Geology and Ground-Water Resources of Thomas County, Kansas

By

JOHN C. FRYE

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BULLETIN 59

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By John C. Frye
with analyses by
Howard Stoltenberg

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

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† Absent on leave for military service.

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BY JOHN C. FRYE

ABSTRACT

This report describes the geography, geology, and ground-water resources of Thomas county in northwestern Kansas. The hydrologic and geologic information was obtained in the field during the summers of 1942, 1943, and 1944. Depths and water levels were determined in 114 wells, and 29 test holes were drilled to determine the thickness and character of the water-bearing sand and gravel. Special attention was given to wells having large capacities, and pumping tests were made on four of the nine irrigation wells in the county. The data obtained from well measurements were utilized to plot water-table and depth to water maps of the county. The surficial deposits were studied in the field and a geologic map prepared.

The county lies in the High Plains section of the Great Plains physiographic province. It is drained by the Saline and Solomon rivers, tributaries to the Smoky Hill river, and by Prairie Dog and Sappa creeks, tributaries to the Republican river. For the most part the topography is a flat to gently rolling plain that slopes from west to east. The climate is subhumid to semiarid, the average annual precipitation being about 18 inches. Nearly all of the county is farm land and wheat is the principal crop.

Although Cretaceous rocks do not crop out any place in the county, the Pierre shale of Upper Cretaceous age underlies the entire county at relatively shallow depths. The Ogallala formation of Pliocene age overlies the Pierre shale and is the principal water-bearing formation of Thomas county. It crops out along the sides of the major valleys. The Sanborn formation overlies the Ogallala and is the surface formation in most of the upland areas of the county. Slope deposits of Recent age are derived from the unconsolidated beds and locally merge with the Sanborn and the alluvium. Thin deposits of alluvium of Recent age occur along the major valleys.

There are no permanently flowing surface streams in Thomas county. However, there is an abundance of ground water in most of the area and wells supply nearly all the water used in the county. Most of the wells obtain water from the Ogallala formation. In the county there are three city supplies (Brewster, Colby, and Rexford), several railroad wells, and nine irrigation wells. Pumping tests were made on four of the irrigation wells. The yields ranged from 295 to 1,021 gallons a minute and the specific capacities ranged from 11.2 to 56.5. The static water levels of the irrigation wells range from about 13 feet to about 130 feet. Conditions seem favorable for the expansion of irrigation developments along parts of the valleys of South Sappa creek, Prairie Dog creek, and the Solomon and Saline rivers. Certain areas on the uplands in the eastern, northern, and central parts of the county may **also** prove to be favorable for irrigation. The uplands in the southwestern part of the county, however, do not present favorable conditions for well irrigation.

Analyses of 27 samples of ground water are given, together with a discussion of the principal chemical constituents in relation to the use and geologic occurrence of the water. All the ground waters produced in the county are satisfactory for most ordinary purposes, but some are sufficiently hard to require softening for special uses.

Tabulated records of 114 water wells in all parts of the county and logs of 30 test holes and wells are given.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

An extensive program of ground-water investigations in the western part of Kansas was initiated in 1937 by the State Geological Survey of Kansas at the University of Kansas and the Geological Survey, United States Department of the Interior, in coöperation with the Division of Sanitation of the Kansas State Board of Health and the Division of Water Resources of the Kansas State Board of Agriculture. As a part of this general program an investigation of the geology and ground-water resources of Thomas county was begun in July, 1942; but due to the concentration of Survey activities on important war jobs and the shortage of personnel, the field work was interrupted and was not completed until the summer of 1944. The investigation was carried out under the general administration of R. C. Moore, State Geologist of Kansas, and O. E. Meinzer, Geologist in Charge of the Division of Ground Water of the Federal Geological Survey, and under the direct supervision of S. W. Lohman, Federal Geologist in Charge of ground-water investigations in Kansas.

Ground water is one of the principal natural resources of Thomas county; thus there is definite need for an adequate understanding of the quantity and quality of the available supply, where and how additional supplies can be obtained, and what measures are necessary to safeguard its continuance. Nearly all public, domestic, railroad, and stock supplies are obtained from wells. Ground water is also being used to some extent for irrigation, and it is possible that this use will increase in the future. At the present rate of withdrawal there seems to be little or no danger of seriously depleting the ground-water supply.

LOCATION AND EXTENT OF THE AREA

Thomas county is located in the High Plains in the northwestern part of Kansas and is bounded on the north by Rawlins county, on the east by Sheridan county, on the south by Logan and Gove counties, and on the west by Sherman county. Most of the area lies between 39° 8′ and 39° 35′ north latitude and 100° 44′ and 101° 22′ west longitude. It contains 30 townships, from T. 6 S., R. 31 W. to T. 10 S., R. 36 W., and has an area of about 1,070 square miles. Thomas county is rectangular in shape and extends about 36 miles east-west and about 30 miles north-south. The location of this county and other areas in which coöperative ground-water investigations have been made are shown in figure 1.

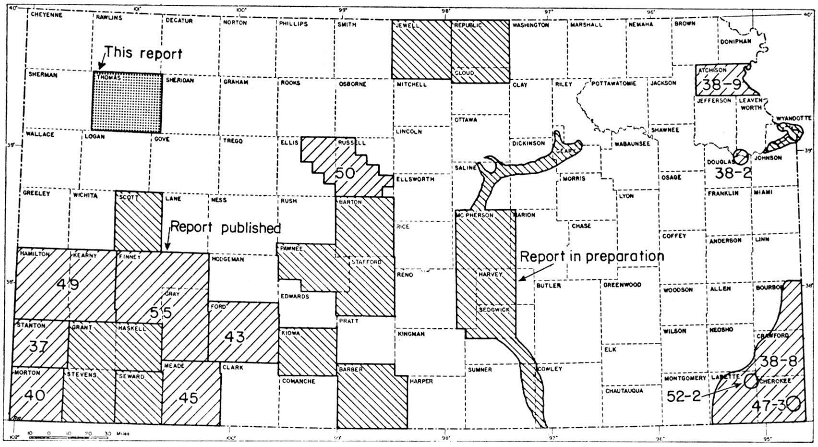


FIG 1. Index map of Kansas showing area covered by this report and areas for which coöperative ground-water reports have been published or are in preparation.

PREVIOUS INVESTIGATIONS

A detailed study of the ground-water resources of any northwestern Kansas county has not previously been undertaken. Haworth in 1895 studied the regional geology and water resources of western Kansas (Haworth, 1897); Johnson (1901, 1902), in his report on the utilization of the Southern High Plains, made special reference to the source, availability, and use of ground water in western Kansas; and Darton (1905) made a study of the geology and ground-water resources of the Central Great Plains. A detailed investigation of the geology of Wallace county, adjacent to Thomas county on the southwest, was published by the State Geological Survey in

1931 (Elias, 1931), and a description of the geology and ground-water resources of Rawlins and Decatur counties was published in 1937 (Elias, 1937). A reconnaissance of the Quaternary deposits of northwestern Kansas has been made recently (Leonard and Frye, 1943; Hibbard, Frye, and Leonard, 1944).

Coöperative ground-water investigations have been undertaken in several southwestern Kansas counties (fig. 1). Those published include reports on Stanton county (Latta, 1941), Morton county (McLaughlin, 1942), Ford county (Waite, 1942), Meade county (Frye, 1942), Hamilton and Kearny counties (McLaughlin, 1943), the oil-field areas of Ellis and Russell counties (Frye and Brazil, 1943), and Finney and Gray counties (Latta, 1944).

METHODS OF INVESTIGATION

Six weeks in the summer of 1942, two weeks in 1943, and one week in 1944 were spent by me in the field in Thomas county collecting data for this report. During this time a large number of the wells listed in table 9 were visited and the depths to water level in them were measured. All measurements of water level were made using a steel tape from a fixed measuring point at the top of the well. W. W. Wilson measured additional wells in the southwestern part of the county during 1943, and in 1942 and 1943 he made periodic measurements of the observation wells. Subsequently the observation wells were measured by Allan Graffham and Howard Palmer.

During the course of the field work the geology of the county was studied and a geologic map (pl. 1) was prepared. The character of the materials below the surface was ascertained by the drilling of 29 test holes through the entire thickness of water-bearing sand and gravel and into the Pierre shale. These test holes were drilled with the hydraulic-rotary drilling machine owned by the State and Federal Geological Surveys and operated by Nick Fent and Milford Klingaman. Logs of the test holes were prepared in the field by Fent, and these were later supplemented by microscopic examination of the cuttings. The altitudes of the measuring points in most of the measured wells and of the test-hole locations were determined using a plane table and alidade by a level party headed by Charles K. Bayne. The wells shown on plate 2 were located within the sections by use of the speedometer, and the locations are believed accurate to within about 0.1 mile. The wells are numbered by townships from north to south and by ranges from east to west;

within a township the wells are numbered in the same order as the sections. For each well shown on plate 2 the number above the line corresponds to the number of the well in the well tables and the number below the line is the depth to the ground-water table below a fixed measuring point.

Samples of water were collected from 24 wells in the county and chemical analyses of them were made by Howard Stoltenberg, Chemist, in the Water and Sewage Laboratory of the Kansas State Board of Health.

The base map of the county used in plates 1 and 2 was compiled by Dorothea Weingartner from the Colby quadrangle (planimetric map) published by the Federal and State Geological Surveys, aerial photographs from the Agricultural Adjustment Administration of the United States Department of Agriculture, and aerial photographs from the Soil Conservation Service of the United States Department of Agriculture. A map of the county compiled by the State Highway Department was used for field mapping.

ACKNOWLEDGMENTS

Thanks and appreciation are expressed to the many residents of Thomas county who supplied information and aided in the collection of field data. Special thanks are extended to the owners of several irrigation wells who permitted pumping tests to be made and to the city officials of Brewster, Colby, and Rexford who furnished information about their respective city wells. George S. Knapp, Chief Engineer of the Division of Water Resources, Kansas State Board of Agriculture, and Elbert Coles, Director of the Colby Experiment Station, supplied measurements made in 1914 and subsequent years and pumping data on a well at the Colby Experiment Station. August Lauterbach assisted me in the field in the measurement of a stratigraphic section of the Ogallala formation. A. Byron Leonard identified fossil snails collected from the Pleistocene deposits and C. W. Hibbard identified fossil vertebrates collected from Pliocene and Pleistocene deposits.

The manuscript for this report has been reviewed critically by S. W. Lohman, O. E. Meinzer, and W. D. Collins of the Federal Geological Survey; J. M. Jewett of the State Geological Survey of Kansas; Paul D. Haney, Director, and Ogden S. Jones, Geologist, of the Division of Sanitation of the Kansas State Board of Health; and George S. Knapp, Chief Engineer of the Division of Water Resources of the Kansas State Board of Agriculture.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

Thomas county lies entirely within the area designated by Fenneman (1931) as the High Plains section of the Great Plains physiographic province. The county consists of nearly flat to gently rolling uplands broken by relatively shallow valleys. The upland-plains surface generally slopes eastward at a rate of somewhat more than 12 feet to the mile. The lowest point in the county is along the valley of Prairie Dog creek where that stream crosses the Sheridan county line, and has an altitude of about 2,845 feet. The highest area in the county is along the Sherman county line south of Brewster where the upland surface attains an altitude of as much as 3,375 feet.

Although the general region of which Thomas county is a part is called the High Plains, it has some of the features of a plateau—that is, it is essentially a flat upland surface that stands distinctly above the surrounding regions. The High Plains are terminated eastward in parts of central Kansas by an escarpment produced by the eroded edge of the Fort Hays limestone member of the Niobrara chalk. At some places a second east-facing escarpment, produced by the loosely cemented conglomerates of the Ogallala formation, occurs to the west of the outcrop of the Fort Hays. A less distinct west-facing escarpment, also formed by the eroded edge of the Ogallala formation, can be seen due west of Thomas county in eastern Colorado. South of Thomas county the High Plains upland stands above the dissected area comprising the Smoky Hill valley.

Thomas county contains the headwater areas of several important streams flowing across northwestern and north-central Kansas. The north and south forks of the Saline river and the north and south forks of the Solomon river, streams that drain most of north-central Kansas and empty into the Smoky Hill river in Saline county, and Prairie Dog creek, an important southern tributary to the Republican river, all originate in Thomas county. In addition to these streams North and South Sappa creeks which originate to the west in Sherman county flow across the northwestern and north-central parts of Thomas county and are also important southern tributaries to the Republican river. The streams of Thomas county make a fan-shaped pattern, originating for the most part in the area south and east of Brewster and diverging toward the north and east. This divergence gives an east-northeasterly course to all the streams of the county with the exception of the Saline river and South Fork of the Solomon river.

In spite of the large number of important streams that originate in or flow across this county, it is not well supplied with surface water and parts of it are not well drained. No stream in the county contains flowing water during dry weather, and, with the exception of South Sappa creek north of Gem and the Saline river east of Oakley, the stream channels contain flowing water only during and after rains. At many places along these channels, however, small ponds contain water for weeks after the streams have ceased to flow.

The upland areas are not everywhere well drained because of their excessive flatness and the presence of shallow depressional areas. Some of these depressions are more than 10 feet deep and contain water several weeks after rains, whereas others are quite shallow and hold ponds only during and immediately after rains.

Climate

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

The average mean annual temperature at Colby is 51.8° F. In general the hottest month is July with an average temperature of 76.0° F. for 33 years of record, and the coldest month is January with 28.6° F. The average growing season—that is, the interval between the last killing frost in the spring and the first killing frost in the fall—is about 159 days. The average date for the last killing frost in the spring is May 1 and for the first killing frost in autumn is October 7. The latest date for a killing frost in the spring has been May 26 and the earliest in the fall has been September 7.

The normal annual precipitation at Colby determined by the U. S. Weather Bureau is 18.39 inches and the average since the beginning of record is 17.95 inches. The range in amount of annual rainfall since 1888 is 25.20 inches. The smallest precipitation of any year of record was in 1910 when only 6.61 inches was recorded at Colby and the greatest of record was that of 1915 when 31.81

inches was recorded. The bulk of the rainfall occurs during the growing season, when the average precipitation for this six-month period in this part of Kansas is approximately the same as that in the Dakotas, and three-fourths of the average for Illinois, Indiana, or Ohio.

The annual rainfall for the period of record and the cumulative departure from normal are shown in figure 2. Although the annual rainfall seems to present an irregular pattern, the cumulative departure from normal has a roughly cyclic pattern of recurrent wet and dry periods. The shape of the graph rather than the area above or below the normal line is the significant feature as the placement of the curve with respect to normal is largely influenced by conditions at the beginning of the period of record.

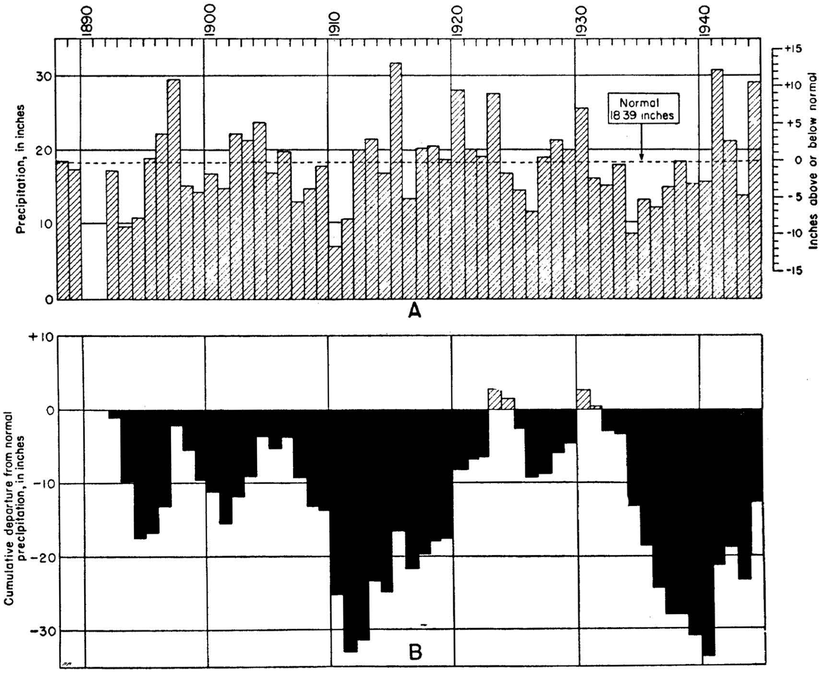


FIG. 2. Graphs showing (A) the annual precipitation at Colby, and (B) the cumulative departure from normal precipitation at Colby. (From records of the U. S. Weather Bureau).

POPULATION

According to the 1940 census, the population of Thomas county was 6,425, an average of 6.0 people per square mile as against 21.9 for the entire state. The population has fluctuated in recent years as shown by the census figures for 1920 and 1930 which were 5,517 and 7,334, respectively. In 1940 more than half the residents of the county lived in five cities. Colby, the county seat and largest city in the county, had a population of 2,458. The Census Bureau lists population figures for four other cities in 1940: Brewster, 408; Rexford, 244; Menlo, 144; and Gem, 125.

TRANSPORTATION

Thomas county is crossed by the main line of the Chicago, Rock Island, and Pacific Railroad from Chicago to Denver, which traverses the county east to west through Rexford, Gem, Colby, Levant, and Brewster. A branch line of the Union Pacific Railroad enters from the east at Menlo and runs westward through Halford to Colby; from Colby this line runs southeastward through Mingo to Oakley, where it connects with the main east-west line of the Union Pacific Railroad.

Several hard-surfaced Federal and State highways pass through Thomas county. U. S. highway 24 crosses east-west about midway from north to south and passes through Menlo, Halford, Colby, Levant, and Brewster. U. S. highway 83 enters the county from the northeast at Rexford and passes southward through Halford to the county line. The remainder of the county is served by numerous improved county and township roads (pl. 1).

AGRICULTURE, NATURAL RESOURCES, AND INDUSTRIES

Agriculture is the chief occupation in Thomas county. In 1940 virtually all the land was in farms. According to the sixteenth U. S. census, in 1939 there were 955 farms having an average size of 735.8 acres. The principal crop is wheat, and Thomas county has been one of the leading producers in the state during recent years. The principal uses of land in 1939 as reported by the U. S. Census Bureau are given in table 1. Although 1939 may not be a typical year for the county, it is the most recent year for which figures are available.

TABLE 1.—*Acreage of principal land uses in Thomas county in 1939*

(Data from U. S. Census Bureau)

USE	Acres	Percent
Wheat threshed	129,560	18.5
Sorghums	38,004	5.4
Barley threshed	29,496	4.2
Small grain hay	5,408	0.8
Idle or fallow	194,823	27.8
Crop failure	106,361	15.1
Plowable pasture	101,809	14.5
Woodlands	795	0.1
All other lands	88,836	12.7

Agriculture, natural resources, and industries have been grouped together for consideration because of the complete overshadowing by agriculture of all other enterprises in the county. No other important industries exist here except as a service to agriculture. The paramount natural resources are the deep and fertile soil and the underground water, a discussion of which occupies many of the succeeding pages of this report. Some sand and gravel are produced for road surfacing and building purposes. Exploration for oil and gas has been carried on in the county and, as rocks that produce these substances elsewhere in the state are known to occur at considerable depth below the surface of Thomas county, it is not unreasonable to expect that continued exploration may be rewarded with a measure of success.

GEOLOGY

SUMMARY OF STRATIGRAPHY

The surface geology of Thomas county is relatively simple. All the rocks that crop out at the surface are sedimentary in origin, are of Quaternary and Tertiary age, and for the most part are unconsolidated. The named formations are listed in table 2, and their areal distribution is shown on plate 1. Cross sections in figures 3 and 4 show the general relationship of the several formations. It will be noted by reference to the geologic map (pl. 1) that somewhat more than 90 percent of the surface area of the county is underlain by deposits of Quaternary age that are assigned to the Pleistocene Sanborn formation and the Recent slope deposits and alluvium. The oldest beds exposed are assigned to the Pliocene Ogallala formation.

Table 2.—*General section of the geologic formations of Thomas county, Kansas*

System	Series	Subdivisions	Thickness, in feet	Character	Water supply
Quaternary	Recent	Alluvium	0–30	Silt, sand, and gravel along the major stream valleys. Mostly sandy silt but locally poorly sorted sand and gravel.	Yields water to wells only at a few places along such valleys as South Sappa and Prairie Dog creeks.
	Recent and Pleistocene	Sanborn formation (Pleistocene) and slope deposits (Recent)	0–65	Silt, massive, with locally some sand and gravel at base. Slope deposits are silt, sand, and gravel.	Generally above the water table and yields little or no water to wells.
Tertiary	Pliocene	Ogallala formation	60–275	Sand, gravel, silt, and clay, some zones cemented with calcium carbonate to form hard "mortar beds." Individual beds generally lenticular.	Yields abundant supplies of water of good quality and is the source of water for nearly all the wells in the county.

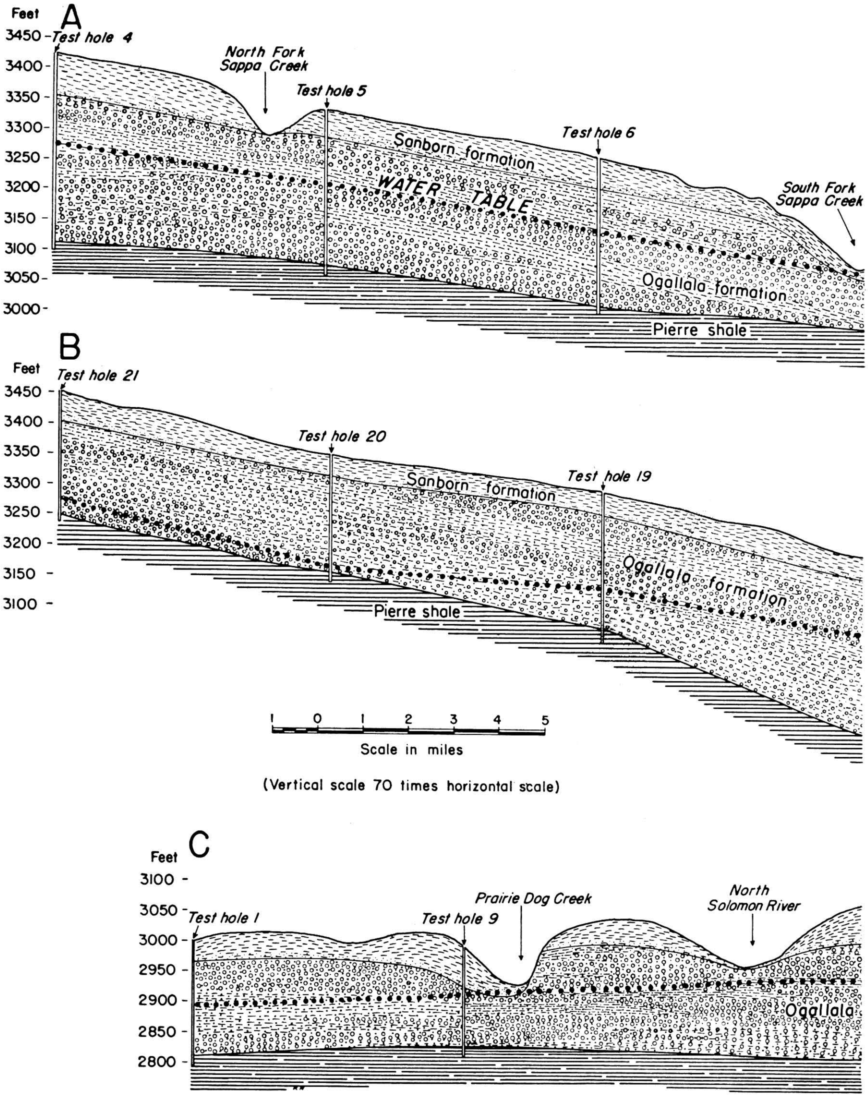
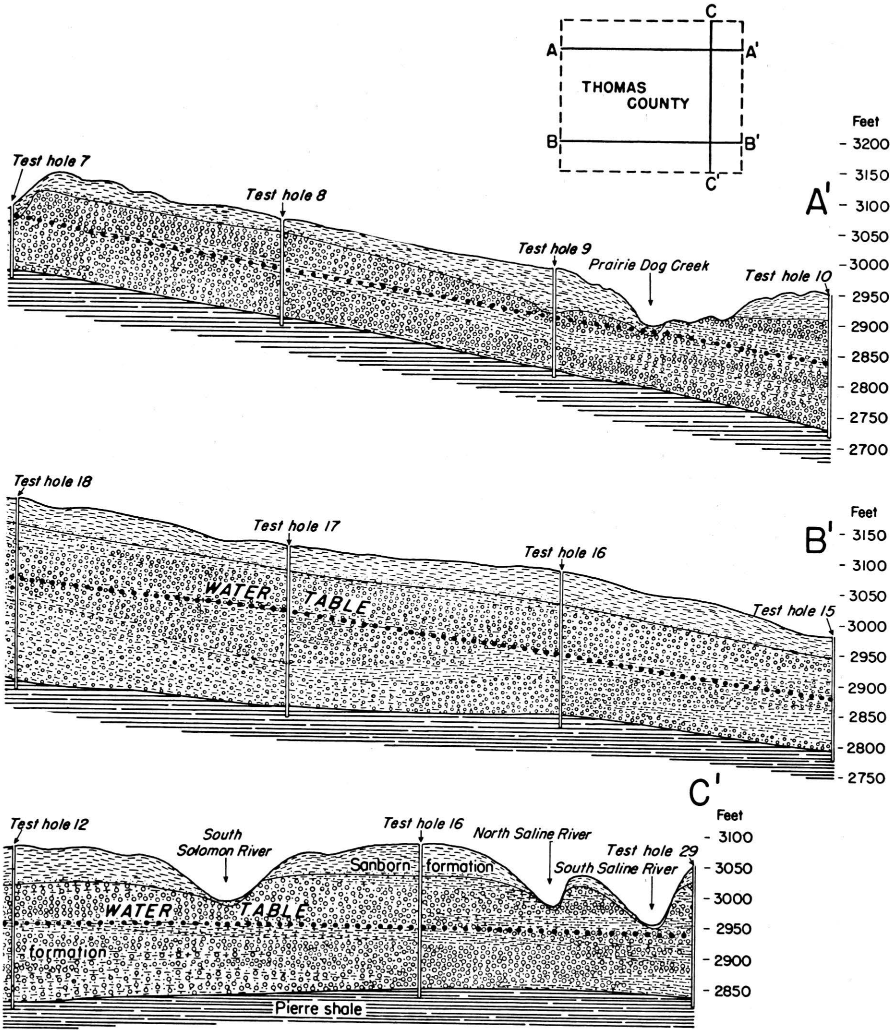


FIG. 3. Cross sections of Tertiary and Quaternary deposits in Thomas section 6 miles north of south county line; *C*, north-south section 6 miles west



county: *A*, east-west section 6 miles south of north county line; *B*, east-west of east county line.

