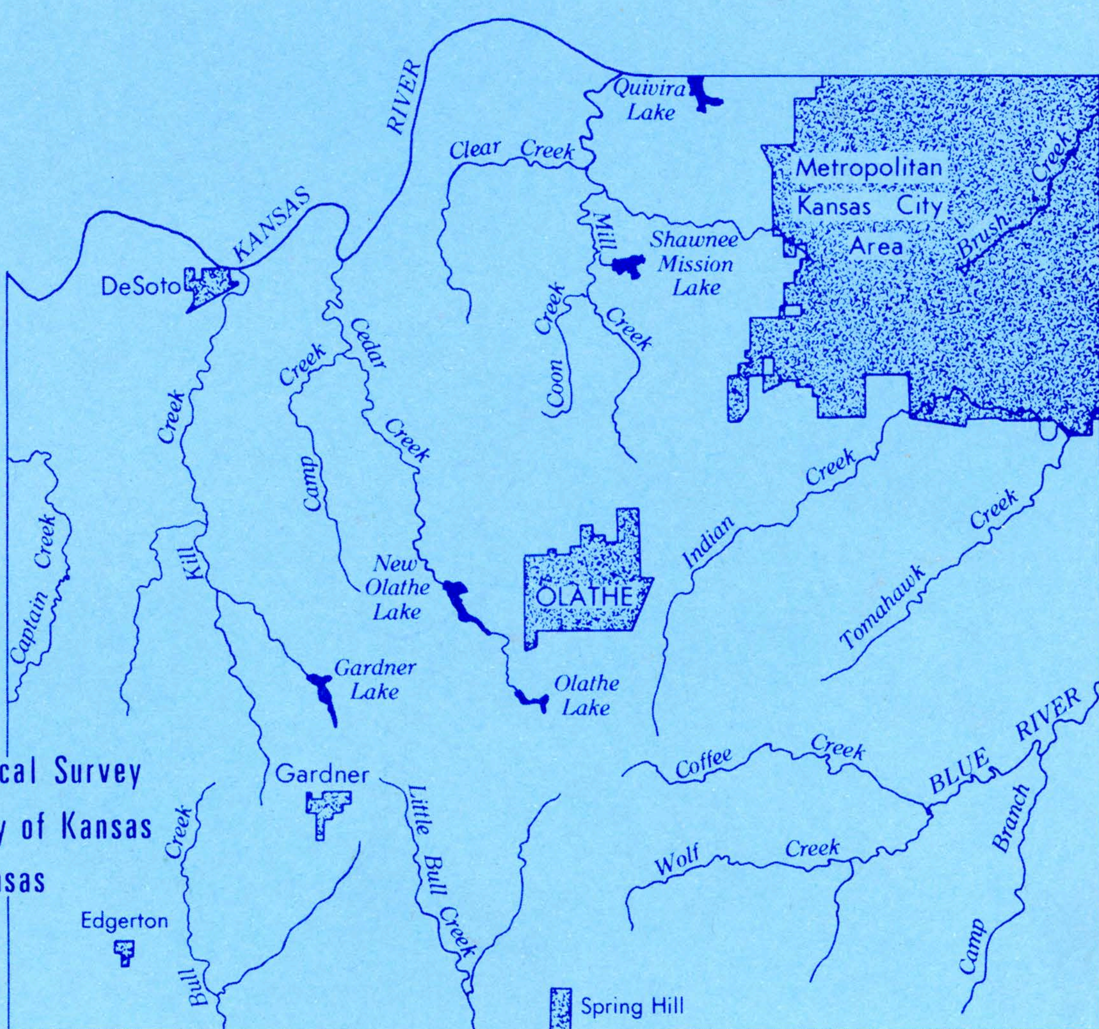
Geology and Ground-Water Resources of
JOHNSON COUNTY
Northeastern Kansas

Howard G. O'Connor

Bulletin 203



State Geological Survey
The University of Kansas
Lawrence, Kansas

1971

Reprinted 1986

BULLETIN 203

Geology and Ground-Water Resources of Johnson County, Northeastern Kansas

By

Howard G. O'Connor

Prepared by the State Geological Survey of Kansas and the United States Geological Survey with the cooperation of the Division of Environmental Health of the Kansas State Department of Health, and the Division of Water Resources of the Kansas State Board of Agriculture.

Printed by authority of the State of Kansas
Distributed from Lawrence

UNIVERSITY OF KANSAS PUBLICATIONS
DECEMBER 1971

Reprinted 1986

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HOWARD G. O'CONNOR *State Geological Survey of Kansas*

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ABSTRACT

Johnson County, Kansas, an area of 478 square miles, had a population of 217,662 in 1970. Oil and gas, sand and gravel, and limestone are produced commercially. Limestone is the most important mineral resource, valued at $1,827,000 in 1966, and the Wyandotte Limestone is the most important limestone unit. In addition, water is marketed commercially, but dollar values are not available.

The rocks above the Precambrian basement are 2,150 to 2,550 feet thick in Johnson County and are all sedimentary in origin. They include rocks of Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, Cretaceous(?), and Quaternary age. The exposed rocks of Pennsylvanian, Cretaceous(?), and Quaternary age are about 700 feet thick.

The outcropping Pennsylvanian rocks have an aggregate thickness of about 500 feet and consist chiefly of alternating shale and limestone units ranging from about 2 to 100 feet in thickness, and minor amounts of fine-grained sandstone. The fresh or slightly saline water supplies available from these rocks are small; well yields average less than 10 gallons per minute, but yields as great as 50 gallons per minute are known. Wells obtain fresh to slightly saline water at a depth of 250 feet or less, but locally ground water at depths of less than 100 feet is moderately saline. The chemical quality of ground water pumped by domestic and stock wells from bedrock aquifers ranges from excellent to poor, but many of the bedrock wells yield water that is more mineralized than ground water pumped from unconsolidated Pleistocene deposits.

Wisconsinan and Recent alluvial deposits 40 to 70 feet thick in the Kansas River valley yield the largest supplies of ground water in the county. Irrigation, industrial, and municipal wells pump water at rates of 150 to 1,000 gallons per minute from the Kansas River alluvium. Alluvial deposits in the smaller stream valleys range from about 20 to 75 feet in thickness. Wells yield 25 to 100 gallons per minute from deposits in the larger tributary valleys and 1 to 10 gallons per minute in the smaller tributary valleys. Kansan deposits, chiefly Atchison Formation and undifferentiated fluvial deposits, are extensive enough southwest of DeSoto and near Holliday to comprise a significant aquifer capable of yielding 1 to 10 gallons per minute to wells in the area. Locally 50 to 100 gallons per minute can be obtained. Ground water from the Pleistocene aquifers is good except for high carbonate hardness and generally excessive iron content.

Water pumped from wells in the Pennsylvanian rocks has a much greater range in chemical quality than ground water in the Pleistocene aquifers; the very shallow wells generally yield water that is hard but otherwise of good quality. Wells tapping aquifers at depths of 50 to 250 feet yield water of generally poorer quality than wells tapping the shallow aquifers.

The dominant regional structure is the Prairie Plains monocline of post-Permian pre-Cretaceous age. The surface rocks in Johnson County dip northwestward at an average rate of about 12 feet per mile. The regional structure is modified across the central part of the county by the northeast-trending Gardner anticline.

INTRODUCTION

Purpose and Scope of Investigation

A study of the geology and ground-water resources of Johnson County was begun in the summer of 1954 by the State Geological Survey of Kansas and the United States Geological Survey in cooperation with the Division of Sanitation of the Kansas State Board of Health (now the Division of Environmental Health of the Kansas State Department of Health) and the Division of Water Resources of the Kansas State Board of Agriculture. In Kansas, water from wells constitutes an important supply for municipal, industrial, irrigation, domestic, and stock needs. This investigation was made to determine the distribution, thickness, and lithologic properties of the outcropping and near-surface rocks and to evaluate the hydrologic properties of the rocks containing potable water in Johnson County.

During the investigation the scope and detail of the report were modified to better meet the needs of the area. Much additional surface and subsurface stratigraphic information was obtained, particularly about the Wyandotte Limestone and adjacent beds because of the commercial importance of limestone quarry rock needed for construction in the rapidly urbanizing Kansas City area.

Because rocks older than Missourian (Pennsylvanian) age are not known to contain potable water, they are considered only briefly in this report. The available quantitative and qualitative data on ground water from pre-Missourian rocks are summarized from oil and gas exploration data. The structural geology and mineral resources other than ground water are also discussed briefly. Data regarding present and potential ground-water developments, together with the effects of pumping on discharge, recharge, and the chemical quality of the water, are summarized for the principal aquifers.

Location and Extent of Area

Johnson County is in northeastern Kansas and is bounded on the east by Jackson and Cass Counties, Mo., on the north by Wyandotte and Leavenworth Counties, Kans., on the west by Douglas County, Kans., and on the south by Miami County, Kans. (fig. 1). It includes all or parts of 21 townships, constituting 478 square miles (Batschelet, 1942).

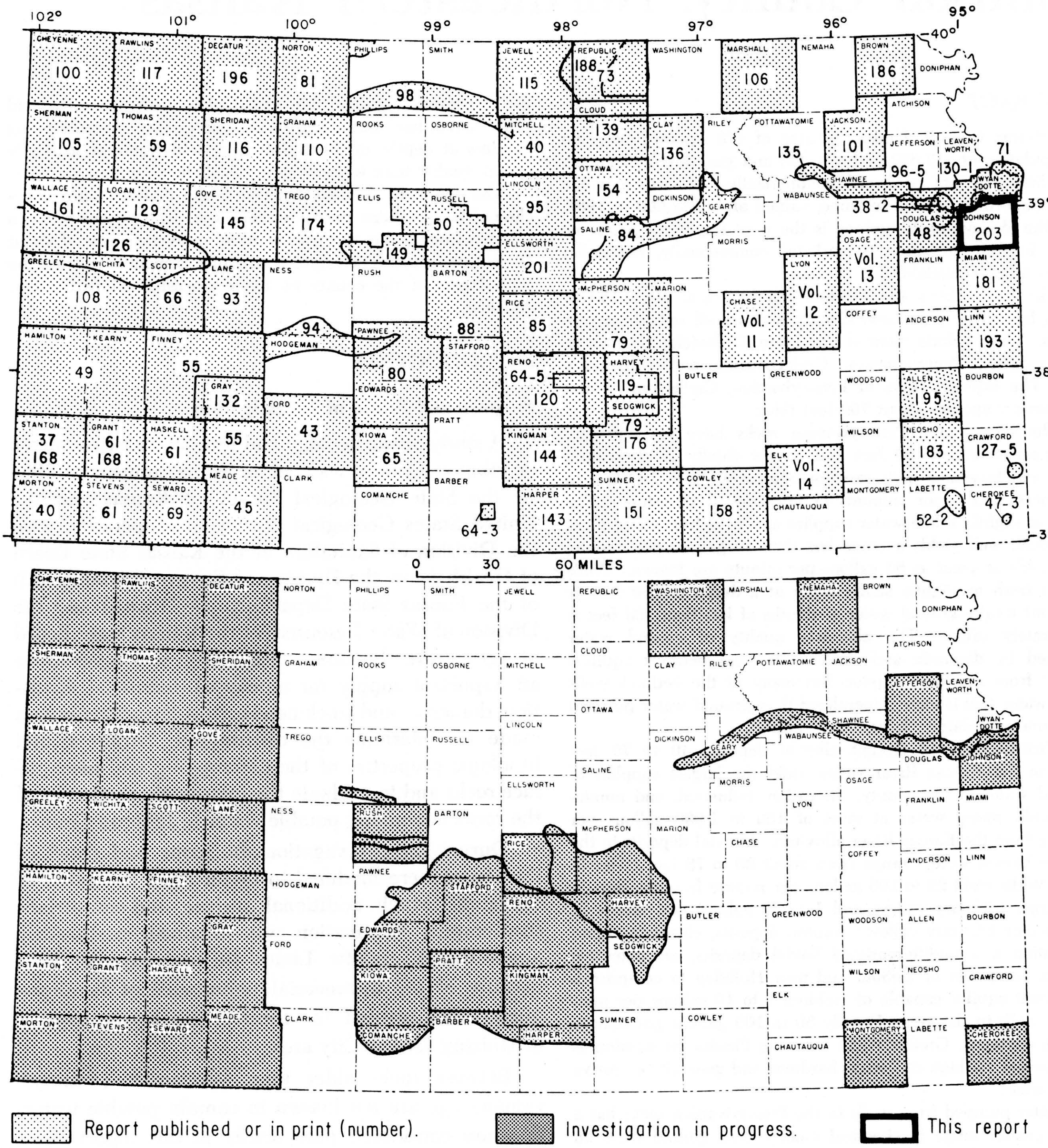

FIGURE 1.—Index maps of Kansas showing area discussed in this report, and other areas for which ground-water reports have been published by the State Geological Survey or are in preparation.

Previous Investigations

The sequence of rocks that crop out in Johnson and adjacent counties has been studied and described by the following geologists: Swallow and Hawn (1865), Haworth (1894, 1895, 1898), Bennett (1896), Keyes (1899), Todd (1909, 1911, 1918), Culbertson (1915), Hinds and Greene (1915), McCourt, Albertson, and Bennett (1917), Schoewe (1923, 1924, 1930a, 1930b, 1930c, 1949), Newell (1931, 1933, 1935), Sayre (1931), Moore (1932, 1935, 1949), Greene (1933), Patterson (1933), Jewett and Newell (1935), Hoover (1936), Moore and Landes (1937), McQueen and Greene (1938), Moore, Frye, and Jewett (1944), Frye and Walters (1950), Lins (1950), Zinser (1950), Moore and others (1951), Frye and Leonard (1952), Lamerson (1956), McManus (1956), Mann (1957), Reynolds (1957), Sanders (1959), Eastwood (1958), Wilson (1959), O'Connor (1960), Ball, Ball, and Laughlin (1963), O'Connor and Fowler (1963), and Miller (1966).

Studies relating to the ground-water resources have been made by Bailey (1902), Haworth (1913), Jewett and Williams (1935), Jewett (1939), Moore (1940), Fishel (1948), Fishel, Searcy, and Rainwater (1953), Foley, Smrha, and Metzler (1955), Grimes (1957), Dufford (1958), and the Kansas Water Resources Board (1959).

The subsurface geology has been described by McClellan (1930), Ockerman (1935), Lee (1939, 1940, 1943), Lee and others (1946), Lee and Merriam (1954), Merriam, Winchell, and Atkinson (1958), Huffman (1959), Merriam (1960), Merriam and Kelly (1960). The geology pertaining to oil and gas has been discussed by Jewett (1949, 1954), Jewett and Abernathy (1945), and Hilpman (1958). The structural geology and the oil and gas resources in adjacent areas of Jackson and Cass Counties, Mo., have been summarized by Clair (1943). Named geologic structures that have geographic application to Johnson County have been listed by Jewett (1951). Farquhar (1957) has summarized information on the geology of the Precambrian rocks of Kansas. The geologic history has been summarized by Merriam (1963).

Methods of Investigation

The data on which this report is based were obtained chiefly in the summers of 1954 and 1955 during which time wells were inventoried, test holes were drilled, water samples were collected for chemical analysis, and most of the areal geology was mapped. About 4 months of additional field work during 1959-61 included drilling additional test holes, collecting about 200 additional well logs, collecting and checking data points used for the structural maps of the report, completing the geologic mapping, and installing four observation wells.

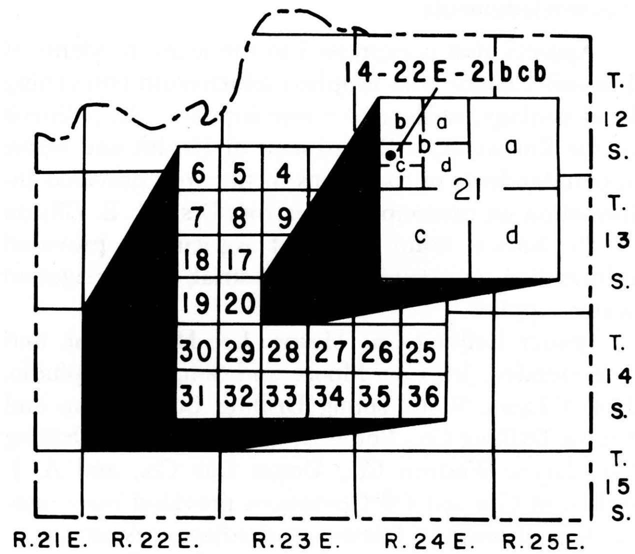

FIGURE 2.—Well-numbering system used in this report.

The geologic and ground-water data collected, and given in reports by earlier workers, were restudied and modified before inclusion in this report. Test holes for this investigation were drilled with a power auger. Drill cuttings were collected in the field and later examined microscopically in the laboratory. Altitudes of wells and test holes were determined with a Paulin surveying altimeter or by interpolation from 7½-minute topographic maps having 10-foot contour intervals.

Well-Numbering System

Well and test-hole numbers used in this report give the location of wells according to General Land Office surveys. The well number is composed of township, range, and section numbers, followed by letters that indicate the subdivision of the section in which the well is located. The first letter denotes the quarter section; the second letter denotes the quarter-quarter section, or 40-acre tract; and the third letter, when used, indicates the quarter-quarter-quarter section, or 10-acre tract. The 160-acre, 40-acre, and 10-acre tracts are designated *a, b, c,* and *d* in a counter-clockwise direction, beginning in the northeast quarter (fig. 2). When two or more wells are located within a 10-acre tract, the wells are numbered serially according to the order in which they were inventoried. For example, well 14-22E-21bcb is in the NW¼ SW¼ NW¼ sec. 21, T.14 S., R.22 E., and is the first well inventoried in that tract.

