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QUATERNARY GEOLOGY AND GROUND-WATER RESOURCES OF KANSAS RIVER VALLEY BETWEEN BONNER SPRINGS AND LAWRENCE, KANSAS

by

Alvin E. Dufford

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QUATERNARY GEOLOGY AND GROUND-WATER RESOURCES OF KANSAS RIVER VALLEY BETWEEN BONNER SPRINGS AND LAWRENCE, KANSAS

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ALVIN E. DUFFORD

ABSTRACT

This report describes the Quaternary geology and ground-water resources of a portion of Kansas River valley between Bonner Springs and Lawrence, Kansas. Unconsolidated Pleistocene sediments are widely distributed over Pennsylvanian bedrock in this part of northeastern Kansas. Glacial till and outwash of Kansan age are found as a discontinuous till sheet mantling the uplands and as an old dissected terrace bordering the larger valleys, but neither deposit is a good aquifer. Fine-grained fluvial deposits of Illinoian age have been destroyed almost completely along the Kansas River valley, but are preserved as isolated terrace remnants lying at intermediate positions along larger tributary valleys and yield a small amount of ground water. Wisconsinan and Recent stream-laid deposits constitute alluvial fills in the Kansas River valley and most tributary valleys, and average approximately 55 feet in thickness in the main valley. Kansas River valley alluvium is the only source of abundant ground-water supplies in this area. In 1953, more than 2,650,000 gallons per day of ground water was pumped from valley alluvium for domestic, stock, municipal, and industrial use, and adequate ground water is available for future industrial and irrigational expansion. The quality of the water is fair, and standard methods of water treatment easily remove carbonate hardness and excessive iron, the most objectionable features.

A map shows the distribution of Pleistocene deposits. Geologic cross sections, maps illustrating the configuration of the water table, a detailed contour map of the bedrock floor of a portion of the valley, and profiles showing the relationship of river terraces are included in the report. General effects of the 1951 flood are discussed, and a detailed map of flood deposits and channel changes has been compiled. Tables include records of typical wells and chemical analyses of water samples. Logs of test holes and water wells are given.

INTRODUCTION

Purpose and Scope of Report

The purpose of this report is to describe the Quaternary geology and ground-water resources of the Kansas River valley between Bonner Springs and Lawrence, Kansas. Brief consideration is given to Pennsylvanian bedrock, which underlies all Pleistocene deposits within the mapped area, as bedrock formations generally are not good aquifers. The only potential source of abundant ground-water supplies in this area is Kansas River valley alluvium; a ground-water inventory dealing chiefly with the alluvium is presented in this report.

This study supplements the cooperative program of ground-water investigations sponsored by the State Geological Survey of Kansas and the U. S. Geological Survey, in cooperation with the Division of Sanitation of the Kansas State Board of Health and the Division of Water Resources of the Kansas State Board of Agriculture. This report serves to complete a series of ground-water investigations of the Kansas River valley between Kansas City and Topeka, Kansas.

The Kansas River valley between Bonner Springs and Lawrence is principally an agricultural area, but industry is expanding westward from the Kansas City area and is exerting a marked influence in this part of the valley. As industry develops, demands for ground-water supplies will inevitably increase. This study is designed to determine the ground-water conditions and to guide future ground-water development in the area.

Location and Extent of Area

This report covers an area in northeastern Kansas that includes the southern part of Leavenworth County, the southwestern part of Wyandotte County, the northeastern part of Douglas County, and the northwestern part of Johnson County (Fig. 1). Bonner Springs, the largest town within the area, lies about 1½ miles west of the eastern edge of the area. Lawrence is situated nearly 2½ miles west of the area. The area is about 9 miles wide and is roughly bisected by the east-trending Kansas River valley. About a 21-mile length of Kansas River valley (measured along the axis of the valley) is included in the area, which totals 177 square miles.

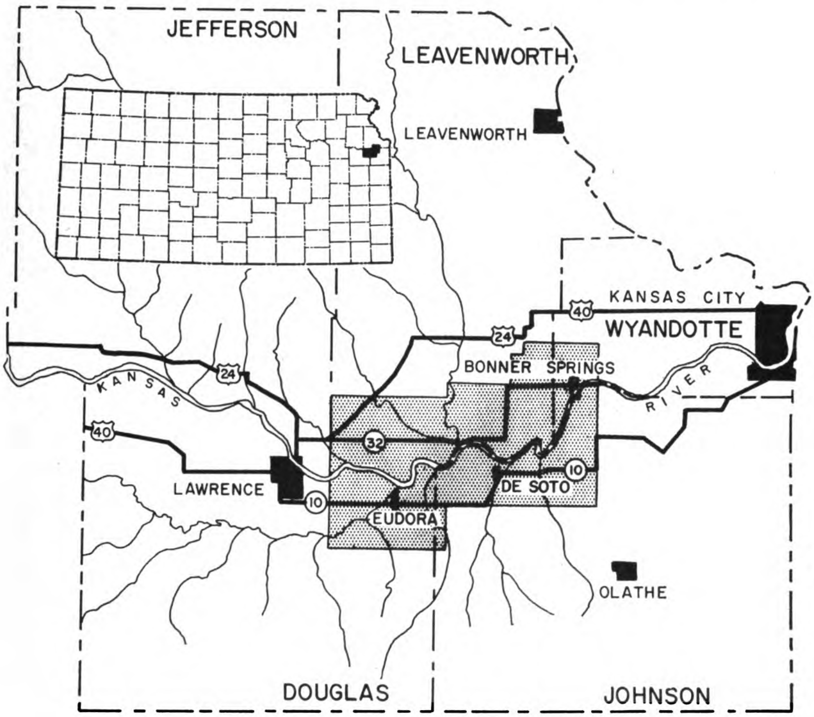


Fig. 1. Index map of Kansas showing location of area discussed.

Previous Investigations

The geology of Wyandotte County was described by Jewett and Newell (1935), and a map showing the distribution of loess of Pleistocene age was included in the report. Newell (1935) described the geology of Johnson and Miami Counties, Kansas. The geology and ground-water resources of Douglas County are being investigated at the present time by Howard O'Conner. Lins (1950) described and mapped the Tonganoxie Sandstone, an important bedrock aquifer that crops out in a large part of the area.

Moore (1936, 1949) described the stratigraphy of Pennsylvanian rocks of Kansas, and the geologic map of Kansas (Moore and Landes, 1937) shows the distribution of Pennsylvanian rocks in the mapped area. Earlier geologic maps of parts of Kansas were published in the geologic atlas of the United States (Hinds and Greene, 1917).

Earliest detailed reports of the Pleistocene geology of this part of northeastern Kansas were those of Todd (1909, 1911, 1923), which described the drainage and geologic history of the glaciated portion of northeastern Kansas. He placed the southern limit of the drift border at a position north of Kansas River valley. Schoewe (1930, 1949) demonstrated, through the recognition of glacial till deposits, that the southern limit of glaciation should be extended to a position several miles south of the Kansas River valley. At Schoewe's suggestion Hoover (1936) made a petrographic study of lithologic samples from scattered Pleistocene deposits along Kansas River between Kansas City and Manhattan. He described terrace, till, and colluvial deposits of Pleistocene age. A subsurface reconnaissance of glacial deposits in northeastern Kansas was made by Frye and Walters (1950), but it included no direct study of the area discussed in this report. The Pleistocene geology and ground-water resources of the Kansas River valley between Lawrence and Topeka were studied in detail by Davis and Carlson (1952). Frye and Leonard (1952) described the Pleistocene geology of Kansas and summarized the existing knowledge in one publication.

The Emergency Relief Committee and the Works Progress Administration carried on ground-water investigations in eastern Kansas in 1934 and 1936 respectively, and community wells that were constructed by those organizations are still used during periods of drought. Moore (1940) summarized the ground-water resources of Kansas. Detailed ground-water investigations have been carried out in the vicinity of Lawrence by Lohman (1941) and in the Kansas River valley between Kansas City and Bonner Springs by Fishel (1948).

Methods of Investigation

The investigation upon which this report is based began in April 1952 when test holes were drilled in the area. Most of the area was mapped in the field during two months of the summer of 1952. In April and May 1952 two observation wells were established in the area; 39 measurements of the depth to water in these wells were made during the subsequent 9 months.

The geology was mapped in the field at scales of about 2.65 and 3.15 inches to the mile on U. S. Geological Survey topographic maps and aerial photographs supplied by the State Geological Survey of Kansas, and the areal geology is shown on the map in Plate 1. The base map of the area used in Plates 1 and 2 was compiled from 7½-minute quadrangles of the U. S. Geological Survey.

Nine test holes were drilled in the area by William Conner and Samuel Bishop, using the portable hydraulic rotary drilling rig owned by the State Geological Survey of Kansas. Lithologic samples were collected from these holes, and logs were prepared in the field by me. Three geologic cross sections (Fig. 2) were compiled from information obtained from sample logs of these test holes, drillers logs of test holes drilled for Sunflower Ordnance Plant at De Soto, and logs of test holes published by Fishel (1948).

Field work included drilling more than 70 auger holes to depths ranging from 2 to 28 feet to collect lithologic samples, to determine the thickness of deposits, to determine the depth to the water table, or to supplement meager outcrop information. Well owners were interviewed regarding the nature and thickness of water-bearing formations, and available logs were obtained. Depths to water level were measured in 30 wells and 4 auger holes, samples of water were collected from 14 wells and 1 spring, altitudes of the water table were surveyed at 3 scour pits, and altitudes of the water surface of streams were determined at 10 localities. Altitudes of the measuring points of wells penetrating valley alluvium and of the land surface at the sites of four auger holes and nine test holes were surveyed from benchmarks of the U. S. Coast and Geodetic Survey, by plane table and telescopic alidade. Altitudes of the measuring points of upland wells were estimated by hand level and U. S. Geological Survey topographic maps. The locations of wells and test holes, altitudes of points on the water table, depths to the water table, and generalized ground-water contours are shown in Figure 3.

Size analyses of selected lithologic samples are tabulated in Table 2. Lithologic samples from nine test holes and many auger holes were examined under the binocular microscope. Information included with logs of Sunflower Ordnance Plant test holes made possible the preparation of detailed contour maps of the bedrock floor and the 1942 water table in a part of the Kansas River valley near De Soto. These maps are shown in Figures 7

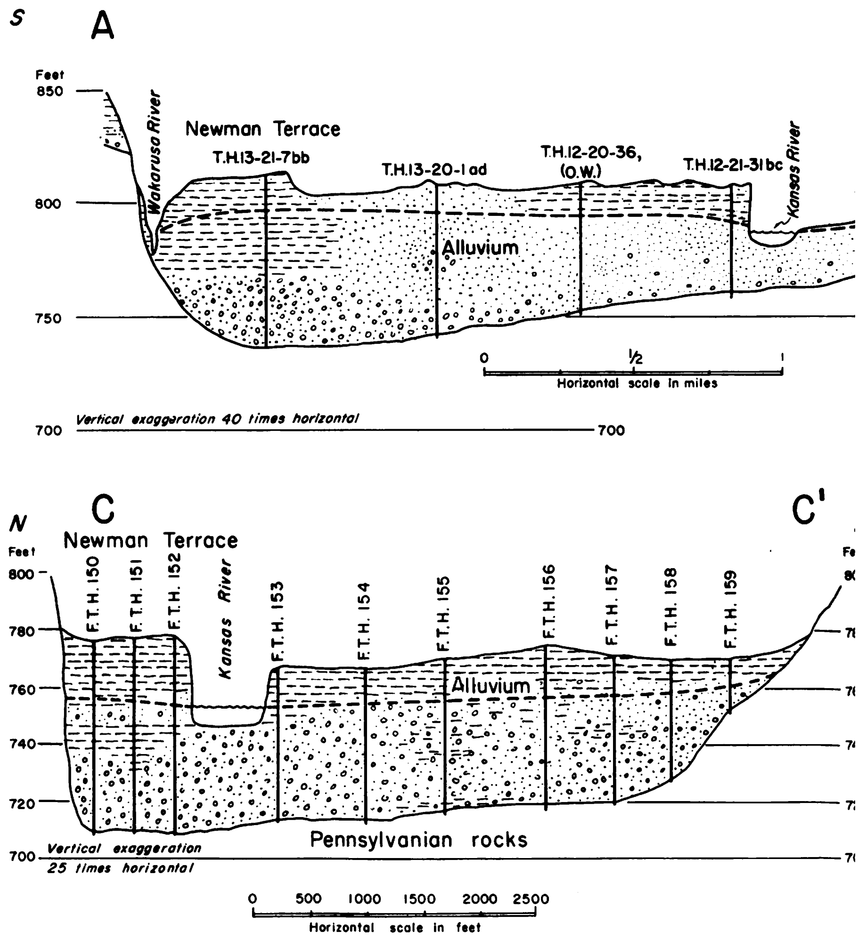
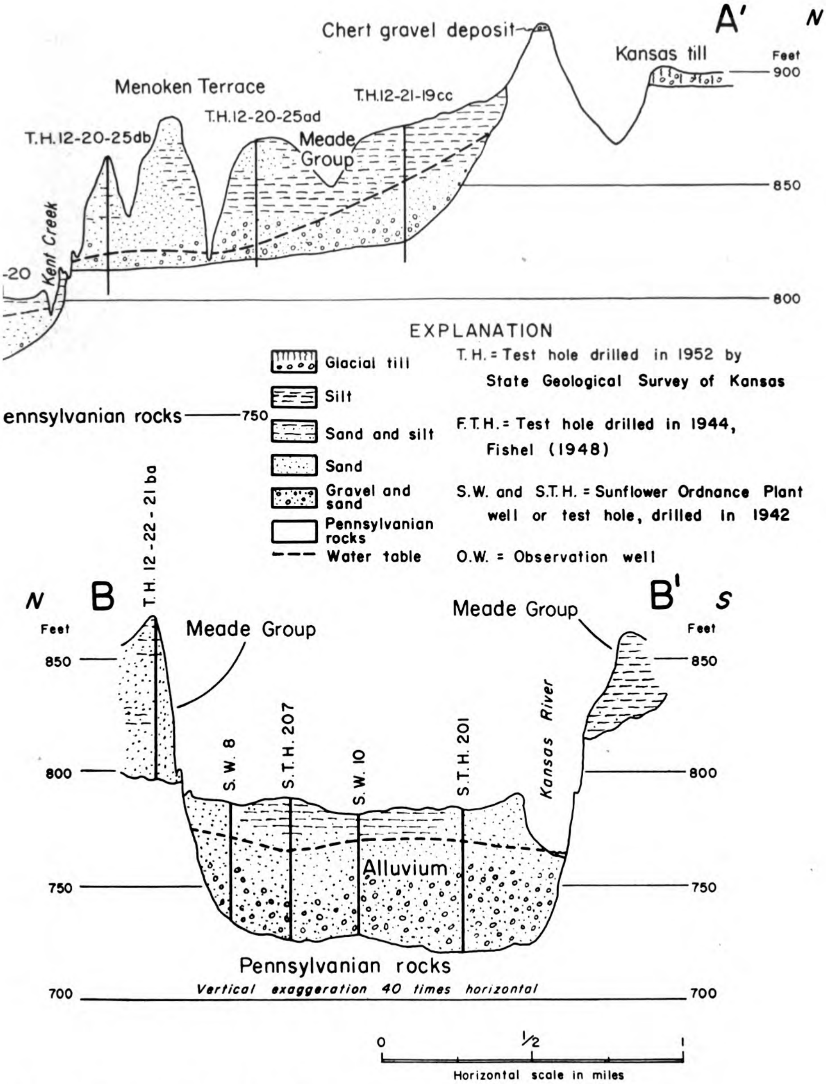


FIG. 2. Geologic sections across Kansas River valley between Lawren



l Bonner Springs. Location of sections is shown on Fig. 3.

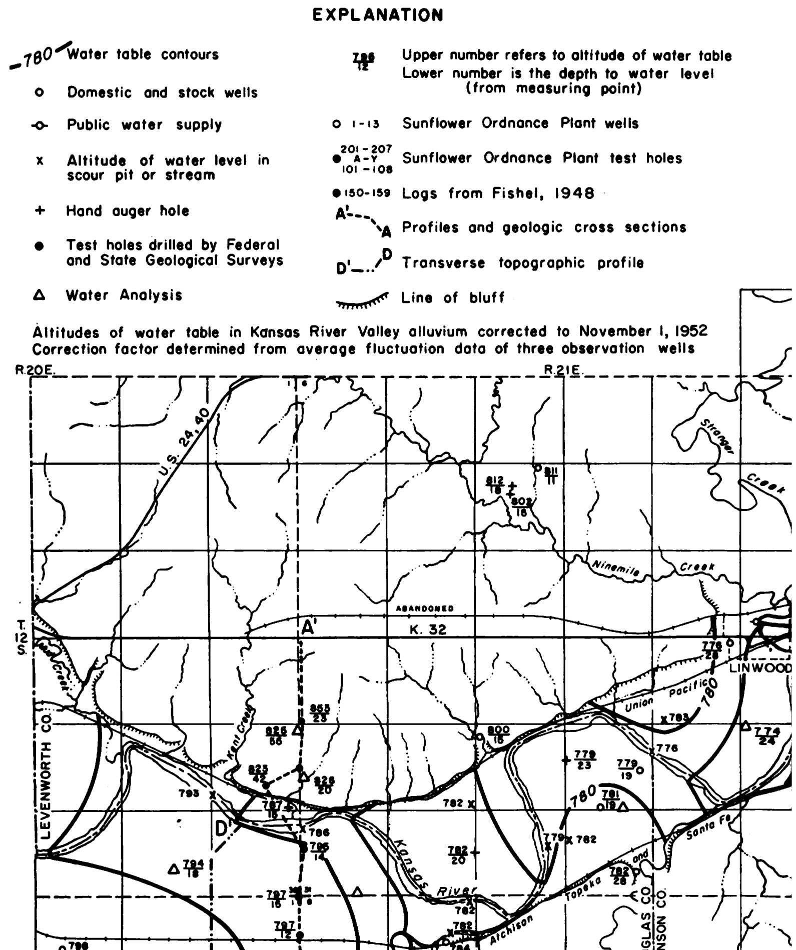
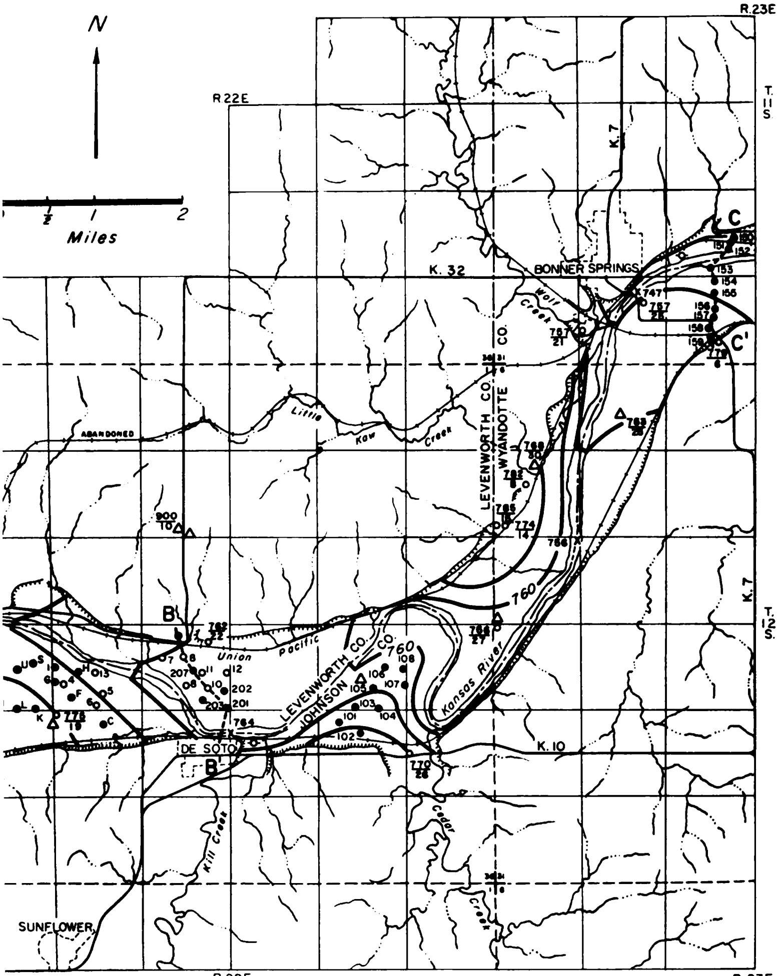


FIG. 3. Map showing generalized contours on wa



le and locations of water wells and test holes.

and 9 respectively. The altitude of the surface of the ground, the depths to the water table, and the depths to bedrock were given for most test holes, as determined by well drillers; the accuracy of the maps depends upon the reliability of that information.

Location and Well-numbering System

The locations of wells, test holes, and auger holes, and of many localized features described in the text are designated according to General Land Office surveys in the following manner. The first three numbers refer to the township, range, and section in that order. Two lower-case letters follow, which represent the 160-acre tract within the section, and the 40-acre tract within the quarter section, respectively. The lower case letters representing

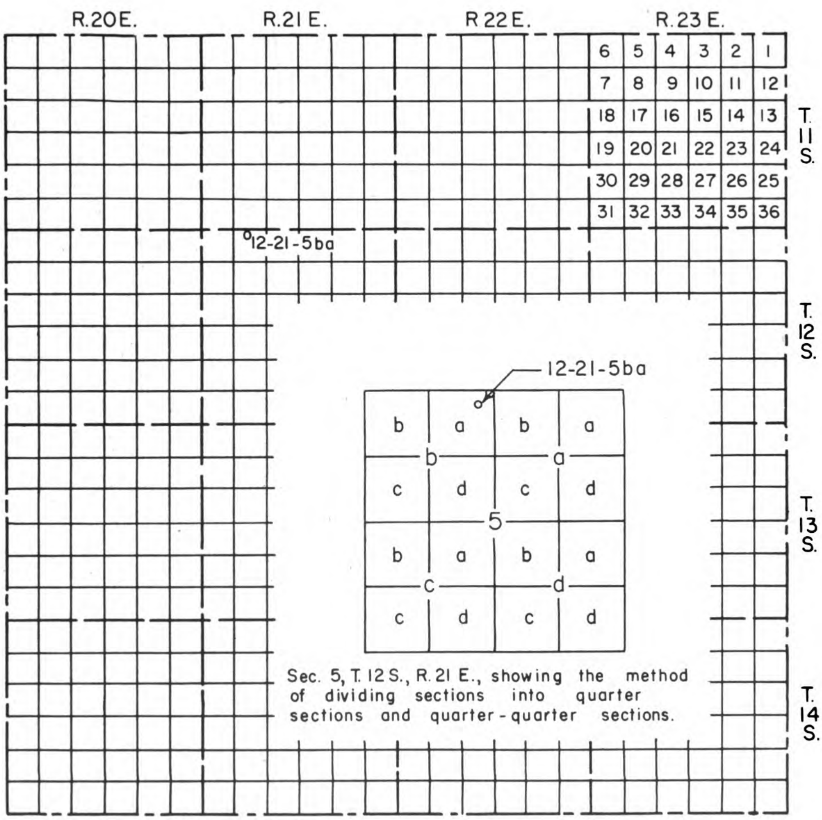


Fig. 4. Map illustrating well-numbering system used in this report.

the 160-acre and 40-acre tract are a, b, c, or d, beginning in the northeast quarter. The others are placed consecutively in the other quarters in a counter-clockwise direction. If two or more wells or test holes are located within a 40-acre tract, the letters are followed by numbers indicating the order in which the wells or test holes were inventoried or drilled, as the case may be. Figure 4 illustrates the relationship described.

Acknowledgments

Appreciation is expressed to the residents and municipal officials of the area who so kindly supplied information and rendered assistance during the course of the field work. Three residents graciously allowed test holes to be drilled on their properties. Acknowledgment is made of the friendly cooperation shown by personnel of Sunflower Ordnance Plant, U. S. Soil Conservation Service county offices in Leavenworth, Johnson, and Douglas Counties, U. S. Army Corps of Engineers in Kansas City, and Water Resources Division of the U. S. Geological Survey in Topeka in making available much important information included in this report. Mr. C. H. Atkinson and other soil scientists affiliated with the U. S. Soil Survey office at Kansas State College spent a day in the field with me disclosing soil characteristics that are found in the Kansas River valley.