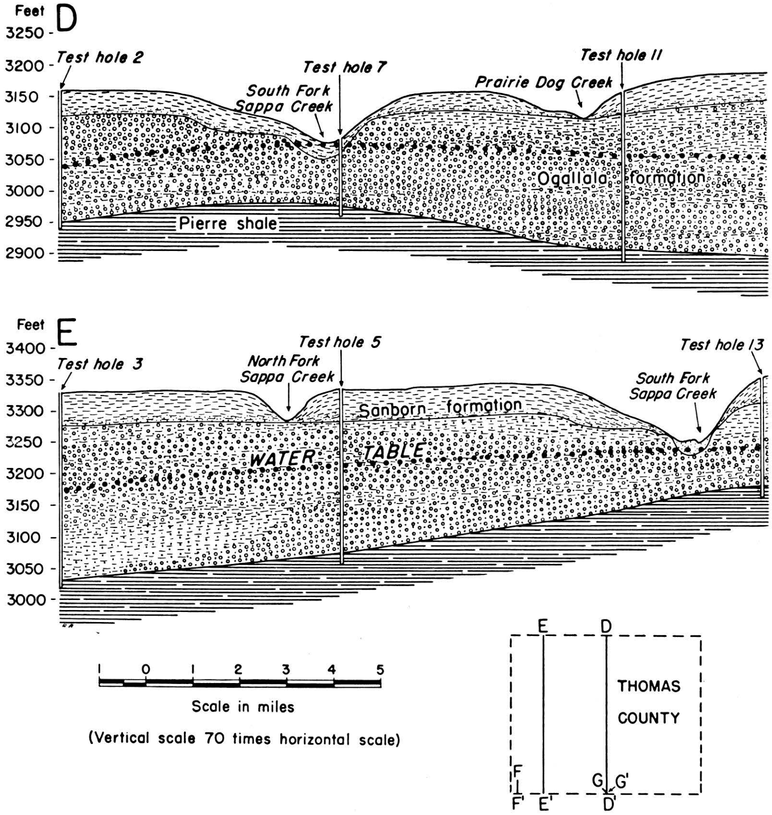
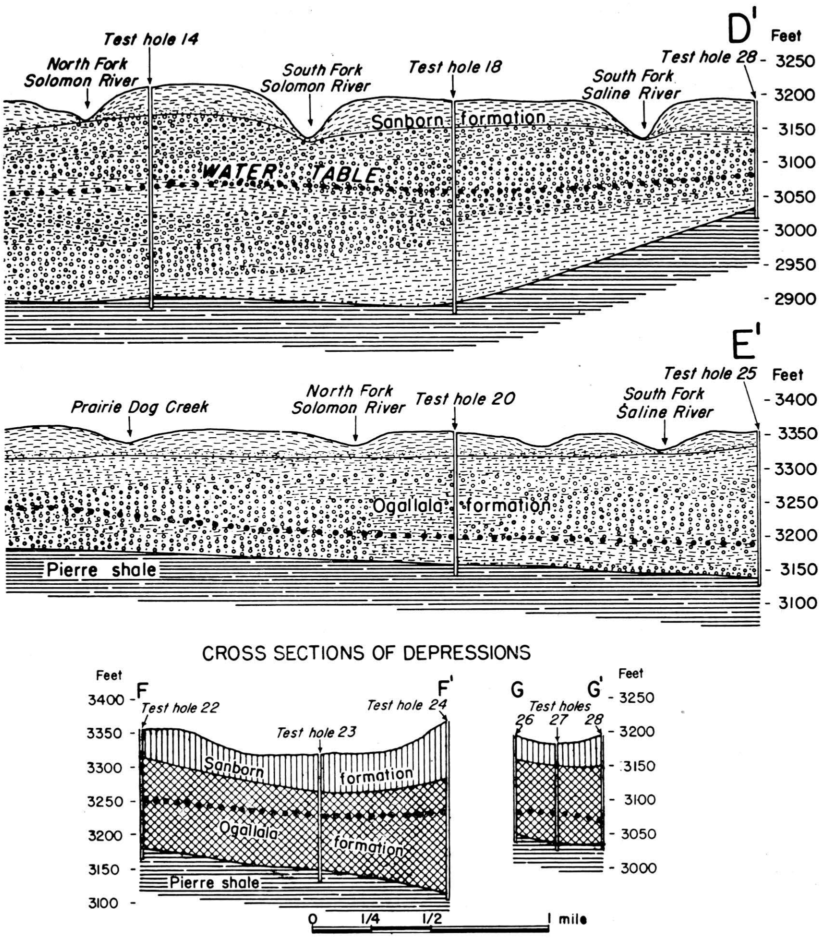


FIG. 4. Cross sections of Tertiary and Quaternary deposits in Thomas east of west county line; *F*, section through depression area, T. 10 S., R. 36



county: *D,* north-south section through Colby; *E,* north-south section 6 miles W.; *G,* section through depression area, sec. 36, T. 10 S., R. 34 W.

GEOLOGIC HISTORY AND GEOMORPHOLOGY

PALEOZOIC ERA

Rocks of Paleozoic age do not crop out in northwestern Kansas, but many facts concerning them and the Paleozoic history of this region are known from deep tests drilled for oil and gas. The known geologic history of this area starts with erosion of the pre-Cambrian basement rocks that occur below the Paleozoic strata. This ancient erosion surface was submerged below sea level and marine sediments were deposited upon it. Throughout much of Paleozoic time the area was successively submerged and elevated. Marine sediments accumulated during periods when the surface was below sea level, and these deposits were subsequently eroded during periods of emergence. The lower Paleozoic rocks consist for the most part of marine limestone, shale, and sandstone.

Thomas county lies just off the southwest flank of the prominent regional structure in the Paleozoic rocks known as the Central Kansas uplift, and the pre-Cambrian surface below the county is less than 2,500 feet below sea level. According to Moore and Jewett (1942) an important structural event occurred in this area between Devonian and Mississippian deposition. This consisted of a regional arching of the strata along a northwest-southeast axis and is indicated by the fact that pre-Mississippian erosion truncated the earlier Paleozoic rocks and stripped off all the beds down to the Arbuckle limestone. Although data from the immediate vicinity of Thomas county are not conclusive as to such a history, it is inferred from relationships farther east, where many more data are available, that Thomas county is included in the general area of the structure designated as the Ellis arch. This period of uplift and subsequent erosion is believed to have been followed by marine inundation and resulting deposition of the Mississippian strata over this part of Kansas.

The rocks of northwestern Kansas were again uplifted and warped along this same general structural trend at the close of Mississipian time or during early Pennsylvanian time to form the structural feature now recognized as the Central Kansas uplift. Moore and Jewett (1942) show that this structure in the central part of Kansas is nearly coincident with the earlier structure they designated as the Ellis arch. In the northwestern part of the state, however, they indicate that the two structures do not occupy the same location. The Ellis arch trended to the west-northwest across this part of the state and included all of Thomas county, but the Central Kansas uplift trends north-northwest and includes the northeastern corner of Sheridan county to the east of Thomas county.

The Mississippian strata believed to have existed across the top of the Central Kansas uplift were largely stripped away by early Pennsylvanian erosion, but more than 250 feet of these rocks remain beneath Thomas county. Coarse clastic sediments accumulated along the flanks of the uplift as a result of this period of erosion, and it is believed that they may have been contemporaneous with the denudation deposits that were spread out toward the east from the ancestral Rocky Mountains.

The sea again invaded the area and marine deposits accumulated across all of northwestern Kansas during Pennsylvanian time. During the latter part of the Paleozoic, marine conditions were less prevalent and at times sediments accumulated on the surface of the land. Thus marine and nonmarine deposits occur alternately throughout rocks representing upper Pennsylvanian and Permian time. Evaporites and nonmarine sediments became more prevalent throughout Permian time, indicating an intermittent but progressive withdrawal of the sea.

MESOZOIC ERA

The sea withdrew completely from the area by the close of Paleozoic time and the surface was eroded, uplifted, and warped. Erosion proceeded throughout much of Triassic time and at least part of the area again received deposits during part of Jurassic time. Landes and Keroher (1939, p. 25) have described the subsurface geology of Logan, Gove, and Trego counties to the south of Thomas county and stated concerning these Jurassic deposits:

> The shale section 100 to 200 feet thick which immediately overlies the Permian, in some places, has been tentatively correlated with the Morrison formation. The age of this formation has not been exactly determined, but evidence based on paleontology strongly indicates that it is Jurassic. These rocks consist predominantly of green shale with an abundance of pink jasper-like chert. Translucent pink gypsum occurs near the base. An interesting zone of doubly terminated quartz crystals which was noted in a number of wells may prove to be useful in correlation. An unconformity at the base of the Jurassic (?) rocks marks the top of the Permian system. Due to the lithologic change in the rocks this unconformity is easily recognized and therefore is a valuable correlation point for geologists.

An erosion interval followed the deposition of these supposed Jurassic deposits and this general area probably stood above sea level during part of Jurassic time and the early part of Cretaceous time. As the early Cretaceous sea inundated this area, clastic sediments accumulated at and near the shore line as beach deposits, deltas, and offshore bars. The sea completely inundated this area and marine sediments were laid down. Nonmarine conditions probably again existed throughout part of the time of deposition of the Dakota formation, and then the sea completely transgressed the area for the last time and the Graneros shale and overlying marine formations of Upper Cretaceous age were deposited. That this area gradually subsided throughout Upper Cretaceous time is indicated by the presence of more than 2,000 feet of fine-textured shallow-water Upper Cretaceous deposits. These strata consist of chalk and chalky limestones (Greenhorn limestone and Niobrara chalk) alternating with shale and calcareous shale (Graneros shale, Carlile shale, and Pierre shale).

CENOZOIC ERA

Tertiary period

Erosion and deposition.—Thomas county, as a part of the Great Plains, must be considered in the light of events affecting the general region lying east of the Rocky Mountains. Since the withdrawal of the Cretaceous sea this area has been continually above sea level, and during early Tertiary time much of the Great Plains region was subjected to subareal erosion. There was extensive uplift in the Rocky Mountain area and streams flowing outward from this region crossed the Great Plains. Deposition of clastic sediments started at an earlier time in the northern part of the plains region than it did in Kansas. In Nebraska sediments of the White River group were deposited in Oligocene time and the Arikaree and Hemingford groups were deposited during Miocene time (Lugn, 1939, p. 1,264) prior to Tertiary deposition in northwestern Kansas. The oldest Tertiary deposits in the vicinity of Thomas county are classed as being part of the Ogallala formation and are believed to be of Pliocene age.

The Tertiary beds of western Kansas were first thought to represent lake deposits (Hay, 1890; Williston, 1895), but a half century ago they were demonstrated to be of fluviatile origin (Gilbert, 1896; Haworth, 1897; Johnson, 1901). Smith (1940, pp. 77, 78) has stated of the Ogallala:

> In the light of present knowledge, the Ogallala may be described as a warped and dissected piedmont alluvial plain deposit. It is not to be regarded as a composite fan deposit as supposed by some workers, however, for its thickness increases away from the mountain front, whereas that of a fan deposit decreases outward from a point near its apex.

Streams flowing outward from the mountain area carried debris eroded from the highlands and deposited this material as a complex sequence of lenticular and sheetlike bodies of gravel, sand, silt, and clay. The surface upon which the Ogallala was deposited was a plains area having a topography of low relief, and the deposits of these streams not only filled their shallow valleys but spread also across the divides.

Events terminating Ogallala deposition.—At the close of the period of deposition of the Ogallala formation the aggradational plain in the Great Plains region merged with an erosional plain in the Rocky Mountain region. Fenneman (1931, p. 107) has summarized the conditions at this time as follows:

> It may be assumed that at the close of the later cycle the greater part of this province and others adjacent were covered by a continuous graded plain, made by degradation of the mountains and aggradation of the Great Plains. The peneplain in the mountain province is believed to correspond in geologic date with the surface of the Pliocene sediments that now cover the High Plains.

This plain of aggradation that covered northern Kansas completely obliterated all preëxisting topography. Such Cretaceous strata as the Fort Hays limestone member of the Niobrara formation and the Greenhorn limestone that now form prominent escarpments along their belts of outcrop were blanketed by at least a thin veneer of Tertiary sediments.

At many places a distinctive hard bed of limestone occurs at the top of the Ogallala. This limestone was described by Elias (1931, pp. 136-141) and named the "*Chlorellopsis* limestone" or "Algal limestone" from the presence of abundant remains of the alga *Chlorellopsis bradleyi* Elias. Wherever observed in northwestern Kansas and Nebraska, this limestone bed marks the top of the Ogallala formation. Elias (1931, p. 141) believed that ". . . this rock was deposited on the nearly flat bottom of a very large and very shallow lake at the close of Ogallala time." Smith (1940, pp. 90-92) raised some questions about the proposed lacustrine origin of the "Algal limestone," and Theis (1936) has attributed the origin of the capping limestone in the area south of Kansas to small lakes produced by the flooding of shallow depressions by a rising water table. A previously unknown occurrence of "Algal limestone" that seems to have some significance concerning the origin of the bed was discovered in east-central Russell county (center east line sec. 3, T. 14 S., R. 11 W.) on the highest part of the divide between the Saline and Smoky Hill rivers. At this locality somewhat less than

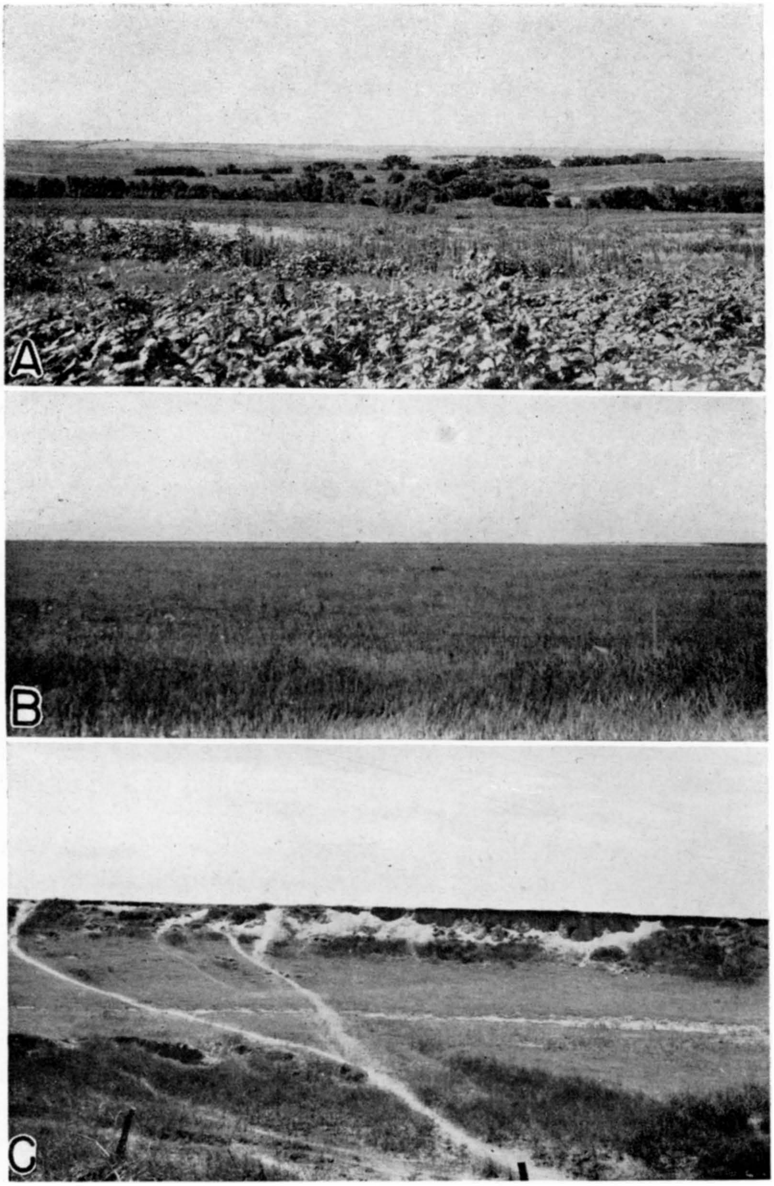


Plate 3. *A,* Valley of South Sappa creek, northeastern Thomas county. *B,* High Plains, NE¼ sec. 19, T. 6 S., R. 33 W., looking east. *C,* Silt of the Sanborn formation along the valley of South Sappa creek, near Rexford.

10 feet of Ogallala beds, consisting mostly of "Algal limestone," is exposed directly in contact with chalky shales of the upper part of the Cretaceous Greenhorn limestone. The abandoned Wilson valley (Frye, Leonard, and Hibbard, 1943), which is cut completely through the Greenhorn and underlying Graneros shale, occurs a short distance to the east of this locality. This exposure has been visited by Elias who identified the beds as "Algal limestone." The locality is remote from other exposures of the Ogallala formation, the nearest being 35 miles to the west in northern Ellis county where it overlies the Fort Hays limestone member of the Niobrara chalk. As this newly discovered exposure of "Algal limestone" is located on top of an upland divide underlain by the Greenhorn limestone, it demonstrates that the outcrop of the Greenhorn, like that of the Fort Hays, was reduced to the general level of the aggradational plain at the close of the period of Ogallala deposition.

At the end of Ogallala deposition, when the streams were no longer spreading sediments in the area and before they had started to dissect the surface of this plain, the channels probably shifted laterally. Stream channels at various times may have occupied most points on this surface. Such lateral shifting of channels would result in the formation of many lakes, for the most part disconnected and occupied by standing water. The water table may have stood at such a level that these lakes were all "water table lakes." Such lakes, consisting of abandoned channel segments and consequent depressions on a plain of alluviation, would meet the environmental requirements stipulated by Elias (1931, p. 141) for the development of the "Algal limestone" without recourse to the complicated diastrophic movements objected to by Smith (1940, p. 91).

Quaternary period

Post "Algal limestone" erosion.—A diastrophic event of major importance occurred in northwestern Kansas after the deposition of the "Algal limestone." As has been pointed out, the streams shifted laterally over the Ogallala deposits, modifying or destroying the former drainage pattern. After the time of deposition of the "Algal limestone" the major streams, in whatever position they happened to occupy, started to entrench their channels through their former deposits and, in those areas where the Ogallala was quite thin, into the underlying bedrock. The causes for this period of erosion are complex and probably include both differential uplift and climatic changes.

Smith (1940, pp. 80-85) reviewed the paleophysiography of the Ogallala formation and after discussing several possible hypotheses stated as follows (p. 84):

> Remaining . . . is the hypothesis of an originally more or less even depositional plain of low latitudinal gradient, subjected later to strong differential tilting. This tilting must have been very moderate along the present Platte and Arkansas valleys, and comparatively steep along the divide between them, the amount of uplift progressively increasing toward the mountains. The Ogallala surface was probably affected as far eastward as the western third of Kansas. The semi-radial drainage pattern of the central High Plains constitutes supporting evidence for this hypothesis, being best explained as of consequent origin on an upwarped depositional surface.

Although this period of erosion produced the most important disconformity within the Cenozoic deposits of northwestern Kansas, the exact time of the event is not definitely known. The Pliocene-Pleistocene time line generally used in North America is based largely on glacial deposits, and in the High Plains area there are many problems concerning its correlation (Frye, 1945). Present data indicate that this erosion period started before the beginning of Pleistocene time as generally used.

Pleistocene deposition.—Alluvial deposits began to accumulate in the valleys of the major streams in northwestern Kansas after the initial entrenchment of the streams in the Tertiary deposits. Elias (1931, p. 163) named these alluvial deposits and the overlying silt or loess the Sanborn formation. Sand and gravel comparable to the lower part of the Sanborn were not deposited widely over Thomas county, and it is probable that no major through-flowing stream from the Rocky Mountain region crossed this county during the Pleistocene epoch. To the southwest in Wallace county, however, coarse gravel which contains boulders with a maximum diameter of as much as 2 feet (Elias, 1931, p. 163; Hibbard, Frye, and Leonard, 1944, p. 25) has been described as occurring above the base of the Pleistocene deposits. A history of successive periods of stream erosion and deposition during the Pleistocene is recorded in the terraces of the major valleys east of Thomas county (Frye, Leonard, and Hibbard, 1943), but if the few scattered gravel deposits of Pleistocene age in Thomas county are of more than one age, the several ages have not been differentiated.

Late in the Pleistocene a thick mantle of silt was spread over this region. This extensive bed of silt is generally called loess, and it seems probable that its deposition was in large part due to wind action. However, it probably has been modified by the action of sheet and rill wash. Stream-deposited silt generally overlies the sand and gravel of the terrace deposits of central and northwestern Kansas. The position of the massive silt on the upland-divide areas indicates that this extremely well-sorted material was blown to its point of deposition by wind. Rain waters probably have been an important factor in shifting this silt from place to place and washing it into the shallow upland depressions common throughout the upland areas.

Slope processes of creep, sheet wash, slump, and others have been important in moving large quantities of material down the present valley sides. The existing slope deposits are Recent in age and probably developed contemporaneously with the development of alluvium along the major valleys. The slope processes have most likely been the major factor in widening the valleys, lateral planation by the streams having been of small importance.

Development of present topography.—The topography of Thomas county, although relatively flat, cannot be said to be completely featureless (pls. 3A and 3B). The major valleys are relatively broad and in some places exhibit a distinct asymmetry of cross section which seems to be related to the weathering and retreat of slopes rather than to the excessive cutting of the streams along one bank. Such valleys as Prairie Dog and Sappa in the north-central part of the county are notably steeper on their south sides than on their north sides. This same relation is exhibited in the cuts along the Rock Island Railroad near Levant (pl. 6C). Along such valleys the steeper south slopes generally afford exposures of the Ogallala formation whereas these beds are completely mantled by slope deposits on the more gentle north slopes.

The most distinctive aspect of the topography of the county probably is the large number of depressions that dot the surface of the uplands and in some places occur on intermediate levels (pls. 5A and 6A). These depressions are of various sizes but in no case do they assume the size of the large solutional-subsidence areas of southwestern Kansas such as the Ashland-Englewood basin (Frye and Schoff, 1942). The origin of these depressions presents a perplexing problem. As can be seen from the location of intermittent ponds on plate 1, depressions occur generally over the county but are more abundant in the western half. Although not apparent on the map, at some localities there are definite alignments of shallow depressions and in some places these alignments are along shallow valleys.

Two of these depressions were selected for testing in an attempt to learn something concerning their origin. Test holes were drilled in each of these near the center of the depression and on each side of the rim, the results of which are shown in figure 4. It will be noted that there is no reflection of the surface depression in the bedrock floors beneath them, and in one case the surface of the Pierre shale is higher below the center of the depression than under the adjacent rim. These data, together with the fact that in the western part of the county about 1,000 feet of shale occurs below the surface of the bedrock floor and above the shallowest soluble bed, seem to demonstrate that these depressions are not due to solution-subsidence but may be due to some other cause unrelated to the bedrock below the Tertiary sediments.

Darton (1915, pp. 36, 37) referred to some of these High Plains depressions as "buffalo wallows" and explained their origin by the action of buffalos and wind. He believed the depressions were started by buffalos, either at wet, salty, or alkali spots, and that they were excavated by tramping hoofs followed by wind scour and also by mud sticking to the shaggy coats of the animals during wet periods. Although this hypothesis might account for some of the small shallow depressions, it hardly seems adequate for the large depressions having depths of 10 feet or more.

Johnson (1901, pp. 702, 712) discussed at some length the origin of High Plains basins. For the large irregular basins in the area of Permian bedrock he advocated an origin by solution of soluble beds of the Permian followed by collapse of the overlying beds and development of surface depressions. In the area of Cretaceous bedrock he recognized the inadequacy of this hypothesis, especially for the small shallow round or oval depressions. These range in size from the small features referred to as "buffalo wallows" to large areas of more than half a mile in diameter. Johnson pointed out the inadequacy of wind scour, as these low places held water for long periods and thus would be points of accumulation rather than areas of erosion of eolian sediments. He also pointed out that such features could not originate as initial irregularities on a depositional surface.

Johnson's hypothesis of origin for these features is as follows (1901, pp. 703, 704):

> Appearances indicate basining of the alluvial surface as a consequence, first, of rain water accumulation in initial faint unevenness of the plain; second, of percolation of this ponded surface water downward to the ground water in largely increased amount from these small areas of concentration, rather

> than from over the whole surface uniformly, with the result that the alluvial mass is appreciably settled beneath the basins only. The inference is at once suggested that this settlement takes place as the combined effect of mechanical compacting of the ground particles and chemical solution of the more soluble particles. Finally, these effects should be cumulative, resulting in the growth noted, since, with enlargement of the basins, concentration of rain water within them will be on an increased scale.
>
> Over comparatively small areas surface effects should be symmetrical, but beneath basins of great breadth—and some have breadths of several miles—the depths of settlement at points wide apart within the same basin, as well as the conformation of the basin rims, should reflect the broader variations of structure beneath. Depths should be least above beds of clay and greatest over areas of coarse channel deposits.

Although Johnson's hypothesis, proposed more than 40 years ago, has not been widely accepted and is very difficult to demonstrate, it nevertheless seems to explain the data concerning the types of depressions found in Thomas county more adequately than any other idea so far expressed. Many depressions, or sinks, that are clearly the result of solution and subsidence are known in other parts of the High Plains. Johnson recognized this fact and did not attempt to stretch his localized compaction hypothesis to cover such features.

GROUND WATER

Source

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

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

In Thomas county, as in other parts of the High Plains, ground water is derived almost entirely from precipitation in the form of rain or snow. Part of the water that falls as rain or snow is carried away by surface runoff and is lost to streams, part of it may evaporate or be absorbed by vegetation and transpired into the atmosphere. The part that escapes surface runoff, evaporation, and transpiration percolates downward through the soil and underlying strata until its reaches the water table, where it joins the body of ground water in the zone of saturation. In the southern High Plains the

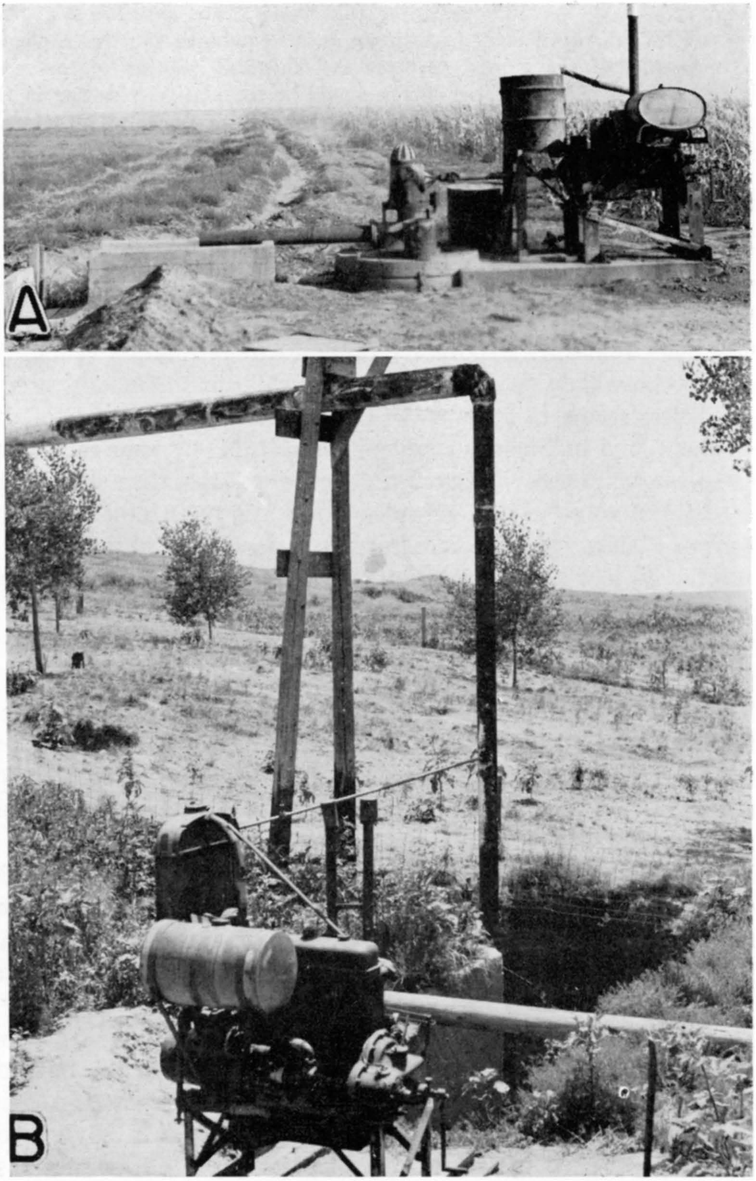


PLATE 4. Irrigation wells in Thomas county: *A,* irrigation well (31) of E. F. Rall, SW¼ SW¼ sec. 26, T. 7 S., R. 31 W.; *B,* Irrigation well (14) of Jones Brothers, SE¼ NW¼ sec. 33, T. 6 S., R. 33 W. Six-inch centrifugal pump mounted in the bottom of the pit is driven by belt from the stationary engine. Elevated discharge pipe extends to left and empties into concrete flume on hillside.

average amount of rainfall entering the ground-water body each year has been determined by two different investigations as about one-fourth inch (Frye, 1942, p. 66) and as about one-half inch (Theis, Burleigh, and Waite, 1935, pp. 1-4). The geologic conditions in Thomas county are somewhat different from those in the two areas farther south, but the average annual rainfall is about the same and the amount of rainfall reaching the ground-water body in this area is probably of the same order of magnitude. Although this is a small percentage of the annual rainfall it should be noted that one-fourth inch of water entering the ground-water reservoir under 1 square mile amounts to 4,344,674 gallons or 13.3 acre feet, and one-half inch of rainfall over 1 square mile amounts to 8,689,348 gallons.