Acknowledgments

Appreciation is expressed to the many residents of Johnson County who supplied information concerning local geology, wells, and water supplies. N. J. Burris of the Kansas State Department of Health and water superintendents of the towns in the area provided information on municipal water supplies. G. E. Gibson of the Kansas State Board of Agriculture provided information on municipal, industrial, and irrigation water supplies.

Breuer Drilling Co., Messrs. Lee Hendee, Sr. and Lee Hendee, Jr., Carl Moore and Son, Fred Spindle, Ernest Lynn, F. E. Young Drilling Co., Cullum and Brown Drilling Co., Boten Drilling Co., Beaty Drilling Co., Layne-Western Co., Union Gas Co., and A. J. Belisle of Gas and Oil Operations provided many useful logs of wells in Johnson and adjacent counties.

Thanks are expressed to Dr. Wallace B. Howe of the Missouri Geological Survey and Water Resources for providing logs of wells drilled in Johnson County, Kans., and adjacent areas of Missouri, and for assistance in field checking geologic features along the State line. L. M. Roper, Hercules Powder Co., kindly permitted access to Sunflower Army Ammunition Plant (formerly Sunflower Ordnance Works) property, and Hugh Jackson, utilities supervisor, furnished data on the ordnance plant water-supply reactivation.

Virgil Burgat, Chief Geologist, and L. W. Fowler, Assistant Chief Geologist of the State Highway Commission of Kansas, made available much useful geologic information, including test-hole logs and unpublished geologic profiles of highway projects in Johnson County.

Stratigraphic sections and other unpublished data on the geology and ground-water resources of the area collected by many members and former members of the U.S. and State Geological Surveys were utilized in the preparation of this report. The help of these individuals is gratefully acknowledged.

GEOGRAPHY

Topography and Drainage

Johnson County lies partly within the Attenuated Drift Border division of the Dissected Till Plains and partly in the Osage Cuestas division of the Osage Plains (Schoewe, 1949). Much of the area consists of gently rolling uplands with hilly areas along the streams. North-flowing streams tributary to the Kansas River, such as Kill Creek, Cedar Creek, and Mill Creek, have steeper gradients and greater local relief than east-flowing and south-flowing streams. Relief of 150 to 250 feet is common within a mile of the north-flowing streams in their more hilly parts. Local relief along the east-flowing tributaries of the Missouri River and the south-flowing tributaries of the Marais des Cygnes River within a mile of the stream generally is less than 150 feet.

The flood plain ranges from about 0.2 to 0.5 mile in width along the principal streams, except along the Kansas River where it ranges from 1 to 2 miles in width.

The highest point in the county, about 1,134 feet above mean sea level, is in the southeastern part (secs. 17 and 18, T.15 S., R.25 E., Bucyrus topographic quadrangle) and the lowest point, about 742 feet, is along the Kansas River where the river flows eastward into Wyandotte County. Maximum relief in the county is about 392 feet.

Climate

According to the U.S. Weather Bureau (Flora, 1948), Johnson County has a modified humid continental climate. It has higher precipitation, a higher relative humidity, less sunshine, and less range between day and night temperatures than counties in central and western Kansas. Winters are milder and the growing season is longer than areas to the west and north. Average midday and early evening relative humidities in eastern Kansas in July range from 45 to 50 percent. In the winter relative humidities average somewhat higher, often to nearly 70 percent.

The average date of the last killing frost in spring is April 17 (Flora, 1948, p. 223), and the average date of the first killing frost in the fall is October 18. Nearly 75 percent of the annual precipitation occurs during the growing season, which averages 184 days.

The mean monthly and mean annual precipitation and temperature at Olathe are given in table 1.

TABLE 1.—Mean monthly and mean annual precipitation and temperature at Olathe, 1931-55 (from records of U.S. Weather Bureau).

Month	Mean precipitation, (inches)	Mean temperature, (°F)
January	1.35	30.6
February	1.25	34.7
March	2.11	44.3
April	3.79	55.0
May	5.29	64.2
June	5.08	74.5
July	3.34	79.6
August	4.06	78.1
September	3.63	70.2
October	2.68	59.6
November	1.93	43.8
December	1.48	34.1
Mean annual, 1931-55	35.99	55.7

Population

Johnson County, one of the original territorial counties, was oganized in 1855. In 1970 it ranked second among the counties of the State, having a population of 217,662 (U.S. Bureau of the Census, 1971). The northeastern fourth of the county is urban and includes more than a dozen cities and villages. The five largest incorporated areas and their 1970 populations are: Overland Park, 76,623; Prairie Village, 28,138; Shawnee, 20,482; Olathe, the county seat, 17,917; and Merriam, 10,851.

Agriculture and Industry

Livestock and poultry having a value of $5,072,640 and crops having a value of $5,209,230 were produced in 1969 on Johnson County farms. According to the 1964 census there were 1,041 farms (Kansas State Board of Agriculture, 1971). The acreage and value of principal crops grown in Johnson County in 1969 are shown in table 2.

Most of the industries in Johnson County are relatively small. The Sunflower Army Ammunition Plant at DeSoto formerly was the largest industry in terms of employment, but the plant was inactive in 1964. It was reactivated in 1966 and again is one of the largest industries in terms of employment. Manufacturing industries in 1959 included metal fabrication and welding, tool and die manufacture, sulfuric acid manufacture, pharmaceutical and veterinary supplies, farm machinery and feed milling equipment, feed and commercial fertilizer manufacture, printing and publishing, cabinet manufacture, storage batteries, boots and shoes, apparel, furniture, and greeting card manufacture (Kansas State Department of Economic Development, 1963).

TABLE 2.—Acreage and value of principal crops grown in 1969 (Kansas State Board of Agriculture, 1971).

Crop	Acres harvested	Value
Wheat	14,000	$ 500,000
Corn, all purpose	26,730	1,943,500
Oats	1,560	42,100
Barley	120	4,100
All sorghum, for grain	13,500	918,000
All sorghum, for forage	100	3,800
All sorghum, for silage	400	37,400
Soybeans	14,800	814,000
All hay and pasture	22,800	898,600
Alfalfa hay	5,800	353,200
Wild hay	3,000	79,200
Other crops	640	47,730
Total	94,650	$5,209,230

Mineral Resources

The U.S. Bureau of Mines (1968) lists oil and gas, sand and gravel, and limestone, having a value of $2,312,252, as minerals produced commercially in Johnson County in 1966.

OIL AND GAS

The Nomenclature Committee of the Kansas Geological Society has designated 10 named areas of oil and gas production in Johnson County—two which have produced oil and gas and eight which have produced gas only (fig. 3). Several of the gas fields are abandoned or produce noncommercial amounts of gas. Oil and gas have been produced from Pennsylvanian sandstone in the Marmaton Group and from the "Squirrel sandstone" and "Bartlesville sandstone" in the Cherokee Group. Gas production has been reported from the "Knobtown sandstone" in the upper part and from a sandstone in the lower part of the Pleasanton Group (Jewett, 1954).

The Cities Service Gas Co. is utilizing the Craig (Craig-Monticello) field for the underground storage of natural gas. Gas is stored at an average depth of 582 feet in the "Bush City sandstone" or "Squirrel sandstone" in the upper part of the Cherokee Group. In 1966 there were 61 storage wells in operation. Storage capacity of the field is reported to be 6,075,820 Mcf (thousand cubic feet) [gas volume computed at 14.65 psia (pounds per square inch, absolute), temperature 60°F] at 205 psig (pounds per square inch, gage) at the wellhead (M. O. Oros, written commun., 1967).

In 1966 the Dallas field produced 75 barrels of oil from 1 well, the Gardner field produced 38,861 barrels from 63 wells, and 1 other well produced 40 barrels. Gas production was estimated to be 280,000 Mcf from two wells in the Gardner field and 228,350 Mcf from an estimated 53 wells in other parts of the county. An estimated 10 new oil and gas wells and dry holes were drilled in 1966 (Oros and Beene, 1968).

SAND AND GRAVEL

Building and paving sand, fill sand, filtration sand, and building gravel are produced by Builders Sand Co. and the Holliday Sand and Gravel Co. (Hardy and Hornbaker, 1968). All the sand and gravel is dredged from the Kansas River or from pits in Kansas River valley alluvium.

LIMESTONE

Limestone is the most important mineral resource in terms of dollar value and the Wyandotte Limestone

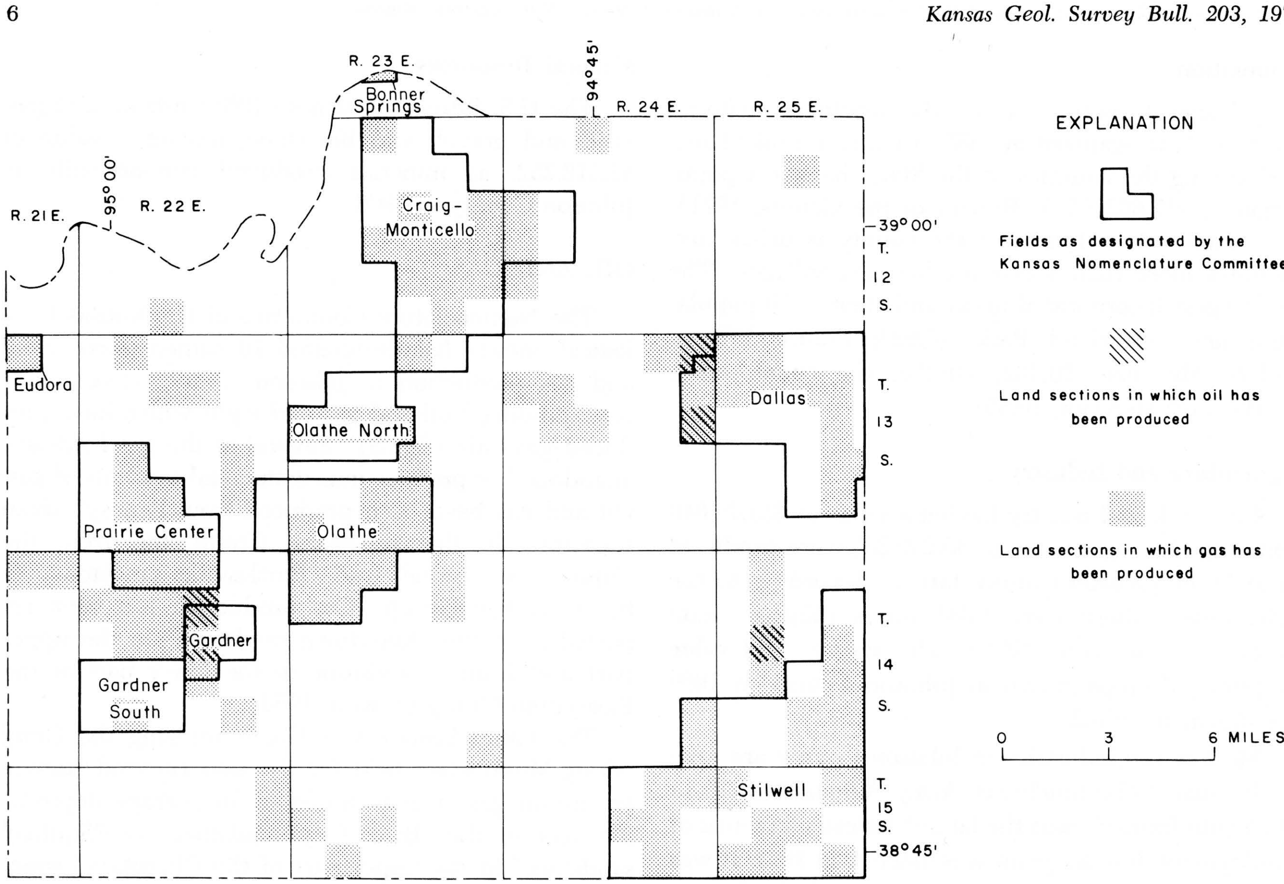

FIGURE 3.—Locations of oil and gas fields in Johnson County as designated by the Kansas Nomenclature Committee, and other land sections in which oil or gas has been produced from Pleasanton, Marmaton, and Cherokee rocks (from records on file at the State Geological Survey of Kansas, June 1963).

is the most important geologic unit in Johnson County. The county ranked first in value of stone produced in Kansas in 1966. According to A. L. Hornbaker (oral commun., 1967) Reno Construction Co., Union Quarries, Inc., and Deitz-Hill Development Co. produced 1,430,000 short tons of crushed limestone for concrete aggregate, roadstone, and agstone (agricultural limestone) having a value of $1,827,000 in 1966. The principal stratigraphic units quarried commercially for concrete aggregate, roadstone, and agstone are the Argentine and Farley Limestone Members of the Wyandotte Limestone and the Stoner Limestone Member of the Stanton Limestone. In addition, the Spring Hill Limestone Member of the Plattsburg Limestone has been quarried at several localities in past years, and the Westerville Limestone Member of the Cherryvale Shale has been quarried in at least two localities.

There were no companies that produced rough building stone, ashlar, or art building stone in 1966, but in past years a light-gray oolitic limestone from the Westerville has been quarried for rubble, hand-dressed stone, and building stone. The stone is known in the Kansas City area as the "Kansas City oolite." It has been used in many public and private buildings, an example of which is the Law Building at The University of Missouri at Kansas City.

Another stratigraphic unit formerly much used as a building stone is the Merriam Limestone Member of the Plattsburg Limestone. The Merriam has been quarried for building stone at several dozen localities in northeastern Johnson County. It has strength, durability, and pleasing appearance and can be quarried in rectangular blocks 0.4 to 1 foot thick that have smooth top and bottom surfaces.

Other limestones have been used as noncommercial sources of rock for roads, farm buildings, and other construction projects.

OTHER MINERAL RESOURCES

Material suitable for the manufacture of brick and tile and light-weight and dense constructional aggregates can be obtained from the Pennsylvanian shales and Pleistocene silt that crop out in Johnson County and adjacent areas (Plummer and Hladik, 1948, 1951). Bowdish and Runnels (1952) have demonstrated that arkosic Kansas River sand can be used to produce a nearly pure feldspar product of commercial grade and a high quality silica sand having less than 0.03 percent iron oxide (Fe_2O_3), suitable for use in the glass, glass fiber, and ceramic industries. Riser (1960) has described the building-stone resources.

STRATIGRAPHY OF SUBSURFACE ROCKS[1]

Sedimentary rocks of Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, Cretaceous(?), and Quaternary age overlie the Precambrian basement in Johnson County. The thickness of Paleozoic rocks ranges from about 2,150 feet near Kenneth in southeastern Johnson County to about 2,550 feet near Edgerton in southwestern Johnson County. The general thickness and character of the subsurface rocks are known through the study of logs and samples of drill cuttings from wells drilled for oil and gas in the area.

An excellent discussion of the stratigraphy and structural development of the Forest City basin, which includes the area of this report, was prepared by Lee (1943). Lee and Merriam (1954) in a geologic section depicted the Paleozoic structural movements that affected the area. Huffman (1959) summarized the major tectonic features that affect the midcontinent region of Kansas and Oklahoma and indicated the stratigraphic and isopachous relations of all pre-Desmoinesian strata. The discussion of pre-Pennsylvanian subsurface stratigraphy is chiefly from these publications.

No detailed subsurface studies in this part of the Forest City basin have been published since Lee's work in 1943. The pre-Pennsylvanian rocks in Johnson County have been penetrated by only a few wells, and potential oil- and gas-bearing strata may yet be discovered in stratigraphic or structural traps in the pre-Mississippian rocks.

Precambrian Rocks

Two wells have been drilled into the Precambrian in Johnson County (Cole and others, 1961). The Kasper No. 1 James (CNL NE¼ NW¼ sec. 8, T.13 S., R.25 E.) encountered pink granite below the Cambrian Lamotte Sandstone at 1,412 feet below msl (mean sea level). The Seminole No. 1 Harrington (NE¼ NE¼ SW¼ sec. 12, T.14 S., R.22 E.) drilled into biotite granite below Lamotte Sandstone at 1,381 feet below msl.

The Precambrian topography slopes northwestward across Johnson County from about 1,300 feet below msl in the southeast corner to about 1,600 feet below msl in the northwest (Farquhar, 1957).

[1] The classification and nomenclature of rock units used in this report are those of the State Geological Survey of Kansas and differ somewhat from those used by the U.S. Geological Survey.

Cambrian Rocks

The Lamotte Sandstone of Late Cambrian age disconformably overlies the Precambrian and is overlain by the Bonneterre Dolomite. Throughout Johnson County, the Lamotte is believed to be generally less than 40 feet thick and locally it may be absent. It is reported to be 30 feet thick in the Kasper No. 1 James well and 37 feet thick in the Seminole No. 1 Harrington well. The Lamotte is a fine- to coarse-grained sandstone composed chiefly of quartz or quartz and feldspar. It is gradational into the overlying Bonneterre Dolomite. The Bonneterre Dolomite has a thickness of about 100 feet.