Appreciation is expressed for the unselfish efforts of Samuel Bishop and John Atchley in helping to set up an observation well and in assisting in surveying.

GEOGRAPHY

Topography

The Kansas River valley between Bonner Springs and Lawrence lies at the border between the Dissected Till Plain and the Osage Plains. These are divisions of the Central Lowlands physiographic province of the Interior Plains as defined by Fenneman (1931). Schoewe (1949) places the area entirely within the Dissected Till Plain, which he further subdivides into two units: the Attenuated Drift Border, which includes most of the mapped area, and the Kansas Drift Plains, comprising small portions of the uplands north of the valley.

The physical setting of the area consists of three gross features: (1) bedrock uplands, (2) high-level alluvial terrace remnants, and (3) the valley system or lowlands containing broad flat alluvial floors. The bedrock uplands in the eastern portion of the area are characterized by prominent east-facing escarpments of resistant limestone formations, which strike northeast and dip gently to the northwest away from the Ozark Uplift. The bedrock uplands in the western portion of the area are more subdued, as they are underlain generally by less resistant sandstone, siltstone, and shale formations. A mantle of glacial till covering much of the uplands tends to mask the irregularities produced by differential erosion of the bedrock.

Dissected alluvial terrace remnants border most of the Kansas River valley. Although the summits of many of these remnants rise 80 to 100 feet above the floodplain, the ill-defined and gently sloping terrace scarps contrast strongly with the precipitous limestone cliffs that form the valley bluff in much of the eastern portion of the area. In some western parts of the area high-level terraces constitute upland interfluves between tributary valleys.

The east-trending Kansas River valley is a conspicuous flat lowland area whose flat-bottomed tributary valleys resemble the major valley on a small scale. Dissection of the Kansas River valley has not been uniform, the western part having been carved in less resistant formations than the eastern part. The Kansas River valley can be divided topographically into a low flat terrace and an irregularly scarred modern floodplain. Another division, not always clearly discernible topographically, lies between the terrace and floodplain. It is an intermediate surface complex containing many surface irregularities and minor scarps. The modern active floodplain is predominant in the narrow parts of the valley, and the terrace is more widely represented in the broad western portion of the valley. Although the terrace is well drained, numerous undrained marshes and ponds fill old meander scars on the floodplain and intermediate surface complex.

The local relief along Kansas River ranges from about 100 feet near the western border to about 250 feet at the eastern border of the area. The high escarpment in the northwestern corner of the area has elevations exceeding 1,080 feet, whereas the channel of Kansas River lies at an elevation of about 750 feet in the eastern extremity of the mapped area. The total relief of the mapped area, therefore, is slightly more than 330 feet.

CLIMATE

The Kansas River valley between Bonner Springs and Lawrence has a humid continental climate. A long growing season is endowed with abundant rainfall and high temperatures. The average length of the growing season is 194 days; it normally begins about April 11, the average date of the last killing frost in the spring, and ends about October 22, the average date of the first killing frost in the fall.

The normal annual precipitation at Bonner Springs is 36.04 inches. Figure 5 shows the normal monthly distribution of rainfall at Bonner Springs. Table 1 lists the monthly precipitation at Bonner Springs for the years 1951 and 1952. Abnormal conditions prevailed in both years; the area received about 50 inches of precipitation in 1951, the year of the disastrous Kansas River flood, and less than 27 inches the following year. The mean annual

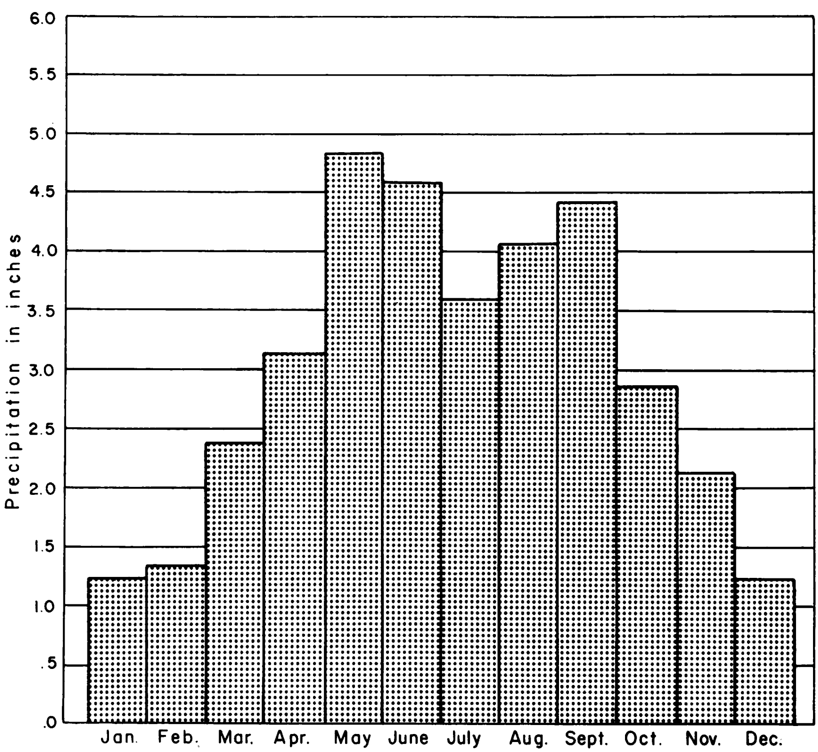


FIG. 5. Chart of normal monthly precipitation at Bonner Springs.

temperature at Lawrence is about 55° F. July and August are the warmest months, having normal monthly temperatures of 79.1° and 77.5° F, respectively, and January is usually the coldest month, having an average temperature of 29.9° F. Daily temperatures rarely exceed 100° F or drop below 0° F for several consecutive days.

TABLE 1. *Monthly precipitation for 1951 and 1952 at Bonner Springs, Kansas*

Month	Precipitation in 1951, inches	Precipitation in 1952, inches
January	0.66	0.48
February	1.72	1.48
March	2.45	......
April	2.89	4.09
May	5.11	3.16
June	9.17	2.52
July	8.94	3.13
August	6.03	5.60
September	6.40	1.59
October	4.32	0.00
November	1.18	1.98
December	0.65	1.28
Annual	49.52	......

POPULATION

The largest town in the area is Bonner Springs, which has a population of 2,241. The population of the other three towns as recorded by the 1950 census are: Eudora, 929; De Soto, 532; and Linwood, 238. The total population, exclusive of the above towns, of the seven townships of which portions are included in the mapped area is 12,699. Inasmuch as only small portions of these townships are included in the area, the combined rural and town population of the mapped area is estimated to be fewer than 7,000. This estimate excludes Sunflower Village, for which no population figures are available.

TRANSPORTATION

The area is served by three state highways; Kansas Highways 32 and 10 roughly parallel Kansas River on the north and south upland respectively, and Kansas Highway 7 crosses Kansas River at Bonner Springs and constitutes much of the east border of the mapped area. U. S. Highways 24 and 40 are merged in their traverse across the northwestern portion of the area. Much of the area is served by well-graded section roads, and little difficulty is encountered in traveling anywhere within the mapped area when the roads are dry.

Main lines of the Union Pacific and the Atchison, Topeka and Santa Fe Railways traverse the area along the foot of the north and south bluff respectively of the Kansas River valley. Branch lines of both railroads cross the area north of Kansas River.

Agriculture

Corn, wheat, and hay are the principal crops raised in the area. Other important crops include potatoes, soybeans, sorghum, and barley. Apples, peaches, grapes, and pears constitute most of the fruit production. Douglas County leads the other counties represented in the area for the value of its crops and fruits. Livestock and poultry production are important in the uplands, particularly where farms are located on steep bedrock slopes. Irrigation has not been carried on extensively in the area, but the drought that has prevailed since 1952 has stimulated an interest in irrigation.

Industry

The only town in the area that has significant industrial development is Bonner Springs; here cement, mill machinery, cereal, and canned goods are manufactured. The largest industry in the area is the Sunflower Ordnance Plant near De Soto operated by Hercules Powder Company for the United States government. Most of the plant is located south of Sunflower outside of the mapped area, but a water-intake plant and 12 water wells supply water to the chemical plant from their sites in the Kansas River valley flat near De Soto. The accessibility of abundant ground-water resources was of primary importance in the establishment of the plant at its present location.

GEOMORPHIC DEVELOPMENT

Pre-Kansan Cenozoic Time

Sedimentation during pre-Kansan Cenozoic time is represented in the area by a few chert gravel deposits lying as isolated remnants high above the modern floodplain of Kansas River. The deposits cap the crests of hills standing higher than adjacent

Menoken Terrace remnants of Kansan age. Two areas of high level chert gravels are preserved. Those on the north bluff of the Kansas River valley 3 miles north of Eudora have bedrock floors at elevations of 930 or 940 feet, at least 40 feet above the highest summits of Menoken Terrace remnants to the south. The bedrock floor of remnants south of the Kansas River valley along Kansas Highway 10 at the extreme western portion of the area lies at elevations ranging from 880 to 890 feet, about 35 feet above the surface of a small Menoken Terrace remnant nearby. Test drilling in Kansas River valley 2 miles west of Eudora has revealed the bedrock floor beneath alluvium at an elevation lower than 740 feet (Fig. 2), indicating that Kansas River has incised its valley between 140 and 200 feet since these early valley floors were carved. Colluvial processes have reworked the chert gravel deposits, resulting in gravel veneers that extend down slopes for many feet below the original bedrock floors. Rude stratification within the gravel veneers is roughly parallel to the slope of the land surface. The high topographic position of these deposits and their almost complete lack of erratic pebbles suggest, but do not prove, a pre-Pleistocene origin.

A low lying deposit of chert gravel along Wakarusa River near Eudora (13-21-7a) is found between Pennsylvanian bedrock and sandy silts identified as glacial outwash of Kansan age. Although it lies at the same stratigraphic and topographic position as basal outwash gravels elsewhere, this chert gravel deposit is inferred to be an early Kansan pro-glacial or pre-Kansan deposit because of the lithologic contrast attested by its lack of erratics.

A high level chert gravel deposit of probable Tertiary age farther upstream near Kiro has been described by Davis and Carlson (1952). Other chert gravels judged to be late Tertiary in age are located at high topographic positions along the Cottonwood-Neosho River valley (Frye and Leonard, 1952).

Kansan Time

The invasion of a continental ice sheet into northeastern Kansas during Kansan time brought to a climax the diverse and profound effects of Pleistocene glaciation in this area. The physical presence of the Kansan glacier, advancing over topography having a less pronounced and widespread drainage system than at present, produced a variety of effects upon the landscape. During glacial advance, pre-existing valleys were scoured deeper, owing to increased water in the streams, and pro-glacial outwash sands and gravels were deposited near the ice margin, only to be overridden during farther advance of the ice sheet (Frye and Leonard, 1952).

Observed glacial striae in this area (Schoewe, 1930) are evidence of glacial scour upon bedrock, although this evidence is not generally seen, because glacial drift and subsequent erosion have obscured or destroyed most of the striae. Glacial scour, however, is evidence that the Kansan glacier crossed the present position of the Kansas River valley during maximum glacial advance (Schoewe, 1930).

When a lobe of the Kansan glacier crossed the position of the Kansas River valley west of Lawrence, meltwaters from the southern edge of the lobe escaped to the east along a temporary spillway in the position of the Wakarusa River valley (Todd, 1911). Most glacial till was deposited during retreat phases of ice-front fluctuation. As much as 40 feet of glacial till is known to mantle crests of hills in this area, and local residents report a maximum of 65 feet of till. Glacial till is found almost exclusively at high topographic positions in this area, because of two factors: (1) post-Kansan erosion has carved valleys deeper, removing much till in the process, and (2) some of the till originally deposited in pre-existing valleys was reworked and redeposited by meltwaters during Kansan time. Areas mantled by Kansas Till generally have a more subdued topography than barren bedrock areas nearby. This distinctive landscape feature results from the less resistant nature of the till and from the downslope action of colluvial processes, which have extended the till over lower bedrock slopes. As the greatest thickness of till is found on the north side of the Kansas River valley, the Kansan glacier was probably stabilized for considerable time at a position just north of the present valley. The bedrock floor underlying 40 feet of till along Kansas Highway 32 about 2½ miles north of De Soto (12-22-9dc) stands at an approximate elevation of 920 feet. The bedrock floor rises northeastward to an elevation of about 1,000 feet in the vicinity of Kansas Highway 7 at the northeastern corner of the mapped area. In that vicinity the till is much thinner and less extensive.

One of the most profound effects of the Kansan glacier was the deposition in pre-existing valley systems of as much as 100 feet of outwash gravel, sand, and silt during glacial retreat, texture of the sediments becoming progessively finer as the glacier receded toward its Canadian center. Dissected remnants of these deposits are preserved as the Menoken Terrace (Davis and Carlson, 1952) in a large portion of this area. Almost continuous remnants form the north bluff of the Kansas River valley from the western border of the area (Pl. 3A) to Bonner Springs, except for a short segment northeast of De Soto. A large area south of Eudora and smaller remnants adjacent to Kansas River near De Soto and along some larger tributary streams are regarded as Menoken Terrace. The precipitous south bluff of the Kansas River valley about 3 miles south of Bonner Springs contains very narrow Menoken Terrace deposits that are too small to be mapped. In the extreme southeastern portion of the mapped area the Menoken Terrace is represented by the dissected surface of an abandoned valley fill. Post-Kansan erosion has destroyed most of the original surface of the Menoken Terrace throughout the mapped area, and an exact accordance of summits is not preserved. Where they are far enough removed from the valley bluff and where they do not occupy divide areas between valleys, the Menoken Terrace summits generally are 80 to 100 feet above the floodplain (Fig. 6).

The bedrock floor of the Menoken Terrace is extremely irregular. At some places bedrock is found at elevations slightly below adjacent floodplain surfaces (12-22-18d), and at others nearby (12-22-18c) it lies more than 20 feet higher. The configuration of the irregular bedrock floor is roughly concave. The concavity of the bedrock floor underlying Menoken Terrace deposits points to the cut-and-fill character of the deposits, because the alluvial veneer of a mature stream undergoing the normal cycle of stream erosion will overlie a flat bedrock floor developed by lateral planation. The irregularity of the bedrock floor emphasizes the limited extent of downcutting in comparison with the tremendous quantities of outwash that subsequently swamped the newly deepened valleys and overflowed to fill even higher areas as well. Extensive gullying of Menoken Terrace deposits reveals small isolated exposures of bedrock at various elevations.

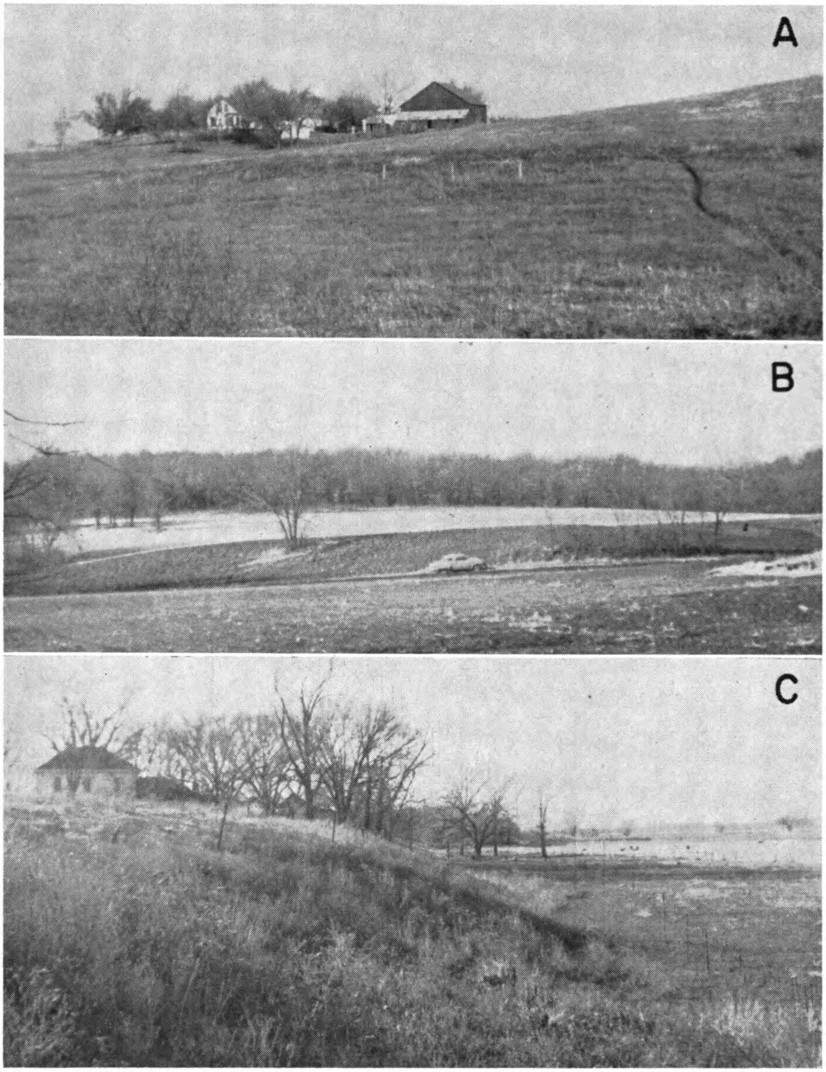


Plate 3. **A.** Menoken Terrace scarp along Kansas Highway 32 near west edge of mapped area. Note subdued and dissected form of high-level terrace. **B.** Buck Creek Terrace along Wolf Creek 3 miles northwest of Bonner Springs. Newman Terrace in foreground constitutes Wolf Creek valley flat. **C.** Newman Terrace scarp near mouth of Cedar Creek, view looking west. Modern floodplain in right foreground.

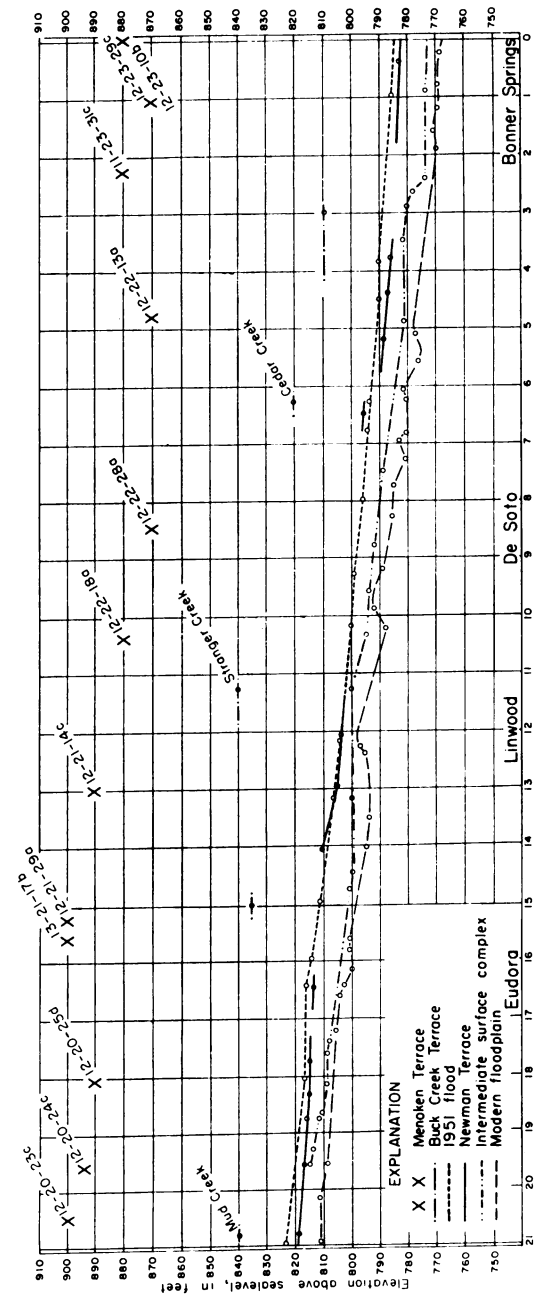


FIG. 6. Longitudinal profiles along Kansas River valley between Lawrence and Bonner Springs.

Illinoian Time

Even at its maximum advance, the Illinoian glacier remained farther from northeastern Kansas than any other Pleistocene glaciation and had no direct effect on the area, as outwash or meltwaters never entered the prevailing drainage systems. Indirect effects, however, include a marked cycle of cutting and filling in the valley system of the area. Such effects are mostly a consequence of widespread drainage changes in the Kansas River drainage basin. A comprehensive history of Pleistocene drainage changes in Kansas has been described by Frye and Leonard (1952). Essentially, valley incision in the Kansas River valley during Illinoian time was due to a progressive increase in the size of the drainage basin after retreat of the Kansan glacier from the area. The Flint Hills divide that existed in early Kansan time separated eastward-flowing drainage of the Kansas River system from southward-flowing drainage west of the Flint Hills. This divide migrated toward the west after retreat of the Kansan glacier. As migration proceeded, the Kansas River drainage system captured more and more tributary streams that formerly flowed southward until the size of the drainage basin was increased severalfold. Valley incision along the eastern part of the Kansas River valley resulted.

No test holes were drilled in Illinoian deposits in this area, but a resident whose home is situated on the scarp of an alluvial terrace of Illinoian age reported the nature of the deposits penetrated by a dug well (12-23-7ba). The bedrock floor was deepened by at least 20 feet after Kansan time. This valley subsequently was filled with more than 55 feet of clastic deposits, mostly silt; the surface of the fill is generally 35 feet above the modern floodplain (Fig. 6). Remnants of this surface have been named Buck Creek Terrace (Davis and Carlson, 1952) for a well-developed surface west of Lawrence. The amount of cutting at the type area has been described as 50 to 60 feet below the floor of Menoken Terrace deposits (Davis and Carlson, 1952).

Only a few small dissected remnants of the Buck Creek Terrace are preserved along the Kansas River valley in this area, and most of these are located at the mouths of large tributary streams. Many tributary streams, however, including ephemeral ones, have a distinct terrace 15 to 25 feet above their alluvium (Pl. 3B), and this terrace is regarded as the Buck Creek Terrace in most valleys. Absence of the Buck Creek Terrace along most of the Kansas River valley results because the areal extent of the fill was much smaller than that of the earlier Kansan fill, and a later cycle of cut-and-fill during Wisconsinan to Recent time was almost as extensive as the Kansan. Hence most of the Buck Creek Terrace was destroyed. Along the tributary valleys, cut-and-fill was less severe during this younger episode.

Wisconsinan and Recent Time

Newman Terrace

Continental glaciation during Wisconsinan time had a marked, though indirect, effect upon the Kansas River valley. The fluctuating Wisconsinan glaciers did not enter northeastern Kansas, but considerable quantities of meltwater and outwash moved into the nearby Missouri River drainage system. This effected a post-Illinoian downcutting of the bedrock floor of the Kansas River valley, followed by a period of aggradation extending into late Wisconsinan or Recent time. Between Bonner Springs and Lawrence the bedrock floor was deepened to a maximum of 70 feet below the modern floodplain (Fig. 2). The irregular configuration of the bedrock floor near De Soto (Fig. 7) confirms the anticipated form of a valley floor excavated by extremely rapid downcutting in bedrock. The anastomosis of narrow channels is probably the typical expression of such extreme conditions.

The subsequent filling resulted in a surface that is generally 8 to 10 feet above the modern floodplain and is still building up by slight vertical accretion during occasional severe floods. Remnants of this surface, which is discontinuous in this area, have been named the Newman Terrace (Davis and Carlson, 1952) for a widely preserved terrace west of Lawrence.