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

OCCURRENCE

Nearly all rocks that underlie the surface of the earth at depths shallow enough to be penetrated by drills contain various percentages of open spaces. These voids or interstices range in size from microscopic openings to the large caverns developed in limestone regions. The percentage of the volume of the rock mass consisting of such open spaces determines the porosity. Therefore, if we know the porosity of any rock we can determine the amount of water that it can hold. Although it is desirable when considering problems of ground-water supply to know the porosity of the strata under an area, it is the permeability of the material that influences the amount of ground water which can move through it toward a pumping well. The permeability of a rock is determined by the size, shape, and arrangement of the openings. For instance, a bed of fine silt or clay might have a relatively high porosity, but because of the size of the particles each opening is very small. As the force known as molecular attraction holds a very thin layer of water on the surface of each grain, these layers of water (that are not free to move) might fill or almost fill all the openings in such a fine-textured sediment; thus the permeability, or water yielding capacity of the rock, is very low even though its porosity, or water holding capacity, is quite high. Likewise, larger openings that are not connected or are poorly connected might produce a high porosity and a low permeability. Water moves most freely through a rock that has relatively large and well-connected openings. Several common types of openings or interstices and the relation of texture to porosity are shown in figure 5.

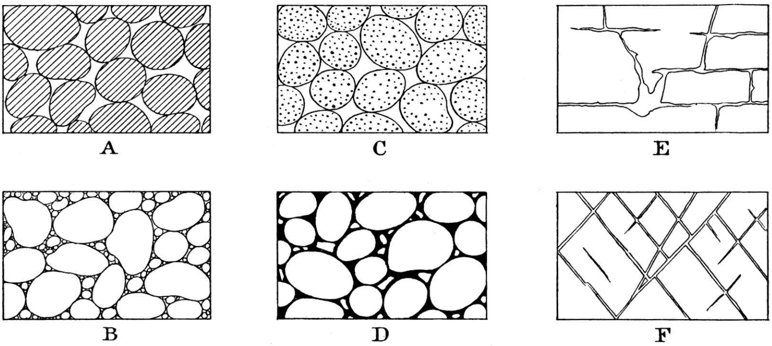


FIG. 5. Diagram showing several types of rock interstices and the relation of rock texture to porosity. *A,* Well-sorted sedimentary deposit having a high porosity; *B,* poorly sorted sedimentary deposit having low porosity; *C,* well-sorted sedimentary deposit consisting of pebbles that are themselves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

THE WATER TABLE AND MOVEMENT OF GROUND WATER

SHAPE AND SLOPE

The water table is defined as the upper surface of the zone of saturation, except where that surface is formed by an impermeable body (Meinzer, 1923a, p. 32). It may also be regarded as the boundary between the zone of saturation and the zone of aeration (fig. 6). The water table is not a static level surface but rather is generally a sloping surface which shows many irregularities caused by differences in permeability of the water-bearing materials or by unequal additions to or withdrawals from the ground-water reservoir at different places.

The shape and slope of the water table in Thomas county are shown on the map (pl. 1) by means of contour lines drawn on the

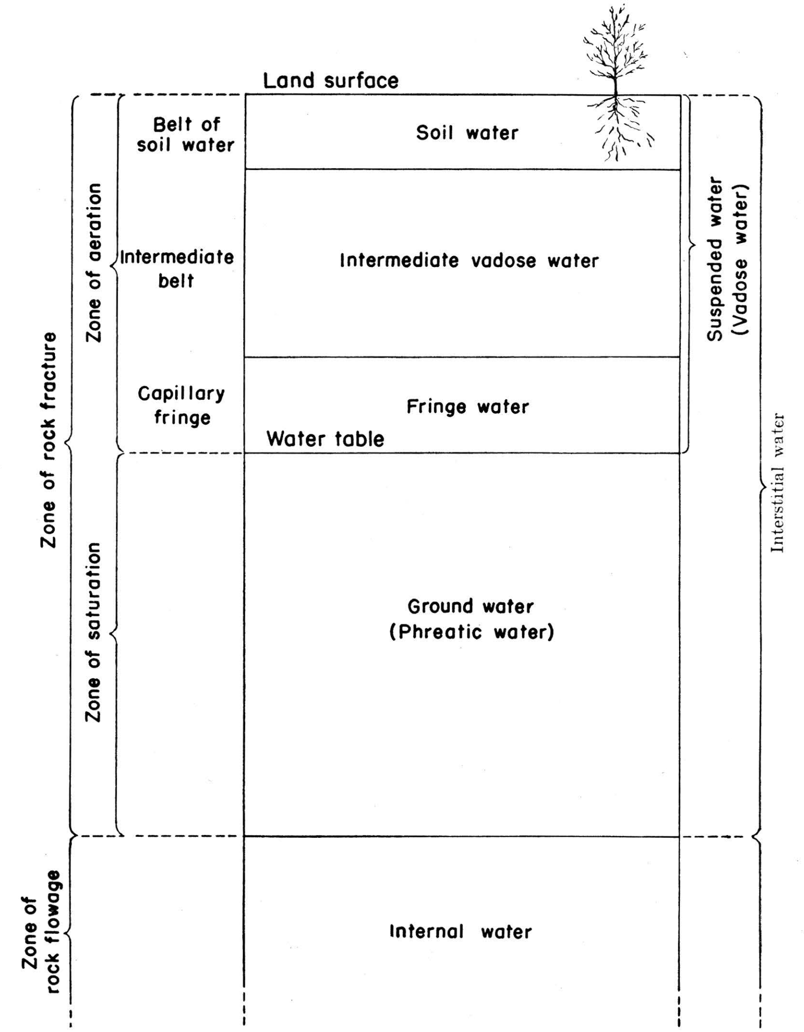


FIG. 6. Diagram showing divisions of subsurface water. (From O. E. Meinzer.)

water table. Each point on the water table along a given contour line has the same altitude. These water-table contours show the configuration of the water surface just as contours on a topographic map show the configuration of the land surface. The direction of movement of the ground water is at right angles to these contour lines—in the direction of the greatest slope.

The map shows that the water under the plains moves through the county in a general easterly direction, but that the direction of movement and the slope are somewhat different in various parts of the county. The average gradient of the water table is about 12.5 feet to the mile. In the area south of Brewster and Levant the slope of the water table is as much as 30 feet to the mile and in an area south of Colby the slope is as little as 6 feet to the mile.

In general the contours show a remarkable evenness of water-table slope throughout the county. In the northern and particularly the northwestern part of the county the shape of the contours indicates a northerly component to the direction of ground-water movement. This is probably caused by the deeply entrenched stream valleys in Rawlins county to the north which afford points of ground-water discharge.

The only stream valley in Thomas county that seems to exert a noticeable influence on the shape of the water table is South Sappa creek. This is probably because South Sappa creek is the only stream that has entrenched its valley to the level of the water table, and this has been accomplished only in the area north of Gem. For several miles upstream from the point where the 3,000-foot contour line crosses the valley the contours under the valley are convex to the east, indicating a slight ridge on the water table; whereas downstream from this point to the Rawlins county line the contours are concave eastward, indicating a depression in the water table. This change in shape is due to the fact that the floor of the valley is slightly above the water table and along the valley surface water enters the ground-water body more rapidly than elsewhere in the county. At the 3,000-foot line the valley floor is just at the level of the water table, and downstream from that point, where the

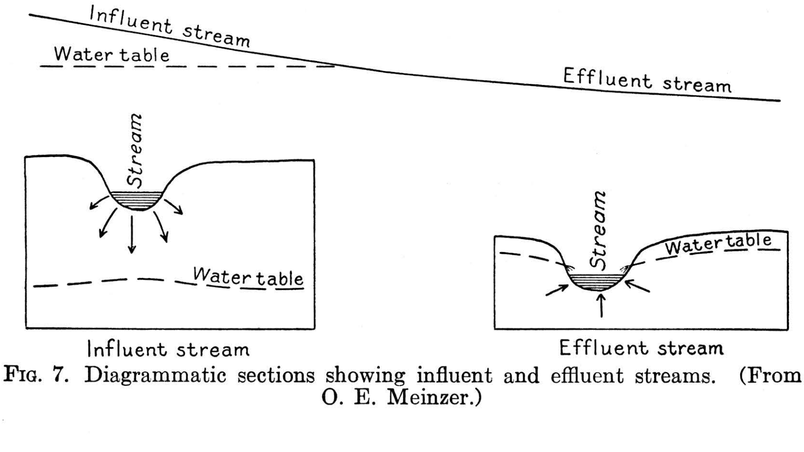


FIG. 7. Diagrammatic sections showing influent and effluent streams. (From O. E. Meinzer.)

valley bottom is slightly below the general level of the water table, some water enters the valley as seepage. A stream whose channel neither gains nor loses with respect to ground water is in equilibrium with respect to the water table. Figure 7 shows these relationships.

Other than South Sappa creek the only stream in the county that has reduced its valley bottom to the level of the water table is the South Fork of the Solomon river. In the first few miles of this valley west of the Sheridan county line and south of Menlo the stream is about at the level of the water table. All other streams in Thomas county flow at a level above the water table and receive no discharge from the ground-water reservoir. The relatively impervious nature of the surficial materials seemingly prevents water in large quantities from entering the ground from the channels as only one stream coincides for any appreciable distance with a "mound" or "ridge" on the water table. As can be seen on plate 1 this stream flows through a valley cut into the sand and gravel beds of the Ogallala formation which are relatively permeable and afford good infiltration possibilities. Stream channels that are above the water table (influent streams) do not gain water from ground-water seepage; thus they contain flowing water only during and immediately after rains.

The elevation of the low water levels in the major streams was determined instrumentally at selected points. These elevations are shown on plate 1 and give a direct comparison between the altitude of stream channels and the surface of the water table.

RELATION TO TOPOGRAPHY

On the map (pl. 2) are shown the depths to water level in Thomas county. In preparing this map the more general irregularities of the topography were taken into account by using aerial photographs and a drainage map. As topographic maps are not available for any part of Thomas county, the depth to water map must be considered generalized and not presumed to be accurate in all details. As shown on the map, the depth to water level ranges from more than 200 feet below the surface in an area north and northeast of Brownville to depths of only a few feet along the lower courses of such valleys as Sappa creek, Prairie Dog creek, and the Solomon and Saline rivers. The water level under several large areas in the east-central part of the county is less than 100 feet below the surface.

In general the shape of the water table conforms to the regional topography but is little affected by minor or local features. That is, the water table is essentially a plane and in that respect conforms to the regional topography of the High Plains, but its shape is not affected by local features of topography, for it passes below the valleys of the area with no perceptible change (with the exceptions noted above). Thus local low areas in the topography result in a reduced depth to water level almost directly proportional to the depth of the surface features.

FLUCTUATIONS OF THE WATER TABLE

The water table does not remain in a stationary position but fluctuates up and down much like the water level in a surface reservoir. If the inflow to the underground reservoir exceeds the draft, the water table will rise; conversely, if the draft exceeds the inflow, the water table will decline. Thus the rate and magnitude of fluctuation of the water table depends upon the rate and magnitude at which the underground reservoir is replenished or depleted.

Factors controlling the rise of the water table in Thomas county are the amount of rainfall within the county that descends through the soil to the water table, the amount of seepage that reaches the underground reservoir from surface streams, and the amount of water entering the county beneath the surface from areas to the west. All these factors depend upon precipitation either in or immediately adjacent to the west edge of the county.

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

Changes in the water levels in wells record the fluctuations of the water table, which in turn record the recharge and discharge of the ground-water reservoir. In order to determine the character and magnitude of water-level fluctuations in Thomas county, 10 wells were selected for observation, and periodic measurements of the depth to water level in them were begun in July, 1942. Since the original measurements by me in 1942, measurements of water levels in these wells have been made by W. W. Wilson, Allan Graffham, and Howard Palmer. Complete records for these wells are published annually by the Federal Geological Survey (Meinzer and Wenzel, 1944, pp. 174-177). The numbers of the observation wells previously published and the numbers used in this report are given in table 3.

TABLE 3.—*Observation wells in Thomas county*

Well No. in this report	Well No. in Meinzer and Wenzel (1944)	Well No. in this report	Well No. in Meinzer and Wenzel (1944)
25	12	60	26
37	9	71	7
43	21	72	2
53	4	82	33
54	13	91	1

The fluctuations of the water level in six typical observation wells in Thomas county during the period of record and the monthly precipitation at Colby are shown in figure 8.

RECHARGE

Recharge is the addition of water to the underground reservoir and may be accomplished in several ways. All ground water within a practicable drilling depth beneath Thomas county—that is, the water in the Tertiary and Quaternary deposits above the Pierre shale—is derived from water that falls as snow or rain either within the area or on nearby areas to the west. Once the water becomes a part of the ground-water body it moves down the slope of the water table, later to be discharged, for the most part at some point beyond the limits of the county.

Recharge from local precipitation.—The average annual precipitation in Thomas county is about 18 inches but probably only a small fraction of this amount enters the zone of saturation, thus serving to recharge the ground-water reservoir. The depth to the water table exerts an important influence on the amount and frequency of recharge. The valley of South Sappa creek receives above average recharge, for the water table stands only a few feet below the surface and the material above the water table consists dominantly of sand and gravel. The gently rolling divide areas underlain by thick silt deposits are areas of below average recharge because of good surface drainage and low permeability of surficial materials.

Rodent burrows and sod cracks probably are important avenues of access for rain water entering the ground. During dry seasons extensive sod cracks are reported to have developed in various parts

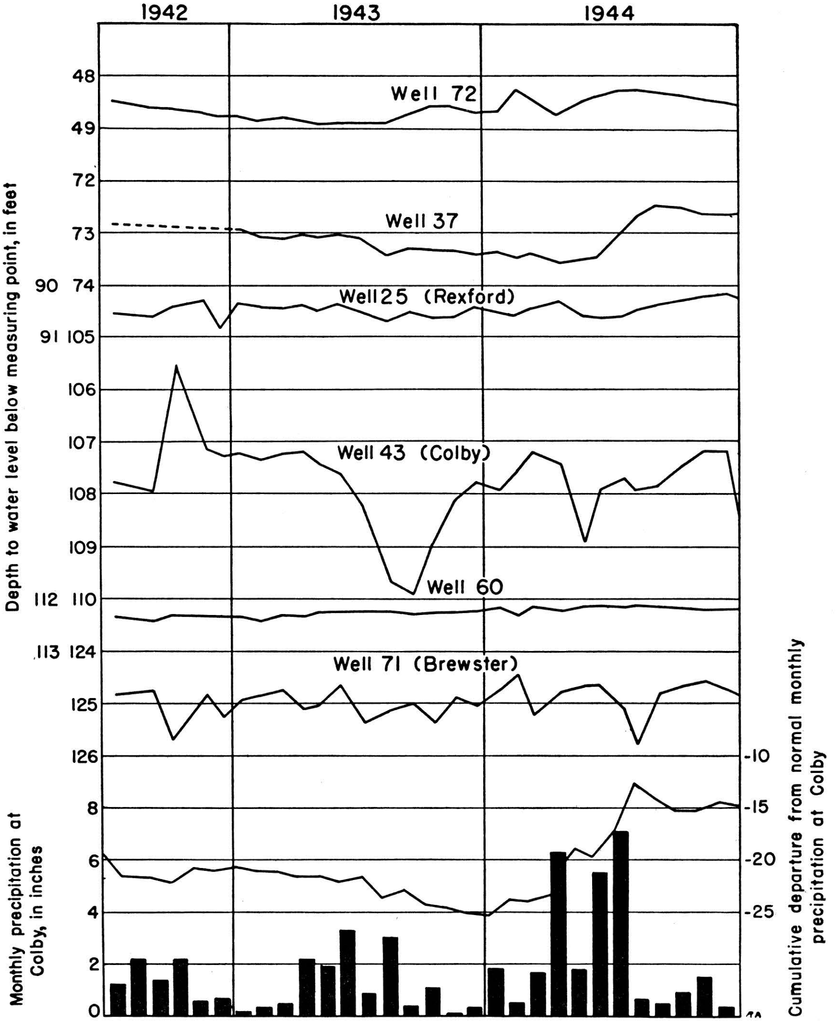


Fig. 8. Hydrographs of six typical observation wells in Thomas county and the monthly precipitation at Colby. (Precipitation data from U. S. Weather Bureau.)

of Thomas county. Although I have not observed these cracks they are reported to attain a width of several inches and to extend along the surface for several hundred feet. Cracks or openings not visible at the surface probably occur within the body of the massive silt. This was demonstrated when the test drill lost circulation while drilling several test holes through this material.

Recharge to the ground-water reservoir is indicated by a rise in the water level in wells not influenced by pumping. Selected wells throughout the county have been measured periodically and the records of six of these are given in figure 8 with the monthly rainfall data at Colby. Three of these wells (25, 43, 71) are less than a half mile from the city pumping plants of Brewster, Colby, and Rexford and therefore may be influenced by the pumping of these city wells. In any case they show no recognizable correlation with rainfall. Well 72 is the only one of the three wells unaffected by pumping having a water level of less than 50 feet. Although the correlation between the water-level fluctuations in this well and the precipitation at Colby is not too apparent, the water level nevertheless seems to exhibit some response to rainfall. Well 37, which has a water level of more than 70 feet, had a pronounced rise in water level starting in July, 1944, in response to the unusually heavy rainfall from April to July, 1944. In well 60, which has a depth to water level of more than 110 feet, there was a slight rise in water level during the period of record.

Recharge from streams and ponds.—During periods of maximum flow in the major streams of the county some water probably leaves the channels and moves into the adjacent alluvium and underlying Ogallala formation. Most of the water from surface streams that recharges the ground-water reservoir represents water that fell as rain within the county, for North and South Sappa creeks are the only two streams that have any appreciable drainage area outside of Thomas county.

The massive silt of the Sanborn formation which underlies much of the upland surface of the county is relatively impervious, thus retarding or preventing the downward percolation of water. Many shallow undrained depressions on this surface catch and hold rain water and prevent surface runoff. The fact that these shallow depressions, some of which are more than 150 feet above the water table, are occupied by shallow ponds for weeks after a heavy rain seems to indicate that even in these areas the water percolates downward very slowly and most of it evaporates (pls. 5A and 6A). Recent studies of recharge from shallow depressions in the High Plains of Texas (White, Broadhurst, and Lang, 1940, pp. 6-8) showed that recharge from some ponds was quite rapid, whereas in others it was slow or nonexistent. The problems of the two areas are not entirely similar, for in the Texas area beds of caliche locally prevent downward movement of water, whereas in Thomas county caliche does not seem to be effective in this respect but nearly all the ponds are underlain by homogeneous deposits of silt. In advocating his hypothesis for the origin of High Plains depressions, Johnson (1901) assumed that significant quantities of water entered the ground from these depression ponds.

Recharge from subsurface inflow.—As indicated by the slope of the water table (pl. 1), the movement of ground water in this area is in an easterly direction; hence recharge from precipitation or stream flow that occurs in areas immediately adjacent to the west eventually moves into this area and contributes to the available supply of ground water. As shown by the cross sections in figures 3 and 4, the water-bearing materials are relatively thin along the western edge of the county in the area south of Brewster; therefore, the quantity of water entering the county as subsurface inflow is probably small.

DISCHARGE

Natural discharge at the surface.—Before any wells were drilled the ground-water reservoir of Thomas county was in a state of approximate equilibrium—that is, the average annual recharge was balanced by an approximately equal average annual discharge. The greater part of the discharge occurred by ground-water movement out of the county beneath the surface to the north, east, and south. A small amount of discharge probably occurred from seeps along the valley of South Sappa creek where it is at the level of the water table and a small amount of water was discharged by direct evaporation and by transpiration from trees, grasses, and shrubs in the shallow water areas along the major valleys.

Discharge from wells.—At the present time wells constitute one of the principal means of discharge of ground water within the county. Although the quantity of water pumped annually from wells in Thomas county is not known, the city supplies of Brewster, Colby, and Rexford and several railroad supplies are obtained from wells, and several irrigation wells have been in operation. Most of the rural residents of the county obtain their domestic and livestock supplies from wells, but the total volume of water pumped for such use is comparatively small.

Fluctuations caused by pumping.—The water table in the vicinity of a well that is being pumped declines and an inverted cone with its apex at the well (fig. 9) is developed. This cone represents a loss of storage by the unwatering of a portion of the previously saturated material surrounding the well. When pumping stops, the

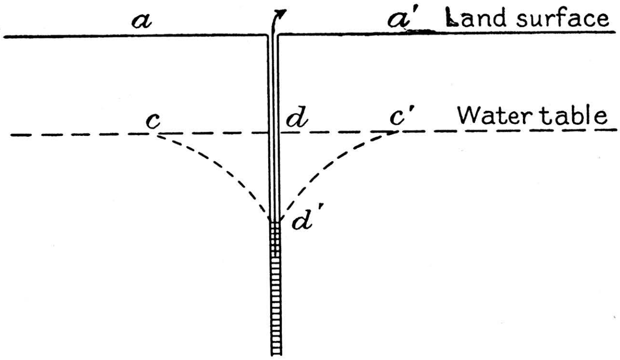


FIG. 9. Diagrammatic section of a well that is being pumped showing its drawdown (dd′), cone of influence (cc′d′), and area of influence (aa′). (From O. E. Meinzer.)

movement of water from surrounding areas into the depressed area continues until the depression is filled. This results in a slight decline of the adjacent regional water table. In an area such as the city well field at Colby where several wells are pumped intermittently, the fluctuations of water level in any one well are complicated and represent the sum of the effects of pumping or recovery from many nearby wells.

RECOVERY OF GROUND WATER

PRINCIPLES OF RECOVERY

The following discussion on the principles of recovery of ground water has been adopted in part from Lohman (1938, pp. 54-56).

When water is withdrawn from a well there is a difference in head between the water inside the well and the water in the surrounding material for some distance from the well. The water table in the vicinity of the well develops a cone of depression (fig. 9). In any given well a higher pumping rate produces a greater drawdown (depression of the water level, commonly expressed in feet), and the diameter of the cone of influence and of the area of influence will be greater.

The specific capacity of a well is its rate of yield per unit of drawdown, and is generally stated in gallons a minute per foot of drawdown. When a well is pumped the water level drops rapidly at first and then more slowly, and it may continue to decline for several hours or days. In testing the specific capacity of a well, therefore, it is important to continue pumping until the water level

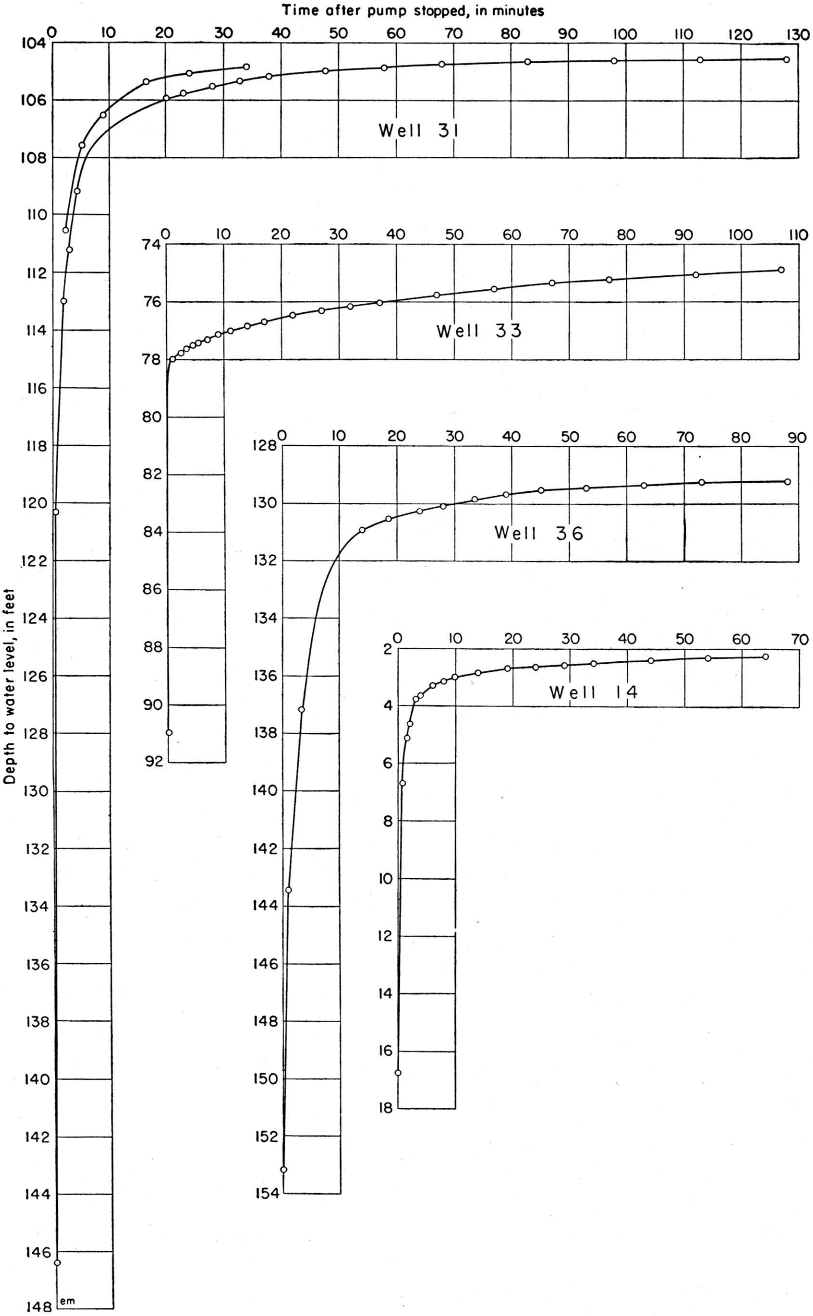


FIG. 10. Recovery curves of wells 14, 31, 33, and 36, based on measurements made at termination of pumping tests. Rate and period of pumping are given in table 4.

remains approximately stationary. When the pump is stopped the water level rises rapidly at first, then more slowly, and may continue to rise long after pumping has ceased (fig. 10).

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

DUG WELLS

Dug wells are excavated with picks, shovels, spades, or by power machinery. They generally are between 2 and 10 feet in diameter and are quite shallow. Many of the early wells in Thomas county were dug by hand, but most of these have since been replaced by drilled wells. A few dug wells are now in use in the major valleys. Of the 114 wells listed in table 9 only three are dug wells, two are bored wells, and 109 are drilled wells.

BORED AND DRIVEN WELLS

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

DRILLED WELLS

A drilled well is one that is excavated by means of a percussion or rotary drill. Most of the wells in Thomas county are drilled wells. The drilled domestic and stock wells generally are 6 inches in diameter and those used for irrigation and public supply purposes generally are 14 to 18 inches in diameter.