Cambrian and Ordovician Rocks

The Arbuckle Group of Late Cambrian and Early Ordovician age consists of four recognizable formations in northeastern Kansas. The lower subdivision of the Arbuckle, of Late Cambrian age, is the Eminence Dolomite. Locally along the Missouri-Kansas boundary, a few feet of Potosi Dolomite may be represented between the Bonneterre and Eminence as a fifth subdivision of the Arbuckle (Lee, 1943). The Eminence ranges from about 150 to 300 feet in thickness. The upper three subdivisions, of Early Ordovician age, are the Gasconade Dolomite (including a slight thickness of Gunter Sandstone Member in the basal part), Roubidoux Formation, and the undifferentiated Cotter and Jefferson City Dolomites. These upper three subdivisions are about 500 feet thick. Except for the Roubidoux Formation, which thickens slightly to the northwest, all the subdivisions of the Arbuckle and the underlying Bonneterre Dolomite range from about 800 feet in the southeast to about 600 feet in the northwest (Lee, 1943; Huffman, 1959, fig. 2). The Cotter and Jefferson City Dolomites are absent locally, and the Arbuckle section is thin where Simpson-filled channels (McQueen and Greene, 1938) or sink holes (Leatherock, 1945, p. 12; Merriam and Atkinson, 1956), are present in the upper part of the Arbuckle, as in the Kasper No. 1 James well.

The configuration of the top of Mississippian rocks and the altitude of the top of the Arbuckle in 10 wells are shown on figure 4.

Ordovician Rocks

The Simpson Group is distributed throughout the county (Moore and others, 1951, fig. 48). In the Forest City basin of northeastern Kansas, Simpson rocks include the St. Peter Sandstone and the overlying Platteville Formation. The St. Peter Sandstone has been considered as Lower Ordovician by some authors and as Middle Ordovician by other authors and the

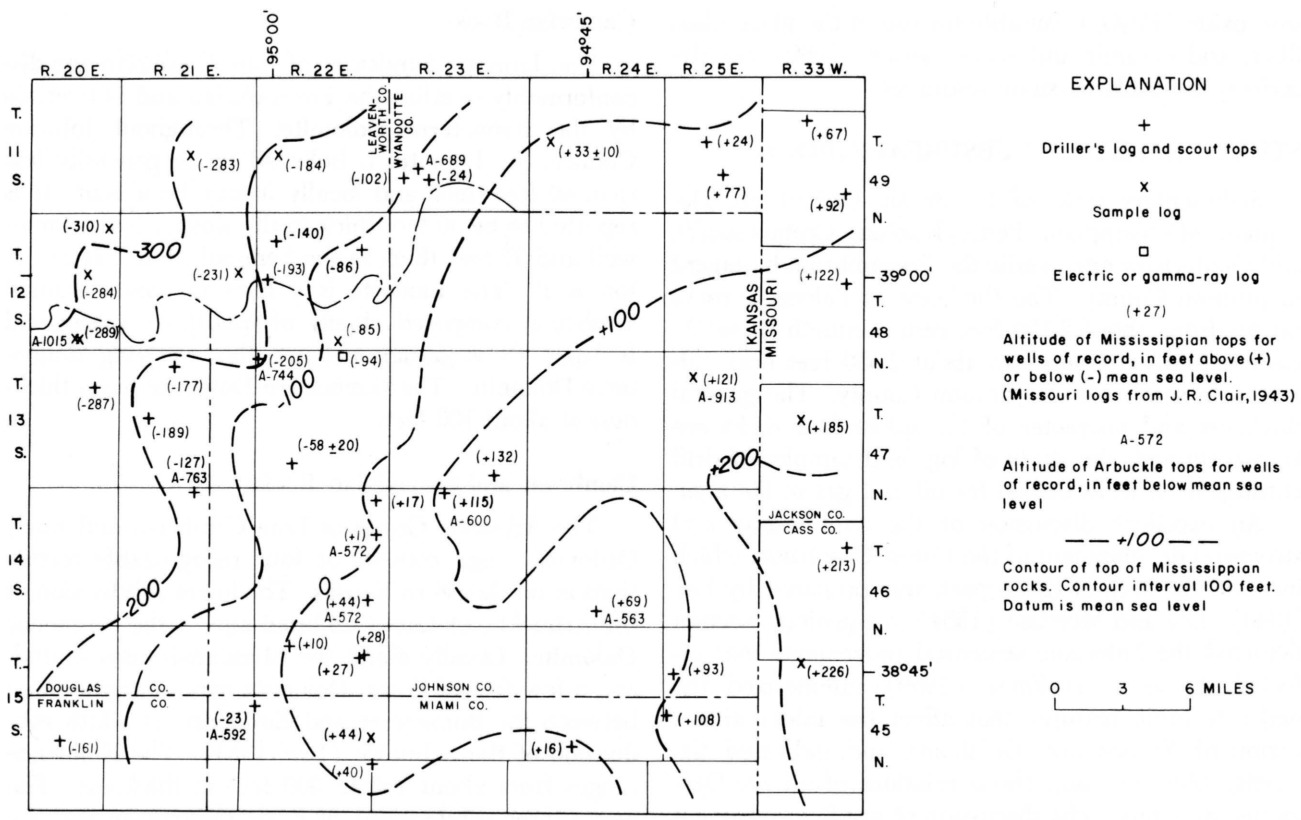

FIGURE 4.—Configuration of the top of Mississippian rocks, and location and altitude of Mississippian and Arbuckle tops for all wells of record (from records on file at the State Geological Survey of Kansas, January 1963).

State Geological Survey. The Platteville Formation is Middle Ordovician in age (Leatherock, 1945). The Simpson of Johnson County consists almost entirely of St. Peter and is about 85 feet thick (Lee, 1943, p. 30). The greatest thickness of the St. Peter in the Forest City basin also is reported in Johnson County at the Kasper No. 1 James well where a thickness of 403 feet is reported in what probably is a Simpson-filled sink.

The Viola Limestone of Middle Ordovician age overlies the Simpson and is reported to be less than 100 feet thick, except in the northwest corner where slightly more than 100 feet is reported (Huffman, 1959, fig. 4).

The Maquoketa Shale (Upper Ordovician) is reported by Lee (1943) to be absent in Johnson County.

Devonian Rocks

Devonian rocks, which constitute the upper part of the "Hunton Group" in eastern Kansas, overlie the Viola Limestone only in the northern three-fourths of Johnson County (Lee and Merriam, 1954, fig. 2). The beds thicken toward the northwest to nearly 50 feet (Huffman, 1959, fig. 6). The rocks are chiefly dolomite and limestone.

Mississippian or Devonian Rocks

The Chattanooga Shale of Mississippian or Devonian age is green, blue, dark gray, and black and unconformably overlies Viola or "Hunton" rocks in all or most of Johnson County. The Chattanooga Shale may directly overlie the Simpson Group in a small area in the southeastern corner of the county (Lee and Merriam, 1954; Huffman, 1959). It is about 60 feet thick in the northwest corner of the county and thins toward the southeast to about 15 feet (Lee, 1940, pl. 3).

Mississippian Rocks

Mississippian rocks are chiefly limestone and dolomite, parts of which are extremely cherty. The thickest Mississippian section in eastern Kansas probably is in Johnson County where 461 feet has been recognized (Lee, 1940; Huffman, 1959). The rocks thin to about 300 feet in the northwest corner. The subdivisions and their thicknesses recognized in the Kasper No. 1 James well are as follows: Chouteau Limestone, 111 feet; Sedalia Dolomite, 30 feet; Burlington Limestone, 145 feet; Warsaw Limestone, 75 feet; Salem Limestone, 50 feet; and St. Louis Limestone, 50 feet (Lee, 1940).

The St. Louis Limestone directly underlies Pennsylvanian rocks throughout Johnson County, except in the northwestern and southeastern corners where the Salem Limestone is the uppermost Mississippian formation (Lee and others, 1946, sheet 5).

Pennsylvanian Rocks

Pennsylvanian rocks are represented, in ascending order, by Desmoinesian, Missourian, and Virgilian Stages. The Cherokee and Marmaton Groups constitute the Desmoinesian Stage. The Missourian Stage consists of the Pleasanton, Kansas City, and Lansing Groups. Only the lower part of the Virgilian Stage, the Douglas Group, is represented in Johnson County. Pennsylvanian rocks exposed in Johnson County are discussed in detail on the following pages.

STRATIGRAPHY OF OUTCROPPING ROCKS

Pennsylvanian System—Missourian Stage

KANSAS CITY GROUP—BRONSON SUBGROUP

Swope Limestone

The Swope Limestone is the oldest formation that crops out in Johnson County. It is exposed only in the bed of Indian Creek in secs. 10 and 11, T.13 S., R.25 E. The formation comprises three members which are, in ascending order: Middle Creek Limestone, Hushpuckney Shale, and Bethany Falls Limestone. The entire formation has a thickness of about 25 feet.

BETHANY FALLS LIMESTONE MEMBER

The Bethany Falls is about 20 feet thick along Indian Creek just east of the State line in Missouri. Only the upper 5 to 10 feet of the member is exposed locally in and along the creek bed in Kansas. Exposures of this unit are limited and are not shown on plate 1.

Galesburg Shale

The Galesburg Shale is exposed only in and along the bed of Indian Creek (sec. 11, T.13 S., R.25 E.). It comprises about 2 feet of medium-gray to medium-bluish-gray argillaceous shale that weathers yellowish to yellowish gray and directly underlies the hard black fissile shale of the Stark Shale Member of the Dennis Limestone.

The thin Canville Limestone Member of the Dennis Limestone is absent in outcrops along Indian Creek in Johnson County and in adjacent Jackson County, Mo., but the Galesburg Shale is readily separable from the overlying Stark Shale Member on the basis of lithology.

Drillers' logs of wells drilled through the Galesburg Shale indicate that the shale ranges in thickness from about 1 to 4 feet. In many drillers' logs the Galesburg Shale and the overlying Stark Shale Member of the Dennis Limestone are not differentiated but are logged as "dark shale." The outcrop of the Galesburg Shale is not extensive enough to show on plate 1.

Dennis Limestone

The Dennis Limestone ranges in thickness from about 28 to 35 feet in outcrops along Indian Creek near the Kansas-Missouri State line. The formation includes one shale and two limestone members in much of eastern Kansas, but the lowermost member, the Canville Limestone, is not identified along Indian Creek or elsewhere in the Kansas City area. A thin limestone, about 1 foot or less thick and in the stratigraphic position of the Canville, is reported in the subsurface of Johnson County in a few well logs.

STARK SHALE MEMBER

The Stark Shale Member comprises about 3 to 4 feet of shale, the lower 1 to 2 feet of which is very dark gray to black, fissile, and carbonaceous and contains numerous small gray or brownish-gray elliptical phosphatic concretions ranging in diameter from about 0.5 to 1.5 inches. The dark-gray or black shale is overlain by about 2 feet of yellowish-gray or light-olive-gray argillaceous slightly calcareous shale. Although fossils are not a conspicuous feature of the Stark, the dark shale contains a few *Lingula* and conodonts, and the light shale contains a few brachiopods and bryozoans in the Kansas City area.

The only exposures of the member are along Indian Creek in secs. 10 and 11, T.13 S., R.25 E. (pl. 1).

WINTERSET LIMESTONE MEMBER

The upper member and predominant part of the Dennis Limestone is the Winterset Limestone. Good exposures of the Winterset are along Indian and Tomahawk Creeks near the State line, but the complete thickness is not well exposed at any one site. The limestone has a thickness of about 30 feet in the outcrop area and is nearly uniform in thickness in the subsurface.

The lower beds are dark-gray to medium-light-gray or dusky-blue medium- to thick-bedded fine-grained limestone. The rock weathers light gray. Individual limestone beds are uneven to slightly wavy bedded and have clayey partings along some of the bedding planes. The limestone contains fine irregular veins of calcite that Moore (1949, p. 92) ascribed as being of probable algal origin. Near the middle of the Winterset the limestone beds are thin to medium bedded and one or more thin dark-gray or grayish-black shale beds as much as 0.5 foot thick are present. Drillers' logs indicate that dark-gray to black shale in one or more beds in the middle to upper part of the member is as much as 2 feet thick locally.

The upper Winterset beds, 12 to 15 feet thick, comprise gray fine-grained thin- to medium-bedded limestone containing scattered nodules of gray to black chert overlain by very light to light-gray cross-bedded oolite that weathers light olive gray. The dark chert is characteristic of the middle and upper beds in the Kansas City area. Oolitic limestone, several feet thick, at the top of the Winterset crops out in the bed of Tomahawk Creek about 50 feet north of 119th Street (SE¼ SE¼ sec. 16, T.13 S., R.25 E.) in Leawood.

The upper Winterset beds contain an abundant fauna that includes many species of mollusks and brachiopods. The lower beds are much less fossiliferous than the upper beds, yet contain a large variety of fossils.

KANSAS CITY GROUP—LINN SUBGROUP

Cherryvale Shale

The Cherryvale Shale comprises five members which are, in ascending order: Fontana Shale, Block Limestone, Wea Shale, Westerville Limestone, and Quivira Shale. In its outcrop area the formation ranges in thickness from about 44 to 60 feet.

FONTANA SHALE MEMBER

The lowermost member of the Cherryvale is generally medium- to dark-gray or greenish-gray argillaceous shale that weathers light olive gray to yellowish gray. It is slightly calcareous and locally contains calcareous nodules. In outcrops along Tomahawk Creek (SW¼ sec. 15, T.13 S., R.25 E.) it is 6 to 8 feet thick. Thicknesses reported in well logs range from 2 to 4 feet in the northeast part to 10 to 12 feet in southern parts of the county. Fossils are generally sparse, but near the top of the member the brachiopod *Chonetina flemingi* occurs in abundance.

BLOCK LIMESTONE MEMBER

The Block is fine-grained gray to bluish-gray limestone that weathers yellowish gray to olive gray. It is a single even bed of limestone 0.5 foot thick in outcrops in the Blue River valley (SE cor. sec. 10, T.14 S., R.25 E.) and about 0.5 to 0.8 foot thick along Tomahawk Creek (SW¼ sec. 15, T.13 S., R.25 E.). Locally in the subsurface it may be thicker and comprise two or more limestone beds separated by shaly partings. It is commonly reported to be 2 to 3 feet thick in drillers' logs. The limestone is fossiliferous with brachiopods, crinoids, and fusulinids being most common, and the lower surface contains many *Chonetina*. It is exposed at only a few localities in Johnson County.

WEA SHALE MEMBER

The Wea is commonly the thickest member of the Cherryvale Shale. It is 25 to 35 feet thick in outcrops along Blue River and Tomahawk Creek valleys but is much thinner along the lower part of Mill Creek and along the Kansas River where it ranges in thickness from about 7 to 20 feet. The member is chiefly medium-gray to dark-greenish-gray argillaceous shale. Drillers' logs indicate the presence of red shale and sandy dark-gray to black shale in the Wea in parts of T.15 S., Rs.21 to 24 E., in southern Johnson County. Clair (1943, p. 20) has described the "Belton sand" of adjacent Cass County, Mo., as stratigraphically replacing the overlying Westerville Limestone Member of the Cherryvale and all or part of the Wea Shale Member. A gray very fine grained quartzose sandstone in the stratigraphic position of the Wea in parts of Tps.14 and 15 S., Rs.24 and 25 E., probably is the "Belton sand" of Clair.

WESTERVILLE LIMESTONE MEMBER

The thickness of the Westerville varies considerably in Johnson County. In outcrops in the eastern and northern parts of the county, the member ranges from about 4 feet (SW¼ sec. 15, T.13 S., R.25 E.) to more than 19 feet (fig. 5A) in thickness; in the subsurface it ranges from 0 to 30 feet in thickness.

The member has two facies: a lower light-gray to light-greenish-gray fine-grained to sublithographic thin- to medium-bedded limestone that is sparingly fossiliferous, and an upper very light gray crossbedded oolitic limestone containing numerous crinoid, bryozoan, mollusk, and brachiopod remains (fig. 5A). The lower part, termed "Bull ledge" by quarry operators in the Kansas City area, is the more persistent facies and is more uniform in thickness, commonly 3 to 6 feet, whereas the upper oolitic part is highly variable in thickness and distribution. The oolitic part has been called the "Kansas City oolite" by quarrymen and has been used as a building stone in this area. In a few exposures the Westerville has a shaly zone between the oolitic and non-oolitic parts. Along the Kansas River valley northeast of Holliday, in Wyandotte County, about 6 feet of calcareous shale interbedded with nodular and irregular-bedded limestone overlies the crossbedded oolite and is included in the Westerville (Newell, 1935, p. 41).

