (feet)		176	– – – –	165	– – – –	156
Drawdown (feet)		46	– – – –	55	– – – –	21
Yield (gpm)		430	600	500	800	230
Annual operation (hours)		1,440	– – – –	1,340	1,340	300
Type of fuel		propane or butane	diesel	diesel	diesel	butane
Method of water distribution		ditches and gated pipe	ditches and siphons	– – – –	ditches and gated pipe	ditches and siphons
Acreage irrigable	maximum available	300	– – – –	400	150	90
	annual average	200	– – – –	100	100	25
Pumpage (acre–feet)	annual total	124	– – – –	124	198	13
	average per acre	.62	– – – –	1.24	1.98	.52

TABLE 9.—*Analyses of water from typical wells and one spring*

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

Number on Fig. 11	Well number	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$ Total	Carbonate	Noncarbonate
1	11-32-2bb1	170	Ogallala formation	8-23-54	55	271	24	0.04	57 *2.84*	20 *1.64*	9.7 *0.42*	246 *4.03*	12 *0.25*	14 *0.39*	0.4 *0.02*	13 *0.21*	224	202	22
2	11-32-27aa	69.0	do.	9- 3-54	....	297	26	.10	49 *2.44*	19 *1.56*	27 *1.18*	240 *3.94*	18 *0.37*	16 *0.45*	1.0 *1.05*	23 *0.37*	200	197	3
3	11-33-4da	....	do.	9-27-55	58	281	23	.46	46 *2.30*	15 *1.23*	32 *1.39*	229 *3.76*	27 *0.56*	12 *0.34*	1.3 *0.07*	12 *0.19*	176	176	0
4	11-33-8cc	182	do.	9-28-55	....	312	24	.28	49 *2.44*	17 *1.40*	36 *1.58*	231 *3.79*	43 *0.89*	18 *0.51*	1.3 *0.07*	9.7 *0.16*	192	190	2
5	11-33-22dd	165.0	do.	9-26-55	56	322	24	.17	63 *3.14*	21 *1.73*	18 *0.77*	242 *3.97*	14 *0.29*	28 *0.79*	0.7 *0.04*	34 *0.55*	244	198	46
6	11-34-8dc	150.0	do.	9- 7-54	....	299	25	.95	43 *2.15*	17 *1.40*	39 *1.68*	238 *3.90*	30 *0.62*	17 *0.48*	1.6 *0.08*	9.3 *0.15*	178	178	0
7	11-34-22cb	132.0	do.	9-26-55	55	331	34	.10	44 *2.20*	18 *1.48*	45 *1.95*	254 *4.16*	31 *0.64*	20 *0.56*	1.6 *0.08*	12 *0.19*	184	184	0
8	11-34-25bc	100.0	do.	9- 3-54	57	313	27	1.3	75 *3.74*	16 *1.32*	9.9 *0.43*	265 *4.35*	7.4 *0.15*	18 *0.51*	0.2 *0.01*	29 *0.47*	253	218	35
9	11-35-5bb1	218	do.	7-24-54	59½	248	22	.11	45 *2.24*	14 *1.15*	23 *1.02*	220 *3.61*	12 *0.25*	12 *0.34*	0.6 *0.03*	11 *0.18*	170	170	0
10	11-35-22ca	50.0	do.	9-26-55	....	426	31	1.2	119 *5.94*	12 *0.99*	9.0 *0.39*	359 *5.89*	10 *0.21*	10 *0.28*	0.2 *0.01*	58 *0.93*	346	294	52
11	11-36-6da	170.0	do.	9- 7-54	57½	223	21	.48	46 *2.30*	9.0 *0.74*	18 *0.78*	185 *3.03*	14 *0.29*	9.0 *0.25*	0.6 *0.03*	14 *0.22*	152	152	0
12	11-37-10ab	83.0	do.	9-27-55	57	218	22	.14	48 *2.40*	6.8 *0.56*	18 *0.78*	190 *3.12*	9.5 *0.20*	6.0 *0.17*	0.7 *0.04*	13 *0.21*	148	148	0

13	11-37-29cc...	53.0	do................	9-27-55	....	346	30	.50	37 1.85	16 1.32	61 2.66	242 3.97	56 1.16	18 0.51	1.2 0.06	8.0 0.13	158	158	0
14	11-37-35ab...	19.0	Alluvium..........	9-27-55	60	351	24	.36	61 3.04	14 1.15	46 1.99	290 4.76	49 1.02	12 0.34	0.9 0.05	0.80 0.01	210	210	0
15	12-32-7bb....	23.0	Ogallala formation...	9-26-55	56½	455	29	.94	82 4.09	23 1.89	41 1.80	295 4.84	81 1.68	30 0.85	0.7 0.04	23 0.37	299	242	57
16	12-32-27aa...	90	do................	9- 3-54	....	327	32	.21	59 2.94	20 1.64	25 1.08	264 4.33	40 0.83	11 0.31	0.6 0.03	9.7 0.16	229	216	13
17	12-32-30bb...	43.0	do................	9-26-55	56	427	36	.15	78 3.89	22 1.81	35 1.52	288 4.72	67 1.39	26 0.73	1.1 0.06	20 0.32	285	236	49
18	12-33-29dc...	67	do................	9- 3-54	59	439	43	.18	44 2.20	22 1.81	72 3.14	249 4.08	104 2.16	24 0.68	3.1 0.16	4.4 0.07	200	200	0
19	12-34-2aa....	....	do................	9- 3-54	58½	278	24	.36	52 2.59	17 1.40	22 0.95	244 4.00	17 0.35	13 0.37	0.6 0.03	12 0.19	200	200	0
20	12-34-7cb....	120	do................	9- 4-54	58½	350	27	.78	46 2.30	25 2.06	39 1.68	237 3.89	52 1.08	26 0.73	1.4 0.07	17 0.27	218	194	24
21	12-34-22bb...	92.5	do................	9-26-55	57½	324	31	2.0	56 2.79	20 1.64	27 1.18	251 4.12	34 0.71	19 0.54	0.9 0.05	12 0.19	222	206	16
22	12-35-7da2....	....	do................	9- 7-54	58	305	29	.22	56 2.79	15 1.23	27 1.16	227 3.72	42 0.87	15 0.42	0.8 0.04	8.0 0.13	201	186	15
23	12-36-19aa...	16.1	Alluvium..........	9-28-54	62	1,240	24	.09	190 9.48	79 6.49	90 3.93	307 5.03	674 14.02	26 0.73	0.8 0.04	5.3 0.08	798	252	546
24	13-32-3ac....	76.0	Ogallala formation...	9-26-55	56½	384	46	.17	51 2.54	26 2.14	40 1.74	262 4.30	62 1.29	25 0.70	1.4 0.07	3.8 0.06	234	215	19
25	13-32-27aa2..	50.0	do................	9-26-55	56	875	43	.08	95 4.74	42 3.45	142 6.18	348 5.71	284 5.91	90 2.54	2.2 0.12	5.8 0.09	410	286	124
26	13-32-34cc2..	200	Niobrara formation..	9- 3-54	59	2,680	18	.86	570 28.44	76 6.25	146 6.36	273 4.48	1,660 34.57	65 1.83	2.0 0.10	4.3 0.07	1,730	224	1,510
27	13-33-6bb....	960.0	Carlile shale........ (Codell zone)	8-20-55	....	7,870	9.5	....	102 5.09	52 4.27	2,910 126.70	415 6.81	33 0.69	4,560 128.45	1.8 0.09	1.3 0.02	468	340	128
28	13-33-6bb....	1,230.0	Dakota formation...	9- 1-55	62	1,100	11	1	3.3 0.16	1.5 0.12	449 19.51	720 11.8	0.0 0.00	271 7.64	6.0 0.32	1.2 0.02	14	14	0

TABLE 9.—*Analyses of water from typical wells and one spring—Concluded*

Number on Fig. 11	Well number	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$ Total	Carbonate	Noncarbonate
29	13-34-2dd	33.5	Meade Group or Sanborn Group or both.	9- 3-54	57	3,620	31	1.2	674 *33.63*	141 *11.59*	221 *9.59*	222 *3.64*	2,040 *42.52*	181 *5.10*	1.2 *0.06*	217 *3.49*	2,260	180	2,080
30	*13-34-29bd	....	do.	9-19-51	....	568	....	....	91 *4.54*	27 *2.22*	57 *2.46*	249 *4.08*	177 *3.68*	29 *0.82*	0.6 *0.03*	16 *0.26*	340	212	128
31	13-35-16ab	....	do.	9- 7-54	59	447	34	.26	77 *3.84*	20 *1.64*	40 *1.76*	210 *3.44*	135 *2.81*	30 *0.85*	0.6 *0.03*	7.1 *0.11*	274	172	102
32	*13-37-23bb	....	do.	9-20-51	55	581	21	.03	81 *4.04*	21 *1.72*	78 *3.40*	255 *4.17*	212 *4.41*	18 *0.51*	1.1 *0.06*	1.6 *0.03*	288	209	79
33	*14-34-26aa	156.0	Niobrara formation	9-19-51	59	....	....	....	....	....	....	....	1,440 *29.98*	24 *0.68*	....	....	....	....	....
34	14-36-10ba	67.0	Ogallala formation	9-28-55	59	323	41	.50	48 *2.40*	22 *1.81*	30 *1.31*	259 *4.25*	31 *0.64*	16 *0.45*	1.5 *0.08*	6.2 *0.10*	210	210	0
35	14-36-34cd	52.0	Sanborn Group	9-28-55	57	1,630	42	.14	382 *19.06*	36 *2.96*	65 *2.83*	249 *4.08*	940 *19.57*	38 *1.07*	1.0 *0.05*	5.3 *0.08*	1,100	200	900
36	*15-32-19bd	....	do.	9-18-51	58	2,430	....	....	477 *23.8*	83 *6.80*	102 *4.43*	270 *4.42*	1,330 *27.7*	31 *0.8*	1.8 *0.09*	44 *0.71*	1,530	221	1,310
37	*15-32-26da	83.5	Ogallala formation	9-18-51	58	338	....	....	54 *2.7*	18 *1.48*	26 *1.11*	196 *3.22*	60 *1.25*	15 *0.4*	1.0 *0.05*	7.8 *0.13*	209	169	40
38	*15-35-2ab	37.0	Sanborn Group	9-19-51	55	3,190	....	....	573 *28.6*	100 *8.21*	203 *1.27*	453 *7.42*	1,760 *36.64*	23 *0.6*	1.2 *0.06*	37 *0.60*	1,840	371	1,470
39	*15-35-28bd	70	Ogallala formation or Sanborn Group or both.	9-19-51	58	446	26	.24	98 *4.9*	19 *1.56*	29 *1.27*	334 *5.47*	89 *1.85*	5.0 *0.14*	2.4 *0.13*	2.7 *0.04*	324	274	50

40	*15-35-32ad2..	21	Alluvium..........	9-19-51	55	1,700	42	.30	256 *12.8*	77 *6.35*	182 *7.91*	348 *5.70*	770 *16.03*	185 *5.2*	1.2 *0.06*	6.7 *0.11*	956	285	671
41	15-36-20dd...	....	Sanborn (?) Group..	9-28-55	....	1,020	39	.52	187 *9.33*	41 *3.37*	74 *3.21*	220 *3.61*	507 *10.54*	53 *1.49*	3.0 *0.16*	7.1 *0.11*	635	180	455
42	15-37-4cb....	17.0	Alluvium or Sanborn Group or both.	9-28-55	59	1,180	35	.16	241 *12.03*	40 *3.29*	76 *3.31*	295 *4.84*	587 *12.21*	51 *1.44*	1.1 *0.06*	5.3 *0.08*	765	240	525
43	*15-37-30cb...	73.0	Ogallala formation...	9-21-51	56	258	27	2.3	37 *1.85*	14 *1.15*	31 *1.36*	204 *3.34*	29 *0.60*	5.5 *0.16*	1.8 *0.09*	8.8 *0.14*	150	150	0

a. One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.

b. An equivalent per million is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing the concentration in parts per million by the chemical combining weight of the substance or ion.

* Samples were collected and analyzed by U. S. Geological Survey laboratory in Lincoln, Nebraska.

available to wells. Thus, the factor limiting the number of acres that can be irrigated on the upland is the amount of ground water that can be pumped without seriously depleting the ground-water resources. The annual discharge from the ground-water reservoir of Logan County that can be diverted for irrigation amounts to less than 3,000 acre-feet in the northern upland plain. The maximum acreage that could be irrigated with 1 foot of water annually would be about 3,000 acres, which is much less than the acreage of suitable land underlain by water-bearing materials. Any development of the ground-water resources beyond 3,000 acre-feet per year probably would result in steadily declining water levels.

The development of stored ground-water reserves—called mining of ground water—is a complex economic problem related to the extent to which the water table could be lowered without imperiling domestic, livestock, and public supplies; the distribution of the pumping; future climatic trends; and the amount of water that could be diverted from parts of the aquifer that cannot be developed because of insufficient saturated thickness or which underlie non-irrigable land.

Chemical Character of Water

The chemical character of ground water in Logan County is known from 34 water samples analyzed by Howard A. Stoltenberg, chemist, of the Water and Sewage Laboratory of the Kansas State Board of Health in Lawrence. The results of these analyses and the analyses of 9 ground-water samples collected in a previous investigation (Bradley and Johnson, 1957) are given in Table 9. In Table 10 are given 6 analyses of surface water also collected in that study.

The analyses show only the dissolved mineral content and not the sanitary condition of the water, except as excessive nitrate may indicate possible pollution by sewage or other organic wastes.

Chemical Constituents in Relation to Use

The following discussion of the chemical constituents of water in relation to use has been adapted from publications of the U. S. Geological Survey and the State Geological Survey of Kansas.

Dissolved solids.—When water is evaporated, the residue consists mainly of mineral constituents and a small quantity of organic material and water of crystallization. The kind and quantity of the soluble mineral constituents in water are major factors in determining its suitability for use. Water containing less than 500 parts per million of dissolved solids generally is satisfactory for domestic use, except for difficulties that may result from hardness or, in some places, excessive iron content. Water having more than 1,000 ppm is likely to contain enough of certain mineral constituents to produce a noticeable taste or to make the water unsuitable in some other respect.

The dissolved solids in samples of water from Logan County ranged from 218 to 7,870 ppm. The amount of dissolved solids exceeded 1,000 ppm in ten samples of ground water and in one sample of water from Twin Butte Creek and one from Chalk Creek.

Hardness.—The hardness of water is recognized most commonly by the quantity of soap needed to produce a lather in washing and by the curdy precipitate that forms before a permanent lather is obtained. Calcium and magnesium cause the hardness of most water.

Hardness is of two types, carbonate and noncarbonate. Hardness caused by calcium and magnesium equivalent to the bicarbonate is carbonate hardness and, because it can be removed almost entirely by boiling, is often called temporary hardness. The remaining hardness often is referred to as permanent hardness, because it cannot be removed by boiling. There is no difference between the effects resulting from carbonate and noncarbonate hardness when water is used with soap.

Water having a hardness of less than 50 ppm is regarded as soft, and treatment to reduce hardness generally is unnecessary. Hardness of 50 to 100 ppm does not seriously interfere with the use of the water for most purposes, but does increase the consumption of soap. Reduction of hardness by a softening process may be profitable for laundries and some other industries. Hardness of more than 150 ppm is very noticeable. Where public water supplies are softened, the hardness is generally reduced to 100 ppm or less.

Hardness of samples of water collected in Logan County ranged from 14 to 2,260 ppm. Most samples were hard or very hard, ranging from 150 to 300 ppm.

Silica.—Silica is a mineral constituent of most ground water. The silica in a water may be deposited with other scale-forming constituents in steam boilers, but otherwise it has no effect in the use of water for most purposes. The silica in samples of ground water from Logan County ranged from 9.5 to 46 ppm.

Iron.—Iron may be present in water in sufficient quantity to give a disagreeable taste or to stain cooking utensils and plumbing fixtures. Normally, if ground water contains much more than 0.3 ppm of iron, the excess will separate out and settle as a reddish sediment when exposed to the air. Iron may be removed from most water by aeration and filtration, but some water requires additional treatment.

Iron content of ground-water samples collected in Logan County ranged from 0.03 to 2.30 ppm; about half the samples had less than 0.3 ppm.

Fluoride.—Fluoride is generally present only in small concentrations in ground water, but the amount of fluoride in drinking water that is used by children should be known. Fluoride in water has been associated with the dental defect known as mottled enamel, which may appear on the teeth of children who drink water containing more than about 1.5 ppm of fluoride during the formation of the permanent teeth.

Recent studies have shown that about 1 ppm of fluoride in drinking water may help to prevent tooth decay in children. The United States Public Health Service (1946) has published standards that limit the amount of certain mineral constituents permissible in drinking water that is used in interstate commerce. The specified maximum amount of fluoride is 1.5 ppm.

The fluoride content of ground-water samples collected in Logan County ranged from 0.2 to 6.0 ppm. Of the 43 samples analyzed, only 11 had fluoride in excess of 1.5 ppm.

Nitrate.—The presence of nitrate in water was given new significance a few years ago when it was discovered that water containing excessive nitrate might cause cyanosis in infants when the water is used in the preparation of their formula (Metzler and Stoltenberg, 1950). In cyanosis the infant becomes drowsy and listless and the skin takes on a blue color. In less severe cases recovery may take place in 8 to 24 hours if a change is made to water of low nitrate content, but death may result if the water supply is not changed. Nitrate in drinking water does not cause cyanosis in adults but may be responsible for certain digestive disorders.

Nitrate is derived from nitrate-bearing rocks and minerals in the water-bearing formations and from direct flow of nitrate-bearing surface water into wells. Soils, especially during the fall and winter, contain nitrate derived principally from plants, from animal wastes, and from nitro-bacterial action. Being very soluble, nitrate salts are readily leached from the soils by rainfall and carried into wells. Because privies, cesspools, and barnyards are sources of organic nitrogen, a large amount of nitrate in well water may indicate pollution from these sources and the possible presence of harmful bacteria.

The Kansas State Board of Health judges that about 45 ppm is the safe limit of nitrate (as NO_3), and to use water having nitrate in excess of this amount in the preparation of an infant's formula may be dangerous. All the water samples from Logan County contained nitrate, but only two contained more than 45 ppm, the maximum being 217 ppm.

Water for Irrigation

The suitability of water for use in irrigation depends mainly upon the total quantity of soluble salts and upon the ratio of the quantity of sodium to the total quantity of sodium, potassium, calcium, and magnesium. In some areas other constituents, such as boron and bicarbonate, may be present in sufficient quantities to cause injury to crops or soil. In a discussion of the interpretation of analyses with reference to irrigation in southern California, Scofield (1933) suggests that if the total concentration of dissolved salts is more than 700 ppm in the water its use for irrigation may be harmful and that dissolved salts in excess of 2,100 ppm may damage crops or land, or both. Water containing more than 60 percent sodium (the percentage being calculated as 100 times the ratio of sodium to the total principal bases listed above, all expressed in equivalents per million) is likely to be injurious to the soil.

Waters from five wells sampled in Logan County contained more than 2,100 ppm of dissolved solids, but the wells were in areas where sufficient water supplies for irrigation could not be obtained. No other water samples showed prohibitive amounts of solids. The alluvium in Logan County commonly yields water containing relatively large amounts of dissolved solids, sodium, and chloride, hence any water that is developed from the alluvium for irrigation should be checked for objectionable quantities of these constituents.

Chemical Character in Relation to Geologic Source

The waters analyzed (Table 9) were classified by types according to a method suggested by Piper (1953, p. 6-7), in which the water is designated by a binomial symbol written in the form of a decimal fraction whose two terms are the percentage of hardness-causing constituents among the cations (bases) and the percentage of bicarbonate and carbonate among the anions (acids). For example, the symbol 57.69 would indicate a water in which the Ca and Mg amount to 57 percent of all the cations in terms of equivalents and the weak anions CO_3 and HCO_3 amount to 69 percent of all the anions in the same terms.

The first term of the symbol indicates relative hardness in percent of total equivalents. If the second term exceeds the first, all the hardness is carbonate ("temporary") hardness. If the second term is small, some of the hardness is noncarbonate and the relative amount of the permanent hardness is in direct proportion to the numerical difference between the two terms. The first term of the symbol subtracted from 100 is equal to the "percent sodium", a term introduced by Scofield (1933, p. 22-23) to measure the effect of water on physical properties of soils. If the first term is greater than about 50, the physical condition of the soil is not likely to be impaired seriously, but if the term is less than 40 such impairment may result.

The two terms taken directly from the analytical data in terms of percentage equivalents per million have been plotted on rectangular coordinates (Fig. 11). The graph shows a tendency to-

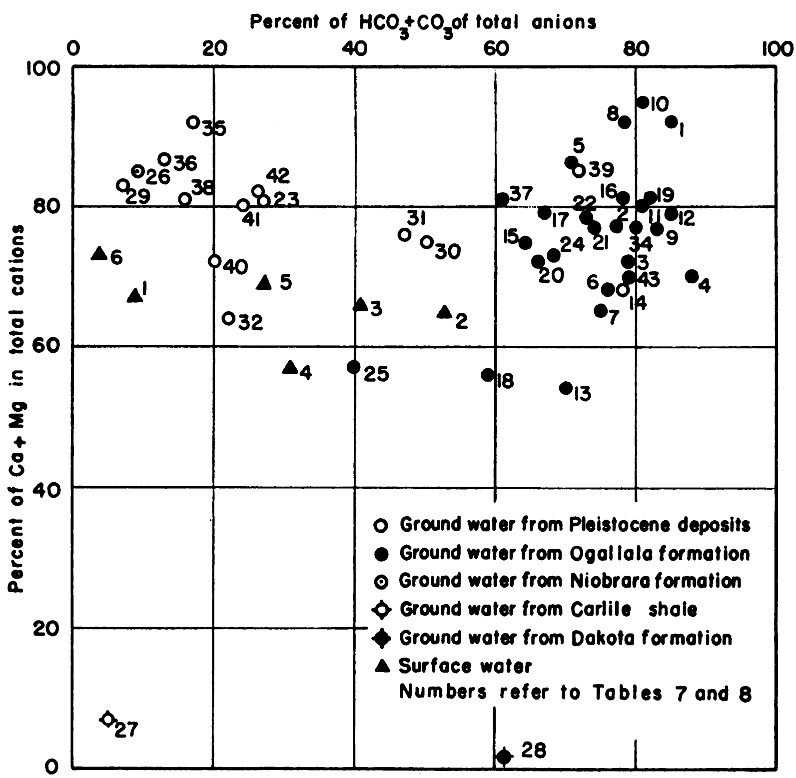


FIG. 11.—Graphical representation of analyses of samples of water, by formations, showing diversity of character.

ward grouping into water types allied with the Ogallala formation and with Pleistocene sediments. Mixtures of water tend to plot between the areas of their chief components.

Dakota Formation

A sample of water was collected from well 13-33-6bb, which taps sandstone of the Dakota formation. The analysis indicates that the water from the Dakota in Logan County approaches 0.100 as a limit, being a nearly pure sodium bicarbonate water. The water in the Dakota formation in Logan County is very soft and has no disagreeable taste, but the one sample from the formation that was analyzed is undesirably high in fluoride content. Strongly mineralized water is characteristic of the Dakota formation in part of Kansas, but western Kansas has many satisfactory water supplies derived from this source.

Wells drilled into the Dakota formation in Gove, Lane (Prescott, 1951), Hamilton and Kearny (McLaughlin, 1943), and Finney and Gray Counties (Latta, 1944) are reported to be in use for livestock and domestic water supplies. Two wells were drilled in Wichita County (Prescott, Branch, and Wilson, 1954) for irrigation and railroad supplies, but the water was found to be too mineralized for these purposes, although it probably would have been satisfactory for livestock and domestic use.

Latta (1944) and Prescott (1951) believed that the water in the Dakota formation has undergone a natural softening in which the original calcium bicarbonate water has exchanged its calcium and magnesium for sodium by base exchange. The base-exchange silicates active in the natural softening process perhaps are the clay minerals in the Dakota formation. The degree of softening depends upon the amount and softening capacity of the clay minerals and upon the length of time the hard water remains in contact with these minerals (Renick, 1924).

Water in the Dakota formation in Logan County contains too large a percentage of sodium for irrigation use, and the fluoride content renders it undesirable for drinking by children, but it is generally satisfactory for most domestic and all livestock purposes.

Carlile Shale

One sample of water was collected from the Codell sandstone zone of the Carlile shale in well 13-33-6bb drilled to the Dakota formation. The water contained 7,870 ppm of dissolved solids and ghum is the crop most commonly irrigated on the upland, but some corn and wheat also are irrigated. On the flood plains alfalfa is the crop most commonly irrigated, and the irrigation season generally is much shorter than that of the upland.

On the uplands the length of the irrigation season and the relatively high lift in irrigation wells necessitate the use of a cheap source of power, such as propane, butane, or diesel fuel. The irrigation wells on the flood plains are powered by gasoline or tractor-fuel engines or by electric motors. Irrigation water most commonly is distributed in open ditches, from which it is conducted into the rows by means of siphon tubes. Pipe having adjustable openings is used to some extent; its initial high cost is offset by eliminating the need to restart siphons whenever the pump is shut off for short periods. Alfalfa is irrigated by flooding or sprinkling.

An area of about 1,000 acres is irrigated annually in Logan County. The quantity of ground water pumped for irrigation probably averages less than 1,000 acre-feet per year.

Aquifer tests were made using two upland irrigation wells to determine the hydraulic characteristics of the Ogallala formation. The results of these tests are discussed in a previous section of the report and are given in Table 6.

Development of ground water for irrigation in Logan County was first started on the flood plain of the Smoky Hill River valley. In 1955, eight wells irrigated crops on the flood plain compared to five in the northern upland area. Because of the small irrigable acreage on the flood plain, future development will be more extensive on the upland plain, where there is much irrigable land and a suitable aquifer. At least 60,000 acres of upland plain is underlain by at least 40 feet of saturated Ogallala formation (Fig. 5). Where this formation has a suitable permeability, this amount of saturated material is sufficient to yield abundant supplies of water to irrigation wells. The major part of this acreage has soil and topography suitable for irrigation.

Records from the upland wells for which irrigation practices were reported suggest that the average annual pumpage for irrigation on the upland plain exceeds 100 acre-feet per well (Table 8). Well 11-34-24ca1 pumps considerably less, but the owner plans to increase this pumpage by modification of his well and expansion of the distribution system so as to bring more land under irrigation.