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

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

Gravel-wall wells generally are effective for obtaining large supplies of water from relatively fine-grained unconsolidated deposits and have been used in many public supply and irrigation wells. In such wells a large-diameter hole is first drilled with a rotary drill or excavated by a hoist and orange-peel bucket and the hole generally is temporarily cased with unperforated casing. A well screen or perforated casing is then centered in the hole opposite the water-bearing material and enough blank casing added to reach the surface. The space between the two casings is filled with carefully screened gravel and all but 20 or 30 feet of the outer casing is pulled from the hole. A well-sorted medium to coarse gravel packing generally gives the best results, but where the water-bearing material is extremely fine a coarse sand or fine gravel may give best results. The slots in the screen or slotted casing should be as large as possible yet small enough to keep out the gravel used for packing the well. If the water-bearing formation consists of well-sorted coarse gravel the capacity of the well probably will not be increased by addition of a gravel pack around the screen.

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

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

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

METHODS OF LIFT AND TYPES OF PUMPS

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

Several types of power-driven pumps are in use on the irrigation and city wells in the county. For the most part these are turbine pumps and are powered by electric motors, stationary gasoline engines, and tractor engines. Data concerning such wells are given in table 9. One irrigation well is equipped with a centrifugal pump powered by a stationary gasoline engine. Several of the city wells at Colby and several of the railroad supply wells in the county are equipped with double action plunger pumps, and one railroad well is powered by a steam engine.

UTILIZATION OF WATER

During the course of this investigation data were obtained on 114 wells in Thomas county. All types of wells in all parts of the county were visited. Of the 114 wells listed in table 9, 13 were used primarily for stock water, 10 for domestic supplies, and 24 for both purposes, making a total of 47 domestic and stock wells listed. Of the remaining wells, 10 were used for public supplies, 9 were irrigation wells, and 2 were railroad supply wells; 23 were not in use at the time they were visited and 23 were test holes drilled by the coöperatively owned drilling machine and subsequently plugged. Although table 9 includes only a small percentage of the domestic and stock wells in the county, all of the public supply and irrigation wells that I could locate in 1942 were visited and are listed.

DOMESTIC AND STOCK SUPPLIES

Nearly all of the domestic and stock supplies in rural areas are obtained from wells—mainly drilled wells. In parts of the county ponds are used to some extent to supply stock water, but ponds are not as extensively used in Thomas county as they are in areas to the east (Moore, 1940, p. 55).

The domestic use of water generally includes drinking, cooking, washing, and in some cases the disposal of sewage. In Thomas county the ground waters are generally satisfactory for all domestic purposes (see "Quality of Water"), and ground water in sufficient quantity for such uses can be obtained at nearly any locality in the county.

PUBLIC SUPPLIES

Three municipalities in Thomas county have public water supplies obtained from wells.

Brewster.—The city of Brewster, located in the west-central part of the county, obtains its water supply from two drilled wells (nos. 69, 70). Water is pumped from these wells to an elevated steel storage tank having a capacity of 50,000 gallons. The daily capacity of the system was reported to be 30,000 gallons, but the average daily consumption is not known. Data on the wells are given in table 9, and a chemical analysis of the water is given in table 5. The water is of good quality and is not treated.

Colby.—Colby, the county seat and largest city in the county, obtains its water supply from five drilled wells (44-48) at the west edge of town. Data concerning these wells are given in table 9, and a chemical analysis of the water is given in table 5. Two of the wells are equipped with turbine pumps and the remaining three with double action plunger pumps. Storage is provided in a reservoir at ground level having a capacity of 500,000 gallons and an elevated tank holding 70,000 gallons.

According to O. L. Day, the largest consumption of the year occurs during the months from June to September. The greatest monthly consumption was in August, 1939, when 21,000,000 gallons was pumped. About 115,500,000 gallons, or 345 acre feet, was pumped during 1941. If the annual recharge is 13.3 acre feet (page 33) per square mile this would amount to the recharge from about 25 square miles.

Rexford.—The city of Rexford, located in the northeastern part of the county, obtains its water supply from two drilled wells (26,

27) at the east edge of town. Water is pumped from the wells to an elevated storage tank having a capacity of 50,000 gallons. Data on the wells are given in table 9, and a chemical analysis of the water is given in table 5.

IRRIGATION SUPPLIES

The only adequate source of irrigation water in Thomas county is from pumped wells. Although irrigation has not been carried on extensively in the county, nine of the wells visited during the summers of 1942 and 1943 and listed in table 9 (7, 13, 14, 31, 33, 35, 36, 37, and 77) are classed as irrigation wells (pl. 4.). Of these, two wells (7 and 37) did not have pumps installed and were not in use, and two others had been used very little since their construction. Of the remaining five irrigation wells, three are located in valley areas and two on intermediate uplands. The static water level in two of the five wells was about 13 feet below land surface, and only one of them had a static water level of more than 100 feet. Chemical analyses of water from four of the irrigation wells (14, 31, 33, and 77) given in table 5 indicate that the quality of the water is satisfactory for irrigation purposes (Scofield, 1933). The total acreage irrigated each year in the county is not known but it is not large.

The yields of irrigation wells in Thomas county range widely. In 1943, pumping tests were conducted on four of the seven irrigation wells in the county equipped with pumps, by Howard Palmer and Allan Graffham of the Division of Water Resources of the Kansas State Board of Agriculture in coöperation with the State and Federal Geological Surveys. The results of these pumping tests are

TABLE 4.—*Pumping tests of irrigation wells in Thomas county*[1]

Well No. in pl. 2 and table 9	Depth to water level at beginning of pumping test	Discharge (gallons a minute)	Length of time well was pumped (minutes)	Drawdown at end of pumping period (feet)	Specific capacity (gallons a minute per foot of drawdown)
14	14.09	637	180	15.37	41.4
31	104.32	588	184	40.08	14.0
33	72.90	1,021	201	18.05	56.5
36	128.01	295	210	26.33	11.2

[1] Pumping tests by Howard Palmer and Allan Graffham, Division of Water Resources, Kansas State Board of Agriculture, in coöperation with State and Federal Geological Surveys.

given in table 4, and the recovery curves are shown in figure 10. It will be noted that the yields of these four wells ranged from 295 to 1,021 gallons a minute and their specific capacities ranged from 11.2 to 56.5. The average specific capacity of the four wells was 30.8.

The most extensive well-irrigation area in Kansas lies due south of Thomas county in the Arkansas river valley and the shallow water basins of Scott, Finney, and Grant counties. In Hamilton and Kearny counties (McLaughlin, 1943, p. 89) the range in yield of eight single-well pumping plants was 480 to 1,280 gallons a minute. The specific capacities of these wells ranged from 8.5 to 55.2 and averaged 20.9. In Finney and Gray counties (Latta, 1944, p. 107), the range in yield of 17 single-well pumping plants was 348 to 1,770 gallons a minute, and the specific capacities ranged from 10 to 141 and averaged 46.9. Although the yields of the four wells tested in Thomas county are slightly lower than in the large irrigation areas to the south, they nevertheless are in the same general range. Also, the specific capacities of these wells compare favorably with wells in Hamilton and Kearny counties but are appreciably lower than the specific capacities of irrigation wells in Finney and Gray counties.

A comparison of depth and diameter of the irrigation wells in Thomas county with those farther south shows that the Thomas county wells are generally deeper and of somewhat smaller diameter. In Hamilton and Kearny counties (McLaughlin, 1943, pp. 92, 93) 77 wells were less than and 19 more than 100 feet in depth, and the prevalent diameters were 16 and 18 inches. In Finney and Gray counties (Latta, 1944, pp. 111, 112) 170 wells were less than and 59 more than 100 feet deep, and the prevalent diameters were 15, 16, 18, and 20 inches. In Thomas county two of the irrigation wells are less than 100 feet in depth and 7 are more than 100 feet. The diameters of the nine wells are: two wells, 14 inches; five wells, 16 inches; one well, 18 inches; and one well, 32 inches.

In 1914 a well-irrigation plant was installed at the Colby experiment station at the southwest corner of the city of Colby, but the irrigation wells were later abandoned. Embert Coles has generously furnished data from his files concerning the operation of this plant. The plant consisted of two wells, 12 feet apart, equipped with 5¾-inch cylinder pumps powered by an eight-horsepower Fairbanks-Morse engine. The log of the well is given at the end of this report (no. 30). The depth to water level was reported to be 112 feet in 1914, and 112.5 feet in November, 1919. On May 18, 1945, the east well was uncovered and measured by George S. Knapp and J. B. Kuska. The depth to water was found to be 114.8 feet below the 1919 measuring point. During 1919 the pumping plant was operated for 318 hours at a rate of 97.8 gallons a minute, which produced about 5.7 acre feet of water. The cost of fuel and oil per acre foot of water pumped was reported to be $5.62, but it was impossible to determine the cost of plant depreciation, repair, and operation of equipment, so the total cost of the water per acre foot is not known. Although the cost of fuel probably could be lowered by using more economical pumping equipment, the fuel cost will be relatively high where the pumping lift (static water level plus drawdown) is great.

POSSIBILITIES OF FUTURE DEVELOPMENT OF IRRIGATION SUPPLIES

The feasibility of further development of irrigation supplies from wells is dependent upon the safe yield of the ground-water reservoir (the amount of water that can be withdrawn annually over a long period of years without depletion), the cost of drilling and pumping, the topography of the land, and the soil and other factors beyond the scope of this report. The ability of an underground reservoir to yield water over a long period of years is limited, as is that of a surface reservoir. If water is withdrawn from an underground reservoir faster than water enters it, the supply will be depleted and the water level in wells will decline. The amount of water that can be withdrawn annually over a long period of years without depletion of the ground-water reservoir is dependent upon the capacity of the underground reservoir and the amount of water added annually by recharge.

The depth to water level and type of water-bearing material determine in part the cost of drilling and pumping. Some wells that may encounter relatively fine-grained material will have relatively small yields. Gravel packing may increase the yield of such wells but it also adds to the cost of construction.

For the purpose of more detailed description, Thomas county may be divided into three general areas. In the order of their irrigation possibilities these are (1) major valleys in northeastern and eastern parts of the county, (2) uplands in the northern and eastern parts of the county, and (3) southwestern upland area.

Major valleys in northeastern area.—With respect to supply and cost of water, the major valleys in northeastern Thomas county present the most favorable areas for future irrigation development.

Plate 2 shows that the depth to water level is less than 50 feet below the valley of South Sappa creek from near Brewster to the Rawlins county line, and that the depth to water level below the valley of Prairie Dog creek is less than 50 feet from east of Colby to the Sheridan county line. From north of Colby eastward the depth to water level below the bottom of South Sappa creek valley is less than 25 feet and under part of the valley the water table stands only a few feet below the surface. Two irrigation wells are in operation along South Sappa creek and pumping test data are given for one of these wells (14) in table 4. This well, which is equipped with a 6-inch centrifugal pump, yielded 637 gallons a minute with a drawdown of 15.37 feet, and had a specific capacity of 41.4. The total pumping lift to land surface (the water is discharged through an elevated pipe as shown in pl. 4B) was less than 30 feet. Such a well compares favorably with many of the wells in the extensive irrigation areas to the south (p. 50) and to the north in Nebraska. The cross sections (figs. 3 and 4) show that more than 100 feet of saturated water-bearing material occurs below the bottoms of these valleys and above the bedrock floor of Pierre shale. None of the wells now in operation in these valleys (with the possible exception of well 13) penetrates the entire thickness of water-bearing material; thus deeper drilling to the top of the Pierre shale would make available a larger quantity of water. Several thousand acres of land along South Sappa creek in north-central Thomas county and Prairie Dog creek near the east county line have suitable topography for irrigation and wells can be obtained that yield more than 500 gallons a minute with a total pumping lift of 50 feet or less. There are smaller areas having equally good possibilities along the valleys of the South Fork of the Solomon river and the North and South Forks of the Saline river in the eastern part of the county. The character of the water-bearing materials varies in short distances; therefore one or more test holes to determine the character of the sand and gravel are advisable before drilling an irrigation well.

Northern and eastern upland areas.—Reference to plate 2 will show that there are extensive areas in northern and eastern Thomas county, in addition to the valley areas, where the depth to water level is less than 100 feet. The cross sections (figs. 3 and 4) show that under the northern, eastern, and central parts of the county there is from 100 to 150 feet of saturated water-bearing material above the floor of Pierre shale. Two of the irrigation wells tested and reported in table 4 are on the upland and intermediate levels in the northeastern part of the county. The static water level in one of these wells was 72.90 feet below the surface and in the other it was 104.32 feet below the surface; they yielded 1,021 and 588 gallons a minute and had specific capacities of 56.5 and 14.0 respectively. One other upland irrigation well north of Colby which was tested had a static water level of 128.01 feet below the surface, a yield of 295 gallons a minute, and a specific capacity of 11.2. The data on these three wells indicate a wide range in the characteristics of upland wells in these parts of the county.

Quantities of water sufficient for irrigation can be obtained at many places on the upland and intermediate levels of northern, eastern, and central Thomas county. The pumping lifts will range generally from slightly less than 100 feet to more than 150 feet. Wells should be drilled through the entire thickness of the water-bearing material to the Pierre shale. The cost of construction and of pumping water from this depth, in addition to other factors, should be considered in any contemplated irrigation undertaking. Owing to the lateral variation in the water-bearing material of this area, one or more test holes should be put down before an irrigation well is drilled.

Southwestern upland area.—As shown on plate 2, the depth to water level under nearly all of southwestern Thomas county is more than 100 feet and at some places it is as much as 200 feet. Cross section B-B′ in figure 3 and cross section E-E′ in figure 4 show that the thickness of saturated water-bearing material under this area is much less than in other parts of the county—in fact at some places there is less than 10 feet of saturated material above the Pierre shale. Although an adequate quantity of water is available for domestic or stock wells at most places in the southwestern part of the county, yields sufficient for irrigation purposes could be obtained at only a few places. The great depth to water level and relatively small quantities of water available under the uplands of the southwestern part of the county make this area generally unsatisfactory for well irrigation.

Quality of Water

The chemical character of ground water in Thomas county is indicated by the analyses in table 5 and in figures 11 and 12. The analyses were made by Howard Stoltenberg in the Water and Sewage Laboratory of the Kansas State Board of Health. Twenty-four samples of water were collected for chemical analysis from representative wells distributed as uniformly as possible within the county. Twenty-three of the water samples were pumped from the Ogallala formation, and one sample (well 14) was pumped from the alluvium and the Ogallala formation. Analyses of the water pumped from the municipal wells at Brewster, Colby, and Rexford are also given in table 5.

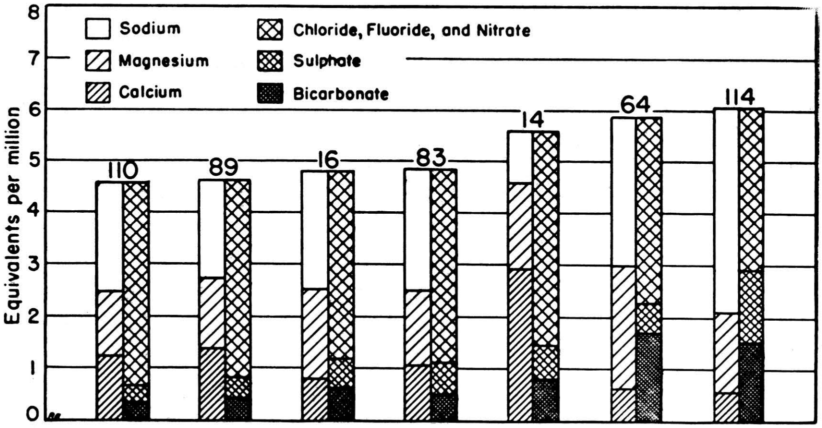


FIG. 11. Analyses of waters from the Ogallala formation in Thomas county. Numbers refer to analyses in table 5.

CHEMICAL CONSTITUENTS IN RELATION TO USE

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

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

The total dissolved solids in samples of water collected from private wells in this area ranged from 225 parts per million in well 101 to 349 parts in well 114. As all of the samples collected contained less than 350 parts per million the water is suitable for most ordinary purposes. Thirteen of the samples contained less than 250 parts per million, eight samples contained between 250 and 300 parts, and only three samples contained more than 300 parts.

Hardness.—The hardness of water, which is the property that generally receives the most attention, is most commonly recognized by its effect when soap is used with the water in washing. Calcium and magnesium cause almost all of the hardness of ordinary water. These constituents are also the active agents in the formation of the greater part of all the scale formed in steam boilers and in other vessels in which water is heated or evaporated.

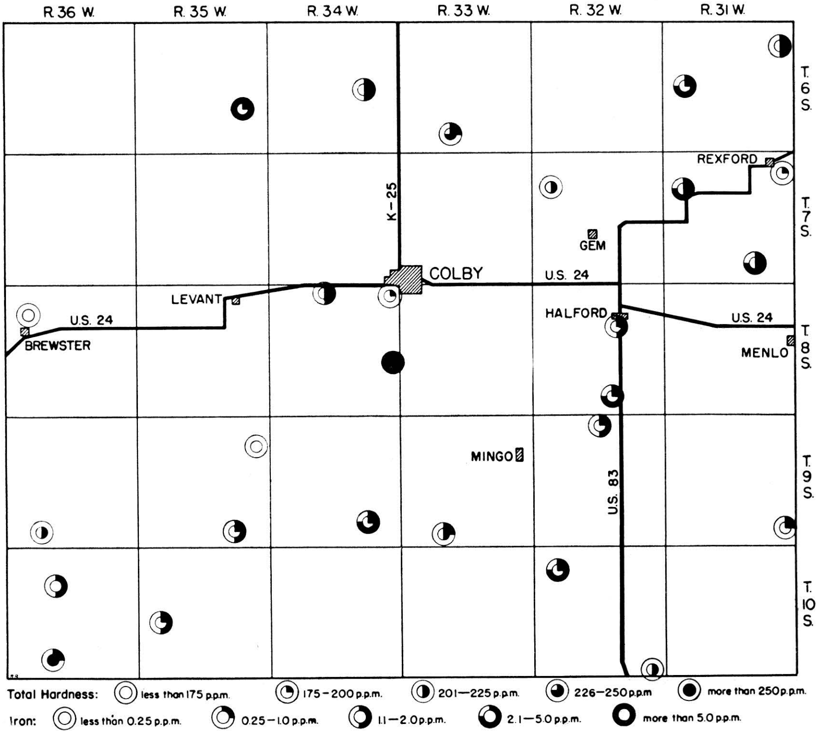


FIG. 12. Map of Thomas county showing areal distribution of iron and total dissolved solids in well waters in Thomas county.

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

Water having a hardness less than 50 parts per million is generally rated as soft, and its treatment for removal of hardness under ordinary circumstances is not necessary. Hardness between 50 and 150 parts per million does not seriously interfere with the use of water for most purposes, but it does slightly increase the consumption of soap; its removal by a softening process is profitable for laundries or other industries using large quantities of soap. Water in the upper part of this range of hardness will cause considerable scale in steam boilers. Hardness exceeding 150 parts per million can be noticed by anyone; if the hardness is 200 or 300 parts per million it is common practice to soften water for household use or to install a cistern to collect soft rainwater. Where municipal water supplies are softened, an attempt is generally made to reduce the hardness to 60 or 80 parts per million. The additional improvement from further softening of a whole public supply is not deemed worth the increase in cost.

The hardness of samples of water collected from wells in Thomas county ranged from 162 (well 89) to 270 (well 114) parts per million. Only two samples had more than 250 parts per million of hardness and 14 samples had less than 200 parts per million of hardness.

Iron.—Next to hardness, iron is the constituent of natural waters that receives the most attention. The quantity of iron in ground waters may differ greatly from place to place, even though the waters are from the same formation. If a water contains much more than 0.1 part per million iron, the excess may separate out and settle as a reddish sediment. Iron, which may be present in sufficient quantity to give a disagreeable taste and to stain cooking utensils, may be removed from most waters by simple aeration and filtration, but a few waters require the addition of lime or some other substance.

Two of the samples collected in Thomas county (wells 33 and 92) contained less than 0.15 part per million of iron; 20 samples contained between 0.15 and 5.0 parts, and two samples (wells 64 and 21) contained more than 5.0 parts. The highest iron content was in the sample collected from well 21, which contained 10 parts per million.

Fluoride.—Although determinable quantities of fluoride are not as common as fairly large quantities of other constituents of natural waters, it is desirable to know the amount of fluoride present in water that is likely to be used by children. Fluoride in water has been shown to be associated with the dental defect known as mottled enamel, which may appear on the teeth of children who drink water containing excessive quantities of fluoride during the period of formation of the permanent teeth. It has been stated that waters containing 1 part per million or more of fluoride are likely to produce mottled enamel, although the effect of 1 part per million is not usually very serious (Dean, 1936). If the water contains as much as 4 parts per million of fluoride, 90 percent of the children exposed are likely to have mottled enamel and 35 percent or more of the cases will be classed as moderate or worse. Recent work has indicated a beneficial effect from the presence of a small amount of fluoride in drinking water in decreasing the incidence of dental caries. Discussions in the literature suggest that this beneficial effect may be produced by quantities of fluoride of less than 1 part per million which would not have any measurable effect upon the quality of tooth enamel (Dean, Jay, Arnold, and Elvove, 1941).

Two samples of water collected from wells 2 and 33 in Thomas county contained 2.0 parts per million of fluoride, 19 samples contained less than 2.0 parts but more than 1.0 part, and 3 samples contained less than 1.0 part. Well 101 had the lowest fluoride content—0.5 part per million.

SANITARY CONSIDERATIONS

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

The entire population of Thomas county and nearly all of the livestock are dependent on well-water supplies as there are no permanently flowing streams in the county. Although the county has three municipal water plants that are safeguarded against pollution, a large percentage of the population is dependent upon private wells, and every precaution should be taken to protect these supplies from pollution. Deep drilled wells on the uplands that penetrate relatively impervious silt above the water table are less subject to pollution than are shallow dug or driven wells in the valleys where pervious sandy material extends from the surface

TABLE 5.—*Analyses of water from typical wells in Thomas county, Kansas*

Analyses by Howard Stoltenberg. Dissolved constituent given in parts per million.[a] Reacting values (in italics) given in equivalents per million

No. on plate 2	LOCATION	Depth (feet)	Geologic subdivision	Date of collection	Temperature (°F)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total dissolved solids	Hardness (calculated as $CaCO_3$)		
																Total	Carbonate	Noncarbonate
	T. 6 S., R. 31 W.																	
1	SE SW sec. 1	76.5	Ogallala	10-24-42	56	1.3	60 *2.99*	16 *1.32*	12 *.53*	238 *3.90*	19 *.40*	10 *.28*	1.0 *.05*	13 *.21*	251	216	195	21
2	SW NW sec. 30	129.5	do	10-24-42	57	2.1	46 *2.30*	20 *1.64*	25 *1.08*	224 *3.67*	30 *.62*	11 *.31*	2.0 *.10*	20 *.32*	268	197	184	13
	T. 6 S., R. 33 W.																	
14	SE SW sec. 33	38.2	Alluvium and Ogallala	10-24-42	56	.41	60 *2.99*	19 *1.56*	26 *1.12*	254 *4.16*	31 *.64*	12 *.34*	1.2 *.06*	29 *.47*	306	228	208	20
	T. 6 S., R. 34 W.																	
16	SE SW sec. 14	133.5	Ogallala	1-11-43	......	1.1	48 *2.40*	20 *1.64*	17 *.74*	224 *3.67*	22 *.46*	10 *.28*	1.4 *.07*	19 *.30*	250	202	184	18
	T. 6 S., R. 35 W.																	
21	SW NW sec. 25	137.0	do	4-13-43	......	10.0	41 *2.05*	22 *1.81*	19 *.81*	227 *3.72*	20 *.42*	7.5 *.21*	1.0 *.05*	17 *.27*	251	193	186	7
	T 7 S., R. 31 W.																	
30	SE NE sec. 18	127.0	do	1-11-43	......	4.7	50 *2.50*	22 *1.81*	10 *.45*	224 *3.67*	26 *.54*	8.5 *.24*	1.8 *.09*	14 *.22*	249	216	184	32
31	SW SW sec. 26	177.0	do	6- 8-43	57	2.2	47 *2.34*	24 *1.97*	13 *.55*	224 *3.67*	31 *.64*	8.5 *.24*	1.4 *.07*	15 *.24*	254	216	184	32
	T. 7 S., R. 31 W.																	
33	NE SW sec. 7	135.0	do	4-12-43	......	c	41 *2.05*	26 *2.14*	15 *.64*	226 *3.71*	24 *.50*	10 *.28*	2.0 *.10*	15 *.24*	246	210	186	24
	T. 8 S., R. 32 W.																	
58	NE SE sec. 10	119.8	do	10-23-42	58	1.4	56 *2.79*	14 *1.15*	16 *.70*	227 *3.72*	21 *.44*	7.5 *.21*	1.1 *.06*	13 *.21*	244	197	186	11
59	SE NE sec. 27	119.5	do	10-23-42	58	4.6	42 *2.10*	20 *1.64*	30 *1.31*	229 *3.76*	30 *.62*	13 *.37*	1.8 *. 9*	13 *.21*	269	187	187 d	0
	T. c S., R. 34 W.																	
62	NE NE sec. 5	116.5	do	10-24-42	57	0.91	45 *2.24*	22 *1.81*	17 *.73*	221 *3.62*	24 *.50*	10 *.28*	1.6 *.08*	19 *.30*	250	202	181	21
64	NE SE sec. 24	148.0	do	1-11-43	......	5.8	58 *2.89*	29 *2.38*	15 *.64*	214 *3.51*	25 *.52*	39 *1.10*	1.8 *.09*	43 *.69*	324	264	176	88

76	*T. 9 S., R. 31 W.* SE NE sec. 36	130.0	Ogallala	1-11-43	......	.57	50 *2.50*	17 *1.40*	18 *.79*	227 *3.72*	18 *.37*	12 *.34*	1.3 *.07*	12 *.19*	242	195	186	9
77	*T. 9 S., R. 32 W.* NW NW sec. 3	142.0	do	4-12-43	......	2.0	41 *2.05*	18 *1.48*	28 *1.24*	246 *4.03*	18 *.33*	8.0 *.22*	1.2 *.06*	8.0 *.13*	245	176	176 e	0
83	*T. 9 S., R. 33 W.* SW NW sec. 33	158.5	do	4-14-43	......	.46	46 *2.30*	18 *1.48*	25 *1.08*	231 *3.79*	30 *.62*	6.5 *.18*	1.8 *.09*	11 *.18*	254	189	189 f	0
85	*T. 9 S., R. 34 W.* NW NW sec. 26	178.5	do	4-14-43	......	3.2	43 *2.15*	19 *1.56*	21 *.91*	238 *3.90*	16 *.33*	5.5 *.16*	1.6 *.08*	9.3 *.15*	238	186	186 g	0
89	*T. 9 S., R. 35 W.* N NE sec. 12	179.5	do	4-13-43	......	0.22	37 *1.85*	17 *1.40*	32 *1.37*	234 *3.84*	18 *.37*	7.5 *.21*	1.2 *.06*	8.8 *.14*	239	162	162 h	0
90	SW SE sec. 27	164.0	do	4-13-43	56	1.6	39 *1.95*	20 *1.64*	23 *1.01*	240 *3.94*	17 *.35*	5.0 *.14*	1.1 *.06*	7.1 *.11*	234	180	180 i	0
92	*T. 9 S., R. 36 W.* SE SE sec. 29	224.5	do	4-13-43	57	c	40 *2.0*	22 *1.81*	21 *0.93*	246 *4.03*	18 *.37*	6.0 *.17*	1.0 *.05*	7.5 *.12*	239	190	190 j	0
99	*T. 10 S., R. 32 W.* NW NW sec. 8	95.5	do	1-11-43	......	0.33	46 *2.30*	17 *1.40*	21 *.90*	232 *3.80*	18 *.37*	6.0 *.17*	1.6 *.08*	11 *.18*	237	185	185 k	0
101	SE SW sec. 36	109.5	do	1-11-43	......	0.17	54 *2.69*	20 *1.64*	3.9 *.17*	234 *3.84*	12 *.25*	7.0 *.20*	0.5 *.03*	11 *.18*	226	216	192	24
108	*T. 10 S., R. 35 W.* NE NE sec. 19	190.5	do	4-15-43	......	1.8	53 *2.64*	15 *1.23*	14 *.59*	226 *3.71*	19 *0.40*	6.0 *0.17*	1.3 *.07*	7.1 *.11*	230	194	186	8
110	*T. 10 S., R. 36 W.* SE SW sec. 9	181.0	do	4-15-43	57	1.3	42 *2.10*	16 *1.32*	27 *1.16*	238 *3.90*	17 *0.35*	6.0 *0.17*	0.9 *0.05*	6.6 *0.11*	236	171	171 l	0
114	NE NE sec. 32	152.8	do	4-15-43	58	0.34	77 *3.84*	19 *1.56*	14 *0.63*	187 *3.07*	66 *1.37*	25 *0.70*	0.8 *.04*	53 *.85*	349	270	154	116
A	City of Brewster	....	do	7-29-44	......	c	38 *1.90*	16 *1.32*	37 *1.58*	214 *3.51*	30 *.62*	13 *.37*	1.6 *.08*	16 *.26*	298	161	161 m	0
B	City of Colby	....	do	2-24-44	......	c	49 *2.45*	18 *1.48*	26 *1.12*	243 *3.98*	24 *.50*	11 *.31*	1.6 *.08*	12 *.19*	301	196	196 n	0
C	City of Rexford	....	do	3-30-44	......	.05	44 *2.20*	21 *1.73*	28 *1.24*	234 *3.84*	31 *.64*	11 *.31*	1.8 *.09*	16 *.26*	321	196	192	4

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a. One part per million is equivalent to 1 pound of substance per million pounds of water or 8.33 pounds per million gallons of water.
b. Calculated.
c. Less than 0.15 part.
d. Total alkalinity, 188 parts per million; excess alkalinity, 1 part per million.
e. Total alkalinity, 202 parts per million; excess alkalinity, 26 parts per million.
f. Total alkalinity, 190 parts per million; excess alkalinity, 1 part per million.
g. Total alkalinity, 195 parts per million; excess alkalinity, 9 parts per million.
h. Total alkalinity, 192 parts per million; excess alkalinity, 30 parts per million.
i. Total alkalinity, 197 parts per million; excess alkalinity, 17 parts per million.
j. Total alkalinity, 202 parts per million; excess alkalinity, 12 parts per million.
k. Total alkalinity, 190 parts per million; excess alkalinity, 5 parts per million.
l. Total alkalinity, 195 parts per million; excess alkalinity, 24 parts per million.
m. Total alkalinity, 175 parts per million; excess alkalinity, 14 parts per million.
n. Total alkalinity, 199 parts per million; excess alkalinity, 3 parts per million.