The Newman Terrace is an essentially flat, featureless surface, which has undergone relatively little gullying or erosion (Pl. 5A). Natural levees have not been well preserved on the Newman Terrace in this area, as most of the terrace has been destroyed, particularly in the central and eastern parts of the valley. The combined valley width is more than 5 miles at the juncture of the Wakarusa and Kansas River valleys. The width of the Kansas River valley progressively diminishes to about 1 mile at the

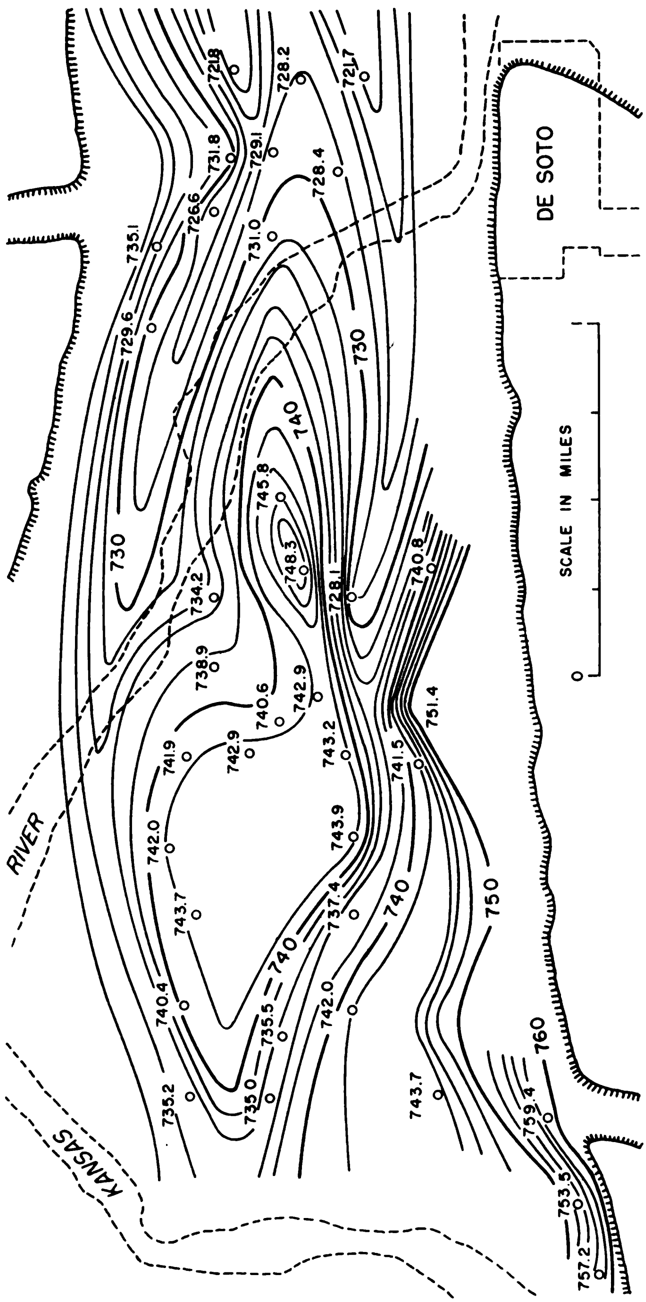


Fig. 7. Detailed contour map of bedrock floor underlying alluvium in part of Kansas River valley near De Soto. Contour interval 2 feet. Dashed lines indicate channel of Kansas River in 1950.

eastern edge of the mapped area, and the Newman Terrace correspondingly decreases in width. The Newman Terrace scarp rarely is well defined except where the terrace has been truncated by the undercut concave bank of Kansas River (Pl. 3C) or a tributary stream and where accretion by tributary streams and slope wash has not added a blanket of sediment that masks the scarp and elevates the original terrace surface. In many places the essentially featureless surface of the Newman Terrace has been modified somewhat by the action of former tributary streams, but these minor irregularities are noticeable only on aerial photographs. Absence of abandoned meander patterns on the Newman Terrace is at least partly the result of the leveling and smoothing action of vertical accretion during Kansas River floods. Most of the Newman Terrace remnants in this area are probably backswamp portions of a former floodplain whose upper surface slopes gently toward the valley bluff.

Intermediate Surface Complex

Sizable remnants of two intermediate surfaces having poorly developed terrace soils and of an extremely youthful floodplain remnant older than the modern active floodplain are found in some parts of the Kansas River valley. This intermediate complex contrasts markedly with the older Newman Terrace in surface configuration and soil development and, to a lesser degree, in elevation. Unfortunately these contrasts are not everywhere conspicuous among the intermediate surfaces themselves, and no attempt has been made to differentiate them in mapping. The

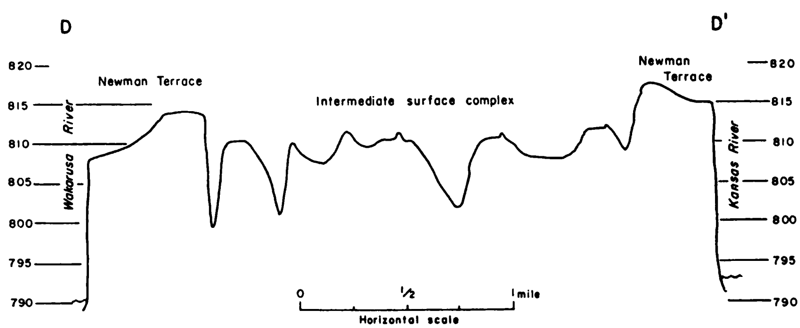


Fig. 8. Profile across Newman Terrace and intermediate surface complex, 2½ miles west of Eudora. Vertical exaggeration 200 times horizontal. Location of profile is shown on Fig. 3.

transverse topographic profile in Figure 8 shows the configuration of the intermediate surface complex along a north-south traverse about 2 miles west of Eudora. The highest intermediate surface remnant shown on the profile lies at elevations that are at least 3 feet below the adjacent Newman Terrace. A lower intermediate surface remnant lies at elevations that are at least 4 feet below the Newman Terrace. Both of these surfaces have complex meander-scroll patterns, which contrast sharply with the relatively smooth surface of the Newman Terrace, and the meander radii are much shorter than those of younger surfaces (Pl. 4). The older of these intermediate surfaces may correlate with an extensive terrace that Beck (personal communication) has found in the Kansas River valley in the vicinity of Manhattan, Kansas. The lower surface may correlate with a terrace that McCrae (1953) has mapped and has named the Holiday Terrace for a well-defined surface in the Kansas River valley west of Lawrence.

Remnants of intermediate surfaces are found farther downstream (Pl. 8B), and distinct scarps are developed about 2 miles west of De Soto (Pl. 5B) and 2 miles south of Bonner Springs where the modern floodplain truncates the surfaces. Longitudinal profiles (Fig. 6) at these localities show that the intermediate surfaces slope gradually downstream from high upstream areas nearby. Prominent scarps as much as 10 feet high progressively diminish eastward and become barely perceptible less than 2 miles downstream. The longitudinal profile of the modern floodplain exhibits similar characteristics (Fig. 6). The profiles and surface characteristics suggest that much of the surface development since the Newman Terrace began to be dissected has been accomplished by gradual downcutting during the progressive downstream migration of meanders whose radii have constantly expanded. Such a process would be expected to result in surfaces showing considerable longitudinal variation in elevation. The highest points of some areas mapped as intermediate surface complex (such as 12-21-24d, 12-23-8c, and possibly 12-22-24d) may be small, ill-defined remnants of natural levees on the Newman Terrace.

In a recent study of soil profiles in the Kansas River valley between Lawrence and Topeka by members of the U. S. Soil Survey, five surfaces have been differentiated on the basis of soil characteristics. Some of the surfaces have terrace soils in varying degrees of development and can be identified in this manner

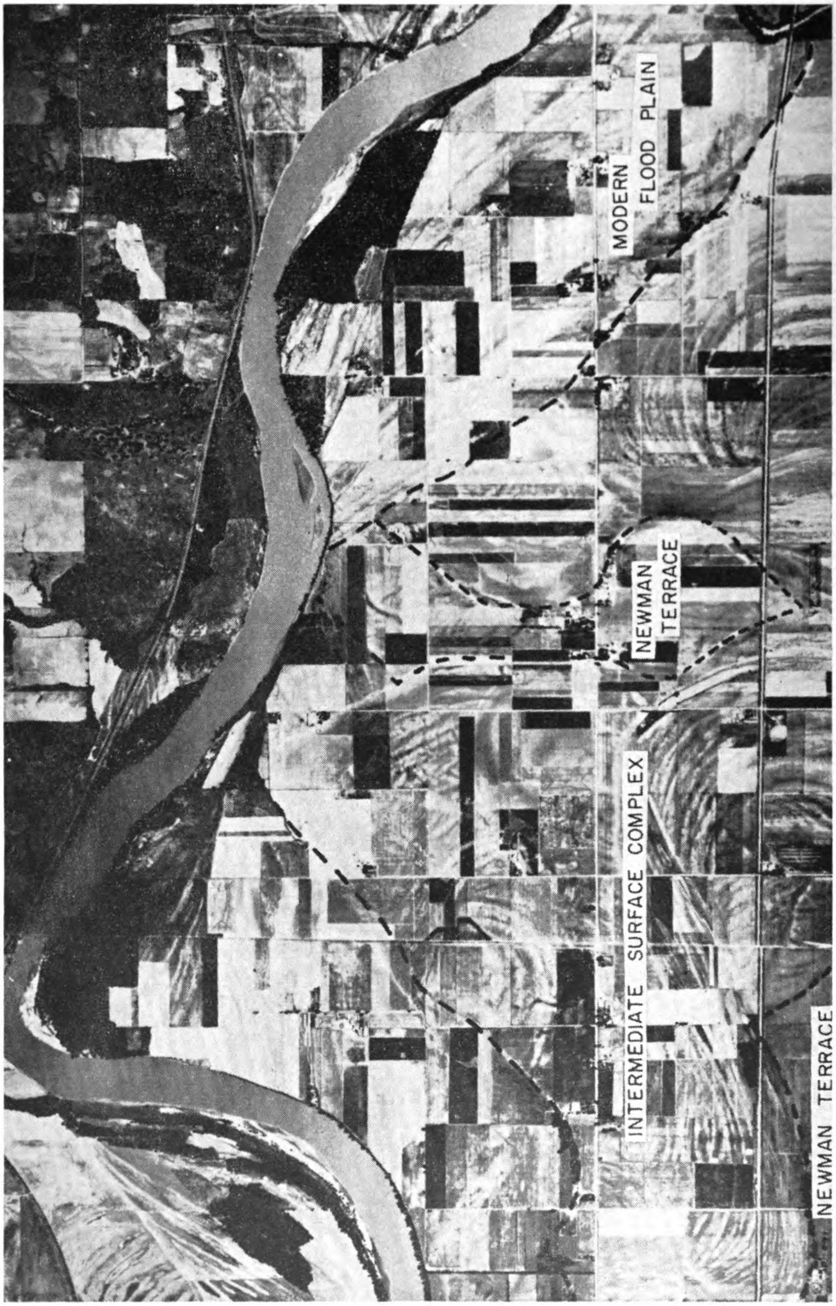


PLATE 4. Aerial mosaic of part of Kansas River valley west of Eudora. Note contrasting surface patterns of Newman Terrace, intermediate surface complex, and modern floodplain.

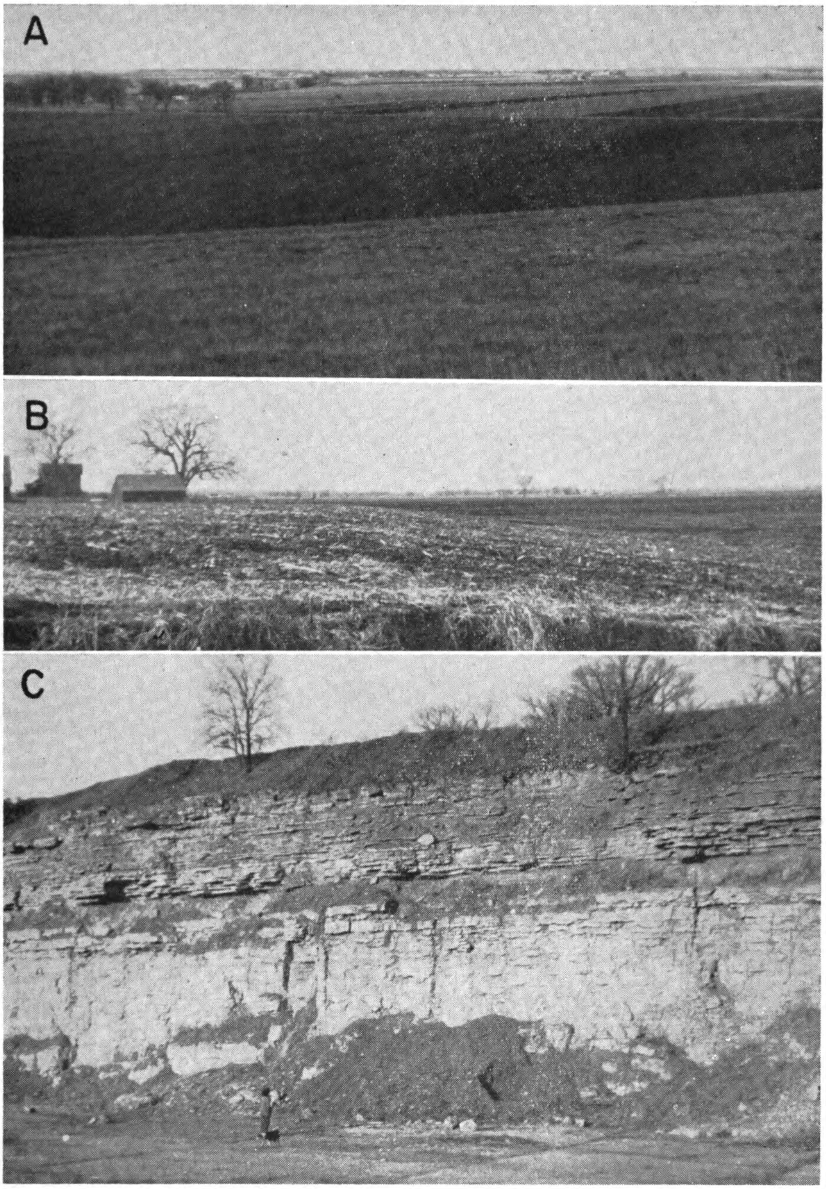


PLATE 5. **A.** Relatively flat, featureless surface of Newman Terrace. View northeast from top of bluff along Kansas Highway 10 at west edge of mapped area. **B.** Scarp 2 miles west of De Soto. Intermediate surface complex is truncated by modern floodplain. **C.** Wyandotte Limestone, of Kansas City Group, a bedrock aquifer in some parts of the area. Quarry ½ mile east of Bonner Springs (11-23-28cb).

(C. H. Atkinson, personal communication). Probably a qualified soil scientist could differentiate the intermediate surfaces in the Kansas River valley between Bonner Springs and Lawrence on the basis of soil characteristics.

An extremely youthful floodplain remnant older than the modern active floodplain is preserved west of Eudora (Pl. 4). The irregular topography reflects recently abandoned channel scars of meanders whose radii are intermediate in length between those of older surfaces and the large meanders of the modern floodplain. The meander pattern of this remnant shows that the course of Kansas River was against the south bluff where Wakarusa River now flows. The cause of the seemingly sudden change of course to the north bluff is not certainly known. One possible explanation may be that during some exceptionally large flood, Kansas River found an easier avenue of escape along the course of a hypothetical channel of Mud Creek, which flowed eastward beyond its present mouth.

The abandoned floodplain remnant is extremely youthful, as is attested by the low elevations on its irregular surface (Fig. 8). Although meander scars of the modern floodplain distinctly truncate those of this remnant (Pl. 4), highest accretions on point bars of the abandoned remnant have elevations comparable with those of the modern floodplain. Some of the deeper meander scars (such as those shown in Figure 8) on this remnant still serve as passageways for major flood currents, and scour, rather than deposition, is predominant (Pl. 2). This remnant represents only a local condition along the valley, and no attempt has been made to correlate this unit with any surface downstream.

Modern Floodplain

The modern active floodplain of Kansas River characteristically shows topographic irregularities caused by inequalities of scour and accretion during the migration of the river in its broadly serpentine course from bluff to bluff. Where the valley narrows at Eudora to a width of less than 2 miles, the meander radii are somewhat larger than half the valley width, and the river impinges against the bedrock bluffs. This constriction hinders further growth of meander radii, and each meander tends to retain its shape and size as it migrates slowly downstream. The channel patterns of the migrating meanders of the modern floodplain are nearly parallel, and the longitudinal profile (Fig. 6) generally indicates a gradual lowering of elevation from one upstream undercut bank to the next downstream. The fact that some of the highest undercut bank portions are preserved remnants of older surfaces (perhaps Newman Terrace in some small areas) suggests three contrasting explanations as to the nature of the downstream movement: (1) Meander migration has been a very slow, progressive process that has not yet had sufficient time to complete its destruction of older and higher surfaces. (2) The actual migration has been rapid, but pulsatory, and frequently interrupted for long periods by certain disturbing factors. These interruptions prolong the preservation of older surfaces. (3) The modern active floodplain is very youthful, and its rapidly migrating meanders will soon destroy all higher and older surfaces.

The 1951 flood reveals examples of rapid downstream migration, as illustrated by certain downstream channel shifts (Pl. 2) of distances nearly as great as the former channel width (12-21-32 and 12-21-26). If such shifts represent typical conditions accompanying severe floods in the Kansas River valley, probably only several thousand years would be required to permit meanders to sweep 1 or 2 miles downstream. Such an advance would easily destroy all intervening remnants of higher and older surfaces.

Complicating factors in the process of progressive sweep render the condition postulated above unusual, rather than typical. The cut-off of meander loops interrupts the process and prolongs the preservation of higher surfaces. Channel changes and erosional effects caused by the 1951 flood in the Eudora "bottom" (Pl. 2) illustrate this disturbing factor. The close alignment of intense undercutting and overbank scour along the north bluff indicates that a cut-off is imminent. As soon as this cut-off is effected during a future flood, the dissection of the higher intermediate surface portion of the meander loop next downstream will be postponed until a future time when another loop has migrated from upstream to the position of the abandoned channel.

The lithology of the undercut bank is another factor that must be considered in the process of sweep. The older intermediate surfaces generally are underlain to depths of 15 feet or more by fine-textured alluvium, whereas the modern floodplain consists of less-resistant sandy sediments, which are undercut much more rapidly. Undercutting of the western portion of Eudora "bottom" during the 1951 flood (Pl. 2) illustrates that the coarse floodplain sediments yielded readily, while the tighter silts of the undercut bank of the Weaver "bottom" acted as a barrier to erosion.

It is concluded that lithologic characteristics and the influence of cut-off meanders play principal roles in the rate of river erosion, particularly in the rate of downstream migration of meander loops. The process of sweep involves many complex interrelationships, and these are only two of many factors that affect the development and destruction of alluvial terraces.

Terrace Development in Tributary Valleys

The largest tributaries in the area are Wakarusa River and Stranger Creek, each of which is about 45 miles long. Other major tributaries are Mud Creek, Ninemile Creek, and Wolf Creek on the north and Captain Creek, Kill Creek, and Cedar Creek on the south. General observations of major tributary streams were made at easily accessible points, and streams whose terrace development is distinct were mapped on aerial photographs. Other deposits along tributaries were mapped as undifferentiated Pleistocene colluvium and terrace deposits. Some general conclusions can be made regarding the geomorphic development of tributary valleys.

The position of the lower reaches of larger southward-flowing tributary valleys has been determined by Kansan cut and fill. This is indicated by the presence of sizable remnants of Menoken Terrace adjacent to the tributary valleys where they approach the Kansas River valley. This is the situation that might be expected if an ice sheet were stabilized for a long period of time not far north of Kansas River. Tremendous quantities of meltwater carved southward-trending passageways to the major trough, and the valleys subsequently were filled with great amounts of outwash. The steep gradient of the bedrock floor underlying Menoken Terrace deposits in Stranger Creek valley suggests that these tributary valleys were short and broad during Kansan time, thus supporting the concept that the Kansas glacier was stabilized near the north bluff.

Most southward-trending tributary valleys underwent moderate incision and deposition during Illinoian time. Small remnants of Buck Creek Terrace have been identified in many larger valleys, and similar remnants probably exist in most smaller ones. Although small Buck Creek Terrace remnants are found in larger tributary valleys on the south, ephemeral streams near the south bluff generally are short and lack terrace development.

All of the major and many of the smaller tributary valleys were affected by late Wisconsinan to Recent cut-and-fill that produced the Newman Terrace of the Kansas River valley. Stranger Creek, however, removed all traces of the Newman Terrace, except at its mouth, during a later epicycle of erosion. Although the Newman Terrace extends up most tributary valleys, variable amounts of vertical accretion, slope wash, and alluvial fan deposits tend to elevate and mask the original surface. The alluvial floor of tributary valleys conceivably could be mapped as tributary stream alluvium, but this practice would prevent correlation with Pleistocene events recorded in the main valley. Although no test holes were drilled in tributary valley deposits, information obtained by drilling an auger hole and driving a sand point into Newman Terrace deposits of Ninemile Creek valley (12-21-9bd) indicates that as much as 32 feet of late Pleistocene and Recent alluvium fills this valley. The fills of other large tributary valleys probably are of a similar magnitude.

All major tributary valleys except Captain Creek show distinct evidence of a post-Newman epicycle of erosion that has developed surfaces corresponding with the intermediate surface complex of the main valley. With one exception (Wakarusa River) the extent of this surface is directly proportional to the size of the valley; for example, Stranger Creek has meandered profusely at this lower position until almost all the Newman Terrace has been destroyed by lateral planation, whereas the much smaller Ninemile Creek has developed only a narrow strip of the lower surface near its mouth. The perched position of all meander scars on this surface, at heights of 10 to 20 feet above the present channel of Stranger Creek, demonstrates that the surface does not correspond with the modern floodplain of the Kansas River valley. Wakarusa River is nearly as large as Stranger Creek but has developed to only a small extent a surface lower than the Newman Terrace. The conspicuous oxbow south of Kansas Highway 10 west of Eudora is an abandoned channel of the intermediate surface developed by Wakarusa River and is perched above the present stream channel. The surface seemingly narrows upstream, and the Newman Terrace constitutes the valley flat of Wakarusa River.

Channels of all perennial tributary streams in the mapped area are regarded as intrenched into their own alluvium. The surface of the alluvium may represent correlatives of Buck Creek Terrace, Newman Terrace, or the intermediate surface complex. The streams are not meandering at the present time, and they have no surface that correlates with the modern floodplain of Kansas River. Downcutting in the main valley was reflected in the tributary valleys and has continued in them until the present time. The tributary streams can be classed as misfit in their present regimen. The only areas where tributary streams have shown any tendency to meander freely are where their courses cross the modern floodplain of Kansas River. Wakarusa River and Stranger Creek show this characteristic at their mouths.

Effects of 1951 Flood

The 1951 flood was a consequence of the longest period of rainfall on consecutive days and the largest annual precipitation in the officially recorded history of the climate of Kansas. At high-water stages the flood extended from bluff to bluff in Kansas River valley and inundated all late Wisconsinan to Recent surfaces in the area. In the De Soto area a sizable portion of "bottomland" that had escaped inundation in 1903 was engulfed during the flood crests of 1951. The 1951 flood exceeded the 1903 flood in height, extent, and destruction.

After the 1951 flood most residents of the modern floodplain portion of the Kansas River valley, where the greatest destruction was concentrated, conceded to the powers of nature and abandoned their homes on the floodplain. Deep plowing, under government sponsorship, has restored most of the valley flat to agricultural usefulness. A few tiny patches of extremely thick sand deposits were not plowed and are now incipient sand-dune tracts.

Some questions remain concerning the net flood damage to Kansas River Valley agricultural land. Many valley residents, surveying their own surroundings, tend to overestimate flood damage. Dr. Harold Myers, chairman of the agronomy department at Kansas State College, announced in a Kansas newspaper

(1952) that he estimated that 80 to 90 percent of the "bottomland" was either benefited or undamaged as a result of the 1951 flood. This conclusion rises from a belief that the deposition of fine-textured sediments (presumably fine sands and silts) is beneficial to areas originally underlain by coarse material. A visual estimate of areas shown in Plate 2 to be unaffected by harmful sand deposition or by moderate or intense erosion suggests that either Dr. Myers' estimate is overoptimistic or the valley area shown on Plate 2 is not representative of the entire Kansas River valley. The latter is probably correct, as this narrow eastern portion has a much larger proportion of modern floodplain than the broad valley upstream.