The annual recharge to the ground-water reservoir beneath the upland plain is less than half an inch, and an estimated 1/6 inch is

TABLE 8.—*Reported use of five upland irrigation wells*

Well number		11-33-14bc1	11-33-19ca	11-33-28ab	11-33-30ba	11-34-24ca1
Date drilled		1947	1947	1947	1941	1945
Depth (feet)		220	- - - -	185	160	147
Lift (feet)		176	- - - -	165	- - - -	156
Drawdown (feet)		46	- - - -	55	- - - -	21
Yield (gpm)		430	600	500	800	230
Annual operation (hours)		1,440	- - - -	1,340	1,340	300
Type of fuel		propane or butane	diesel	diesel	diesel	butane
Method of water distribution		ditches and gated pipe	ditches and siphons	- - - -	ditches and gated pipe	ditches and siphons
Acreage irrigable	maximum available	300	- - - -	400	150	90
	annual average	200	- - - -	100	100	25
Pumpage (acre-feet)	annual total	124	- - - -	124	198	13
	average per acre	.62	- - - -	1.24	1.98	.52

TABLE 9.—*Analyses of water from typical wells and one spring*

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

Number on Fig. 11	Well number	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$ Total	Carbonate	Noncarbonate
1	11-32-2bb1...	170	Ogallala formation...	8-23-54	55	271	24	0.04	57 *2.84*	20 *1.64*	9.7 *0.42*	246 *4.03*	12 *0.25*	14 *0.39*	0.4 *0.02*	13 *0.21*	224	202	22
2	11-32-27aa...	69.0	do................	9- 3-54	....	297	26	.10	49 *2.44*	19 *1.56*	27 *1.18*	240 *3.94*	18 *0.37*	16 *0.45*	1.0 *1.05*	23 *0.37*	200	197	3
3	11-33-4da....	....	do................	9-27-55	58	281	23	.46	46 *2.30*	15 *1.23*	32 *1.39*	229 *3.76*	27 *0.56*	12 *0.34*	1.3 *0.07*	12 *0.19*	176	176	0
4	11-33-8cc....	182	do................	9-28-55	....	312	24	.28	49 *2.44*	17 *1.40*	36 *1.58*	231 *3.79*	43 *0.89*	18 *0.51*	1.3 *0.07*	9.7 *0.16*	192	190	2
5	11-33-22dd...	165.0	do................	9-26-55	56	322	24	.17	63 *3.14*	21 *1.73*	18 *0.77*	242 *3.97*	14 *0.29*	28 *0.79*	0.7 *0.04*	34 *0.55*	244	198	46
6	11-34-8dc....	150.0	do................	9- 7-54	....	299	25	.95	43 *2.15*	17 *1.40*	39 *1.68*	238 *3.90*	30 *0.62*	17 *0.48*	1.6 *0.08*	9.3 *0.15*	178	178	0
7	11-34-22cb...	132.0	do................	9-26-55	55	331	34	.10	44 *2.20*	18 *1.48*	45 *1.95*	254 *4.16*	31 *0.64*	20 *0.56*	1.6 *0.08*	12 *0.19*	184	184	0
8	11-34-25bc...	100.0	do................	9- 3-54	57	313	27	1.3	75 *3.74*	16 *1.32*	9.9 *0.43*	265 *4.35*	7.4 *0.15*	18 *0.51*	0.2 *0.01*	29 *0.47*	253	218	35
9	11-35-5bb1...	218	do................	7-24-54	59½	248	22	.11	45 *2.24*	14 *1.15*	23 *1.02*	220 *3.61*	12 *0.25*	12 *0.34*	0.6 *0.03*	11 *0.18*	170	170	0
10	11-35-22ca...	50.0	do................	9-26-55	....	426	31	1.2	119 *5.94*	12 *0.99*	9.0 *0.39*	359 *5.89*	10 *0.21*	10 *0.28*	0.2 *0.01*	58 *0.93*	346	294	52
11	11-36-6da....	170.0	do................	9- 7-54	57½	223	21	.48	46 *2.30*	9.0 *0.74*	18 *0.78*	185 *3.03*	14 *0.29*	9.0 *0.25*	0.6 *0.03*	14 *0.22*	152	152	0
12	11-37-10ab...	83.0	do................	9-27-55	57	218	22	.14	48 *2.40*	6.8 *0.56*	18 *0.78*	190 *3.12*	9.5 *0.20*	6.0 *0.17*	0.7 *0.04*	13 *0.21*	148	148	0

13	11-37-29cc...	53.0	do.	9-27-55	....	346	30	.50	37 *1.85*	16 *1.32*	61 *2.66*	242 *3.97*	56 *1.16*	18 *0.51*	1.2 *0.06*	8.0 *0.13*	158	158	0
14	11-37-35ab...	19.0	Alluvium	9-27-55	60	351	24	.36	61 *3.04*	14 *1.15*	46 *1.99*	290 *4.76*	49 *1.02*	12 *0.34*	0.9 *0.05*	0.80 *0.01*	210	210	0
15	12-32-7bb....	23.0	Ogallala formation	9-26-55	56½	455	29	.94	82 *4.09*	23 *1.89*	41 *1.80*	295 *4.84*	81 *1.68*	30 *0.85*	0.7 *0.04*	23 *0.37*	299	242	57
16	12-32-27aa...	90	do.	9- 3-54	....	327	32	.21	59 *2.94*	20 *1.64*	25 *1.08*	264 *4.33*	40 *0.83*	11 *0.31*	0.6 *0.03*	9.7 *0.16*	229	216	13
17	12-32-30bb...	43.0	do.	9-26-55	56	427	36	.15	78 *3.89*	22 *1.81*	35 *1.52*	288 *4.72*	67 *1.39*	26 *0.73*	1.1 *0.06*	20 *0.32*	285	236	49
18	12-33-29dc...	67	do.	9- 3-54	59	439	43	.18	44 *2.20*	22 *1.81*	72 *3.14*	249 *4.08*	104 *2.16*	24 *0.68*	3.1 *0.16*	4.4 *0.07*	200	200	0
19	12-34-2aa....	....	do.	9- 3-54	58½	278	24	.36	52 *2.59*	17 *1.40*	22 *0.95*	244 *4.00*	17 *0.35*	13 *0.37*	0.6 *0.03*	12 *0.19*	200	200	0
20	12-34-7cb....	120	do.	9- 4-54	58½	350	27	.78	46 *2.30*	25 *2.06*	39 *1.68*	237 *3.89*	52 *1.08*	26 *0.73*	1.4 *0.07*	17 *0.27*	218	194	24
21	12-34-22bb...	92.5	do.	9-26-55	57½	324	31	2.0	56 *2.79*	20 *1.64*	27 *1.18*	251 *4.12*	34 *0.71*	19 *0.54*	0.9 *0.05*	12 *0.19*	222	206	16
22	12-35-7da2...	....	do.	9- 7-54	58	305	29	.22	56 *2.79*	15 *1.23*	27 *1.16*	227 *3.72*	42 *0.87*	15 *0.42*	0.8 *0.04*	8.0 *0.13*	201	186	15
23	12-36-19aa...	16.1	Alluvium	9-28-54	62	1,240	24	.09	190 *9.48*	79 *6.49*	90 *3.93*	307 *5.03*	674 *14.02*	26 *0.73*	0.8 *0.04*	5.3 *0.08*	798	252	546
24	13-32-3ac....	76.0	Ogallala formation	9-26-55	56½	384	46	.17	51 *2.54*	26 *2.14*	40 *1.74*	262 *4.30*	62 *1.29*	25 *0.70*	1.4 *0.07*	3.8 *0.06*	234	215	19
25	13-32-27aa2..	50.0	do.	9-26-55	56	875	43	.08	95 *4.74*	42 *3.45*	142 *6.18*	348 *5.71*	284 *5.91*	90 *2.54*	2.2 *0.12*	5.8 *0.09*	410	286	124
26	13-32-34cc2..	200	Niobrara formation	9- 3-54	59	2,680	18	.86	570 *28.44*	76 *6.25*	146 *6.36*	273 *4.48*	1,660 *34.57*	65 *1.83*	2.0 *0.10*	4.3 *0.07*	1,730	224	1,510
27	13-33-6bb....	960.0	Carlile shale (Codell zone)	8-20-55	....	7,870	9.5	....	102 *5.09*	52 *4.27*	2,910 *126.70*	415 *6.81*	33 *0.69*	4,560 *128.45*	1.8 *0.09*	1.3 *0.02*	468	340	128
28	13-33-6bb....	1,230.0	Dakota formation	9- 1-55	62	1,100	11	1	3.3 *0.16*	1.5 *0.12*	449 *19.51*	720 *11.8*	0.0 *0.00*	271 *7.64*	6.0 *0.32*	1.2 *0.02*	14	14	0

TABLE 9.—*Analyses of water from typical wells and one spring—Concluded*

Number on Fig. 11	Well number	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$		
																	Total	Carbonate	Noncarbonate
29	13-34-2dd....	33.5	Meade Group or Sanborn Group or both.	9- 3-54	57	3,620	31	1.2	674 *33.63*	141 *11.59*	221 *9.59*	222 *3.64*	2,040 *42.52*	181 *5.10*	1.2 *0.06*	217 *3.49*	2,260	180	2,080
30	*13-34-29bd...	....	do................	9-19-51	....	568	....	....	91 *4.54*	27 *2.22*	57 *2.46*	249 *4.08*	177 *3.68*	29 *0.82*	0.6 *0.03*	16 *0.26*	340	212	128
31	13-35-16ab...	....	do................	9- 7-54	59	447	34	.26	77 *3.84*	20 *1.64*	40 *1.76*	210 *3.44*	135 *2.81*	30 *0.85*	0.6 *0.03*	7.1 *0.11*	274	172	102
32	*13-37-23bb...	....	do................	9-20-51	55	581	21	.03	81 *4.04*	21 *1.72*	78 *3.40*	255 *4.17*	212 *4.41*	18 *0.51*	1.1 *0.06*	1.6 *0.03*	288	209	79
33	*14-34-26aa...	156.0	Niobrara formation..	9-19-51	59	....	....	....	....	....	....	....	1,440 *29.98*	24 *0.68*	....	....	....	....	....
34	14-36-10ba...	67.0	Ogallala formation...	9-28-55	59	323	41	.50	48 *2.40*	22 *1.81*	30 *1.31*	259 *4.25*	31 *0.64*	16 *0.45*	1.5 *0.08*	6.2 *0.10*	210	210	0
35	14-36-34cd...	52.0	Sanborn Group.....	9-28-55	57	1,630	42	.14	382 *19.06*	36 *2.96*	65 *2.83*	249 *4.08*	940 *19.57*	38 *1.07*	1.0 *0.05*	5.3 *0.08*	1,100	200	900
36	*15-32-19bd...	....	do................	9-18-51	58	2,430	....	....	477 *23.8*	83 *6.80*	102 *4.43*	270 *4.42*	1,330 *27.7*	31 *0.8*	1.8 *0.09*	44 *0.71*	1,530	221	1,310
37	*15-32-26da...	83.5	Ogallala formation...	9-18-51	58	338	....	....	54 *2.7*	18 *1.48*	26 *1.11*	196 *3.22*	60 *1.25*	15 *0.4*	1.0 *0.05*	7.8 *0.13*	209	169	40
38	*15-35-2ab....	37.0	Sanborn Group.....	9-19-51	55	3,190	....	....	573 *28.6*	100 *8.21*	203 *1.27*	453 *7.42*	1,760 *36.64*	23 *0.6*	1.2 *0.06*	37 *0.60*	1,840	371	1,470
39	*15-35-28hd...	70	Ogallala formation or Sanborn Group or both.	9-19-51	58	446	26	.24	98 *4.9*	19 *1.56*	29 *1.27*	334 *5.47*	89 *1.85*	5.0 *0.14*	2.4 *0.13*	2.7 *0.04*	324	274	50

40	*15-35-32ad2..	21	Alluvium..........	9-19-51	55	1,700	42	.30	256 *12.8*	77 *6.35*	182 *7.91*	348 *5.70*	770 *16.03*	185 *5.2*	1.2 *0.06*	6.7 *0.11*	956	285	671
41	15-36-20dd...	....	Sanborn (?) Group..	9-28-55	....	1,020	39	.52	187 *9.33*	41 *3.37*	74 *3.21*	220 *3.61*	507 *10.54*	53 *1.49*	3.0 *0.16*	7.1 *0.11*	635	180	455
42	15-37-4cb....	17.0	Alluvium or Sanborn Group or both.	9-28-55	59	1,180	35	.16	241 *12.03*	40 *3.29*	76 *3.31*	295 *4.84*	587 *12.21*	51 *1.44*	1.1 *0.06*	5.3 *0.08*	765	240	525
43	*15-37-30cb...	73.0	Ogallala formation...	9-21-51	56	258	27	2.3	37 *1.85*	14 *1.15*	31 *1.36*	204 *3.34*	29 *0.60*	5.5 *0.16*	1.8 *0.09*	8.8 *0.14*	150	150	0

a. One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.

b. An equivalent per million is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing the concentration in parts per million by the chemical combining weight of the substance or ion.

* Samples were collected and analyzed by U. S. Geological Survey laboratory in Lincoln, Nebraska.

available to wells. Thus, the factor limiting the number of acres that can be irrigated on the upland is the amount of ground water that can be pumped without seriously depleting the ground-water resources. The annual discharge from the ground-water reservoir of Logan County that can be diverted for irrigation amounts to less than 3,000 acre-feet in the northern upland plain. The maximum acreage that could be irrigated with 1 foot of water annually would be about 3,000 acres, which is much less than the acreage of suitable land underlain by water-bearing materials. Any development of the ground-water resources beyond 3,000 acre-feet per year probably would result in steadily declining water levels.

The development of stored ground-water reserves—called mining of ground water—is a complex economic problem related to the extent to which the water table could be lowered without imperiling domestic, livestock, and public supplies; the distribution of the pumping; future climatic trends; and the amount of water that could be diverted from parts of the aquifer that cannot be developed because of insufficient saturated thickness or which underlie non-irrigable land.

Chemical Character of Water

The chemical character of ground water in Logan County is known from 34 water samples analyzed by Howard A. Stoltenberg, chemist, of the Water and Sewage Laboratory of the Kansas State Board of Health in Lawrence. The results of these analyses and the analyses of 9 ground-water samples collected in a previous investigation (Bradley and Johnson, 1957) are given in Table 9. In Table 10 are given 6 analyses of surface water also collected in that study.

The analyses show only the dissolved mineral content and not the sanitary condition of the water, except as excessive nitrate may indicate possible pollution by sewage or other organic wastes.

Chemical Constituents in Relation to Use

The following discussion of the chemical constituents of water in relation to use has been adapted from publications of the U. S. Geological Survey and the State Geological Survey of Kansas.

Dissolved solids.—When water is evaporated, the residue consists mainly of mineral constituents and a small quantity of organic material and water of crystallization. The kind and quantity of the soluble mineral constituents in water are major factors in determining its suitability for use. Water containing less than 500 parts per million of dissolved solids generally is satisfactory for domestic use, except for difficulties that may result from hardness or, in some places, excessive iron content. Water having more than 1,000 ppm is likely to contain enough of certain mineral constituents to produce a noticeable taste or to make the water unsuitable in some other respect.

The dissolved solids in samples of water from Logan County ranged from 218 to 7,870 ppm. The amount of dissolved solids exceeded 1,000 ppm in ten samples of ground water and in one sample of water from Twin Butte Creek and one from Chalk Creek.

Hardness.—The hardness of water is recognized most commonly by the quantity of soap needed to produce a lather in washing and by the curdy precipitate that forms before a permanent lather is obtained. Calcium and magnesium cause the hardness of most water.

Hardness is of two types, carbonate and noncarbonate. Hardness caused by calcium and magnesium equivalent to the bicarbonate is carbonate hardness and, because it can be removed almost entirely by boiling, is often called temporary hardness. The remaining hardness often is referred to as permanent hardness, because it cannot be removed by boiling. There is no difference between the effects resulting from carbonate and noncarbonate hardness when water is used with soap.

Water having a hardness of less than 50 ppm is regarded as soft, and treatment to reduce hardness generally is unnecessary. Hardness of 50 to 100 ppm does not seriously interfere with the use of the water for most purposes, but does increase the consumption of soap. Reduction of hardness by a softening process may be profitable for laundries and some other industries. Hardness of more than 150 ppm is very noticeable. Where public water supplies are softened, the hardness is generally reduced to 100 ppm or less.

Hardness of samples of water collected in Logan County ranged from 14 to 2,260 ppm. Most samples were hard or very hard, ranging from 150 to 300 ppm.

Silica.—Silica is a mineral constituent of most ground water. The silica in a water may be deposited with other scale-forming constituents in steam boilers, but otherwise it has no effect in the use of water for most purposes. The silica in samples of ground water from Logan County ranged from 9.5 to 46 ppm.

Iron.—Iron may be present in water in sufficient quantity to give a disagreeable taste or to stain cooking utensils and plumbing fixtures. Normally, if ground water contains much more than 0.3 ppm of iron, the excess will separate out and settle as a reddish sediment when exposed to the air. Iron may be removed from most water by aeration and filtration, but some water requires additional treatment.

Iron content of ground-water samples collected in Logan County ranged from 0.03 to 2.30 ppm; about half the samples had less than 0.3 ppm.

Fluoride.—Fluoride is generally present only in small concentrations in ground water, but the amount of fluoride in drinking water that is used by children should be known. Fluoride in water has been associated with the dental defect known as mottled enamel, which may appear on the teeth of children who drink water containing more than about 1.5 ppm of fluoride during the formation of the permanent teeth.

Recent studies have shown that about 1 ppm of fluoride in drinking water may help to prevent tooth decay in children. The United States Public Health Service (1946) has published standards that limit the amount of certain mineral constituents permissible in drinking water that is used in interstate commerce. The specified maximum amount of fluoride is 1.5 ppm.

The fluoride content of ground-water samples collected in Logan County ranged from 0.2 to 6.0 ppm. Of the 43 samples analyzed, only 11 had fluoride in excess of 1.5 ppm.

Nitrate.—The presence of nitrate in water was given new significance a few years ago when it was discovered that water containing excessive nitrate might cause cyanosis in infants when the water is used in the preparation of their formula (Metzler and Stoltenberg, 1950). In cyanosis the infant becomes drowsy and listless and the skin takes on a blue color. In less severe cases recovery may take place in 8 to 24 hours if a change is made to water of low nitrate content, but death may result if the water supply is not changed. Nitrate in drinking water does not cause cyanosis in adults but may be responsible for certain digestive disorders.

Nitrate is derived from nitrate-bearing rocks and minerals in the water-bearing formations and from direct flow of nitrate-bearing surface water into wells. Soils, especially during the fall and winter, contain nitrate derived principally from plants, from animal wastes, and from nitro-bacterial action. Being very soluble, nitrate salts are readily leached from the soils by rainfall and carried into wells. Because privies, cesspools, and barnyards are sources of organic nitrogen, a large amount of nitrate in well water may indicate pollution from these sources and the possible presence of harmful bacteria.

The Kansas State Board of Health judges that about 45 ppm is the safe limit of nitrate (as NO_3), and to use water having nitrate in excess of this amount in the preparation of an infant's formula may be dangerous. All the water samples from Logan County contained nitrate, but only two contained more than 45 ppm, the maximum being 217 ppm.

Water for Irrigation

The suitability of water for use in irrigation depends mainly upon the total quantity of soluble salts and upon the ratio of the quantity of sodium to the total quantity of sodium, potassium, calcium, and magnesium. In some areas other constituents, such as boron and bicarbonate, may be present in sufficient quantities to cause injury to crops or soil. In a discussion of the interpretation of analyses with reference to irrigation in southern California, Scofield (1933) suggests that if the total concentration of dissolved salts is more than 700 ppm in the water its use for irrigation may be harmful and that dissolved salts in excess of 2,100 ppm may damage crops or land, or both. Water containing more than 60 percent sodium (the percentage being calculated as 100 times the ratio of sodium to the total principal bases listed above, all expressed in equivalents per million) is likely to be injurious to the soil.

Waters from five wells sampled in Logan County contained more than 2,100 ppm of dissolved solids, but the wells were in areas where sufficient water supplies for irrigation could not be obtained. No other water samples showed prohibitive amounts of solids. The alluvium in Logan County commonly yields water containing relatively large amounts of dissolved solids, sodium, and chloride, hence any water that is developed from the alluvium for irrigation should be checked for objectionable quantities of these constituents.

Chemical Character in Relation to Geologic Source

The waters analyzed (Table 9) were classified by types according to a method suggested by Piper (1953, p. 6-7), in which the water is designated by a binomial symbol written in the form of a decimal fraction whose two terms are the percentage of hardness-causing constituents among the cations (bases) and the percentage of bicarbonate and carbonate among the anions (acids). For example, the symbol 57.69 would indicate a water in which the Ca and Mg amount to 57 percent of all the cations in terms of equivalents and the weak anions CO_3 and HCO_3 amount to 69 percent of all the anions in the same terms.

The first term of the symbol indicates relative hardness in percent of total equivalents. If the second term exceeds the first, all the hardness is carbonate ("temporary") hardness. If the second term is small, some of the hardness is noncarbonate and the relative amount of the permanent hardness is in direct proportion to the numerical difference between the two terms. The first term of the symbol subtracted from 100 is equal to the "percent sodium", a term introduced by Scofield (1933, p. 22-23) to measure the effect of water on physical properties of soils. If the first term is greater than about 50, the physical condition of the soil is not likely to be impaired seriously, but if the term is less than 40 such impairment may result.

The two terms taken directly from the analytical data in terms of percentage equivalents per million have been plotted on rectangular coordinates (Fig. 11). The graph shows a tendency to-

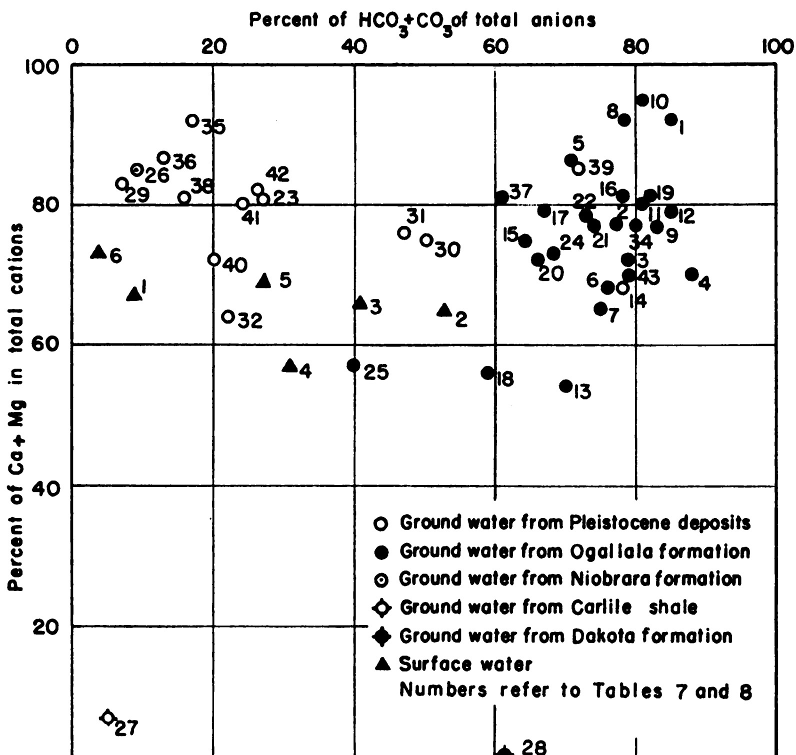


FIG. 11.—Graphical representation of analyses of samples of water, by formations, showing diversity of character.

ward grouping into water types allied with the Ogallala formation and with Pleistocene sediments. Mixtures of water tend to plot between the areas of their chief components.

Dakota Formation

A sample of water was collected from well 13-33-6bb, which taps sandstone of the Dakota formation. The analysis indicates that the water from the Dakota in Logan County approaches 0.100 as a limit, being a nearly pure sodium bicarbonate water. The water in the Dakota formation in Logan County is very soft and has no disagreeable taste, but the one sample from the formation that was analyzed is undesirably high in fluoride content. Strongly mineralized water is characteristic of the Dakota formation in part of Kansas, but western Kansas has many satisfactory water supplies derived from this source.

Wells drilled into the Dakota formation in Gove, Lane (Prescott, 1951), Hamilton and Kearny (McLaughlin, 1943), and Finney and Gray Counties (Latta, 1944) are reported to be in use for livestock and domestic water supplies. Two wells were drilled in Wichita County (Prescott, Branch, and Wilson, 1954) for irrigation and railroad supplies, but the water was found to be too mineralized for these purposes, although it probably would have been satisfactory for livestock and domestic use.

Latta (1944) and Prescott (1951) believed that the water in the Dakota formation has undergone a natural softening in which the original calcium bicarbonate water has exchanged its calcium and magnesium for sodium by base exchange. The base-exchange silicates active in the natural softening process perhaps are the clay minerals in the Dakota formation. The degree of softening depends upon the amount and softening capacity of the clay minerals and upon the length of time the hard water remains in contact with these minerals (Renick, 1924).

Water in the Dakota formation in Logan County contains too large a percentage of sodium for irrigation use, and the fluoride content renders it undesirable for drinking by children, but it is generally satisfactory for most domestic and all livestock purposes.

Carlile Shale

One sample of water was collected from the Codell sandstone zone of the Carlile shale in well 13-33-6bb drilled to the Dakota formation. The water contained 7,870 ppm of dissolved solids and was very high in sodium and chloride; therefore, the water was unfit for domestic, livestock, or irrigation use.

Niobrara Formation

The Niobrara formation supplies strongly mineralized water to wells and also influences ground water in other formations that is or has been in contact with it. The water generally contains large amounts of dissolved solids and is high in noncarbonate or "permanent" hardness. Water of the type in the Niobrara approaches 100.0 as a limit. The water in many places is unpalatable, but generally it is satisfactory for use by livestock. Even if large supplies were available from the Niobrara, the water would be unfit for irrigation.

Pierre Shale

The Pierre shale does not contribute water to wells in Logan County, but its abundant gypsum influences the quality of water that comes in contact with it. Calcium and magnesium constitute 50 to 60 percent of the cations in water from the Pierre shale; bicarbonate content is moderate, relative to total anions (Fig. 11).

Ogallala Formation

Figure 11 shows that water from the Ogallala formation has a high percentage of calcium, magnesium, and bicarbonate and approaches 100.100 as a limit. The water is characterized by weak acids, alkaline earths, and carbonate hardness. The hardness of the water from the Ogallala ranges from 148 to 410 ppm, the greatest number of samples of water being in the range from 200 to 350 ppm.

The quality of water in the Ogallala formation is related to the thickness of saturated material. Comparison of Figure 12, which shows distribution of dissolved solids, with Figure 5, which shows distribution of saturated thickness, demonstrates that the amount of dissolved solids in the ground water of the Ogallala formation in Logan County tends to vary inversely with the saturated thickness. Where the water-bearing Tertiary rocks are thin a greater percent of the water comes in contact with the strongly mineralized Cretaceous formations; conversely, where the water-bearing materials of the Ogallala formation are thick, the water that is mineralized by contact with the Cretaceous formations is diluted by the greater amount of overlying high bicarbonate water that has not been in contact with the Cretaceous formations. Evidence of the influence of the underlying rock on quality of water was obtained by plotting the analyses of water from wells 13-32-27aa2, 12-33-29dc, and 11-

37-29cc according to a method suggested by Piper (1953), which confirmed that the samples were simple mixtures of two components. The three sampled wells derive water from a thin water-bearing

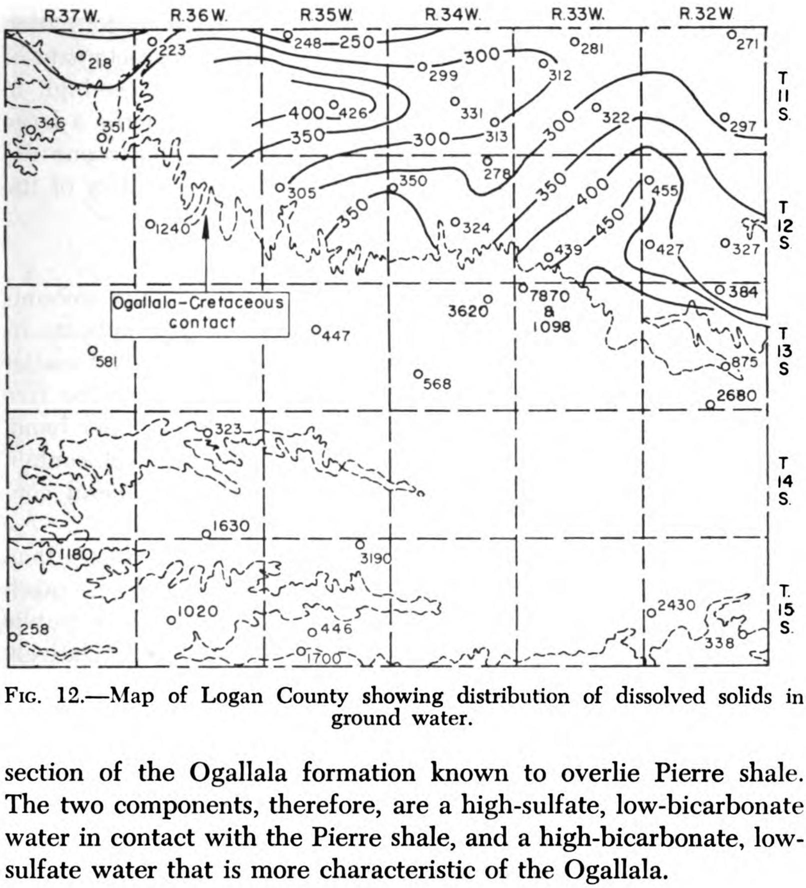


FIG. 12.—Map of Logan County showing distribution of dissolved solids in ground water.

section of the Ogallala formation known to overlie Pierre shale. The two components, therefore, are a high-sulfate, low-bicarbonate water in contact with the Pierre shale, and a high-bicarbonate, low-sulfate water that is more characteristic of the Ogallala.

Pleistocene Deposits

The water from wells in the alluvium, Meade Group, or Sanborn Group has a wide range in chemical quality. The quality of water in the Pleistocene rocks is affected by contact with underlying formations or by the local nature of the recharge water. Because of their low topographic position, the Pleistocene deposits in the stream valleys tend to accumulate ground water that has been in contact with other geologic sources. Locally, therefore, the Pleistocene deposits contain water that is characteristic of the formation with which they are in contact. For example, well 15-32-19bd obtains water from a Pleistocene sand overlying the Niobrara formation and below a large outcrop area of the Niobrara formation. The water has much the same chemical character as water from the Niobrara formation. On the other hand, well 11-37-35ab is adjacent to and downstream from outcrops of the Ogallala formation and contains a water of high carbonate hardness characteristic of the Ogallala formation. Well 13-34-2dd produces water high in chloride and nitrate from Pleistocene deposits that underlie a large intermittent lake. Generally, the water from the Pleistocene deposits is very hard and may be unpalatable, but the quality of the water is dependent on local conditions.

Sanitary Considerations

The analyses of water given in Table 9 show only the amounts of dissolved mineral matter in the water and do not indicate its sanitary quality. The water in a well may contain mineral matter that imparts an objectionable taste or odor and yet may be free from harmful bacteria and safe for drinking. On the other hand, the water in a well may be clear and palatable and yet contain harmful bacteria. An abnormal amount of certain mineral constituents, such as nitrate or chloride, may indicate pollution.

Dug wells are more subject to pollution by organic wastes than properly constructed drilled wells, but great care should be taken to protect from pollution every well used for domestic or public supply. Drilled wells on the uplands generally penetrate relatively impervious silt above the water table and are less subject to pollution than shallow wells in valleys, where pervious sandy material may extend from the surface to the water table. Every well should be tightly sealed and, if possible, should be located so as to prevent inflow from surface drainage. Wells should not be located near possible sources of contamination such as buildings, barnyards, or cesspools.

Chemical Character of Surface Water

Analyses of samples of water from four streams (Bradley and Johnson, 1957) are given in Table 10. The streams were sampled at low stages when the dominant part of the flow was derived from the ground-water reservoir. The analyses demonstrate the influence of various formations upon the quality of water.

TABLE 10.—*Analyses of water from streams*

Analyzed by U. S. Geological Survey, Lincoln, Nebr.

Dissolved constituents given in parts per million [a] *and equivalents per million* [b] (in italics)

Number on Fig. 11	Stream	Location of sampling site	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
1	Chalk Creek	NE NE sec. 12, *T. 15 S., R. 33 W.*	9–19–51	76	1,160	....	....	156 *7.78*	51 *4.22*	139 *6.06*	101 *1.66*	713 *14.84*	55 *1.55*	....	0.5 *0.01*	600	83	517
2	Ladder (Beaver) Creek	NE NE sec. 12, *T. 15 S., R. 33 W.*	9–19–51	74	425	....	....	60 *2.99*	23 *1.93*	61 *2.66*	230 *3.77*	130 *2.71*	24 *0.67*	....	3.1 *0.05*	246	207	39
3	Ladder (Beaver) Creek	SE NE sec. 34, *T. 14 S., R. 32 W.*	9–19–51	71	556	....	....	80 *3.99*	28 *2.27*	74 *3.21*	233 *3.82*	222 *4.62*	27 *0.76*	....	2.6 *0.04*	313	203	110
4	Smoky Hill River	NW NW sec. 23, *T. 13 S., R. 37 W.*	9–19–51	75	685	....	....	81 *4.04*	28 *2.28*	111 *4.81*	207 *3.39*	338 *7.04*	24 *0.68*	....	1.2 *0.02*	316	170	146
5	Smoky Hill River	SE NE sec. 34, *T. 14 S., R. 32 W.*	9–19–51	70	626	....	....	89 *4.44*	30 *2.46*	75 *3.25*	158 *2.59*	325 *6.77*	27 *0.76*	....	1.6 *0.03*	345	130	215
6	Twin Butte Creek	NE NE sec. 12, *T. 15 S., R. 33 W.*	9–19–51	77	2,460	....	....	440 *21.96*	89 *7.28*	185 *8.06*	88 *1.44*	1,650 *34.35*	53 *1.49*	....	1.2 *0.02*	1,460	72	1,390

a. One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.

b. An equivalent per million is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing the concentration in parts per million by the chemical combining weight of the substance or ion.