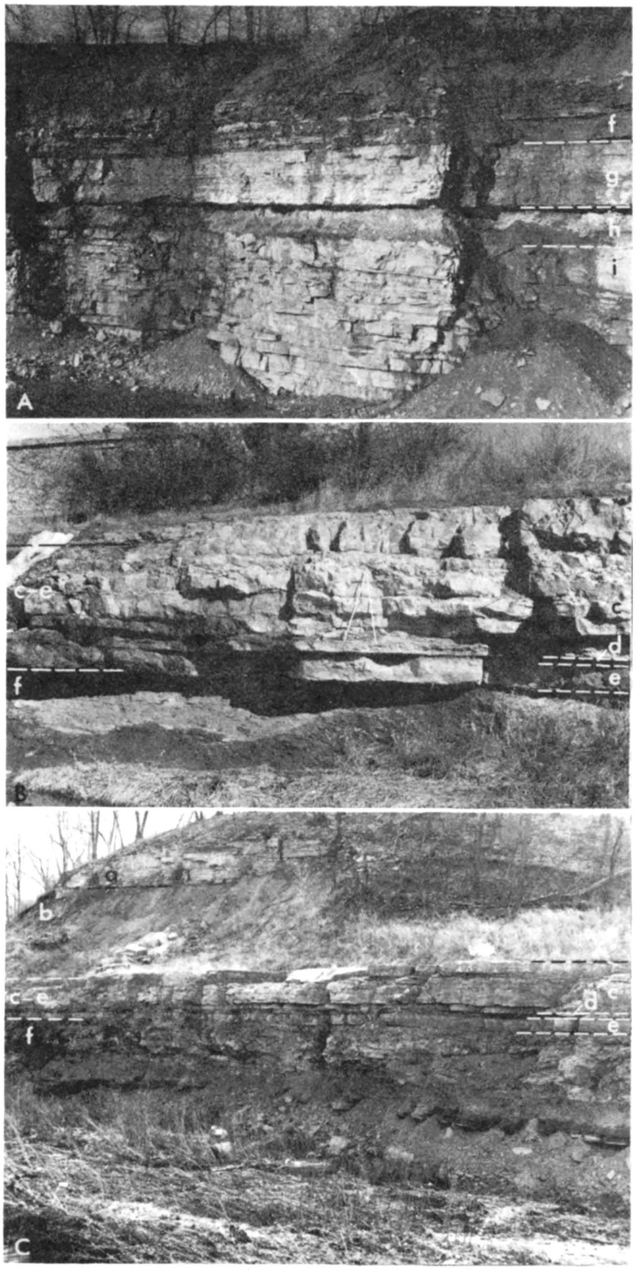

FIGURE 5.—*A*, Quarry exposure of the Chanute Shale, Drum Limestone, and Cherryvale Shale in the NW¼ NW¼ sec. 35, T.12 S., R.25 E. *B*, Creek exposure of Iola Limestone and Chanute Shale in the SW¼ NW¼ SW¼ sec. 15, T.12 S., R.25 E. Folding carpenters rule is 6 feet long. *C*, Wyandotte Limestone, Lane Shale, Iola Limestone, and Chanute Shale exposed along Turkey Creek in the SE¼ NW¼ sec. 6, T.12 S., R.25 E. *a*, Wyandotte Limestone. *b*, Lane Shale. *c-e*, Iola Limestone; *c*, Raytown Limestone Member, *d*, Muncie Creek Shale Member, *e*, Paola Limestone Member. *f*, Chanute Shale. *g*, Drum Limestone. *h-i*, Cherryvale Shale; *h*, Quivira Shale Member, *i*, Westerville Limestone Member.

The Westerville Limestone Member and the Drum Limestone have considerable similarity in lithology and thickness along the Blue River valley but generally can be differentiated by their relation to the overlying and underlying shales, by the presence of *Triticites* sparsely distributed through the non-oolitic part of the Westerville but absent in the Drum, and by the characteristic coral *Caninia torquia* in the Drum but not in the Westerville.

QUIVIRA SHALE MEMBER

In most exposures the Quivira ranges from 2 to 11 feet in thickness. Commonly the Quivira is thin at localities of thick Westerville (fig. 5A). In nearly all exposures the Quivira consists of three lithologic units. The lower part is grayish-green or greenish-gray argillaceous shale that contains a few mollusks and, in some exposures, an impure, soft, limy or calcareous zone. The middle unit is dark-gray to grayish-black fissile bituminous shale containing sparse *Orbiculoidea.* The dark shale commonly is 0.3 to 1.0 foot thick, but locally may be absent. The upper unit of Quivira is green shale and claystone, predominantly argillaceous, but locally calcareous enough to be quite hard.

Red rather than green shale is reported below the black shale in some well logs in T.13 S., R.23 E. Red shale also is present in outcrops along the east side of sec. 21, T.13 S., R.25 E.

DRUM LIMESTONE

In Kansas the Drum Limestone consists of the Dewey Limestone Member and the overlying Corbin City Limestone Member. In Johnson County, however, the Dewey Limestone Member represents all, or nearly all, the formation. The Drum ranges in thickness from about 4 to 15 feet, averaging about 10 feet in the northern and central parts of the county and about 5 feet in outcrops along the Blue River and in well logs in T.15 S.

The Dewey Limestone Member is a massive-appearing limestone ledge in fresh exposures, but upon weathering appears to be thin to medium bedded and wavy (fig. 5A). In outcrops in northern Johnson County the member is medium light gray to light gray and yellowish gray. Much of the rock matrix is very finely crystalline to sublithographic and only sparsely fossiliferous. Locally, small nodules of pyrite 1 to 5 mm (millimeters) in diameter are present in the rock. Clear crystalline calcite is present as veins and nodular masses and as replacement and fillings of fossils. Locally along the Kansas River, Mill Creek, and Tomahawk Creek, the Dewey contains scattered small pink or light-gray chert nodules in the middle or lower part. Along Mill Creek there are chert nodules also in the upper part of the member. Fossils are not abundant in the Dewey, although brachiopods, crinoids, and bryozoans are common; near the top is a persistent zone of the horn coral *Caninia torquia*. This coral is not found in the Westerville or the Iola Limestone and, therefore, is a useful aid in identifying the Dewey.

The upper member of the Drum is tentatively identified in Johnson County. A coquinoid to suboolitic limestone less than 1 foot thick (generally less than 0.2 foot thick) is separated from the remainder of the Drum Limestone by a parting of a few tenths of a foot of green shale containing *Teguliferina*. This upper limestone is considered by Moore (1935, p. 107) to represent the Corbin City Limestone Member, because of its lithologic character and its position as a "super" limestone of a Missourian Stage megacyclothem. The green shale separating the thin Corbin City from the Dewey is unnamed.

Chanute Shale

Argillaceous, silty, and sandy shale beds and some sandstone beds compose the Chanute Shale (fig. 5A, C). The formation ranges in thickness from about 12 to 32 feet in outcrops, being thinnest along Mill Creek and the Kansas River and thickest along the Blue River in southeastern Johnson County. A maximum of 33 feet of Chanute is indicated in logs of wells drilled in southeastern Johnson County, but elsewhere in the subsurface it is commonly 15 to 25 feet thick. Exposures of Chanute along the Blue River and Tomahawk Creek, where the thickness of the formation is greatest, show the lower few feet to be grayish-black, dark-greenish-gray, or grayish-blue silty to sandy shale, locally containing small calcareous nodules, overlain by 4 to 6 feet of red to very-dusky-red to purple silty to sandy shale. The red to purple shale is overlain by a few feet of grayish-green to dark-greenish-gray shale, which locally contains a thin impure "marly" limestone as much as 1 foot thick near the base and a thin coal smut at or near the top.

A bed of very fine grained micaceous sandstone, as much as 4 feet thick, locally overlies the greenish-gray shale in parts of Tps.13 and 14 S., R.25 E., just above the middle of the formation. Strata above the sandstone and greenish-gray shale are mostly gray to green sandy to silty shale. A gray coquinoid limestone less than 0.5 foot thick is present locally about 2 feet below the top of the formation in the area south of James Branch along Lee Boulevard in Leawood (SE¼ sec. 3, T.13 S., R.25 E.).

In sections exposed along Mill Creek and the Kansas River, the lower half of the Chanute is green argillaceous shale and claystone, overlain by interbedded green and gray calcareous claystone and nodular limestone. The upper half of the formation is green to gray shale and claystone, which locally contains a thin red zone.

In well logs the Chanute is represented chiefly as gray, green, and blue shale, which locally is sandy or includes a thin bed of sandstone. The formation contains a red or purple zone in the southeastern and southern parts of the county. In a few well logs the "marly" impure limestone above the red shale is logged as much as 4 feet thick.

Iola Limestone

The thickness of the Iola Limestone in outcrops ranges from about 6 to 10 feet (fig. 5B,C). The formation includes two limestones and one shale member.

Paola Limestone Member

The Paola is the basal member of the Iola Limestone. It is a dense olive-gray to bluish-gray very fine grained to sublithographic limestone that ranges from 1 to 2.4 feet in thickness. The rock is hard and brittle and breaks with a subconchoidal fracture. The Paola is typically a single bed containing prominent closely spaced vertical joints. The weathered rock is lighter gray than the unweathered rock. Although the basal contact is relatively smooth, the upper contact is highly irregular and pitted. Uneven iron-stained cylindrical tubes of limestone having slightly different texture extend downward a few inches from the top of the member. Within the drainage area of Tomahawk Creek, small medium-gray to grayish-black phosphatic nodules are embedded partly in the upper 0.05 foot of the Paola and partly in the overlying shale member. The presence of the phosphatic nodules embedded in the top of the Paloa seems to be restricted to the areas where the overlying Muncie Creek Shale Member is very thin. This feature is well exposed along the small intermittent streams in the N½ SW¼ sec. 20, T.13 S., R.25 E., and in the SE¼ SE¼ sec. 30, T.13 S., R.25 E.

Although the Paola is fossiliferous, fossils are not always a conspicuous feature of the rock. Cryptozoan algal structures, crinoid fragments, gastropods, cephalopods, and brachiopods are the most common fossils.

Muncie Creek Shale Member

Grayish-black fissile shale containing small (0.5 to 1 inch) ellipsoidal phosphatic concretions is the distinctive and identifying feature of the Muncie Creek Shale Member. At several outcrops of the Iola near Mission Hills, Prairie Village, and Leawood, the Muncie Creek is represented by only 0.1 to 0.2 foot of gray shale, and the grayish-black fissile shale is absent or poorly represented, although the phosphatic nodules are present (fig. 5B,C). Along the Kansas River and

Cedar Creek the member is locally 2.2 feet or more thick and consists of three distinct parts. The basal part is 0.1 to 0.3 foot of dark-gray to olive-gray fissile shale with sparse *Lingula.* The middle part is 1 to 1.5 feet of grayish-black hard fissile shale containing conodonts, sparse *Conularia,* and the typical grayish-black phosphatic concretions. Upon weathering, the surface of the concretions becomes light gray. The upper part is gray to green shale and blocky-weathering claystone about 0.5 foot thick.

Although the *Conularia* are not abundant, they probably are much more abundant in the Muncie Creek than in any of the other outcropping strata in the county.

RAYTOWN LIMESTONE MEMBER

The Raytown ranges from 4 to about 14 feet in thickness and averages slightly more than 5 feet. It consists principally of very light gray to medium-gray fine- to medium-crystalline limestone that has slightly uneven or wavy beds, 0.2 to 0.8 foot thick. Thin shale partings locally separate the limestone beds. The basal and most distinctive part of the Raytown in northeastern and northern Johnson County is a thin (0.1 to 0.5 foot) generally light to very light gray calcarenite or calcirudite (Pettijohn, 1957) composed chiefly of crinoid or crinoid and brachiopod fragments (fig. 5B,C). Small amounts of sand-sized fragments of green calcareous clay or shale are associated with the fossil detritus.

In the urban area of northeastern Johnson County, north of Indian Creek, the thin basal crinoidal bed is as useful and distinctive as the phosphatic nodules of the Muncie Creek in discriminating the Iola Limestone from the similar sequence of limestone and shale beds in the lower part of the Wyandotte Limestone. In many poorly exposed outcrops the crinoidal bed can be distinguished and the member identified. The crinoidal calcarenite is separated from the overlying limestone by about 0.1 to 0.5 foot of light- to medium-gray shale.

In outcrops, the main ledge of the Raytown, which is 4 to 6 feet thick, has a mottled appearance because of irregular coloration in the upper beds. Shades of pink, yellow, and gray in irregular patches about 1 to 4 inches in maximum diameter give the limestone a distinctive coloration and account for the term "calico bed" given to it by quarrymen in the Kansas City area. Weathered outcrops of the Raytown become yellowish brown or yellowish orange.

At a few localities along Tomahawk and Indian Creeks, a gray shale bed and a limestone bed overlie the main ledge of the Raytown and locally increase the thickness of the member to about 14 feet. The gray shale may be as much as 3 feet thick and the overlying limestone may be as much as 5 feet thick. These upper limestone and shale beds in the Raytown become more persistent southward in Miami County (Miller, 1966, p. 15, 16).

Productids, especially *Linoproductus, Echinaria,* and *Juresania,* are abundant. *Neospirifer,* crinoid fragments, and several species of bryozoans also are abundant.

KANSAS CITY GROUP—ZARAH SUBGROUP

LANE SHALE

The Lane Shale (fig. 5C) includes the strata, chiefly shale, between the underlying Iola Limestone and the overlying Wyandotte Limestone. The Lane Shale and the overlying Wyandotte Limestone and Bonner Springs Shale compose a complex of shale and limestone beds that varies greatly in thickness and character across Johnson County. Thickening or thinning of the Wyandotte Limestone commonly is accompanied by changes in thickness of the Lane and Bonner Springs Shales. Each of these three units has a much greater range in thickness than any of the other units in the Kansas City and Lansing Groups.

In outcrops the Lane Shale ranges in thickness from about 70 feet in the area south of and along Brush Creek in secs. 15, 21, and 22, T.12 S., R.25 E., to 10 feet locally along Tomahawk Creek in the southern part of T.13 S., R.25 E., and along Negro Creek in T.14 S., R.25 E. (pl. 1). About 68 feet of the formation was measured in sec. 5 and in the SW¼ sec. 7, T.13 S., R.25 E. Only the upper part of the Lane is exposed along Little Bull Creek in T.15 S., R.23 E., but outcrop measurements and well-log data indicate that the lower Wyandotte beds become lenticular and thin or are absent southward in this area, resulting in an abrupt thickening of the shale between the Iola Limestone and the remaining Wyandotte Limestone. This thickened shale interval is considered to be Lane Shale rather than a Lane-Wyandotte combination following the practice of Newell (1935) and Moore (1935). Therefore, the Lane has a thickness locally of about 95 feet in T.15 S., R.23 E. In much of the county the formation is 20 to 50 feet thick (fig. 6).

The Lane Shale is primarily argillaceous and silty shale, but parts of the formation are thin-bedded claystone and siltstone that break into blocky or splintery fragments. Where the formation is thick, the middle and upper parts commonly are silty or sandy and locally contain a few feet of very fine grained micaceous sandstone. The silty and sandy beds may be carbonaceous locally. Megascopic marine fossils are

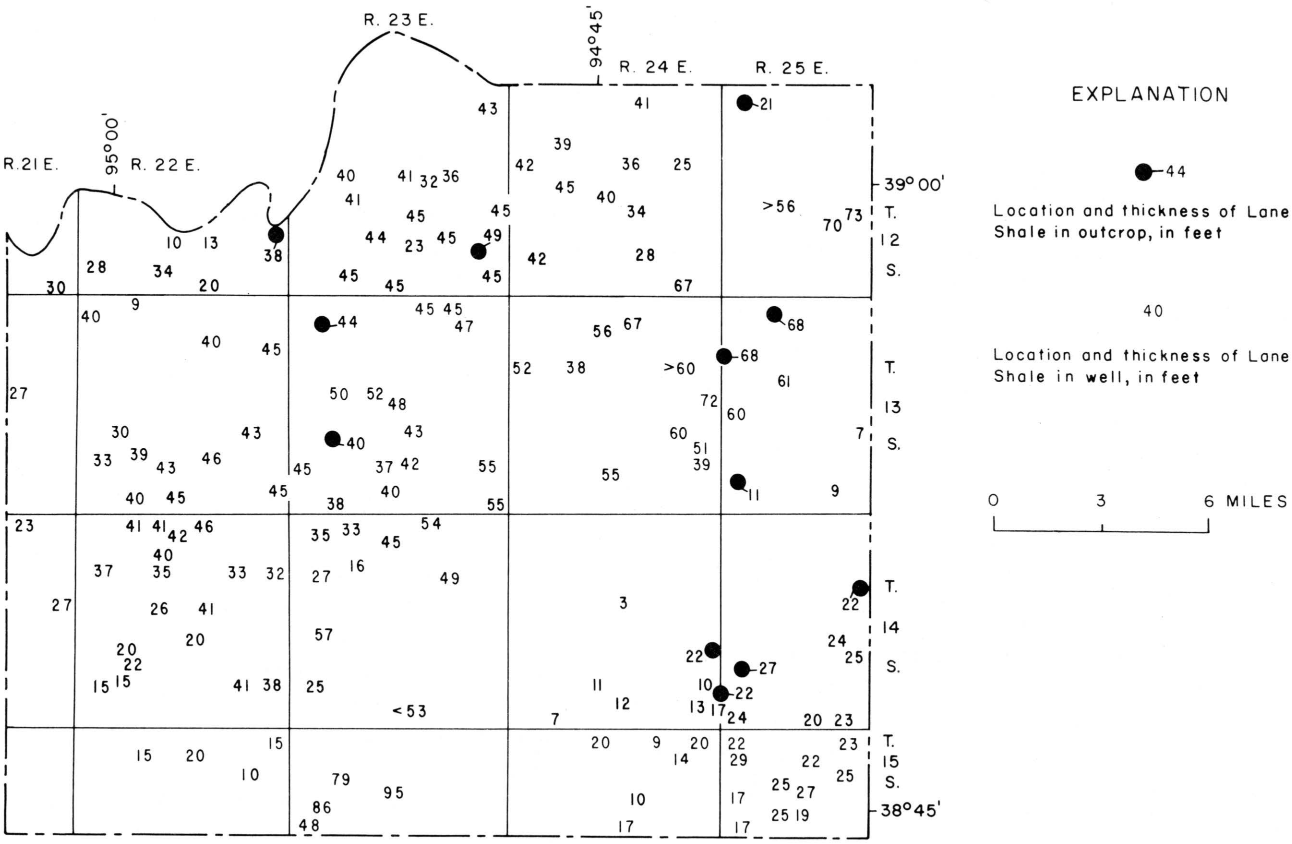

FIGURE 6.—Thicknesses of Lane Shale in outcrops and wells.

sparse or absent in most Lane exposures, but small pelecypods and gastropods locally are common in the upper part. Good specimens of small pelecypods have been collected about 7 feet below the top of the shale in a railroad cut (NE¼ sec. 1, T.13 S., R.23 E.) in Mill Creek valley. Ammonites, pelecypods, gastropods, crinoids, brachiopods, and bryozoans are abundant in the upper 2 feet of Lane Shale in a quarry 0.4 mile east of the SW cor. sec. 23, T.14 S., R.25 E., along the State line in Missouri. Some of the fossils have been replaced by pyrite.