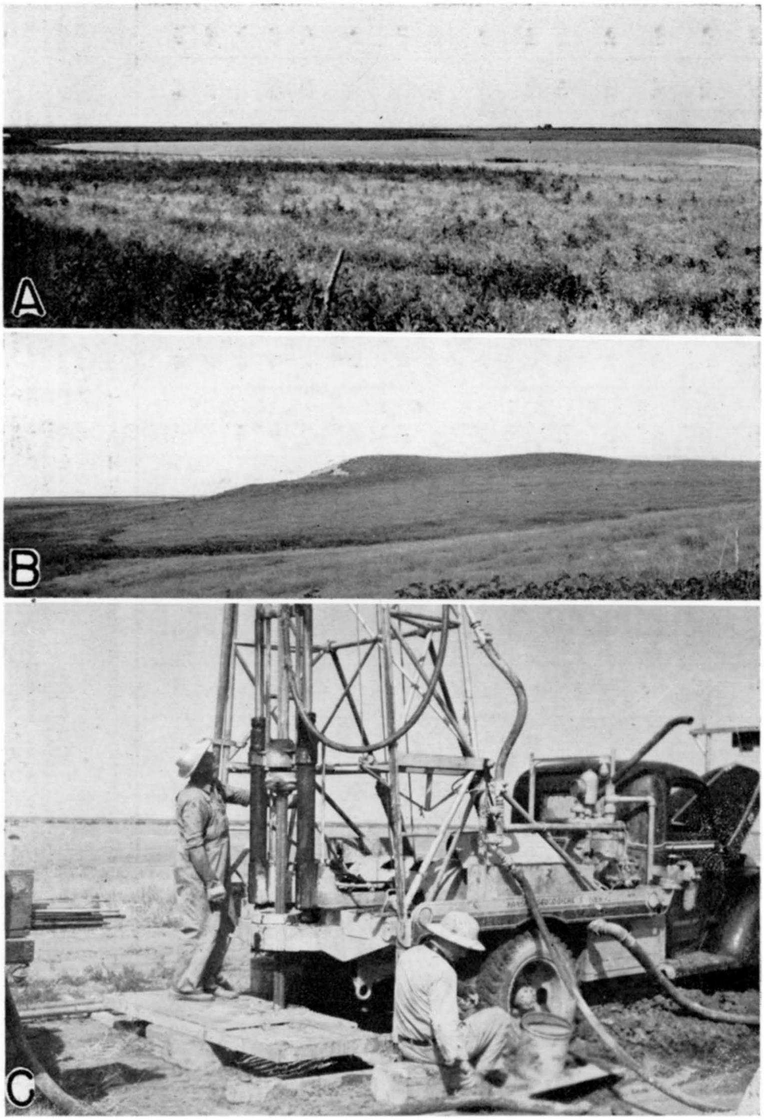

PLATE 5. *A,* Undrained upland depression, sec. 25, T. 6 S., R. 35 W., looking northeast. *B,* Hill of the Ogallala formation protruding through Sanborn formation and valley side deposits north of Brewster, SW¼ sec. 7, T. 8 S., R. 36 W. The "Algal limestone" marks the top of the Ogallala in this area. *C,* Hydraulic-rotary test drill in operation at test hole 12, southeast of Halford.

down to the shallow water table. A well should not be located close to or below possible sources of pollution, such as barnyards, privies, and cesspools, and every well should be tightly sealed down to a level somewhat below the water table. It is generally advisable to locate a well on a spot that is slightly higher than the surrounding ground, or bank earth around the top of the well so that surface drainage will run away from rather than into the well. If a well must be located near a source of possible pollution it should be up slope from it so that rain water will run from the location of the well toward the source of pollution rather than toward the well. Drilled wells are generally satisfactorily protected by the casing, although some are poorly sealed at the top.

QUALITY IN RELATION TO STRATIGRAPHY

Nearly all the water wells in Thomas county obtain water from the sand and gravel beds of the Ogallala formation, but a few wells draw water from the alluvial deposits along the valleys and some wells penetrate water-bearing material in both the alluvium and the Ogallala formation. Although thin beds of sand and gravel occur locally in the basal part of the Sanborn formation, very few wells obtain any water from that source. The Pierre shale, which underlies the Ogallala formation, is encountered at greater depths than the other water-bearing formations, and because of its impervious nature it is not a good water-bearing formation.

With the exception of the sample of water from well 14 that encounters both alluvium and the Ogallala sediments, all of the analyses reported in table 5 and figure 11 are of water pumped from the Ogallala formation; therefore the general discussion of chemical constituents in relation to use applies specifically to water in the Ogallala formation.

WATER-BEARING FORMATIONS

Cretaceous System

PIERRE SHALE

Rocks of Cretaceous age do not crop out in Thomas county. However, the Pierre shale of Cretaceous age crops out along valleys immediately adjacent to the county on the southwest, along Beaver creek valley in Rawlins county to the north, and in large areas of central Wallace and Logan counties. The Pierre shale underlies all of Thomas county at relatively shallow depths and serves as an impervious floor below the water-bearing sediments. It retards the downward percolation of water in much the same manner as the floor of a tank. Although the thickness of the Pierre shale below all parts of the county is not known, it is probably nowhere less than 100 feet thick and may be as much as 1,000 feet thick under the northwestern part of the county. Contours that show the topography of the Pierre shale surface have been plotted from test-hole data and are shown in figure 13.

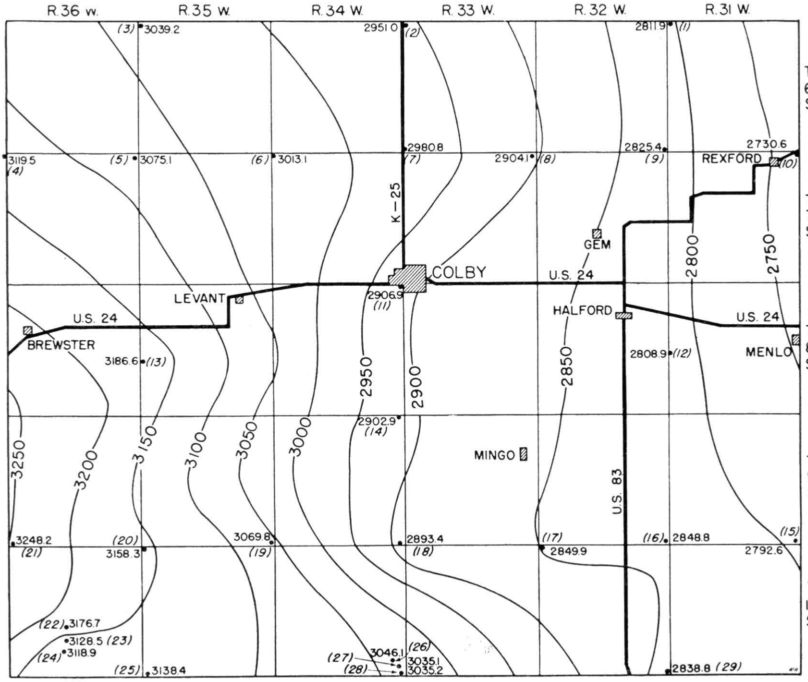

FIG. 13. Contour map showing the topography of the Pierre shale surface. Figures denote altitude of the Pierre shale surface in test holes, and figures in parentheses are the test-hole numbers which correspond to the numbers of the logs included in this report.

The Pierre shale of northwestern Kansas has been studied in detail by Elias (1931). It consists of gray, blue-gray, and black clayey shale containing zones of abundant concretions and thin beds of bentonite. Elias divided the Pierre shale into five named members and one unnamed unit. These are, in ascending order: Sharon Springs shale, Weskan shale, Lake Creek shale, Salt Grass shale, an unnamed shale interval, and the Beecher Island shale at the top. Probably all but the uppermost of the named members are present under Thomas county. The Pierre shale does not yield water to wells in Thomas county.

TERTIARY SYSTEM

OGALLALA FORMATION

The Ogallala formation was named by Darton in 1899 (pp. 734, 735, 741, 742, pl. 84) from a locality in southwestern Nebraska. In 1920 Darton (p. 6) referred to the type locality as near Ogallala station in western Nebraska. Elias (1931) has made detailed studies of the Ogallala formation in Wallace county, Kansas, adjacent to Thomas county on the southwest. In 1937 he (Elias, 1937) briefly described the Ogallala deposits in Rawlins and Decatur counties to the north, and in 1942 (Elias, 1942) described the Tertiary fossil seeds and other plant remains of the central High Plains. Smith (1940) has discussed the character and origin of the Ogallala, especially in southwestern Kansas, and these deposits have recently been described in detail in several southwestern Kansas counties (Frye, 1942; Latta, 1941, 1944; McLaughlin, 1942, 1943; Waite, 1942).

Character.—The Ogallala formation consists of clay, silt, sandy silt, cross-bedded sand and gravel (pl. 6B), and locally sandy limestone. In areas adjacent to Thomas county it also contains beds of volcanic ash, diatomaceous marl, bentonitic clay, and hard silicified beds that resemble chert or quartzite. The generalized character of the Ogallala is given by the logs of test holes included in this report. As there are no exposures that permit a continuous examination of any considerable thickness of these strata in Thomas county, the beds were examined along canyon walls in southern Rawlins county and also in northeastern Wallace county. The following stratigraphic section was measured 1.4 miles north of the Thomas county line in eastern Rawlins county.

Measured section of the Ogallala formation, SE¼ sec. 30, T. 5 S., R. 32 W., Rawlins county. (Measured by John C. Frye and August Lauterbach).

Bed No.		Thickness (feet)
13	Mostly covered, capped by nodular mortar bed, irregular, hard, gray,	6.0
12	Mortar bed, coarse gravel to sand cemented by calcium carbonate; weathers irregularly cavernous	5.5
11	Silt, sand, and gravel; massive; poorly sorted; red-tan	7.0
10	Mortar bed, sand and some fine gravel; loosely cemented by calcium carbonate; friable; gray	1.5
9	Silt, sand, and gravel; massive; poorly sorted; red-tan	17.8
8	Mortar bed, hard, massive, gray	4.0
7	Sand, fine, and some silt; tan to red-buff; partly covered	7.5
6	Mortar bed, hard, gray	3.5
5	Sand, fine to medium, tan to buff, partly covered	6.0

4	Mortar bed, sand and coarse gravel; hard; gray	2.2
3	Sand and gravel; tan	9.5
2	Caliche and mortar bed; massive; having thin lenses of clay and silt interbedded; light gray to light gray-tan	8.0
1	Silt and fine sand; massive; gray; covered in lower part	13.7
	Total thickness of beds measured	92.2

A section of the Ogallala formation was measured along a creek bank and road cut in northwestern Thomas county. The total thickness is much less than that in the measured section in Rawlins county but the general character of the beds is about the same.

Measured section in the SW corner sec. 26, T. 6 S., R. 31 W., Thomas county (Measured by John C. Frye).

Bed No.		Thickness (feet)
	Sanborn formation	
10	Silt and fine sand; gray; containing concretions of calcium carbonate	20.0
	Ogallala formation	
9	Sand, silt, and caliche; buff	10.0
8	Mortar bed of sand and gravel; gray	0.4
7	Clay and silt; blocky; gray with yellow along some bedding planes; containing some carbonaceous material	0.6
6	Sand and silt containing some soft caliche; light gray	1.8
5	Silt and sand; tan; containing a few pebbles and caliche	5.2
4	Sand and some gravel; cemented; gray	0.5
3	Silt, sand, and gravel; containing some stringers of caliche; red-tan and gray	12.4
2	Mortar bed of sand, gray	1.5
1	Silt and sand; red-tan and gray; containing some caliche	4.8
	Total thickness of beds measured	57.8

In order to determine the grain size and sorting, the percentage of soluble material, and the permeability of the several beds, samples were collected from seven of the beds described in the stratigraphic section measured in Rawlins county. Analyses of these samples were made by Ada Swineford and Carrie Thurber and are reported in table 6. The solubility was determined by digesting a known quantity of sample in dilute hydrochloric acid, the spent acid and dissolved material were then washed from the sample and the residue was caught on filter paper, dried, and weighed. A mechanical analysis, or sieve analysis, was made of the insoluble fraction of each sample by placing a known weight of dry sample in a set of sieves and agitating the sieves for 20 minutes in a mechanical shaker. The fraction caught on each sieve was then weighed and

TABLE 6.—*Physical properties of samples of the Ogallala formation from the measured section in sec. 30, T. 5 S., R. 32 W., Rawlins county*

(By Ada Swineford and Carrie B. Thurber)

No. of bed in measured section	Mechanical analysis (percent by weight)								Coefficient of permeability*	Percent soluble in dilute HCl
	Coarse gravel (larger than 4.0 mm.)	Medium gravel (4.0–2.0 mm.)	Fine gravel (2.0–1.0 mm.)	Coarse sand (1.0–0.5 mm.)	Medium sand (0.5–0.25 mm.)	Fine sand (0.25–0.125 mm.)	Very fine sand (0.125–0.062 mm.)	Silt and clay (less than 0.062 mm.)		
9	2.0	5.6	9.2	11.7	17.2	16.4	16.0	21.9	107	9.3
7	....	.1	.5	3.6	25.1	36.9	18.2	15.6	154	9.4
5	.2	2.0	4.3	11.1	24.1	31.8	18.4	8.0	172	4.2
4	.6	4.5	9.5	16.1	28.1	27.0	10.8	3.3	....	38.1
3	5.4	4.3	12.1	27.2	33.1	15.2	2.2	.4	609	1.9
2	....	tr.	1.6	11.4	30.5	36.5	11.4	8.4	....	23.4
1	....	....	.1	5.5	20.3	26.8	19.2	28.1	107	3.0

* Gallons of water a day, at 60° F., that is conducted laterally through each mile of water-bearing bed under investigation (measured at right angles to the direction of flow), for each foot of thickness of the bed and for each foot per mile of hydraulic gradient.

the percentage calculated. The analyses of loess and slope deposits reported in tables 7 and 8 were made by the same method supplemented by pipette determinations of grade sizes less than 0.062 mm.

A comparison of the analyses in table 6 with the descriptions of the beds given in the measured section in Rawlins county indicates that the caliche and mortar beds have a high percentage of calcium carbonate, which represents the soluble fraction. In these two beds (2 and 4) the percentage of soluble material was 23 and 38. The insoluble fraction of the mortar beds corresponds closely to the sand and gravel beds that contain a smaller amount of soluble material. It will be noted that none of the samples is very well sorted. The highest percentage of material in any one grade is 36.91 in the fine-sand fraction of the sample from bed 7. The Ogallala formation consists essentially of partly discontinuous and interconnected lenticular bodies of stream-deposited sand and gravel interspersed through an enclosing mass of poorly sorted stream-deposited clay, silt, sand, and gravel. Locally where the top of the formation has not been eroded away, there is a capping layer of sandy ("Algal") limestone. The logs and measured sections give the general character of the formation but because of its manner of deposition the details of lithology range widely in short horizontal distances in some places, whereas they may be quite persistent in other places.

Distribution and thickness.—The Ogallala formation underlies all of Thomas county and rests directly upon the Pierre shale. As shown in plate 1, it is overlain in most parts of the county by the Sanborn formation, slope deposits, or alluvium. The thickness of the Ogallala under Thomas county is shown by the 29 logs of test holes to range from 77 feet in test hole 7 to 266 feet in test hole 14. The average thickness in the 29 test holes is 165 feet. In general the Ogallala is thick under northwestern, central, and eastern Thomas county and thin under the southwestern and north-central parts.

Age and correlation.—The beds in the type area of the Ogallala formation near Ogallala, Nebraska, have been studied by Elias (1931) and the fossil vertebrates have been described and discussed (Hibbard, 1933; Hesse, 1935; Stirton, 1935, p. 444). A committee report on the nomenclature and correlation of the North American continental Tertiary (Wood, *et al.*, 1941, pl. 1, pp. 12, 27) placed the Ogallala of Kansas and eastern Colorado in the Blancan, Hemphillian and Clarendonian, and the Ogallala of Nebraska and eastern Wyoming in the lowermost Blancan, the Hemphillian, Clarendonian, and upper part of the Barstovian, North American provincial age zones, which they correlated with the upper, middle, and lower Pliocene and upper Miocene, respectively. They listed the characteristic fossil vertebrates for each of these provincial age zones. Lugn (1939) presented a classification of the Tertiary formations of Nebraska in which he considered the Ogallala as a group containing the following formations in ascending order: Valentine, Ash Hollow, Sidney gravel, and Kimball, all of Pliocene age (p. 1266). Elias (1931, pp. 149-153; 1932; 1942) described plant remains from the Ogallala of the High Plains region and correlated certain zones over wide areas. The Ogallala is generally agreed to be of Pliocene age.

During the progress of field work in Thomas county, I collected from the Ogallala formation (middle North line sec. 13, T. 8 S., R. 36 W.) one fossil tooth (Kansas University Museum of Vertebrate Paleontology no. 6550) that has been identified by C. W. Hibbard of the University of Kansas as ?*Pliohippus*. Allan Graffham collected fossil vertebrates from a gravel pit south of Brewster (sec. 29, T. 8 S., R. 36 W.). One fossil from the Ogallala in the lower part of the pit has been identified by C. W. Hibbard as *Pliohippus* cf. *ansae* (Matthew and Stirton).

For the purpose of this paper the Ogallala is classed as a formation rather than as a group as used by Lugn, and definite correlation is not made with the stratigraphic units widely used in Nebraska. A sample of limestone from an outcrop just northwest of Brewster was submitted to M. K. Elias of the Nebraska Geological Survey, who identified it as a typical specimen of the "*Chlorellopsis* limestone" (personal communication dated September 22, 1944). The presence of this bed, which marks the top of the Ogallala of Nebraska, indicates that the Thomas county section includes stratigraphic equivalents of the upper part of the Ogallala of Nebraska. Although the limits of the several stratigraphic units have not been drawn in this area, age equivalents of Lugn's Kimball, Sidney gravel (?), and Ash Hollow are probably included within the Ogallala, but it is my opinion that most of the Ogallala in this area is of Ash Hollow age. The lower part of the Ogallala formation is not exposed in Thomas county and it may include beds equivalent in age to the Valentine or even older beds in Nebraska.

A clay zone having the appearance of a bentonitic clay is present in some of the test holes between the base of the Ogallala and the top of the Pierre shale. This clay is tan to light gray and seems to grade downward into typical blue-gray or black Pierre shale, thus probably representing the product of weathering of the Pierre prior to the deposition of the Ogallala. It is possible, however, that in some places this may represent the Woodhouse clay described by Elias (1931, pp. 155-158) as occurring at the base of the Ogallala in Wallace county.

Water supply.—The sand and gravel of the Ogallala formation is the primary source of ground water in Thomas county. Nearly all the wells in the county obtain all or part of their water from this formation. The finer materials of the formation generally are porous and hold considerable water but are not permeable enough to yield water freely. The coarser materials, the gravels in particular, commonly yield abundant supplies of water.

Mechanical analyses and coefficients of permeability of samples from a measured stratigraphic section of the Ogallala are given in table 6. The permeability of a water-bearing material is its capacity for transmitting water under pressure. The coefficient of permeability, as determined in the field or laboratory, is expressed by O. E. Meinzer as the number of gallons of water a day at 60° F. that is conducted laterally through each mile of the water-bearing bed under investigation (measured at right angles to the direction of flow), for each foot of thickness of the bed, and for each foot per mile of hydraulic gradient (Stearns, 1927, p. 148). The coefficients of permeability given in table 6 were determined by means of a portable apparatus designed by V. C. Fishel of the Federal Geological Survey. It will be noted that the coefficient of permeability of five samples ranged from 107 to 609.

Concerning the relation of the permeability of water-bearing material to the yield of wells, Wenzel (1942, p. 11) stated:

> Although there are many water-bearing materials of low permeability, most formations that are sufficiently water-bearing to be utilized by wells have coefficients that are whole numbers of two or more figures when expressed in Meinzer's units—that is, above 10. The yields of wells depend, of course, not only on the permeability of the formations they tap but also on the thickness of the formations, the drawdown of the water level, and the diameter and construction of the wells. For many places in the United States the physical and economic conditions are such that wells with moderate to high yields—100 gallons a minute or more—generally penetrate materials with coefficients of permeability of 100 or more.

This indicates that the permeability of the sand and gravel beds of the Ogallala formation is sufficient to permit the development of wells of large capacity—it is not as high, however, as the permeability of some of the materials yielding water to irrigation wells in southwestern Kansas. By comparison the coefficient of permeability of four samples of Dakota sandstone in Ford county (Waite, 1942, p. 48) ranged from less than 1 to 28, and the coefficients of test-hole samples of the Ogallala in Meade county (Frye, 1942, p. 92) ranged from 22 to 5,300. Coefficients of permeability determined by pumping tests on irrigation wells in Finney and Gray counties (Latta, 1944, p. 54) ranged from 235 to 1,040. Coefficients determined by the same method in Hamilton and Kearny counties (McLaughlin, 1943, p. 47) ranged from 280 to 9,113. For the most part the materials of very high permeabilities were tapped by irrigation wells drawing water from alluvium and not from the Ogallala formation.

The Ogallala formation is a large underground reservoir that is only partly filled with water. The thickness of saturated material is shown in the cross sections in figures 3 and 4. Logs and test holes indicate that a large percentage of the saturated zone of the Ogallala is composed of sand and gravel; therefore the amount of water available is large.

All but one of the analyses in table 5 are of water pumped from the Ogallala formation; thus the section on quality of water refers especially to this formation.

Quaternary System

SANBORN FORMATION

In 1931 Elias (pp. 163-181) described unconsolidated Pleistocene deposits, consisting mostly of silt—or loess—in northwestern Cheyenne county, Kansas, and named these deposits the Sanborn formation from the town of Sanborn, located just north of the type area in Nebraska. Beds of similar character in Nebraska have been studied and described by Lugn (1935, pp. 128-168). Elias (1937, p. 7) briefly described the occurrence of this formation in Rawlins and Decatur counties, and the stratigraphy, fossil mollusks, and fossil vertebrates have recently been studied (Leonard and Frye, 1943; Hibbard, Frye, and Leonard, 1944).

Character.—In north-central Kansas, the Sanborn formation generally consists of a basal sand and gravel that ranges in texture and composition from grains and pebbles of chalk and shale to boulders of igneous rocks; this is overlain by heterogeneous deposits of clay, silt, sand, and gravel that are light gray to red-brown. A distinct soil zone is present at the top of these heterogeneous deposits and separates them from the overlying beds. The beds above the soil zone consist of massive silt—or loess—containing some zones of fine

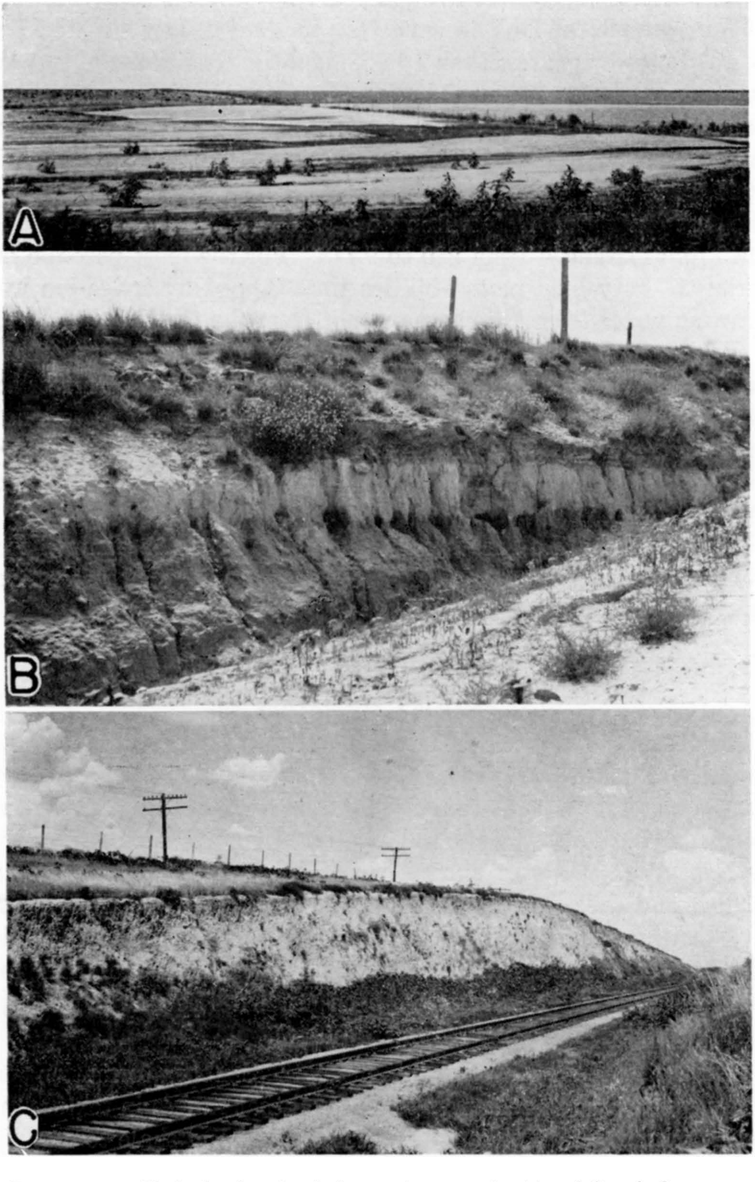

PLATE 6. *A,* Undrained upland depression, north side of South Sappa creek due north of Levant. *B,* Exposure of Ogallala formation along road cut south of Prairie Dog creek due north of Rexford. *C,* Silt of the Sanborn formation in railroad cut (Chicago, Rock Island and Pacific) west of Levant.

to very fine sand (Hibbard, Frye, and Leonard, 1944). In Thomas county, which was probably a part of an upland divide area during Sanborn time, the prominent soil zone and lower beds of the Sanborn seemingly were not formed. At a few places very coarse sand and gravel containing cobbles several inches in diameter have been observed overlying the Ogallala at the base of the Sanborn formation, but for the most part the Sanborn of this area consists of massive silt containing a thin sandy zone at the base (see well logs, and cross-sections in figs. 3 and 4).