Chalk Creek

Chalk Creek was sampled in its lower reaches above its confluence with Ladder Creek. The valley of Chalk Creek is cut into the Ogallala formation in its upper stretch and into the Niobrara formation as it flows eastward. No outcrops of the Pierre shale are adjacent to the stream. The analysis indicates definite affinities with the group of analyses representative of water in contact with the Niobrara formation (Fig. 11).

Ladder Creek

Ladder Creek has the softest and least mineralized water of the streams sampled. The creek has a perennial base flow from the Ogallala formation, into which it is deeply incised. One of the samples was collected above the confluence of the creek with Chalk and Twin Butte Creeks. The plot of the analysis shows that the water is similar to that in the Ogallala (Fig. 11). The other sample was collected below the confluence of Chalk and Twin Butte Creeks, and the noticeable increase in sulfate and concomitant reduction in the percentage of HCO_3 and CO_3 results from the inflow of the more mineralized water from the two smaller streams.

Smoky Hill River

The two samples of water from Smoky Hill River were collected at opposite ends of Logan County. The analysis of the sample collected from the western part of the county clearly shows the influence of water typical of the Pierre shale, which is exposed extensively upstream in Wallace County.

Farther east the valley of Smoky Hill River is cut into the chalk of the Niobrara formation. The analysis of the sample collected at Elkader shows that the water is of the type characteristic of the Niobrara (Fig. 11) and indicates the progressive influence of this formation as the stream flows eastward.

Twin Butte Creek

Twin Butte Creek was sampled during low stage at a point upstream from its confluence with Ladder Creek. Because the valley is cut into the Niobrara formation in the eastern part of the county, the stream contains water typical of the Niobrara formation (Fig. 11). It has a disagreeable salty taste and the analysis shows the water is extremely hard and mineralized.

SUMMARY AND CONCLUSIONS

Logan County is divisible into three parts on the basis of geology and ground-water conditions: (1) an upland plain composing about 35 percent of the county, (2) a small area of flood plain along Smoky Hill River and its tributaries, and (3) rolling, dissected "pediment" slopes. The streams have gradients between 14 and 24 feet per mile and drain eastward and southeastward across the county. Lakes in the county are intermittent and are of four types: (1) large, deep depressions originating by subsidence of Cretaceous rocks, (2) small, shallow depressions enlarged by deflation from smaller undrained areas in broad, shallow upland valleys, (3) ponds along intermittent and ephemeral watercourses, and (4) artificial livestock ponds.

The Pierre shale and the shaly chalk of the Niobrara formation, of Gulfian age, exposed along the major valleys are intricately faulted. Features of the jointing and folding associated with the faults aided in the field mapping, but no definite conclusion as to origin of the faults was reached.

The Ogallala formation underlies the upland plain and was deposited on an erosional surface developed in pre-Pliocene time on the Gulfian (Cretaceous) rocks. The surface seems to be influenced in part by regional structure, of which the chief feature is the gentle northeast dip of the east flank of the Las Animas Arch. The drainage on the pre-Ogallala surface trends north and northeast in the northern upland and east and southeast in the southern upland. The principal valleys contain the thickest sediments of the Ogallala formation, which is chiefly calcareous silty sandstone and thin persistent shale layers and which includes much sand and gravel, particularly in the deeper valleys in the bedrock. The upland plains and "pediment" slopes are mantled by Pleistocene deposits, which are chiefly loess in the uplands, underlain by coarse quartzose sand and gravel at the edge of the "pediment".

One of the most important mineral resources of Logan County is ground water. The Ogallala formation beneath the large northern upland plain yields moderate to abundant supplies of hard calcium magnesium bicarbonate water to domestic, livestock, public, and irrigation wells. The large wells for public supply and irrigation are mainly in the troughs of the pre-Pliocene valleys where saturated water-bearing materials are thickest. The permeability of the formation as determined by four aquifer tests ranged from 230 to 1,150 gpd per square foot. Contours drawn to represent the upper surface of the ground water in the Ogallala formation reveal general eastward movement of the water at an average gradient of about 10 feet per mile. The configuration of the water table is in part dependent upon the configuration of the underlying pre-Pliocene surface, which is relatively impervious and confines the ground water to the permeable beds of the Ogallala. The influence of soluble materials in pre-Pliocene rocks is reflected in the chemical character of the ground water, which shows an inverse relation between amount of dissolved solids and saturated thickness.

The area of rolling dissected "pediment" slopes from which the Ogallala formation has been stripped by erosion is not underlain by a continuous sheet of water-bearing material at shallow depths. The wells obtain hard and mostly unpalatable water from Pleistocene sand and gravel in small disconnected areas of valley fill and in "pediment" deposits. Where saturated Pleistocene deposits are thin or absent, a few wells are drilled into the Niobrara formation to obtain livestock water where the shaly chalk is sufficiently fractured to yield water to wells. Wells drilled into the fractured zone adjacent to faults in the Niobrara formation or into the Dakota formation probably will yield water of satisfactory quality for livestock in those localities to which water is now being hauled from Winona and Oakley. Alluvium and Pleistocene deposits beneath flood plains and low terraces yield small to abundant amounts of hard and in many places strongly mineralized water to domestic, livestock, and irrigation wells.

The chemistry of the ground waters in Logan County is related to geologic source. Five chemical types of water occur in the area: (1) water from the Ogallala formation, having a high percentage of Ca and Mg and bicarbonate, (2) water from the Niobrara formation, high in Ca and Mg and low in CO_3 and HCO_3, (3) water from the Pierre shale, having about 50 percent Ca and Mg and 50 percent CO_3 and HCO_3, (4) water from the Codell sandstone zone of the Carlile shale, having a low percentage of Ca and Mg and CO_3 and HCO_3, and (5) soft water from the Dakota formation, low in Ca and Mg and high in CO_3 and HCO_3. The water from the Ogallala is low in sodium and other dissolved solids and is satisfactory for irrigation unless admixed with large quantities of water of other type. Analyses of water from the base flow of streams show a close relation of water quality to geologic source.

The principal development of ground water in Logan County at the present time is for livestock and domestic use because wheat farming, cattle-raising, and general farming rather than irrigation are the dominant economic activities. The development of ground water for irrigation on the upland probably exceeds 600 acre-feet pumped by five wells irrigating a total of about 1,000 acres annually. At least 60,000 acres of irrigable land is underlain by water-bearing material, and the utilization of the ground-water for irrigation probably will increase greatly in the future.

The amount of future development will be limited by the quantity of water that can be pumped from storage without imperiling the ground-water supply of livestock and domestic water wells and by the average annual rate of recharge to the Ogallala formation. In the northern upland area the annual recharge available for irrigation from deep wells is approximately the annual volume of flow passing eastward through the aquifers near the east edge of the county. The permeability of the Ogallala was estimated as 440 gpd per square foot, the average gradient of the water table shown on cross section A-A′ was 10 feet per mile, and the cross-sectional area of the water-bearing materials was about 2,750,000 square feet. The volume of annual recharge available for irrigation, as computed from these data, was somewhat less than 3,000 acre-feet.

RECORDS OF TYPICAL WELLS, TEST HOLES, AND ONE SPRING

Descriptions of 276 wells and 1 spring inventoried in Logan County or counties adjacent to Logan County are given in Table 11. Depths of wells given to the nearest tenth of a foot and depths to water levels given to the nearest hundredth of a foot were measured; all other depths were reported.

TABLE 11.—*Records of typical wells, test holes, and one spring*

Well number (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, in.	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
10–32–36dd	*T. 10 S., R. 32 W.* SE SE sec. 36	Geological Survey of Kansas	Dr	250.0	4	N	Sandstone	Ogallala formation	N	O	Edge of test hole	0.0	3,053.8	106	....	Test hole in Thomas County
10–34–36dd	*T. 10 S., R. 34 W.* SE SE sec. 36	do.	Dr	175.0	4	N	do.	do.	N	O	do.	0.0	3,191.2	123	....	do
10–35–31cc	*T. 10 S., R. 35 W.* SW SW sec. 31	do.	Dr	230.0	4	N	do.	do.	N	O	do.	0.0	3,353.4	....	....	do
10–35–32da	NE SE sec. 32	....	Dr	....	5.50	GI	do.	do.	Cy, W	D, S	Hole in top of platform	0.5	3,349.8	172.45	8–24–54	In Thomas Co.
10–36–34cc	*T. 10 S., R. 36 W.* SW SW sec. 34	....	Dr	176.5	5.50	GI	do.	do.	Cy, W	N	Top of concrete curb	0.2	3,405.1	172.82	7– 9–54	Not in use; in Thomas County
10–37–32cc	*T. 10 S., R. 37 W.* SW SW sec. 32	Geological Survey of Kansas	Dr	130.0	4	N	do.	do.	N	O	Edge of test hole	0.0	3,307.8	....	....	Test hole in Sherman County
10–37–32dc	SW SE sec. 32	J. S. Garvey	Dr	63.0	5.50	GI	do.	do.	Cy, W	S	Top of curb	1.2	3,325.6	60.30	7–21–54	In Sherman Co.
11–31–30cb	*T. 11 S., R. 31 W.* NW SW sec. 30	....	Dr	39.0	5.50	GI	Sand	Ogallala formation or alluvium or both	Cy, W	S	Top of casing	0.5	2,958.8	31.04	6–25–54	In Gove County
*11–32–2bb1	*T. 11 S., R. 32 W.* NW NW sec. 2	City of Oakley	Dr	170	18	GI	Sandstone	Ogallala formation	T, E	P	Hole in pump base	1.5	3,063.5	116.24	8–20–54	Measured yield 320; drawdown 27
11–32–2bb2	NW NW sec. 2	do.	Dr	155	18	GI	do.	do.	T, E	P	do.	2.0	3,064.6	116.96	8–20–54	
11–32–2bb3	NW NW sec. 2	do.	Dr	155	16	GI	do.	do.	T, E	P	Top of pipe in pump base	4.0	3,065.8	118.27	8–20–54	Used only in emergency
11–32–2bc	SW NW sec. 2	do.	Dr	200	4	N	do.	do.	N	O	....	....	....	....	....	Test hole
11–32–2cc	SW SW sec. 2	Mr. Organ	Dr	104.5	5.50	GI	do.	do.	N	N	Top of casing	0.4	3,046.5	96.93	7–20–54	Abandoned

11-32-3bd1	SE NW sec. 3	City of Oakley	Dr	250	......	GI	do.	do.	S, E	P	Hole in steel curb	4.0	3,055.9	101.22	8-29-54	Recently pumped
11-32-3bd2	SE NW sec. 3	Geological Survey of Kansas	Dr	159.0	1.25	GP	do.	do.	N	O	Top of casing	0.5	3,054.9	102.74	8-27-54	Installed for aquifer test.
11-32-5ba	NE NW sec. 5	F. Heyen	Dr	116.3	5.50	GI	do.	do.	Cy;W,G	D, S	do.	0.0	3,083.6	108.16	7-25-54	
11-32-10ba	NE NW sec. 10	R. H. West	Dr	113.0	5.50	GI	do.	do.	Cy, W	N	Base of pump	0.0	3,048.8	94.08	7- 2-54	Not in use
11-32-14cb	NW SW sec. 14	Geological Survey of Kansas	Dr	192.1	4	N	do.	do.	N	O	Edge of test hole	0.0	3,050.1	....	....	Test hole
11-32-24aa	NE NE sec. 24	Cleal M. Harrison	Dr	81.0	5.50	GI	do.	do.	Cy, W	S	Top of casing	0.5	2,990.1	58.00	6-26-54	
11-32-26cb	NW SW sec. 26	Geological Survey of Kansas	Dr	130.0	4	N	do.	do.	N	O	Edge of test hole	0.0	3,038.4	....	....	Test hole
*11-32-27aa	NE NE sec. 27	H. P. Kurtz	Dr	69.0	5.50	GI	do.	do.	Cy, W	S	Top of plank under pump	0.5	3,002.6	51.08	6-26-54	Measured yield 4.3
11-32-31cb	NW SW sec. 31	J. L. Phillipi	Dr	89.5	5.50	GI	do.	do.	Cy, W	S	Top of casing	0.8	3,059.3	71	6-25-54	Unable to obtain accurate water-level measurement
11-32-34bb	NW NW sec. 34	Sylvester Mader	Dr	112.0	4	N	do.	do.	N	O	....	......	3,038.0	....	....	Test hole
11-32-34cb	NW SW sec. 34	do.	Dr	83.0	5.50	GI	do.	do.	Cy, W	N	Top of casing	0.5	3,024.3	69.05	6-25-54	Not in use
11-32-34dd	SE SE sec. 34	J. J. Schulz	Dr	69.0	5.50	GI	do.	do.	Cy, W	N	do.	1.0	3,007.3	59.67	10-12-49	
	T. 11 S., R. 33 W.															
11-33-4cc	SW SW sec. 4	Jean Nollette	Dr	117.0	5.50	GI	do.	do.	Cy, W	S	Top of steel clamp	0.5	3,130.3	111.35	6-29-54	
*11-33-4da	NE SE sec. 4	do.	Dr	....	5.50	GI	do.	do.	Cy, W	S	....	......	......	....	....	
*11-33-8cc	SW SW sec. 8	....	Dr	182	5.50	GI	do.	do.	Cy, W	D	....	......	......	....	....	Not in use
11-33-13aa	NE NE sec. 13	H. H. Lintel	Dr	83.0	5.50	GI	do.	do.	Cy, W	N	Top of casing	1.0	3,060.8	74.50	6-26-54	
11-33-14bc1	SW NW sec. 14	James Ahrens	Dr	220	......	......	do.	do.	T, B	I	Hole in pump base	1.0	3,134.0	134.97	8-25-54	Measured yield 430; drawdown 46
11-33-14bc2	SW NW sec. 14	Geological Survey of Kansas	Dr	160.0	1.25	GP	do.	do.	N	O	Top of casing	0.7	3,132.5	133.84	8-25-54	Installed for aquifer test
11-33-14cd	SE SW sec. 14	E. M. Cook	Dr	130.0	5.50	GI	do.	do.	N	N	do.	0.5	3,116.4	119.50	8-24-54	Abandoned
11-33-14db	NW SE sec. 14	A. F. Hueftle	Dr	148.0	5.50	GI	do.	do.	Cy, W	N	do.	0.5	3,112.2	119.74	8-24-54	Not in use
11-33-19ca	NE SW sec. 19	Jess Lee	Dr	....	16	GI	do.	do.	T, D	I	Hole in pump base	1.7	3,128.9	87.30	6-30-54	Reported yield 600
11-33-20bb	NW NW sec. 20	A. Nollette	Dr	127.5	5.50	GI	do.	do.	Cy, N	N	Top of casing	1.0	3,145.5	112.35	6-30-54	Abandoned
*11-33-22dd	SE SE sec. 22	Ethel Mun	Dr	165.0	5.50	GI	do.	do.	Cy, W	D, S	do.	0.5	3,139.8	135.16	6-29-54	
11-33-24ad	SE NE sec. 24	Devisees of Martha Shippert	Dr	113.0	5.50	GI	do.	do.	Cy, W	N	do.	0.0	3,091.4	105.45	6-26-54	Not in use
11-33-28ab	NW NE sec. 28	Duttlinger Bros.	Dr	185	16	GI	do.	do.	T, D	I	Hole in pump base	1.5	3,129.8	107.42	6-29-54	Reported yield 500; reported drawdown 55
11-33-30ba	NE NW sec. 30	Duttlinger Bros.	Dr	160	16	GI	do.	do.	T, D	I	Top of casing	0.0	3,126.8	79.65	6-29-54	Reported yield 800
11-33-33cc	SW SW sec. 33	E. Beacham	Dr	99.5	5.50	GI	do.	do.	Cy, W	S	do.	0.0	3,122.4	88.36	6-29-54	

TABLE 11.—*Records of typical wells, test holes, and one spring*—*Continued*

Well number (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, in.	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 11 S., R. 34 W.															
11-34-2dd	SE SE sec. 2	T. Huelsman	Dr	142.0	5.50	GI	Sandstone	Ogallala formation	Cy, W	N	Top of casing	0.3	3,195.3	129.40	6-30-54	Not in use
11-34-6dc	SW SE sec. 6	F. M. and Wm. Schertz	Dr	156.0	5.50	GI	do	do	Cy, W	S	Hole in pump base	1.4	3,232.5	122.27	7- 1-54	Recently pumped
*11-34-8dc	SW SE sec. 8	Fred Martin	Dr	150.0	5.50	GI	do	do	Cy, W	D, S	Top of casing	0.5	3,233.5	141.05	7- 1-54	
11-34-13bb	NW NW sec. 13	Geological Survey of Kansas	Dr	180.0	4	N	do	do	N	O	Edge of test hole	0.0	3,169.8	115.5	8- 9-54	Test hole
11-34-13cc	SW SW sec. 13	F. J. Wassemiller	Dr	95.0	5.50	GI	do	do	Cy, W	S	Top of casing	0.8	3,141.6	82.34	6-30-54	
11-34-16cc	SW SW sec. 16	A. T. and Helen Peterson	Dr	143.0	5.50	GI	do	do	N	N	do	0.7	3,218.1	126.15	7- 1-54	Abandoned
11-34-18dc	SW SE sec. 18	C. W. Bahret	Dr	126.5	5.50	GI	do	do	Cy, W	N	Base of pump	0.0	3,237.4	116.07	7- 2-54	Not in use
*11-34-22cb	NW SW sec. 22	R. H. West, et al	Dr	132.0	5.50	GI	do	do	Cy, W	N	Top of casing	1.5	3,176.4	97.04	7- 1-54	do
11-34-24ca1	NE SW sec. 24	Horace Holmes	Dr	147.5	12	GI	do	do	T, B	I	Hole in pump base	3.7	3,114.8	59.83	7- 6-54	Measured yield 230; drawdown 21
11-34-24ca2	NE SW sec. 24	Geological Survey of Kansas	Dr	140.0	1.25	GP	do	do	N	O	Top of casing	0.4	3,110.0	57.00	8-24-54	Installed for aquifer test
*11-34-25bc	SW NW sec. 25	Horace Holmes	Dr	100.0	6	OW	do	do	Cy, W	D, S						
11-34-29bb	NW NW sec. 29	Harold Sweeney	Dr	136.0	12	BS	do	do	N	N	Top of casing	1.0	3,206.7	96.36	7- 6-54	Not in use
11-34-30cb	NW SW sec. 30	Jacob Herdt	Dr	101.5	5.50	GI	do	do	Cy, W	N	Hole in pump base	1.0	3,229.5	100.00	7- 2-54	do
11-34-32cb	NW SW sec. 32	Oscar Colglazier	Dr	141.5	5.50	GI	do	do	Cy, W	S	Top of casing	1.0	3,229.4	122.01	7- 2-54	
11-34-33ad	SE NE sec. 33	C. J. Peterson	Dr	139.0	5.50	GI	do	do	Cy, W	N	do	0.0	3,213.5	134.17	7- 1-54	Not in use
11-34-35cd	SE SW sec. 35	Jeanne Nollette	Dr	145.5	5.50	GI	do	do	Cy, N	N	do	0.4	3,211.6	139.37	7- 1-54	Abandoned
	T. 11 S., R. 35 W.															
11-35-1aa	NE NE sec. 1	Geological Survey of Kansas	Dr	192.0	4	N	do	do	N	O	Edge of test hole	0.0	3,268.8			Test hole
11-35-2dd	SE SE sec. 2	J. and V. A. James	Dr	187.5	5.50	GI	do	do	Cy, W	S	Top of casing	0.5	3,286.3	162.06	7- 6-54	

*11-35-5bb1	NW NW sec. 5	City of Winona	Dr	218	12	BS	do	do	S, E	P	Top of vent pipe	5.0	3,341.3	171.01	8-24-54	Measured yield 300; drawdown 15
11-35-5bb2	NW NW sec. 5	do	Dr	237	12	GI	do	do	S, E	P	do	3.5	3,343.0	169.92	8-24-54	Reported yield 240
11-35-7cc	SW SW sec. 7	Geological Survey of Kansas	Dr	90.0	4	N	do	do	N	O	Edge of test hole	0.0	3,294.3	....	....	Test hole
11-35-8dd	SE SE sec. 8	F. W. Lowe	Dr	136.0	5.50	GI	do	do	Cy, W	N	Top of platform	1.0	3,305.5	128.69	7- 7-54	Not in use
11-35-10bd	SE NW sec. 10	D. Council	Dr	167.5	5.50	GI	do	do	Cy, W	N	Top of casing	0.7	3,305.5	161.25	7- 6-54	do
11-35-12dd	SE SE sec. 12	A. F. Hueftle	Dr	159.5	4	GI	do	do	Cy, W	N	Hole in casing	0.8	3,265.5	152.25	7- 2-54	do
11-35-18dd	SE SE sec. 18	D. Council	Dr	41.5	5.50	GI	do	do	Cy, W	D, S	Top of platform	0.8	3,255.7	35.40	7- 7-54	Recently pumped
*11-35-22ca	NE SW sec. 22	A. F. Stramel	Dr	50.0	5.50	GI	do	do	Cy, W	S	Top of casing	0.0	3,224.4	39.58	7- 6-54	
11-55-23cb	NW SW sec. 23	W.H. Homewood	Dr	65.0	5.50	GI	do	do	Cy, W	S	do	0.5	3,215.2	49.40	7- 6-54	Recently pumped
11-35-24dd	SE SE sec. 24	Geological Survey of Kansas	Dr	108.0	4	N	do	do	N	O	Edge of test hole	0.0	3,193.0	56.15	8-19-54	Test hole
11-35-26cc	SW SW sec. 26	D. Keller, Jr.	Dr	134.5	5.50	GI	do	do	N	N	Top of casing	0.0	3,275.8	133.48	7- 6-54	Abandoned
11-35-31ad	SE NE sec. 31	....	Dr	137.8	5.50	GI	do	do	Cy, N	N	do	0.4	3,319.9	129.03	7-20-54	do
	T. 11 S., R. 36 W.															
*11-36-6da	NE SE sec. 6	J. Henry Hauptmann	Dr	170.0	5.50	GI	do	do	Cy, W	S	do	0.6	3,385.7	148.44	7-21-54	
11-36-12aa	NE NE sec. 12	Geological Survey of Kansas	Dr	130.0	4	N	do	do	N	O	Edge of test hole	0.0	3,314.8	110.4	8-19-54	Test hole
11-36-12cc	SW SW sec. 12	Fred G. Ludlow	Dr	35.5	5.50	GI	do	do	Cy, W	N	Hole in pump base	1.5	3,281.0	29.70	7- 9-54	Not in use
11-36-25aa	NE NE sec. 25	Geological Survey of Kansas	Dr	90.0	4	N	do	do	N	O	Edge of test hole	0.0	3,276.7	40.00	8-19-54	Test hole
11-36-35dd	SE SE sec. 35	D. A. Unruh	Dr	132.0	5.50	GI	do	do	Cy, W	N	Top of platform	1.2	3,331.7	123.07	7- 7-54	Not in use
11-36-36da	NE SE sec. 36	Geological Survey of Kansas	Dr	190.0	4	N	do	do	N	O	Edge of test hole	0.0	3,333.1	145.6	8-19-54	Test hole
	T. 11 S., R. 37 W.															
11-37-2ac	SW NE sec. 2	P. J. Washburn	Dr	49.0	5.50	GI	Sand	Alluvium or Sanborn Group or both	Cy, W	S	Top of casing	1.2	3,287.5	41.10	7-21-54	
11-37-3cd	SE SW sec. 3	J. A. Gunnels, et al	Dr	105.5	5.50	GI	Sandstone	Ogallala formation	Cy, W	S	do	1.0	3,309.0	71.30	7-21-54	
11-37-4bb	NW NW sec. 4	Mabel E. Knox	Dr	155.0	5.50	GI	do	do	Cy, W	S	do	1.3	3,381.9	140.05	7-21-54	Recently pumped and not fully recovered
*11-37-10ab	NW NE sec. 10	W. C. Niswonger	Dr	83.0	5.50	GI	do	do	Cy, W	S	Hole in pump base	0.5	3,297.5	59.92	8-18-55	
11-37-11ad	SE NE sec. 11	C. G. Yeoman	Dr	50.5	5.50	GI	do	do	Cy, N	N	Top of casing	0.8	3,282.9	40.71	7-21-54	Abandoned
11-37-27ab	NW NE sec. 27	C. H. Ward	Du	13.7	16	S	Sand	Alluvium	VC, E	S	Hole in top of platform	0.8	....	8.89	7-21-54	
*11-37-29cc	SW SW sec. 29	Will Reimers	Dr	53.0	5.50	GI	Sandstone	Ogallala formation	Cy, W	S	Top of casing	1.0	3,380.3	31.76	7-17-54	
11-37-30bb	NW NW sec. 30	E. F. and E. A. Langdon	Dr	43.8	5.50	GI	do	do	Cy, N	N	Top of platform	0.5	3,405.1	38.84	7-20-54	Abandoned
*11-37-35ab	NW NE sec. 35	C. H. Ward	B	19.0	5.50	GI	Sand	Alluvium	Cy, W	S	Top of casing	0.6	3,154.1	5.61	7- 9-54	

TABLE 11.—*Records of typical wells, test holes, and one spring*—*Continued*

Well number (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, in.	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 11 S., R. 38 W.															
11-38-1dd	SE SE sec. 1	....	Dr	16.0	5.50	GI	Sand	Alluvium	Cy, W	N	Top of casing	0.6	3,272.2	11.90	7-21-54	Not in use
11-38-13dd	SE SE sec. 13	....	Dr	44.0	5.50	GI	Sandstone	Sanborn Group or Meade Group or both	Cy, W	D, S	do.	0.6	3,353.5	38.74	7-20-54	In Wallace County
	T. 12 S., R. 31 W.															
12-31-6bb	NW NW sec. 6	Geological Survey of Kansas	Dr	120.0	4	N	do.	Ogallala formation	N	O	Edge of test hole	0.0	3,014.3	89.35	....	Test hole in Gove County
12-31-30cd	SE SW sec. 30	....	Dr	81.5	5.50	GI	do.	do.	Cy, W	N	Hole in pump base	1.0	2,939.9	66.70	6-23-54	Not in use; in Gove County
	T. 12 S., R. 32 W.															
12-32-1dc	SW SE sec. 1	W. A. Hoggatt	Dr	43.0	5.50	GI	do.	do.	Cy, W	S	Top of casing	1.0	2,957.7	26.00	6-23-54	
12-32-2cb	NW SW sec. 2	M. Honish	Dr	96.5	5.50	GI	do.	do.	Cy, N	N	Hole in pump base	1.5	3,025.6	83.76	7- 6-54	Abandoned
*12-32-7bb	NW NW sec. 7	J. A. Johnston	Dr	23.0	5.50	GI	do.	do.	Cy, W	S	Top of casing	1.0	3,015.8	20.30	6-25-54	Recently pumped
12-32-11cc	SW SW sec. 11	Geological Survey of Kansas	Dr	70.0	4	N	do.	do.	N	O	Edge of test hole	0.0	2,998.3	....	....	Test hole
12-32-13aa	NE NE sec. 13	F. C. Hullet	Dr	81.0	5.50	GI	do.	do.	Cy, W	D, S	Top of casing	0.5	2,970.1	53.42	6-25-54	
12-32-17ad	SE NE sec. 17	C. W. Hays	Dr	16.8	5.50	GI	Sand	Alluvium or Ogallala formation or both	Cy, W	S	do.	1.0	2,969.6	10.85	6-25-54	Recently pumped
12-32-22ad	SE NE sec. 22	Glen Honeyman	Dr	83.0	5.50	GI	Sandstone	Ogallala formation	Cy, W	D, S	Base of pump	0.5	3,020.3	74	6-23-54	Unable to obtain accurate measurement
12-32-26bc	SW NW sec. 26	Geological Survey of Kansas	Dr	90.0	4	N	do.	do.	N	O	Edge of test hole	0.0	3,023.6	70.2	7-31-54	Test hole
*12-32-27aa	NE NE sec. 27	Glen Honeyman	Dr	90	5.50	GI	do.	do.	Cy, W	S	....	....	....	75	9- 3-54	
12-32-27ba	NE NW sec. 27	Mamie L. Landon	Dr	86.0	5.50	GI	do.	do.	Cy, H	N	Top of casing	0.5	3,032.2	79.03	6-23-54	Abandoned
*12-32-30bb	NW NW sec. 30	Lawrence Stoecker	Dr	43.0	5.50	GI	do.	do.	Cy, E	D, S	....	....	....	....	....	