Scattered small spheroidal or disk-shaped concretions are found locally in the middle or upper parts of the shale. The Lane is medium to moderately dark gray and blue in unweathered outcrops and well samples, but weathered exposures are light gray, yellowish gray, and yellowish orange.

WYANDOTTE LIMESTONE

The Wyandotte Limestone consists of five members designated, in ascending order: Frisbie Limestone, Quindaro Shale, Argentine Limestone, Island Creek Shale, and Farley Limestone. Although the formation crops out extensively in Johnson County, it cannot everywhere be divided into its five members. It ranges in thickness from a reported maximum of 103 feet in sec. 15, T.15 S., R.24 E., to a minimum of possibly 2 feet in the SE cor. sec. 36, T.13 S., R.24 E. Along Tomahawk Creek, in the SW cor. T.13 S., R.25 E., and the SE cor. T.13 S., R.24 E., the formation is less than 5 feet thick. The minimum thickness recorded on well logs is 16 feet (fig. 7). Where the Wyandotte is thin, it is overlain by a thick shale and sandstone section in the Bonner Springs Shale, and is underlain by a thin section of Lane Shale. Because of the Wyandotte's extensive distribution, relatively great thickness, and economic importance as a source of commercially minable limestone in a metropolitan market, the stratigraphy of this unit is described in greater detail than the stratigraphy of other outcropping limestones.

The Wyandotte Limestone, of which the Argentine and Farley Members constitute the dominant part, may be divided into three major facies. The facies have been delineated chiefly from data on the Argentine and Farley Members. A detailed study of the entire formation probably would indicate two or more major facies in the Frisbie, Quindaro, and Island Creek Members also. Areas A, B, and C on figure 7 show the approximate distribution of the three major facies. In areas A and B, the Wyandotte is thick (35 to 103 feet)

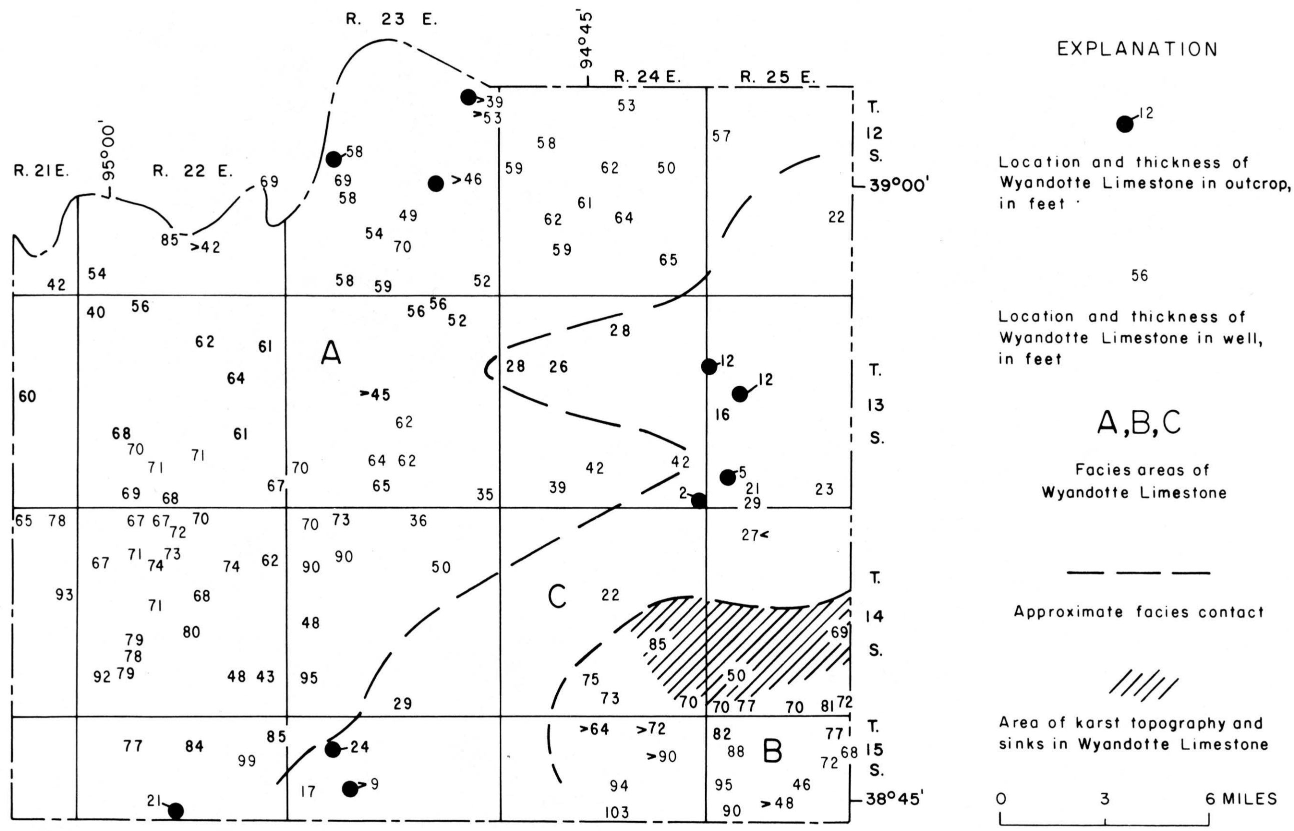

FIGURE 7.—Thicknesses of Wyandotte Limestone in outcrops and wells.

and contains a high percentage of limestone beds that were deposited in a shallow marine environment that was subject to repeated wave and current agitation. The Wyandotte in areas A and B contains shallow-shelf facies deposited within the zone of wave action—the undathem-type deposits of Rich's (1951) terminology. Most of the Argentine and much of the Farley in areas A and B consist of abundantly fossiliferous thin- to medium-wavy-bedded limestone containing many broken and abraded shells in a fine-grained matrix. Other parts of the two members consist of oolite, coquinite, and pseudo-brecciated algal limestone, which locally exhibit crossbedding or other evidence of wave and current action. The hachured part of area B (fig. 7) is underlain by a thick section of Wyandotte in which 95 percent or more of the formation is limestone. Because of the high proportion of limestone, and perhaps other favorable factors, a karst topography has developed in this local area where the Wyandotte is at or near the land surface, and several dozen sink holes of various sizes have formed. One of the other factors that may have resulted in karst topography development is that the Wyandotte in area B contains a limestone facies that is somewhat more coarsely textured and contains less shale than the facies in area A.

Area C is underlain by a Wyandotte facies deposited chiefly on sloping and deeper parts of the sea floor below the zone of effective wave action—comparable to the clinothem and fondothem deposits of Rich (1951). For the most part, the limestone and shale members in area C cannot be identified and related with any certainty to the named Wyandotte members in areas A and B.

During deposition of thick Wyandotte Limestone material, chiefly carbonates, in areas A and B, only a small amount of carbonate material was being deposited in area C. Some of the shale and sandstone where the Lane and Bonner Springs Shales are thick in area C was deposited contemporaneously with the thick Wyandotte carbonates in areas A and B. A good example of the abrupt lateral change from carbonate to shale, together with a distinct primary dip of the carbonate beds at the edge of the carbonate shelf, can be observed along Coffee Creek in secs. 14 and 23, T.14 S., R.24 E., and along Wolf Creek in sec. 34, T.14 S., R.24 E.

FRISBIE LIMESTONE MEMBER

The type locality of the Frisbie Limestone Member is near Frisbie in northern Johnson County, and the member is typically exposed in a road cut at the east side of the NE¼ NW¼ sec. 17, T.12 S., R.23 E. The Frisbie is characteristically dark-gray to medium-light-gray, brownish-gray, or bluish-gray limestone that ranges from about 1 to 5 feet in thickness. In the type locality the member is composed of a single massive bed of dense fine-grained limestone that is 1.5 feet thick. The member contains a sparse fauna of brachiopods and crinoid fragments and more abundant *Ottonosia* algae and fragments of leaflike algae represented by veinlets of clear calcite. The base of the limestone is generally even but the upper surface is irregular.

Near Craig, the Frisbie attains the maximum thickness observed in the county. Along the south side of the county road (SW¼ sec. 25, T.12 S., R.23 E.) the Frisbie is a massive limestone, 5.1 feet thick, but otherwise is similar to the member in the type area. Along road exposures near the center of sec. 34, T.12 S., R.23 E., the lower part is massive, but the upper part consists of about 0.5 foot of thin fine-grained limestone and shale interbeds overlain by about 0.7 foot of coarse-grained limestone that contains abundant algae and shell fragments in a fine-grained matrix. The Frisbie is about 4.7 feet thick at this exposure. In some exposures the Frisbie has several mound-like structures, or bioherms (Thornbury, 1954), that comprise the upper part of the member (fig. 8A). The lower 1 to 2.5 feet consist of massive medium-gray dense hard calcilutite beds that are jointed vertically and break with sharp edges. Overlying this interval are lense-shaped limestone beds as much as 4 feet thick and 10 to 40 feet wide that have an entirely different character. These beds consist of light- to medium-gray and yellowish-gray poorly bedded brecciated-appearing mottled limestone of the type that has been considered to be of algal origin by many workers. The overlying Quindaro Shale Member is reduced in thickness as a result of the bioherm developments, and the base of the Frisbie is depressed or downwarped.

In outcrops in eastern Johnson County within the drainage areas of Turkey Creek, Indian Creek, and Blue River, the Frisbie is less certainly defined inasmuch as the overlying Quindaro Shale Member is absent or gradational with the lower part of the Argentine Limestone Member. However, many outcrops of lower Wyandotte have a very light to medium-gray or grayish-blue dense massive fine-grained limestone, lithologically and paleontologically similar to typical Frisbie, at their base. In the Blue River area, limestone of the basal Wyandotte is less dense, more fossiliferous, and lighter in color, suggesting an environment of deposition different from that of type-locality Frisbie.

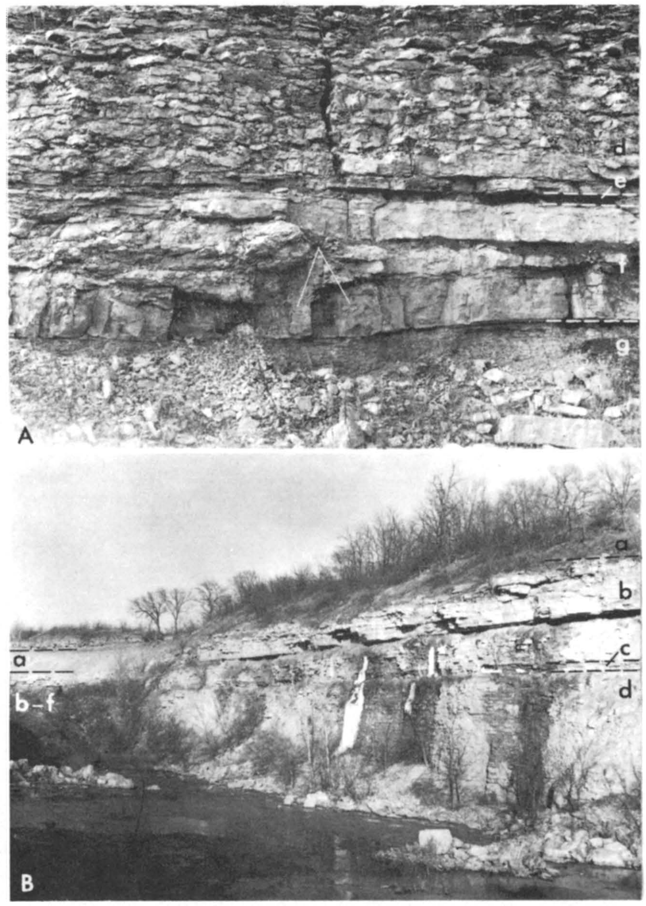

FIGURE 8.—*A*, Lower part of the Wyandotte Limestone and upper beds of the Lane Shale along the Atchison, Topeka, and Santa Fe Railroad in the NE¼ sec. 1, T.13 S., R.23 E. Folding carpenters rule is 6 feet long. *B*, Bonner Springs Shale and Wyandotte Limestone in a quarry in the SE¼ NW¼ sec. 9, T.13 S., R.22 E. *a*, Bonner Springs Shale. *b-f*, Wyandotte Limestone; *b*, Farley Limestone Member, *c*, Island Creek Shale Member, *d*, Argentine Limestone Member, *e*, Quindaro Shale Member, *f*, Frisbie Limestone Member. *g*, Lane Shale.

In the area drained by Tomahawk Creek, much of the Wyandotte cannot be divided reliably into its five component members, and in parts of this area the Frisbie cannot be identified. Typical Frisbie has not been recognized along Bull Creek and Little Bull Creek in southern Johnson County.

QUINDARO SHALE MEMBER

The Quindaro Shale Member has a maximum observed thickness of about 7.5 feet along the Kansas River (NW¼ NE¼ sec. 25, T.12 S., R.22 E.), but thicknesses of 2 to 5 feet are more common along the Kansas River and in Cedar Creek and Mill Creek drainage areas. Only about 0.3 foot of Quindaro is present in spillway exposures at New Olathe Lake. The Quin-

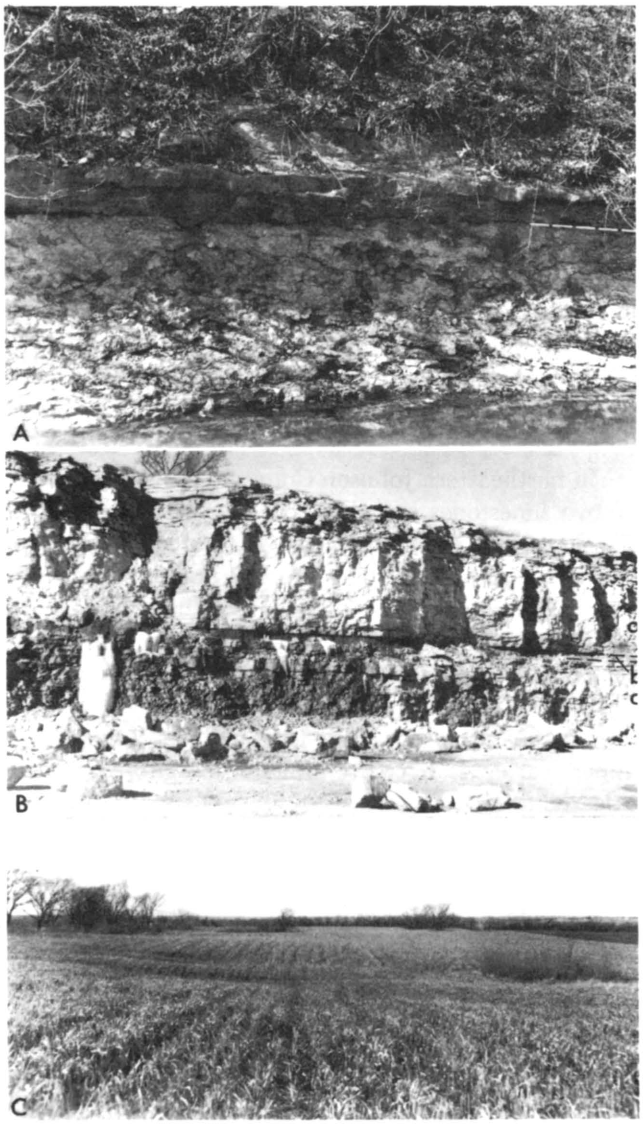

FIGURE 9.—*A*, Massive calcarenite bed in upper part of the Argentine Limestone Member disconformably overlying the irregular-bedded main part of the member in the SE¼ NE¼ NW¼ sec. 31, T.13 S., R.23 E. *B*, Upper part of the Wyandotte Limestone in a quarry in the SW¼ SW¼ sec. 29, T.13 S., R.23 E. *C*, Sink holes in Wyandotte Limestone. View is west from the SW¼ SE¼ SE¼ sec. 30, T.14 S., R.25 E. *a-c*, Wyandotte Limestone; *a*, Farley Limestone Member, *b*, Island Creek Shale Member, *c*, Argentine Limestone Member.

daro is absent or doubtfully identified in eastern and southern Johnson County.

Along Turkey Creek in northeastern Johnson County, the lower Wyandotte beds grade upward from a "Frisbie type" limestone to about 0.3 foot of dark-gray shale to about 8 feet of thin-bedded to nodular limestone interbedded with calcareous and fossiliferous shale. The thin dark-gray shale is included in the Quindaro, but the interbedded limestone and shale beds are not easily classified. They are more logically placed with the overlying Argentine Limestone Member.