Along the Rock Island Railroad near Levant (SW¼ NW¼ sec. 8, T. 8 S., R. 35 W.) more than 30 feet of this massive silt, or loess, is exposed in the nearly vertical side of a cut (pl. 6C). Samples were collected from this cut at vertical intervals of 5 feet and mechanical analyses of them were made by Ada Swineford and Carrie B. Thurber. The results of these analyses are given in table 7. The uppermost sample, no. 7, was collected from the upper 8 inches of soil.

The high degree of sorting displayed by this material is indicated in table 7 by the fact that more than 50 percent by weight of six of the seven samples was included in the single fraction 0.062-0.031 mm. Russell (1944, p. 3) stated concerning the definition of loess: "In the writer's experience the single fraction 0.01-0.05 mm. ordinarily constitutes at least 50 percent (by weight) of a sample and in many cases amounts to 75 percent." Although these exact units were not used in the analyses reported here, Ada Swineford (personal communication) determined graphically the percentage of each sample included in this fraction, and found that from 59 to 70 percent of the material was included in the fraction 0.01-0.05 mm. indicating a degree of sorting comparable to that required by Russell for loess. The sorting and major grades of these samples are comparable to those of other samples of loess from the High Plains and of wind blown dust reported by Swineford and Frye (1945).

The origin of loess deposits has been discussed at length by Russell (1944) who concluded that loess is generally not formed by eolian processes but is produced by a process he called loessification, operating on water deposited material. Frye (1945, p. 86) discussed the problems of the loess in northwestern Kansas and pointed out that although Russell's hypothesis of origin seems to explain adequately some of the deposits of massive silt along terraces in central and southern Kansas and some of the valley-side or slope deposits in northwestern Kansas, it cannot be accepted for

TABLE 7.—*Mechanical analyses of samples of loess collected at vertical intervals of 5 feet from Rock Island Railroad cut, SW¼ NW¼ sec. 8, T. 8 S., R. 35 W.*

(By Ada Swineford and Carrie B. Thurber)

Sample No.	Mechanical analysis (percent by weight)										
	1.0–0.5 mm.	0.5–0.25 mm.	0.25–0.125 mm.	0.125–0.062 mm.	0.062–0.031 mm.	0.031–0.0156 mm.	0.0156–0.0078 mm.	0.0078–0.0039 mm.	0.0039–0.00195 mm.	0.00195–0.00098 mm.	Less than 0.00098 mm.
7	0.8	2.9	3.4	9.3	52.3	17.1	4.8	3.8	1.4	1.1	2.9
6	.1	.8	2.1	6.0	61.9	15.1	5.5	4.0	1.4	1.0	2.1
5	.1	.4	.7	4.1	46.3	30.6	6.8	4.7	1.8	1.2	3.3
4	.2	1.1	1.7	7.4	64.3	15.3	4.1	2.3	1.0	.6	2.0
3	....	.2	.4	6.1	57.6	22.1	5.7	3.7	1.1	1.0	2.1
2	....	.5	.9	5.1	54.7	23.5	6.1	4.2	1.2	1.0	2.8
1	....	....	.3	5.0	64.2	18.5	4.2	3.1	1.2	1.0	2.4

the extensive loess—or silt—deposits that comprise the upper part of the Sanborn formation. The cross sections (figs. 3 and 4) show that this deposit blankets the highest part of the uplands to depths of more than 40 feet and therefore no parent material seems to be available for the loessification process. There may be a question, based on Russell's discussion, as to whether or not an eolian deposit such as this should be called "loess."

Distribution, thickness, and surface form.—As shown on plate 1, the Sanborn formation and associated slope deposits underlie the surface of most of Thomas county. The logs of test holes included with this report indicate that the Sanborn formation attains a maximum thickness of more than 80 feet and commonly is 35 to 40 feet thick in the county. In the upland-divide areas the surface developed on the Sanborn formation is a flat to gently rolling plain (pl. 3B). In some places low bluffs (pl. 3C) were formed along valley sides, and along the major valleys these deposits merge with slope deposits to produce gentle well-rounded valley slopes.

Age and correlation.—The Sanborn formation is separated from the underlying Pliocene Ogallala formation by a prominent disconformity, which is evidence of an important erosion interval after the deposition of the "Algal limestone" and before deposition of the lowermost beds of the Sanborn. This stratigraphic relationship and the fossil mollusks and fossil vertebrates that have been described from these beds in northwestern Kansas (Leonard and Frye, 1943; Hibbard, Frye, and Leonard, 1944) indicate a middle and upper Pleistocene age for the Sanborn formation; but the uppermost part may be Recent.

Definite correlation with the extensive Pleistocene formations of southwestern Kansas has not been made. It is my opinion that age equivalents to the lower part of the Meade formation are absent in this area, but the Sanborn may be in part equivalent to the upper part of the Meade formation and the Kingsdown silt. To the north of this area beds of similar character have been described as the Loveland and Peorian formations separated by a prominent soil zone (Lugn, 1935). In Thomas county the extensive tan loess, or silt, of the Sanborn formation may be equivalent in part to the Peorian of western Nebraska, but as the soil zone was not observed in this area correlation of the lower part of the Sanborn with the Nebraska section is not attempted.

Water supply.—In most parts of Thomas county the Sanborn formation lies wholly above the water table and hence is dry. None of the wells visited in the county and reported in table 9 obtain water from this formation. The local deposits of sand and gravel at the base of the formation would constitute good water-bearing material if they were saturated with water. The primary importance of the Sanborn with respect to water supply is its retarding effect on recharge.

SLOPE DEPOSITS

In Elias' (1931, pp. 179-180) original description of the Sanborn formation he stated that only the loess on the divides should be considered Pleistocene in age and a part of the Sanborn formation.

> The loess of the valley slopes, which is reworked loess of the divides and must not be called Sanborn formation, attains a thickness of 50 feet, but approaches that thickness in only a few places, usually along a narrow zone high on the slopes. This loess is usually distinctly stratified, which is due to the interbedded layers composed of fragments of locally outcropping rocks (chiefly Ogallala) mixed with loess. The valley-bottom loess is more evenly distributed and is usually 10 to 15 feet thick. It passes downward into alluvial sands and gravel and it also must be regarded as a part of the alluvial deposits.

Slope deposits such as those described by Elias are extensive in Thomas county. They mantle the slopes of large and small valleys alike and in some places, where the parent material consists entirely of loess of the Sanborn formation, they are virtually indistinguishable from the Sanborn. Deposits of a comparable origin along major valleys south of this area have been described by Frye and Smith (1942, p. 220) who stated:

> Along certain segments of the valleys of such streams as the Smoky Hill and Cimarron rivers, both of which head in the Great Plains province and have a relatively small flow, it seems that lateral planation by the larger streams is of very limited effectiveness as an erosional process. Valley flats are typically narrow, and the graded slopes into which they merge are characteristically broad. Slope processes and side stream work are largely responsible for the lowering of the land surface. The trunk streams to which these processes are graded exhaust their energies in transportation, and have little power to erode, save in comparatively brief interludes following rejuvenation.
>
> The conditions summarized above are comparable to those of more arid regions where pediments are widespread and constitute the dominant landform. The latter, also, are formed by the work of slope processes and of many small streams, graded either to a through-going trunk stream or to the advancing edge of alluvial fill in an enclosed basin. In such regions, the erosive work of any through-going streams that are present generally lags far behind that of the slope processes, and is commonly limited to a comparatively narrow belt.

TABLE 8.—*Mechanical analyses of samples of slope deposits from roadside cut along south side of South Sappa creek valley, W. center sec. 25, T. 7 S., R. 35 W.*

(By Ada Swineford and Carrie B. Thurber)

Sample No.	Mechanical analysis (percent by weight)												
	Larger than 4 mm.	4–2 mm.	2–1 mm.	1.0–0.5 mm.	0.5–0.25 mm.	0.25–0.125 mm.	0.125–0.062 mm.	0.062–0.031 mm.	0.031–0.0156 mm.	0.0156–0.0078 mm.	0.0078–0.0039 mm.	0.0039–0.00195 mm.	0.00195–0.00098 mm.	Less than 0.00098 mm.
11	......	......	......	0.1	0.4	0.8	4.8	49.8	22.8	8.6	4.3	3.0	2.0	3.5
10	......	......	......	.3	1.2	.9	4.9	53.2	20.5	7.9	4.2	2.1	1.7	3.1
9	......	......	......	.4	1.2	1.1	5.0	50.2	20.6	8.0	3.6	2.3	1.5	6.1
8	......	......	......	2.1	6.3	2.4	4.8	44.1	20.7	7.1	3.4	2.0	1.3	5.8
7	......	......	......	2.0	6.2	3.1	4.4	43.9	19.9	7.4	3.8	2.0	1.6	5.6
6	......	......	......	2.8	13.1	4.8	4.7	39.6	17.4	5.7	2.9	2.0	1.3	5.6
5	......	......	......	.1	.7	.8	6.2	49.2	22.6	8.3	3.7	1.8	1.4	5.1
4	......	......	......	.4	1.9	1.7	5.2	49.2	22.9	7.5	3.3	1.6	1.2	5.0
3	0.8	6.6	12.3	16.8	19.3	9.6	7.0	16.5	3.4	1.5	1.1	.7	.4	3.9
2	......	......	.3	2.2	4.2	12.3	9.8	50.9	8.2	2.2	2.8	1.5	1.0	4.5
1	......	......	......	1.0	4.3	3.1	8.3	49.3	16.6	4.3	4.3	1.9	1.6	5.2

The slope deposits observed in Thomas county differ from those described by Frye and Smith primarily because of the different nature of the beds that underlie the valleys. The massive silt of the Sanborn formation that underlies the uplands of Thomas county has little resistance to processes of slope erosion so that rounded shoulders were formed where the Sanborn and slope deposits merge (pl. 3A). The more resistant Tertiary and Cretaceous formations underlying the valleys studied by Frye and Smith, on the other hand, produced distinct escarpments at the crests of the valley walls so that the slope deposits constitute a wedge of material which thickens down slope toward the main channel.

Down-slope migration of unconsolidated deposits is not unique to semiarid regions. Mass movement of thick soils from deeply weathered crystalline rock in the Piedmont region of South Carolina has been described by Ireland, Sharpe, and Eargle (1939, pp. 20-24). They stated that the A and B horizons migrate down slope and that this movement produces a sharp line of demarcation between the B and C horizons with a concentration of rock fragments, a "stone line," near or at the base of the B horizon. The mechanics of this soil migration seem to have much in common with the movement of the slope deposits described here—the slope deposits being comparable to the A and B horizons and the unconsolidated parent material below the slope deposits being in the same relative position as the C horizon of the southern Piedmont region. There are several important points of difference, however. The slope deposits attain a greater thickness, have a greater range in thickness, formed more rapidly and during a much shorter span of geologic time, probably migrate down slope at a greater rate of speed, and the character of the deposits has been altered but little from that of its source material.

In an attempt to discover the differences in mechanical composition between the silt of the Sanborn formation and the slope deposits that so closely resemble it in appearance, a sequence of samples was collected along a roadside cut that ascends the south valley wall of South Sappa creek in the west-central part of the county. Mechanical analyses of these samples which were collected 18 to 20 inches below the surface are given in table 8. Sample 1 was collected at the level of the flood plain, and samples 2 to 9 at 5-foot vertical intervals up the valley wall. Sample 10 was collected 10 feet higher up the slope than sample 9, and sample 11, 10 feet above sample 10. These last two samples were collected from above the rounded shoulder of the valley wall and are believed to represent loess of the Sanborn that has not been moved by slope processes. The next several samples (9, 8, 7, 6, 5, and 4) seem to be derived mostly from silt of the Sanborn. Sample 3 contains an admixture of coarser sediments and may be the highest sample that contains an appreciable amount of material derived from the Ogallala formation, although the top of the Ogallala (obscured by the slope deposits) is believed to occur at a higher level.

These analyses indicate that where the slope deposits are derived from the upper massive silt of the Sanborn formation they cannot be distinguished from it on the basis of grain size and sorting. The loess-like character of the slope deposits seems to extend some distance down the slope below the top of the Ogallala formation and the failure to differentiate this material from the Sanborn would result in an erroneous idea of the thickness of the Sanborn. On the geologic map (pl. 1) the slope deposits were mapped with the Sanborn formation where they were of sufficient thickness and continuity to obscure the underlying beds even along road cuts and sides of gullies. Where these deposits mantle the Ogallala thinly or intermittently, they were ignored in the mapping and the material is mapped as the Ogallala formation.

As pointed out above, Russell's (1944) recent discussion of loess raises some question as to the application of that term to the massive silt of the Sanborn formation and to the slope deposits of similar character. Elias (1931) applied the term loess to both the massive silt and the slope deposits that were largely derived from it. Russell stated concerning loess (1944, pp. 4, 5):

> The definition should include the following essential characteristics: Loess is unstratified, homogeneous, porous, calcareous silt; it is characteristic that it is yellowish or buff, tends to split along vertical joints, maintains steep faces, and ordinarily contains concretions, and snail shells. From the quantitative standpoint at least 50 percent, by weight, must fall within the grain size fraction 0.01-0.05 mm, and it must effervesce freely with dilute hydrochloric acid.

The massive silt of the Sanborn formation fills all the requirements of this definition. In some places the slope deposits also fill these requirements with the exception of lack of stratification, for most exposures of this material exhibit at least an indistinct stratification. In this report the term loess is not applied to the slope deposits.

The slope deposits are quite young and probably all reached their present position during the Recent epoch. Actually, the processes that gave rise to these deposits are probably still in operation and this material is slowly migrating down slope, being added to from the underlying beds and modified in character. The slope deposits on continuous slopes between the uplands and the stream channels are sediments in transit, even though the movement is imperceptible. These deposits are intimately related to the alluvium along the narrow valley bottoms and in fact the part of the sheet of slope deposit nearest the stream channel is acted upon by stream processes during flood periods and by slope processes during intervening periods.

ALLUVIUM

General features.—Alluvial deposits occur along the bottoms of all the major valleys of the county. In most places the alluvium is relatively fine-textured and consists of the materials supplied to the channel by the lower edge of the sheet of slope deposits. The streams for the most part are not actively eroding the valley sides, but are serving merely as transportation lines for the sediment furnished to them. The general distribution of alluvium is shown on the geologic map (pl. 1.). The field mapping of the alluvium was more or less arbitrary in some places, for there is not a distinct boundary line between the slope deposits and alluvium.

Along a few of the major valleys where the valley floor is some distance below the top of the Ogallala formation, the alluvium includes a relatively large percentage of sand and gravel derived from the Ogallala.

Water supply.—Along some of the valleys in Thomas county the alluvium is above the water table and therefore is dry except during rainy periods. In some other valleys the alluvium does not yield appreciable quantities of water to wells because of the fine texture and poor sorting of the material. Along parts of South Sappa creek, Prairie Dog creek, and the Saline river near the east county line, the alluvium is derived largely from the Ogallala formation and is below the water table; therefore, it yields some water to wells. In these areas, however, the alluvium is so thin that wells should be drilled into the underlying Ogallala to obtain a permanent supply of water.

RECORDS OF TYPICAL WELLS

Descriptions of the wells visited in Thomas county are given in the table that follows (table 9). The wells are listed in order by townships from north to south and by ranges from east to west. Within a township the wells are listed in the order of the sections. All information classed as "reported" was obtained from the owner or tenant. Depths of wells not classed as "reported" were measured and are given to the nearest tenth of a foot below the measuring point described in the table. Depths to water level not classed as "reported" were measured and are given to the nearest hundredth of a foot.

TABLE 9.—*Records of typical wells in Thomas county, Kansas*

No. on pl. 2	LOCATION	Owner or tenant	Type of well (1)	Depth of well (feet) (2)	Diameter of well (in.)	Type of casing (3)	Principal water-bearing bed		Method of lift (4)	Use of water (5)	Measuring point			Depth to water level below measuring point (feet) (6)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
							Character of material	Geologic subdivision			Description	Distance above (+) or below (—) land surface (feet)	Height above sea level (feet)			
	T. 6 S., R. 31 W.															
(1)	SE SW sec. 1...	H. A. Tecklenburg.....	Dr	76.5	6	GI	Sand and gravel	Ogallala......	Cy, W	S	Top of concrete curb, east side	+0.6	2,903.0	73.46	9-10-42	
(2)	SW NW sec. 30.......	Foster Farms.........	Dr	129.5	6	GI	do..........	do..........	Cy, W	D, S	Top of concrete curb, south side	+ .4	3,015.9	120.23	9-10-42	
3	NW NW sec. 25......	Mary L. Osborn.......	Dr	34.2	6	GI	do............	do..........	Cy, W	S	Top of casing, north side	+ .8	2,870.8	22.59	9-10-42	
4	SE SE sec. 31.........	E. D. Mustow........	Dr	74.0	6	GI	do............	do..........	Cy, W	D, S	Top of concrete curb, east side	+1.3	2,968.3	54.82	9-10-42	
5	NE NE sec. 32........	Foster Farms.........	Dr	61.5	6	GI	do............	do..........	Cy, W	S	Top of casing, east side	+ .5	2,945.8	49.05	9-10-42	
	T. 6 S., R. 32 W.															
6	NE NE sec. 8.........	Henry Knudson.......	Dr	61.2	6	GI	do............	do..........	Cy, H	P	Top of casing, north side	+ .9	2,980.5	55.62	6- 8-43	
7	NW SW sec. 12.......	Roy Zeiglemeyer......	Dr	168.5	16	I	do............	do..........	N	I	Top of casing, west side	— .3	3,019.8	115.83	7-16-42	
8	SE NE sec. 24........	Foster Farms.........	Dr	167.0	6	GI	do............	do..........	Cy, W	D, S	Top of concrete curb, south side	+ .8	3,042.4	135.46	9-10-42	
9	SE NE sec. 24........	Foster Farms.........	Dr	147.5	6	GI	do............	do..........	Cy, W	D, S	Top of concrete curb, north side	+ .6	3,042.5	135.83	9-10-42	
	T. 6 S., R. 33 W.															
10	NW NW sec. 6........	(Public road).........	Dr	215.0	3	N	do............	do..........	N	N	Land surface..........	.0	3,159.0	93.0	10- -43	Test hole 2.
11	SW NW sec. 15.......	Ruth Rowe...........	Dr	116.5	6	GI	do............	do..........	N	N	Top of casing, north side	+0.5	3,114.1	107.56	9-12-42	
12	SW SW sec. 31........	(Public road).........	Dr	130.0	3	N	do............	do..........	N	N	Land surface..........	.0	3,083.8	23.58	9- -43	Test hole 7.
13	SW NE sec. 32........	Dr. Murry Eddy......	Dr	85	32	GI	do............	do..........	T, E	I	do...................	.0	3,065.4	13	7-28-42	
(14)	SE NW sec. 33........	Jones Bros............	Dr	38.2	16	I	do	Alluvium and Ogallala	C, G	I	Top of concrete curb to pump cistern	.0	3,047.9	13.46	7-29-42	Measured yield in 1943, 637; drawdown, 15.37 (7); specific capacity 41.44.

15	*T. 6 S., R. 34 W.* SE NE sec. 6	Fed. Farm Mort. Corp.	Dr	56.0	6	GI	do.	Ogallala	N	N	Top of casing, east side	+0.1	3,154.0	52.79	7–27–42	
(16)	SE SW sec. 14	Walter Callahan	Dr	133.5	6	GI	do.	do.	Cy, W	D, S	Top of casing, west side	+ .5	3,199.3	129.26	9–12–42	
17	NW NE sec. 28	John Donn	Dr	129.5	6	GI	do.	do.	Cy, W	S	Top of casing, south side	+1.2	3,217.3	116.25	9–11–42	
18	*T. 6 S., R. 35 W.* NW NW sec. 6	(Public road)	Dr	300.0	3	N	do.	do.	N	N	Land surface	.0	3,330.2	139.0	9– –43	Test hole 3.
19	NE NW sec. 9	Albert Coughey	Dr	168.5	3	I	do.	do.	Cy, W	D, S	Top of casing	+3.5	3,310.5	155.49	9– 9–42	
20	SE SE sec. 14	G. W. van Horn	Dr	114.0	6	GI	do.	do.	Cy, W	D, S	Top of concrete curb, west side	+ .2	3,237.5	101.91	9– 9–42	
(21)	SW NW sec. 25	Bill Sible	Dr	137.0	4	GI	do.	do.	Cy, W	D, S	Top of concrete curb	+ .4	3,275.8	133.12	9– 9–42	
22	SE SW sec. 28	Roy Bayrd	Dr	151.5	6	GI	do.	do.	N	N	Top of casing, south side	+ .2	3,222.0	148.76	9–12–42	
23	*T. 6 S., R. 36 W.* SE SE sec. 11	Willard W. Miller	Dr	171	6	GI	do.	do.	Cy, W	D	Top of casing at level of concrete	+ .5	3,350.5	160	6– 9–43	
24	NE NE sec. 21	Stanley Marrs	Dr	156.7	6	GI	do.	do.	N	N	Top of concrete curb, north side	+ .5	3,381.4	152.32	7–13–42	
25	*T. 7 S., R. 31 W.* NW SE sec. 2	W. A. Athla	Dr	93.5	6	GI	do.	do.	Cy, H	D	Top of concrete curb, south side	+ .4	2,956.7	90.56	7–14–42	
26	NE SE sec. 2	City of Rexford	Dr	130	12	I	do.	do.	T, E	P	Land surface	.0	2,949.9	100	7–14–42	Pump capacity, 50.
27	NE SE sec. 2	do.	Dr	128	12	I	do.	do.	T, E	P	do.	.0	2,944.4	100	7–14–42	Pump capacity, 70.
28	NE SE sec. 5	H. Dible est	Dr	36.6	6	GI	do.	do.	Cy, W	N	Top of casing, west side	+ .4	2,937.8	36.4	7–17–42	
29	SE SE sec. 7	Foster Farms	Dr	139.5	6	GI	do.	do.	Cy, W	D, S	Top of concrete curb, west side	+ .8	3,033.6	111.06	9–10–42	
(30)	SE NE sec. 18	do.	Dr	127.0	6	GI	do.	do.	Cy, H	D	Top of concrete curb	+0.3	3,027.7	102.20	9–10–42	
(31)	SW SW sec. 26	E. F. Rall	Dr	177	16	GI	do.	do.	T, G	I	Hole in pump base	+2.0	2,991.3	104.85	7–29–42	Measured yield in 1943, 588; drawdown, 42.08 (7); specific capacity 13.97.
32	*T. 7 S., R. 32 W.* NW NW sec. 1	Foster Farms	Dr	61.8	5	GI	do.	do.	N	N	Top of casing, west side	+ .7	2,993.9	60.03	9–10–42	
(33)	NE SE sec. 7	Horace Anderson	Dr	135	16	I	do.	do.	T, G	I	Hole in pump base, south side	+ .8	3,057.0	72.74	7–16–42	Measured yield in 1943, 1,021; drawdown, 18.05 (7); specific capacity 56.5.

TABLE 9.—Records of typical wells in Thomas county, Kansas—*Continued*

No. on pl. 2	LOCATION	Owner or tenant	Type of well (1)	Depth of well (feet) (2)	Diameter of well (in.)	Type of casing (3)	Principal water-bearing bed		Method of lift (4)	Use of water (5)	Measuring point			Depth to water level below measuring point (feet) (6)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
							Character of material	Geologic subdivision			Description	Distance above (+) or below (—) land surface (feet)	Height above sea level (feet)			
	T. 7 S., R. 33 W.															
34	NE NE sec. 1	(Public road)	Dr	170.0	3	N	Sand and gravel	Ogallala	N	N	Land surface	.0	3,062.1	75.64	9- -43	Test hole 8.
35	SW SE sec. 9	Frank Cercovoski	Dr	170	14	I	do	do	T, G	I	Hole in pump base, west side	+1.4	3,163.4	133.35	7-15-42	
36	NW SW sec. 10	Edward Cercovoski	Dr	195	16	I	do	do	T	I	Hole in pump base	+ .7	3,151.9	128.58	7-15-42	Measured yield in 1943, 295; drawdown, 26.33 (7); specific capacity 11.2.
37	NW NW sec. 26	H. E. Sloan	Dr	101.5	16	I	do	do	N	I	Top of casing, west side	+ .4	3,090.8	72.83	7-14-42	
38	SW SW sec. 31	(Public road)	Dr	260.0	3	N	do	do	N	N	Land surface	.0	3,157.9	98.4	10- -43	Test hole 11.
39	SW SE sec. 34	H. E. Sloan	Dr	161.8	6	GI	do	do	N	N	Top of wooden cover of casing	— .3	3,172.3	145.77	7-14-42	
	T. 7 S., R. 34 W.															
40	SE SE sec. 3	F. D. McKinney	Dr	32.5	5	GI	do	do	N	N	Top of casing, east side	+ .3	3,127.7	31.76	9-11-42	
41	NW NW sec. 6	(Public road)	Dr	260.0	3	N	do	do	N	N	Land surface	.0	3,259.1	119.67	9- -43	Test hole 6.
42	NE NE sec. 27	H. A. Hills	Dr	120.5	5	GI	do	do	N	N	Top of casing, west side	+ .4	3,200.4	118.04	9-11-42	
43	NE SE sec. 36	Wm. J. Campbel	Dr	110.5	6	GI	do	do	Cy, H	D	Top of casing, east side	+ .4	3,166.6	107.76	7-15-42	
44	SW SE sec. 36	City of Colby	Dr	165	10	I	do	do	T, E	P	Land surface	.0	3,161.4	105	7-15-42	Pump capacity, 200.
45	SW SE sec. 36	do	Dr	137	9	I	do	do	P, E	P	Land surface	.0	3,165.4	105	7-15-42	Pump capacity, 100.
46	SW SE sec. 36	do	Dr	147	9	I	do	do	P, E	P	do	.0	3,163.9	105	7-15-42	do
47	SE SE sec. 36	do	Du, Dr	158	72, 18	I	do	do	T, E	P	Concrete floor of pump house, west side	+ .6	3,165.7	110.72	7-15-42	Pump capacity, 400.
48	SE SE sec. 36	do	Dr	165	10	I	do	do	P, E	P	Land surface	.0	3,162.2	105	7-15-42	Pump capacity, 100.