12-32-30da	NE SE sec. 30	J. and M. Munk	Dr	46.5	5.50	GI	do.	do.	Cy, W	S	Base of pump	1.0	3,022.3	29.17	6-23-54	Recently pumped
12-32-35cb	NW SW sec. 35	John Kowalski	Dr	44.5	5.50	GI	do.	do.	J, E	D, S	Top of casing	0.0	2,977.1	35.58	7-20-54	
	T. 12 S., R. 33 W.															
12-33-6ab	NW NE sec. 6	Martha R. Johnston	Dr	131.0	5.50	GI	do.	do.	Cy, W	N	Hole in pump base	0.0	3,186.0	126.60	6-30-54	Not in use
12-33-9cb	NW SW sec. 9	I. W. Gaylord	Dr	111.5	5.50	GI	do.	do.	Cy, W	N	Top of casing	0.5	3,147.4	103.48	6-29-54	do
12-33-10aa	NE NE sec. 10	G. J. Scheetz	Dr	84.5	5.50	GI	do.	do.	Cy, W	S	do.	0.5	3,109.1	80.01	6-29-54	
12-33-17da	NE SE sec. 17	J. E. and R. Bertrand	Dr	59.5	5.50	GI	do.	do.	Cy, W	N	do.	0.0	3,121.7	51.60	6-29-54	Not in use
12-33-18ba	NE NW sec. 18	Bruce Martin	Dr	102.5	5.50	GI	do.	do.	Cy, W	D, S	Hole in pump base	1.0	3,153.5	90.38	6-29-54	
12-33-23cb	NW SW sec. 23	Mamie L. Landon	Dr	34.0	5.50	GI	do.	do.	Cy, W	N	Top of casing	1.0	3,081.2	21.40	6-29-54	
*12-33-29dc	SW SE sec. 29	Anna E. Smith	Dr	67	5.50	GI	do.	do.	Cy, W	D, S	do.	0.5	3,154.8	60	9-3-54	
12-33-32ba	NE NW sec. 32	J. R. Lee	Dr	68.0	5.50	GI	do.	do.	N	N	do.	1.5	3,162.2	62.68	6-23-54	Abandoned
12-33-35cb	NW SW sec. 35	E. and Eleanor Wassemiller	Dr	34.0	5.50	GI	do.	do.	Cy, W	S	do.	1.0	3,099.0	29.08	6-29-54	Recently pumped
	T. 12 S., R. 34 W.															
12-34-1bb	NW NW sec. 1	Geological Survey of Kansas	Dr	190.0	4	N	do.	do.	N	O	Edge of test hole	0.0	3,204.1	....	....	Test hole
*12-34-2aa	NE NE sec. 2	B. M. Colglazier	Dr	....	....	....	do.	do.	Cy, W	D, S	....	....	....	....	....	Measured yield 6
12-34-2dd	SE SE sec. 2	F. J. Herl	Dr	138.8	5.50	GI	do.	do.	Cy, W	D, S	Top of platform	0.0	3,203.8	133.14	7-25-54	
*12-34-7cb	NW SW sec. 7	R. E. Hill	Dr	120	....	....	do.	do.	Cy, W	D, S	....	0.5	3,214.7	100	9-4-54	
12-34-9cc	SW SW sec. 9	O. Colglazier	Dr	104.0	5.50	GI	do.	do.	Cy, W	S	Top of casing	1.0	....	69	7-2-54	Could not measure accurately
12-34-11dd	SE SE sec. 11	Geological Survey of Kansas	Dr	156.0	4	N	do.	do.	N	O	Edge of test hole	0.0	3,192.0	....	....	Test hole
12-34-12bc	SW NW sec. 12	C. Ellis	Dr	130.5	5.50	GI	do.	do.	Cy, W	N	Top of casing	0.0	3,191.5	119.80	6-30-54	Abandoned
12-34-14da	NE SE sec. 14	Thomas Rowland	Dr	116.5	5.50	GI	do.	do.	Cy, N	N	Top of pipe clamp	1.4	3,180.1	107.59	6-30-54	do
12-34-16ab	NW NE sec. 16	F. Martin	Dr	115.8	5.50	GI	do.	do.	Cy, W	N	Top of casing	1.7	3,183.0	95.58	7-2-54	Not in use
*12-34-22bb	NW NW sec. 22	G. C. Van Eaton	Dr	92.5	5.50	GI	do.	do.	Cy, W	S	Hole in pump base	1.0	3,161.1	77.10	7-1-54	
12-34-26ba	NE NW sec. 26	W. Dornon	Dr	85.0	5.50	GI	do.	do.	Cy, W	S	Top of casing	1.0	3,163.7	78.43	6-30-54	
12-34-26da	NE SE sec. 26	Geological Survey of Kansas	Dr	70.0	4	N	do.	do.	N	O	Edge of test hole	0.0	3,158.2	....	....	Test hole
12-34-33dc	SW SE sec. 33	Chester Fritts	Dr	16.5	5.50	GI	Sand	Alluvium	Cy, W	N	do.	0.6	....	5.65	7-30-55	
12-34-35dc	SW SE sec. 35	F. J. Dornon	Du	36.5	48	N	do.	Meade Group or Sanborn Group or both	Cy, W	S	Hole in pump base	0.5	3,031.8	23.77	6-30-54	
	T. 12 S., R. 35 W.															
12-35-1ad	SE NE sec. 1	Geological Survey of Kansas	Dr	210.0	4	N	Sandstone	Ogallala formation	N	O	Edge of test hole	0.0	3,255.3	143.5	8-19-54	Test hole
12-35-1ba	NE NW sec. 1	C. Bertrand	Dr	163.0	5.50	GI	do.	do.	N	N	Top of casing	1.0	3,258.7	138.45	7-6-54	Abandoned
12-35-5cb	NW SW sec. 5	F. M. Schertz	Dr	129.0	5.50	GI	do.	do.	Cy, W	N	do.	0.6	3,272.8	115.68	7-7-54	do

TABLE 11.—*Records of typical wells, test holes, and one spring*—*Continued*

Well number (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, in.	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 12 S., R. 35 W.															
12-35-7da1	NE SE sec. 7	City of Winona	Du	100	120	C	Sandstone	Ogallala formation	T, N	N	Top of platform	1.0	3,219.4	70.50	7- 7-54	Abandoned
*12-35-7da2	NE SE sec. 7	J. Vejl	Dr	......	....	....	do	do	Cy, W	S	....	.....	3,213.3	......	......	Measured yield 3
12-35-10aa	NE NE sec. 10	V. G. Morgan	Dr	133.5	5.50	GI	do	do	Cy, W	N	Top of platform	0.0	3,247.6	116.66	7- 6-54	Not in use
12-35-13dd	SE SE sec. 13	F. M. and W. M. Schertz	Dr	103.0	5.50	GI	do	do	Cy, W	N	Top of casing	0.8	3,211.9	100.30	7- 2-54	do.
12-35-14bb	NW NW sec. 14	B. E. Eaton	Dr	138.0	5.50	GI	do	do	N	N	do	1.0	3,253.9	127.64	7- 8-54	Abandoned
12-35-20ab	NW NE sec. 20	A. L. Swart	Dr	107.0	5.50	GI	do	do	Cy, H	N	do	0.5	....	87.05	8-15-55	Not in use
12-35-20cc	SW SW sec. 20	E. Ochs	......	9.5	5.50	GI	do	Sanborn Group	N	N	do	1.3	3,105.6	8.22	7- 8-54	Abandoned
12-35-25dd	SE SE sec. 25	Geological Survey of Kansas	Dr	100.0	4	N	do	Ogallala formation	N	O	Edge of test hole	0.0	3,166.9	69.15	8-19-54	Test hole
12-35-27ac	SW NE sec. 27	F. M. and W. M. Schertz	Dr	26.0	5.50	GI	Sand	Ogallala formation or Sanborn Group or both	Cy, W	S	Top of casing	1.3	3,125.2	19.96	7- 8-54	Recently pumped
	T. 12 S., R. 36 W.															
12-36-5cd	SE SW sec. 5	F. M. Hartman, et al.	Dr	12.5	5.50	GI	do	Alluvium	Cy, W	N	Top of platform	1.0	3,145.3	6.92	7- 9-54	Not in use
12-36-11dd	SE SE sec. 11	H. R. Harper	Dr	44.0	6	OW	do	Ogallala formation or Sanborn Group or both	Cy, W	S	Top of casing	3.7	3,200.5	35.20	7- 8-54	
12-36-12aa	NE NE sec. 12	H. Stricker	Dr	99.0	5.50	GI	Sandstone	Ogallala formation	Cy, W	N	Top of platform	1.0	3,253.2	91.74	7- 7-54	Abandoned
12-36-12dd	SE SE sec. 12	Geological Survey of Kansas	Dr	140.0	4	N	do	do	N	O	Edge of test hole	0.0	3,272.3	......	......	Test hole
12-36-16ad	SE NE sec. 16	Jas. S. Hart	Dr	23.0	5.50	GI	Sand	Alluvium (?)	Cy, W	N	do	2.8	3,148.6	11.12	7- 8-54	Not in use
*12-36-19aa	NE NE sec. 19	Joseph Porter III, et al.	Dr	16.1	5.50	GI	do	Alluvium	Cy, W	S	Top of casing	1.8	....	11.30	9-27-55	
12-36-24bd	SE NW sec. 24	R. E. Eaton	B	9.2	48	R	do	do	Cy, W	S	Top of platform	0.5	3,146.3	7.92	7- 8-54	
12-36-25aa	NE NE sec. 25	Geological Survey of Kansas	Dr	80.0	4	N	Shale	Pierre shale	N	O	Edge of test hole	0.0	3,167.4	......	......	Test hole
12-36-28dd	SE SE sec. 28	W. B. and V. Berry	......	19.5	......	......	Sand	Alluvium	Cy, N	N	do	1.2	3,034.8	16.27	7- 8-54	Not in use

12-36-33da	NE SE sec. 33	U. S. Geologic Survey	Dr	13.7	.75	GP	do.	do.	N	O	Top of casing	0.7	3,004.8	4.85	7- 8-54	
	T. 12 S., R. 37 W.														
12-37-1ba1	NE NW sec. 1	C. L. and G. Collins	Du	14.8	.....	.....	do.	Sanborn Group or Meade Group or both	N	N	Hole in top of platform	0.0	3,137.3	11.08	7-21-54	Abandoned
12-37-1ba2	NE NW sec. 1	do.	Dr	33.5	15	GI	do.	do.	N	I	Top of casing	1.0	.....	8.06	8-12-55	New irrigation well
12-37-8ac1	SW NE sec. 8	S. Carr and Mary L. Strueby	.....	28.5	30	C	do.	Alluvium or Ogallala formation or both	Cy, W	S	Top of platform	1.2	3,276.8	24.48	7- 9-54	
12-37-8ac2	SW NE sec. 8	do.	.....	45.0	48	C	Sandstone	Ogallala formation	N	D	do.	0.6	3,288.1	34.61	7- 9-54	New well
12-37-10ac	SW NE sec. 10	W. A. and P. Marshall	Du	14.7	72	C	Sand	Sanborn Group	N	N	do.	1.0	3,158.8	11.53	7-17-54	Abandoned
12-37-13aa	NE NE sec. 13	A. W. Luther	.....	17.0	5.50	GI	do.	Alluvium, Meade Group or Sanborn Group	Cy, G	S	do.	0.5	3,103.4	13.30	7- 9-54	
12-37-13ab	NW NE sec. 13	do.	Dr	20.3	5.50	GI	do.	Alluvium or Sanborn Group or both	P, H	D, S	Top of casing	0.5	3,108.2	13.60	9-27-55	
12-37-15cb	NW SW sec. 15	E. J. Gfeller	Dr	27.6	5.50	GI	do.	Sanborn Group or Ogallala formation or both	Cy, N	N	do.	0.8	3,215.5	22.57	7-20-54	Abandoned
12-37-19aa	NE NE sec. 19	Garvin E. Gfeller	Dr	67	4	N	.....	.....	N	O	Edge of test hole	0.0	.....	.....	.....	Test hole
12-37-21aa	NE NE sec. 21	do.	Dr	115	4	N	.....	.....	N	O	do.	0.0	.....	.....	.....	do
12-37-21dd	SE SE sec. 21	do.	Dr	110	4	N	.....	.....	N	O	do.	0.0	.....	.....	.....	do
12-37-23ab	NW NE sec. 23	J. E. Bertrand	Du	24.6	.....	.....	do.	Meade Group or Sanborn Group or both	Cy, H	N	Top of platform	1.0	3,154.1	15.40	7-20-54	Not in use
12-37-27aa	NE NE sec. 27	do.	Dr	53.0	5.50	GI	do.	do.	N	N	Top of casing	1.2	3,184.7	43.99	7-28-54	Abandoned
12-37-31da	NE SE sec. 31	B. A. and W. Summers	Dr	24.0	5.50	GI	do.	Sanborn Group	N	N	do.	1.1	3,158.6	19.41	7-17-54	do
	T. 12 S., R. 38 W.														
12-38-24aa	NE NE sec. 24	Garvin E. Gfeller	Du	24.6	5.50	GI	do.	do.	Cy, E	D	do.	-4.6	3,214.2	24.30	7-20-54	In Wallace Co.
	T. 13 S., R. 32 W.														
13-32-1aa	NE NE sec. 1	M. P. Cook, et al	Dr	44.0	5.50	GI	Sandstone	Ogallala formation	Cy, W	S	do.	0.5	2,917.3	31.77	6-21-54	Recently pumped
13-32-2cc	SW SW sec. 2	Geological Survey of Kansas	Dr	90.0	4	N	do.	do.	N	O	Edge of test hole	0.0	3,024.1	.....	.....	Test hole
*13-32-3ac	SW NE sec. 3	Fannie M. Ripley	Dr	76.0	5.50	GI	do.	do.	Cy, W	S	Top of casing	0.5	3,003.7	62.67	6-21-54	Recently pumped
13-32-8cb	NW SW sec. 8	Lulu Crouse	Du	19.5	48	R	Sand	Sanborn Group or alluvium or both	Cy, W	S	Top of platform	2.0	2,961.9	15.67	6-21-54	do
13-32-10dd	SE SE sec. 10	C. Bertrand	Dr	38.0	8	GI	Sandstone	Ogallala formation	N	N	Top of casing	0.0	.....	32.32	10-13-48	Destroyed in 1949

TABLE 11.—*Records of typical wells, test holes, and one spring*—*Continued*

Well number (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, in.	Type of casing (4)	Principal water-bearing bed		Method of lift (5)	Use of water (6)	Measuring point			Depth to water level below land surface, 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. 13 S., R. 32 W.															
13-32-12cd...	SE SW sec. 12..	C. M. Miller...	Du	26.5	36	R	Sand........	Sanborn Group or alluvium or both	N	N	Top of platform	1.0	2,976.4	20.05	6-21-54	Abandoned
13-32-14bb..	NW NW sec. 14	A. C. Ziegler....	Dr	31.0	5.50	GI	Shale........	Pierre (?) shale....	Cy, N	N	Top of casing...	1.0	2,975.8	26.36	6-21-54	do
13-32-16ab..	NW NE sec. 16	L. F. Glassman..	Dr	23.0	5.50	GI	Sand........	Sanborn Group or alluvium or both	Cy, W	S	do............	1.0	2,946.1	15.15	6-21-54	Recently pumped
13-32-20cc...	SW SW sec. 20..	H. Hampton....	Dr	22.0	5.50	GI	do..........	do..............	Cy, W	S	do............	1.5	3,009.3	15.80	6-21-54	
13-32-21ba..	NE NW sec. 21	Mollie E. Mershon and Walter Sherman....	Dr	72.0	5.50	GI	Sandstone....	Ogallala formation	Cy, W	N	do............	0.5	3,019.0	54	6-21-54	Unable to obtain accurate water-level measurement
13-32-23ab..	NW NE sec. 23	D. Frey........	.....	19.0	5.50	GI	Sand........	Meade Group or Sanborn Group or both........	N	N	Top of casing...	1.0	2,908.7	15.36	7-25-54	Abandoned
13-32-24dc...	SW SE sec. 24..	Moses H. Eaton	B	23.0	5.50	GI	do..........	Sanborn Group or alluvium or both	Cy, W	S	do............	1.0	2,886.6	13.98	6-21-54	
13-32-27aa1	NE NE sec. 27..	F. Cunningham	Dr	50.0	5.50	GI	Sandstone....	Ogallala formation	Cy, W	N	do............	1.0	3,004.6	41.20	6-21-54	Not in use
*13-32-27aa2	NE NE sec. 27..	do............	Dr	50.0	5.50	GI	do..........	do..............	Cy, W	S	do............	0.5	3,003.2	38	9-4-54	
13-32-27aa3	NE NE sec. 27..	Geological Survey of Kansas	Dr	60.0	4	N	do..........	do..............	N	O	Edge of test hole	0.0	3,002.4	....	....	Test hole
13-32-34cc1..	SW SW sec. 34..	B. Andrasek....	Dr	43.0	5.50	GI	Sand........	Sanborn Group....	Cy, W	N	Top of casing...	1.0	2,867.7	18.50	6-21-54	Not in use
*13-32-34cc2..	SW SW sec. 34..	B. Andrasek....	Dr	200	5.50	GI	Chalk........	Niobrara formation	Cy, W	S	....	.....	2,877.7	....	....	Estimated yield 5
	T. 13 S., R. 33 W.															
13-33-1bb...	NW NW sec. 1..	C. Flax.......	Dr	51.0	5.50	GI	Sandstone....	Ogallala formation	Cy, W	S	do............	0.5	3,067.7	29.90	6-23-54	
13-33-5dd...	SE SE sec. 5....	J. R. Lee......	Dr	26.0	5.50	GI	Sand and shale	Alluvium or Pierre shale or both........	Cy, W	S	do............	1.0	2,946.3	16.17	6-23-54	
13-33-6ba...	NE NW sec. 6..	S. Dirks........	B	25.5	24	N	Fine sand....	Sanborn Group.... or alluvium or both.......	Cy, G	S	Top of platform	0.3	3,035.3	24.18	6-30-54	

*13-33-6bb	NW NW sec. 6	do.	Dr	1,230.0	8	OW	Sandstone	Dakota formation	Cy, E	S	Top of casing	1.0	3,055.0	695	9-2-55	
13-33-10cd	SE SW sec. 10	C. L. Cunningham	Dr	23.0	5.50	GI	Sand	Sanborn Group or alluvium or both	Cy, W	S	do.	1.0	2,958.2	11.80	6-23-54	
13-33-12bd	SE NW sec. 12	F. H. and W. O. Martin	Du	12.5	36	R	do.	do.	Cy;W,G	D, S	Top of platform	0.5	3,021.1	10.03	6-23-54	
13-33-16dc	SW SE sec. 16	Miles Collins	Du	16.0	......	R	do.	do.	Cy, W	S	Top of casing	1.0	2,880.3	14.50	9-7-54	Estimated yield 1
13-33-22cd	SE SW sec. 22	Fourth National Bank of Wichita, Kansas	Du	15.4	48	R	do.	do.	Cy, W	S	Top of platform	1.0	2,867.0	13.70	6-7-54	
13-33-32dd	SE SE sec. 32	Zenobia E. Ross and Helen Delaney	......	25.0	5.50	GI	do.	do.	N	N	Top of casing	1.0	2,784.2	12.26	7-15-54	
	T. 13 S., R. 34 W.															
*13-34-2dd	SE SE sec. 2	F. J. Dornon	Dr	33.5	5.50	GI	do.	Meade Group or Sanborn Group or both	Cy, W	S	do.	1.6	2,979.6	16.00	6-30-54	Measured yield 2
13-34-3cd	SE SW sec. 3	Marion Verhoeff	Dr	8.0	5.50	GI	do.	Alluvium	Cy, W	N	do.	1.3	....	3.84	7-28-55	
13-34-14ca	NE SW sec. 14	A. Wheeler	Dr	56.0	5.50	GI	do.	Sanborn Group or alluvium or both	Cy, W	S	do.	1.0	2,903.8	23.03	7-1-54	
13-34-25cd	SE SW sec. 25	H. Hampton	Du	17.5	60	N	do.	do.	Cy, W	S	Top of platform	1.0	2,855.5	15.68	7-1-54	
*13-34-29bd	SE NW sec. 29	G. H. Newcom	Du	....	36	C	do.	Meade Group or Sanborn Group or both	Cy, W	D, S	do.	0.5	2,890.3	10.58	7-15-54	
13-34-34aa	NE NE sec. 34	do.	......	11.6	5.50	GI	do.	Alluvium	Cy, W	S	Top of casing	0.6	2,803.4	7.36	7-15-54	
	T. 13 S., R. 35 W.															
13-35-2dd	SE SE sec. 2	D. Keller, Jr.	......	17.0	5.50	GI	do.	do.	Cy, W	N	do.	1.8	2,992.9	9.97	7-8-54	Not in use
*13-35-16ab	NW NE sec. 16	F. L. McGlachlin	Dr	....	5.50	GI	do.	Meade Group or Sanborn Group or both	Cy, W	D, S	....	......	......	......	......	Measured yield 4
13-35-22ba	NE NW sec. 22	Clara Repshire	......	21.5	5.50	GI	do.	Sanborn Group or alluvium or both	Cy, H	N	Top of casing	1.9	2,921.9	14.88	7-8-54	Not in use
13-35-23ac	SW NE sec. 23	....	Dr	26.3	5.50	GI	do.	Sanborn Group	N	N	do.	0.7	2,910.5	21.17	7-15-54	Abandoned
13-35-29ab	NW NE sec. 29	E. E. Repshire	Dr	32.0	5.50	GI	do.	Alluvium or Meade Group or both	Cy, W	N	do.	1.7	2,926.0	24.86	7-13-54	Not in use
13-35-32bc	SW NW sec. 32	J. W. King	Dr	29.7	5.50	GI	do.	Alluvium	Cy, W	N	Top of pipe clamp	1.0	2,907.5	22.75	8-4-55	do
13-35-35ac	SW NE sec. 35	Helen and H. Jordan	......	18.0	5.50	GI	do.	Alluvium or Sanborn Group or both	Cy, W	S	Top of casing	2.8	2,908.6	12.44	7-13-54	Recently pumped
13-35-36bd	SE NW sec. 36	Wycoff Bros.	......	30.0	5.50	GI	do.	Alluvium	Cy, W	S	do.	2.4	2,904.5	26.50	7-13-54	Recently pumped and not fully recovered

TABLE 11.—*Records of typical wells, test holes, and one spring*—*Continued*

Well number (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, in.	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
13-36-8dc	*T. 13 S., R. 36 W.* SW SE sec. 8	B. Shremmer	Dr	73.0	5.50	GI	Sand	Meade Group or Sanborn Group or both	Cy, H	N	Top of platform	0.4	3,086.9	59.78	7- 9-54	New well
13-36-10ad	SE NE sec. 10	J. L. Settle	......	19.5	5.50	GI	do	Alluvium or Meade Group or both	Cy, W	N	Top of casing	0.0	3,000.8	12.86	9- 7-54	Not in use
13-36-12aa	NE NE sec. 12	Geological Survey of Kansas	Dr	92.0	4	N	do	Sanborn Group or Meade Group or both	N	O	Edge of test hole	0.0	3,077.7	....	....	Test hole
13-36-16cc	SW SW sec. 16	H. O. Williams	Dr	21.5	5.50	GI	do	Alluvium or Meade Group or both	Cy, W	N	Top of casing	0.4	3,018.9	14.31	7- 9-54	Not in use
13-36-20cc	SW SW sec. 20	Charles Lamb	Dr	32	16	BS	do	do	VC, B	I	do	1.0	3,023.0	7.31	7- 9-54	
13-36-25aa	NE NE sec. 25	C. C. Ware and J. R. Haverfield	Dr	13.0	12	GI	do	Alluvium	Cy, W	S	do	2.6	2,940.9	8.91	7-13-54	
13-36-27aa	NE NE sec. 27	do	Dr	42.5	10	GI	do	Meade Group or Sanborn Group or both	Cy, W	S	do	3.0	2,993.0	26.33	9- 7-54	Estimated yield 2
13-36-28ba	NE NW sec. 28	Pleasant Valley Lutheran Church	Dr	35.0	5.50	GI	do	do	Cy, H	D	do	1.0	3,023.4	19.30	7- 5-51	
13-36-31cb	NW SW sec. 31	Vira McMillan	Dr	47.0	5.50	GI	do	do	Cy, W	S	do	2.5	3,183.5	32.20	7-15-54	
13-36-34dd	SE SE sec. 34	J. R. Haverfield and C. C. Ware	Du	15.5	36	R	do	Alluvium	Cy, W	N	do	2.0	3,080.0	13.20	7-15-54	Abandoned
13-37-4bb	*T. 13 S., R. 37 W.* NW NW sec. 4	J. E. Bertrand	Dr	28.0	5.50	GI	do	Alluvium or Sanborn Group or both	Cy, N	N	do	1.0	3,135.4	16.64	7-15-54	do
13-37-10cc	SW SW sec. 10	Wm. McMillen	Dr	18.0	5.50	GI	do	Alluvium	Cy, W	S	do	0.9	3,089.2	15.43	7-17-54	
13-37-13dd	SE SE sec. 13	O. Poppe, et al.	Dr	16.0	5.50	GI	do	do	Cy, W	S	do	1.7	3,046.5	13.33	7- 9-54	

13-37-15ac..	SW NE sec. 15..	Wm. McMillen..	Dr	45.1	18	GI	do..........	Alluvium or Meade Group or both........	T, T	I	Hole in pump base.........	0.5	....	9.34	7-18-51	
13-37-15bc...	SW NW sec. 15	W. P. Kirkham	Dr	40.4	16	BS	do..........	do..............	T, T	I	Edge of pump base.........	0.5	....	7.20	7-18-51	Estimated yield 400; estimated drawdown 28
13-37-16ac...	SW NE sec. 16..	Wm. Teichmer..	Dr	63.5	20	GI	do..........	do..............	T, T	I	Hole in pump base.........	1.5		33.93	7-18-51	
13-37-18dd..	SE SE sec. 18...	T. J. Bussen....	Dr	41.0	5.50	GI	do..........	Sanborn Group....	N	N	Top of casing...	0.3	....	34.68	7-17-54	Abandoned
*13-37-23bb..	NW NW sec. 23	M. P. Sunrati...	Sp	....	......	......	do..........	Sanborn Group or Meade Group or both........	N	N	....	......	....	0.00	....	Measured yield 65
13-37-28bb..	NW NW sec. 28	D. Unruh......	Dr	11.0	5.50	GI	do..........	Sanborn Group....	Cy, W	S	Top of casing...	0.1	3,106.5	9.02	7-17-54	
	T. 14 S., R. 32 W.															
14-32-2db...	NW SE sec. 2...	J. L. McQuire...	Du	26.0	48	R	do..........	do..............	Cy, W	S	Top of platform	0.5	2,793.8	17.98	6-18-54	
14-32-14bb..	NW NW sec. 14	do..........	Du	14.2	......	......	do..........	Alluvium.........	Cy, W	S	do.............	0.8	2,741.0	10.25	7-20-54	Recently pumped
14-32-21bc...	SW NW sec. 21	R. H. Steele....	Dr	16.5	5.50	GI	do..........	Sanborn Group....	Cy, W	S	Top of casing...	1.0	2,699.4	15.02	6-18-54	
14-32-23bb..	NW NW sec. 23	Geological Survey of Kansas	Dr	69.5	4	N	do..........	....	N	O	Edge of test hole	0.0	2,820.3	....	....	Test hole
14-32-34da..	NE SE sec. 34...	G. C. Wren.....	Dr	15	5.50	GI	do..........	Alluvium.........	Cy, W	S	do.............	0.0	2,634.7	7.06	7- 5-51	
14-32-36cd...	SE SW sec. 36..	R. B. Christy...	Dr	31.0	5.50	GI	do..........	Sanborn Group or Meade Group or both........	Cy, N	N	Hole in casing...	3.5	2,614.2	23.07	6-18-54	Abandoned
	T. 14 S., R. 33 W.															
14-33-6cc....	SW SW sec. 6...	Tuck Smith.....	......	38.0	5.50	GI	do..........	do..............	Cy, W	D, S	Top of casing...	0.5	2,794.7	20.46	5-31-51	
14-33-31bb..	NW NW sec. 31	R. C. Gates.....	Du	22.0	36	C	do..........	Sanborn (?) Group	Cy, W	S	Top of platform	0.5	2,856.8	21.00	7-13-54	
14-33-33bd..	SE NW sec. 33..	J. J. Clark......	Du	50.0	36	R	do..........	Sanborn Group....	Cy, W	D, S	do.............	0.5	2,796.3	34.71	7-13-54	
	T. 14 S., R. 34 W.															
14-34-8bc...	SW NW sec. 8..	Nettie Walz....	Du	....	36	R	do..........	do..............	Cy, W	S	Top of casing...	2.0	....	45.32	7-13-54	
*14-34-26aa...	NE NE sec. 26..	A. L. Kendrick..	Dr	156.0	......	OW	Chalk........	Niobrara formation......	Cy, W	D, S	Hole in pump base.........	0.7	2,953.8	56.93	7-13-54	
14-34-29bb..	NW NW sec. 29	O. V. Boston and K. J. Benson..	Dr	70.0	......	......	Sand........	Sanborn Group....	Cy, W	S	Top of platform	0.5	3,072.7	45.50	7-13-54	
	T. 14 S., R. 35 W.															
14-35-5cd...	SE SW sec. 5...	F. E. Ausmus...	Du	48.0	......	N	do..........	Sanborn Group or Niobrara formation or both....	N	N	do.............	1.0	....	46.19	7-13-54	Abandoned
14-35-6cd...	SE SW sec. 6...	C. C. Ware.....	Dr	26.5	5.50	GI	do..........	Alluvium.........	Cy, W	S	Top of casing..	2.0	....	13.84	7-22-55	
14-35-9aa...	NE NE sec. 9...	W. W. Wilson...	Dr	20.7	5.50	GI	do..........	do..............	Cy, W	N	Top of platform	2.6	....	9.28	7-24-54	Not in use
14-35-12bc...	SW NW sec. 12	M. A. Griffith...	Dr	53.0	5.50	GI	do..........	Meade Group or Sanborn Group or both........	Cy, W	S	Top of casing...	0.7	3,023.2	36.90	7-28-54	
14-35-21ad..	SE NE sec. 21..	J. R. Haverfield and C. C. Ware	Dr	85.5	5.50	GI	do..........	Sanborn Group or Meade Group or both........	Cy, W	S	do.............	1.2	....	62.84	7-22-55	
14-35-23bd..	SE NW sec. 23..	H. Unruh......	Du	53.0	36	R	do..........	Sanborn Group....	Cy, W	S	do.............	0.5	3,113.4	51.98	7-13-54	Recently pumped