Along the Kansas River, Cedar Creek, and Mill Creek where the member is best developed, the Quindaro has a thin (0.1 to 0.3 foot) dark-gray shale at the base overlain by several feet of interbedded gray to yellowish-gray and greenish-gray calcareous shale and gray irregular thin-bedded or nodular limestone. *Composita*, bryozoans, crinoid fragments, sparse sponges, and echinoid fragments are the typical fossils.

ARGENTINE LIMESTONE MEMBER

The Argentine Limestone Member (figs. 8A,B; 9A) is commonly the thickest and most prominent member of the Wyandotte Limestone; it is recognized in the Kill Creek, Cedar Creek, Mill Creek, Turkey Creek, and Blue River drainage areas. The member can be divided into upper and lower distinctive parts. The lower part consists of very light to medium-gray or bluish-gray thin to medium irregular- to wavy-bedded limestone with several very thin, but uneven, gray shale partings; it comprises all but the upper few feet of the member. In some exposures, the shale partings are thicker and more apparent in the lower few feet than elsewhere and tend to mask the contact between the Argentine and the underlying Quindaro. The lower limestone beds of the lower Argentine are aphanitic to finely crystalline, but have recrystallized fossils and void fillings of brownish-gray, olive-gray, or colorless fine- to very coarsely crystalline calcite scattered through the beds. Fossils are abundant and include several brachiopods, namely *Composita, Antiquatonia, Echinaria*, and *Enteletes*, ramose and fenestrate bryozoans, and crinoid fragments. Less abundant but still common are small gastropods, small horn corals, and fusulinids. The basal part generally contains a few sponges having an algal coating or overgrowth. The upper part of the lower Argentine locally is gray, pinkish gray, and bluish gray, mottled and brecciated appearing; it probably is partly algal in origin.

The upper part of the Argentine consists of about 1 to 4 feet of massive coarse-grained calcarenite or more rarely of oolite, which locally disconformably overlies the finer grained beds (fig. 9A,B). The change in texture and bedding between the lower and upper Argentine beds generally is very sharp in weathered exposures.

The upper Argentine calcarenite is light to medium gray, bluish gray, and light olive gray. It consists chiefly of coated grains *(Osagia?)* and crinoid and brachiopod remains, and usually has a molluscan fauna, especially *Myalina*, and large gastropods in the lower part of the bed. Oolite locally forms a part of the massive bed above the molluscan zone and in some exposures limestone beds contain very abundant remains of encrusting algae.

The upper Argentine massive bed and a few feet of the underlying mottled algal limestone are more resistant to weathering than the lower Argentine beds and in some areas make an overhanging bench or ledge along the hillsides. This feature is well developed along the lower part of Cedar Creek valley.

At one locality (NW¼ NW¼ sec. 1, T.13 S., R.22 E.) in a quarry exposure, the upper Argentine massive bed is not represented. Overlying the wavy beds of limestone that comprise much of the lower Argentine is about 3 to 4 feet of light-gray to yellowish-gray oolite and calcarenite mixed with calcilutite beds. Overlying this bed is another 3 feet of grayish-blue, pale-red, and medium-light-gray mottled brecciated-appearing algal limestone containing abundant *Archaeolithophyllum* fragments.

Along Little Bull Creek in the NE¼ sec. 8, T.15 S., R.23 E., about 1,000 feet downstream from the section-line road, a limestone about 7 feet thick crops out which may be the facies in area C (fig. 7) equivalent of part of the Argentine. The upper 5 to 6 feet of the 7-foot bed consists of yellowish-gray to light-olive-gray oolitic and molluscan limestone, and the lower 1 to 2 feet consists of greenish-gray and bluish-gray silty limestone that weathers dark yellowish orange. The lower part contains crinoid and brachiopod fragments. This limestone may be a local lenticular bed in the Lane Shale rather than a part of the Wyandotte, but has been included with the Wyandotte, shown as 24 feet thick on figure 7.

ISLAND CREEK SHALE MEMBER

The Island Creek Shale Member ranges in thickness from less than 1 to 16 feet, but is most commonly 2 to 8 feet thick. The least thickness of well-defined Island Creek measured was 0.4 foot (NE¼ NW¼ sec. 9, T.13 S., R.22 E.) and the thickest section measured was 15.5 feet (SW¼ SW¼ sec. 17, T.12 S., R.24 E.). The member is typically medium- to dark-gray and greenish-gray shale; it commonly is calcareous and clayey in the upper part and silty or sandy in the lower part. Where thin, the member is fossiliferous; *Derbyia, Neospirifer, Aviculopinna, Myalina, Bellerophon, Pharkidonotus,* crinoids, and bryozoans are abundant. Locally in the DeSoto area, small slender fusulinids are found in the upper part (quarry at NW¼ NW¼ sec. 1, T.13 S., R.22 E.). Fusulinids also are abundantly exposed in a quarry north of Stilwell (SW¼ SE¼ sec. 31, T.14 S., R.25 E.) and along a railroad cut about 4 miles east of Stilwell in Cass County, Mo. (NW¼ sec. 33, T.46 N., R.33 W.).

The Island Creek Shale Member was not identified in areas of Johnson County where the Argentine and Farley Limestone Members could not be differentiated (area C, fig. 7).

FARLEY LIMESTONE MEMBER

The upper member of the Wyandotte Limestone is the Farley, which may comprise a single limestone, or two or three limestones, separated by shale beds (figs. 8B, 9B). The member commonly is 15 to 35 feet thick. In some outcrops the Farley is similar to the Argentine in lithology and thickness. However, in other outcrops the Farley is distinctly more massive, has fewer shale partings, and contains less impurities than the Argentine. It also is less cherty and more crystalline than the Argentine.

In northeastern Johnson County the Farley consists of two limestones separated by several feet of shale. The lower Farley is gray massive medium- to coarse-grained locally oolitic fossiliferous limestone, 3 to 12 feet thick. Shale beds, 7 to 11 feet thick, which are argillaceous in the upper part and sandy and micaceous in the lower part, constitute the middle Farley. The upper Farley is a medium- to dark-gray massive fossiliferous limestone, 2 to 10 feet thick. Locally the upper Farley is a coarse-grained "osagite," or algal calcarenite.

Near Craig, the Farley is about 28 feet thick with massive limestone beds at the top and bottom separated by reddish-gray and brownish-green shale that is interbedded with argillaceous and unfossiliferous limestone beds. This shale is interpreted to be equivalent to the green and maroon clay described by Newell (1935, p. 64, 90) in the SW¼ SW¼ sec. 17, T.12 S., R.24 E. The upper massive bed, about 10 feet thick, is coarse-grained oolitic fragmental crossbedded limestone with a very irregular or hummocky upper surface; it overlies about 4.5 feet of yellowish-gray to olive-gray sandy-appearing limestone. The lower bed is gray medium- to thin-bedded fine-grained fossiliferous limestone, about 9.5 feet thick.

Near DeSoto, several unusual exposures of the Farley may be seen in quarries and stream banks. Newell (1935) was the first to call attention to the complex stratigraphy in the DeSoto area, and more recently Wilson (1959) has compiled additional data regarding the stratigraphy of the Wyandotte beds in this area.

About 16 feet of Farley is exposed below the overlying thin (1.1 feet) Bonner Springs Shale in a small quarry along the railroad in the northwest part of DeSoto (SE¼ NE¼ sec. 28, T.12 S., R.22 E.). The upper 1 to 3 feet of Farley consists of light-gray to light-yellowish-brown crossbedded oolite and sand-size fossil detritus, which changes laterally along the quarry face to grayish-pink, pale-red, and gray mottled brecciated-appearing algal limestone. Below the oolite about 13 feet of gray, pinkish-gray, and yellowish-gray even to slightly wavy medium-bedded fine-grained limestone is exposed. This limestone contains stringers and veinlets of crystalline calcite that are probably leaflike or matlike remains of algae, or voids filled and partially filled with sparry calcite. Other small voids are filled with a moderate-brown to dark-yellowish-orange earthy limonite.

At this same locality, Newell (1935, p. 68) considered the Bonner Springs Shale to be absent and the oolitic and brecciated-appearing limestone to be the basal bed of the Plattsburg Limestone unconformably overlying the Wyandotte. The normal sequence of beds above the Farley, which has not yet been fully described, is the Bonner Springs Shale and the Merriam Limestone, Hickory Creek Shale, and Spring Hill Limestone Members of the Plattsburg Limestone. Newell also considered (1) the upper Farley beds exposed along Kill Creek bridge east of DeSoto to be a breccia bed in the Bonner Springs Shale and (2) the Hickory Creek Shale Member to be 20 feet thick rather than its common thickness of 1 or 2 feet. Wilson (1959) and this writer (this report), utilizing the same exposures as Newell and additional quarry and highway exposures and test-hole data not available to Newell, interpreted the stratigraphy somewhat differently. Wilson identified about 1 foot of Merriam underlain by about 30 feet of Bonner Springs Shale along the Kill Creek road south of the Kansas Highway 10 bridge, and about 20 feet of Farley along the east bank of the creek.

Along the north sides of Kansas Highway 10 and of Kill Creek, at the south edge of DeSoto (cen. SE¼ sec. 28, T.12 S., R.22 E.), the lower part of the Plattsburg Limestone, including part of the Spring Hill Limestone Member, all the Hickory Creek Shale Member, and all the Merriam Limestone Member, a thin Bonner Springs Shale, and the top of the Farley are exposed. In the creek bank on the south side of the highway about 30 feet of the Farley Limestone Member is well exposed. Farley beds dip eastward as much as 14 degrees locally along the creek, and the local unconformity within the Farley that is seen at the Kill Creek bridge also is exposed. The Farley is approximately 20 feet thick in the DeSoto area and, in addition to its usual fauna of crinoids, bryozoans, and brachiopods, contains abundant fusulinids in the lower part.

In the Blue River valley and its tributaries south of Stanley (southeastern Johnson County), the Farley is part of a nearly continuous limestone sequence that averages 70 to 90 feet thick. At a quarry in the SW¼ SE¼ sec. 31, T.14 S., R.25 E., at least 77 feet of Wyandotte Limestone was cored and about 70 feet occurs at the face of the quarry. The Farley at this location is about 31 feet thick and consists of two limestones separated by a thin but variable thickness of shale. The main (lower) Farley ledge comprises about 25 feet of light-gray and light-yellowish-gray limestone that weathers light shades of gray, red, and brown. It is predominantly finely crystalline to sublithographic but has irregular "veins" of crystalline calcite that may be crystallized remains of algae. Brachiopods, especially *Composita,* and crinoid fragments are sparse to common. The lower 1 foot or less of the Farley contains abundant fusulinids, a feature noted elsewhere, and a thin zone of chert nodules is present 2 or 3 feet above the base. The lower limestone is overlain by light-olive-gray argillaceous shale that ranges in thickness from 0.2 foot to 3 feet. The shale is thickest in the area where the overlying limestone is thin. The shale overlies the main Farley ledge, which has an irregular upper surface with as much as 1.5 feet of relief. The upper limestone bed is pinkish-gray to light-olive-gray granular to crystalline limestone containing voids that are filled or partly filled with sparry calcite. *Myalina,* gastropods, *Composita,* and crinoid fragments are the common fossils. The bed ranges in thickness from about 2.3 to 5.6 feet along the face of the quarry. Within this area the Farley, as well as the Argentine, locally has a karst topography (fig. 9C).

In the drainage area of Tomahawk Creek north of Stanley (area C, fig. 7), the Farley Limestone Member is not recognized locally, or is only doubtfully recognized. About 50 to 100 feet north of the center of the east line of sec. 18, T.13 S., R.25 E., along U.S. Highway 69, a light-gray to light-yellowish-gray limestone mottled and speckled with moderate-brown ferruginous clay crops out and is separated from underlying typical Argentine beds by a thin shale. The speckled gray and brown limestone beds probably are a facies of the Farley. The limestone is crossbedded and consists of sand-size grains of crinoid fragments, oolites, pellets, foraminifera, and sparse quartz grains in a finely crystalline calcite matrix. About 1 mile west (NE¼ NE¼ sec. 13, T.13 S., R.24 E.) a similar facies of the Farley is exposed. The Wyandotte at this location is about 12 feet thick, and the uppermost few inches locally includes limestone having a speckled gray and brown color and a lithology and fauna similar to that exposed along U.S. Highway 69. If these beds are correctly interpreted as Farley, the member lies directly on the Argentine, and the Island Creek Shale Member is absent. Elsewhere in the Tomahawk Creek drainage area, as in the NW¼ NE¼ sec. 31, T.13 S., R.25 E., the Farley cannot be differentiated, or is doubtfully differentiated, from other thin beds in the Wyandotte Limestone.

Along Little Bull Creek in southern Johnson County (NE¼ NE¼ NW¼ sec. 8, T.15 S., R.23 E.) about 9 feet of limestone having two distinct lithologies is exposed along the road below a complete and well-exposed section of Bonner Springs Shale. The upper 2 to 3 feet of limestone is a pale-yellowish-brown to light-olive-gray calcarenite consisting principally of fusulinids, crinoid and echinoid fragments, less abundant brachiopod and gastropod fragments, and probably also the algae *Epimastopora.* Much of the fossil material is recrystallized and the limestone matrix is finely crystalline calcite. Below this calcarenite is about 7 feet of medium-light-gray wavy thin-bedded brecciated-appearing fine-grained limestone mottled with dark-yellowish-orange ferruginous and argillaceous limestone patches. The middle of this lower limestone contains abundant *Composita* and crinoid fragments; the lower part is poorly exposed.

About 1 mile south (NW cor. sec. 16, T.15 S., R.23 E.), below a complete section of Bonner Springs Shale, upper Wyandotte Limestone beds are exposed that have a similar two-fold division of lithologies. The upper 1 to 2 feet (of about 9 feet of limestone exposed) is a calcarenite, somewhat finer grained than noted in the previous exposure. At this location the calcarenite is pale-yellowish-brown to light-brownish-gray slightly sandy limestone that consists primarily of crinoidal remains but includes lesser amounts of *Aviculopecten* and other clams and gastropods. Brachiopod, bryozoan, and trilobite fragments also were identified. Much of the shell material is recrystallized, and the intergranular space is filled with finely crystalline calcite. The lower beds in the 9-foot exposure consist of medium-light-gray to yellowish-gray slightly mottled irregular to wavy thin-bedded limestone. Blotches and irregular "vein" and cavity fillings of dark-yellowish-orange to grayish-brown limonite or goethite occur irregularly through the limestone, as does void-filling spar calcite. The limestone is predominantly fine-grained calcite. Identifiable fossil material is not common but includes brachiopods, especially *Composita,* bryozoans, and ostracodes. Much of the limestone is probably of algal origin.

The last two described exposures are within area C (fig. 7) where the Wyandotte members are not easily defined or differentiated. The calcarenite bed in these two exposures may be a part of the Farley because of the abundance of slender fusulinids, which were noted previously near the base of Farley at several other exposures in areas A and B (fig. 7). Limestone beds below the calcarenite cannot be identified definitely as Farley or Argentine on the basis of lithology or fauna. However, if the calcarenite with abundant fusulinids is basal Farley, the underlying beds probably are Argentine. It is possible also that the Farley is absent in these two exposures, and that the calcarenite bed with abundant fusulinids and the underlying thin- to irregular-bedded limestone constitute the Argentine Limestone Member of the Wyandotte Limestone.

Bonner Springs Shale

The Bonner Springs Shale is a composite unit, consisting predominantly of shale (fig. 8B), which locally includes beds and lenses of sandstone or siltstone and minor amounts of limestone, conglomerate, and coal. In outcrops it ranges in thickness from about 1 foot along the south bluff of the Kansas River at DeSoto (SW¼ NE¼ sec. 28, T.12 S., R.22 E.) to more than 70 feet in the SW¼ NW¼ sec. 33, T.14 S., R.24 E. In the subsurface it has a thickness of about 80 feet locally in T.13 S., R.25 E., and T.14 S., R.24 E. (fig. 10). Throughout much of the county, however, it is 15 to 30 feet thick.

The lower part of the Bonner Springs is characteristically gray or greenish-gray sandstone and gray, blue, or green sandy to silty shale. Carbonized plant fragments are fairly common. The upper part consists of gray and green argillaceous shale, generally with a 0.5- to 2.0-foot red zone 2 to 8 feet below the top. Other beds characteristic of the upper part include a grayish-orange or yellowish-orange and brown impure argillaceous limestone just above the red shale, which Newell (1935, p. 68) described as a "marlite." The "marlite" may have a tinge of green, and in some exposures has a thin basal conglomerate consisting of pebbles of yellowish-orange and brown calcareous mudstone or argillaceous limestone, light-olive-gray mudstone, and light-gray to pinkish-gray fossil fragments, chiefly gastropods and pelecypods. Locally the conglomerate is several feet thick and crossbedded (SE¼ SE¼ sec. 33, T.12 S., R.22 E.). In some exposures only the conglomerate (0.1 to 1.0 foot thick) is present. In the DeSoto area along a creek in the east half of the SE¼ sec. 27, T.12 S., R.22 E., the Bonner Springs Shale is about 28 feet thick; it is sandy in the lower part.