A program of detailed mapping of flood deposits was carried out by members of the U. S. Soil Conservation Service during the winter of 1951 and the spring of 1952. The purpose of the program was to determine the extent of harmful deposition and erosion so that measures could be taken to return the land to productiveness. Deep plowing buried medium and coarse sand deposits, and leveling helped to restore some scoured areas.

A map showing the erosional and depositional effects of the 1951 flood in the vicinity of De Soto and Eudora has been compiled from U. S. Soil Conservation Service data (Pl. 2). Although the data are assumed to be correct, the fact that field parties worked out of three different county offices may have resulted in differences of interpretation. Flood deposits have been differentiated texturally into fine and medium sand size, since fine sands and silts are not regarded by soil experts as detrimental to agricultural land.

The map in Plate 2 shows a distinct correlation between the distribution of flood deposits and the topographic divisions of the valley flat. The Newman Terrace, which generally was covered with about 3 or 4 feet of water during the flood crest (Fig. 6), received almost no deposition. Deposition on the intermediate surface complex was restricted to fine-grained sediments (silt and fine sand) or to negligible amounts of medium sand. The greatest accumulation of flood deposits was concentrated on the modern floodplain, where the thickness of newly deposited sand commonly exceeded 1 foot.

Significant erosional effects of the 1951 flood were restricted to the modern floodplain and parts of the intermediate surface complex. The more prominent scarps of the Newman Terrace underwent moderate scour, but scouring action on the terrace itself was insignificant. Undercutting of banks and intense gullying by overbank scour were most effective on the modern floodplain, although a few scour pits were excavated on the intermediate surface complex. Pronounced meander scars and scarps of the intermediate surface complex were scoured moderately by flood currents. Most exceptions to these broad generalities can be accounted for by such local conditions as valley constriction and conflicting currents.

GEOLOGY IN RELATION TO GROUND WATER

Paleozoic Rocks

Missourian and Virgilian rocks of Pennsylvanian age crop out in the mapped area. These are underlain by older Paleozoic rocks having an average thickness of about 2,100 feet. Subsurface rocks include formations of the Pennsylvanian, Mississippian, Devonian, and Cambro-Ordovician Systems, dipping gently westward.

Three groups of Pennsylvanian rocks were mapped: Kansas City, Lansing, and Douglas. No attempt was made to study Pennsylvanian rocks or their contained ground water in detail. Most ground water obtained from bedrock in this area is scanty and poor in quality. Nevertheless, most upland farms in the mapped area rely upon bedrock as the source for their domestic and stock water. Prolonged periods of drought dry up many bedrock wells and create a serious rural water shortage. Where the depth to the water table is less than 20 feet, wells may be dug, but where the static water level lies at much greater depths drilling is more economical.

Owing to the diverse nature of the strata, a simple and continuous water table does not exist in Pennsylvanian bedrock. Most water-bearing formations consist of permeable sandstone or limestone containing abundant solution cavities. Where a saturated permeable rock is confined between two impervious beds the static water level in wells is higher than the top of the permeable layer. Just back of the bluffs of the Kansas River valley, where gullies and streams have dissected the bedrock formations deeply, an adequate supply of ground water can be obtained only by drilling into a saturated permeable rock lying at elevations below the depth of valley incision.

Kansas City Group

Zarah Subgroup.—The Zarah Subgroup consists of a thick compact limestone formation, containing two thin shale members, and less prominent shale formations above and below the limestone (Pl. 5C). Moderate supplies of ground water of fair to poor quality are obtained from the thick limestone members.

Lansing Group

The Lansing Group comprises two prominent limestone formations separated by a relatively thin shale formation (Pl. 7B). Interbedded shale and limestone are characteristic of a large portion of the group. Ground-water supplies from the Lansing Group are small, owing to the thinness of the limestone beds within the group.

Douglas Group

The Douglas Group is the thickest and most extensive bedrock group that crops out in the area. It consists chiefly of thick shale formations containing massive cross-bedded sandstone members and minor limestone members and coal beds. Sandstone members of the Douglas Group are the best bedrock aquifers in the area. The Tonganoxie Sandstone member of the Stranger Formation is a basal channel sandstone, which locally yields large supplies of ground water of good quality near the outcrop, but the erratic distribution of permeable zones and the variable quality of the water reduce its value as an aquifer.

Quaternary Deposits

Pre-Kansan Gravel

High-level chert gravel deposits are located on hill crests on both the north and south bluff of the Kansas River valley. These deposits are deeply weathered and generally much less than 5 feet thick. A chert gravel deposit is found at lower elevation underlying glacial outwash along the south bluff of Wakarusa River. All deposits consist predominantly of subangular chert pebbles ranging from ½ to 2 inches in diameter and contained in a red sandy-clay matrix. No glacial erratics have been found imbedded in any of these deposits, although a few granite and quartzite cobbles were found associated with deeply weathered outcrop debris of high-level gravels. The low-level deposit underlies outwash silts of Kansan age, but it is lithologically dissimilar from outwash gravels found at the base of Menoken Terrace deposits in other areas. The high topographic position and absence of glacial erratics date the high-level chert gravel deposits as pre-Kansan—late Tertiary or early Pleistocene age. The chert pebbles are typical of Pennsylvanian and Permian bedrock cropping out between the mapped area and the line of outcrop of the Herington Limestone of late Wolfcampian age (Frye and Walters, 1950). These gravels are thought to have been deposited in preglacial stream valleys of a drainage system lying entirely east of the Flint Hills region; the drainage of northeastern Kansas did not extend west of that divide area until after the invasion of the Kansan glacier into northeastern Kansas.

The lower-lying chert gravel deposit is very thin, is composed of discontinuous lenticular bodies, few of which attain a thickness of 3 feet, and is limited to an outcrop length of about ½ mile. This deposit differs lithologically from the other chert gravels in its slightly lesser degree of leaching and weathering; a few limestone, sandstone, and shale pebbles were found. The lack of glacial erratics, its position between Pennsylvanian bedrock and Kansan outwash, and the thin and localized nature of the deposit suggest a pre-Kansan origin. Locally derived and transported gravels were deposited within a local drainage basin prior to glaciation. Meltwaters from the periphery of the approaching Kansan glacier entered the valleys and initiated a period of incision that swept out most prevailing stream deposits. Some preglacial deposits remained, however, because the dominant process was rapid downcutting rather than lateral planation. Many tributary valleys, especially to the south of the principal valley, were left stranded at high levels. During the subsequent advance and retreat of the Kansan glacier, outwash buried and preserved the chert gravel deposit.

These deposits are too thin and localized to provide a source for ground water.

Atchison Formation

Sand and gravel of the Atchison Formation have not been positively identified in the area. As this member represents pro-glacial outwash (Moore and others, 1951), a conformable relationship of Atchison Formation and overlying Kansas Till must be demonstrated clearly before conclusive identity can be established.

Kansas Till

Large portions of the uplands are blanketed with glacial till. It consists of a spotty thin veneer of weathered clay or isolated cobbles and boulders in some places, but is found as thick till deposits in others. Inasmuch as the upland area is covered with a dense vegetal mantle, and as outcrops generally are limited to small gullies and shallow ditches, the glacial till as mapped includes some colluvially reworked till. For this reason the extent of till deposits undoubtedly is exaggerated at some localities. The upland area south of Kansas River in the southeastern portion of the area is known to be discontinuously mantled with thin and patchy deposits of till and loess, but only clearly defined till deposits were mapped in that area because the lack of freshly scraped ditches made surface mapping almost impossible.

The till observed in the area is a heterogeneous accumulation of boulders, cobbles, and pebbles composed of granite, chert, quartz, quartzite, sandstone, dark igneous rocks, and metamorphic rocks intermixed with sand grains of quartz and feldspar in a sticky silty-clay matrix (Pl. 6A). Locally, the till is composed almost entirely of silty clay, without boulders, cobbles, or pebbles; elsewhere, selective weathering has concentrated the coarser fraction at the surface. The till observed in ditches is red to brown and generally is thoroughly leached and oxidized. In some places, thin veneers of glacial till contain locally derived boulders and cobbles of limestone (Pl. 6B). A till deposit penetrated by drilling (12-22-15cb), although thoroughly oxidized, was calcareous below a depth of 16 feet.

Loess and water-stratified deposits are closely associated with Kansas Till, which contains numerous lenses of fluviatile sand and gravel (Pl. 7A). In many places patches of weathered loess overlie Kansas Till as a black silty clay. No attempt was made to differentiate these deposits, and both are included with Kansas

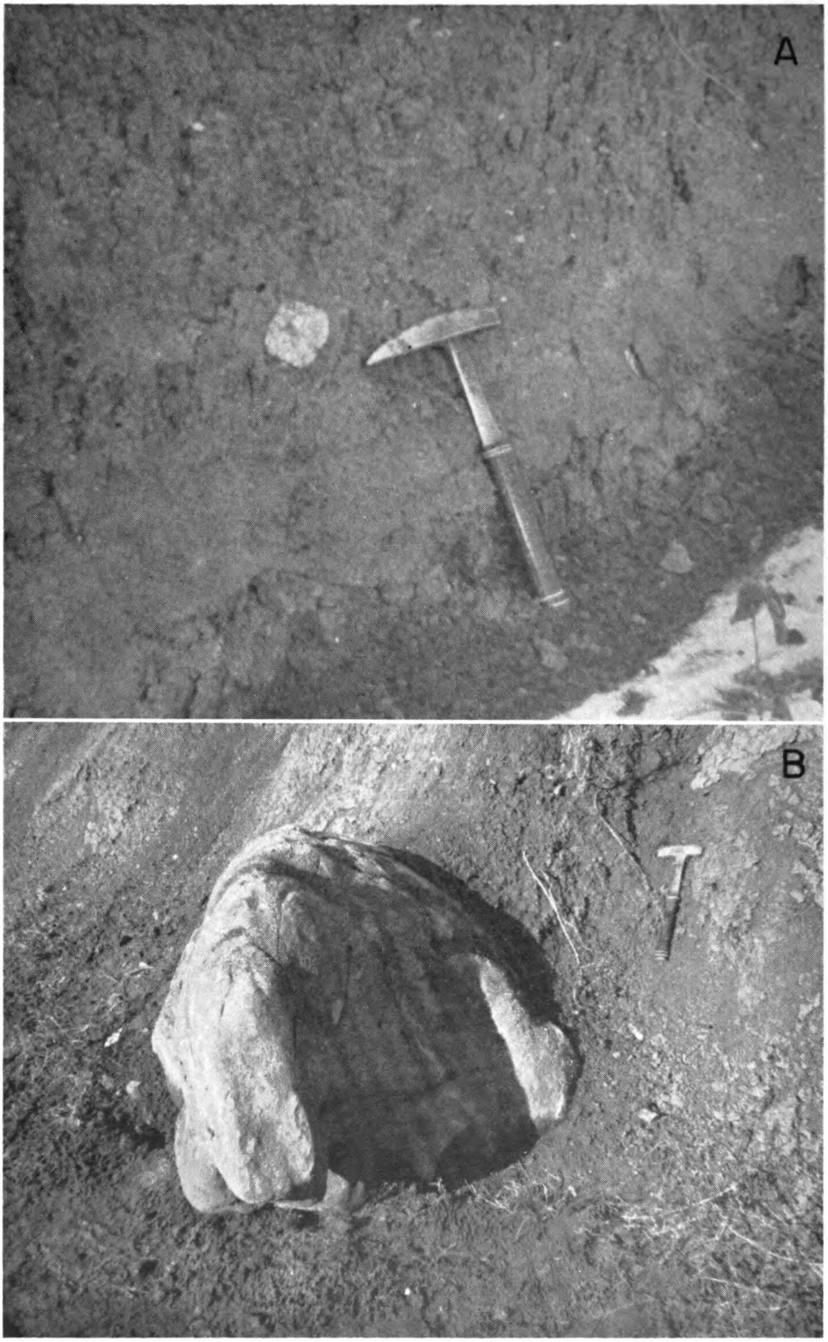


PLATE 6. **A.** Typical Kansas Till exposed in freshly scraped ditch along section road on north bluff of Kansas River valley in southeastern Leavenworth County (12-22-11ac). **B.** Worn limestone boulder exposed in gully carved in thin veneer of Kansas Till about ¼ mile south of Kansas Highway 32, 1½ miles east of west border of area (12-20-23ac).

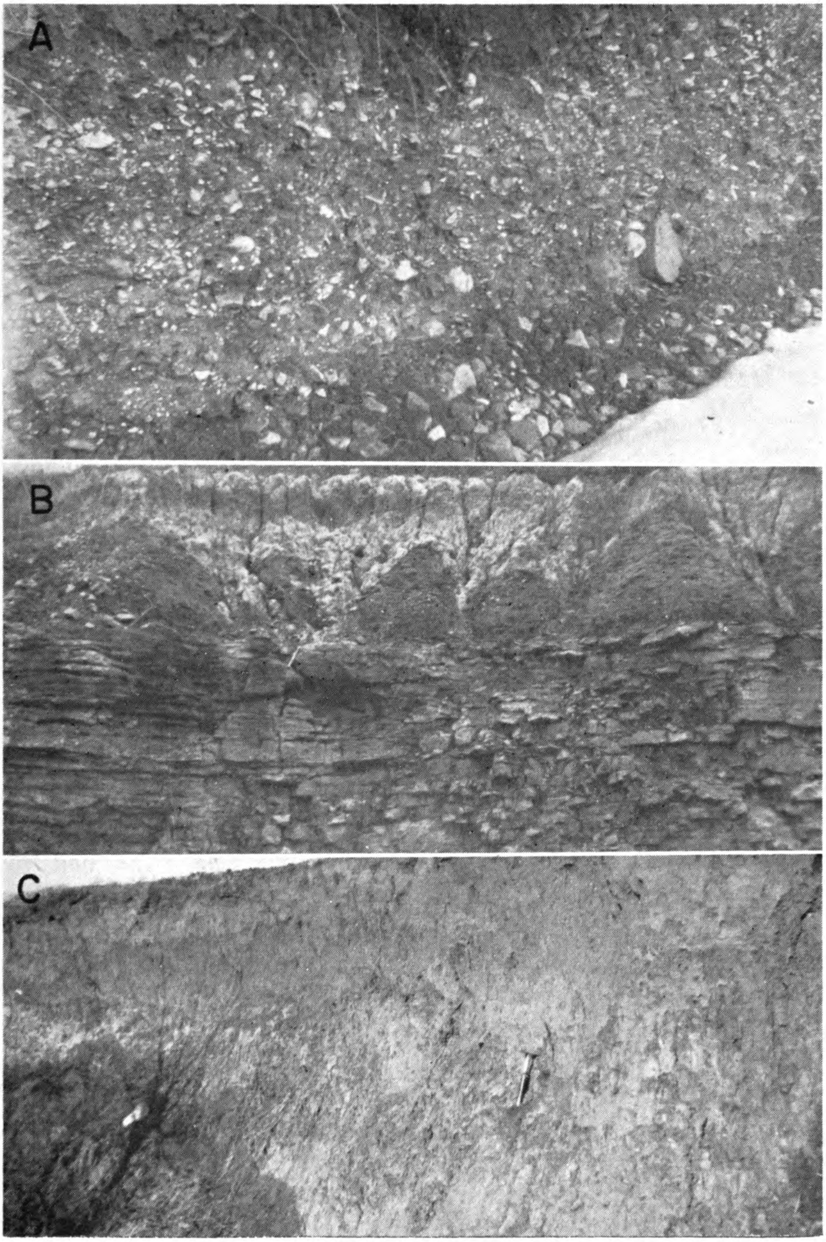


PLATE 7. **A.** Small lenticular gravel deposit within Kansas Till in road cut 3 feet deep on north bluff of Kansas River valley about 2½ miles north-northeast of De Soto (12-22-11cc). **B.** Grand Island Member of Meade Group. Note basal gravel and weathered sand above. Overlies limestone strata of Lansing Group. Quarry 1 mile northeast of Eudora (13-21-4aa). **C.** Sappa Member of Meade Group. Massive red sandy silt characterizes upper portion of Menoken Terrace deposits. About 2½ miles northwest of Eudora (12-21-30bc).

Till in the mapping. The sand and gravel lenses are important because they provide small quantities of ground water from a few shallow wells, but inasmuch as these bodies are small and discontinuous, extensive recharge is impossible, and no large supplies are available. Till itself does not yield water to wells, because the large clay content renders till virtually impermeable.

Meade Group

Outwash gravel, sand, and silt deposited by meltwaters from the margin of the stabilized and retreating Kansan glacier are classed as Meade Group (Frye and Leonard, 1952). The Meade Group comprises the extensive Menoken Terrace deposits in the area (Pl. 7B). Upper parts of the Meade Group are mantled with thin and patchy loess deposits, and rain wash has combined with colluvial processes to rework parts of these intensely gullied deposits.

The zone of coarse arkosic gravel and sand, generally less than 10 feet thick, which is commonly found at the base of the Meade, is regarded as the Grand Island Member, although clear differentiation from the overlying sandy silt called the Sappa Member usually is not possible. The coarse constituents of the Grand Island correspond lithologically with material of similar size ranges in Kansas Till, except for a slightly greater proportion of limestone and feldspar. Samples from four test holes drilled through the Meade deposits contained sediments that were all leached and oxidized. Rude stratification and sorting generally distinguish the Grand Island Member from Kansas Till, and a smaller percentage of clay generally is included in the matrix of outwash gravels. The base of the best exposure of the Meade in the area (12-22-21b) is composed of gravels containing 1- or 2-foot lenses of well sorted sand. The basal unit is overlain by a darkened clay zone containing numerous calichelike nodules having diameters of about 3 inches. This zone is overlain by several feet of light-brown sandy silt, which becomes more red and less sandy toward the top. The darkened zone probably represents a local area of stagnation in a rapidly aggrading stream valley. This valley was eventually engulfed by the sandy silts of the Sappa Member. The calcareous nodules probably are the result of deposition from ground water.

The Sappa Member is composed of red to light-brown sandy silt (Pl. 7C) overlying sand and gravel of the Grand Island Member where that unit is present. Locally, however, the entire stratigraphic sequence underlying the Menoken Terrace consists of massive sandy silt. More than 80 feet of Sappa silt is present in some parts of the area (12-22-18b). In weathered outcrops, till and Meade sediments exhibit similar characteristics, both having been altered effectively by intense weathering and colluvial reworking.

The broad flat upland area south of Eudora between Little Wakarusa and Captain Creeks is believed to be a Menoken Terrace deposit. This deposit has been described by Schoewe (1930) and Hoover (1936) as reworked till. The agents that reworked the till are listed as gravity and rain.

The following considerations have led to the conclusion that the upland area south of Eudora is predominantly glacial outwash underlying the Menoken Terrace: (1) the topographic position of the deposit in relation to Menoken Terrace remnants elsewhere, (2) grain size distribution within the deposit, and (3) the permeability of the deposit, as illustrated by the activity of its contained ground water.

The upper surface of the deposit is one of extreme uniformity of elevation, its flatness making it unique along a river valley flanked by rugged bedrock cliffs or by extremely worn remnants of the Menoken Terrace. Appreciable portions of this surface lie at elevations of 890 feet near the south bluff of the Kansas River valley east of Eudora. An almost imperceptible rise brings the highest part of the surface to an elevation of 920 feet at Hesper, more than 3 miles to the south. Thus, the surface of this deposit slopes gently toward the river at less than 10 feet per mile. As there is discontinuous loess deposition not exceeding 5 or 6 feet over much of this surface, the actual terrace summits lie at even lower elevations.

Although the bedrock floor underlying the deposit contains local irregularities, exposures reveal a fairly uniform bedrock surface, which rises from elevations of about 830 feet at the valley bluff to a maximum elevation of 870 feet 4 miles to the south. The Kansas River floodplain lies at an elevation of about 800 feet near Eudora. The bedrock floor underlying the deposit at the southern edge of the mapped area stands about 70 feet higher than that floodplain.

Summits of the dissected Menoken Terrace 2 miles north of Eudora attain elevations of 890 and 900 feet. More than 100 feet of glacial outwash is known to have been deposited in an abandoned valley of Kansan age at the southeastern edge of the mapped area. Therefore, the deposit has a position comparable to other Menoken Terrace deposits in the mapped area.

There is a vertical gradation into finer grain sizes from the base of the deposit toward the top. In a complete section, sand and gravel deposits directly overlie bedrock and grade upward into silty sand, sandy silt, and a loess cap, in that order. Size analyses (Table 2) indicate that the percentage of clay is not appreciably greater than in Menoken Terrace deposits elsewhere. That zones of similar texture persist laterally is illustrated by the fact that coarse sand or gravel was found at nearly every exposure of the bedrock floor underlying the deposit. A random

TABLE 2. *Sediment size analyses of Menoken and Buck Creek Terrace deposits, Kansas Till, and Kansas River alluvium*

		Percent in size range						
Sample	Formation or Group	>2 mm	1-2 mm	0.5-1.0 mm	0.25-0.5 mm	0.125-0.25 mm	0.062-0.125 mm	<0.062 mm
12-20-15dc	Meade			21.2	69.7	7.5	0.5	0.8
12-20-23db	Meade		1.1	45.5	49.3	2.4	0.5	1.4
13-20-10ac	Meade	2.4	2.9	28.3	32.2	8.6	6.6	19.4
12-21-9bd	Sanborn (Buck Creek Terrace deposit)			7.1	21.2	15.4	15.9	40.3
12-21-30ad	Meade			33.6	58.3	5.7	0.9	1.4
12-21-31bb	Kansas River alluvium	1.4	1.4	35.9	55.5	1.8	2.0	1.9
12-21-32ad	Kansas River alluvium			0.7	22.8	52.3	13.4	4.4
12-21-33dd	*Meade	36.8	4.3	17.4	19.6	6.9	5.0	9.9
13-21-8ba	*Meade	5.2	4.9	45.8	17.6	7.4	6.7	13.3
13-21-27aa	*Meade			18.9	36.4	19.8	6.5	19.9
12-22-2da	Meade Grand Island Mem.)	43.5	12.0	26.8	7.3	4.0	2.7	3.9
12-22-15db	Kansas Till	0.9	2.4	17.3	24.2	12.3	8.7	32.8
12-22-21bb	Meade (Sappa Mem.)			0.3	1.2	1.8	40.6	55.7

*Eudora area

distribution of exposures should not reveal almost unanimous similarity of lithologies at the same stratigraphic position unless lateral uniformity exists.

The persistent ground-water discharge from numerous springs and water wells in the area testifies to permeability throughout most of the deposit. This evidence alone precludes the possibility that this deposit is glacial till, because till adversely affects ground-water motion. During the summer and fall of 1952 and the winter of 1953, one of the driest periods in the history of this region, springs issuing from these relatively thin (generally less than 40 feet) Pleistocene deposits never ceased flowing. It is therefore concluded that deposits of the area south of Eudora are glacial outwash of Kansan age, whose upper surface is known as Menoken Terrace.

The sands and gravels of the Meade Group are a potential source of moderate supplies of ground water of very good quality, but the high topographic position of the underlying bedrock floor permits escape of large quantities of water as the discharge of springs. This condition and the small recharge area combine to restrict greatly its water-bearing capabilities. Many dug wells yield small quantities of water of good quality for domestic and stock use. In order to obtain larger supplies, many farmers supplement or replace these shallow water supplies by having deeper wells drilled into underlying Pennsylvanian bedrock.

Sanborn Group

In Kansas the Sanborn Group includes deposits laid down during two glacial ages, Illinoian and Wisconsinan (Frye and Leonard, 1952). Deposits of the Illinoian glacial stage include the Crete and Loveland Formations (Pl. 8A), which underlie remnants of the Buck Creek Terrace in this area. Four feet of silty sand recovered from an auger hole drilled to a depth of 24 feet in a Buck Creek Terrace deposit along Ninemile Creek (12-21-9b) probably represents the Crete Formation, the upper, yellow sandy silt portion of the same deposit is the valley phase of the Loveland Formation. The eolian phase of the Loveland Formation has not been recognized in this area. The characteristic red clayey silt, underlying the exposed section of all Buck Creek Terrace remnants throughout the area, is generally mottled.