TABLE 11.—*Records of typical wells, test holes, and one spring*—*Continued*

Well number (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, in.	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 14 S., R. 35 W.															
14-35-24bb	NW NW sec. 24	Geological Survey of Kansas	Dr	38.0	4	N	....	....	N	O	Edge of test hole	0.0	3,202.0	....	....	Test hole
14-35-33ba	NE NW sec. 33	C. C. Ware	......	17.0	5.50	GI	Sand	Sanborn Group	Cy, W	S	Top of casing	1.0	3,028.6	4.64	6- 4-51	
	T. 14 S., R. 36 W.															
14-36-5cc	SW SW sec. 5	P. and Theoni P. Fotopoulos	Dr	67.6	5.50	GI	Sandstone	Ogallala formation	Cy;W,G	D, S	Top of platform	0.0	3,347.2	52.80	7-16-54	
*14-36-10ba	NE NW sec. 10	L. T. Fairchild	Dr	67.0	5.50	GI	do.	do.	Cy, W	S	Top of casing	0.7	3,330.7	60.08	7-16-54	
14-36-10cd	SE SW sec. 10	J. F. Barton	Dr	47.5	......	......	Sand	Sanborn Group	Cy, G	S	Top of platform	1.6	....	9.70	7-28-54	
14-36-29dc	SW SE sec. 29	R. Herschberger	Du	43.4	40	C	do.	do.	Cy, W	D, S	Top of casing	2.5	3,176.4	27.98	7-16-54	
*14-36-34cd	SE SW sec. 34	F. Hoover and P. D. Rishel	Dr	52.0	5.50	GI	do.	do.	Cy, W	S	do.	1.0	3,131.1	33.29	7-16-54	
	T. 14 S., R. 37 W.															
14-37-2ba	NE NW sec. 2	M. P. Surratt	Du	30.5	60	R	do.	do.	N	N	Top of platform	1.0	3,167.1	26.76	7-15-54	Abandoned
14-37-20ab	NW NE sec. 20	W. Purviance	Du	13.3	60	R	do.	do.	N	N	do.	1.2	3,345.9	7.47	7-15-54	do
14-37-24cd	SE SW sec. 24	G. H. Jones	Du	....	72	R	do.	do.	Cy, W	D, S	do.	1.5	3,226.7	10.33	7-15-54	
14-37-28cb	NW SW sec. 28	U. S. Geological Survey	J	....	.75	GP	do.	do.	N	O	Top of casing	3.5	3,297.8	13.37	7-28-54	
14-37-29da	NE SE sec. 29	M. P. Surratt	Dr	19.7	5.50	GI	do.	do.	Cy, W	S	do.	2.0	3,301.8	12.62	7-15-54	Recently pumped
14-37-30cc	SW SW sec. 30	do.	Du	12.7	30	R	do.	Alluvium	N	N	Top of platform	0.5	....	8.44	7-27-55	
	T. 15 S., R. 32 W.															
15-32-4aa	NE NE sec. 4	R. B. Christy	......	10.3	5.50	GI	do.	Sanborn Group or alluvium or both	P, H	N	Top of casing	1.5	2,644.5	8.48	6-17-54	Not in use
15-32-5cc	SW SW sec. 5	A. Turley	Dr	21.5	5.50	GI	do.	Sanborn Group	Cy, W	S	do.	0.0	2,670.0	15.77	6-16-54	
15-32-9ba	NE NW sec. 9	Dale Rohrbough	......	21.0	......	......	....	....	Cy, W	S	Top of platform	0.3	2,691.7	17.44	5-29-51	
15-32-10bc	SW NW sec. 10	W. C. Wright	......	18.0	......	......	do.	Sanborn Group	VC, G	I, S	Top of casing	0.0	2,670.8	12.05	6-17-54	
15-32-16ca	NE SW sec. 16	D. A. Been	Dr	14.8	......	......	do.	do.	Cy, W	S	Top of platform	2.5	2,722.7	3.98	5-29-51	
*15-23-19bd	SE NW sec. 19	H. T. Young	Dr	....	5.50	GI	do.	do.	Cy, W	S	Top of casing	0.5	....	18.10	7-12-54	
*15-32-26da	NE SE sec. 26	A. E. Ryan	Dr	83.5	5.50	GI	Sandstone	Ogallala formation	Cy, W	S	do.	0.5	2,952.5	78.65	6-17-54	
15-32-27cb	NW SW sec. 27	R. B. Christy	Dr	67.0	5.50	GI	do.	do.	Cy, W	S	do.	0.5	2,978.0	63.80	6-17-54	
15-32-33bc	SW NW sec. 33	do.	Dr	137.0	5.50	GI	do.	do.	Cy, W	S	do.	0.5	3,013.0	125.78	7-12-54	

15-32-34cc	SW SW sec. 34	Geological Survey of Kansas	Dr	155.0	4	N	do	do	N	O	Edge of test hole	0.0	3,007.7	....	....	Test hole
	T. 15 S., R. 33 W.															
15-33-5ac	SW NE sec. 5	D. L. Staats	Dr	42.4	5.50	GI	Sand	Sanborn Group	Cy, W	S	Top of platform	1.0	2,794.0	23.40	7-12-54	
15-33-7cb	NW SW sec. 7	W. A. Wood, et al	Dr	27.0	8	GI	do	do	Cy, W	S	Top of casing	1.0	2,832.8	13.80	7-12-54	
15-33-8bc	SW NW sec. 8	D. L. Staats	Dr	42.6	5.50	GI	do	do	Cy, W	S	do	1.5	2,813.5	18.69	7-12-54	Recently pumped
15-33-11bd	SE NW sec. 11	F. Steckel	Dr	22.6	5.50	GI	do	do	Cy, W	S	do	0.0	2,735.3	19.95	7-12-54	do
15-33-22ad	SE NE sec. 22	R. S. Irvin	......	14.0	5.50	GI	do	do	Cy, W	S	do	0.3	2,779.7	13.24	7-12-54	
15-33-28ab	NW NE sec. 28	J. R. and Lois M. Hollister	Dr	31.0	5.50	GI	Sandstone	Ogallala (?) formation	N	N	do	0.2	....	20.00	7-22-54	Abandoned
15-33-30cc	SW SW sec. 30	J. R. Radnor	......	14.4	7	GI	Sand	Sanborn Group	N	N	do	0.0	2,893.3	10.77	7-22-54	do.
15-33-33cc	SW SW sec. 33	J. R. Hollister	Dr	36.5	5.50	GI	Sandstone	Ogallala formation	Cy, H	D, S	do	0.7	2,981.3	27.60	7-12-54	
15-33-34ca	NE SW sec. 34	George Edler	......	12.0	5.50	GI	Sand	Alluvium or Ogallala formation or both	Cy, W	S	Top of platform	0.0	2,931.0	8.42	7-12-54	
	T. 15 S., R. 34 W.															
15-34-3cc	SW SW sec. 3	W. A. Wood, et al	Dr	30.0	5.50	GI	do	Sanborn Group	Cy, W	S	Top of casing	0.5	2,902.4	17.65	7-13-54	Recently pumped
15-34-13cd	SE SW sec. 13	Geological Survey of Kansas	Dr	20.0	4	N	....	....	N	O	Edge of test hole	0.0	....	....	....	Test hole
15-34-26ac	SW NE sec. 26	Eric Warren	......	22.0	5.50	GI	do	Sanborn Group	Cy, W	S	Top of platform	1.0	2,925.8	11.78	7-12-54	
15-34-27da	NE SE sec. 27	Logan County	Dr	23.5	5.50	GI	do	do	Cy, W	D	Top of casing	0.3	2,944.0	13.86	7-12-54	
15-34-28dd	SE SE sec. 28	W. A. Wood, et al	......	25.5	5.50	GI	do	do	Cy, W	S	Top of platform	0.0	2,988.4	19.65	6- 1-51	
15-34-30cd	SE SW sec. 30	L. F. Palen	Dr	40.8	5.50	GI	do	do	Cy, W	S	Top of casing	0.5	3,061.2	27.92	6- 5-51	
15-34-32ca	NE SW sec. 32	Zita Palen	Dr	38.5	5.50	GI	do	Sanborn Group or Meade Group or both	Cy, W	S	do	0.5	3,026.9	15.90	7-12-54	
	T. 15 S., R. 35 W.															
*15-35-2ab	NW NE sec. 2	J. R. Haverfield and C. C. Ware	......	37.0	5.50	GI	do	Sanborn Group	Cy, G	S	do	1.5	2,986.3	15.19	7-13-54	
15-35-6ba	NE NW sec. 6	Foot Hills Corp.	Du	30.8	24	R	do	Alluvium or Sanborn Group or both	Cy, W	S	Top of pump clamp	0.6	3,074.4	16.45	7-14-54	Recently pumped
15-35-12ba	NE NW sec. 12	T. Wright	......	......	5.50	GI	do	Sanborn Group	Cy, W	S	Top of platform	0.5	2,962.1	18.70	7-14-54	
15-35-19cc	SW SW sec. 19	G. W. Bowman	Dr	86.0	12	GI	Sandstone	Ogallala formation	N	N	Top of casing	0.6	3,249.7	30.37	7-14-54	Abandoned
15-35-25cd	SE SW sec. 25	J. S. Palen	Dr	22.8	5.50	GI	Sand	Sanborn Group or Meade Group or both	Cy, W	S	do	0.1	3,066.1	12.54	7-14-54	Recently pumped
*15-35-28bd	SE NW sec. 28	H. F. Johnson	Dr	70	5.50	GI	Sandstone	Ogallala formation or Sanborn Group or both	Cy, W	D, S	....	......	....	....	....	
15-35-32ad1	SE NE sec. 32	do	Dr	18.0	5.50	GI	Sand	Sanborn Group or Meade Group or both	N	N	Top of casing	0.0	3,161.6	14.28	7-14-54	Abandoned
15-35-32ad2	SE NE sec. 32	do	Dr	21	5.50	GI	do	Alluvium	Cy, W	S	....	......	....	....	....	

TABLE 11.—*Records of typical wells, test holes, and one spring—Concluded*

Well number (1)	Location	Owner or tenant	Type of well (2)	Depth of well, feet (3)	Diameter of well, in.	Type of casing (4)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Method of lift (5)	Use of water (6)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Height above mean sea level, feet	Depth to water level below land surface, feet (7)	Date of measurement	REMARKS (Yield given in gallons a minute; drawdown in feet)
	T. 15 S., R. 36 W.															
15-36-16dd	SE SE sec. 16	M. E. Weed	Dr	92.0	5.50	GI	Sandstone	Ogallala formation	Cy, W	D	Top of casing	1.0	3,337.2	58.78	7-14-54	
15-36-19bb	NW NW sec. 19	Geological Survey of Kansas	Dr	73.5	4	N	do.	do.	N	O	Edge of test hole	0.0	3,372.0	....	....	Test hole
15-36-20cd	SE SW sec. 20	J. K. Granville	Du	68.0	48	R	do.	do.	Cy, W	S	Top of platform	1.0	3,329.9	53.38	7-14-54	
*15-36-20dd	SE SE sec. 20	do.	Dr	....	....	....	....	Sanborn (?) Group	....	....	....	....	....	....	....	
15-36-23bd	SE NW sec. 23	E. H. Smith	Dr	72.0	5.50	GI	Sandstone	Ogallala formation	Cy, W	S	Top of casing	0.1	3,281.3	40.38	7-14-54	Recently pumped
15-36-26aa	NE NE sec. 26	F. Wing	Dr	59.0	5.50	GI	do.	do.	Cy, W	S	Top of platform	2.0	3,254.6	32.15	6-22-55	
15-36-28ba	NE NW sec. 28	Grace E. Granville	Du	17.3	......	......	do.	Ogallala formation or Sanborn Group or both	N	N	do.	0.5	3,269.6	13.27	6-22-55	Abandoned
15-36-32dd	SE SE sec. 32	J. F. Gerstberger	Dr	18.7	5.50	GI	do.	Ogallala formation	N	N	Top of casing	0.0	3,251.6	12.30	7-14-54	do
15-36-34ca	NE SW sec. 34	L. H. Smith	Dr	31.0	5.50	GI	Sand	Sanborn Group or Ogallala formation or both	Cy, W	S	do.	0.5	3,222.2	13.88	7-14-54	Recently pumped
15-36-36db	NW SE sec. 36	L. H. Strickert	Dr	18.9	5.50	GI	do.	Sanborn Group or Meade Group or both	Cy, W	S	do.	0.0	3,196.2	11.75	7-14-54	
	T. 15 S., R. 37 W.															
15-37-1ba	NE NW sec. 1	R. B. Christy	Dr	23.0	5.50	GI	do.	Sanborn Group	Cy, W	S	Top of platform	0.1	3,205.5	17.10	7-14-54	
*15-37-4cb	NW SW sec. 4	M. P. Surratt	Du	17.0	......	......	do.	Alluvium or Sanborn Group or both	Cy, W	S	do.	1.0	3,311.1	15.58	7-14-54	Recently pumped
15-37-10cd	SE SW sec. 10	H. C. Saforius	Du	51.0	48	N	Sandstone	Ogallala formation	N	N	Top of stone curb	0.0	3,392.2	40.59	7-14-54	Abandoned
15-37-12da	NE SE sec. 12	H. D. Ford	B	15.5	8	N	Sand	Sanborn Group	N	N	Top of hole	0.0	3,237.5	14.30	7-17-54	Undeveloped test hole
15-37-18cd	SE SW sec. 18	H. Burk	Dr	69.0	5.50	GI	Sandstone	Ogallala formation	Cy, W	S	Top of casing	1.4	3,459.6	58.93	7-14-54	
15-37-22dd	SE SE sec. 22	R. L. Sargent	Du	47.0	48	R	do.	do.	N	N	Top of platform	0.0	3,396.0	....	....	Abandoned
15-37-24db	NW SE sec. 24	Mary Blau	Du	87.0	48	R	do.	do.	N	N	Top of casing	0.2	3,380.5	70.66	7-14-54	do
*15-37-30cb	NW SW sec. 30	Ben H. Atkisson	Dr	73.0	5.50	GI	do.	do.	Cy, W	S	do.	0.8	3,434.8	48.75	7-14-54	

15-37-31bc...	SW NW sec. 31	C. E. Brown....	Dr	96.0	5.50	GI	do..........	do..............	Cy, W	S	do.	0.7	3,443.2	64.74	7-22-54	Recently pumped
15-37-33dd..	SE SE sec. 33...	E. A. Niswonger	Dr	73.5	5.50	GI	do..........	do..............	N	N	do............	1.7	3,389.5	67.99	7-14-54	Abandoned
	T. 16 S., R. 32 W.															
16-32-2bc...	SW NW sec. 2..	Roy G. Browning	Dr	135	5.50	GI	do..........	do..............	Cy;W,G	D	do............	0.5	2,976.2	122.58	5-31-51	In Scott County
	T. 16 S., R. 34 W.															
16-34-2bd...	SE NW sec. 2...	....	Dr	139.0	5.50	GI	do..........	do..............	Cy, W	S	do............	0.5	2,996.0	117.25	7-22-54	do
16-34-5ad...	SE NE sec. 5...	Roy Tucker....	B	8.9	5.50	GI	do..........	do..............	N	N	do............	0.0	3,029.4	8.70	7-22-54	In Scott County; abandoned
	T. 16 S., R. 35 W.															
16-35-3da...	NE SE sec. 3...	Blair Kough....	B	9.0	5.50	GI	do..........	do..............	Cy, H	S	do............	0.5	3,096.7	8.40	7-22-54	In Wichita Co.
16-35-6aa...	NE NE sec. 6...	O. T. Redding...	Dr	67.0	5.50	GI	do..........	do..............	Cy, W	S	do............	2.0	3,190.4	57.50	7-22-54	In Wichita Co.; recently pumpe
	T. 16 S., R. 37 W.															
16-37-2bc...	SW NW sec. 2..	K. Woods......	Dr	80.3	5.50	GI	do..........	do..............	S, E	D, S	Top of platform	-3.6	3,354.8	67.47	7-22-54	In Wichita Co.
16-37-4ba...	NE NW sec. 4..	H. A. Barr.....	Dr	82.5	5.50	GI	do..........	do..............	Cy, W	N	Top of casing...	0.5	3,366.7	72.05	7-22-54	In Wichita Co.; not in use
16-37-6aa2...	NE NE sec. 6...	E. R. Langley...	Dr	97.5	5.50	GI	do..........	do..............	Cy, W	N	do............	0.5	3,398.5	73.47	7-22-54	do

1. Asterisk beside number indicates that analysis of water is given in Table 9.
2. B, bored well; DD, dug and drilled well; Dn, driven well; Dr, drilled well; Du, dug well; J, jetted; Sp, spring.
3. Reported depths below the land surface are given in feet; measured depths are given in feet and tenths below measuring points.
4. BS, boiler steel; C, concrete; GI, galvanized sheet iron; GP, galvanized-iron pipe; I, iron; N, none; OB, oil barrels; OW, oil-well casing; R, rock; S, steel; W, wood.
5. Method of lift: C, horizontal centrifugal; Cy, cylinder; F, natural flow; N, none; P, pitcher pump; S, submersible turbine; T, turbine; VC, vertical centrifugal. Type of power: B, butane; D, diesel; E, electric; G, gas engine; H, hand operated; T, tractor; W, windmill.
6. D, domestic; I, irrigation; N, not being used; O, observation; P, public supply; S, stock.
7. Measured depths to water level are given in feet, tenths, and hundredths; reported depths to water level are given in feet.

LOGS OF TEST HOLES AND WELLS

On the pages that follow are given the logs of 43 test holes and wells drilled in Logan County and adjoining areas (Pl. 2). Nine of the logs were supplied by drillers (drillers logs); the other 34 logs are of test holes and wells drilled by the State Geological Survey (sample logs). The test drilling by the Geological Survey was concentrated in upland areas to obtain detailed information on the thickness and character of the Ogallala formation. The geologic sections shown in Plates 3 and 4 are based mainly on data obtained from these logs.

Samples from test holes drilled by the State Geological Survey were collected every 10 feet or at each noticeable change in lithology. The samples were examined and logged in the field and later studied microscopically in the laboratory.

10-32-36dd. *Sample log of test hole in the SE cor. sec. 36, T. 10 S., R. 32 W., Thomas County* (Frye, 1945, p. 104). *Surface altitude, 3,053.8 feet; depth to water, 106 feet.*

	Thickness, feet	Depth, feet
Soil, gray brown to black	3	3
QUATERNARY—Pleistocene		
Sanborn Group		
Silt and very fine sand, yellow gray	20	23
Silt, buff to white; contains clay, fine gravel, and caliche	2	25
TERTIARY—Pliocene		
Ogallala formation		
Gravel, sand, and caliche	13	38
Silt, pink tan; contains sand, caliche, and gravel	32	70
Gravel and sand	12	82
Silt, sand, and caliche, tan	6	88
Gravel and sand, buff	6	94
Silt, gravel, and sand, buff	21	115
Gravel and sand, buff	10	125
Silt, sand, and gravel, gray	9	134
Gravel and sand	7	141
Silt, gravel, and sand	2	143
Gravel, sand, and silt, buff	13	156
Silt, sand, and gravel, tan	8	164
Gravel, sand, and silt, cemented with calcium carbonate, gray	16	180
Silt, gravel, sand, and caliche, tan to gray	35	215
CRETACEOUS—Gulfian		
Pierre shale		
Shale, green gray and yellow	5	220
Shale, yellow to light gray blue	10	230
Shale, gray	20	250

10-34-36dd. *Sample log of test hole in the SE¼ SE¼ sec. 36, T. 10 S., R. 34 W., Thomas County* (Frye, 1945, p. 103). *Surface altitude, 3,191.2 feet.*

	Thickness, feet	Depth, feet
Soil, silty, gray	2	2
QUATERNARY—Pleistocene		
Sanborn Group		
Silt and very fine sand, tan gray	21	23
Silt and clay, gray brown	12	35
Silt and clay, tan buff; contains gravel and caliche,	12	47
TERTIARY—Pliocene		
Ogallala formation		
Gravel, sand, silt, and caliche, buff	9	56
Silt, sand, gravel, and caliche, tan	2	58
Gravel and sand, partly cemented	3	61
Clay, bentonitic (?), silty, yellow buff	4	65
Silt, tan and gray; contains sand and gravel	9	74
Gravel, sand, and caliche, gray and buff	30	104
Silt, caliche, and sand, tan to gray	7	111
Gravel, sand, and caliche, yellow gray	19	130
Sand, gravel, and clay, yellow gray	15	145
Silt, caliche, and sand, yellow gray	7	152
Gravel	4	156
CRETACEOUS—Gulfian		
Pierre shale		
Shale, light green, mottled yellow	4	160
Shale, gray green and gray	15	175

10-35-31cc. *Sample log of test hole in the SW cor. sec. 31, T. 10 S., R. 35 W., Thomas County* (Frye, 1945, p. 101). *Surface altitude, 3,353.4 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Sanborn Group		
Silt and very fine sand, yellow gray	15	17
Silt, gray brown to white; contains sand, gravel, and caliche	3	20
TERTIARY—Pliocene		
Ogallala formation		
Silt, clay, sand, gravel, and caliche, white	12	32
Gravel and sand, cemented	13	45
Silt, caliche, sand, and gravel, light brown	10	55
Gravel, sand, and caliche	14	69
Silt, clay, sand, and caliche, light green yellow to light brown	29	98
Sand, cemented	22	120
Gravel and sand	20	140
Silt, green and brown; contains sand, caliche, and clay	24	164

	Thickness, feet	Depth, feet
Sand, yellow brown; contains silt	12	176
Silt, clay, sand, and caliche, yellow brown	11	187
Gravel and sand	7	194
Clay and silt, yellow buff and light gray green	7	201
Gravel and sand	14	215
CRETACEOUS—Gulfian		
Pierre shale		
Shale, light gray green and gray	5	220
Shale, gray	10	230

10-37-32cc. *Sample log of test hole in the SW cor. sec. 32, T. 10 S., R. 37 W.; drilled August 1949. Sherman County* (Prescott, 1953, p. 118-119). *Surface altitude, 3,307.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn Group—Peoria formation		
Silt, dark brown	9	9
Silt, light brown; contains snail shells; contains sand from 40 to 44 feet	35	44
Silt, black; contains many snail shells	2	46
TERTIARY—Pliocene		
Ogallala formation		
Sand, coarse, and fine to coarse gravel	7	53
Mortar bed	3	56
Sand, fine to medium; contains some cemented layers between 60 and 70 feet	14	70
Sand, fine to coarse, and fine gravel; contains some medium to coarse gravel	10	80
Sand, fine to coarse; contains cemented layers of sand and gravel	17	97
Mortar bed	5	102
Sand, medium to coarse; contains some gravel; partly cemented	6	108
Sand, fine to medium	4	112
Gravel, medium to coarse	4	116
CRETACEOUS—Gulfian		
Pierre shale		
Shale, light gray to red brown	4	120
Shale, light gray	3	123
Shale, dark blue	7	130

11-32-2bc. *Drillers log of test hole in the City of Oakley in the SW¼ NW¼ sec. 2, T. 11 S., R. 32 W., drilled October 21, 1946, by Wesley Page, Oakley, Kansas.*

	Thickness, feet	Depth, feet
Surface material	4	4
QUATERNARY—Pleistocene		
Sanborn Group		
Clay	29	33

	Thickness, feet	Depth, feet
TERTIARY—Pliocene		
Ogallala formation		
Sand	9	42
Clay	6	48
Sandstone, firm	8	56
Gravel, small	32	88
Clay and sandstone	3	91
Gravel, small	11	102
Clay	6	108
Gravel	28	136
Clay	13	149
Clay and small gravel streaks 1 inch thick	11	160
Clay, mostly, with small gravel streaks	20	180
Clay and sandstone streaks	3	183
Gravel	8	191
CRETACEOUS—Gulfian		
Pierre(?) shale		
Clay	9	200

11-32-3bd1. *Drillers log of public-supply well of the City of Oakley in the SE¼ NW¼ sec. 3, T. 11 S., R. 32 W., drilled July 22, 1948, by Norton Manufacturing Company, Norton, Kansas. Surface altitude, 3,055.9 feet.*

	Thickness, feet	Depth, feet
Soil, black	3	3
QUATERNARY—Pleistocene		
Sanborn Group		
Clay, yellow	19	22
TERTIARY—Pliocene		
Ogallala formation		
Clay, light colored	6	28
Clay, sandy	12	40
Clay, sandy, gray	5	45
Clay, sandy	3	48
Gravel, dry	7	55
Clay, yellow	2	57
Rock, magnesia	2	59
Clay	5	64
Formation, sandy	6	70
Formation, clay, sandy	13	83
Gravel, 30 percent of sample 1/16 to ⅛ inch in diameter	9	92
Clay	5	97
Gravel, 1/16 to ⅛ inch in diameter	1	98
Rock, hard	3	101
Gravel, 1/16 to ⅛ inch in diameter	2	103
Clay, gray	3	106
Rock, soft, white	4	110
Rock	3	113
Sandstone, hard	5	118

	Thickness, feet	Depth, feet
Gravel, 20 percent of sample 1/16 to 1/8 inch in diameter	1	119
Clay, gray	7	126
Gravel, 20 percent of sample 1/16 to 1/8 inch in diameter	9	135
Gravel, 50 percent of sample 1/16 to 1/8 inch in diameter	9	144
Rock	7	151
Sand and gravel	25	176
Clay	5	181
Sand and gravel	7	188
Sandstone, hard	1	189
Clay	6	195
Gravel	5	200
Sandstone, very hard	5	205
Rock, very hard	5	210
Sand and gravel	5	215
Gravel, 30 percent of sample 1/16 inch in diameter	2	217
Clay	3	220
Sand	10	230
Clay, sandy	6	236
Gravel, 30 percent of sample 1/16 to 1/4 inch in diameter	5	241
Sand, fine	3	244
Rock	1	245
Gravel, 30 percent of sample 1/8 to 1/4 inch in diameter,	3	248
CRETACEOUS—Gulfian		
Pierre (?) shale		
Rock	2	250

11-32-3bd2. *Sample log of observation well in the SE¼ NW¼ sec. 3, T. 11 S., R. 32 W., drilled August 16, 1954. Surface altitude, 3,054.9 feet; depth to water, 102.74 feet.*

	Thickness, feet	Depth, feet
Soil, silty and clayey, weakly cemented, slightly calcareous, light olive gray	3	3
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, weakly cemented, calcareous, yellowish gray; contains some gastropods and fragments	2	5
Silt, weakly cemented, calcareous, yellowish gray; contains abundant gastropods	10	15
Silt, weakly cemented, calcareous, yellowish gray; few gastropods	5	20
TERTIARY—Pliocene		
Ogallala formation		
Siltstone, slightly sandy, weakly cemented, very calcareous, yellowish gray	2.5	22.5

	Thickness, feet	Depth, feet
Siltstone, clayey, slightly sandy, moderately cemented, very calcareous, pale grayish orange; contains much white calcareous material	7.5	30.0
Shale, sandy and silty, compact, argillaceous, calcareous, pale grayish orange	10	40
Siltstone, sandy and clayey, much fine sand, quartzose, moderately cemented, calcareous, pale grayish orange	2	42
Sandstone, silty, fine grained, quartzose and feldspathic, moderately cemented, calcareous, grayish orange	5	47
Sandstone, medium to coarse grained, much fine gravel and some silt, loose, calcareous, grayish orange	4	51
Siltstone, clayey, quartzose, slightly calcareous, yellowish gray	9	60
Siltstone, clayey, some fine sand, quartzose, slightly calcareous, yellowish gray	4	64
Sandstone, silty, fine grained, quartzose, moderately cemented, calcareous, pale reddish orange,	15	79
Sandstone, fine to medium grained, some fine gravel, quartzose and feldspathic, loose, calcareous, pale grayish orange	6	85
Sandstone, fine grained, much silt, quartzose and feldspathic, moderately cemented, very calcareous, pale grayish orange	5	90
Siltstone, much fine sand, quartzose, moderately cemented, calcareous, yellowish gray	4	94
Siltstone, much fine sand, quartzose, firmly cemented, very calcareous, yellowish gray	0.5	94.5
Conglomerate, fine to coarse grained, some fine to coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange; contains some granite cobbles	7.5	102
Siltstone, sandy and clayey, moderately cemented, yellowish gray	6	108
Shale, moderately cemented, yellowish gray	3	111
Sandstone, fine grained, much silt and some coarse sand, quartzose, mcderately cemented, calcareous, moderate reddish orange	5	116
Sandstone, fine to coarse grained, some fine to medium gravel, quartzose and feldspathic, some large rock fragments, moderately cemented, calcareous, moderate reddish orange	6	122
Siltstone, much fine to medium sand, quartzose, firmly cemented, calcareous, moderate orange pink	8	130

	Thickness, feet	Depth, feet
Sandstone, fine to coarse grained, some silt and fine gravel, quartzose, moderately cemented, calcareous, grayish orange pink	9	139
Sandstone, fine grained, much silt and some fine gravel, quartzose and feldspathic, moderately to firmly cemented, calcareous, grayish orange pink,	1	140
Siltstone, much fine to medium sand, quartzose, moderately to firmly cemented, very calcareous, very pale orange	6	146
Siltstone, much fine sand, quartzose, moderately cemented, very calcareous, grayish orange pink,	4	150
Conglomerate, fine to medium grained, some fine sand and silt, quartzose and feldspathic, moderately cemented, calcareous, moderate orange pink,	8.5	158.5
Siltstone, much fine sand, quartzose, moderately cemented, very calcareous, very pale orange	0.5	159

11-32-14cb. ***Sample log of test hole on east shoulder of road 0.30 mile north of section corner in the NW¼ SW¼ sec. 14, T. 11 S., R. 32 W., drilled July 29, 1954. Surface altitude, 3,050.1 feet.***

	Thickness, feet	Depth, feet
Soil, black	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, clayey, weakly cemented, yellowish gray	2	3
Silt, sandy, weakly cemented, calcareous, yellowish gray; contains gastropods	7	10
Silt, sandy, weakly cemented, calcareous, yellowish gray; contains abundant gastropod fauna	9	19
Silt, clayey and sandy, weakly cemented, very calcareous, very pale orange; contains some gastropod fragments	4.5	23.5
Sand, fine to coarse grained, much gravel and silt, weakly cemented, calcareous, grayish pink orange	6.6	30.1
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, silty, fine to coarse grained, some gravel, firmly cemented, very calcareous, grayish orange	2	32.1
Sandstone, fine to coarse grained, some fine gravel, quartzose and feldspathic, weakly cemented, calcareous, very pale to grayish orange	7.5	39.6
Shale, silty, some sand, argillaceous and calcareous, very pale yellow and brown; contains much white calcareous material	5.5	45.1
Sandstone, fine to coarse grained, much gravel, quartzose and feldspathic, very weakly cemented, calcareous, very pale yellowish brown	3	48.1

	Thickness, feet	Depth, feet
Shale, sandy, argillaceous and calcareous, pale olive	2	50.1
Siltstone, clayey, some sand, weakly cemented, calcareous, moderate reddish orange	10	60.1
Siltstone, clayey, slightly sandy, weakly cemented, calcareous, moderate reddish orange	10	70.1
Shale, silty, some sand, weakly cemented, argillaceous and calcareous, light greenish gray	7	77.1
Sandstone, medium to coarse grained, much fine gravel and some clay, loose, calcareous, reddish gray	9	86.1
Sandstone, medium to coarse grained, much fine to medium gravel, moderately well cemented, pale grayish red	1	87.1
Siltstone, much sand and medium gravel, firmly cemented, calcareous, pale grayish red	4	91.1
Siltstone, sandy, some clay and gravel, firmly cemented, calcareous, light reddish gray	6	97.1
Siltstone, much sand, moderately cemented, calcareous, grayish orange	7	104.1
Conglomerate, fine to medium grained, much sand, quartzose and feldspathic, loose, calcareous, grayish orange	3	107.1
Sandstone, fine to coarse grained, and fine gravel, quartzose and feldspathic, loose, calcareous, grayish orange	5	112.1
Conglomerate, fine to medium grained, much sand, quartzose and feldspathic, loose, calcareous, grayish orange	15	127.1
Conglomerate, fine to medium grained, much sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange	5	132.1
Siltstone, sandy, calcareous, moderate orange red; contains woody fragments	5	137.1
Siltstone, sandy, moderately cemented, calcareous, grayish orange	3	140.1
Conglomerate, coarse grained, some sand, quartzose and feldspathic, loose, calcareous, grayish orange,	4	144.1
Siltstone, clayey, some sand, moderately cemented, very calcareous, light grayish orange	10	154.1
Siltstone, clayey, some sand, very firmly cemented, very calcareous, pale orange pink	3	157.1
CRETACEOUS—Gulfian		
Pierre (?) shale		
Shale, very calcareous, pale yellowish orange	10	167.1
Shale, very calcareous, pale yellowish orange and light greenish gray	10	177.1
Shale, firmly cemented, very calcareous, medium gray	15	192.1