	T. 7 S., R. 35 W.															
49	SW SE sec. 13	Lena Evelyn Beck	Dr	90.1	6	GI	do	do	Cy, W	D, S	Top of casing, north side	+1.3	3,238.3	87.06	6- 9-43	
50	SE SE sec. 17	Marian Tally	Dr	120.5	6	GI	do	do	N	N	Top of casing, north side	+ .8	3,315.3	116.87	9- 9-42	
	T. 7 S., R. 36 W.															
51	NE NE sec. 1	(Public road)	Dr	270.0	3	N	do	do	N	N	Land surface	......	3,333.6	119.98	9- 43	Test hole 5.
52	SE NE sec. 18	W. A. Bear	Dr	94.5	5	GI	do	do	Cy, W	N	Top of casing, east side	+ .1	3,362.4	82.91	6- 9-43	
53	SW NW sec. 35	Will Guise	Dr	96.5	6	GI	do	do	Cy, W	S	Top of concrete curb, north side	+ .5	3,337.8	84.02	7-13-43	
	T. 8 S., R. 31 W.															
54	SW NE sec. 13	H. V. Christensen	Dr	73.8	6	GI	do	do	N	N	Top of concrete curb, east side	+ .3	2,948.9	63.34	7-14-42	
55	NW SE sec. 13	U. P. Ry. Co	Dr	126	12	I	do	do	Cy, S	R	Land surface	.0	2,946.4	74	7-14-42	
56	NW SE sec. 13	do	Dr	126	12	I	do	do	Cy, W	R	do	.0	2,945.6	74	7-14-42	
57	NW NW sec. 19	(Public road)	Dr	270.0	3	N	do	do	N	N	do	.0	3,066.9	126.9	9- 43	Test hole 12.
	T. 8 S., R. 32 W.															
(58)	NE SE sec. 10	H. C. Chambers	Dr	119.8	6	GI	do	do	Cy, W	D	Top of casing, north side	+0.8	3,079.9	112.68	7-17-42	
(59)	SE NE sec. 27	Thomas A. Ryan	Dr	119.5	6	GI	do	do	Cy, W	D	Top of concrete curb, north side	+1.5	3,080.9	115.94	7-28-42	
60	NE SE sec. 27	Thomas A. Ryan	Dr	158.8	8	I	do	do	N	N	Top of casing, west side	+0.6	3,079.0	112.38	7-16-42	
	T. 8 S., R. 33 W.															
61	SW NW sec. 36	Vivian D. Phillips	Dr	136.0	6	GI	do	do	N	N	Top of casing, north side	+0.1	3,154.3	130.51	10-22-42	
	T. 8 S., R. 34 W.															
(62)	NE NE sec. 5	Raymond Barnette	Dr	116.5	6	GI	do	do	Cy, W	D, S	Top of casing, east side	+ .2	3,211.7	111.18	9-12-42	
63	E NE sec. 20	Thomas Callihan	Dr	198.5	6	GI	do	do	Cy, W	D	Top of casing, east side	+1.2	3,260.1	169.72	4-14-43	
(64)	NE SE sec. 24	County Poor Farm	Dr	148	6	GI	do	do	Cy, W	D, S	Top of casing	+1.0	3,190.8	132	10-26-43	
	T. 8 S., R. 35 W.															
65	NE SW sec. 2	F. D. Harner	Dr	156.8	6	I	do	do	N	N	Edge of tin cover to concrete basement	+1.5	3,319.2	149.98	7-17-42	
66	SE NW sec. 5	N. Eberle	Du	45	228	W	do	Alluvium and Ogallala	N	N	Land surface	.0	3,241.7	22	7-29-42	
67	NW NW sec. 19	(Public road)	Dr	200.0	3	N	do	Ogallala	N	N	do	.0	3,358.6	119.0	9- 43	Test hole 13.
68	NE NE sec. 32	F. B. Dawes	Dr	162.3	6	GI	do	do	Cy, W	D	Top of casing, east side	+0.1	3,338.1	145.30	4-14-43	

Table 9.—Records of typical wells in Thomas county, Kansas—*Continued*

No. on pl. 2	Location	Owner or tenant	Type of well (1)	Depth of well (feet) (2)	Diameter of well (in.)	Type of casing (3)	Principal water-bearing bed		Method of lift (4)	Use of water (5)	Measuring point			Depth to water level below measuring point (feet) (6)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
							Character of material	Geologic subdivision			Description	Distance above (+) or below (—) land surface (feet)	Height above sea level (feet)			
	T. 8 S., R. 36 W.															
69	NW NE sec. 18	City of Brewster	Dr	203	12	I	Sand and gravel	Ogallala	T, E	P	Land surface	.0	3,330.0	133	7-13-42	Reported capacity 100.
70	NW NE sec. 18	do	Dr	202	12	I	do	do	T, E	P	do	.0	3,330.2	133	7-13-42	Reported capacity 100.
71	NW NE sec. 18	George Strait	Dr	139.4	6	GI	do	do	N	N	Top of casing, west side	+ .3	3,331.4	124.82	7-13-42	
72	SE SE sec. 30	Lem Fulwider	Dr	57.8	6	GI	do	Alluvium and Ogallala	Cy, W	S	Hole in pipe clamp, northeast side	+ .2	3,365.3	48.51	7-13-42	
	T. 9 S., R. 31 W.															
73	NE NE sec. 8	J. T. Duffey	Dr	77.5	6	GI	do	Ogallala	Cy, W	S	Top of concrete curb, west side	+ .8	2,993.7	65.22	7-30-42	
74	NW NE sec. 12	J. S. Moss	Dr	65.5	6	GI	do	do	Cy, W	D	Top of concrete curb, east side	+ .8	2,947.9	65.18	10-20-42	
75	SW SE sec. 29	Leo Murphy	Dr	124.5	6	GI	do	do	Cy, W	S	Top of casing, east side	+1.4	3,044.5	118.26	7-16-42	
(76)	SE NE sec. 36	A. F. Ostmuyer	Dr	130	6	GI	do	do	Cy, W	D, S	Top of pipe clamp, west side	+1.5	3,002.8	121.05	10-20-42	
	T. 9 S., R. 32 W.															
(77)	NW NW sec. 3	Tony Cercovoski	Dr	142	18	I	do	do	T, G	I	Hole in pump base	+1.2	3,062.4	84.79	7-16-42	
78	NW SW sec. 18	Dave Keller	Dr	82.8	6	GI	do	do	N	N	Top of concrete curb, west side	+1.2	3,089.0	77.14	10-22-42	
79	NW NW sec. 23	Pete Renner	Dr	86.6	6	GI	do	do	N	N	Top of casing, north side	+ .4	3,047.8	78.61	10-22-42	
80	NE NE sec. 34	M. W. Cave	Dr	110.0	6	GI	do	do	N	N	Top of casing, north side	.0	3,079.6	109.44	10-20-42	
81	SE SW sec. 35	R. Nye	Dr	145	6	GI	do	do	Cy, W	D, S	Land surface	.0	3,080.3	114	10-20-42	

	T. 9 S., R. 33 W.													
82	NW NW sec. 7	Arch Ball	Dr	136.8	6	GI	do	do	Cy, W	S	Top of cyl. in motor block, south side	+1.6	3,182.8	118.71	7-18-42	
(83)	SW NW sec. 33	S. A. Lunsway	Dr	158.5	6	GI	do	do	Cy, W	D	Top of casing, west side	+ .5	3,179.8	158.5	4-14-43	
	T. 9 S., R. 34 W.													
84	NE NE sec. 1	(Public road)	Dr	320.0	3	N	do	do	N	N	Land surface	.0	3,212.9	146.5	10- 43	Test hole 14.
(85)	NW NW sec. 26	J. C. Woofter	Dr	178.5	6	GI	do	do	Cy, W	D, S	Top of casing, west side	+ .6	3,235.3	157.83	4-14-43	
86	SW SW sec. 31	(Public road)	Dr	250.0	3	N	do	do	N	N	Land surface	.0	3,293.8	109.89	9- 43	Test hole 19.
87	SE SE sec. 36	do	Dr	310.0	3	N	do	do	N	N	do	.0	3,193.4	143.9	9- 43	Test hole 18.
	T. 9 S., R. 35 W.													
88	SE SE sec. 6	Luther H. Thiel	Dr	......	5	GI	do	do	Cy, W	D, S	Bottom of hole in pump side	+2.25	3,345.2	176.62	6- 9-43	
(89)	N NE sec. 12	Fannie Harner	Dr	179.5	4	GI	do	do	Cy, W	D, S	Top of casing, south side	+ .4	3,289.5	176.22	4-13-43	
(90)	SW SE sec. 27	Homer Mundell	Dr	164.0	6	GI	do	do	Cy, W	D, S	Top of casing, west side	+ .9	3,321.9	158.66	4-13-43	
	T. 9 S., R. 36 W.													
91	NW SW sec. 9	Earl W. Dawes	Dr	130.5	6	GI	do	do	Cy, N	N	Top of concrete curb, west side	+1.5	3,424.0	126.67	7-13-42	
(92)	SE SE sec. 29	C. F. Diederich	Dr	224.5	4	GI	do	do	Cy, W	D, S	Top of hole in cover plate	+ .6	3,465.7	218.89	4-13-43	
93	SW SW sec. 31	(Public road)	Dr	220.0	3	N	do	do	N	N	Land surface	.0	3,450.2	97.3	9- 43	Test hole 21.
	T. 10 S., R. 31 W.													
94	SE NE sec. 20	Kathryn B. Hood	Dr	36.8	6	GI	do	Alluvium and Ogallala	Cy, W	S	Top of casing, north side	+1.3	2,947.4	32.17	7-16-42	
95	SE SW sec. 24	A. J. Robbin	Du	20	48	W	do	do	N	N	Land surface	.0	2,884.6	12	10-22-42	Reported to yield 400.
96	SW SE sec. 24	P. J. Ladenburger	B	10.4	6	GI	do	do	N	N	Top of casing, north side	+ .3	2,880.0	8.60	10-20-42	
97	SW SE sec. 32	Albert R. Miller	Dr	47.5	6	GI	do	Ogallala	Cy, W	S	Top of pipe clamp, south side	+1.2	2,962.2	40.04	10-20-42	
	T. 10 S., R. 32 W.													
98	NW NW sec. 6	(Public road)	Dr	487.0	3	N	do	do	N	N	Land surface	.0	3,116.9	106.1	9- 43	Test hole 17.
(99)	NW NW sec. 8	Arthur Talburt	Dr	95.5	6	GI	do	do	Cy, W	S	Top of casing, east side	−5.6	3,084.8	87.82	10-22-42	
100	NE NW sec. 33	John Sim	B	36.5	6	GI	do	Alluvium and Ogallala	N	N	Top of casing, north side	+ .6	3,014.8	33.26	10-22-42	
(101)	SE SW sec. 36	Herman Anderson	Dr	109.5	6	GI	do	Ogallala	Cy, W	D, S	Top of steel cover to casing	+ .1	3,050.7	106.13	10-22-42	

TABLE 9.—Records of typical wells in Thomas county, Kansas—*Concluded*

No. on pl. 2	LOCATION	Owner or tenant	Type of well (1)	Depth of well (feet) (2)	Diameter of well (in.)	Type of casing (3)	Principal water-bearing bed		Method of lift (4)	Use of water (5)	Measuring point			Depth to water level below measuring point (feet) (6)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
							Character of material	Geologic subdivision			Description	Distance above (+) or below (—) land surface (feet)	Height above sea level (feet)			
102	*T. 10 S., R. 33 W.* NW NW sec. 14	H. E. Cline	Dr	143.0	6	GI	Sand and gravel	Ogallala	Cy, W	N	Top of hole in steel plate, west side	+ .3	3,146.4	135.24	4–14–43	
103	*T. 10 S., R. 34 W.* NE NE sec. 27	H. A. Hills	Dr	113.8	6	GI	do	do	N	N	Top of casing, west side	+ .4	3,187.8	98.14	9–14–42	
104	NW SE sec. 36	G. J. Hills	Dr	165.0	3	N	do	do	N	N	Land surface	.0	3,192.6	111.85	10– 43	Test hole 26.
105	SE SE sec. 36	G. J. Hills	Dr	155.0	3	N	do	do	N	N	do	.0	3,182.6	99.2	10– 43	Test hole 27.
106	SE SE sec. 36	(Public road)	Dr	175.0	3	N	do	do	N	N	do	.0	3,191.2	123.2	10– 43	Test hole 28.
107	*T. 10 S., R. 35 W.* NW NW sec. 6	do	Dr	193.0	3	N	do	do	N	N	do	.0	3,351.3	96.4	9– 43	Test hole 20.
(108)	NE NE sec. 19	Edith J. Nichols	Dr	190.5	6	GI	do	do	Cy, W	D, S	Top of casing, north side	+1.1	3,343.9	164.22	4–15–43	
109	NE NE sec. 27	C. J. Lahman	Dr	176.6	6	GI	do	do	Cy, W	D, S	Top of casing, north side	+1.15	3,295.6	147.08	4–13–43	
(110)	*T. 10 S., R. 36 W.* SE SW sec. 9	Henry H. Goetsch	Dr	181.0	6	GI	do	do	Cy, W	D, S	Top of casing, south side	+ .5	3,390.9	166.29	4–15–43	
111	SE SE sec. 17	(Public road)	Dr	185.0	3	N	do	do	N	N	Land surface	.0	3,352.7	100.45	10– 43	Test hole 22.
112	NE SE sec. 20	do	Dr	220.0	3	N	do	do	N	N	do	.0	3,322.5	87.08	9– 43	Test hole 23.
113	NE NE sec. 29	do	Dr	255.0	3	N	do	do	N	N	do	.0	3,365.9	127.57	9– 43	Test hole 24.

(114)	NE NE sec. 32........	C. F. Kammer........	Dr	152.8	6	GI	do.............	do...........	Cy, W	D, S	Hole in steel plate, west side	+ .9	3,377.3	142.07	4-15-43	
	Sherman county *T. 7 S., R. 37 W.* NE NE sec. 1.........	(Public road).........	Dr	310.0	3	N	do.............	do...........	N	N	Land surface..........	.0	3,417.5	140.03	9- 43	Test hole 4.

1. B, bored; Dr, drilled; Du, dug.
2. Measured depths given in feet and tenths; reported depths given in feet.
3. GI, Galvanized iron; I, iron; N, none; W, wood.
4. Pumps: C, centrifugal; Cy, cylinder; N, none; P, double action plunger; T, turbine. Power: E, electric motor; G, gasoline engine; S, steam engine; H, hand; W, wind.
5. D, domestic; I, irrigation; N, none; P, public supply; R, railroad; S, stock.
6. Measured water levels given in feet, tenths, and hundredths; reported water levels given in feet.
7. Pumping test conducted and the results furnished by the Division of Water Resources, Kansas State Board of Agriculture.

LOGS OF TEST HOLES AND WELLS

Listed in the following pages are logs of 29 test holes and one irrigation well in Thomas county. The test holes were drilled by the State and Federal Geological Surveys during 1943 and 1944. Samples of the material penetrated by the test holes were examined in the field by Nick Fent, who supervised the drilling and prepared logs of the holes. The samples were subsequently studied microscopically by me and the descriptions in the logs were changed where necessary. The log and data concerning the irrigation well at the Colby Agricultural Experiment Station were supplied by George S. Knapp and Embert Coles. Samples obtained from the test holes are on file for general use in the offices of the State Geological Survey at the University of Kansas in Lawrence. The locations of the test holes within the county are shown in figure 13.

1. Log of test hole 1 in the NW corner sec. 6, T. 6 S., R. 31 W. Surface altitude, 2,997.9 feet.

	Thickness, feet	Depth, feet
Road fill	3	3
Sanborn formation		
Silt and very fine sand; yellow-gray; containing abundant snails	20	23
Silt, clay, and sand; light buff to brown	11	34
Ogallala formation		
Gravel, sand, and silt; buff and gray; partly cemented by calcium carbonate	23	57
Silt and sand; pink-tan	7	64
Gravel and sand	21	85
Silt, sand, and caliche; gray and buff	27	112
Gravel and sand	6	118
Silt, sand, and caliche; grading downward into silt, clay, and caliche; gray	31	149
Sand, becoming coarser downward and containing some clay at base	37	186
Pierre shale		
Shale, dark gray	14	200

2. Log of test hole 2 in the NW corner sec. 6, T. 6 S., R. 33 W. Surface altitude, 3,159.0 feet.

	Thickness, feet	Depth, feet
Sanborn formation		
Silt, containing admixtures of fine sand and clay in some zones and some nodules of caliche; tan to gray; containing abundant snails	33	33
Silt, sand, and caliche; gray-white	7	40

Ogallala formation		
Silt, sand, and gravel; buff; partly cemented by calcium carbonate	10	50
Gravel and sand; gray-buff to brown; containing some zones cemented by calcium carbonate	54	104
Silt and caliche; pink-tan; containing some clay and sand	18	122
Gravel, medium to fine, and sand; containing some silt	8	130
Silt, sand, gravel, and caliche; gray to tan	30	160
Gravel and sand; cemented by calcium carbonate; gray to brown	9	169
Caliche, clay, and silt; containing some sand; light tan to white	25	194
Gravel, fine, and sand	11	205
Silt, clay, sand, and gravel	3	208
Pierre shale		
Shale, light blue-gray mottled with yellow-brown	2	210
Shale, blue-gray	5	215

3. Log of test hole 3 in the NW corner sec. 6, T. 6 S., R. 35 W. Surface altitude, 3,330.2 feet.

	Thickness, feet	Depth, feet
Sanborn formation		
Silt, yellow-gray; containing abundant snails	50	50
Ogallala formation		
Silt, caliche, sand, and gravel; tan	29	79
Gravel and sand	21	100
Silt, caliche, sand, and gravel; buff	23	123
Gravel, sand, and caliche	34	157
Silt, caliche, sand, and gravel	53	210
Sand, medium to fine, loosely cemented with calcium carbonate	20	230
Silt and sand; containing caliche, gray	9	239
Sand, medium to fine	11	250
Silt, sand, and caliche; light brown	8	258
Sand and silt; buff	33	291
Pierre shale		
Shale, light yellow grading downward to dark gray	9	300

4. Log of test hole 4 in the NE corner sec. 1, T. 7 S., R. 37 W. (Sherman county). Surface altitude, 3,417.5 feet.

	Thickness, feet	Depth, feet
Soil, dark gray-brown	4	4
Sanborn formation		
Silt, yellow-gray, containing abundant snails	46	50
Silt, containing clay, sand, and caliche; tan	17	67
Ogallala formation		
Gravel, containing sand and caliche	6	73
Silt, containing sand, gravel, and caliche; gray	15	88

Gravel and sand	19	107
Silt, containing gravel, sand, and caliche; buff	23	130
Gravel, fine, containing sand and caliche	6	136
Silt, sand, and caliche; gray to buff	17	153
Gravel, sand, and caliche	4	157
Silt and caliche; light brown	2	159
Gravel and sand	18	177
Silt, sand, and caliche; gray and tan	19	196
Gravel, medium to fine, and sand	4	200
Sand and caliche	7	207
Gravel, sand, and caliche; gray-buff	15	222
Silt, yellow-gray, and caliche	4	226
Sand, gravel, and caliche	37	263
Clay, sand, and caliche; gray	9	272
Gravel, fine, and sand, gray	9	281
Silt and sand; gray-green	3	284
Gravel and sand; gray	14	298
Pierre shale		
Shale, light blue-gray and yellow	2	300
Shale, dark gray	10	310

5. Log of test hole 5 in the NE corner sec. 1, T. 7 S., R. 36 W. Surface altitude, 3,333.1 feet.

	Thickness, feet	Depth, feet
Soil, dark gray-brown	2	2
Sanborn formation		
Silt and sand, very fine; gray-brown	48	50
Ogallala formation		
Silt, sand, gravel, and caliche; buff	17	67
Gravel and sand; loosely cemented with calcium carbonate	29	96
Silt and sand; pink-tan; containing gravel and caliche	34	130
Gravel, coarse to fine, and sand; loosely cemented	20	150
Silt, tan, containing sand and caliche	7	157
Gravel, sand, silt, and caliche	8	165
Silt, sand, and caliche; buff	29	194
Gravel and sand; loosely cemented with calcium carbonate	6	200
Caliche, sandy, hard, gray	9	209
Gravel and sand	31	240
Sand, gray	18	258
Pierre shale		
Shale, light blue-gray mottled yellow	2	260
Shale, gray	10	270

6. Log of test hole 6 in the NW corner sec. 6, T. 7 S., R. 34 W. Surface altitude, 3,259.1 feet.

	Thickness, feet	Depth, feet
Soil, gray	2	2
Sanborn formation		
Silt and sand, very fine; buff-gray	28	30
Silt and clay; buff	20	50
Ogallala formation		
Silt, buff; containing sand, gravel, and nodules of caliche,	30	80
Gravel, sand, and silt; buff	5	85
Silt, sand, gravel, and caliche	4	89
Gravel and sand	6	95
Silt, sand, and caliche	23	118
Gravel and sand; gray; containing silt and caliche	41	159
Silt, caliche, sand, and gravel; pink-tan	20	179
Gravel, sand, and caliche	6	185
Silt, sand, gravel, and caliche	15	200
Gravel and sand; gray and yellow	46	246
Pierre shale		
Shale, light blue-gray and yellow	4	250
Shale, dark gray	10	260

7. Log of test hole 7 in the SW¼ SW¼ sec. 31, T. 6 S., R. 33 W. Surface altitude, 3,083.8 feet.

	Thickness, feet	Depth, feet
Soil, gray-black	3	3
Sanborn formation		
Silt and very fine sand; containing nodules of caliche and fragments of snails	23	26
Ogallala formation		
Gravel and sand; buff; containing silt and caliche	19	45
Silt, tan; containing sand, gravel, and caliche	6	51
Gravel and sand; loosely cemented; buff	23	74
Silt, sand, gravel, and caliche; buff	6	80
Gravel, sand, and caliche	7	87
Caliche, silt, and sand	12	99
Gravel and sand	4	103
Pierre shale		
Shale, light blue-gray and yellow	7	110
Shale, dark gray	20	130

8. Log of test hole 8 in the NE corner sec. 1, T. 7 S., R. 33 W. Surface altitude, 3,062.1 feet.

	Thickness, feet	Depth, feet
Road fill	3	3
Sanborn formation		
Silt, tan; containing sand, very fine, and clay	15	18
Ogallala formation		
Gravel and sand	9	27
Silt, sand, and gravel; light brown	3	30
Gravel, medium to fine, and sand	10	40
Silt, sand, gravel, and caliche; buff-tan	8	48
Gravel and sand	16	64
Silt, sand, and caliche; buff	15	79
Gravel and sand; loosely cemented	9	88
Silt and sand; buff	10	98
Gravel, sand, and silt; yellow	18	116
Silt and sand; buff	1	117
Gravel, sand, and silt; buff	12	129
Silt, sand, and clay; blue-gray	2	131
Gravel, sand, and silt; buff	9	140
Silt, caliche, and sand; containing a few zones of very hard white caliche	11	151
Gravel and sand	7	158
Pierre shale		
Shale, yellow and light gray	9	167
Shale, dark gray	3	170

9. Log of test hole 9 in the SE corner sec. 36, T. 6 S., R. 32 W. Surface altitude, 2,992.4 feet.

	Thickness, feet	Depth, feet
Soil, dark gray-brown	2	2
Sanborn formation		
Silt and very fine sand; yellow-gray; containing snails	18	20
Silt, containing some sand and fine gravel; yellow-gray	18	38
Silt, clay, and very fine sand; containing abundant snails,	7	45
Silt, tan; containing gravel, fine, and sand	15	60
Silt and very fine sand; gray; containing snails	12	72
Ogallala formation		
Gravel, fine, and sand	4	76
Silt, caliche, and sand	2	78
Gravel and sand; loosely cemented	15	93
Silt, sand, and caliche; gray and buff	27	120
Gravel, sand, silt, and caliche, gray	9	129
Caliche, sand, hard, white	6	135
Gravel and sand; loosely cemented	3	138
Caliche, very hard, white	3	141
Gravel, fine, sand, and clay; orange-brown	16	157
Silt, gravel, sand, and caliche; gray to buff	10	167
Pierre shale		
Shale, greenish-gray	3	170
Shale, gray streaked with yellow	20	190

10. Log of test hole 10 in the NE corner sec. 1, T. 7 S., R. 31 W. Surface altitude, 2,950.6 feet.

	Thickness, feet	Depth, feet
Soil, dark gray	3	3
Sanborn formation		
Silt and very fine sand; yellow-gray	24	27
Silt and clay; buff; containing a small amount of sand and fine gravel	8	35
Ogallala formation		
Gravel, sand, and silt; loosely cemented; buff	5	40
Silt, sand, gravel, and caliche; tan	5	45
Gravel and sand; cemented with calcium carbonate	8	53
Silt, gravel, sand, and caliche; tan	4	57
Gravel and sand; containing caliche	21	78
Silt, caliche, sand, and gravel; tan	11	89
Gravel and sand	4	93
Silt, clay, sand, gravel, and caliche; gray	11	104
Sand, fine, and silt, brown	9	113
Gravel and sand	8	121
Silt, gravel, sand, and caliche; brown to gray	9	130
Gravel and sand	13	143
Silt, sand, gravel, and clay; light buff	7	150
Sand, tan, containing gravel and silt	28	178
Gravel, fine, and sand; loosely cemented	7	185
Sand and some gravel	5	190
Gravel, buff, containing sand, silt, and clay	10	200
Silt, buff, containing sand	8	208
Gravel, fine, and sand	12	220
Pierre shale		
Shale, bentonitic (?), yellow grading downward to blue-gray	10	230
Shale, gray-black	8	238

11. Log of test hole 11 in the SW corner sec. 31, T. 7 S., R. 33 W. Surface altitude, 3,157.9 feet.

	Thickness, feet	Depth, feet
Sanborn formation		
Silt, buff, containing some very fine sand. Nodules of caliche at base	31	31
Ogallala formation		
Silt, gravel, sand, and caliche; buff	4	35
Gravel and sand; loosely cemented	5	40
Silt, gravel, sand, and caliche; gray	5	45
Gravel and sand; loosely cemented	3	48
Silt, gravel, sand, and caliche; gray and tan	10	58
Gravel and sand; partly cemented	8	66
Silt, gravel, sand, and caliche; tan	31	97
Gravel and sand	9	106
Silt, tan, containing sand and caliche	14	120

Gravel and sand	27	147
Silt, tan, containing gravel, sand and caliche	11	158
Gravel and sand	2	160
Silt, caliche, gravel, and sand; gray	18	178
Gravel and sand; containing silt	34	212
Silt and clay, yellow-gray	2	214
Gravel and sand	6	220
Silt, gravel, sand, and caliche; tan	15	235
Gravel and sand	16	251
Pierre shale		
Shale, light gray-green mottled yellow	6	257
Shale, dark gray	3	260

12. Log of test hole 12 in the NW corner sec. 19, T. 8 S., R. 31 W. Surface altitude, 3,066.9 feet.

	Thickness, feet	Depth, feet
Road fill and soil	3	3
Sanborn formation		
Silt and very fine sand; gray-buff; containing snails	47	50
Silt, buff, containing sand and fine gravel	13	63
Ogallala formation		
Sand and fine gravel; loosely cemented	5	68
Silt, caliche, sand, and fine gravel; buff	5	73
Gravel, fine, and sand	6	79
Silt, pink-tan, containing gravel, sand, and caliche	4	83
Gravel, fine, sand, and caliche	25	108
Silt, pink-tan, containing sand and fine gravel	4	112
Gravel and sand	8	120
Sand and fine gravel	5	125
Silt, gravel, sand, and caliche; gray-buff	13	138
Gravel and sand	8	146
Silt, sand, gravel, and caliche; pink-tan	11	157
Gravel and sand	13	170
Sand	3	173
Silt and sand; buff	4	177
Gravel, sand, silt, and caliche; gray	23	200
Silt, gravel, and sand; tan	10	210
Gravel and sand	7	217
Silt, sand, and caliche; pink-tan	3	220
Gravel, fine, sand, and buff silt	10	230
Sand, silt, and caliche; light brown	10	240
Gravel, fine, and sand	10	250
Sand, silt, and caliche; tan	8	258
Pierre shale		
Shale, orange-yellow at top to dark gray at bottom	12	270