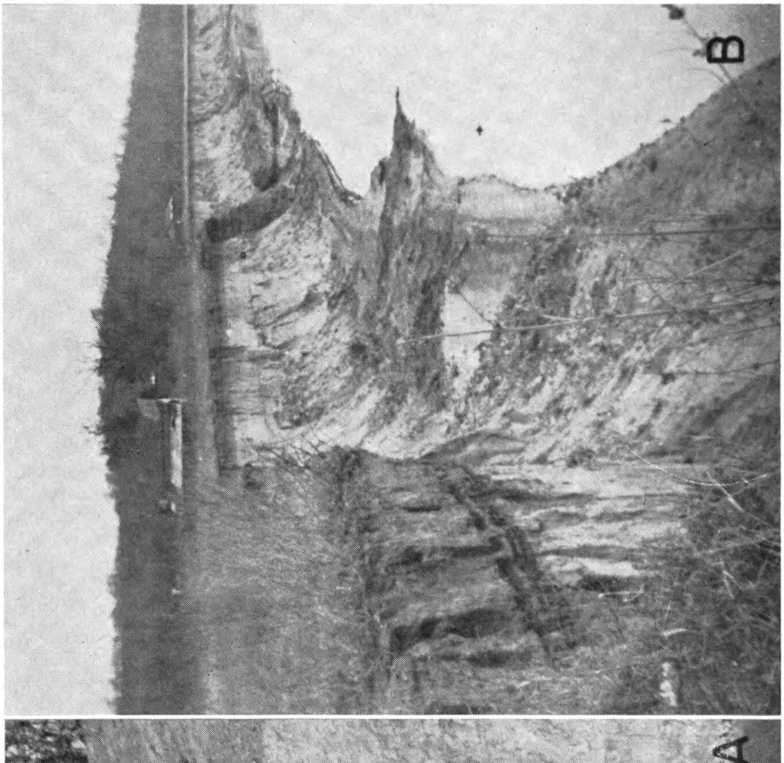


PLATE 8. **A.** Red clayey silt of Sanborn Group underlying Buck Creek Terrace in road cut 2½ miles north of Eudora (12-21-20dd). **B.** Soil profile on intermediate surface complex exposed in recently undercut right bank of Kansas River 2½ miles south of Bonner Springs (12-23-8cb).

Loess deposits of Wisconsinan age are widely distributed over the uplands as thin and discontinuous deposits called the Peoria Formation. Only the "bottomland" of the present Kansas River valley system is completely free of these loess deposits. The Peoria Formation includes both loess and water-laid silt found to be stratigraphically continuous with it (Frye and Leonard, 1952), but the fluvial phase has not been recognized at the surface in this area. It may be included in deeply buried deposits of Wisconsinan age, which form the basal portion of Kansas River valley alluvium.

None of the lithologic units of the Sanborn Group is a favorable aquifer except the Crete (sand and gravel) Formation, found at the base of Buck Creek Terrace deposits in some places. Although a few wells in the area obtain small amounts of water from it, the extremely limited extent of the Crete Formation makes it a very minor source of ground water.

Undifferentiated Wisconsinan and Illinoian Colluvium and Terrace Deposits

Deposits in minor tributary valleys and indistinct terraces along the northern portion of Ninemile Creek have not been differentiated in mapping. The terrace deposits generally consist of clayey silts in their exposed portions, and they are believed to correlate with Buck Creek and Newman Terrace deposits of the main valley. The upper portions of many gullies and valleys of intermittent streams are filled with a sticky red silty clay, which probably is colluvially transported material from the higher Kansas Till and Menoken Terrace deposits. These colluvial deposits were called *swales* by Hoover (1936).

Wisconsinan and Recent Alluvium

Underlying the Newman Terrace, the intermediate surface complex, and the modern floodplain of the Kansas River valley is a thick fluvial deposit of Wisconsinan and Recent alluvium. The average thickness of the alluvium in the mapped area is 55 feet, and the maximum thickness is 76 feet. Table 3 contains thickness data for different parts of the area.

Wisconsinan age is assigned to the coarse, basal portion of the valley alluvium, which was presumably deposited as glacial out-

TABLE 3. *Average thickness of alluvium in Kansas River valley as determined by logs of test holes*

Locality	Number of test holes	Greatest thickness penetrated, feet	Least thickness penetrated, feet	Average thickness of alluvium, feet
Cross section, 2 miles west of Eudora	4	76	46	61
Des Soto area	44	68	38	54
Cross section, 1 mile east of Bonner Springs	10	71	17	51
Total valley area	58	76	17	54

wash from the Wisconsinan glaciers. Aggradation has continued to the present, as was demonstrated by slight vertical accretion on the Newman Terrace during the 1951 flood.

Logs of test holes and wells drilled into the alluvium reveal that the basal portion of the alluvium everywhere consists of several feet of sand or gravel. The response of drilling tools in these basal gravels indicates the presence of abundant cobbles and boulders at some localities. Sand, interbedded with lenses of silt and clay, almost everywhere underlies several feet of surficial material composed chiefly of silt.

Logs from four test holes reveal that the silts underlying the Newman Terrace are dark and clayey to depths ranging from 8 to 41 feet. One test hole (11-23-28db) shows 22 feet of dark yellow-gray sandy silt underlying the Newman Terrace. A sandy silt typically underlies the natural levee of the Newman Terrace in the Kansas River valley. U. S. Soil Survey scientists have found that most of the Newman Terrace has a well-developed silty-clay loam type of terrace soil (Atkinson, personal communication).

The intermediate surface complex and modern floodplain generally are underlain by 5 to 10 feet of light-colored sandy silt or silty sand, which grades downward into coarse sand and gravel. In these portions of the valley, dark clayey silt is found only in "clay plugs", channel scars filled with silt by vertical accretion.

The lithologic distinctions of underlying surficial sediments have been used as criteria for distinguishing Newman Terrace from intermediate surfaces in questionable areas. That most of the distinct surface west of De Soto is not a Newman Terrace remnant is demonstrated by the sandy character of the underlying surficial material, as recorded in the logs of all but one of eleven test holes that penetrated this surface. The presence of conspicuous undulations of meander-scroll patterns on this surface also indicates that it is not the Newman Terrace.

Valley alluvium is the only source of abundant supplies of ground water in the area. Alluvium underlying major tributary valleys yields moderate supplies of ground water, but the great extent and saturated thickness of its extremely permeable alluvium make Kansas River valley the only area that can supply ground water in large enough quantities to satisfy existing and potential industrial, municipal, and irrigational demands.

GROUND WATER

Source, Occurrence, and Movement

The following discussion on the source, occurrence, and movement of ground water has been adapted from Meinzer (1923, p. 2-102), who gives a comprehensive treatment of the subject. Moore (1940) summarized ground-water conditions in Kansas, and detailed cooperative ground-water reports have been published by the State Geological Survey of Kansas for many counties in Kansas. Ground-water reports of nearby areas have been made by Lohman (1941), Davis and Carlson (1952), and Fischel (1948), including the Lawrence area, the Lawrence—Topeka area, and the Kansas City—Bonner Springs area, respectively.

Ground water is water that occupies open spaces or pores of rocks within the zone of saturation. The zone of saturation is the zone in rocks in which all pores or interstices are completely filled. The upper surface of the zone of saturation is called the water table, except where the zone intersects an impermeable bed. The water in the upper part of the zone of saturation is derived almost entirely from precipitation in the form of rain or snow. A large part of the water that falls on the surface is lost as surface runoff, which replenishes the streams. Part of the water is absorbed by vegetation and is returned to the atmosphere by transpiration. A small amount of the water percolates downward through the soil and rock until it reaches the zone of saturation.

Nearly all of the ground water in the Bonner Springs—Lawrence area consists of water that has fallen as rain or snow within or adjacent to the area. Heavily pumped areas, such as the valley flat near De Soto, may have a water table lower than the water surface of the river. Where such conditions prevail, the zone of saturation is replenished by river water. In some upland areas minor tributary streams lie at altitudes higher than the water table; if the underlying rock is permeable, water percolates to the water table from the channels of these streams.

The amount of ground-water in any region depends upon the character of the rocks. The porosity, or percentage of open space in a rock, determines the amount of water a rock can hold. The permeability of a rock is the ability of the rock to transmit water. An aquifer is a rock that has sufficient permeability to allow ground water to move rapidly enough and in sufficient quantities to supply water to wells. Many rocks that have a high porosity are not aquifers, because they have a low permeability. Permeability is determined by the size, shape, and arrangement of the pore spaces. As molecular attraction retains a thin layer of water on the surface of each grain, only rocks containing interconnected openings larger than the space occupied by this retained water are permeable. Thus beds of rock containing an appreciable percentage of fine silt or clay are not good aquifers. As the shape and arrangement of the openings also influence permeability, well-sorted sand, gravel, poorly cemented sandstone, and limestone containing abundant solution cavities provide the best sources for ground water. The degree of cementation within sandstone formations may be of considerable importance in delimiting bedrock aquifers in this area. This is suggested by the erratic nature of the Tonganoxie Sandstone as an aquifer. Although the Tonganoxie is generally a well-sorted friable sandstone where observed in outcrop in the area, information provided by local residents indicates that wells drilled into the Tonganoxie Sandstone yield water of variable quantity and nonuniform quality.

Ground-water movement is controlled by the shape of the water table. The water table in homogeneous materials is a subdued reflection of the topography. As most rock formations are not homogeneous, the water table generally has an irregular shape controlled by differences in permeability and rates of ground-water discharge. Records of typical wells in the area are compiled in Table 6. Figure 3 shows the configuration of the water table in

Kansas River valley alluvium. The water table has been contoured at 5-foot contour intervals, and minor irregularities due to differences in permeability, recharge, or discharge generally are not indicated. As ground water moves in the direction of the greatest slope of the water table, the movement is at right angles to the contour lines shown on the map. The generalized contour map was based on information obtained during an abnormally dry year, during which time elevations of the river surface and of the ground-water table progressively declined. Therefore, the depths to water are probably at least 3 feet greater than would be expected during a year having normal precipitation. The river stage is represented on the map by uncorrected altitudes taken at different times during the winter of 1952 and may not represent true relationships that existed on November 1, 1952, the date to which all water-table altitudes have been corrected. Regardless of these abnormal relationships, the generalized contour map roughly shows the normal configuration of the water table. Kansas River is effluent; that is, it gains water from the water table, as is illustrated by the direction of movement perpendicular to the contour lines. Contours in the divide area between Kansas River and Wakarusa River show that both of these streams are effluent, movement being away from the interstream ground-water ridge and toward the rivers.

The movement of ground-water into Wakarusa River is very slow, and the slope of the water table is fairly steep (Geologic cross section A—A′, Fig. 2) owing to the relatively impervious nature of the silts that constitute a significant thickness of surficial material underlying the Newman Terrace.

A detailed contour map of the water table in Kansas River valley alluvium in the De Soto area is shown in Figure 9. It has been prepared from information obtained from logs of test holes drilled during July and August 1942 for the Sunflower Ordnance Plant. Altitudes of the ground surface (surveyed to tenths or hundredths of a foot) and depth to water (measured to tenths of a foot or inches) were included with the logs. The contour interval of 2 feet makes possible a clearer observation of the configuration and movement of the water table in Kansas River valley alluvium. The movement of ground water primarily is toward the river. The configuration of the water table shows a greater tendency for movement at right angles to the valley bluff than down-

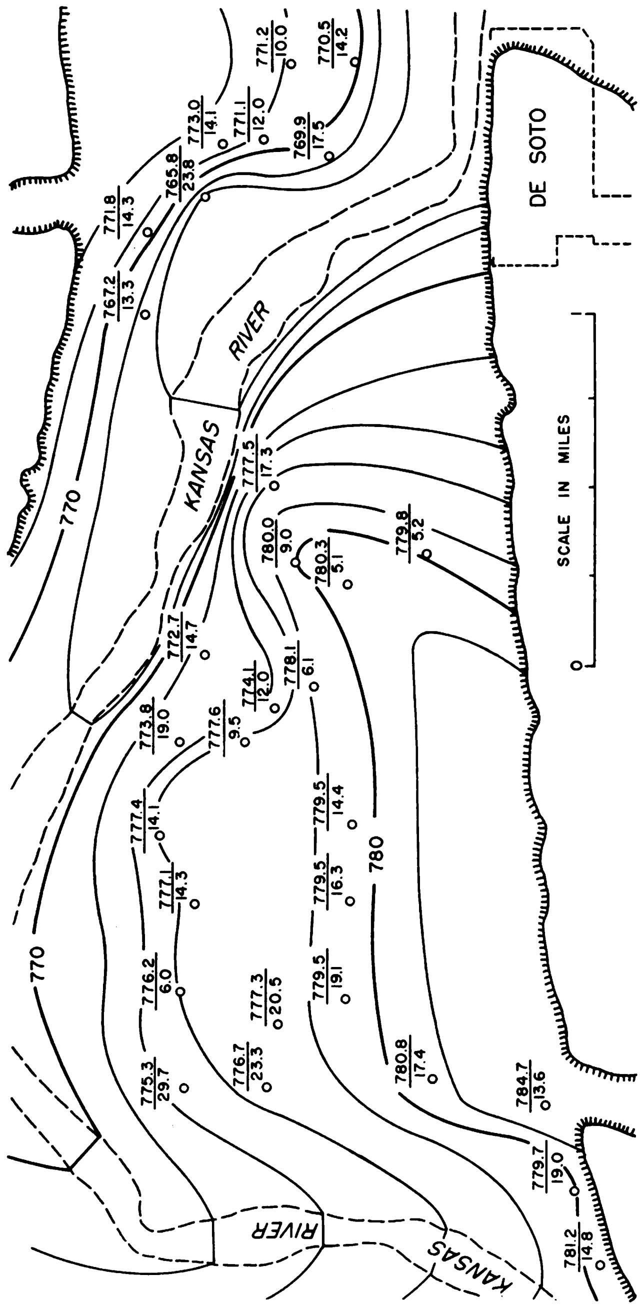


Fig. 9. Detailed contour map of water table in alluvium in part of Kansas River valley near De Soto during summer of 1942. Contour interval 2 feet. Number above line is altitude of water table, and number below line is depth to water below ground surface at test hole or well indicated by circle.

stream toward the east. This results in a greater gradient on the water table near the river at places where the course of the river is at right angles to the valley bluff. Discharge into the river at this position is greater than where the course of the river parallels the valley sides. Since 1942, 12 wells have been pumped heavily in the area, and the river in the De Soto area has been influent during periods of heavy pumpage.

Recharge

Ground-water recharge is the addition of water to the aquifer. Water is added by the percolation of local precipitation, through infiltration from streams or ponds, and by subsurface inflow. The amount of recharge in the Bonner Springs—Lawrence area is variable, owing to the diversity of geologic formations. Areas underlain by shale, clay, or glacial till receive little recharge by the downward percolation of local precipitation, as such fine-grained materials are almost impervious. Kansas River valley alluvium in the mapped area offers excellent conditions for recharge by percolation of local precipitation.

The silts and sandy silts underlying the intermediate surface complex and the modern active floodplain allow large quantities of recharge by slow percolation from the surface to the water table. Newly formed scour pits and recently abandoned channels that have cut deep enough into the alluvium to truncate sand are excellent sites of recharge because much of the surface runoff is concentrated in these areas. Older features of similar origin generally have become filled with fine silts deposited by vertical accretion (the so-called "clay plugs"), and the efficiency of recharge is correspondingly reduced. The silty clay underlying the Newman Terrace is not favorable for recharge through additions of local precipitation, although small sandy areas of former natural levees of the Newman Terrace permit local increments of recharge.

The amount of recharge from ponds and streams in the area normally is small, as most streams are effluent. In upland areas having abundant stock ponds and intermittent streams, however, the water table may receive moderate recharge after rainstorms that follow prolonged periods of dryness. Of course, the floor of well-constructed stock ponds is composed of impervious material, making recharge from this source negligible.

One of the most important sources of recharge in Kansas River valley alluvium is the infiltration of river water to the ground-water body during periods of heavy pumpage in certain areas. This increases the amount of available ground water severalfold and helps to insure abundant supplies of water from wells in Kansas River valley alluvium.

Discharge

Ground-water is discharged by transpiration by plants whose roots tap the zone of saturation, by discharge into streams through bank seepage or springs, and by the pumpage of wells. Transpiration by plants probably accounts for little discharge in the area except after floods or during long periods of heavy precipitation when the water table may be near the surface in local areas. Discharge through springs is important in bedrock and Menoken Terrace deposits. Bank seepage in Kansas River valley alluvium provides the means for natural discharge from the underground reservoir to Kansas River. This is especially true after the valley has been flooded, when great quantities of ground water are locked up as bank storage. A comparison of the hydrographs of three observation wells in Kansas River valley alluvium with river stage fluctuations and monthly precipitation during the period from April 1952 to February 1953 shows a marked correlation between the progressive lowering of the water table and the gradual decrease in base flow of Kansas River (Fig. 10). Inasmuch as the area received subnormal precipitation during that period, the general decline in water table and river surface elevations must be attributed to the dissipation of bank storage after the 1951 flood. The significant amount of local precipitation during August 1952 is reflected in the hydrographs of all three observation wells by a slight rise in the water table after a short lag. The observation well closest to the river (12-20-25dd) is the only one whose hydrograph shows any tendency of the water table to reverse the downward trend. This is probably due to the combined influence of local precipitation and slightly rising river stage.

One of the principal means of ground-water discharge is through the pumpage of wells. The effect this discharge has upon the ground-water body of any aquifer depends upon the size, extent, and permeability of the aquifer and the quantity of water

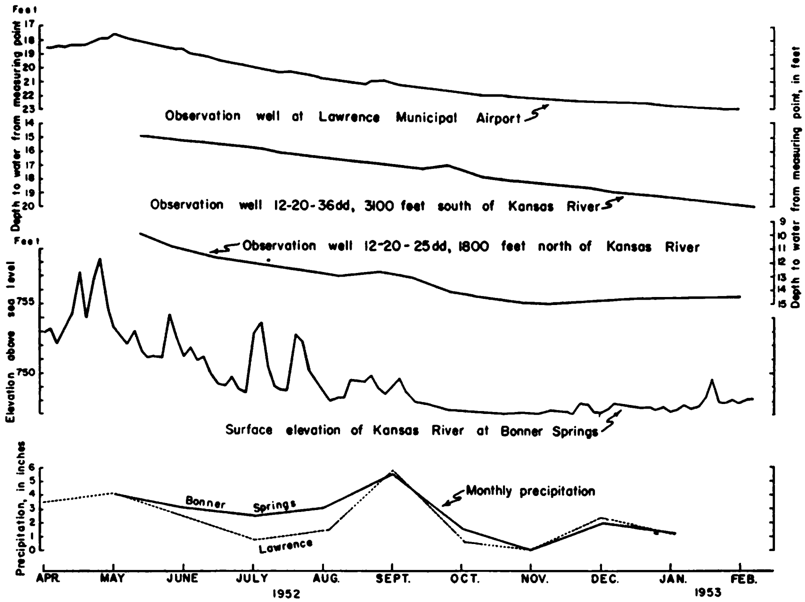


FIG. 10. Graphs showing fluctuations of water level in observation wells and in Kansas River and monthly precipitation at Lawrence and Bonner Springs.

pumped from all wells penetrating it. Discharge from domestic and stock wells driven into Kansas River alluvium produces little effect upon that ground-water reservoir, whereas discharge from similar wells in bedrock or in discontinuous remnants of terrace deposits may exhaust the entire supply temporarily.

The total lowering of the static water table in the area during the period of investigation was more than 6 feet. A graphic illustration showing the nature of this phenomenon is at least partly recorded in the deepest scour pits excavated in Kansas River valley alluvium during the 1951 flood. Total fluctuations of the static water table in the alluvium during a normal year probably do not exceed 4 feet.

Utilization

Domestic and Stock

Three types of domestic and stock wells are found in the area: driven wells, drilled wells, and dug wells. Most older wells in upland areas or in tributary valley alluvium are shallow dug wells. Most of the more recent wells in Pennsylvanian bedrock are drilled. Nearly all of the domestic wells in Kansas River valley alluvium and a few in older terrace deposits are driven wells.

Most driven wells are constructed in unconsolidated deposits by augering to the first saturated sand layer and driving the sand point and pipe several feet into the water-bearing sand or gravel. Hand pumps may be installed in such a way that the cylinder is in a pit or buried a few feet below the ground surface. Many electrically operated pumps for shallow wells are placed in basements of houses. These practices place the cylinders as close to the water table as possible and prevent freezing during the winter. A few pitcher pumps are found in the area. The convenience and inexpensiveness of constructing driven wells makes them particularly attractive for domestic and stock use, where relatively small quantities of water are needed.

Drilled wells may be required where moderate supplies of ground water are desired for domestic and stock use. Both rotary and percussion methods of drilling have been employed to construct wells of various types. Most bedrock wells are open-end construction; casing is used only to prevent inflow of surface water, caving of higher wall materials, or seepage from higher undesirable aquifers. Most wells drilled in alluvium or terrace deposits are screened to prevent caving of the unconsolidated sand and gravel. If maximum efficiency is desired from a well drilled in almost any formation, gravel packing is an essential part of the construction, but probably few residents in the area need large enough quantities of water for domestic and stock use to make the added expense economically worthwhile.

Most of the dug wells were constructed before modern methods of well drilling came into general use. Most of the dug wells are shallow, but some have been dug to depths exceeding 47 feet. Diameters of dug wells range from 2 to 15 feet. Brick or limestone curbs line the walls, and mortar is used to seal the upper portion, preventing the inflow of surface water. The amount of ground water pumped for domestic and stock wells in this area is estimated at about 300,000 gallons per day.

Irrigation

Irrigation using ground water has not been extensive in this area even during recent years. Local residents report that an early irrigation project using ground water (a large potato farm near Bonner Springs) was abandoned several years ago. Large quantities of ground water in Kansas River valley alluvium are available for irrigation, as the construction of large wells becomes economically feasible for that purpose. The period of prolonged drought in the area beginning in 1952 emphasized the need for having good wells available for irrigation in preparation for future droughts.

Municipal

The four towns in the area obtain their entire city water supplies from gravel-packed wells in valley alluvium. Linwood provides its municipal supply from one well drilled in Stranger Creek valley alluvium, and each of the other towns has two wells in Kansas River valley alluvium.

After the 1951 flood two new wells were drilled on the north side of Kansas River for Bonner Springs. The old wells were located just south of Kansas River and are described by Fishel (1948). About 4,500,000 gallons of water per month is pumped from the two wells, which are equipped with electrically driven turbine pumps having a capacity of 500 gallons per minute. The wells are 85 and 90 feet deep, and the deeper one penetrates 46 feet of saturated sand and gravel. Chlorination is the only treatment that this water receives before entering the storage tank. Chemical analyses of water samples collected from these wells soon after drilling show dissolved solids of 603 and 534 parts per million and total hardness of 436 and 409 ppm. Neither contains much iron.

Pumping tests of both municipal wells at Bonner Springs were made soon after drilling was completed. The pumping test of the east well is shown in Table 4. The specific yields of the wells are 65 and 68 gallons per minute per foot of drawdown. The average specific yield of representative industrial and irrigation wells in Kansas River alluvium between Lawrence and Topeka was re-

TABLE 4. *Pumping test of the east municipal well of Bonner Springs, conducted by Layne-Western Company on September 6, 1951*

Time	Discharge, gallons a minute	Pumping level, feet and inches	Drawdown, feet and inches
11:00 a.m.	0	23 2	0 0
12:00 noon	457	29 11	6 9
12:30 p.m.	do	30 0	6 10
1:00	do	30 1	6 11
1:30	453	do	do
2:00	do	do	do
2:30	do	30 2	7 0
3:00	do	do	do
3:30	457	do	do
4:00	do	30 3	7 1
4:30	do	do	do
5:00	do	30 4	7 2
5:30	200	26 10	3 8
6:00	300	28 2	4 0
6:30	400	29 10	6 8
7:00	500	32 0	9 10
7:05	0	24 7	1 5
7:10	0	24 0	10

ported to be 53 gallons per minute per foot of drawdown (Davis and Carlson, 1952).

De Soto derives its water supply from two wells located near the mouth of Kill Creek valley. An average of 70,000 gallons per day is pumped from these wells. Electrically operated turbine pumps having a capacity of 115 gallons per minute pump water from these wells, which are 59 and 57 feet deep. The water is aerated and filtered through a hermetically sealed tank containing white limestone and a tank containing river gravel. Then it is softened by means of the zeolite process. The water is treated with chlorine and soda ash.