11-32-26cb. *Sample log of test hole 0.3 mile north of SW cor. sec. 26, T. 11 S., R. 32 W., drilled July 30, 1954. Surface altitude, 3,038.4 feet.*

	Thickness, feet	Depth, feet
Soil, weakly cemented, gray	0.7	0.7
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, clayey, weakly cemented, calcareous	1.3	2
Silt, clayey, some fine sand, quartzose, weakly cemented, calcareous, yellowish gray; contains gastropod fragments	8	10
Silt, quartzose, weakly cemented, calcareous, yellowish gray	3	13
Silt, clayey, some fine sand, quartzose, weakly cemented, calcareous, pale grayish orange pink	4	17
Silt, clayey, some fine sand and gravel, quartzose, weakly cemented, calcareous, pale orange pink,	3	20
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, fine grained, some silt and some medium and coarse sand, quartzose, very firmly cemented, calcareous, grayish orange	7	27
Sandstone, fine to medium grained, and some fine gravel, quartzose, moderately cemented, calcareous, grayish orange	3	30
Sandstone, fine to coarse grained, some fine gravel, quartzose and feldspathic, moderately cemented, very calcareous, pale grayish orange	4	34
Siltstone, clayey, some fine and coarse sand, quartzose, very firmly cemented, very calcareous, very pale orange	3	37
Siltstone, clayey, some sand, quartzose, firmly cemented, calcareous, pale reddish orange	7	44
Siltstone, very sparse sand, quartzose, firmly cemented, calcareous, pale orange pink	5	49
Siltstone, some fine sand and clay, quartzose, moderately cemented, calcareous, pale grayish orange pink	1	50
Sandstone, fine to medium grained, some silt, quartzose, calcareous, pale orange pink	5	55
Sandstone, fine to coarse grained, some silt and fine gravel, quartzose, calcareous, pale orange pink,	4	59
Siltstone, some fine sand, quartzose, very firmly cemented, very calcareous, light gray	4	63
Sandstone, medium to coarse grained, some fine gravel, quartzose and feldspathic, calcareous, pale grayish orange	6	69

	Thickness, feet	Depth, feet
Shale, compact, very calcareous, very pale orange,	1	70
Siltstone, clayey, some fine sand, quartzose, moderately cemented, very calcareous, pale grayish orange pink	2	72
Sandstone, very fine grained, much silt, quartzose, moderately cemented, calcareous, pale reddish orange	6	78
Siltstone, some light-gray clay, quartzose, moderately cemented, calcareous, pale orange pink	2	80
Siltstone, some fine sand, quartzose, firmly cemented, calcareous, moderate reddish orange	3	83
Sandstone, fine to coarse grained, some silt and some fine gravel, quartzose, loose, calcareous, pale orange pink	6	89
Siltstone, clayey, some fine sand, quartzose, moderately cemented, very calcareous, grayish pink	1	90
Siltstone, some fine sand, quartzose, moderately cemented, calcareous, grayish orange pink	2	92
Shale, silty, very compact, very calcareous, grayish orange pink	5	97
Siltstone, some medium to coarse gravel, quartzose and feldspathic, moderately cemented, very calcareous, grayish orange pink	3	100
Siltstone, some clay, fine sand, and gravel, very firmly cemented, calcareous, moderate orange pink	5	105
Sandstone, fine to coarse grained, some fine gravel, quartzose and somewhat feldspathic, moderately cemented, calcareous, moderate orange pink	3	108
Conglomerate, fine to medium grained, some fine to coarse sand and some silt, quartzose and feldspathic, loose, calcareous, grayish orange	2	110
Sandstone, medium to coarse grained, much fine gravel, quartzose and feldspathic, loose, calcareous, grayish orange	7	117
CRETACEOUS—Gulfian		
Pierre (?) shale		
Shale, fairly compact, calcareous, pale orange to dusky yellow	3	120
Shale, compact, calcareous, light yellow and dark yellow orange	5	125
Shale, compact, calcareous, light gray and yellow orange	5	130

11-32-34bb. *Drillers log of test hole of Sylvester Mader in the NW¼ NW¼ sec. 34, T. 11 S., R. 32 W., drilled in 1953 by Struckoff Brothers, Grinnell. Kansas. Surface altitude, 3,038 feet.*

	Thickness, feet	Depth, feet
No sample	64	64
TERTIARY—Pliocene		
Ogallala formation		
Rock	1	65
Sand and clay	7	72
Gravel, coarse	3	75
Clay	3	78
Rock	2	80
Gravel, good, medium	14	94
Clay	2	96
Gravel, medium	10	106
CRETACEOUS—Gulfian		
Pierre (?) shale		
Clay, soapy	6	112

11-33-14bc2. *Sample log of observation well 178 feet south of irrigation well in the SW¼ NW¼ sec. 14, T. 11 S., R. 33 W., drilled August 17, 1954. Surface altitude, 3,132.5 feet; depth to water, 133.84 feet.*

	Thickness, feet	Depth, feet
Soil	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, very pale yellowish brown	5	6
Silt, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains many gastropods,	4	10
Silt, quartzose, weakly cemented, calcareous, very pale yellowish brown	10	20
Silt, and some clay, quartzose, weakly cemented, calcareous, grayish orange pink	2	22
Silt, and some clay, quartzose, weakly to moderately cemented, very calcareous, pale grayish orange pink	2	24
Silt, and some clay, quartzose, moderately cemented, very calcareous, light gray to white	3	27
Silt, some clay, and a few grains of coarse sand, quartzose, weakly to moderately cemented, very calcareous, very pale grayish orange pink	5	32
Silt, some fine to coarse sand, and some clay, quartzose, weakly to moderately cemented, very calcareous, very pale grayish orange pink	4.5	36.5
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, fine to medium grained, some silt and clay and some fine gravel, quartzose, moderately cemented, very calcareous, grayish orange pink	5.5	42

	Thickness, feet	Depth, feet
Siltstone, much clay, quartzose, moderately cemented, very calcareous, pale orange	8	50
Sandstone, fine grained, some silt and medium sand, quartzose, moderately cemented, calcareous, reddish orange	7.5	57.5
Sandstone, fine grained, some silt, quartzose, moderately to firmly cemented, calcareous, reddish orange	2.5	60
Sandstone, fine grained, much silt and reddish clay, quartzose, moderately cemented, very calcareous, pale orange	8	68
Sandstone, fine to medium grained, much silt and coarse sand and some fine to medium gravel, quartzose and feldspathic, weakly cemented, calcareous, pale orange	3.5	71.5
Sandstone, fine to medium grained, some silt and reddish clay, quartzose, moderately cemented, calcareous, orange pink	6	77.5
Conglomerate, fine to medium grained, much fine to coarse sand and some clay, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink	7.5	85
Shale, much silt and some sand, moderately to firmly cemented, calcareous, grayish orange	1	86
Sandstone, medium to coarse grained, fine gravel and fine sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange	7.5	93.5
Sandstone, fine to medium grained, much fine gravel and coarse sand, quartzose and feldspathic, moderately to firmly cemented, calcareous, grayish orange pink	6.5	100
Conglomerate, fine to coarse grained, some coarse sand, quartzose and feldspathic, calcareous, weakly cemented, grayish orange pink	18	118
Siltstone, some clay, quartzose, moderately cemented, calcareous, grayish orange pink	2	120
Sandstone, fine grained, much silt, quartzose, moderately cemented, calcareous, grayish orange pink	10	130
Sandstone, fine to medium grained, much fine gravel and some silt, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink; contains thin beds or lenses of conglomerate	10	140
Sandstone, medium to coarse grained, much fine gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	10	150

	Thickness, feet	Depth, feet
Sandstone, fine to medium grained, small amount of gravel and silt, quartzose and feldspathic, moderately to firmly cemented, calcareous, grayish orange pink	7	157
Sandstone, fine to medium grained, much silt and reddish clay, quartzose and feldspathic, moderately to very firmly cemented, grayish orange pink	3	160

11-34-13bb. *Sample log of test hole in the NW cor. sec. 13, T. 11 S., R. 34 W., drilled August 5, 1954. Surface altitude, 3,169.8 feet; depth to water, 115.5 feet.*

	Thickness, feet	Depth, feet
Soil, silty, somewhat clayey, quartzose, weakly cemented, slightly calcareous, yellowish brown	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, pale yellowish brown	4	5
Silt, some clay, quartzose, weakly cemented, calcareous, pale yellowish brown; contains a few gastropods	10	15
Siltstone, much clay, and slightly sandy, quartzose, moderately cemented, calcareous, pale grayish orange pink	7	22
Siltstone, considerable clay, quartzose, moderately cemented, very calcareous, pale grayish orange,	3	25
Siltstone, much clay and some medium to coarse sand, quartzose, moderately cemented, very calcareous, pale grayish orange	5	30
Siltstone, much fine sand, quartzose, moderately cemented, very calcareous, pale grayish orange pink	5	35
Siltstone, much fine to coarse sand, quartzose, moderately cemented, very calcareous, pale grayish orange pink	1.5	36.5
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, medium to coarse grained, some fine gravel and silt, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	3.5	40
Sandstone, medium to coarse grained, some fine to very coarse gravel and fine sand, quartzose and feldspathic, loose, slightly calcareous, grayish orange pink	10	50
Conglomerate, coarse sand, and medium to fine gravel, quartzose and feldspathic, loose, slightly calcareous, grayish orange pink	15	65

	Thickness, feet	Depth, feet
Sandstone, fine to medium grained, much silt, quartzose, moderately cemented, slightly calcareous, reddish orange	5	70
Conglomerate, fine grained, some coarse sand, quartzose and feldspathic, loose, slightly calcareous, grayish orange pink	4	74
Conglomerate, fine to medium grained, some coarse sand, quartzose and feldspathic, loose, slightly calcareous, grayish orange pink	3	77
Siltstone, some fine sand, quartzose, moderately to firmly cemented, very calcareous, pale grayish orange	9	86
Sandstone, fine to coarse grained, some fine to medium gravel, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink	14	100
Shale, silty, moderately to firmly cemented, calcareous, grayish orange pink	10	110
Siltstone, much clay, quartzose, firmly cemented, calcareous, pale grayish orange pink	5	115
Shale, silty, quartzose, moderately to firmly cemented, very calcareous, pale grayish orange pink,	9	124
Sandstone, fine to coarse grained, much fine gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	6	130
Sandstone, fine to medium grained, some silt and coarse sand, quartzose, moderately cemented, calcareous, reddish orange	10	140
Sandstone, fine grained, some silt and medium to coarse sand, quartzose, moderately cemented, very calcareous, pale grayish orange pink	2	142
Siltstone, much fine sand, quartzose, moderately cemented, very calcareous, pale grayish orange pink,	7.5	149.5
Sandstone, fine to coarse grained, some silt and fine gravel, quartzose, moderately cemented, very calcareous, pale grayish orange pink; contains a very firmly cemented layer at 149.5 feet	10.5	160
Sandstone, fine to coarse grained, much fine gravel, quartzose, moderately cemented, very calcareous, pale grayish orange pink	6	166
CRETACEOUS—Gulfian		
Pierre shale		
Shale, somewhat bentonitic, firmly cemented, slightly calcareous, light gray and pale yellowish orange	9	175
Shale, clayey, firmly cemented, noncalcareous, dark medium gray	5	180

11-34-24ca1. *Drillers log of irrigation well of Horace Holmes in the NE¼ SW¼ sec. 24, T. 11 S., R. 34 W., drilled in 1945 by C. A. Robbin, Norton, Kansas. Surface altitude, 3,114.8 feet; depth to water, 59.83 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn Group		
Soil, dark	10	10
Clay, yellow	15	25
TERTIARY—Pliocene		
Ogallala formation		
Gravel, dry	4	29
Clay, gray	1	30
Gravel, dry	8	38
Clay, yellow	3	41
Gravel, 20 percent of sample ⅛ to 1/16 inch in diameter	5	46
Clay, gray	3	49
Gravel, 30 percent of sample ¼ inch in diameter	2	51
Clay, yellow	9	60
Gravel, 25 percent of sample 1/16 to ⅛ inch in diameter	10	70
Gravel, 30 percent of sample 1/16 to ⅛ inch in diameter	12	82
Clay, yellow	2	84
Sand, coarse, or plaster sand	9	93
Clay, sandy, yellow	8	101
Sand, fine	4	105
Clay, gray	7	112
Sand, fine	2	114
Clay, sandy, brown	11	125
Sand, coarse	2	127
Gravel, 20 percent of sample 1/16 inch in diameter	7	134
Gravel, 25 percent of sample 1/16 to ⅛ inch in diameter	6	140
Gravel, 20 percent of sample 1/16 to ⅛ inch in diameter	7	147
CRETACEOUS—Gulfian		
Pierre shale		
Shale	0.5	147.5

11-34-24ca2. *Sample log of observation well in the NE¼ SW¼ sec. 24, T. 11 S., R. 34 W., drilled August 17, 1954. Surface altitude, 3,110 feet; depth to water, 57.00 feet.*

	Thickness, feet	Depth, feet
Soil, silty, quartzose, weakly cemented, slightly calcareous, light brownish gray	2	2
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, some clay, quartzose, moderately cemented, very calcareous, very pale grayish orange; contains many gastropod fragments	3	5

	Thickness, feet	Depth, feet
Silt, some clay, quartzose, weakly cemented, very calcareous, very pale orange	5	10
Silt, much fine sand, quartzose, weakly cemented, noncalcareous, grayish orange	2	12
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, medium to coarse grained, quartzose, loose, noncalcareous, grayish orange	5	17
Conglomerate, fine to coarse grained, much medium to coarse sand, quartzose and feldspathic, loose, noncalcareous, grayish orange; contains pebbles as much as 3 centimeters in diameter	4	21
Siltstone, much reddish clay and fine sand, moderately cemented, noncalcareous, grayish orange pink	15.5	36.5
Sandstone, medium to coarse grained, much fine gravel, quartzose and feldspathic, loose, noncalcareous, grayish orange	5.5	42
Siltstone, some reddish clay, quartzose, moderately cemented, calcareous, grayish orange pink	3	45
Siltstone, some clay, quartzose, moderately cemented, calcareous, very pale yellowish brown	11	56
Sandstone, coarse grained, much fine gravel, quartzose and feldspathic, weakly cemented, slightly calcareous, grayish orange pink	4	60
Sandstone, fine to coarse grained, much fine to medium gravel, quartzose and feldspathic, loose, slightly calcareous, grayish orange pink	10	70
Conglomerate, fine to coarse grained, much fine to coarse sand, quartzose and feldspathic, loose, slightly calcareous, grayish orange pink; contains pebbles as much as 3 centimeters in diameter and black coating upon much of the gravel	12	82
Shale, much silt and fine sand, moderately cemented, calcareous, grayish orange pink	6	88
Sandstone, fine grained, some silt and reddish clay, quartzose, moderately to firmly cemented, calcareous, grayish orange	2	90
Sandstone, fine grained, much silt and some reddish clay, quartzose, moderately to firmly cemented, calcareous, pale reddish orange	10	100
Sandstone, fine grained, much silt and clay, quartzose, moderately to firmly cemented, very calcareous, grayish orange	3	103
Sandstone, fine to medium grained, much silt and some fine gravel, quartzose, weakly cemented, calcareous, grayish orange	2	105

	Thickness, feet	Depth, feet
Siltstone, much fine sand and reddish clay, quartzose, moderately cemented, calcareous, grayish orange pink	3	108
Siltstone, much clay and fine sand, quartzose, moderately to firmly cemented, very calcareous, pale grayish orange pink	2	110
Sandstone, fine grained, some silt and reddish clay, quartzose, moderately cemented, calcareous, pale reddish orange	7	117
Sandstone, fine to coarse grained, some silt and reddish clay, quartzose, moderately cemented, calcareous, pale reddish orange	3	120
Sandstone, medium to coarse grained, much silt and fine sand, quartzose, moderately cemented, calcareous, grayish orange pink	10	130
Conglomerate, fine to medium grained, much coarse sand, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink; contains gravel with black coating and fragments of yellow and light-gray shale	5	135
CRETACEOUS—Gulfian		
Pierre shale		
Shale, moderately cemented, noncalcareous, very light gray to dark yellowish gray	5	140

11-35-1aa. *Sample log of test hole 50 feet west of the NE cor. sec. 1, T. 11 S., R. 35 W., drilled August 9-10, 1954. Surface altitude, 3,268.8 feet.*

	Thickness, feet	Depth, feet
Road fill, silty, some clay, quartzose, weakly cemented, slightly calcareous, brownish gray	2	2
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, pale yellowish brown	3	5
Silt, clayey. quartzose, weakly cemented, calcareous, pale yellowish brown; contains an abundant gastropod fauna	10	15
Silt, quartzose, weakly cemented, calcareous, pale yellowish brown; contains some gastropod fragments	12	27
Silt, quartzose, moderately cemented, very calcareous, pale grayish orange	3	30
Silt, slightly sandy. quartzose, moderately cemented, very calcareous, pale grayish orange	10	40
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, fine to medium grained, much silt and clay, quartzose, moderately to firmly cemented, very calcareous, grayish orange pink	5	45

	Thickness, feet	Depth, feet
Sandstone, fine to medium grained, some silt and coarse sand, quartzose, moderately cemented, calcareous, pale reddish orange	5	50
Sandstone, fine grained, very much silt, quartzose, moderately cemented, very calcareous, grayish orange	2	52
Siltstone, some fine sand and clay, quartzose, moderately to firmly cemented, very calcareous, white to very pale orange	2.5	54.5
Sandstone, fine to coarse grained, some fine to medium gravel, quartzose, weakly cemented, calcareous, pale grayish orange pink	10.5	65
Sandstone, fine to medium grained, much silt and clay, quartzose, moderately to firmly cemented, calcareous, reddish orange	2	67
Conglomerate, fine to medium grained, much coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	8	75
Conglomerate, medium to coarse grained, some sand, quartzose and feldspathic, loose, calcareous, grayish orange pink	5	80
Conglomerate, fine to medium grained, much coarse sand, quartzose and feldspathic, loose, calcareous, grayish orange pink	5	85
Conglomerate, medium to coarse grained, much fine gravel, quartzose and feldspathic, loose, calcareous, grayish orange pink	5	90
Sandstone, medium to coarse grained, some fine gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	5	95
Conglomerate, fine to medium grained, much fine to coarse sand, quartzose and feldspathic, moderately to firmly cemented, calcareous, grayish orange pink; contains two very firmly cemented layers at 96 and 99.5 feet	5	100
Sandstone, fine to medium grained, some silt, quartzose, moderately cemented, calcareous, reddish orange	7	107
Sandstone, fine grained, much silt and medium sand, quartzose, moderately cemented, very calcareous, grayish orange pink	3	110
Siltstone, much clay, and some fine sand, quartzose, moderately cemented, very calcareous, very pale orange	4	114
Siltstone, much clay, and some fine sand, quartzose, moderately to firmly cemented, calcareous, yellowish gray	6	120

	Thickness, feet	Depth, feet
Shale, some silt and fine sand, moderately to firmly cemented, calcareous, yellowish gray	10	130
Siltstone, much clay, slightly sandy, quartzose, moderate to firmly cemented, slightly calcareous, yellowish gray	2	132
Sandstone, medium to coarse grained, much fine to medium gravel, quartzose and feldspathic, moderately cemented, slightly calcareous, pale grayish orange pink	8	140
Conglomerate, medium grained, much coarse sand and fine gravel, quartzose and feldspathic, weakly cemented, slightly calcareous, pale grayish orange pink	10	150
Conglomerate, fine grained, much medium sand and medium gravel, weakly cemented, slightly calcareous, pale grayish orange pink	9.5	159.5
Sandstone, fine to medium grained, much silt, quartzose, moderately cemented, calcareous, grayish orange	0.5	160
Sandstone, fine to medium grained, very silty and clayey, some gravel, quartzose, moderately cemented, calcareous, grayish orange; contains some fragments of gray clay shale	10	170
Sandstone, fine grained, very silty and clayey, quartzose, moderately cemented, calcareous, pale yellowish brown	5	175
Sandstone, fine grained, much silt and clay, quartzose, some gypsum, moderately cemented, calcareous, yellowish brown	5	180
Sandstone, medium to coarse grained, much fine sand and silt and some gravel, quartzose, some gypsum, moderately cemented, calcareous, pale yellowish brown	5	185
CRETACEOUS—Gulfian		
Pierre shale		
Shale, containing gypsum, moderately to firmly cemented, slightly calcareous, medium light gray	5	190
Shale, some bentonite and gypsum, firmly cemented, noncalcareous, medium dark gray	2	192

11-35-5bb1. *Drillers log of public-supply well of City of Winona in the NW¼ NW¼ sec. 5, T. 11 S., R. 35 W., drilled in 1949 by Devlin Construction Company. Surface altitude, 3,341.3 feet; depth to water, 171.01 feet.*

	Thickness, feet	Depth, feet
Soil, black	3	3
QUATERNARY—Pleistocene		
Sanborn Group		
Clay and silt	25	28

	Thickness, feet	Depth, feet
TERTIARY—Pliocene		
Ogallala formation		
Clay and fine sand	16	44
Clay, sand, and silt	6	50
Sand and gravel	10	60
Sand and clay	20	80
Sand, clay, and gravel	13	93
Clay and fine sand	7	100
Sand, cemented	10	110
Sand and gravel	10	120
Sand, fine; contains clay and silt	30	150
Sand and clay	44	194
Sand, cemented	6	200
Gravel, coarse	17	217
CRETACEOUS—Gulfian		
Pierre shale		
Shale	1	218

11-35-7cc. *Sample log of test hole 100 feet north of SW cor. sec. 7, T. 11 S., R. 35 W., drilled August 14, 1954. Surface altitude, 3,294.3 feet.*

	Thickness, feet	Depth, feet
Road fill, silty	3	3
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, very pale yellowish brown	2	5
Silt, slightly sandy. quartzose, weakly cemented, very pale yellowish brown; contains a few gastropod fragments	5	10
Silt, slightly sandy and clayey, quartzose, weakly cemented, calcareous, very pale yellowish brown,	10	20
Silt, much clay, and some sand, quartzose, moderately cemented, calcareous, grayish orange	10	30
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, fine to medium grained, some fine gravel and coarse sand, quartzose and feldspathic, weakly cemented, calcareous, grayish orange	4	34
Sandstone, medium to coarse grained, much fine gravel and silt, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink	6	40
Sandstone, medium to coarse grained, some silt, quartzose, weakly cemented, calcareous, pale grayish orange	5	45
Sandstone, fine grained, much silt and clay, quartzose, moderately cemented, calcareous, grayish orange pink	5	50
Sandstone, fine grained, much silt and some clay and fine gravel, moderately cemented, calcareous, grayish orange pink	7	57

	Thickness, feet	Depth, feet
Limestone or caliche, moderately to firmly cemented, very calcareous, white	0.5	57.5
Sandstone, fine grained, much silt and medium sand, quartzose, moderately cemented, calcareous, grayish orange pink	2.5	60
Sandstone, fine grained, some clay and silt, quartzose, moderately cemented, calcareous, pale grayish orange	3.5	63.5
Siltstone, much clay, quartzose, moderately to firmly cemented, calcareous, very pale yellowish brown,	2.5	66
CRETACEOUS—Gulfian		
Pierre shale		
Shale, firmly cemented, noncalcareous, very pale olive to yellowish gray	4	70
Shale, firmly cemented, noncalcareous, yellowish gray	6	76
Shale, firmly cemented, noncalcareous, yellowish brown	1	77
Shale, bentonitic, moderately to firmly cemented, noncalcareous, yellowish gray	3	80
Shale, moderately to firmly cemented, noncalcareous, yellowish gray; contains some very dark gray shale	10	90

11-35-24dd. *Sample log of test hole 0.9 mile south of U. S. Highway 40 in the SE cor. sec. 24, T. 11 S., R. 35 W., drilled August 10, 1954. Surface altitude, 3,193.0 feet; depth to water, 56.15 feet.*

	Thickness, feet	Depth, feet
Soil, silty, slightly calcareous, yellowish brown	1.5	1.5
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, clayey, quartzose, weakly cemented, calcareous, yellowish brown	3.5	5
Silt, clayey, quartzose, weakly cemented, calcareous, pale yellowish brown; contains some gastropods,	5	10
Silt, clayey, quartzose, weakly cemented, calcareous, pale yellowish brown; contains an abundant gastropod fauna	5	15
Silt, some clay, quartzose and slightly ferruginous, weakly cemented, very calcareous, very pale orange	5	20
TERTIARY—Pliocene		
Ogallala formation		
Conglomerate, fine to medium grained, some coarse sand, quartzose and feldspathic, loose, calcareous, grayish orange pink	8	28

	Thickness, feet	Depth, feet
Sandstone, medium to coarse grained, much fine gravel, quartzose and feldspathic, loose, calcareous, grayish orange pink	4	32
Siltstone, much fine sand, quartzose, loose, slightly calcareous, grayish to reddish orange	3	35
Sandstone, medium grained, much fine and coarse sand and fine gravel, quartzose and feldspathic, loose, slightly calcareous, grayish orange pink	11	46
Shale, some silt, moderately cemented, noncalcareous, pale yellowish brown	2	48
Sandstone, medium to coarse grained, some fine gravel, quartzose and feldspathic, loose, noncalcareous, grayish orange pink	6	54
Siltstone, much fine sand, quartzose, moderately cemented, slightly calcareous, reddish orange	4	58
Sandstone, medium to coarse grained, quartzose and feldspathic, loose, slightly calcareous, grayish orange pink	10	68
Sandstone, medium grained, much fine and some coarse sand, quartzose, loose, slightly calcareous, grayish orange	6	74
Siltstone, some fine sand, quartzose, moderately cemented, calcareous, pale grayish orange pink	4	78
Siltstone, much clay, and some fine sand, quartzose, moderately cemented, very calcareous, pale grayish orange pink	5	83
Limestone or caliche, somewhat clayey, very firmly cemented, white to very pale orange	5	88
Siltstone, some fine sand, quartzose, moderately cemented, very calcareous, very pale orange	2	90
Sandstone, fine grained, much silt, quartzose, moderately cemented, calcareous, grayish orange pink,	3	93
Shale, some silt and sand, quartzose, moderately cemented, calcareous, very pale orange; contains firmly cemented silty and sandy layers	4	97
CRETACEOUS—Gulfian		
Pierre shale		
Shale, moderately cemented, noncalcareous, light gray to dark yellowish orange	10.5	107.5
Shale, moderately to firmly cemented, noncalcareous, medium dark gray	0.5	108

11-36-12aa. *Sample log of test hole 20 feet southwest of the NE cor. sec. 12, T. 11 S., R. 36 W., drilled August 14, 1954. Surface altitude, 3,314.8 feet; depth to water, 110.4 feet.*

	Thickness, feet	Depth, feet
Soil, silty, some clay, quartzose, weakly cemented, noncalcareous, dark yellowish brown	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, some clay, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains many gastropods	14	15
Silt, some medium to coarse sand, slightly clayey, quartzose, weakly cemented, very calcareous, pale grayish orange	1.5	16.5
Silt, some fine to coarse sand, slightly clayey, moderately cemented, very calcareous, pale orange	3.5	20
TERTIARY—Pliocene		
Ogallala formation		
Siltstone, much fine sand and clay and some medium to coarse sand, moderately cemented, quartzose, very calcareous, pale grayish orange	5	25
Sandstone, coarse grained, much fine gravel, quartzose and feldspathic, loose, calcareous, grayish orange pink	3	28
Siltstone, much reddish clay, quartzose, moderately cemented, calcareous, pale red	6	34
Siltstone, much fine sand, quartzose, moderately to firmly cemented, very calcareous, white	6	40
Siltstone, much fine to medium sand, quartzose, firmly cemented, very calcareous, white	6	46
Sandstone, medium to coarse grained, much silt and clay and fine to medium gravel, moderately cemented, calcareous, pale grayish orange pink	4	50
Sandstone, fine to coarse grained, much fine to coarse gravel, quartzose and feldspathic, weakly cemented, calcareous, pale grayish orange pink; contains layers of very coarse gravel conglomerate	19	69
Sandstone, fine to coarse grained, some gravel, quartzose, very firmly cemented, siliceous, white to pale grayish orange pink	2	71
Conglomerate, fine to coarse grained, some coarse sand, quartzose and feldspathic, moderately cemented, calcareous, pale grayish orange pink	1.5	72.5
Siltstone, much fine sand, quartzose, moderately to firmly cemented, very calcareous, very pale grayish orange	3.5	76
Conglomerate, fine to medium grained, fine to coarse sand, quartzose, very firmly cemented, calcareous, white to very pale orange	1.5	77.5

	Thickness, feet	Depth, feet
Conglomerate, medium to coarse grained, some sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	2.5	80
Sandstone, fine to medium grained, some coarse sand and fine to medium gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	10	90
Sandstone, fine grained, some silt and medium to coarse sand, quartzose, loose, calcareous, grayish orange	6	96
Sandstone, fine grained, some silt and medium to coarse sand and gravel, quartzose, moderately cemented, calcareous, grayish orange	20	116
Conglomerate, fine to medium grained, some fine to coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink; a dark coating is prevalent on the coarser sand and gravel grains	4	120
Conglomerate, fine to medium grained, some coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange; contains some shale and ferruginous concretionary material	3.5	123.5
CRETACEOUS—Gulfian		
Pierre shale		
Shale, moderately to firmly cemented, noncalcareous, yellowish gray	3.5	127
Shale, somewhat micaceous or gypsiferous, moderately to firmly cemented, noncalcareous, yellowish gray	3	130