13. Log of test hole 13 in the NW corner sec. 19, T. 8 S., R. 35 W. Surface altitude, 3,358.6 feet.

	Thickness, feet	Depth, feet
Soil, dark gray-brown	2	2
Sanborn formation		
Silt and very fine sand; yellow-gray	31	33
Silt, buff-white, containing clay, sand, and fine gravel	13	46
Ogallala formation		
Silt, buff, containing sand, gravel, and caliche	4	50
Gravel and sand; loosely cemented	3	53
Silt, sand, and gravel; buff and white	11	64
Gravel and sand	14	78
Silt and clay; gray-white	5	83
Gravel and sand	4	87
Silt, gravel, and sand; tan and buff	10	97
Gravel and sand; buff; containing silt and caliche	26	123
Sand and gravel; cemented with calcium carbonate	15	138
Silt, buff, containing gravel, sand, and caliche	25	163
Gravel, sand, silt, and caliche; buff to white	9	172
Pierre shale		
Shale, gray-green mottled yellow-brown	18	190
Shale, dark gray with some yellow mottling	10	200

14. Log of test hole 14 in the NE corner sec. 1, T. 9 S., R. 34 W. Surface altitude, 3,212.9 feet.

	Thickness, feet	Depth, feet
Road fill	3	3
Sanborn formation		
Silt and very fine sand; yellow-buff; containing snails	27	30
Silt, light buff, containing sand and gravel	14	44
Ogallala formation		
Gravel and sand; loosely cemented	3	47
Silt, gravel, sand, and caliche; tan	3	50
Gravel and sand; containing caliche and silt	10	60
Silt, pink-tan to yellow-buff; containing sand, gravel, and caliche	47	107
Gravel and sand	4	111
Silt, gravel, sand, and caliche; pink-tan	22	133
Gravel, sand, and caliche	4	137
Silt, sand, and clay; yellow-brown	7	144
Gravel and sand; partly cemented	9	153
Silt, sand, and clay; gray-white	2	155
Gravel, sand, and caliche	8	163
Silt, pink-tan, containing gravel, sand, and caliche	9	172
Gravel and sand	10	182
Silt, sand, and caliche; pink-tan to buff; containing zones of clay and of gravel	48	230
Gravel, containing clay	50	280
Sand, silt, clay, and gravel; containing coarse gravel at base	20	300
Silt and sand, light brown	10	310
Pierre shale		
Shale, yellow-brown at top to blue-gray at bottom	10	320

15. Log of test hole 15 in the SE corner sec. 36, T. 9 S., R. 31 W. Surface altitude, 2,979.6 feet.

	Thickness, feet	Depth, feet
Soil, light brown	2	2
Sanborn formation		
Silt and very fine sand; yellow-gray; containing many snails	21	23
Silt, containing fine gravel and nodules of caliche	3	26
Silt and clay; light brown	5	31
Silt, light brown, containing some caliche	2	33
Ogallala formation		
Silt, gravel, sand, and caliche; buff	17	50
Gravel, buff and gray, containing silt	12	62
Silt, pink-tan, containing gravel, sand, and caliche	40	102
Gravel and sand	13	115
Silt, pink-tan, containing gravel, sand, and caliche	5	120
Gravel, sand, silt, and caliche; light brown	10	130
Silt, yellow-buff to pink-tan, and caliche; containing gravel, sand, and clay	49	179
Gravel and sand	8	187
Pierre shale		
Shale, light greenish-yellow	7	194
Shale, dark gray	6	200

16. Log of test hole 16 in the SE corner sec. 36, T. 9 S., R. 32 W. Surface altitude, 3,081.8 feet.

	Thickness, feet	Depth, feet
Road fill	3	3
Sanborn formation		
Silt, light gray in upper part to gray-black in lower part	2	5
Silt and very fine sand; yellow-gray	21	26
Silt, clay, and sand; buff	10	36
Silt and clay; buff	14	50
Ogallala formation		
Silt, gravel, sand, and caliche; buff	20	70
Gravel and sand; cemented	32	102
Silt, gravel, and sand; tan and gray	6	108
Gravel, sand, and caliche	33	141
Silt, light tan, containing sand, gravel, and caliche	29	170
Sand and gravel; containing clay	17	187
Silt, tan, containing sand	3	190
Sand and gravel; containing zones of caliche, coarse gravel, and clay	43	233
Pierre shale		
Shale, light gray-green in upper part to gray-blue in lower part	7	240
Shale, dark gray	10	250

17. Log of test hole 17 in the NW corner sec. 6, T. 10 S., R. 32 W. Surface altitude, 3,116.9 feet.

	Thickness, feet	Depth, feet
Soil, dark gray	1	1
Sanborn formation		
Silt and very fine sand; yellow-gray	24	25
Silt, buff, containing sand and fine gravel	8	33
Sand, medium to fine, loosely cemented, light brown; containing fragments of snails	6	39
Ogallala formation		
Silt, sand, caliche, and gravel; tan	20	59
Gravel, sand, and caliche; buff	22	81
Silt, gravel, and sand; pink-tan	4	85
Gravel, very coarse to fine, buff; containing sand and silt	11	96
Silt and sand; buff	4	100
Gravel and sand	5	105
Silt, sand, and caliche; buff	2	107
Gravel and sand	7	114
Silt, sand, and caliche; pink-tan	11	125
Gravel and sand	10	135
Silt, gravel, sand, and caliche; pink-tan	9	144
Gravel, sand, and silt; tan	6	150
Silt, clay, sand, and caliche; pink-tan	14	164
Gravel, sand, and silt	13	177
Silt, buff	4	181
Gravel and sand	15	196
Silt, sand, and caliche; buff	16	212
Gravel, sand, and silt; buff	8	220
Sand, gravel, and silt; buff	13	233
Silt, sand, and gravel; gray	21	254
Gravel and sand; loosely cemented	13	267
Pierre shale		
Shale, orange-yellow	3	270
Shale, light green-gray to light gray	10	280
Shale, dark gray to gray-black; containing pyrite and a few thin zones of bentonite	207	487

18. Log of test hole 18 in the SE corner sec. 36, T. 9 S., R. 34 W. Surface altitude, 3,193.4 feet.

	Thickness, feet	Depth, feet
Soil, gray-brown to yellow-brown	3	3
Sanborn formation		
Silt and very fine sand; yellow gray	27	30
Silt, tan, containing sand and fine gravel	10	40
Silt and very fine sand; tan	5	45
Ogallala formation		
Silt, sand, and gravel; buff	9	54
Gravel, sand, caliche, and silt; buff	3	57

Silt and clay; light brown; containing gravel, sand and caliche	19	76
Gravel, sand, silt, clay, and caliche; light brown	4	80
Silt, sand, and gravel; gray	10	90
Gravel, sand, and silt; loosely cemented; blue-gray	13	103
Gravel, sand, and caliche	7	110
Silt, gravel, sand, and caliche; light brown	8	118
Gravel and sand; in part cemented	44	162
Silt, sand, gravel, and caliche; pink-tan	26	188
Gravel, sand, and caliche	10	198
Silt, sand, and caliche; gray	22	220
Sand, tan, containing gravel, silt, and caliche	70	290
Silt and sand; yellow-gray	7	297
Gravel	3	300
Pierre shale		
Shale, dark blue-gray	10	310

19. Log of test hole 19 in the SW corner sec. 31, T. 9 S., R. 34 W. Surface altitude, 3,293.8 feet.

	Thickness, feet	Depth, feet
Road fill	4	4
Sanborn formation		
Silt and very fine sand; yellow-gray; containing snails	23	27
Silt, buff, containing sand and fine gravel	8	35
Ogallala formation		
Silt, pink-tan, containing sand, gravel, and caliche	5	40
Sand and silt; loosely cemented; brown	3	43
Gravel, sand, silt, and caliche; brown	5	48
Silt, light brown, containing sand, gravel, and caliche	4	52
Sand, silt, and caliche; brown	16	68
Gravel and sand; containing caliche	5	73
Silt, gravel, sand, and caliche; buff	9	82
Gravel, sand, and caliche; gray	8	90
Silt, sand, and caliche; pink-tan	20	110
Gravel	2	112
Silt, caliche, and sand; gray	8	120
Gravel, caliche, and sand; yellow-tan	10	130
Silt, sand, caliche, and gravel; buff	12	142
Gravel, sand, and caliche; yellow-gray	12	154
Silt and sand; gray-buff	6	160
Sand, partly cemented	43	203
Silt, sand, and caliche; pink-tan to gray	10	213
Gravel and sand	11	224
Pierre shale		
Clay-shale, yellow-gray mottled with gray	6	230
Shale, greenish-yellow and dark gray	10	240
Shale, gray	10	250

20. Log of test hole 20 in the NW corner sec. 6, T. 10 S., R. 35 W. Surface altitude, 3,351.3 feet.

	Thickness, feet	Depth, feet
Soil, dark gray	2	2
Sanborn formation		
Silt and very fine sand; yellow-gray	25	27
Silt and clay; buff; containing sand and fine gravel and a few snails	6	33
Ogallala formation		
Gravel and sand; containing silt and caliche	4	37
Silt, pink-tan, containing sand and gravel	7	44
Gravel and sand; loosely cemented	7	51
Silt, tan, containing sand and gravel	21	72
Gravel and sand	11	83
Silt, clay and caliche; gray	11	94
Gravel and sand	10	104
Silt, light tan, containing gravel and sand	1	105
Gravel and sand; cemented	16	121
Silt and clay; buff	2	123
Gravel and sand	5	128
Silt, gray, containing sand and caliche	6	134
Gravel and sand	10	144
Clay and silt; gray to brown; containing a small amount of sand and gravel	16	160
Gravel and sand	8	168
Silt, sand, gravel, and caliche; buff	14	182
Gravel, sand, and caliche	11	193
Pierre shale		
Shale, light green and yellow	7	200
Shale, gray	10	210

21. Log of test hole 21 in the SW corner sec. 31, T. 9 S., R. 36 W. Surface altitude, 3,450.2 feet.

	Thickness, feet	Depth, feet
Soil, dark gray downward to light gray	3	3
Sanborn formation		
Silt and very fine sand; yellow-gray	27	30
Silt, buff, containing sand and fine gravel	10	40
Silt, compact, light gray	10	50
Ogallala formation		
Silt, gray, containing sand and gravel	9	59
Gravel and sand	5	64
Silt, pink-tan, containing gravel and sand	23	87
Gravel and sand	15	102
Silt, sand, and caliche; buff	16	118
Gravel, sand, silt, and caliche; yellow-gray	14	132
Clay, silt, and caliche; white	12	144
Gravel and sand; yellow and gray; containing silt. A few zones are cemented	26	170

Silt, sand, and caliche; tan	9	179
Gravel and sand; gray; containing silt	23	202
Pierre shale		
Shale, yellow-green and gray	8	210
Shale, dark gray	10	220

22. Log of test hole 22 in the SE corner sec. 17, T. 10 S., R. 36 W. Surface altitude, 3,352.7 feet.

	Thickness, feet	Depth, feet
Sanborn formation		
Silt and very fine sand; gray to tan	27	27
Silt, gray, containing clay, sand, gravel, and caliche	1	28
Silt and very fine sand; yellow-gray	1	29
Silt with clay; yellow-buff; containing sand, caliche, gravel, and fragments of snails	11	40
Ogallala formation		
Gravel and sand; partly cemented	26	66
Silt, pink-tan, containing sand, gravel, and caliche	12	78
Gravel and sand	6	84
Silt, sand, and gravel; gray-buff	6	90
Gravel and sand	32	122
Silt, sand, and gravel; tan	4	126
Gravel and sand	10	136
Silt, light yellow-gray	2	138
Gravel and sand; gray; containing silt	12	150
Silt, gray-buff, containing sand, caliche and gravel	10	160
Gravel and sand	16	176
Pierre shale		
Shale, light gray-green	4	180
Shale, dark gray	5	185

23. Log of test hole 23 in the NE¼ SE¼ sec. 20, T. 10 S., R. 36 W. Surface altitude, 3,322.5 feet.

	Thickness, feet	Depth, feet
Sanborn formation		
Clay and silt; compact; gray	10	10
Clay and silt; light gray; containing nodules of caliche and pebbles	16	26
Silt and clay; buff; containing gravel and sand	14	40
Gravel, sand, and silt; containing abraded pebbles of caliche	16	56
Ogallala formation		
Gravel, sand, and silt; cemented; buff	4	60
Silt, buff; containing sand	6	66
Gravel and sand; containing silt	24	90
Silt, buff, containing sand and caliche	7	97
Gravel and sand	37	134
Silt, sand, and caliche; buff	7	141

Gravel, sand, silt, clay, and caliche; white	9	150
Silt and clay; light buff; containing caliche, sand, and gravel	24	174
Gravel and sand	4	178
Clay, white, containing silt and sand	7	185
Gravel and sand; buff; containing silt and caliche	9	194
Pierre shale		
Shale, yellow in upper part to light blue-gray in lower part.	6	200
Shale, dark gray	20	220

24. Log of test hole 24 in the NE¼ NE¼ sec. 29, T. 10 S., R. 36 W. Surface altitude, 3,365.9 feet.

	Thickness, feet	Depth, feet
Soil, light gray-brown	2	2
Sanborn formation		
Silt and very fine sand; buff	44	46
Clay and silt; light gray-green; containing sand and gravel	19	65
Gravel and sand; buff; interbedded with silt and pebbles of caliche	17	82
Silt, light buff	6	88
Ogallala formation		
Gravel and sand; cemented in zones	37	125
Silt, caliche, sand, and gravel; gray	10	135
Gravel and sand	3	138
Silt, light gray; containing sand, gravel, and caliche	4	142
Gravel and sand	4	146
Silt, yellow-gray; containing sand, gravel and caliche	4	150
Gravel, sand, and caliche	20	170
Silt, gravel, sand, and caliche; yellow-buff	6	176
Gravel and sand; containing clay	9	185
Silt and caliche; gray; containing sand	2	187
Gravel and sand	18	205
Silt, light gray; containing sand and caliche	7	212
Gravel and sand	11	223
Silt, buff; containing gravel, sand, and caliche	9	232
Gravel and sand	15	247
Pierre shale		
Shale, light yellow-green in upper part to gray in lower part	8	255

25. Log of test hole 25 in the SW corner sec. 31, T. 10 S., R. 35 W. Surface altitude, 3,353.4 feet.

	Thickness, feet	Depth, feet
Road fill	2	2
Sanborn formation		
Silt and very fine sand; yellow-gray	15	17
Silt, gray-brown to white; containing sand, gravel, and caliche	3	20

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; containing sand, caliche and clay	24	164
Sand, yellow-brown; containing 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
Pierre shale		
Shale, light gray-green and gray	5	220
Shale, gray	10	230

26. Log of test hole 26 in the NW¼ NW¼ sec. 36, T. 10 S., R. 34 W. Surface altitude, 3,192.6 feet.

	Thickness, feet	Depth, feet
Sanborn formation		
Silt and very fine sand; yellow-gray	23	23
Silt and clay; tan; containing sand and gravel	7	30
Silt and clay; light buff	6	36
Ogallala formation		
Silt, clay, sand, and gravel; buff	6	42
Gravel, sand, and caliche; buff	15	57
Silt, pink-tan; containing gravel and sand	10	67
Gravel and sand	21	88
Silt, tan; containing gravel and sand	6	94
Gravel and sand	7	101
Silt, pink-tan; containing sand and gravel	4	105
Gravel, sand, silt, and caliche; tan	5	110
Silt and clay; gray; containing gravel, sand and caliche	12	122
Sand and gravel	8	130
Gravel and sand; containing silt and caliche	17	147
Pierre shale		
Shale, greenish-gray, mottled yellow-brown and red	11	158
Shale, dark gray	7	165

27. Log of test hole 27 in the SE¼ SE¼ sec. 36, T. 10 S., R. 34 W. Surface altitude, 3,182.6 feet.

	Thickness, feet	Depth, feet
Sanborn formation		
Clay and silt; compact; gray	6	6
Silt and clay; yellow-gray; containing very fine sand	14	20
Silt and clay; yellow-gray; containing a small amount of fine gravel	12	32
Ogallala formation		
Silt, dull tan; containing clay, sand, and gravel	3	35
Gravel, sand, silt, and caliche; tan	7	42
Silt and clay; tan and gray; containing sand and caliche	16	58
Gravel and sand	20	78
Silt, tan, containing sand	5	83
Gravel, sand, and caliche	5	88
Silt and sand; compact; tan	4	92
Gravel, sand, silt, and caliche; tan and gray	8	100
Silt, sand, and gravel; gray and tan	8	108
Gravel, sand, and caliche	29	137
Silt, clay, sand, and caliche	10	147
Pierre shale		
Shale, light green-gray mottled with yellow and brown	8	155

28. Log of test hole 28 in the SE¼ SE¼ sec. 36, T. 10 S., R. 34 W. Surface altitude, 3,191.2 feet.

	Thickness, feet	Depth, feet
Soil, silty, gray	2	2
Sanborn formation		
Silt and very fine sand; tan-gray	21	23
Silt and clay; gray-brown	12	35
Silt and clay; tan-buff; containing gravel and caliche	12	47
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; containing 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
Pierre shale		
Shale, light green, mottled yellow	4	160
Shale, gray-green and gray	15	175

29. Log of test hole 29 in the SE corner sec. 36, T. 10 S., R. 32 W. Surface altitude, 3,053.8 feet.

	Thickness, feet	Depth, feet
Soil, gray-brown to black	3	3
Sanborn formation		
Silt and very fine sand; yellow-gray	20	23
Silt, buff to white; containing clay, fine gravel, and caliche	2	25
Ogallala formation		
Gravel, sand, and caliche	13	38
Silt, pink-tan; containing 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
Pierre shale		
Shale, green-gray and yellow	5	220
Shale, yellow to light gray-blue	10	230
Shale, gray	20	250

30. Log of irrigation well at Colby Experiment Station, in the NE¼ sec. 2, T. 8 S., R. 34 W.

	Thickness, feet	Depth, feet
Soil	6	6
Sanborn formation		
Clay, white	30	36
Ogallala formation		
Sand rock	3	39
Sand, fine	10	49
Clay, red	52	101
Sand (good water sand)	7	108
Clay, red	9	117
Sand (good water sand)	32	149
Clay, red	11	160

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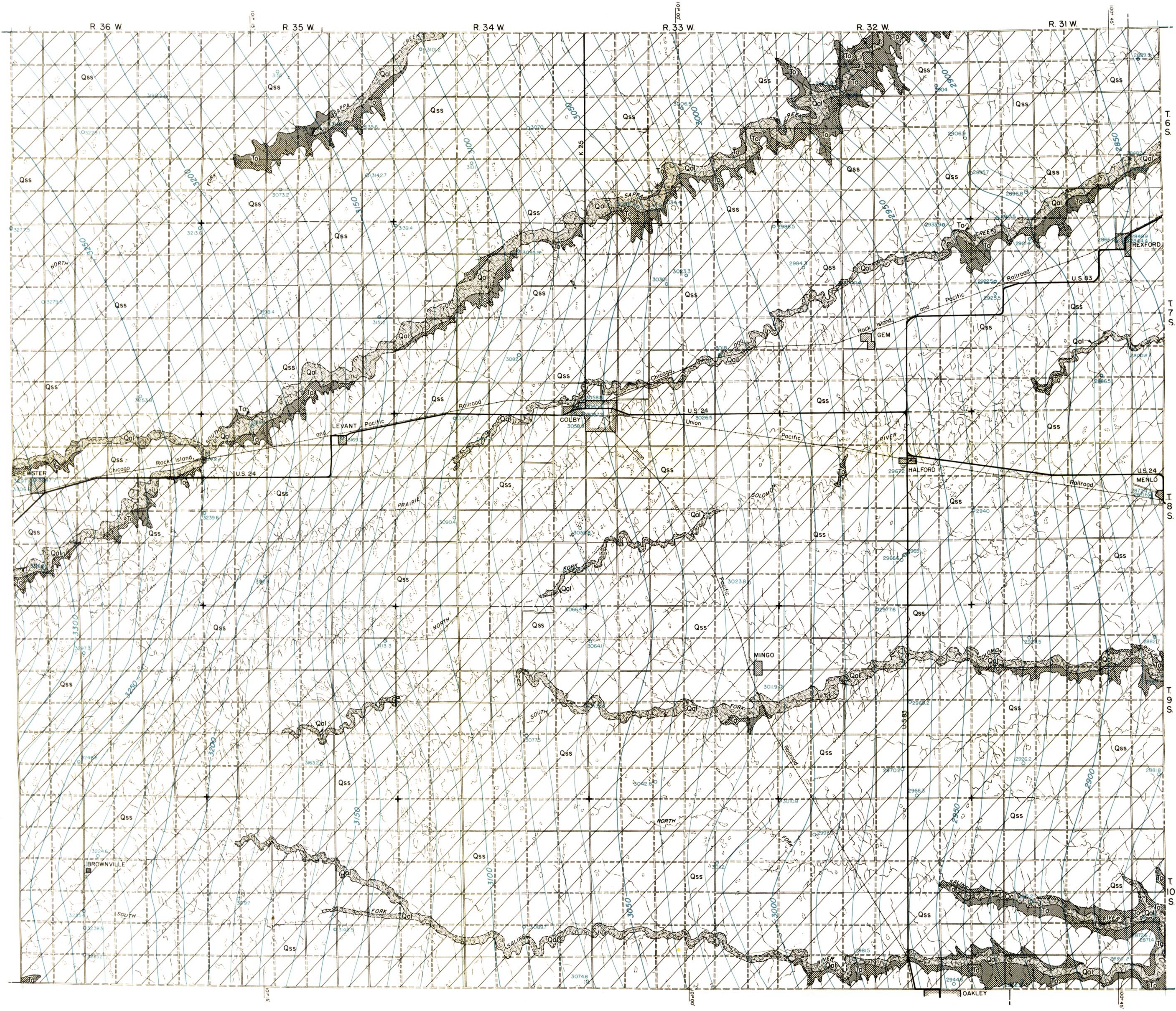
MAP OF THOMAS COUNTY, KANSAS
Showing Geology and Water-Table Contours, 1943

by John C. Frye

State Geological Survey of Kansas

Bulletin 59
Plate 1



EXPLANATION

Qal

Alluvium

Silt and sand, with some clay and gravel, comprising stream deposits of the several shallow valleys. Due to the low permeability and small extent of the alluvium it does not yield large quantities of water. In much of the valley areas the alluvium occurs above the water table.

RECENT

Qss

Sanborn formation and valley side slope deposits

Silt and very fine sand, with locally sand and gravel at base. The valley side slopes are in many places mantled with thick slump or creep deposits, and in areas where such deposits completely obscure the underlying Tertiary or Pleistocene deposits they are mapped with this symbol. Yields small quantities of water to wells in local areas.

PLEISTOCENE AND RECENT

QUATERNARY

To

Ogallala formation

Gravel, sand, silt, clay, and caliche, locally sand and gravel beds cemented by calcium carbonate to form a hard conglomerate. This formation underlies the entire county. *Nearly all of the well water supplies* of Thomas county are obtained from the sand and gravel beds of this formation.

PLIOCENE

TERTIARY

Contour interval 10 feet

2950	Water-table contours based on instrumental levels (dashed in areas of contradictory or inadequate data).
○2977.6	Well location. Number refers to altitude of water level
× 2890.2	Altitude of stream channel

Federal or State highway
Graded road
Ungraded road
Township line (no road)
Section line (no road)
Railroad
Intermittent stream

0 1 2 3 4 5 6
Scale in miles

Drainage of area outside limits of Colby Quadrangle from aerial photographs of the United States Department of Agriculture.

Base modified from map prepared by Kansas State Highway Department and from the Colby Quadrangle, surveyed cooperatively by the United States Geological Survey and the State Geological Survey of Kansas.

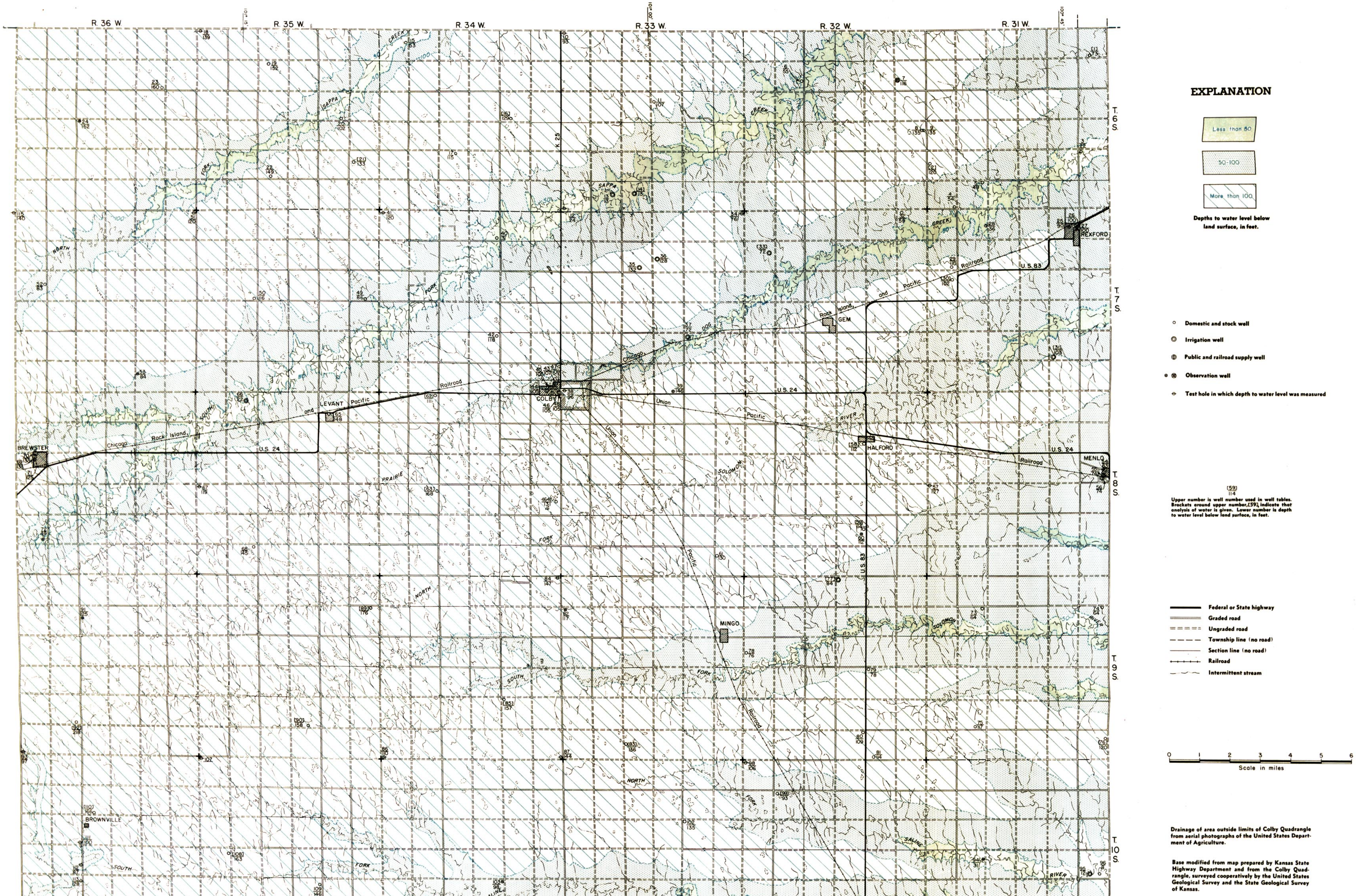
MAP OF THOMAS COUNTY, KANSAS

Showing the depths to Water Level and the Location of Wells for which Records are given, 1943

by John C. Frye

State Geological Survey of Kansas

Bulletin 59
Plate 2



Drainage of area outside limits of Colby Quadrangle from aerial photographs of the United States Department of Agriculture.

Base modified from map prepared by Kansas State Highway Department and from the Colby Quadrangle, surveyed cooperatively by the United States Geological Survey and the State Geological Survey of Kansas.