Eudora has two wells about 65 feet deep, which supply an average of 60,000 gallons per day for the city water supply. The wells are pumped by electrically driven turbine pumps having capacities of 150 gallons per minute. This water is aerated in a settling basin, filtered through 4 feet of sand and gravel, and chlorinated. Iron content of a water sample from these wells is 9.5 ppm, and total hardness is 446 ppm.

Linwood receives its municipal supply from a well drilled after the flood in 1951. It is 66 feet deep and is cased with 8-inch iron pipe. An electrically operated turbine pump supplies about 200,000 gallons per month. The water is aerated and chlorinated.

A total of 287,000 gallons per day generally is pumped from all seven municipal wells in the area.

Industrial

The largest industrial supply of ground water in the area is that obtained from twelve gravel-packed wells owned by Sunflower Ordnance Plant near De Soto. These wells were drilled in Kansas River alluvium to depths ranging from 40 to 60 feet. The wells are used to supplant large quantities of water obtained from Kansas River; the average daily pumpage of well water is about 2,000,000 gallons. About 8,000,000 gallons per day of river water was being used in 1953. The water from wells generally has a total hardness of about 400 parts per million. Total hardness of river water is variable but averaged about 350 ppm during March 1953. Well water is aerated and softened to a total hardness of about 70 or 80 ppm. The slaked lime and soda ash process is used to soften the water. Finished well water is also subjected to the zeolite process. All water is chlorinated and stabilized. Water is used at the Sunflower Plant in boilers and for making high explosives.

The Lone Star Cement Company, at the extreme eastern edge of the area, pumps about 350,000 gallons per day of ground water from wells in Kansas River valley alluvium (Fishel, 1948). The combined use of ground water for industrial purposes in the mapped area is about 2,350,000 gallons per day. The total average utilization of ground water for all purposes in the area covered by this report is estimated to be about 3,000,000 gallons per day.

Quality

The quality of ground water in the area has been determined from chemical analyses of samples of water collected from 14 representative wells and one spring. Nine of these wells are distributed as uniformly as possible throughout the valley flat of Kansas River. The others are completed in typical upland water-bearing formations. Analyses of samples from municipal wells of four towns in the area are included in the discussion. All analyses were made by Howard Stoltenberg in the Water and Sewage Laboratory of the Kansas State Board of Health. Only dissolved mineral contents were determined. Analyses are tabulated in Table 5.

TABLE 5. *Chemical analyses of water from 14 typical domestic wells, four municipal wells, and one spring in the Kansas River valley between Bonner Springs and Lawrence, Kansas*

Well location	Depth, feet	Geologic source	Date collected	Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$: Total	Carbonates	Noncarbonates
13-21-17dc	0.0	Meade Group	2-24-53	220	8.8	0.06	34	7	35	176	14	7	0.1	27	114	114	0
13-21-5db	65	Kansas River alluvium	2-27-50	990	23	.58	240	16	49	417	250	100	.1	35	665	342	323
13-20-11ba	41	Newman Terrace deposits	12-29-52	516	20	.08	153	14	14	451	31	27	.1	35	439	370	69
12-23-5ca	36	Kansas River alluvium	2- 7-53	444	23	17	120	21	14	448	37	60	.4	1.8	386	368	18
12-23-7ba	47	Kansas City Gr.	do	867	25	.37	223	19	27	418	85	56	.1	226	634	343	291
12-23-18cc	28	Kansas River alluvium	do	585	27	.94	165	21	10	449	99	23	.3	19	498	368	130
12-22-9cd	55	Stanton Ls.	2-24-53	412	9.8	.31	100	15	26	304	84	12	.3	15	311	250	61
12-22-9dc	41	Kansas Till	do	486	18	.69	117	17	23	323	11	35	.2	106	362	265	97
12-22-23ca	35	Kansas River alluvium	2- 1-53	553	36	.08	145	13	10	314	65	14	.3	115	416	258	158
12-22-27bc	58	do	2-27-52	568	27	9.5	149	23	20	511	60	19	.4	1.3	466	419	47
12-22-30aa	29	do	1- 3-53	485	32	.14	130	14	13	351	57	13	.3	53	382	288	94
12-21-13cc	66	Stranger Creek alluvium	5-15-52	450	16	2.6	114	12	13	337	53	21	.2	.88	334	276	58
12-21-25bb	28	Kansas River alluvium	2- 1-53	364	17	3.9	106	10	12	333	47	6	.3	1.3	306	273	33
12-21-27dc	22	do	12-29-52	569	22	.11	168	15	14	468	75	21	.2	23	480	384	96
12-21-30cb	27	Meade Group	2- 7-53	155	21	.08	25	5.4	17	105	9.1	9	.1	16	84	84	0
12-21-31dc	18	Kansas River alluvium	12-29-52	504	34	.08	138	14	17	422	40	15	.3	38	402	346	56
12-20-25aa	108	Tonganoxie Ss.	2-19-53	212	14	.41	49	10	16	222	4.1	7	.1	2.8	163	163	0
12-20-35dc	25	Kansas River alluvium	12-29-52	639	24	1.4	187	20	18	515	67	65	.1	4.2	548	422	126
11-23-28cc	85	do	9- 6-51	602	15	.10	155	12	16	306	177	16	.2	15	436	251	185

Dissolved Solids

Solids that are dissolved in natural water are left as a residue of mineral matter after the water has been evaporated. Some organic materials and a small amount of water of crystallization may be included in the residue. Water containing less than 500 ppm of dissolved solids is satisfactory for domestic use and most industrial purposes, except for difficulties that result from hardness or a possible excess of iron content. Water containing more than 1000 ppm of dissolved solids generally contains enough of certain constituents to produce a noticeable taste or to make the water unsuitable in other respects.

The dissolved solids in samples of water from municipal and private wells in this area ranged from 155 to 990 ppm. Water from 13 wells in the valley flat contained more than 364 ppm of dissolved solids and that from nine contained more than 500 ppm of dissolved solids. Three samples of water from Menoken Terrace deposits and Tonganoxie Sandstone contained less than 220 ppm of dissolved solids.

Hardness

The hardness of water is generally recognized by the amount of soap needed to produce a lather, and by the curdlike scum that forms before a permanent lather is obtained. Calcium and magnesium are the constituents that cause almost all of the hardness of ordinary water and are the active agents that form most of the scale in steam boilers and other containers in which water is heated or evaporated.

The tables of analyses show not only total hardness but also carbonate hardness and noncarbonate hardness. The presence of calcium and magnesium bicarbonates causes carbonate hardness. Inasmuch as boiling removes most of the calcium and magnesium bicarbonates, this type of hardness is called *temporary hardness* in some reports. The noncarbonate hardness is due to the presence of chlorides and sufates of calcium and magnesium, which cannot be removed by boiling. This type of hardness has been called *permanent hardness*. Either type of hardness will produce similar reactions with soap, but the noncarbonate hardness usually forms a harder adhering scale in steam boilers.

Water that has hardness of less than 50 ppm generally is regarded as soft, and its treatment for the removal of hardness usually is not necessary. Water having hardness between 50 and 150 ppm generally is satisfactory for most purposes, but its treatment by a softening process is profitable for laundries or other industries that use large quantities of soap. Hardness in the upper part of this range produces considerable scale in steam boilers and should be reduced. Hardness of more than 150 ppm is apparent to anyone, and most water having a hardness in the ranges of 200 to 300 ppm is softened for domestic purposes or replaced by soft rain water collected in cisterns.

Water samples collected from 15 wells and 4 municipal water supplies ranged in hardness from 84 to 665 ppm. All water samples collected in the Kansas River valley flat had a hardness of more than 306 ppm; eleven samples contained less than 500 ppm and four had less than 400 ppm. A water sample from a spring in the Meade Group was the softest water analyzed; it had a hardness of only 84 ppm.

Iron

Iron is present in various amounts in most aquifers; the quantity of iron may differ greatly from place to place in the same formation. If more than about 0.2 ppm of iron is present, the excess iron in the water may separate as a reddish precipitate. The presence of iron is undesirable because it may stain containers or clothing and may give a disagreeable taste. Iron can be removed from most waters by aeration and filtration, although some water may require the addition of lime or some other substance.

Analyses of all but seven water samples listed in Table 5 show more than 0.2 ppm of iron. Iron content of water samples collected from wells in the Kansas River valley flat ranged from 0.08 to 17 ppm. The lowest iron content, however, was 0.06 ppm, from a water sample obtained from a well in the Meade Group.

Chloride

Water that contains less than 150 ppm of chloride is satisfactory for most uses, but that which has more than 350 ppm is objectionable for irrigation or industrial use. If water contains more than about 500 ppm, it has a disagreeable taste.

All the water samples analyzed contained 100 ppm or less of chloride. All but three samples contained less than 50 ppm of chloride; in 14 water samples it ranged from 6 to 23 ppm.

Fluoride

The fluoride content of most ground water is very small, but it is desirable to know the exact amount of fluoride in water that is used by children. Water that contains 1.5 ppm or more of fluoride is likely to produce mottled enamel on the teeth of children who drink the water during the formation of their permanent teeth. If the water contains as much as 4 ppm of fluoride, 90 percent of the children exposed are likely to have mottled enamel, and at least 35 percent of the cases will be classified as moderate or worse (Dean, 1936). Dean and others (1941) have found that small quantities of fluoride that are not sufficient to cause mottled enamel are actually beneficial in decreasing dental cavities.

The fluoride content of 15 water samples collected from domestic wells in this area ranged from 0.1 to 0.4 ppm. Of these samples, six contained 0.1 ppm, two contained 0.2 ppm, and six contained 0.3 ppm. The fluoride content of a water sample from one municipal water supply was 0.4 ppm.

Nitrate

A knowledge of the nitrate content of water is important because an unusually large amount of nitrate in well water used in the preparation of a baby's formula may cause cyanosis. The nitrate content differs greatly from well to well and seemingly is not related to any aquifer. The presence of large amounts of nitrate in well water may be due to the inflow of surface water into the well or to the movement of the water through soils that have been enriched in nitrate by certain plants, particularly legumes. Shallow wells that are not properly sealed and wells that do not have surface water properly cased off may yield water containing excessive nitrate.

Although all the water samples analyzed contained some nitrate, only three samples had more than 90 ppm, the lower limit of the range that the Kansas State Board of Health regards as likely to cause infant cyanosis. Four samples from municipal water supplies contained nitrate ranging from 0.08 to 35 ppm.

CONCLUSIONS

Several general conclusions may be drawn from the study of the Quaternary geology and ground-water resources in this part of the Kansas River valley:

1. Pleistocene deposits of Kansan, Illinoian, and Wisconsinan and Recent age are represented in the area, but only stream-deposited alluvium of Wisconsinan and Recent age provides abundant ground water.

2. Kansan Till and the Meade Group, deposited during Kansan time, are widespread in the area. The till mantles the uplands, and the Meade Group occurs as dissected terrace deposits or abandoned valley fills laid down as glacial outwash.

3. Illinoian deposits are quantitatively insignificant in the area, being represented only by fluvial deposits underlying discontinuous terraces at intermediate levels, generally along tributary streams.

4. Alluvium of Wisconsinan and Recent age underlies the relatively flat alluvial floor of the Kansas River valley and most tributary valleys. The upper surface of the alluvium comprises a low terrace, an intermediate surface complex, and a modern floodplain. The boundaries between these divisions are not everywhere distinct, possibly as a result of an essentially progressive downcutting of Kansas River since the initial dissection of the low terrace.

5. The low terrace (called Newman Terrace) extends up most tributary valleys, large or small, whereas the intermediate surface complex extends up the major tributary valleys only. Tributary streams have not developed modern floodplains with free meanders, except where tributary streams cross the Kansas River floodplain. Tributary streams are intrenched in their alluvial fills and may be regarded as misfit in their present regimen.

6. Wisconsinan and Recent alluvium in this portion of the Kansas River valley has an average thickness of 55 feet. This alluvium is an excellent aquifer, because the lower portion everywhere consists of several feet of permeable sand or gravel. Surficial silts several feet thick generally overlie the coarse-textured deposits and, where sandy, permit recharge from local precipitation. During periods of heavy pumpage the ground-water body, which normally discharges into Kansas River, receives large quantities of recharge from the river, increasing severalfold

the amount of ground water available to properly spaced and constructed wells. Adequate quantities of ground water of fair quality are available for future municipal, irrigational, and industrial expansion in this part of the Kansas River valley.

RECORDS OF TYPICAL WELLS

Information regarding the water table in wells and test holes in the area is tabulated in Table 6. Numbers or letters in the first column represent field numbers used in test drilling for Sunflower Ordnance Plant near De Soto and index numbers of test holes drilled in the Bonner Springs area (Fishel, 1948). Numbers in the second column were determined by the location and well-numbering system described in this report.

TABLE 6. *Records of wells, springs, and test holes in Kansas River valley in Lawrence—Bonner Springs area*

							Principal water-bearing bed			Measuring point				
Field no.	Well no.	Owner or tenant	Type of well (1)	Depth of well, feet (2)	Diameter of well, in.	Type of casing (3)	Character of material	Geologic source	Use of water (4)	Description	Distance above land surface, feet	Hgt. above mean sea level, feet (5)	Dpth. to water level below measuring point, feet (6)	Date of measurement
	13-20-1ad	....	TH	66.5	3	N	Sand and gravel	Kansas River alluvium	N	Ground surface	0.0	808.7	11.5	4-19-52
	13-20-1dd	C. A. Spray	Du	25.5	48	R	Sand	do	D, S	Top of concrete cover	1.0	813.6	19.50	11- 1-52
	13-20-3ca	D. W. Brunk	Du	24.0	30	R	do	do	D, S	Top of wood platform	1.0	814.0	15.58	11- 1-52
*	13-20-11bb	J. D. Martin	Dr	43.0	8.3	I	Sand and gravel	do	N	Top of casing	1.0	816.7	14.67	11- 1-52
	13-20-15ba	H. Eisele	Du	36	36	R	?	Sanborn Group (?)	D, S	Top of concrete cover	1.0	837.0	18	10- 1-52
	13-20-15db	E. K. Patterson	Du	26.0	32	R	Sand	Wakarusa River alluvium	N	do	1.3	815.1	19.00	11- 1-52
*	13-21-5db	Eudora Mun.	Dr	64.2	12	I	do	Kansas River alluvium	M	Top, pumphouse floor	3.1	817.5	33.85	2-14-53
*	13-21-17dc	H. Giertz	Du	8.6	60	R	do	Meade Group	N	Top of wood platform	0.3	888.5	3.00	2-24-53
*	12-20-25aa	A. Reetz	Dr	108	6	I	Sandstone	Tonganoxie Sandstone	D, S	Top of concrete cover	0.5	880	55.20	2-19-53
	12-20-25db	....	TH	64.0	3	N	Sand	Meade Group	N	Ground surface	0.0	864.6	41.6	4-16-52
	12-20-25dd	....	Dn	21	3	GP	do	Kansas River alluvium	O	Top of pipe	2.0	802.0	14.54	12-20-52
*	12-20-35db	H. C. Altenbernd	Dn	27.0	1.3	GP	do	do	N	Top of concrete curb	0.0	812.0	18.17	11- 1-52
	12-20-36dd	....	TH	55.5	3	GP	do	do	O	Top of pipe	2.2	812.1	14.90	4-19-52
	12-21-9ab	B. Wagnon	Du	18.4	48	R	Limestone	Stanton Limestone	S	Top of wood platform	1.0	821	10.51	11-28-52
	12-21-9bd1	M. F. Black	Au	24	3	N	Silty sand	Sanborn Group	N	Ground surface	0.0	830.0	17.92	12-11-52
	12-21-9bd2	do	Au	28	3	N	Silt	Nine Mile Creek alluvium	N	do	0.0	817.0	14.58	12-11-52
	12-21-19cc	....	TH	60.0	3	N	Sand and gravel	Meade Group	N	do	0.0	876.0	23.2	4-16-52
	12-21-23aa	Browning	Dr	52.0	5.3	I	do	Kansas River alluvium	N	Top of casing	0.5	804.7	28.42	11-11-52
	12-21-23cc	C. H. Mosser	SP	....	....	....	Fine sand	do		Water table	....	783.1	....	11-11-52
Q	12-21-25dba	SOP†	TH	45.3	....	....	Sand and gravel	do	N	Ground surface	0.0	798.7	19.0	7-27-42
P	12-21-25daa	do	TH	38.8	....	....	do	do	N	do	0.0	798.3	13.6	7-27-42
R	12-21-25dbc	do	TH	38.8	....	....	do	do	N	do	0.0	796.0	14.8	7-28-42
*	12-21-25bb	R. C. Sullivan	Dn	28.2	0.75	GP	Sand	do	N	Top of concrete curb	0.3	798.3	24.42	2- 1-53
	12-21-27bc	Kindred	Au	23	3	N	Sand	do	N	Ground surface	0.0	802	23	12- 3-52
	12-21-27cd	C. Westerhams	Dn	32.8	1.3	GP	do	do	N	Top of pipe	1.5	799.5	19.42	1- 6-53
	12-21-27da	C. Broers	Dn	26	1.3	GP	Sand and gravel	do	N	Ground surface	0.0	797.5	19	12- 6-52

	12-21-28bb	G. J. Votaw	Du	19.5	48	R	Sand	Tributary stream alluvium	D, S	Top of concrete cover	0.7	814.8	14.75	11- 2-52
	12-21-29dd	....	SP	....	....	....	do	Kansas River alluvium	....	Water table	....	781.6	....	1- 6-53
*	12-21-30cb	F. Reetz	Du	24.7	24	R	do	Meade Group	D	Top of concrete cover	0.3	846	19.93	2-19-53
	12-21-31bc	....	TH	48.0	3	N	do	Kansas River alluvium	N	Ground surface	0.0	808.4	13.7	4-18-52
	12-21-32ad	....	Au	22	3	N	do	do	N	do	0.0	801.0	20	12- 1-53
	12-21-34bc	....	SP	....	....	....	Fine sand	do		Water table	....	781.9	....	11- 2-52
	12-21-34da	W. Spitzli	Du	34.0	36	R	Sand	do	D, S	Top of concrete cover	0.3	810.0	27.74	11- 4-52
*	12-22-9cd	C. E. Groh	Du	34.3	72	R	Limestone	Stanton Limestone	S	Top of wood platform	0.3	910	9.7	3-22-53
S	12-22-19acd	SOP†	TH	49.5	....	....	Sand and gravel	Kansas River alluvium	N	Ground surface	0.0	791.5	14.1	8- 3-42
W	12-22-19bdc	do	TH	41.8	....	....	do	do	N	do	0.0	782.2	6.0	8- 5-42
Y	12-22-19cbb	do	TH	69.8	....	....	do	do	N	do	0.0	805.0	29.7	7-29-42
2	12-22-19cca	do	Dr	60.0	....	....	do	do	In	do	0.0	797.8	20.4	8- 8-42
1	12-22-19ccb	do	Dr	65.0	....	....	do	do	In	do	0.0	800.0	23.3	7-28-42
M	12-22-19cdc	do	TH	56.6	....	....	do	do	N	do	0.0	798.6	19.1	7-23-42
U	12-22-19dbb	do	TH	47.8	....	....	do	do	N	do	0.0	791.4	14.3	8- 4-42
L	12-22-19dcc	do	TH	58.4	....	....	do	do	N	do	0.0	795.8	16.3	7-22-42
K	12-22-19ddc	do	TH	50.0	....	....	do	do	N	do	0.0	793.9	14.4	7-22-42
I	12-22-20bcc	do	TH	50.8	....	....	do	do	N	do	0.0	792.8	19.0	8-11-42
H	12-22-20cab	do	TH	54.5	....	....	do	do	N	do	0.0	787.4	14.6	8-12-42
G	12-22-20cbc1	do	TH	44.2	....	....	do	do	N	do	0.0	787.1	9.5	7-19-42
4	12-22-20cbc2	do	Dr	45.5	....	....	do	do	In	do	0.0	786.1	12.0	8-24-42
F	12-22-20cca	do	TH	41.3	....	....	do	do	N	do	0.0	784.2	6.1	7-20-42
5	12-22-20dcb	do	Dr	40.7	....	....	do	do	In	do	0.0	789.0	9.0	8-17-42
6	12-22-20dcc	do	Dr	57.3	....	....	do	do	In	do	0.0	780.3	5.1	7-21-42
	12-22-21ab	Union Pacific RR	Dr	33.1	4.8	I	do	do	N	Top of casing	0.7	784.3	23.00	3-22-53
7	12-22-21bca	SOP†	Dr	56	....	....	do	do	In	Ground surface	0.0	780.4	13.3	8-27-42
8	12-22-21bda	do	Dr	51.0	....	....	do	do	In	do	0.0	786.1	14.3	8-27-42
12	12-22-21daa	do	Dr	59.0	....	....	do	do	In	do	0.0	780.8	13.2	8-25-42
11	12-22-21dba	do	Dr	55.3	....	....	do	do	In	do	0.0	787.1	14.9	8-27-42
207	12-22-21dbb	do	TH	63.0	....	....	do	do	N	do	0.0	789.6	23.8	8-25-42
10	12-22-21dbd	do	Dr	54.0	....	....	do	do	In	do	0.0	783.1	12.0	8-27-42
203	12-22-21dca	do	TH	59.0	....	....	do	do	N	do	0.0	787.4	17.5	8-26-42
202	12-22-21dda	do	TH	53.0	....	....	do	do	N	do	0.0	781.2	10.0	8-27-42
201	12-22-21ddd	do	TH	63.0	....	....	do	do	N	do	0.0	784.7	14.2	8-27-42
105	12-22-23dbd	do	TH	52.5	....	....	do	do	N	do	0.0	782.9	16.0	8-28-42
104	12-22-23dcd	do	TH	54.8	....	....	do	do	N	do	0.0	779.8	13.1	8-28-42
	12-22-25db	R. Frisbie	Dr	65.0	5	GP	Sand	do	D	Top of concrete curb	1.0	796.0	26.14	11- 8-52
102	12-22-26bda	SOP†	TH	65.5	....	....	Sand and gravel	do	N	Ground surface	0.0	778.6	10.3	8-29-42

TABLE 6. *Records of wells, springs, and test holes in Kansas River valley in Lawrence—Bonner Springs area* (Cont.)

Field no.	Well no.	Owner or tenant	Type of well (1)	Depth of well, feet (2)	Diameter of well, in.	Type of casing (3)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source	Use of water (4)	Measuring point: Description	Measuring point: Distance above land surface, feet	Measuring point: Hgt. above mean sea level, feet (5)	Dpth. to water level below measuring point, feet (6)	Date of measurement
C	12-22-29abc	do	TH	44.2	....	....	do	do	N	do	0.0	785.0	5.2	7-20-42
	12-22-29bb	C. B. Soule	Dn	31.4	1.3	GP	Sand	do	N	Top of casing	—1.45	794.3	19.46 20.46	11- 6-52 1- 3-53
O	12-22-30bbc	SOP†	TH	54.5	....	....	Sand and gravel	do	N	Ground surface	0.0	798.2	17.4	7-25-42
*	12-23-5ca	W. Knipp	Dr	35.5	6	I	do	do	D, S	Top of casing	1.2	778.4	25.79	2- 7-53
*	12-23-7ba	E. Malone	Du	47.1	36	R	Limestone	Kansas City Group	D, S	Top of concrete curb	0.2	797.1	29.58	11-15-52
	12-23-7bd	A. Mann	Du	27.5	180	R	Sand	Buck Creek Terrace deposits	D, S	do	1.0	788.7	8.00	11-15-52
	12-23-7cc1	C. S. Kreider	Du	36.0	36	R	do	do	D, S	Top of wood platform	1.0	799.5	14.71	11-15-52
	12-23-7cc2	do	Dr	50.8	8	I	Sand and gravel	Kansas River alluvium	N	Top of casing	0.0	788.5	14.21	11-15-52
	12-23-19bb	F. L. Goble	Dr	59.0	6	I	do	do	D, S	Top of concrete curb	0.3	883.2	27.71	2- 7-53
150	11-23-28dab	....	TH	69	....	N	do	do	N	Ground surface	0.0	776.6	22.2	6-23-44
151	11-23-28dba	....	TH	69	....	N	do	do	N	do	0.0	777.2	23.8	6-22-44
152	11-23-28dbd	....	TH	72	....	N	do	do	N	do	0.0	779.1	26.0	6-21-44
153	11-23-28dcc	....	TH	56	....	N	Silty sand	do	N	do	0.0	767.7	15.0	6-27-44
	11-23-32ac	B. L. Rehm	Dr	54.0	16	I	Gravel	do	N	Top of concrete floor	0.0	781.8	24.90	11- 8-52
	11-23-32cb	R. B. Rice	Du	24.2	36	R	Sand	do	N	Top of concrete curb	0.0	777.6	21.00	11-15-52
154	11-23-33abb	....	TH	55	3.0	N	Sand and gravel	do	N	Ground surface	0.0	766.4	14.2	6-28-44
155	11-23-33abc	....	TH	55	3.0	N	do	do	N	do	0.0	769.9	13.8	6-29-44
156	11-23-33acb	....	TH	58	3.0	N	do	do	N	do	0.0	774.9	19.3	7- 1-44
157	11-23-33acc	....	TH	52	3.0	N	do	do	N	do	0.0	770.6	15.1	7- 1-44
158	11-23-33dbb	....	TH	42	3.0	N	do	do	N	do	0.0	768.8	16.5	7- 3-44
159	11-23-33dbc	....	TH	18	3.0	N	do	do	N	do	0.0	769.9	9.7	7- 3-44
	11-23-33db	J. R. Coleman	Du	13.2	24	B		Colluvium	D, S	Top of concrete curb	0.5	784.8	6.02	11- 8-52

†SOP—Sunflower Ordnance Plant
*Chemical analysis included in Table 5

ABBREVIATIONS

(1) Au, auger hole
Dn, driven well
Dr, drilled well
Du, dug well
Sp, spring
TH, test hole
SP, scour pit

(2) Reported depth below land surface given in feet; measured depth and SOP test hole and well depths given in feet and tenths of feet below measuring points; depth of auger holes given in feet.