In some places there is about 1 foot of grayish-green and grayish-yellow silty micaceous impure limestone locally with sand and pebble-size fragments of yellowish-orange calcareous mudstone or argillaceous limestone above the "marlite." Fossils are common and include *Composita* and other brachiopods, crinoids, *Osagia,* and *Aviculopecten.* This limestone is separated from the overlying Plattsburg Limestone by about 1 foot of shale in exposures along the east-west road in the NE¼ NE¼ sec. 23, T.13 S., R.24 E., but is

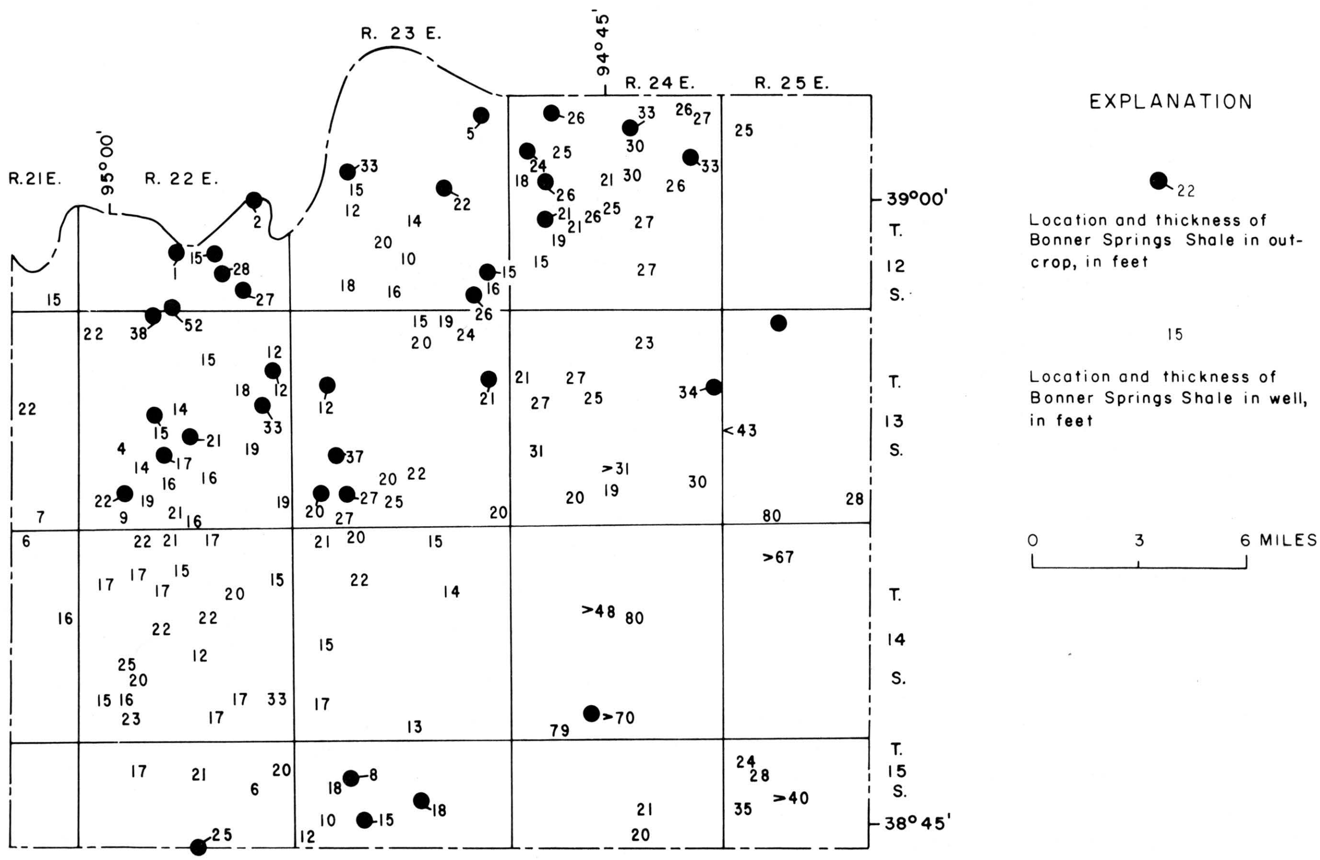

FIGURE 10.—Thicknesses of Bonner Springs Shale in outcrops and wells.

directly below the Plattsburg Limestone northeast of the U.S. Highway 50-Interstate Highway 35 interchange (SW¼ SE¼ sec. 12, T.12 S., R.24 E.). At the interchange exposure (see measured section, p. 23), the Bonner Springs Shale is complete and is about 33 feet thick. It consists of about 15 feet of bluish-gray silty shale that grades upward into about 12 feet of very fine to fine-grained micaceous quartzose sandstone. This is overlain by about 6 feet of green and gray shale that contains a yellowish-orange-weathering impure nodular limestone or "marlite" near the middle. The "marlite" is overlain by silty fossiliferous shale and a thin conglomerate. At the top is an impure silty fossiliferous limy shale with a thin zone of pebbles or "marlite" at its base. Except for the lack of a red shale and a thin coal, this section contains all the common Bonner Springs lithologies. A similar section, about 34 feet thick, is exposed in an east-west road ditch in the NE¼ NE¼ sec. 13, T.13 S., R.24 E. This section contains a thin 0.1-foot coal seam in the shale below the conglomerate in the upper part of the formation.

In the area of thick Bonner Springs Shale, which trends generally southwest to south-southwest from T.13 S., R.25 E., there is a thin (0.1 foot) coal below a few feet of carbonaceous quartzose sandstone. This coal is above the middle of the formation and may not be the same coal noted previously. It is underlain by 50 feet or more of dark-green and gray sandy to argillaceous shale. These units are well exposed in a gully about 200 feet east of the section-line road and south of Wolf Creek in the SW¼ NW¼ sec. 33, T.14 S., R.24 E.

Along Little Bull Creek (NE¼ NW¼ sec. 8, T.15 S., R.23 E.) the Bonner Springs Shale is about 8 feet thick; it consists of gray sandy shale in the lower part, green argillaceous shale in the middle part, and calcareous grayish-yellow shale and a thin yellow impure molluscan limestone in the upper part. At another exposure about 1 mile southeast (NW cor. sec. 16, T.15 S., R.23 E.), the Bonner Springs is about 15.5 feet thick and has red shale in the upper part. At several of the southern exposures, the upper 2 or 3 feet of the shale is calcareous and contains *Derbyia, Juresania, Aviculopecten,* and fragments of *Myalina.*

In the DeSoto area, previous workers have correlated parts of the Bonner Springs Shale with the Farley Limestone Member of the Wyandotte Limestone and with the Plattsburg Limestone. Changes in the thickness of some units and the thinning or absence of other units have complicated interpretation and correlation of the Bonner Springs Shale and adjacent units in the DeSoto area.

The Bonner Springs Shale has a thickness of 20 to 30 feet at the Kansas Highway 10 bridge over Kill Creek (cen. sec. 27, T.12 S., R.22 E.) and in the area south and southeast of the bridge for a distance of about 1 mile. The lower three-fourths of the unit contains sandstone and siltstone. The upper fourth is argillaceous silty shale with yellow or brown impure limestone and limestone conglomerate. The conglomerate and upper shale beds are fossiliferous, with gastropods and pelecypods being most abundant.

At a small quarry in the northern part of DeSoto (NW¼ SW¼ NE¼ sec. 28, T.12 S., R.22 E.) and also at exposures along Kansas Highway 10 at the south edge of town (NW¼ SE¼ SE¼ sec. 28, T.12 S., R.22 E.), the Bonner Springs is only about 1 foot thick. The unit here consists of green and gray shale containing gastropods and pelecypods and apparently represents only the uppermost beds of the formation.

Along the south side of sec. 33, T.12 S., R.22 E., in the east bluff of Kill Creek valley, the Bonner Springs is about 52 feet thick. A 3.5-foot-thick bed of fossiliferous limestone conglomerate occurs about 1 foot below the top of the formation, and a 5.5-foot-thick bed of gray coarse-grained detrital limestone containing abundant shell fragments occurs 15 feet above the base of the formation.

A similar sequence, including thick beds of limestone, breccia, and conglomerate, is exposed along the county road and the government railroad in the NW¼ sec. 4, T.13 S., R.22 E., west of Kill Creek. The overlying Plattsburg Limestone is well exposed in a railroad cut. In contrast to Newell's (1935, p. 111) interpretation of the Hickory Creek Shale Member being 20 feet thick and the Merriam Limestone Member ranging from 0.8 to 15 feet or more at his measured sections 61 and 62 at and near this locality, both members have normal thickness and character. Most of the beds in the Hickory Creek and Merriam that Newell considered to have unusual thicknesses are here considered to be the upper part of the Bonner Springs Shale.

LANSING GROUP

Plattsburg Limestone

The Plattsburg Limestone is the lowermost of the three formations in the Lansing Group. It is divided into three members: Merriam Limestone, Hickory Creek Shale, and Spring Hill Limestone. The formation ranges in thickness from about 7.5 to 23 feet in surface exposures. Drillers' logs indicate a range in thickness from about 7.5 to 29 feet in the subsurface.

MERRIAM LIMESTONE MEMBER

The Merriam Limestone Member was named by Newell (*in* Moore, 1932) for exposures in the town of Merriam, Kans., but no measured section of the "type" Merriam was published. The rocks exposed at the type locality (quarry at NW cor. sec. 7, T.12 S., R.25 E.), as later defined by Moore (1935, p. 128), are stratigraphically below the Merriam. Therefore, a detailed standard reference section of the Merriam in the type locality still was not available. Considerable confusion regarding the Merriam and adjacent beds exists in Johnson County because, in earlier stratigraphic works, a limestone in the Bonner Springs Shale was identified as Merriam, and, in another instance, a limestone conglomerate or breccia stratigraphically below the Merriam was included in the Merriam.

There seems to be no question as to what beds Newell intended to designate as the Merriam Limestone Member, yet the lack of a published type section has resulted in miscorrelations. The following graphic column and measured section of the Merriam Limestone Member and adjacent beds, therefore, are included as a standard reference section in the type locality. The graphic column is illustrated on figure 11.

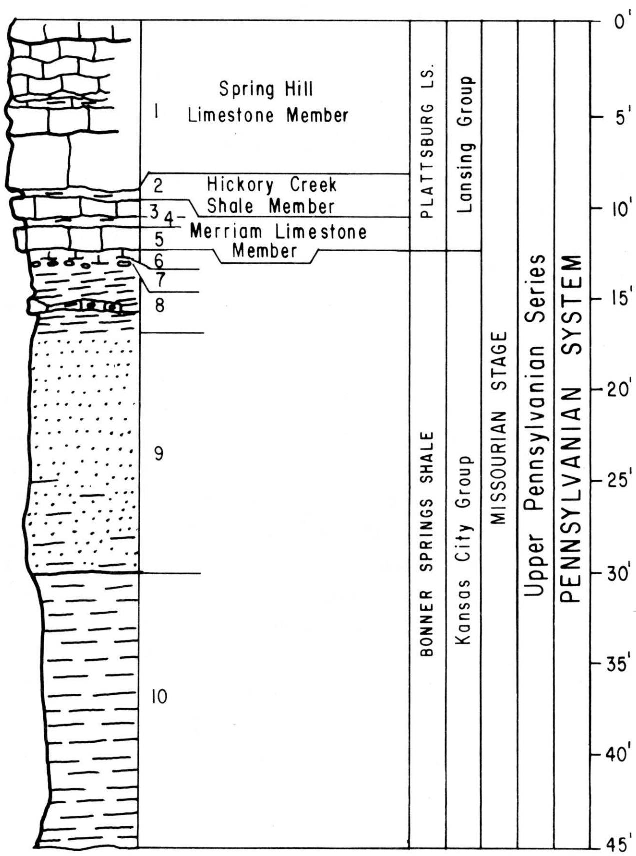

Figure 11.—Graphic column of the reference section of the Merriam Limestone Member of the Plattsburg Limestone and adjacent beds, SE¼ SW¼ SE¼ sec. 12, T.12 S., R.24 E. Numbers refer to measured section in text.

Reference measured section of the Merriam Limestone Member of the Plattsburg Limestone and adjacent beds exposed along the northeast loop of the U.S. Highway 50-Interstate Highway 35 interchange at Merriam, Kans. (SE¼ SW¼ SE¼ sec. 12, T.12 S., R.24 E.).

	Thickness, feet
Plattsburg Limestone	
Spring Hill Limestone Member	
(1) Limestone, light-gray, medium- to thick-bedded, fine-grained; weathers yellowish brown to yellowish orange; fossiliferous uppermost part weathered and partly eroded	> 9.
Hickory Creek Shale Member	
(2) Shale, medium-gray; weathers olive gray	avg. 0.3
Merriam Limestone Member	
(3) Limestone, light-gray; weathers yellowish gray; upper part contains numerous ferruginous clay-filled borings and is sparsely fossiliferous; lower part is slightly argillaceous and contains abundant fusulinids and crinoid fragments, and a few brachiopods	avg. 1.5
(4) Shale, greenish-gray; abundant bryozoans	0.2
(5) Limestone, very light gray; the alga *Osagia* is abundant in the upper and lower parts and *Composita* is abundant in the middle part; productids locally numerous in the upper middle part; sparse *Myalina* at base	1.1
Bonner Springs Shale	
(6) Shale, gray to olive-gray, silty, micaceous, calcareous; abundant fossils in upper part, especially *Composita*, and *Aviculopecten*	avg. 0.8
(7) Conglomerate and impure limestone or "marlite," gray and yellowish-brown to yellowish-orange; thickness is variable	avg. 0.1
(8) Shale, olive-gray to greenish-gray, and green claystone; contains near the middle a yellowish-brown to yellowish-orange impure limestone or "marlite," 0.5 to 1.0 foot thick, which grades laterally into yellow and gray conglomerate	4.7
(9) Sandstone, grayish-blue to gray, very fine to fine-grained, quartzose, micaceous; upper part more massive bedded; lower part is shaly	12.3
(10) Shale, bluish-gray, silty, micaceous, sandy at top; weathers yellowish gray	15.1

The Merriam Limestone Member in the foregoing reference section is 2.8 feet thick and consists of two limestones separated by a thin shale parting. In Johnson County the lower blocky limestone bed is light gray to yellowish gray and is characterized by a molluscan zone with *Myalina, Aviculopecten,* and gastropods common at the base, a zone of abundant *Composita* in the middle or lower part, and abundant *Osagia.* The middle and upper parts of the bed locally are oolitic limestone. Crinoid and bryozoan fragments are fairly common but are not diagnostic of the bed. The bed is commonly about 1 foot thick, but locally may be as much as 4.2 feet thick; it consists largely of algal and oolitic limestone, as in road cuts in the SW¼ SW¼ SE¼ sec. 30, T.13 S., R.23 E.

Overlying the lower limestone bed of the Merriam is a thin blue or bluish-gray calcareous shale that weathers green or gray and contains sparse bryozoans and *Aviculopecten.* At the reference section the shale ranges in thickness from a parting to about 0.2 foot.

The upper limestone bed of the Merriam is generally a single light-gray massive vertically jointed limestone, 0.5 to 1 foot thick, that weathers light gray, yellowish gray, or dusky yellow. It is fine grained and dense, but some crystalline limestone has replaced shell fragments. It has a characteristic fauna of fusulinids, brachiopods, and crinoid fragments. The upper part is characterized by a pitted upper surface and small borings, considered by some to be worm borings, about one-fourth of an inch in diameter and as much as 3 to 5 inches in length, filled with a soft yellow ferruginous clay. The borings commonly are steeply inclined. The Merriam described in the reference section is judged to be the unit defined by Newell. Locally, the Merriam contains small nodules of gray chert. In some exposures one or the other of the distinctive lithologies may be absent or poorly represented, but the member is one of the more easily identified units in the county. It ranges in thickness from about 0.8 foot to about 6 feet.

In the reference section the 6 feet of shale between the Merriam and the quartzose sandstone in the middle part of the Bonner Springs contains calcareous and silty molluscan limestones, thin zones of conglomerate or pebbles containing mollusks, green and gray shales, and a "marlite" bed. This interval in the upper Bonner Springs is widely distributed in Johnson County and should not be considered as part of the Merriam.

HICKORY CREEK SHALE MEMBER

The Hickory Creek Shale Member consists chiefly of calcareous shale that ranges in color from light olive gray to greenish black, being darkest in the northeastern part of the county. The shale weathers yellowish gray to grayish orange. The Hickory Creek locally includes nodules of limestone or an impure argillaceous irregular bed of fine-grained limestone, commonly 0.2 to 0.4 foot thick, that weathers yellowish orange. Both the shale and the limestone are fossiliferous; brachiopods, crinoids, and bryozoans are common, fenestrate bryozoans being very abundant in some outcrops. Fusulinids occur locally in the member. The member ranges in thickness from 0 to about 3 feet but commonly is about 1 foot thick. A restudy of the Hickory Creek Shale Member in the DeSoto area, where it was earlier reported by Newell (1935, p. 69) to be 20 feet thick, indicates that the Merriam Limestone Member and the upper beds of the Bonner Springs Shale were included in the Hickory Creek.

SPRING HILL LIMESTONE MEMBER

The upper and predominant part of the Plattsburg Limestone is the Spring Hill Limestone Member. It ranges in thickness from about 8 to 23 feet in outcrops and also in the subsurface.