11-36-25aa. *Sample log of test hole 30 feet south of the NE cor. sec. 25, T. 11 S., R. 36 W., drilled August 14, 1954. Surface altitude, 3,276.7 feet; depth to water, 40.00 feet.*

	Thickness, feet	Depth, feet
Soil	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, some fine to coarse sand, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains an abundant gastropod fauna	9	10
Silt, some fine to coarse sand, quartzose, weakly cemented, calcareous, very pale yellowish brown	7	17
Silt, fine grained, some clay, slightly sandy, weakly cemented, calcareous, pale grayish orange	13	30
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, fine to medium grained, much clay and coarse sand and fine gravel, quartzose, weakly cemented, calcareous, grayish orange	2	32

	Thickness, feet	Depth, feet
Siltstone, much clay, quartzose, moderately to firmly cemented, calcareous, pale grayish orange	5	37
Conglomerate, fine to medium grained, some medium to coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange; contains grains of quartz, feldspar, and granite partly covered with a black (manganese?) coating,	3	40
Sandstone, fine to medium grained, much silt and some coarse sand, quartzose, moderately cemented, noncalcareous, pale reddish orange	10	50
Shale, much silt, and some fine sand, moderately to firmly cemented, very calcareous, pale red; contains much white calcareous material	5	55
Shale, much silt and fine sand, moderately cemented, very calcareous, grayish orange pink; contains much white calcareous material	5	60
CRETACEOUS—Gulfian		
Pierre shale		
Shale, moderately to firmly cemented, yellowish gray to light gray, noncalcareous	20	80
Shale, moderately to firmly cemented, calcareous, very pale yellowish brown	6	86
Shale, moderately to firmly cemented, noncalcareous, medium gray	4	90

11-36-36da. *Sample log of test hole on the SW cor. of intersection of U. S. Highway 40 and east edge of the SE¼ sec. 36, T. 11 S., R. 36 W., drilled Aug. 13, 1954. Surface altitude, 3,333.1 feet; depth to water, 145.6 feet.*

	Thickness, feet	Depth, feet
Soil	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, some fine to medium sand, slightly clayey, quartzose, weakly cemented, calcareous, very pale yellowish brown	9	10
Silt, slightly sandy and clayey, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains gastropod fragments	10	20
Silt, some sand and gravel, quartzose, moderately cemented, calcareous, pale grayish orange	7	27
Silt, much clay, and some fine to coarse sand and gravel, quartzose, moderately cemented, very calcareous, very pale orange	14.5	41.5
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, fine to coarse grained, much silt and fine gravel, quartzose, moderately cemented, very calcareous, very pale orange	2	43.5

	Thickness, feet	Depth, feet
Sandstone, fine grained, much silt and medium sand, quartzose, moderately cemented, calcareous, pale reddish orange	5	48.5
Conglomerate, fine to coarse grained, some fine to coarse sand, quartzose and feldspathic, weakly cemented, calcareous, grayish orange	1.5	50
Conglomerate, fine to coarse grained, some coarse sand, quartzose and feldspathic, loose, calcareous, grayish orange pink	10	60
Conglomerate, fine to medium grained, some medium to coarse sand, quartzose and feldspathic, loose, calcareous, grayish orange pink	15	75
Sandstone, fine to medium grained, much pale-red clay, and some silt, quartzose, moderately to firmly cemented, slightly calcareous, reddish orange	3	78
Conglomerate, fine to coarse grained, some medium to coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	12	90
Conglomerate, medium to coarse grained, some coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink,	10	100
Conglomerate, fine grained, some coarse sand and medium gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	2	102
Siltstone, much clay, and some fine sand, quartzose, moderately to firmly cemented, calcareous, pale yellowish brown	4	106
Siltstone, much clay, quartzose, moderately to firmly cemented, slightly calcareous, pale yellowish brown to grayish orange	3	109
Sandstone, fine to coarse grained, much fine gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink; contains some large pebbles and cobbles	5	114
Siltstone, much clay, slightly sandy, quartzose, moderately to firmly cemented, calcareous, pale grayish orange; contains a firmly cemented layer at 116.5 feet	6	120
Siltstone, much clay, and some fine sand, quartzose, moderately to firmly cemented, calcareous, very pale yellowish brown	14	134
Sandstone, medium to coarse grained, much fine gravel, and some medium to coarse gravel, quartzose and feldspathic, moderately cemented, slightly calcareous, grayish orange pink	6	140

	Thickness, feet	Depth, feet
Conglomerate, fine grained, some medium to coarse sand, and some medium to coarse gravel, quartzose and feldspathic, moderately cemented, slightly calcareous, grayish orange pink	5	145
Shale, much silt, and some sand, moderately cemented, slightly calcareous, pale red	5	150
Siltstone, much clay, slightly sandy, quartzose, moderately cemented, calcareous, grayish orange	3	153
Sandstone, fine to coarse grained, some fine to medium gravel, and much clay and silt, quartzose, very calcareous, yellowish gray; contains white calcareous material	5	158
CRETACEOUS—Gulfian		
Pierre shale		
Shale, moderately cemented, noncalcareous, yellowish gray	18	176
Shale, moderately cemented, noncalcareous, medium light gray	4	180

12-31-6bb. *Sample log of test hole in the NW cor. sec. 6, T. 12 S., R. 31 W., Gove County, 90 feet south of road intersection and 35 feet east of centerline of road, drilled September 1952. Surface altitude, 3,014.3 feet; depth to water, 89.35 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn Group		
Clay, silty, dark brown	1	1
Clay, gray; contains some gravel	2	3
Silt, tan gray to tan brown	14	17
Clay, silty to very limy, tan to tan white	13	30
TERTIARY—Pliocene		
Ogallala formation		
Clay, limy, tan to white; contains sand and gravel,	17	47
Sand and gravel, clayey, cemented in part	11	58
Clay, compact to sandy in lower part, light gray to red brown	22	80
Sand and gravel, silty, loosely cemented	10	90
Sand, fine, silty to limy, cemented	8	98
Sand, fine to medium, clayey to cemented, dark gray	8	106
Clay, sandy, light gray; contains weathered shale fragments	11	117
CRETACEOUS—Gulfian		
Pierre shale		
Shale, bentonitic, yellow and yellow brown	3	120

12-32-11cc. ***Sample log of test hole in the SW cor. sec. 11, T. 12 S., R. 32 W., drilled July 30, 1954. Surface altitude, 2,998.3 feet.***

	Thickness, feet	Depth, feet
Soil, black	0.5	0.5
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, clayey, weakly cemented, calcareous, yellowish gray; contains abundant gastropod fauna	11.5	12
Siltstone, clayey, some coarse sand, moderately cemented, very calcareous, grayish orange	5	17
Siltstone, clayey and sandy, some gravel	2	19
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, silty, fine to coarse grained, quartzose and feldspathic, weakly cemented, calcareous, grayish orange	6	25
Sandstone, medium to coarse grained, much gravel, quartzose and feldspathic, unconsolidated, calcareous, grayish orange	5	30
Conglomerate, fine to medium grained, much sand, quartzose and feldspathic, loose, calcareous, grayish orange	7	37
Shale, silty, calcareous, yellowish gray	3	40
Sandstone, fine to coarse grained, much silt and clay, quartzose and feldspathic, firmly cemented, moderate orange gray	6	46
Sandstone, fine to coarse grained, much clay and silt, quartzose and feldspathic, firmly cemented, calcareous, orange pink	4	50
Sandstone, fine to coarse grained, considerable clay, quartzose and feldspathic, calcareous, grayish orange	5	55
Sandstone, fine to coarse grained, some silt and gravel, quartzose and feldspathic, loose, calcareous, grayish orange	4	59
Conglomerate, sandy, fine to medium grained, quartzose and feldspathic, loose, slightly calcareous, grayish orange	1	60
Sandstone, fine to medium grained, some gravel, quartzose and feldspathic, loose, noncalcareous, grayish pink	4	64
CRETACEOUS—Gulfian		
Pierre shale		
Shale, noncalcareous, light gray and yellow	4	68
Shale, bentonitic, noncalcareous, medium gray	2	70

12-32-26bc. *Sample log of test hole in the SW¼ NW¼ sec. 26, T. 12 S., R. 32 W., drilled July 30, 1954. Surface altitude, 3,023.6 feet; depth to water, 70.2 feet.*

	Thickness, feet	Depth, feet
Soil, medium gray	0.5	0.5
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, clayey, quartzose, weakly cemented, calcareous, yellowish gray	6.5	7
Siltstone, considerable fine to coarse sand, quartzose, firmly cemented, very calcareous, grayish pink	3	10
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, fine to coarse grained, much silt, and some fine gravel, quartzose, firmly cemented, very calcareous, grayish orange pink	5	15
Sandstone, fine to coarse grained, some fine to medium gravel, quartzose and feldspathic, loose, calcareous, grayish orange pink	5	20
Sandstone, medium to coarse grained, some fine to medium gravel, quartzose and feldspathic, loose, calcareous, grayish orange pink; contains hard cemented layers of white calcareous material	10	30
Sandstone, medium to coarse grained, some fine to medium gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	4	34
Sandstone, fine grained, very silty, quartzose, firmly cemented, very calcareous, moderate orange pink	6	40
Sandstone, fine grained, very silty, quartzose, very firmly cemented, very calcareous, moderate orange pink	4	44
Sandstone, fine to coarse grained, some silt, quartzose, very firmly cemented, very calcareous, moderate orange pink	6	50
Siltstone, some fine to medium sand, quartzose, very firmly cemented, very calcareous, moderate orange pink	6	56
Siltstone, some fine sand, quartzose, extremely hard and well cemented, very calcareous, very pale orange	1	57
Siltstone, clayey, quartzose, moderately cemented, very calcareous, very pale orange	3	60
Sandstone, fine to coarse grained, some silt, quartzose, moderately cemented, calcareous, grayish orange; contains white to vitreous cherty material,	6	66
Sandstone, fine grained, some medium and coarse sand and silt, quartzose, firmly cemented, calcareous, moderate orange pink	6	72

	Thickness, feet	Depth, feet
Conglomerate, sandy, fine to medium grained, much coarse sand, quartzose and feldspathic, loose, calcareous, grayish orange	8	80
Conglomerate, fine grained, medium to coarse sand, quartzose and feldspathic, moderately cemented, calcareous, pale grayish orange	2	82
Sandstone, medium to coarse grained, some fine gravel, quartzose and feldspathic, very firmly cemented, calcareous, pale grayish orange	2	84
Cretaceous—Gulfian		
Pierre shale		
Shale, bentonitic, compact, very calcareous, yellowish orange and light gray	4	88
Shale, bentonitic, compact, noncalcareous, medium gray	2	90

12-34-1bb. *Sample log of test hole in the NW cor. sec. 1, T. 12 S., R. 34 W., drilled August 4-5, 1954. Surface altitude, 3,204.1 feet.*

	Thickness, feet	Depth, feet
Road fill	2.5	2.5
Quaternary—Pleistocene		
Sanborn Group		
Silt, clayey, quartzose, weakly cemented, calcareous, pale yellowish brown	2.5	5
Silt, clayey, quartzose, weakly cemented, calcareous, pale yellowish brown; contains gastropods	5	10
Silt, quartzose, weakly cemented, calcareous, pale grayish orange; gastropods very abundant	10	20
Silt, clayey, quartzose, weakly cemented, calcareous, pale grayish orange	6	26
Tertiary—Pliocene		
Ogallala formation		
Siltstone, clayey, some sand, quartzose, weakly cemented, very calcareous, pale grayish orange pink	2	28
Siltstone, clayey, some fine sand, quartzose, weakly cemented, very calcareous, pale grayish orange pink	3	31
Limestone or caliche, clayey, firmly cemented, pale grayish orange pink	5	36
Limestone or caliche, clayey, firmly cemented, pale grayish orange pink; interbedded with thin, moderately cemented silty sandstone layers	7	43
Sandstone, fine grained, very much silt, quartzose, firmly cemented, very calcareous, very pale orange	2	45
Sandstone, fine grained, some silt, quartzose, firmly cemented, very calcareous, very pale orange	1	46

	Thickness, feet	Depth, feet
Sandstone, fine grained, some silt and medium sand, quartzose, moderately cemented, calcareous, grayish orange pink	4	50
Conglomerate, medium to coarse grained, some coarse sand and fine gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	10	60
Conglomerate, fine to medium grained, some coarse sand and coarse gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	9.5	69.5
Sandstone, fine grained, some silt and medium sand, quartzose, moderately cemented, calcareous, reddish orange	2.5	72
Sandstone, fine grained, some silt and medium sand, quartzose, moderately cemented, very calcareous, moderate orange pink	4	76
Siltstone, some fine sand and clay, quartzose, moderately cemented, very calcareous, very pale orange	2	78
Siltstone, much clay and fine to medium sand, quartzose, moderately cemented, very calcareous, very pale orange	6	84
Conglomerate, fine to coarse grained, some medium to coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink,	8	92
Sandstone, fine grained, some silt and clay, quartzose, firmly cemented, very calcareous, grayish orange pink	1	93
Sandstone, fine grained, much medium sand, and some silt, quartzose, moderately cemented, calcareous, moderate reddish orange	7	100
Sandstone, fine grained, some silt and medium sand, quartzose, moderately cemented, calcareous, moderate reddish orange	5	105
Sandstone, fine grained, much silt and clay, quartzose, moderately cemented, calcareous, grayish orange	5	110
Siltstone, much clay and fine sand, quartzose, moderately cemented, very calcareous, pale orange,	2	112
Siltstone, some fine sand and clay, quartzose, moderately to firmly cemented, calcareous, grayish orange pink	2	114
Sandstone, fine grained, some silt and clay, quartzose, moderately cemented, calcareous, grayish orange pink	6	120

	Thickness, feet	Depth, feet
Siltstone, much fine sand, and some clay, quartzose, moderately cemented, very calcareous, pale orange	12	132
Sandstone, medium to coarse grained, some fine gravel and fine sand and silt, quartzose, moderately cemented, calcareous, grayish orange pink,	5	137
Conglomerate, fine to medium grained, some fine to coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink,	8	145
Siltstone, clayey, quartzose, moderately to firmly cemented, calcareous, grayish orange pink	4	149
Siltstone, very much clay, quartzose, firmly cemented, calcareous, pale grayish orange	1	150
Siltstone, some clay and fine sand, quartzose, moderately to firmly cemented, calcareous, pale grayish orange	6	156
Siltstone, much fine sand, quartzose, moderately cemented, calcareous, reddish orange	5	161
Sandstone, coarse grained, some silt, fine to medium sand, and fine gravel, quartzose, moderately cemented, calcareous, grayish orange pink	4	165
Sandstone, fine grained, much silt, and some medium sand, quartzose, moderately cemented, calcareous, reddish orange	9	174
Sandstone, medium grained, much silt, clay, and fine sand, quartzose, moderately cemented, calcareous, pale grayish orange	1	175
Siltstone, some fine to medium sand and clay, quartzose, moderately cemented, very calcareous, pale grayish orange; interbedded with thin, moderately cemented conglomerate layers	8	183
Sandstone, medium to coarse grained, some silt and fine sand, quartzose, weakly cemented, calcareous, pale grayish orange	3	186
CRETACEOUS—Gulfian		
Pierre shale		
Shale, moderately to firmly cemented, noncalcareous, light gray to pale yellowish orange	4	190

12-34-11dd. *Sample log of test hole in the SE cor. sec. 11, T. 12 S., R. 34 W., drilled August 4, 1954. Surface altitude, 3,192.0 feet.*

	Thickness, feet	Depth, feet
Soil, medium gray	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, clayey, quartzose, weakly cemented, slightly calcareous, pale yellowish brown	1	2

	Thickness, feet	Depth, feet
Silt, very little clay, weakly cemented, calcareous, very pale yellowish brown	2	4
Silt, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains gastropod fauna,	16	20
Silt, much clay, quartzose, moderately cemented, calcareous, very pale yellowish brown; contains gastropod fragments	5	25
Silt, some clay and fine to coarse sand, quartzose, moderately cemented, calcareous, very pale yellowish brown	2	27
Silt, clayey, some fine to coarse sand, moderately cemented, calcareous, grayish orange	3	30
TERTIARY—Pliocene		
Ogallala formation		
Siltstone, some clay and fine to coarse sand, quartzose, moderately to firmly cemented, very calcareous, very pale orange	10	40
Siltstone, some fine to medium sand, and much clay, quartzose, moderately cemented, very calcareous, very pale orange	4.5	44.5
Sandstone, medium to coarse grained, some fine gravel and sand, quartzose, weakly cemented, very calcareous, grayish orange pink	5.5	50
Sandstone, medium grained, much fine gravel and fine sand, weakly cemented, calcareous, grayish orange pink	4	54
Conglomerate, fine grained, some fine to coarse sand and silt, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink	3	57
Conglomerate, fine to medium grained, some fine to coarse sand and silt, quartzose and feldspathic, loose, calcareous, grayish orange pink	3	60
Conglomerate, fine to coarse grained, some fine to coarse sand and cobbles, quartzose and feldspathic, loose, calcareous, grayish orange pink	5	65
Shale, some silt and fine sand, moderately to firmly cemented, calcareous, grayish orange pink	5	70
Siltstone, much fine sand, and some medium to coarse sand, quartzose, moderately to firmly cemented, very calcareous, very pale orange	5	75
Sandstone, fine grained, some silt, medium to coarse sand, and gravel, quartzose, moderately cemented, calcareous, grayish orange	1	76
Conglomerate, fine to medium grained, some medium to coarse sand and coarse gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	4	80

	Thickness, feet	Depth, feet
Conglomerate, fine grained, some fine to coarse sand and silt, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	4.5	84.5
Sandstone, fine grained, much silt, quartzose, firmly cemented, calcareous and siliceous, white to very pale orange	1	85.5
Conglomerate, fine grained, some fine to coarse sand and silt, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink; a very hard layer or boulder about 6 inches thick at 89 feet	4.0	89.5
Sandstone, fine grained, much silt and clay, quartzose, moderately cemented, calcareous, grayish orange	5.5	95
Siltstone, some fine sand and clay, quartzose, moderately cemented, calcareous, grayish orange	5	100
Siltstone, much clay, and some fine to medium sand, quartzose, moderately cemented, calcareous, grayish orange	5	105
Sandstone, fine to medium grained, some silt, quartzose, loose, calcareous, grayish orange pink	1	106
Siltstone, much clay, and some fine to coarse sand, quartzose, moderately cemented, calcareous, grayish orange	4	110
Sandstone, fine grained, some silt and medium to coarse sand, quartzose, moderately cemented, calcareous, moderate reddish orange	6	116
Sandstone, fine to medium grained, much silt, and some coarse sand and fine to medium gravel, quartzose, moderately cemented, calcareous, grayish orange pink	7	123
Sandstone, fine grained, much silt, and some clay and medium sand, moderately cemented, calcareous, moderate reddish orange	7	130
Sandstone, fine grained, much medium to coarse sand, quartzose, moderately cemented, calcareous, moderate reddish orange	3.5	133.5
Sandstone, medium to coarse grained, some fine to medium gravel and yellow shale fragments, quartzose, moderately cemented, calcareous, grayish orange	4.5	138
CRETACEOUS—Gulfian		
Pierre shale		
Shale, moderately cemented, noncalcareous, light gray to dark yellowish orange	16	154
Shale, bentonitic, firmly cemented, noncalcareous, dark gray	2	156

12-34-26da. *Sample log of test hole 50 feet south of the NE cor. SE¼ sec. 26, T. 12 S., R. 34 W., drilled August 3, 1954. Surface altitude, 3,158.2 feet.*

	Thickness, feet	Depth, feet
Soil, medium gray	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, pale yellowish brown	4	5
Silt, some fine and medium sand, quartzose, weakly cemented, calcareous, pale yellowish brown; contains some gastropods	4	9
Silt, some clay and fine sand, quartzose, moderately cemented, calcareous, pale yellowish brown	1	10
TERTIARY—Pliocene		
Ogallala formation		
Shale, some silt and fine to coarse sand, moderately to firmly cemented, calcareous, pale brown	5	15
Sandstone, fine grained, some silt and medium to coarse sand, quartzose, moderately to firmly cemented, very calcareous, grayish orange pink	5	20
Sandstone, fine to medium grained, some coarse sand and silt, quartzose, moderately to firmly cemented, very calcareous, grayish orange pink	5	25
Sandstone, fine to medium grained, some silt and coarse sand, moderately to firmly cemented, very calcareous, grayish orange pink to very pale orange	14.5	39.5
Sandstone, coarse grained, much fine gravel, quartzose, moderately cemented, calcareous, grayish orange pink	6.5	46
Sandstone, fine to coarse grained, many shale fragments, quartzose, weakly cemented, calcareous, grayish orange	3	49
Shale, moderately compact, noncalcareous, grayish yellow	6	55
Shale, moderately to firmly cemented, noncalcareous, grayish yellcw	7	62
CRETACEOUS—Gulfian		
Pierre shale		
Shale, somewhat bentonitic, firmly cemented, noncalcareous, medium gray	3	65
Shale, bentonitic, firmly cemented, noncalcareous, medium gray; contains unabraded crystals of gypsum	5	70

12-35-1ad. *Sample log of test hole 6 feet north of the SE cor. of NE¼ sec. 1, T. 12 S., R. 35 W., drilled August 10-11, 1954. Surface altitude, 3,255.3 feet; depth to water, 143.5 feet.*

	Thickness, feet	Depth, feet
Soil and road fill, silty, some clay and humic material, quartzose, weakly cemented, calcareous, yellowish brown	4	4
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, clayey, quartzose, weakly cemented, calcareous, pale yellowish brown	6	10
Silt, much clay, quartzose, weakly cemented, calcareous, pale yellowish brown; contains some gastropods	7	17
Silt, much clay, quartzose, weakly cemented, calcareous, pale yellowish brown; contains an abundant gastropod fauna	8	25
Siltstone, slightly sandy and clayey, quartzose, moderately cemented, calcareous, grayish orange brown	3	28
Siltstone, some fine sand and clay, quartzose, moderately cemented, very calcareous, pale grayish orange pink	9	37
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, silty, fine grained, much medium sand, quartzose, moderately cemented, calcareous, grayish orange pink	3	40
Sandstone, medium to coarse grained, some fine gravel, quartzose, weakly cemented, calcareous, grayish orange pink	10	50
Siltstone, some fine sand, quartzose, moderately cemented, very calcareous, very pale orange	4.5	54.5
Siltstone, much fine sand, quartzose, weakly cemented, very calcareous, very pale orange	4.5	59
Sandstone, fine grained, some silt and medium sand, quartzose, weakly cemented, calcareous, reddish orange	1	60
Sandstone, fine to medium grained, much reddish clay, quartzose, weakly cemented, reddish orange,	10	70
Sandstone, medium to coarse, some fine gravel, quartzose, loose, calcareous, grayish orange pink,	2	72
Sandstone, silty, fine grained, much medium sand, quartzose, moderately cemented, calcareous, grayish orange pink; contains white calcareous layers,	5	77
Conglomerate, fine to medium grained, some coarse sand, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink	3	80

	Thickness, feet	Depth, feet
Conglomerate, medium to coarse grained, some fine gravel and coarse sand, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink,	16	96
Conglomerate, fine to medium grained, some fine to coarse sand and silt, quartzose and feldspathic, firmly cemented, very calcareous, pale grayish orange pink	1.5	97.5
Conglomerate, fine to medium grained, some medium to coarse sand, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink,	16.5	114
Shale, silty, moderately cemented, very calcareous, grayish orange pink	2	116
Sandstone, medium to coarse grained, some fine gravel, quartzose, weakly cemented, calcareous, grayish orange pink	20	136
Siltstone, clayey, quartzose, moderately cemented, calcareous, very pale yellowish brown	4	140
Siltstone, clayey, quartzose, moderately cemented, calcareous, pale grayish orange	5	145
Sandstone, fine grained, much clay and silt, quartzose, moderately cemented, calcareous, reddish orange	5	150
Siltstone, coarse, much fine sand, quartzose, moderately cemented, calcareous, grayish orange pink	3	153
Sandstone, medium to coarse grained, some fine to medium gravel, quartzose and feldspathic, loose, calcareous, grayish orange pink	7	160
Siltstone, much fine sand, quartzose, moderately cemented, calcareous, grayish orange	24	184
Sandstone, coarse grained, much fine gravel, quartzose, weakly cemented, calcareous, grayish orange pink; contains fragments of greenish and yellowish shale	6	190
Sandstone, coarse grained, some fine gravel, quartzose, weakly cemented, calcareous, grayish orange; contains abundant shale fragments	4	194
CRETACEOUS—Gulfian		
Pierre shale		
Shale, moderately cemented, noncalcareous, light gray and yellowish orange	6	200
Shale, moderately to firmly cemented, noncalcareous, light gray and yellowish orange; contains dark medium-gray noncalcareous clay shale	10	210

12-35-25dd. ***Sample log of test hole 0.1 mile north of the SE cor. sec. 25, T. 12 S., R. 35 W., drilled August 11, 1954. Surface altitude, 3,166.9 feet; depth to water, 69.15 feet.***

	Thickness, feet	Depth, feet
Soil	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, some medium to coarse sand, quartzose, weakly cemented, calcareous, pale yellowish brown; contains some gastropod fragments	4	5
Silt, some medium to coarse sand and fine gravel, quartzose, weakly cemented, calcareous, pale yellowish brown	2	7
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, fine to coarse grained, much fine gravel, and some silt, quartzose and feldspathic, loose, calcareous, grayish orange	3	10
Sandstone, fine to coarse grained, much fine gravel, quartzose and feldspathic, loose, calcareous, grayish orange pink	7	17
Shale, moderately cemented, calcareous, very pale yellowish brown	3	20
Shale, moderately cemented, calcareous, pale yellowish brown; contains white calcareous flecks	2	22
Limestone or caliche, clayey, moderately cemented, white	3	25
Sandstone, medium to coarse grained, much fine gravel, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink	2	27
Shale, moderately to firmly cemented, noncalcareous, grayish orange pink	3	30
Shale, some silt, moderately to firmly cemented, slightly calcareous, grayish orange pink to pale yellowish brown	5	35
Shale, some silt and fine sand, moderately to firmly cemented, calcareous, pale yellowish brown	15	50
Shale, silty, somewhat micaceous, moderately to firmly cemented, calcareous, pale yellowish brown,	6	56
Conglomerate, fine to medium grained, some medium and coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange,	6	62
Shale, slightly calcareous, pale red	6	68
Sandstone, fine grained, some silt and medium sand, quartzose, moderately cemented, calcareous, pale reddish orange	2	70
Sandstone, fine to medium grained, some silt and coarse sand, quartzose, moderately cemented, calcareous, grayish orange	6	76

	Thickness, feet	Depth, feet
Sandstone, medium to coarse grained, some fine gravel and fine sand, quartzose and feldspathic, weakly cemented, calcareous, grayish orange	5	81
CRETACEOUS—Gulfian		
Pierre shale		
Shale, moderately to firmly cemented, noncalcareous, light gray and yellowish orange	9	90
Shale, bentonitic, moderately to firmly cemented, noncalcareous, light gray and yellowish orange	4	94
Shale, bentonitic, firmly cemented, noncalcareous, medium dark gray	6	100

12-36-12dd. *Sample log of test hole 0.2 mile north of the SE cor. sec. 12, T. 12 S., R. 36 W., drilled August 12-13, 1954. Surface altitude, 3,272.3 feet.*

	Thickness, feet	Depth, feet
Soil	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains some gastropods,	5	6
Silt, slightly clayey, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains an abundant gastropod fauna	4	10
Silt, slightly clayey, quartzose, weakly cemented, calcareous, very pale yellowish brown	5	15
Silt, some fine to coarse sand, quartzose, weakly cemented, very pale yellowish brown	5	20
TERTIARY—Pliocene		
Ogallala formation		
Sandstone, fine to coarse grained, much clay and silt, and some fine gravel, quartzose, moderately cemented, calcareous, grayish orange to grayish orange pink	6	26
Sandstone, fine to coarse grained, some fine to medium gravel, quartzose and feldspathic, moderately to firmly cemented, calcareous, grayish orange pink; contains firmly cemented layers	4	30
Sandstone, fine to coarse grained, much fine gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	5	35
Conglomerate, fine to medium grained, much coarse sand, and some coarse gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	5	40
Sandstone, coarse grained, some fine and medium gravel, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink	3	43
Shale, much silt, moderately cemented, calcareous, very pale grayish orange	16	59

	Thickness, feet	Depth, feet
Siltstone, much clay and fine sand, quartzose, moderately cemented, calcareous, very pale yellowish brown	8	67
Siltstone, much clay and fine sand, quartzose, firmly cemented, calcareous, very pale yellowish brown,	16.5	83.5
Sandstone, medium to coarse grained, much fine gravel, quartzose and feldspathic, weakly cemented, calcareous, pale grayish orange	7.5	91
Sandstone, fine grained, much silt, and some medium sand, quartzose, moderately cemented, calcareous, pale reddish orange	16.5	107.5
Sandstone, fine to medium grained, some coarse sand and fine gravel, quartzose and feldspathic, moderately cemented, calcareous, pale grayish orange	2.5	110
Sandstone, coarse grained, much fine gravel, quartzose and feldspathic, moderately cemented, calcareous, pale grayish orange	3.5	113.5
Sandstone, fine grained, much clay and silt, quartzose, moderately to firmly cemented, calcareous, pale grayish orange	6.5	120
Sandstone, fine to medium grained, much silt, and some clay and fine gravel, quartzose, moderately cemented, calcareous, pale grayish orange	5	125
Sandstone, fine grained, much clay and silt, quartzose, moderately to firmly cemented, calcareous, pale yellowish brown	3	128
CRETACEOUS—Gulfian		
Pierre shale		
Shale, bentonitic, moderately to firmly cemented, noncalcareous, grayish to yellowish orange	12	140

12-36-25aa. *Sample log of test hole 100 feet south of the NE cor. sec. 25, T. 12 S., R. 36 W., drilled August 12, 1954. Surface altitude, 3,167.4 feet.*

	Thickness, feet	Depth, feet
Soil	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, very pale yellowish brown	4	5
Silt, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains gastropods	5	10
Silt, some clay, slightly sandy, quartzose, weakly cemented, calcareous, very pale yellowish orange	3	13
Siltstone, fine grained, some clay, slightly sandy, quartzose, moderately cemented, calcareous, very pale yellowish brown to grayish orange	4	17