(3) B, brick
C, concrete
GP, galvanized iron pipe
I, iron
N, none
R, rock

(4) D, domestic
I, irrigation
In, industrial
M, municipal
N, not being used
O, observation
S, stock

(5) Elevations from reports and elevations that have been surveyed are given in feet and tenths of feet; estimated elevations given in feet.

(6) Measured depths to water level are given in feet and in tenths and hundredths of feet; those from reports are given in feet and in tenths of feet; depth to water level determined from auger holes given in feet.

LOGS OF WELLS, TEST HOLES, AND AUGER HOLES

On the following pages are 9 logs of test holes drilled by the State Geological Survey of Kansas during the investigation, 10 logs of test holes drilled in 1944 (Fishel, 1948), 4 logs of auger holes, 37 logs of test holes and wells provided by Sunflower Ordnance Plant, and 1 log of a municipal well. The location of each hole is plotted on the map (Fig. 3).

13-20-1ad—*Sample log of test hole in the SE¼ NE¼ sec. 1, T. 13 S., R. 20 E., Douglas County, drilled by Kansas Geological Survey, 1952. Surface altitude, 808.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, silty, gray	3	3
Sand, coarse to very fine, poorly sorted, quartz and feldspar	7	10
Sand, medium, poorly sorted, quartz and feldspar	15	25
Sand, coarse, fairly well sorted, quartz and feldspar	5	30
Sand, very coarse; some fine gravel containing granules of granite, chert, basalt, and siltstone	10	40
Sand, medium, poorly sorted	16	56
Gravel, fine, fair sorting	9.5	65.5
PENNSYLVANIAN—Missourian		
Limestone, gray	1	66.5

13-21-7bb—*Sample log of test hole in the NW¼ NW¼ sec. 7, T. 13 S., R. 21 E., Douglas County, drilled by Kansas Geological Survey, 1952. Surface altitude, 812.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy, argillaceous, black	2	2
Clay, gray; some fine silt	3	5
Clay, silty, light brown	23	28
Clay, silty, dark blue gray	9.5	37.5
Clay, silty, black	3.5	41
Gravel, medium to fine, fairly well sorted; some coarse sand; granules mostly quartz, some feldspar, few schist and basalt	35	76
PENNSYLVANIAN—Missourian		
Limestone, gray	0.5	76.5

12-20-25ad—*Sample log of test hole in the SE¼ NE¼ sec. 25, T. 12 S., R. 20 E., Leavenworth County, drilled by Kansas Geological Survey, 1952. Surface altitude, 869.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Meade Group		
Silt, coarse, sandy, pale reddish brown, leached and oxidized	3	3
Sand, very fine, pale reddish brown, poorly sorted; some medium to fine sand of quartz and feldspar	5	8
Sand, very fine, reddish brown, poorly sorted, leached and oxidized	8	16
Silt, sandy, pale reddish brown; few fine to medium sand grains; leached and oxidized	16	32
Gravel, fine, sandy; small pebbles and granules of quartz and feldspar	13	45
Gravel, medium, sandy; pebbles of quartz, feldspar, and some chert	6	51
PENNSYLVANIAN—Virgilian		
Siltstone, argillaceous, blue gray, micaceous	3	54

12-20-25db—*Sample log of test hole in the NW¼ SE¼ sec. 25, T. 12 S., R. 20 E., Leavenworth County, drilled by Kansas Geological Survey, 1952. Surface altitude, 864.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Meade Group		
Sand, coarse, light brown, fairly well sorted, quartz and feldspar; leached and oxidized	8	8
Sand, medium, light brown, fairly well sorted, quartz and feldspar; leached and oxidized	8	16
Clay, red	1	17
Sand, medium, light brown, fairly well sorted, quartz and feldspar; leached and oxidized	11	28
Sand, medium to coarse, light brown, poorly sorted, quartz and feldspar; leached and oxidized	23	51
PENNSYLVANIAN—Virgilian		
Siltstone, very light brown, deeply weathered, micaceous	10.5	61.5

12-20-36dd—*Sample log of test hole in the SE¼ SE¼ sec. 36, T. 12 S., R. 20 E., Douglas County, drilled by Kansas Geological Survey, 1952. Surface altitude, 809.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, silty, gray	6	6
Silt, argillaceous, gray	10	16
Sand, fine to medium, mostly quartz and feldspar	4	20
Sand, medium, fairly well sorted, quartz and feldspar	9	29
Sand, coarse, well sorted, quartz and feldspar	26.5	55.5
PENNSYLVANIAN—Missourian		
Limestone, gray	0.5	56

12-21-9bd$_1$—*Log of auger hole in the SE¼ NW¼ sec. 9, T. 12 S., R. 21 E., Leavenworth County, drilled 1952. Surface altitude, 830.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Sanborn Group		
Silt, yellow speckled pink; few medium sand grains	5	5
Silt, yellow speckled pink; few sandstone pebbles	0.5	5.5
Clay, yellow	4.5	10
Sand, very fine, silty, yellow	5	15
Silt, argillaceous, yellow	2	17
Sand, very fine, silty, yellow	1	18
Silt, argillaceous, gray; few medium to coarse sand grains	2	20
Sand, very fine, silty, light gray	1.5	21.5
Sand, very fine, silty, light gray; few coarse sand grains	0.5	22
Sand, fine, silty	1	23
Sand, medium, silty	1	24

12-21-9bd$_2$—*Log of auger hole in the SE¼ NW¼ sec. 9, T. 12 S., R. 21 E., Leavenworth County, drilled 1952. Surface altitude, 817.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, silty, black	0.5	0.5
Silt, argillaceous, gray	1.0	1.5
Clay, black; contains few limestone pebbles	2.5	4
Clay, silty, dark brown	1	5
Clay, silty, brown	12	17
Silt, clayey, brown	5	22
Silt, argillaceous, gray	5	27

Note: Auger free to 28.0 feet. Probably loose sand.

12-21-19cc—*Sample log of test hole in the SW¼ SW¼ sec. 19, T. 12 S., R. 21 E., Leavenworth County, drilled by Kansas Geological Survey, 1952. Surface altitude, 876.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Meade Group		
Soil, sandy clay, mottled black and orange; leached and oxidized	3	3
Clay, silty, yellow, few medium sand grains; leached and oxidized	5	8
Silt, sandy; abundant fine sand and few coarse sand grains; leached and oxidized	5	13
Silt, sandy, very light yellow; leached and oxidized	10	23
Silt, argillaceous, very light yellow, few coarse sand grains of quartz; leached and oxidized	6	29
Sand, very coarse, poorly sorted, abundant quartz and feldspar; leached and oxidized	9	38
Gravel, fine, sandy, mostly quartz and feldspar	11.5	49.5
PENNSYLVANIAN—Virgilian		
Siltstone, slightly calcareous, light blue gray	10.5	60

12-21-24ddd—*Log of test hole N, Sunflower Ordnance Plant, in the SE¼ SE¼ SE¼ sec. 24, T. 12 S., R. 21 E., Johnson County, drilled 1942.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, silty	3	3
Sand, fine, silty	10.5	13.5
Clay, blue	5.5	19
Sand, medium, brown, and clay	14	33
Sand, coarse, blue; gravel, small; some clay, blue	15.5	48.5
Sand, coarse, blue; gravel, small; clay balls; boulders	8.5	57
PENNSYLVANIAN—Missourian		
Shale, blue	11.2	68.2
Limestone		68.2

12-21-25daa—*Log of test hole P, Sunflower Ordnance Plant, in the NE¼ NE¼ SE¼ sec. 25, T. 12 S., R. 21 E., Johnson County, drilled 1942. Surface altitude, 798.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, black	1	1
Clay, brown	3	4
Sand, fine, silty, and clay	5	9
Sand, very fine, tan	12	21
Clay, sandy, blue and tan	4	25
Sand, fine, blue, streaks of blue-gray clay	10	35
Sand, medium to coarse, blue; streaks of blue-gray clay	1	36
Sand, coarse, blue; boulders; streaks of blue clay	2.8	38.8
PENNSYLVANIAN—Missourian		
Limestone		38.8

12-21-25dba—*Log of test hole Q, Sunflower Ordnance Plant, in the NE¼ NW¼ SE¼ sec. 25, T. 12 S., R. 21 E., Johnson County, drilled 1942. Surface altitude 798.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, black	1	1
Clay, sandy, brown	9	10
Clay, brown	3	13
Sand, very fine, tan, streaks of brown clay	9	22
Sand, fine, light tan, streaks of brown clay	9	31
Sand, medium to fine, tan to yellow	8.5	39.5
Clay, tan	0.5	40
Sand, medium to coarse, tan to yellow	1	41
Sand, medium to coarse; gravel and boulders	4.2	45.2
PENNSYLVANIAN—Missourian		
Limestone		45.2

12-21-25dbc—*Log of test hole R, Sunflower Ordnance Plant, in the SW¼ NW¼ SE¼ sec. 25, T. 12 S., R. 21 E., Johnson County, drilled 1942. Surface altitude, 796.01 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, black	1	1
Clay, brown	7	8
Clay, gray to brown	2	10
Sand, silty, streaks of gray and brown clay	15	25
Sand, very fine, blue, streaks of gray clay	5	30
Sand, medium, blue; boulders; streaks of blue clay	5	35
Sand, fine, blue; boulders; streaks of blue shale	3.8	38.8
PENNSYLVANIAN—Missourian		
Limestone		38.8

12-21-27bc—*Log of auger hole in the SW¼ NW¼ sec. 27, T. 12 S., R. 21 E., Douglas County, drilled 1952. Surface altitude, 802 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, silty, black	0.3	0.3
Sand, very fine, silty, brown	1.7	2
Sand, fine, light brown	5	7
Sand, medium, light brown	2	9
Sand, medium, and gravel, fine	1.5	10.5
Sand, medium, light brown	1	11.5
Sand, fine, gray	1	12.5
Sand, medium, light brown	4.5	17
Sand, fine, light brown	0.5	17.5
Sand, medium, light brown	5.5	23

12-21-31bc—*Sample log of test hole in the SW¼ NW¼ sec. 31, T. 12 S., R. 21 E., Douglas County, drilled by Kansas Geological Survey, 1952. Surface altitude, 808.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, silty, gray; many fine sand grains	12	12
Sand, medium, fairly well sorted; grains are quartz, feldspar, and some sandstone and basalt	8	20
Sand, coarse, fairly well sorted; grains are quartz, feldspar, and some basalt and limonite	8	28
Sand, medium, blue gray, well sorted	16.5	44.5
Sand, medium, fairly well sorted	2	46.5
PENNSYLVANIAN—Missourian		
Limestone, gray, weathered	1.5	48

12-21-32ad—*Log of auger hole in the SE¼ NE¼ sec. 32, T. 12 S., R. 21 E., Leavenworth County, drilled 1952. Surface altitude, 798.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Sand, medium, poorly sorted	0.5	0.5
Silt, dark brown	1.5	2
Sand, very fine, silty	0.3	2.3
Sand, fine	5.7	8
Sand, very fine, silty, gray	0.5	8.5
Sand, fine	6.5	15
Sand, medium	4	19

12-22-15cb—*Sample log of test hole in the NW¼ SW¼ sec. 15, T. 12 S., R. 22 E., Leavenworth County, drilled by Kansas Geological Survey, 1952. Surface altitude, 947.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Kansas Till		
Soil, sandy, orange	1	1
Till, sandy; silty clay matrix, few granules of quartz, feldspar, and sandstone; leached and oxidized	15	16
Till, sandy; silty clay matrix, few granules of quartz and feldspar, fewer grains of limestone and dark igneous rocks; oxidized, but not thoroughly leached	4	20
Till, sandy, light brown; silty clay matrix, some granules of quartz, fewer rose quartz, schist, feldspar, shale, and limestone; oxidized but slightly calcareous	7.5	27.5
Till, sandy, light brown; few pebbles of quartz and feldspar; oxidized but very calcareous silty clay matrix	3.5	31
PENNSYLVANIAN—Virgilian		
Sandstone, fine grained, yellow, micaceous, weathered	0.5	31.5

12-22-19acd—*Log of test hole S, Sunflower Ordnance Plant, in the SE¼ SW¼ NE¼ sec. 19, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 791.5 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, black	1	1
Sand, silty, tan	4	5
Mud, silty, tan, streaks of gray clay	4	9
Sand, fine, white	11	20
Sand, medium to coarse, brown, streaks of gray clay	6	26
Sand, medium to coarse, blue, streaks of gray clay	3	29
Sand, medium, blue; few blue clay balls	3	32
Clay, blue, some blue sand	4	36
Sand, medium, blue; gravel and a few clay balls	11	47
Gravel, coarse; boulders	2.5	49.5
PENNSYLVANIAN—Missourian		
Limestone		49.5

12-22-19bdc—*Log of test hole W, Sunflowerd Ordnance Plant, in the SW¼ SE¼ NW¼ sec. 19, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 782.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy, blue	1	1
Sand, fine, whitish tan	9	10
Sand, medium to fine, tan and white	9	19
Sand, medium to fine, blue	6	25
Sand, medium to fine, blue; few clay balls	5	30
Sand, coarse, blue; many blue clay balls	3	33
Sand, coarse, blue; few blue clay balls	7	40
Gravel; sand, coarse, blue; boulders	1.8	41.8
PENNSYLVANIAN—Missourian		
Limestone		41.8

12-22-19cbb—*Log of test hole Y, Sunflower Ordnance Plant, in the NW¼ NW¼ SW¼ sec. 19, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 805.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy	1.5	1.5
Soil, sandy, blue	2.5	4
Clay, sandy, brown	13	17
Silt, fine, streaks of brown clay	8	25
Clay, sandy, brown to gray	14	39
Sand, medium to coarse, yellow reddish; clay balls	7	46
Sand, blue; few clay balls	9	55
Sand, blue, streaks of shale	0.5	55.5
Sand, coarse, blue	9.5	65
Sand, coarse, blue; gravel, boulders, and streaks of clay	3.5	68.5
PENNSYLVANIAN—Missourian		
Shale, blue	1.3	69.8
Limestone		69.8

12-22-19cca—*Log of water well 2, Sunflower Ordnance Plant, in the NE¼ SW¼ SW¼ sec. 19, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 797.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy	1	1
Clay, silty, sandy, tan	5	6
Clay, sandy, dark gray	4	10
Sand, fine, silty, tan	8	18
Sand, very fine, brown	3	21
Sand, fine, brown, streaks of gray clay	2	23
Sand, fine, brown	3.5	26.5
Sand, fine, brown, streaks of blue-gray clay	1	27.5
Sand, fine, brown, streaks of blue sand	2.5	30
Sand, medium to coarse, brown, streaks of blue-gray clay	8	38
Sand, medium to coarse, brown; clay balls	2	40
Gravel, coarse, blue; boulders	5	45
Sand, medium to coarse, blue	2	47
Boulders	1	48
Sand, medium to coarse, blue	5	53
Boulders	4	57
PENNSYLVANIAN—Missourian		
Shale, soft, blue gray	3	60

12-22-19ccb—*Log of water well 1, Sunflower Ordnance Plant, in the NW¼ SW¼ SW¼ sec. 19, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 800.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, black	1	1
Sand, fine, silty, tan	10	11
Sand, fine, silty, tan, streaks of gray clay	4	15
Clay, brown gray, streaks of sand	4.5	19.5
Clay, brown gray	3.5	23
Sand, very fine, yellow white	8	31
Sand, fine, yellow white	4.5	35.5
Sand, fine to medium, blue	5.5	41
Sand, medium, blue	8	49
Sand, medium, blue, streaks of blue shale	1	50
Sand, coarse, blue	1.5	51.5
Sand, coarse, blue; boulders	7.5	59
PENNSYLVANIAN—Missourian		
Shale, blue	6	65
Limestone		65

12-22-19cdc—*Log of test hole M, Sunflower Ordnance Plant, in the SW¼ SE¼ SW¼ sec. 19, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 798.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	3	3
Soil, sandy, soft	19	22
Sand, fine to coarse, light; few clay balls	18	40
Sand, coarse, blue; gravel, small; few clay balls	11	51
Sand, coarse, blue; gravel, small; few clay balls; boulders	5.6	56.6
PENNSYLVANIAN—Missourian		
Limestone		56.6

12-22-19dbb—*Log of test hole U, Sunflower Ordnance Plant, in the NW¼ NW¼ SE¼ sec. 19, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 791.42 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy	5	5
Sand, very fine, silty	5	10
Sand, fine, yellow	9.5	19.5
Old tree limb	0.5	20
Sand, fine to medium, brown	2.5	22.5
Sand, medium to coarse, blue	3.5	26
Sand, fine to medium, brown	4	30
Sand, coarse, blue; blue clay balls	5	35
Clay, blue	1	36
Sand, coarse, blue; blue clay balls	6	42
Boulders	1	43
Sand, coarse, blue; gravel; clay balls	2.7	45.7
PENNSYLVANIAN—Missourian		
Limestone		45.7

12-22-19dcc—*Log of test hole L, Sunflower Ordnance Plant, in the SW¼ SW¼ SE¼ sec. 19, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 795.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	3	3
Sand, fine, silty, brown	3	6
Sand, silty, brown, and clay	27	33
Sand, coarse, brown, and gray clay	3	36
Sand, coarse, brown, some clay	4	40
Sand, coarse, brown, and gravel	6	46
Sand, coarse, blue gray; gravel and boulders	10	56
PENNSYLVANIAN—Missourian		
Shale, blue	2.4	58.4
Limestone		58.4

12-22-19ddc—*Log of test hole K, Sunflower Ordnance Plant, in the SW¼ SE¼ SE¼ sec. 19, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 793.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	3	3
Sand, fine, silty, brown	3	6
Gumbo, black	3	9
Clay, gray to brown	10	19
Sand, fine, brown	7	26
Sand, medium, brown	7.5	33.5
Sand, coarse, blue gray; clay showing	8.5	42
Sand, coarse, blue gray; gravel, fine sand, and boulders	6.3	48.3
Sand, coarse; gravel and boulders	1.7	50
PENNSYLVANIAN—Missourian		
Limestone		50

12-22-20bcc—*Log of test hole I, Sunflower Ordnance Plant, in the SW¼ SW¼ NW¼ sec. 20, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 792.75 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy, black	1	1
Sand, very fine, silty, tan	16.5	17.5
Sand, fine to medium, yellow brown	4	21.5
Sand, very fine, blue gray; few gray clay balls	1.5	23
Sand, medium, brown	5	28
Sand, medium, blue gray; few brown clay balls	6	34
Clay, blue gray	1	35
Sand, medium to coarse, blue gray	3	38
Sand, coarse, blue gray; gravel; streaks of blue-gray clay	6	44
Boulders	2	46
Sand, coarse, blue gray; gravel	3	49
Gravel, very coarse; boulders; streaks of blue-gray clay	1.8	50.8
PENNSYLVANIAN—Missourian		
Limestone		50.8

12-22-20cab—*Log of test hole H, Sunflower Ordnance Plant, in the NW¼ NE¼ SW¼ sec. 20, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 787.36 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy, black	1	1
Silt, sandy, streaks of gray clay	9	10
Sand, medium, grayish brown; few gray clay balls	14	24
Sand, medium, grayish brown, streaks of gravel; few gray clay balls	5	29
Sand, coarse, blue gray, streaks of gray clay	4	33
Sand, medium to coarse, blue gray; coarse gravel	2	35
Sand, blue gray, and gravel	7	42
Boulders	0.5	42.5
Sand, medium to coarse, blue gray, and gravel	1.5	44
Boulders	0.5	44.5
Sand, medium to coarse, and gravel	3.2	47.7
PENNSYLVANIAN—Missourian		
Shale, blue	6.8	54.5

12-22-20cbc$_1$—*Log of test hole G, Sunflower Ordnance Plant, in the SW¼ NW¼ SW¼ sec. 20, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 787.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy	5	5
Sand, fine to medium, brown	11	16
Sand, coarse, brown, and gravel, fine	5	21
Sand, coarse, gray, and gravel, small	7	28
Clay, blue	2.9	30.9
Sand, coarse, gray, and gravel	6.4	37.3
Sand, coarse, gray, and gravel; few clay balls	5.2	42.5
Sand, coarse, gray, and gravel; boulders; broken rock	1.7	44.2
PENNSYLVANIAN—Missourian		
Limestone		44.2

12-22-20cbc$_2$—*Log of water well 4, Sunflower Ordnance Plant, in the SW¼ NW¼ SW¼ sec. 20, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 786.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Sand, silty	13	15
Sand, fine	5	20
Sand, coarse; clay balls	6	26
Sand, gravel, and boulders	9	35
Sand, gravel, and large boulders	10.5	45.5
PENNSYLVANIAN—Missourian		
Limestone		45.5

12-22-20cca—*Log of test hole F, Sunflower Ordnance Plant, in the NE¼ SW¼ SW¼, sec. 20, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 784.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Gumbo	2.5	4.5
Clay, sandy, blue	3.5	8
Sand, fine, brown	6	14
Sand, coarse, brown	2	16
Sand, coarse, brown; gravel and clay	5	21
Sand, gray; gravel and clay balls	9	30
Sand, coarse, gray, and gravel; clay showing	5	35
Sand, coarse, gray, and gravel	6.3	41.3
PENNSYLVANIAN—Missourian		
Limestone		41.3

12-22-20dcb—*Log of water well 5, Sunflower Ordnance Plant, in the NW¼ SW¼ SE¼ sec. 20, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 789.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, black	2	2
Clay, grayish brown	6	8
Clay, gray; few sandstone fragments	2	10
Sand, fine, light brown	5	15
Sand, medium, light brown	5	20
Sand, fine, gray	3	23
Sand, medium to coarse, gray	2	25
Sand, medium to coarse, light gray	2.5	27.5
Sand, coarse, and small gravel; streaks of blue clay	2.5	30
Sand, coarse, and small gravel	4	34
Boulders	0.5	34.5
Sand, coarse, and gravel	1.5	36
Boulders	1	37
Sand, coarse, and gravel	2	39
Boulders	1.7	40.7
PENNSYLVANIAN—Missourian		
Limestone		40.7

12-22-21ba—*Sample log from test hole in the NE¼ NW¼ sec. 21, T. 12 S., R. 22 E., Leavenworth County, drilled by Kansas Geological Survey, 1952. Surface altitude, 869.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Meade Group		
Soil, sandy, brown	2	2
Silt, sandy, pale reddish brown, containing medium and coarse sand grains, mostly quartz and feldspar; leached and oxidized	6	8
Sand, medium to coarse, poorly sorted, quartz and feldspar; leached and oxidized	11	19
Sand, fine, silty; many medium to coarse sand grains, mostly quartz and feldspar; leached and oxidized	17	36
Sand, very fine, poorly storted; quartz and feldspar abundant; leached and oxidized	12	48
Clay, gray	1	49
Sand, fine, poorly sorted; quartz and feldspar abundant; leached and oxidized	23.5	72.5
PENNSYLVANIAN—Missourian		
Bedrock (?) lithology unknown, owing to loss of circulation		72.5

12-22-21bca—*Log of water well 7, Sunflower Ordnance Plant, in the NE¼ SW¼ NW¼ sec. 21, T. 12 S., R. 22 E., Leavenworth County, drilled 1942. Surface altitude, 780.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	1	1
Fill, sandy	9	10
Sand, fine, silty	10	20
Sand, fine	5	25
Sand, coarse, and gravel; few clay balls	15	40
Clay	1	41
Sand, coarse, gravel, and boulders	15	56
PENNSYLVANIAN—Missourian		
Limestone		56

12-22-21bda—*Log of water well 8, Sunflower Ordnance Plant, in the NE¼ SE¼ NW¼ sec. 21, T. 12 S., R. 22 E., Leavenworth County, drilled 1942. Surface altitude, 786.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Fill, sandy	11	13
Sand, fine	7	20
Sand, fine to medium	5	25
Sand, coarse, and gravel	10	35
Clay	1	36
Sand, coarse, gravel, and boulders	15	51
PENNSYLVANIAN—Missourian		
Limestone		51

12-22-21daa—*Log of water well 12, Sunflower Ordnance Plant, in the NE¼ NE¼ SE¼ sec. 21, T. 12 S., R. 22 E., Leavenworth County, drilled 1942. Surface altitude, 780.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Fill, sandy	8	10
Sand, fine, brown	10	20
Sand, fine, gray	6	26
Sand, medium to coarse	4	30
Sand, coarse, and gravel	9	39
Sand, coarse, and gravel; some clay balls	4	43
Sand, gravel, and boulders	16	59
PENNSYLVANIAN—Missourian		
Limestone		59

12-22-21dba—*Log of water well 11, Sunflower Ordnance Plant, in the NE¼ NW¼ SE¼ sec. 21, T. 12 S., R. 22 E., Leavenworth County, drilled 1942. Surface altitude, 787.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, black	3	3
Clay, sandy, tan	2	5
Sand, silty, tan	5	10
Sand, silty, streaks of gray clay	5	15
Sand, medium, light brown	8	23
Sand, medium to coarse, gray	8	31
Clay, blue gray	2	33
Sand, coarse, gray green	3	36
Sand, medium, gray green	4	40
Sand, coarse, gray green, and gravel	6.5	46.5
Sand, coarse, gray green, and boulders	3.5	50
Gravel, coarse, gray green	3	53
Sand, coarse, gray green, and gravel	2.2	55.2
PENNSYLVANIAN—Missourian		
Limestone		55.2

12-22-21dbb—*Log of test hole 207, Sunflower Ordnance Plant, in the NW¼ NW¼ SE¼ sec. 21, T. 12 S., R. 22 E., Leavenworth County, drilled 1942. Surface altitude, 789.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy, brown	2	2
Clay, sandy, tan	6	8
Silt, sandy, and tan clay	5	13
Sand, very fine, light brown	7	20
Sand, fine, light brown	6	26
Clay, gray	1	27
Sand, medium, blue gray; few clay balls	6	33
Clay, blue gray	2	35
Sand, medium, blue gray	3	38
Sand, medium, light blue gray	2	40
Sand, medium to fine, blue gray; few clay balls	5	45
Boulders, small	1	46
Sand, medium; clay balls	1	47
Sand, medium to coarse, and gravel	6.2	53.2
Sand, medium to coarse, and boulders	6.8	60
Sand, medium to coarse	3	63
PENNSYLVANIAN—Missourian		
Limestone		63

12-22-21dca—*Log of test hole 203, Sunflower Ordnance Plant, in the NE¼ SW¼ SE¼ sec. 21, T. 12 S., R. 22 E., Leavenworth County, drilled 1942. Surface altitude, 787.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Sand, fine to medium, brown	1	1
Clay, sandy, gray	14	15
Sand, medium, light brown, streaks of clay	3	18
Sand, medium to coarse, brown	5	23
Sand, coarse, gray	1	24
Clay, blue	1	25
Sand, coarse, blue gray, and gravel	4	29
Clay, blue	1	30
Sand, coarse, blue gray, and gravel	2	32
Clay, blue	1	33
Sand, coarse, blue gray, and gravel	4	37
Clay, blue	1	38
Sand, coarse, and gravel; blue clay balls	2	40
Boulders, coarse gravel, and medium to coarse sand	7	47
Sand, coarse, and very coarse gravel	3	50
Sand, very coarse, gravel, and boulders	5	55
Gravel, very coarse	4	59
PENNSYLVANIAN—Missourian		
Limestone		59

12-22-21dda—*Log of test hole 202, Sunflower Ordnance Plant, in the NE¼ SE¼ SE¼ sec. 21, T. 12 S., R. 22 E., Leavenworth County, drilled 1942. Surface altitude, 781.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Clay, sandy	7	9
Sand, fine, brown	9	18
Sand, medium to fine, gray	8	26
Sand, coarse	6	32
Sand and gravel	7	39
Clay, blue	4	43
Sand, gravel, and boulders	10	53
PENNSYLVANIAN—Missourian		
Limestone		53

12-22-21ddd—*Log of test hole 201, Sunflower Ordnance Plant, in the SE¼ SE¼ SE¼ sec. 21, T. 12 S., R. 22 E., Leavenworth County, drilled 1942. Surface altitude, 784.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Sand, fine	9	11
Sand and clay	3	14
Sand, fine	12	26
Sand, coarse, and gravel	24	50
Sand, coarse, gravel, and boulders	13	63
PENNSYLVANIAN—Missourian		
Limestone		63

12-22-23adc—*Log of test hole 106, Sunflower Ordnance Plant, in the SW¼ SE¼ NE¼ sec. 23, T. 12 S., R. 22 E., Johnson County, drilled 1942.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Clay, sandy	6	8
Sand, very fine, brown	16	24
Sand, fine to medium, gray	7	31
Sand, gray; clay balls	4	35
Sand, coarse, gray; a few boulders	14	49
PENNSYLVANIAN—Missourian		
Shale	1	50
Limestone		50

12-22-23add—*Log of test hole 108, Sunflower Ordnance Plant, in the SE¼ SE¼ NE¼ sec. 23, T. 12 S., R. 22 E., Johnson County, drilled 1942.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil	2	2
Sand, fine, silty	13	15
Sand, fine, brown	11	26
Sand, coarse	4	30
Sand, coarse, and gravel; clay balls	4	34
Sand, fine to coarse, and gravel	8	42
Sand and gravel; clay balls	5	47
PENNSYLVANIAN—Missourian		
Limestone		47

12-22-23cdd—*Log of test hole 103, Sunflower Ordnance Plant, in the SE¼ SE¼ SW¼ sec. 23, T. 12 S., R. 22 E., Johnson County, drilled 1942.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Clay, sandy	5	7
Sand, fine, silty	11	18
Sand, fine, brown	4	22
Sand, coarse, and gravel	11	33
Sand, fine to coarse; a few clay balls	5	38
Sand, coarse, and gravel; some boulders	21	59
PENNSYLVANIAN—Missourian		
Shale, blue	1	60
Limestone		60

12-22-23dad—*Log of test hole 107, Sunflower Ordnance Plant, in the SE¼ NE¼ SE¼ sec. 23, T. 12 S., R. 22 E., Johnson County, drilled 1942.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Clay, sandy	7	9
Sand, very fine, brown	11	20
Sand, fine, gray	10	30
Sand and gravel	5	35
Sand, fine to medium	3	38
Sand, gravel, and boulders	10	48
PENNSYLVANIAN—Missourian		
Limestone		48

12-22-23dbd—*Log of test hole 105, Sunflower Ordnance Plant, in the SE¼ NW¼ SE¼ sec. 23, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 782.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy, tan	8	8
Sand, fine, silty, tan, streaks of gray clay	7	15
Sand, fine to medium, light brown, streaks of gray clay	5	20
Sand, medium, light brown	8	28
Sand, medium to coarse, gray	2	30
Sand, coarse, gray green; blue clay balls	8	38
Sand, fine to medium, gray green	2	40
Sand, coarse, gray green, and gravel	11	51
PENNSYLVANIAN—Missourian		
Shale, gray blue	1.5	52.5
Limestone		52.5

12-22-23dcd—*Log of test hole 104, Sunflower Ordnance Plant, in the SE¼ SW¼ SE¼ sec. 23, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 779.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy, tan	8	8
Clay, silty, gray	6	14
Sand, medium, light brown, streaks of gray clay	2	16
Sand, medium, blue	4	20
Sand, coarse, blue, streaks of blue clay	3	23
Clay, blue	5	28
Sand, coarse, blue, streaks of blue clay	3	31
Sand, fine to medium, streaks of blue clay	4	35
Sand, coarse, gray; a few clay balls	3	38
Sand, coarse, gray, and gravel	2	40
Sand, very coarse, and gravel	5	45
Gravel, very coarse, and boulders	9.7	54.7
PENNSYLVANIAN—Missourian		
Limestone		54.7

12-22-26bda—*Log of test hole 102, Sunflower Ordnance Plant, in the NE¼ SE¼ NW¼ sec. 26, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 778.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, black	4	4
Clay, sandy, tan	10	14
Clay, gray	8	22
Sand, coarse, gray, and small gravel; heavy streaks of blue-gray clay	11	33
Sand, coarse, gray, and small gravel	3	36
Sand, coarse, gray, gravel, and boulders	4	40
Sand, coarse, gray, and small gravel	4	44
Sand, coarse, gray; boulders	4	48
Sand, coarse, gray, and gravel	2	50
Sand, coarse, gray, and gravel; traces of blue clay	3	53
Sand, very coarse, gravel, and boulders	7	60
Sand, very coarse, and coarse gravel	4.5	64.5
PENNSYLVANIAN—Missourian		
Shale, blue	1	65.5
Limestone		65.5

12-22-26bbd—*Log of test hole 101, Sunflower Ordnance Plant, in the SE¼ NW¼ NW¼ sec. 26, T. 12 S., R. 22 E., Johnson County, drilled 1942.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	2	2
Sand, fine, dirty	12	14
Clay, sandy	7	21
Sand, fine	7	28
Sand, coarse, and some gravel; a few clay balls	12	40
Sand, gray, and boulders	27	67
PENNSYLVANIAN—Missourian		
Shale	2	69
Limestone		69

12-22-29abc—*Log of test hole C, Sunflower Ordnance Plant, in the SW¼ NW¼ NE¼ sec. 29, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 785.0 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Soil, sandy	3.5	3.5
Gumbo	4.5	8
Soil, sandy	4.5	12.5
Sand, medium to coarse, brown	13.5	26
Sand, coarse, gray, and gravel	5	31
Sand, coarse, gray, and gravel; a few clay balls	4	35
Sand, coarse, gray, and fine gravel	6	41
Sand, coarse, gray, fine gravel, and a few boulders	3.2	44.2
PENNSYLVANIAN—Missourian		
Limestone		44.2

12-22-30bbc—*Log of test hole O, Sunflower Ordnance Plant, in the SW¼ NW¼ NW¼ sec. 30, T. 12 S., R. 22 E., Johnson County, drilled 1942. Surface altitude, 798.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, sandy	2	2
Top soil, blue	3	5
Sand, very fine, and clay	5	10
Quicksand, fine	14	24
Sand, fine, white	10	34
Sand, fine to medium, blue	5	39
Clay, blue	1	40
Sand, blue, streaks of blue clay, and boulders	5	45
Sand, blue, and boulders	5	50
Sand, coarse, blue, some gravel and boulders	4	54
Boulders	0.5	54.5
PENNSYLVANIAN—Missourian		
Limestone		54.5

11-23-28cc—*Log of west Municipal Well, Bonner Springs, in the SW¼ SW¼ sec. 28, T. 11 S., R. 23 E., Wyandotte County, drilled 1951.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Top soil, clayey, brown	5	5
Clay, brown	35	40
Clay, sandy, dark brown	2.5	42.5
Sand, fine, brown	17.5	60
Sand, fine to medium	7.5	67.5
Sand, medium to coarse	5	72.5
Sand, coarse	10	82.5
Sand, coarse, and gravel	2.5	85
Sand, coarse, gravel, and boulders	3.5	88.5
PENNSYLVANIAN—Missourian		
Shale, blue	1.5	90
Limestone		90

11-23-28dab—*Log of test hole 150 (Fishel) in the NW¼ NE¼ SE¼ sec. 28, T. 11 S., R. 23 E., 78 feet south and 3 feet east of center of intersection of lane with highway, Wyandotte County, drilled by Kansas Geological Survey, 1944. Surface altitude, 776.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, clayey, dark gray	8	8
Silt, soft, yellow gray	17	25
Sand, coarse to fine, and silt, gray to yellow gray	5	30
Silt, clayey, blue gray, medium sand, and medium gravel	10	40
Sand, coarse to fine, some medium gravel and clayey, blue-gray silt	10	50
Gravel, medium to fine, and medium sand, greenish to brown	18	68
PENNSYLVANIAN—Missourian		
Limestone, very hard, gray white	1	69

11-23-28dba—*Log of test hole 151 (Fishel) in the NE¼ NW¼ SE¼ sec. 28, T. 11 S., R. 23 E., on west side of lane running south from highway, 63 feet south and 15 feet west of center of railroad crossing, Wyandotte County, drilled by Kansas Geological Survey, 1944. Surface altitude, 777.2 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, partly clayey, yellow gray downward to gray	12	12
Silt, soft, buff	14	26
Sand, coarse to fine, and some fine gravel	5	31
Silt, clayey, blue gray	13	44
Silt, clayey, blue gray; contains some medium to fine sand	4	48
Gravel, coarse to fine, and sand, brown	20	68
PENNSYLVANIAN—Missourian		
Limestone, hard, gray white	1	69

11-23-28dbd—*Log of test hole 152 (Fishel) in the SE¼ NW¼ SE¼ sec. 28, T. 11 S., R. 23 E., on west side of lane running south from highway, 12 feet north of river and 6 feet west of center of lane, Wyandotte County, drilled by Kansas Geological Survey, 1944. Surface altitude, 779.1 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, dark yellow gray; contains much fine sand	22	22
Sand, coarse to fine, and some fine gravel	9	31
Sand, coarse to fine, silt, clayey, blue gray, and some medium gravel	7	38
Gravel, medium to fine, medium sand, and some clay, greenish gray	17	55
Gravel, coarse to fine, and coarse sand	5	60
Gravel, coarse to fine, and some coarse sand	11	71
PENNSYLVANIAN—Missourian		
Limestone, very hard, white	1	72

11-23-28dcc—*Log of test hole 153 (Fishel) in the SW¼ SW¼ SE¼ sec. 28, T. 11 S., R. 23 E., on south bank of river and just northwest of curve of lane, Johnson County, drilled by Kansas Geological Survey, 1944. Surface altitude, 767.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, light buff; contains much medium to fine sand	17	17
Silt, blue gray, fine gravel, and medium sand	3	20
Gravel, fine to medium, and medium sand; contains some blue-gray silt at depth of 34 feet	20	40
Gravel, medium to fine, and medium sand	10	50
Gravel, coarse to fine, and medium sand	5	55
PENNSYLVANIAN—Missourian		
Limestone, hard, white and light brown	1	56

11-23-33abb—*Log of test hole 154 (Fishel) in the NW¼ NW¼ NE¼ sec. 33, T. 11 S., R. 23 E., 10 feet east of center of lane, 0.15 mile south of river, and 0.45 mile north of highway, Johnson County, drilled by Kansas Geological Survey, 1944. Surface altitude, 766.4 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, gray brown and gray buff	6	6
Sand, medium to fine, brown, and some light-gray-buff silt	4	10
Sand, coarse to fine, brown	9	19
Gravel, fine to medium, and medium sand	11	30
Gravel, coarse to fine, medium sand, and some silt, gray green	10	40
Gravel, coarse to fine, and medium sand	10	50
Gravel, coarse to fine	3	53
PENNSYLVANIAN—Missourian		
Limestone, hard, buff and pink	0.5	53.5
Shale, hard, calcareous, fossiliferous, yellow to buff	1.5	55

11-23-33abc—*Log of test hole 155 (Fishel) in the SW¼ NW¼ NE¼ sec. 33, T. 11 S., R. 23 E., on east side of lane, 3 feet west and 6 feet south of corner fence post, 0.25 mile south of river and 0.35 mile north of highway, Johnson County, drilled by Kansas Geological Survey, 1944. Surface altitude, 769.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, dark gray	2	2
Silt, gray buff to light gray	8	10
Silt, soft, light gray	5	15
Sand, medium to fine, and some fine gravel	5	20
Gravel, medium, medium sand, and silt, gray	10	30
Gravel, medium to fine, medium sand, and much silt, gray	10	40
Gravel, medium to fine	8.5	48.5
Boulders, consisting of limestone, pink quartzite, and coarse gravel	1.5	50
Clay, blue gray, yellow, and buff; contains some gravel and sand	3	53
PENNSYLVANIAN—Missourian		
Limestone, fairly hard, light buff and brown	2	55

11-23-33acb—*Log of test hole 156 (Fishel) in the NW¼ SW¼ NE¼ sec. 33, T. 11 S., R. 23 E., 15 feet east of center of lane, 0.45 mile south of river, and 0.15 mile north of highway, Johnson County, drilled by Kansas Geological Survey, 1944. Surface altitude, 774.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, gray buff; contains much medium sand	8	8
Sand, medium to fine, interbedded with silt, blue gray	11	19
Sand, coarse to fine, some medium to fine gravel, and some silt	11	30
Gravel, medium to fine, and medium sand	2	32
Gravel, medium to fine, medium sand, and silt, blue gray	4	36
Gravel, medium to fine, and medium sand	14	50
Gravel, coarse to fine, and medium sand	6	56
PENNSYLVANIAN—Missourian		
Limestone, hard, light buff and brown; some blue-gray shale	2	58

11-23-33acc—*Log of test hole 157 (Fishel) in the SW¼ SW¼ NE¼ sec. 33, T. 11 S., R. 23 E., 8 feet east of center of road, 0.55 mile south of river, and 0.05 mile north of highway, Johnson County, drilled by Kansas Geological Survey, 1944. Surface altitude, 770.6 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, gray buff; contains much sand	7	7
Sand, coarse to fine, and some medium gravel	18	25
Gravel, coarse to fine, medium sand, and some silt, blue gray	5	30
Gravel, medium to fine, medium sand, and some pebbles	10	40
Gravel, coarse to fine, and coarse sand	11	51
PENNSYLVANIAN—Missourian		
Limestone, hard, light gray	1	52

11-23-33dbb—*Log of test hole 158 (Fishel) in the NW¼ NW¼ SE¼ sec. 33, T. 11 S., R. 23 E., on west side of highway, 0.65 mile south of river and 0.05 mile south of turn in highway, 66 feet north and 6 feet west of telephone pole, Johnson County, drilled by Kansas Geological Survey, 1944. Surface altitude, 768.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, gray and light buff	6	6
Sand, coarse to fine	7	13
Sand, coarse to fine, and some fine gravel	7	20
Gravel, fine, and medium sand	10	30
Gravel, medium to fine, and medium sand	11.5	41.5
PENNSYLVANIAN—Missourian		
Limestone, hard, gray white	0.5	42

11-23-33dbc—*Log of test hole 159 (Fishel) in the SW¼ NW¼ SE¼ sec. 33, T. 11 S., R. 23 E., 0.15 mile south of turn in highway, 75 feet west and 30 feet north of center of south railroad crossing, Johnson County, drilled by Kansas Geological Survey, 1944. Surface altitude, 769.9 feet.*

	Thickness, feet	Depth, feet
QUATERNARY—Upper Pleistocene to Recent		
Alluvium		
Silt, gray and buff	8	8
Sand, medium to fine	2	10
Sand, coarse to fine, some medium gravel, and many concretions of sand-limonite	5	15
Limestone block	0.5	15.5
Gravel, coarse to medium	1	16.5
PENNSYLVANIAN—Missourian		
Limestone, very hard, light gray	0.5	17
Shale, yellow buff	1	18

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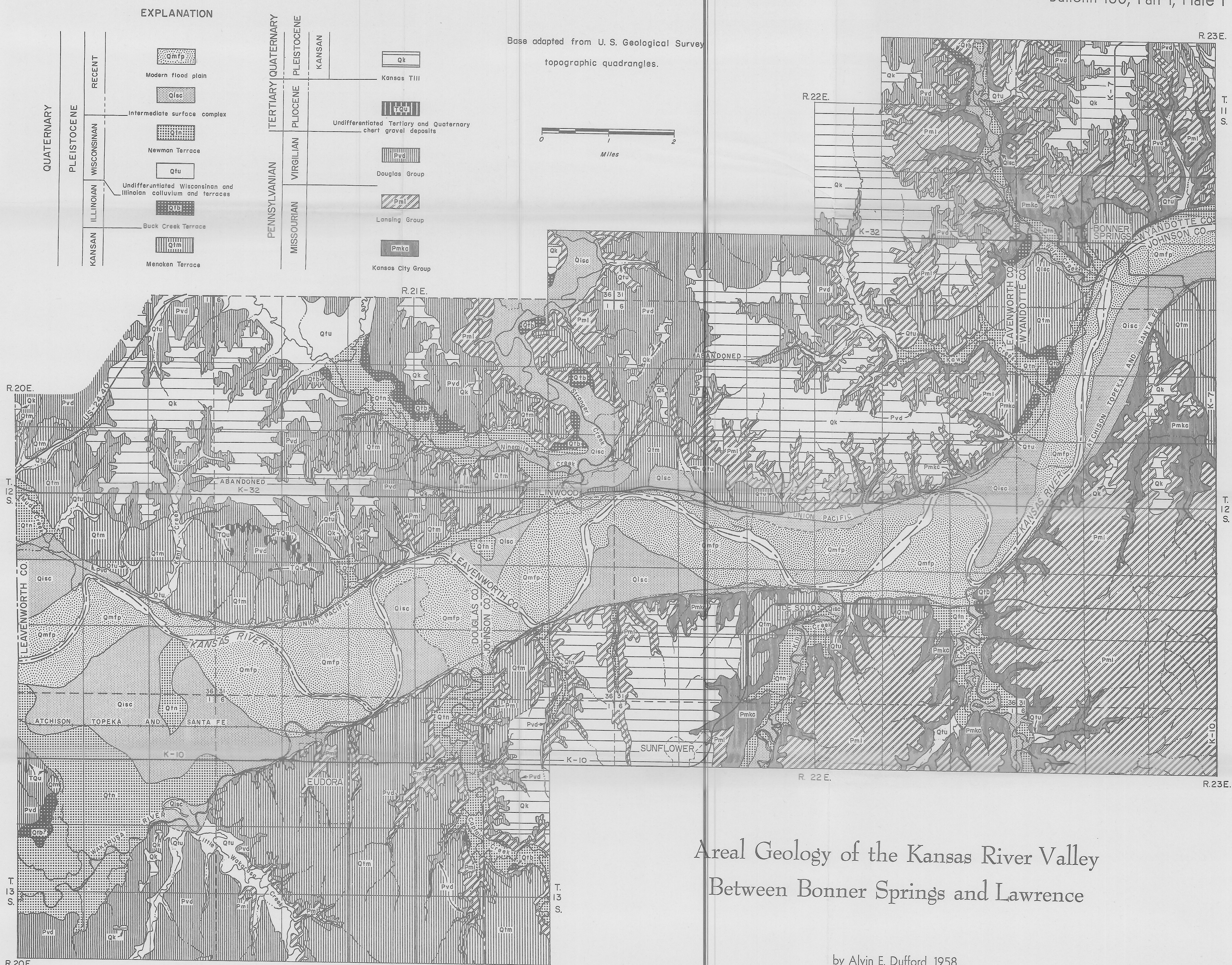

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