	Thickness, feet	Depth, feet
Siltstone, fine grained, much clay, slightly sandy, quartzose, moderately cemented, calcareous, grayish orange	3	20
Siltstone, much clay and fine sand, quartzose, moderately cemented, calcareous, grayish orange,	2	22
CRETACEOUS—Gulfian		
Pierre shale		
Shale, considerable gypsum, moderately to firmly cemented, noncalcareous, grayish orange	6	28
Shale, very much crystalline gypsum, firmly cemented, noncalcareous, yellowish gray	12	40
Shale, bentonitic, much crystalline gypsum, firmly cemented, noncalcareous, yellowish gray	6	46
Shale, much crystalline gypsum, firmly cemented, noncalcareous, yellowish gray to grayish orange,	4	50
Shale, bentonitic, much crystalline gypsum, firmly cemented, noncalcareous, yellowish gray	26	76
Shale, bentonitic, much crystalline gypsum, firmly cemented, noncalcareous, light olive gray to medium dark gray	4	80

12-37-19aa. *Drillers log of test hole of Garvin E. Gfeller in the NE¼ NE¼ sec. 19, T. 12 S., R. 37 W.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn Group		
Soil and clay	33	33
Clay	12	45
Sand	6	51
Meade (?) Group		
Clay	3	54
Gravel	8	62
Clay	3	65
CRETACEOUS—Gulfian		
Pierre shale		
"Soapstone"	2	67

12-37-21aa. *Drillers log of test hole of Garvin E. Gfeller in the NE¼ NE¼ sec. 21, T. 12 S., R. 37 W.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn Group and Meade (?) Group		
Clay, sandy	45	45
Clay, yellow	20	65
CRETACEOUS—Gulfian		
Pierre shale		
Shale, blue	50	115

12-37-21dd. *Drillers log of test hole of Garvin E. Gfeller in the SE¼ SE¼ sec. 21, T. 12 S., R. 37 W.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn Group and Meade (?) Group		
No sample	26	26
Clay, sandy	22	48
Clay	13	61
CRETACEOUS—Gulfian		
Pierre shale		
Shale	49	110

13-32-2cc. *Sample log of test hole 300 feet north of the SW cor. sec. 2, T. 13 S., R. 32 W., drilled July 31, 1954. Surface altitude, 3,024.1 feet.*

	Thickness, feet	Depth, feet
Soil, gray	0.5	0.5
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, yellowish gray; contains gastropod fragments	4.5	5
Silt, slightly sandy, weakly cemented, calcareous, yellowish gray; contains many gastropods	4	9
TERTIARY—Pliocene		
Ogallala formation		
Siltstone, clayey, some sand, quartzose, firmly cemented, very calcareous, pale grayish orange pink,	1	10
Siltstone, clayey and somewhat sandy, some fine gravel, quartzose, firmly cemented, very calcareous, pale grayish orange pink	7	17
Siltstone, clayey, some sand and gravel, quartzose, very firmly cemented, very calcareous, white	1	18
Sandstone, fine to coarse grained, some fine to medium gravel and considerable silt, moderately cemented, calcareous, grayish orange pink; contains alternating layers of silt and sandstone	2	20
Siltstone, well-sorted coarse silt and fine sand, quartzose, very firmly cemented, very calcareous, very pale orange	4	24
Conglomerate, fine grained, some coarse sand, quartzose and feldspathic, loose, calcareous, grayish orange pink	1	25
Siltstone, much fine sand, quartzose, firmly cemented, very calcareous, white	4	29
Sandstone, fine grained, some silt, quartzose, moderately cemented, calcareous, moderate reddish orange	1	30
Sandstone, fine grained, much silt, quartzose, firmly cemented, calcareous, moderate reddish orange	5.5	35.5
Sandstone, fine grained, some silt, quartzose, moderately to firmly cemented, calcareous, moderate orange pink	8.5	44

	Thickness, feet	Depth, feet
Sandstone, fine grained and very silty, some coarse sand, quartzose, moderately cemented, calcareous, moderate orange pink	6	50
Siltstone, clayey, slightly sandy, quartzose, moderately to firmly cemented, calcareous, pale orange,	3	53
Sandstone, fine to coarse grained, some silt, quartzose, moderately cemented, calcareous, pale grayish orange	2	55
Sandstone, fine to coarse grained, some silt and fine to medium gravel, quartzose, moderately to firmly cemented, calcareous, pale grayish orange,	4.5	59.5
Sandstone, medium to coarse grained, some fine gravel and clay, quartzose, moderately cemented, calcareous, pale grayish orange; large shale boulder at 59.5 feet	4.5	64
Conglomerate, fine to medium grained, some clay-shale fragments and sand, quartzose and feldspathic, moderately cemented, calcareous, very pale yellowish orange	7	71
CRETACEOUS—Gulfian		
Pierre shale		
Shale, compact, slightly calcareous, grayish yellowish green	7.5	78.5
Shale, compact, slightly calcareous, grayish yellowish green and yellowish orange	0.5	79
Shale, compact, slightly calcareous, light medium gray	1	80
Shale, compact, noncalcareous, medium gray; contains ferruginous material and gypsum crystals,	2	82
Shale, bentonitic, compact, noncalcareous, medium gray; contains abundant gypsum crystals	8	90

13-32-27aa3. *Sample log of test hole in the NE cor. sec. 27, T. 13 S., R. 32 W., drilled August 2, 1954. Surface altitude, 3,002.4 feet.*

	Thickness, feet	Depth, feet
Soil, light medium gray	0.7	0.7
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, yellowish gray; contains an abundant gastropod fauna	9.3	10
Silt, some fine to medium sand, quartzose, weakly cemented, calcareous, yellowish gray	4	14
Silt, considerable fine to medium sand, weakly cemented, calcareous, grayish orange	2	16
Silt, some fine to coarse sand, quartzose, weakly cemented, calcareous, grayish orange; contains gastropod fragments and some gypsum	2	18

	Thickness, feet	Depth, feet
Silt and fine to coarse sand, quartzose, some crystals of gypsum, weakly cemented, calcareous, grayish orange	2	20
Silt, some fine to coarse sand and clay, quartzose, moderately cemented, calcareous, grayish orange,	6	26
TERTIARY—Pliocene		
Ogallala formation		
Shale, some silt and fine to coarse sand, moderately cemented, calcareous, grayish orange pink	2	28
Shale, some silt and fine to coarse sand, compact, calcareous, pale grayish orange pink	3	31
Sandstone, fine to coarse grained, some fine gravel, quartzose, loose, calcareous, grayish orange pink,	2	33
Siltstone, much fine sand, quartzose, very firmly cemented, very calcareous, light gray to white	1	34
Sandstone, medium to coarse grained, some fine gravel, quartzose, loose, calcareous, grayish orange pink	3.5	37.5
Shale, compact, slightly calcareous, pale olive to grayish orange pink	1.5	39
Sandstone, medium to coarse grained, some fine gravel, quartzose, some feldspar, weakly cemented, slightly calcareous, pale grayish orange,	1	40
Sandstone, fine to coarse grained, some fine gravel, quartzose, weakly cemented, slightly calcareous, pale grayish orange	3.5	43.5
Sandstone, clayey, fine grained, shale and bentonite fragments, weakly cemented, slightly calcareous, grayish orange	6	49.5
CRETACEOUS—Gulfian		
Pierre shale		
Shale, bentonitic, compact, slightly calcareous, pale yellowish orange and light gray	0.5	50
Shale, bentonitic, compact, noncalcareous, medium gray	10	60

13-33-6bb. *Drillers log of livestock well owned by S. Dirks in the NW¼ NW¼ sec. 6, T. 13 S., R. 33 W., drilled in 1955 by John Heim. Surface altitude, 3,055 feet; depth to water, 695 feet.*

	Thickness, feet	Depth, feet
Soil	2	2
QUATERNARY—Pleistocene		
Meade Group or Sanborn Group		
Silt and clay, yellow	38	40
CRETACEOUS—Gulfian		
Pierre shale		
Shale, dark gray, tough drilling	125	165

	Thickness, feet	Depth, feet
Niobrara formation		
Chalk, light gray	35	200
Chalk, medium gray	580	780
Limestone, white	55	835
Carlile shale		
Shale, sandy, dark gray	15	850
Shale, dark gray	195	1,045
Sandstone, clayey	5	1,050
Greenhorn limestone		
Limestone, gray	25	1,075
Shale, dark gray	55	1,130
Graneros shale		
Shale, sandy, dark gray	45	1,175
Dakota formation		
Sandstone, silty and clayey, dark gray	20	1,195
Sandstone, white	25	1,220
Shale, compact, dark gray	10	1,230

13-36-12aa. *Sample log of test hole 40 feet west of the NE cor. sec. 12, T. 13 S., R. 36 W., drilled August 12, 1954. Surface altitude, 3,077.7 feet.*

	Thickness, feet	Depth, feet
Soil, silty, somewhat clayey, quartzose, weakly cemented, calcareous, pale yellowish brown	4	4
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains some gastropods and white calcareous material	11	15
Silt, slightly sandy, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains a few gastropods	5	20
Silt, some medium to coarse sand and clay, quartzose, weakly cemented, calcareous, very pale yellowish brown; contains some gastropods	6	26
Silt, much fine to coarse sand and clay, weakly cemented, calcareous, grayish orange	3	29
Silt, much fine to coarse sand and clay, quartzose, weakly cemented, very calcareous, pale grayish orange pink; contains much white calcareous material	3	32
Sanborn Group or Meade Group		
Conglomerate, medium to coarse grained, some fine gravel and medium to coarse sand, quartzose and feldspathic, loose, calcareous, grayish orange pink	8	40
Siltstone, coarse grained, much fine to medium sand, quartzose, moderately to weakly cemented, calcareous, grayish orange	12	52

	Thickness, feet	Depth, feet
Conglomerate, fine grained, some fine to coarse sand and medium gravel, quartzose and feldspathic, loose, calcareous, grayish orange pink	8	60
Conglomerate, fine grained, some fine to coarse sand and medium gravel, quartzose and feldspathic, weakly cemented, calcareous, grayish orange pink; contains some large cobbles or boulders	10	70
Conglomerate, fine to medium grained, some sand, quartzose and feldspathic, loose, slightly calcareous, grayish orange pink	7	77
Conglomerate, fine to medium grained, some sand, quartzose and feldspathic, very firmly cemented, very calcareous, very pale orange	2	79
Conglomerate, medium to coarse grained, some fine gravel, quartzose and feldspathic, loose, calcareous, grayish orange pink	9.5	88.5
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, moderately cemented, pale yellowish orange,	2.5	91
Chalk, moderately to firmly cemented, medium light gray	1	92

14-32-23bb. *Sample log of test hole in the NW cor. sec. 23, T. 14 S., R. 32 W., drilled August 2, 1954. Surface altitude, 2,820.3 feet.*

	Thickness, feet	Depth, feet
Soil, medium gray	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, pale yellowish brown; contains gastropods	6	7
Silt, considerable clay, and some fine sand, moderately cemented, calcareous, pale yellowish brown,	5	12
Meade (?) Group		
Shale, some silt and fine to coarse sand, moderately cemented, calcareous, pale grayish orange	5	17
Shale, much silt, and some fine to coarse sand, moderately cemented, calcareous, very pale orange	3	20
Shale, very silty, very little sand, moderately cemented, calcareous, very pale orange	5	25
Siltstone, some fine to coarse sand, and considerable clay, moderately cemented, calcareous, pale yellowish orange; contains some gypsum	8	33
Shale, some fine to coarse sand and silt, moderately cemented, very calcareous, very pale orange	3	36
Shale, some silt and medium to coarse sand, moderately cemented, very calcareous, very pale orange,	4	40

	Thickness, feet	Depth, feet
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, clayey, moderately compact, pale yellowish orange	3	43
Chalk, clayey, moderately to firmly cemented, pale yellowish orange and reddish orange layers	7	50
Chalk, some clay and gypsum crystals, moderately to firmly cemented, pale yellowish orange; contains gray clayey chalk	10	60
Chalk, clayey, moderately to firmly cemented, pale grayish orange	5	65
Chalk, clayey, firmly cemented, light to medium light gray	4.5	69.5

14-35-24bb. *Sample log of test hole 325 feet south of the NW cor. sec. 24, T. 14 S., R. 35 W., drilled August 3, 1954. Surface altitude, 3,202 feet.*

	Thickness, feet	Depth, feet
Road fill	2	2
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, quartzose, weakly cemented, calcareous, pale yellowish brown; contains an abundant gastropod fauna	8	10
Silt, much fine to medium sand, quartzose, weakly cemented, very calcareous, grayish orange pink,	5	15
Silt, some fine sand, quartzose, weakly cemented, calcareous, grayish orange pink; contains gastropod fragments	1	16
TERTIARY—Pliocene		
Ogallala formation		
Siltstone, some fine sand, quartzose, very firmly cemented, very calcareous and siliceous, white to grayish orange pink; extremely hard layer at 19.5 feet cemented by clear vitreous siliceous material,	4	20
Siltstone, much fine to coarse sand, quartzose, very firmly cemented, calcareous and siliceous, white to grayish orange pink	5	25
Conglomerate, fine to medium grained, some medium to coarse sand, quartzose and feldspathic, moderately cemented, calcareous, grayish orange pink to gray	5	30
Shale, clayey, moderately cemented, noncalcareous, yellowish gray	7	37
Shale, clayey, moderately cemented, slightly calcareous, yellowish gray	1	38

15-32-34cc. *Sample log of test hole in the SW cor. sec. 34, T. 15 S., R 32 W., drilled August 2, 1954. Surface altitude, 3,007.7 feet.*

	Thickness, feet	Depth, feet
Soil, medium gray	1	1
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, clayey, quartzose, weakly cemented, calcareous, dark yellow gray	2	3
Silt, quartzose, weakly cemented, calcareous, yellowish gray; contains gastropods	2	5
Silt, quartzose, weakly cemented, calcareous, yellowish gray; contains a very abundant gastropod fauna	5	10
Silt, clayey, quartzose, weakly cemented, calcareous, yellowish gray; contains many gastropods	6	16
Silt, considerable clay, quartzose, weakly cemented, calcareous, yellowish gray; contains gastropod fragments	2	18
Silt, clayey, some fine to coarse sand, quartzose, weakly cemented, very calcareous, pale grayish orange; contains much white calcareous material,	2	20
TERTIARY—Pliocene		
Ogallala formation		
Shale, somewhat silty, and some fine to coarse sand, moderately cemented, very calcareous, very pale orange; contains fragments of white calcareous siltstone	7	27
Shale, much silt and fine sand, moderately cemented, very calcareous, very pale orange	2	29
Sandstone, fine to coarse grained, some silt and clay, quartzose, loose, calcareous, grayish orange pink,	1	30
Siltstone, much clay, quartzose, firmly cemented, very calcareous, very pale orange	5.5	35.5
Siltstone, some clay and fine to coarse sand, firmly cemented, very calcareous, very pale orange	4.5	40
Siltstone, some fine to coarse sand and clay, quartzose, firmly cemented, very calcareous, very pale orange	5	45
Siltstone, some fine sand and clay, quartzose, moderately to firmly cemented, calcareous, pale grayish orange pink	3	48
Siltstone, some fine sand and clay, quartzose, moderately to firmly cemented, calcareous, pale grayish orange pink; contains white calcareous fragments	2	50
Siltstone, sandy, quartzose, moderately to firmly cemented, calcareous, pale grayish orange	4	54

	Thickness, feet	Depth, feet
Sandstone, fine grained, considerable silt, and some medium sand, quartzose, moderately to firmly cemented, calcareous, pale reddish orange	6	60
Sandstone, medium to coarse grained, much silt and fine sand, quartzose, moderately cemented, calcareous, very pale orange	5	65
Sandstone, medium to coarse grained, much silt and fine gravel, quartzose, moderately cemented, calcareous, pale grayish orange pink	5	70
Sandstone, medium to coarse grained, some fine gravel and silt, quartzose and somewhat feldspathic, loose, calcareous, pale grayish orange pink	3	73
Shale, much fine sand and silt, firmly cemented, very calcareous, white to very pale orange	1	74
Conglomerate, fine to medium grained, some coarse sand, quartzose and feldspathic, moderately cemented, calcareous, pale grayish orange pink	1	75
Siltstone, clayey, quartzose, moderately to firmly cemented, very calcareous, very pale orange; contains siliceous fragments	5	80
Siltstone, some fine to medium sand, quartzose, moderately cemented, calcareous, pale reddish orange	2	82
Siltstone, some fine to medium sand, quartzose, moderately cemented, very calcareous, very pale orange	8	90
Sandstone, fine grained, some silt and medium sand, quartzose, moderately to firmly cemented, very calcareous, very pale orange	10	100
Sandstone, fine grained, very much silt, quartzose, moderately to firmly cemented, very calcareous, moderate orange pink	5	105
Sandstone, fine grained, some silt and medium sand, quartzose, moderately to firmly cemented, very calcareous, very pale orange	8	113
Sandstone, coarse grained, some silt and fine to medium sand, quartzose, moderately cemented, very calcareous, pale grayish orange pink	3	116
Siltstone, some fine to medium sand, quartzose, moderately cemented, very calcareous, very pale orange	4	120
Siltstone, some fine sand and clay, quartzose, moderately cemented, very calcareous, very pale orange	4	124
Sandstone, fine to coarse grained, some fine gravel and silt, quartzose, weakly cemented, calcareous, pale grayish orange pink	11	135

	Thickness, feet	Depth, feet
Conglomerate, fine to medium grained, some medium to coarse sand and silt, quartzose and feldspathic, weakly cemented to loose, calcareous, grayish orange pink; a very hard cemented zone at 138.5 feet	5	140
Sandstone, fine to medium grained, much reddish clay, and some fine gravel and silt, quartzose, moderately to firmly cemented, calcareous, pale grayish orange	6	146
Shale, much silt, and some fine sand, moderately cemented, very calcareous, pale yellowish orange,	4	150
Shale, chalky, much clay, and some sand, moderately cemented, very calcareous, pale yellowish brown	3	153
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, clayey, moderately to firmly cemented, medium light gray	2	155

15-34-13cd. *Sample log of test hole in the SE¼ SW¼ sec. 13, T. 15 S., R. 34 W., drilled August 3, 1954.*

	Thickness, feet	Depth, feet
Road fill	3	3
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, clayey, quartzose, weakly cemented, calcareous, pale yellowish brown; contains some chalk fragments and many gastropods	3	6
Silt, clayey, quartzose, weakly cemented, calcareous, pale yellowish brown; contains abundant yellow chalky fragments	1	7
Silt, much clay, and some medium sand, quartzose, weakly cemented, calcareous, pale yellowish brown; contains fragments of yellow chalk as much as 10 mm in diameter	3	10
Silt, considerable clay and yellow chalky fragments, and some sand, quartzose, weakly cemented, very pale yellowish orange	5	15
CRETACEOUS—Gulfian		
Niobrara formation		
Chalk, clayey, firmly cemented, white to yellowish orange	5	20

15-36-19bb. *Sample log of test hole in the NW¼ NW¼ sec. 19, T. 15 S., R. 36 W.* (Bradley and Johnson, 1957), *drilled by State Geological Survey, 1951. Surface altitude, 3,372.0 feet.*

	Thickness, feet	Depth, feet
Soil, silt and clay, black	2	2
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, tan gray; contains some tan clay	10	12
Silt, tan gray and brown; contains some tan clay	7	19
TERTIARY—Pliocene		
Ogallala formation		
Clay, limy to silty, tan to light tan	10.5	29.5
Sand, fine to coarse, silty to sandy, embedded clay, tan	5.5	35
Sand, fine to coarse, and some limy to sandy clay	14	49
Opaline quartzite	5.5	54.5
Sand, fine to coarse, and some clay	6.5	61
Sand, fine to coarse, and tan-yellow clayey silt	5	66
CRETACEOUS—Gulfian		
Niobrara formation		
Clay, silty, yellow to yellow orange	5.5	71.5
Shale, clayey, gray	2	73.5

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MAP OF LOGAN COUNTY SHOWING AREAL GEOLOGY,

Water-Table Contours, and Contours at Base of Ogallala Formation

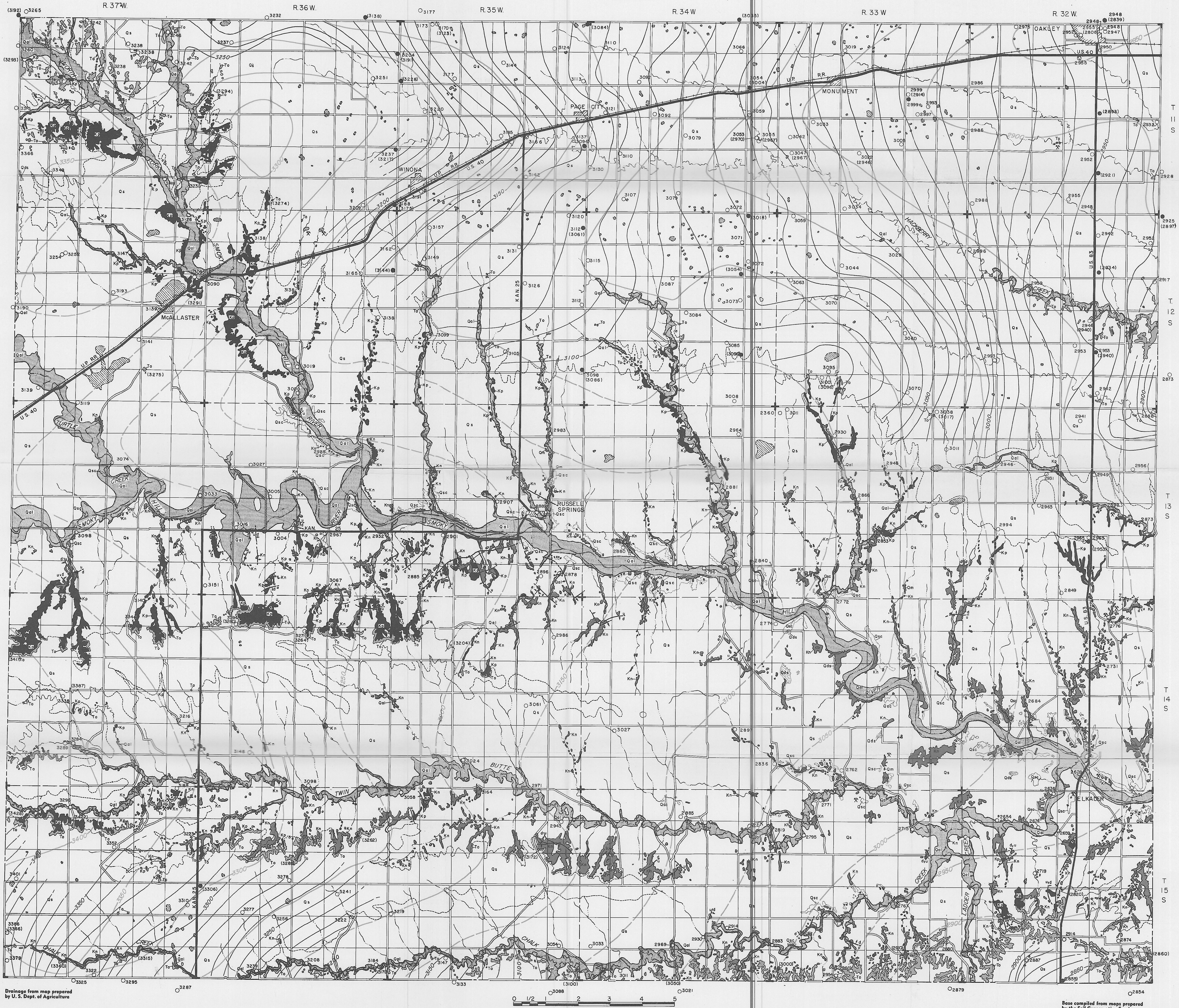
State Geological Survey of Kansas

By Carlton R. Johnson

1954

Bulletin 129

Plate 1



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

Base compiled from maps prepared by the Soil Conservation Service

EXPLANATION

QUATERNARY — PLEISTOCENE

Qal — **Alluvium**

Sand, gravel, silt, and clay along major valleys. Yields moderate to large amounts of water to wells.

Qds — **Dune sand**

Fine sand and silt on high ridges on south side of major valleys. Does not yield water to wells in Logan County.

Qs / Qsc — **Sanborn group**

In upper part, yellowish-gray silt (Qs) grading downward in some localities to fine to coarse sand; chiefly Bignell and Peoria formations; generally above the water table but yields water to some wells in valleys. In lower part, fine to coarse sand and some reddish-gray silt (Qsc), chiefly Crete formation; mapped along valleys where sufficiently thick to be of probable economic value; generally above the water table but yields water to some wells in valleys.

Qm — **Meade group**

Fine sand, shale, and volcanic ash along tributaries to major valleys. Generally is above the water table but may yield water to wells in some localities.

TERTIARY — PLIOCENE

To — **Ogallala formation**

Calcareous sandstone and interbedded reddish-gray clayey silt and persistent shale layers. Yields moderate to large amounts of water to wells in upland areas.

CRETACEOUS — GULFIAN

Kp — **Pierre shale**

Shale, medium gray, fissile. Not known to yield water to wells in Logan County.

Kn — **Niobrara formation**

Shaly chalk, yellow grayish orange to light gray. Yields water to a few wells where fractured.

Inferred contact between Ogallala formation and Cretaceous rocks.

○ 3247 (3120)

Well location. Number without parentheses refers to altitude of water table. Number in parentheses refers to altitude of base of Ogallala formation.

● 3200 (3116)

Test-hole location. Number without parentheses refers to altitude of water table. Number in parentheses refers to altitude of base of Ogallala formation.

x 3116

Location of known altitude of base of Ogallala formation.

2900

Contours connecting points of equal altitude of water table based on instrumental levels (omitted where water table is discontinuous).

Contour interval 10 feet

3150

Contours connecting points of equal altitude of base of Ogallala formation based on instrumental levels (dashed where erosion has removed Ogallala formation).

Contour interval 50 feet

- Federal or State Highway
- Graded road
- Railroad
- County line (no road)
- Township line (no road)
- Section line (no road)
- Intermittent stream
- Intermittent lake
- Fault (arrow indicates direction of dip)
- Quarry or pit

MAP OF LOGAN COUNTY

Showing Depth to Water and Location of Wells and Test Holes for which Records Are Given

State Geological Survey of Kansas

By Carlton R. Johnson

1954

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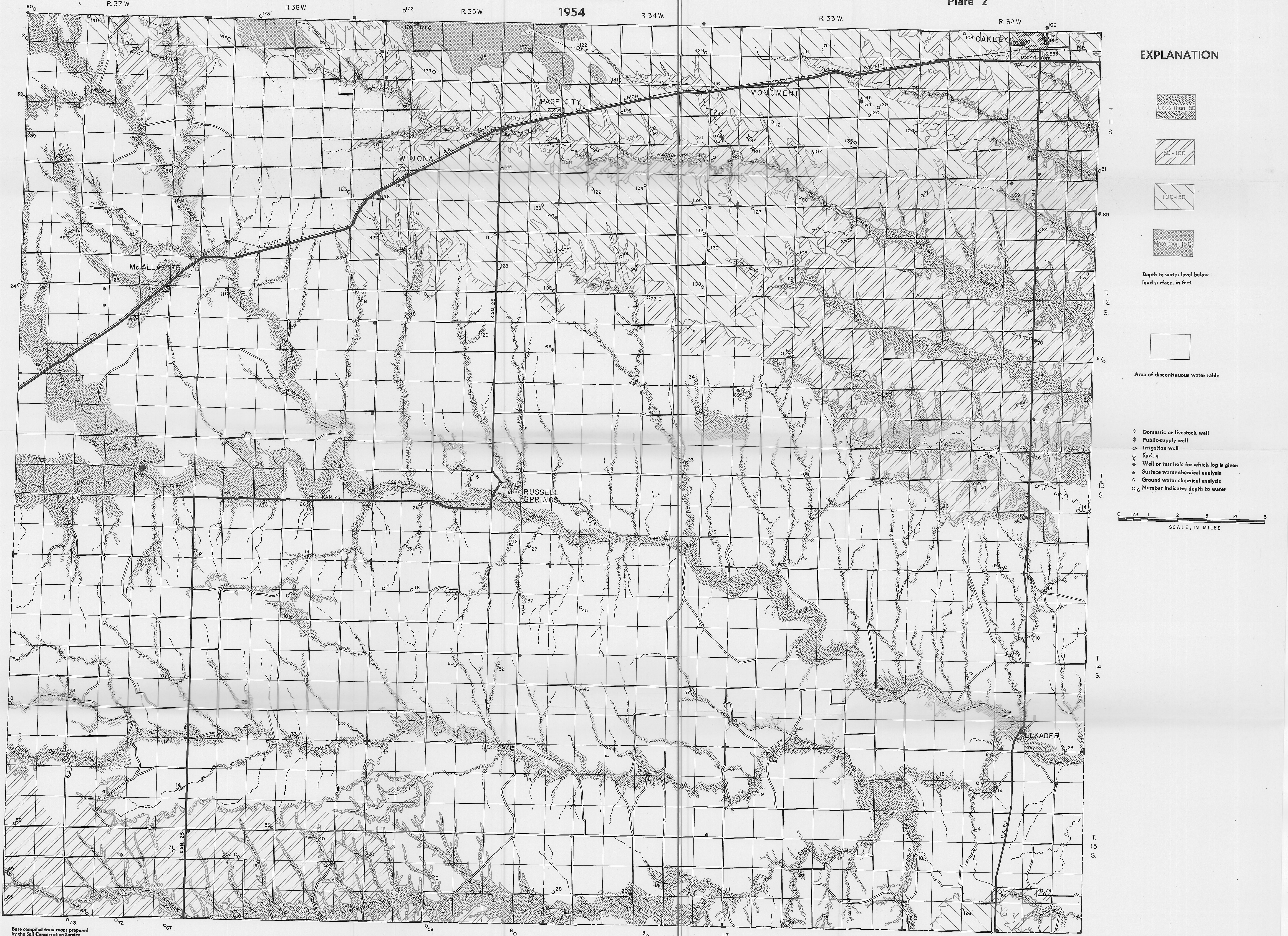
Plate 2



Base compiled from maps prepared by the Soil Conservation Service

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

State Geological Survey of Kansas

GEOLOGIC CROSS SECTIONS D-D', E-E'

LOGAN COUNTY, KANSAS

By Carlton R. Johnson

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Plate 4