The limestone can be differentiated into several faunal and lithologic zones. The lower part, commonly a third to half of the member, appears massive in fresh outcrops, but, upon weathering, thin shaly partings that separate the even to slightly wavy beds of limestone, 2 to 12 inches thick, become evident. This part of the member is light to medium gray or light olive gray in fresh exposures but weathers grayish orange to yellowish orange. The limestone is fine grained with coarser grained fossil debris unevenly distributed through the rock. The lower beds contain abundant bryozoans and brachiopods, especially *Enteletes* and *Marginifera,* crinoids, and fusulinids. Nodules of light-gray chert commonly are found in the lower beds, but locally in the Wolf Creek and Little Bull Creek drainage areas, the Spring Hill contains abundant large chert nodules.

The middle part of the member consists of yellowish-gray to light-olive-gray limestone beds, which contain much finely broken fossil detritus composed of bryozoan, crinoid, and echinoid fragments, foraminifera, brachiopods, small gastropods, and *Osagia.* At the top of the middle beds in many outcrops fewer broken fossils are noted and, locally, unbroken *Composita* shells are abundant. Elsewhere, especially in southern Johnson County, the middle beds consist almost entirely of oolitic and pelletal limestone with small amounts of *Osagia,* bryozoan fragments, and foraminifera. The pellets are filled with a mosaic of crystalline calcite or dark-yellowish-orange limonite in weathered exposures. The pelletal limestone ranges from medium dark gray to nearly white and weathers very light gray to yellowish gray. Original void space between ooliths or pellets is cemented with very finely crystalline limestone or with sparry calcite.

The upper Spring Hill beds are about 1 to 5 feet thick and consist of gray argillaceous massive finely crystalline to granular limestone that weathers yellowish orange or yellowish brown. An algal and molluscan fauna is common, but echinoderms, bryozoans, and brachiopods are predominant in some exposures. Several thin gray fossiliferous shale partings, which are as much as 0.5 foot thick, separate some of the limestone beds but are not persistent from one exposure to the next.

Vilas Shale

The Vilas Shale is the middle formation of the Lansing Group. Measured sections of this unit average about 15 feet thick, but the unit ranges in thickness from about 8 feet (SW¼ sec. 9, T.15 S., R.22 E.) to 25 feet (NE¼ NE¼ SE¼ sec. 12, T.12 S., R.23 E.), being thickest in the northern part of the county and thinnest in the southwestern part.

The lower third to half of the formation is medium- to dark-gray and dark-greenish-gray mudstone and silty or sandy and micaceous shale with carbonized plant fragments. As much as 11 feet of sandstone and siltstone is found locally in the lower and middle parts (NE¼ NE¼ SE¼ sec. 12, T.12 S., R.23 E.). Exposures of the lower Vilas beds west of Bull Creek along Interstate Highway 35 (SW¼ sec. 9, T.15 S., R.22 E.) are about 2.7 feet thick and contain a thin intraformational conglomerate of limestone and shale fragments about 2 feet above the base of the formation.

Middle Vilas beds range from about 0.5 to 4 feet in thickness and, in most exposures, are either calcareous and fossiliferous fine-grained sandstone or fossiliferous sandy limestone. Very thin beds of sandy limestone locally contain abundant bryozoans, especially *Rhombopora* and *Fenestella,* as well as *Composita, Neospirifer* and other brachiopods, crinoid fragments, *Myalina,* and *Aviculopecten.* In a few exposures, caliche-like nodules of limestone are scattered through the sandy beds, and bedded sandy limestone is absent.

The upper Vilas beds are chiefly gray and olive-gray shale, which locally is sandy or silty. Near DeSoto, in exposures along the east side of a lake (SW¼ NW¼ sec. 28, T.12 S., R.22 E.), a thin very fine grained sandstone occurs about 5 feet above the middle fossiliferous sandy limestone. In most exposures, the uppermost part of the Vilas is light-colored calcareous shale that weathers yellowish gray.

Stanton Limestone

The Stanton Limestone comprises three limestone and two shale members. It lies at or near the surface in much of the upland area in central Johnson County. The formation ranges in thickness from about 36 to 47 feet.

Captain Creek Limestone Member

The lowermost unit of the Stanton Limestone is the Captain Creek Limestone Member. The member has a minimum thickness of about 4.5 feet in northeastern and northwestern Johnson County and a maximum observed thickness of 10 feet in southwestern Johnson County (fig. 12). Most of the member consists of even to slightly uneven beds of limestone, 4 to 12 inches thick.

The lower part of the Captain Creek consists of one or two beds of medium-gray to olive-gray fine- to medium-grained limestone containing abundant *Osagia* and lesser amounts of Cryptozoan algal structures, gastropods, *Myalina,* crinoid fragments, fusulinids, and *Composita.* Locally a thin gray shale, ranging in thickness from 0 to about 0.2 foot and containing fusulinids,

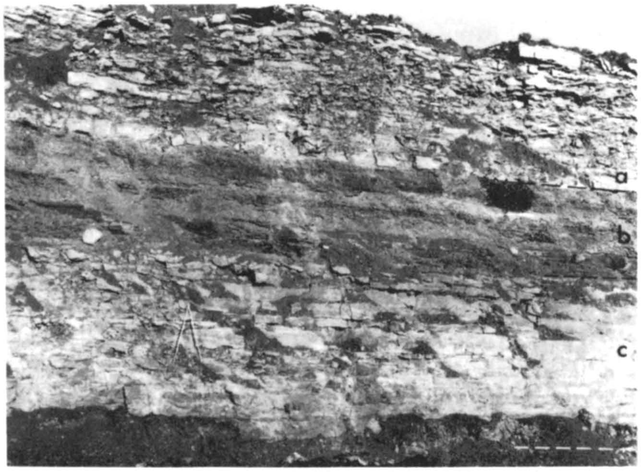

FIGURE 12.—Stanton Limestone along Interstate Highway 35 near the center of the north side of the NW¼ sec. 16, T.15 S., R.22 E. *a*, Stoner Limestone Member. *b*, Eudora Shale Member. *c*, Captain Creek Limestone Member. Folding carpenters rule is 6 feet long.

crinoids, and brachiopods, overlies and separates the lower beds from the rest of the member.

The upper part of the Captain Creek is about 3 to 8 feet thick and constitutes most of the member; it is medium-gray to light-bluish-gray medium-bedded fine-grained to aphanitic limestone. Brachiopods, crinoid remains, fusulinids, byrozoans, and algae are common. *Composita, Enteletes,* and algae are the most conspicuous and abundant fossils. Algae are particularly abundant near the top of the member. The algae occur as thin irregular veins or crusts of clear crystalline calcite, ranging in thickness from about 0.2 to 3 mm, in a very fine grained lime-mud matrix. In many exposures the top part (less than 2 feet) of this bed has a distinctive mottled and brecciated appearance that has been noted in previous reports (Newell, 1935, p. 77; Moore, 1935, p. 133). The limestone is very light gray to grayish black, mottled with pale to moderate red. Like other mottled limestones of the Kansas City and Lansing Groups, it has been considered to be of algal origin. The mottled bed locally is separated from the other limestone beds by a shale parting.

Gray chert nodules are found locally near the middle of the member, but are nowhere very abundant. Small pink or gray chert nodules locally are found in the mottled bed at the top also.

EUDORA SHALE MEMBER

The Eudora Shale Member (fig. 12) includes a zone of grayish-black fissile to platy shale in the lower part, which is distinctive in the Lansing Group. The Eudora is 6 to 8 feet thick in most exposures, but, according to Newell (1935, p. 77), may be as much as 11 feet thick locally.

The lower 0.1 to 1.5 feet of the member is gray to greenish-gray calcareous to limy shale, which is overlain by 2 to 4.5 feet of more resistant grayish-black hard fissile to platy shale, which, in turn, is overlain by 3 to 6 feet of light- to dark-gray or greenish-gray partly calcareous shale. Small elliptical gray or brownish-gray phosphatic nodules are scattered through the grayish-black fissile shale. Conodonts, a few *Orbiculoidea, Lingula,* and *Conularia,* and carbonized plant fragments also are found in the black shale. A few small clams and brachiopods occur in the overlying gray shale.

STONER LIMESTONE MEMBER

The Stoner Limestone Member, which averages 13 to 18 feet thick, is the thickest unit of the Stanton Limestone. The Stoner forms the most prominent bench along the Stanton outcrop. The member consists of medium-light-gray to very light gray and greenish-gray thin- to medium-bedded irregular wavy limestone with thin shale partings (fig. 12). In some outcrops the lowermost limestone bed is more massive and even-bedded than middle beds of the member.

The wavy thin- to medium-bedded fine- to medium-grained limestone that comprises the middle part of the member is not as fossiliferous in general as similar wavy-bedded limestones in the Kansas City and Lansing Groups. Brachiopods, bryozoans, horn corals, crinoid and echinoid remains, fusulinids, and ostracodes are common, with large brachiopods such as *Antiquatonia, Composita,* and *Echinaria* being most conspicuous. Parts of the limestone beds contain coarsely crystalline calcite as void fillings and replacement of shell material.

The uppermost 0.5 to 3 feet of limestone in many exposures consists of "osagite" or calcarenite, or of brecciated or nodular-appearing limestone. Both the calcarenite and the nodular limestone are well developed in the Olathe area and are exposed in road cuts along Kansas Highway 150 (NE¼ NE¼ sec. 31, T.13 S., R.24 E.) and Kansas Highway 7 (SE¼ NE¼ sec. 27, T.13 S., R.23 E.). The nodular beds consist of medium- to dark-gray or olive-gray dense sublithographic limestone in a matrix of greenish-gray fine-grained argillaceous limestone. The fine-grained limestone matrix locally contains gastropods, clams, productid brachiopods, and finely broken fragments of bryozoan and other fossil material.

ROCK LAKE SHALE MEMBER

The Rock Lake Shale Member consists chiefly of shale and sandstone but also includes siltstone and conglomerate. In the northwestern part of the county grayish-black carbonaceous shale and a thin laminated limestone are present. The member ranges in thickness from about 2 to 14 feet, but averages 8 feet.

The shale is medium light gray to dark gray or olive gray. Locally the shale beds are conglomeratic and have subrounded to subangular shale pebbles of one lithology enclosed in shale of slightly different lithology. Several exposures of the Rock Lake along Captain Creek in western Johnson County (SE cor. sec. 26, T.13 S., R.21 E., and near the NW¼ SW¼ SW¼ sec. 1, T.14 S., R.21 E.) have a grayish-black carbonaceous shale, 0.5 foot thick, overlain by a medium- to dark-gray laminated limestone containing abundant ostracodes, foraminifera, carbonized plant fragments, and spores.

The sandstone is gray but weathers yellowish gray to dark yellowish orange and is very fine to fine grained, quartzose, and micaceous. It may be weakly cemented and friable or strongly cemented with calcite as seen in surface exposures. Locally, where the member attains its greatest thickness, it includes beds of sandstone and siltstone. In places, nearly the entire unit is sandstone. Marine fossils, especially large *Myalina* and *Aviculopecten*, are found in the sandstone; small *Myalina* and fragments of other fossils are found in some of the shale beds, but other shale beds apparently are barren of marine macrofossils. The shales, siltstones, and sandstones all contain carbonized plant fragments.

In several exposures the upper part of the Rock Lake is gradational upward from sandstone to sandy limestone, and the boundary between the Rock Lake and the overlying South Bend Limestone Member is not clearly defined. Locally, the sandstone beds contain a sandy limestone conglomerate.

SOUTH BEND LIMESTONE MEMBER

The uppermost member of the Stanton Limestone is the South Bend. The member is medium- to thick-bedded dense very fine grained limestone that ranges in thickness from about 1.5 to 5 feet. In the thicker exposures, the lower part commonly is a sandy or sandy and conglomeratic limestone. Where the member overlies sandstone in the Rock Lake, the boundary may be gradational. The fresh rock is medium to dark gray or bluish gray, but weathered exposures are yellowish gray to olive gray or yellowish brown. The limestone is fossiliferous, containing abundant fusulinids, crinoids, and brachiopods. *Meekella* and *Composita* are common brachiopods. The lower sandy part is less fossiliferous and contains a molluscan fauna. Although the South Bend is near land surface in much of the upland area of central Johnson County, it is rarely well exposed except in manmade exposures.

Pennsylvanian System—Virgilian Stage

DOUGLAS GROUP

STRANGER FORMATION

The Stranger Formation, as defined in Kansas by S. M. Ball (O'Connor, 1963, p. 1877), consists of five members designated, in ascending order: Weston Shale, Iatan Limestone, Tonganoxie Sandstone, Westphalia Limestone, and Vinland Shale. Only the Weston Shale Member was definitely identified in Johnson County. The Stranger Formation conformably overlies the Stanton Limestone.

WESTON SHALE MEMBER

The Weston Shale Member is grayish-blue and medium-gray clayey shale that weathers yellowish gray to light olive gray. The lower part is more gray than the upper part and contains several zones of light-brownish-gray dense ironstone concretions that are 2 to 12 inches in diameter. The concretions weather to shades of brown and yellowish orange, and occur both in layers and scattered. Upper beds of the Weston locally have carbonized plant fragments along the bedding planes and are siltier and bluer in color than the lower beds. In the area of maximum thickness (T.14 S., Rs.21 and 22 E.), the Weston is about 80 to 100 feet thick.

Marine macrofossils are nowhere abundant in the Weston, but thin fossiliferous zones contain fragments of crinoids, brachiopods, and bryozoans. Small mollusks are abundant locally in the basal 5 to 10 feet; for example, in the exposures along Interstate Highway 35 in the NW¼ NW¼ sec. 29, T.14 S., R.23 E.

Much of the area underlain by Weston is upland having low relief. The Weston may be deeply weathered and may have a thin cover of colluvial deposits overlying it. Consequently, exposures of Weston are restricted to areas of active stream erosion and manmade excavations.

OTHER MEMBERS

None of the members above the Weston Shale Member, with the possible exception of the Tonganoxie Sandstone Member, are recognized in Johnson County; the units either were eroded or were never deposited. Sandstone and sandy shale beds overlying the Weston are identified as the Ireland Sandstone Member of the Lawrence Formation, chiefly because stratigraphic studies, mapping, and test-hole data immediately to the west in southeastern Douglas County indicate that thick Ireland deposits rest disconformably on shale of the Weston and that the Tonganoxie Sandstone Member is very thin and does not contain massive beds of sandstone (O'Connor, 1960). The Iatan and Westphalia Limestone Members were not identified in outcrops or in the subsurface of Johnson County.

Newell (1935) described and mapped the first sandstone beds above the Weston as Tonganoxie. Although these sandstone beds are considered here as the Ireland Sandstone Member of the overlying Lawrence Formation, they may include, at the base, beds equivalent to the Tonganoxie. However, this relationship cannot be demonstrated, because the bounding Iatan and Westphalia limestones are absent, and the Ireland deposits just west of the county line are more than 130 feet thick in channels eroded into the Stranger Formation to within 30 feet of the Stanton Limestone. The Ireland and Tonganoxie are not lithologically distinct enough to identify one from the other where only a small outcrop of sandstone or sandy shale is observed.

Lawrence Formation

The Lawrence Formation, as designated by S. M. Ball (O'Connor, 1963), includes the Haskell Limestone Member, Robbins Shale Member, Ireland Sandstone Member, and Amazonia Limestone Member. Only the Ireland Sandstone Member has been recognized in Johnson County.

The Lawrence Formation is the youngest unit of Pennsylvanian age exposed in Johnson County.

IRELAND SANDSTONE MEMBER

The Ireland Sandstone Member consists of very fine to fine-grained quartzose micaceous sandstone, but contains minor amounts of shale, conglomerate, and coal. The sandstone beds may contain carbonaceous plant fragments, and locally are silty and argillaceous. Unoxidized samples of the sandstone are light to medium gray, but the beds as seen in exposures are almost always oxidized to shades of olive or greenish gray, yellowish gray, and yellowish orange. In exposures, the sandstone commonly is poorly cemented and may be quite friable; locally, however, the sandstone is well cemented with calcite. The Ireland overlies an irregular surface from which the Robbins Shale and Haskell Limestone Members of the Lawrence Formation, and the Vinland Shale, Westphalia Limestone, Tonganoxie Sandstone, and Iatan Limestone Members of the Stranger Formation either have been eroded prior to deposition of the Ireland or were never deposited. The Ireland exposed in southwestern Johnson County lies chiefly or entirely on an irregular erosion surface cut into the Weston Shale Member of the Stranger Formation. The local relief of the disconformity at the base of the Ireland is about 70 feet in Johnson County, and locally Ireland deposits are separated from the Stanton Limestone by less than 35 feet of Weston.

The maximum thickness of the Ireland recognized in Johnson County is about 49 feet (test hole 14-21E-25aaa).

Cretaceous System(?)—Lower Cretaceous Series(?)

Dakota(?) Formation

Gravel, of possible Cretaceous age, having a distinctive lithology was found at one site on the upland surface in central Johnson County. Because Cretaceous rocks have not been described previously in the county, a brief description of their present and probably former distribution in Kansas and nearby areas is given, and the lithology of the basal Cretaceous rocks is described.

Outcrops of Dakota Formation in central Kansas (Jewett, 1954) and in southwestern Iowa (Hershey and others, 1960, p. 5) are about 125 miles from Johnson County. The basal Cretaceous rocks in Kansas have been considered by some authors to have been derived from the north and east and to formerly have been much more extensive in northeastern Kansas than they are today. In early Cretaceous time erosion beveled the Pennsylvanian and Permian rocks in eastern Kansas. The erosion surface was of moderate relief and is covered in central Kansas by the progressively overlapping Cheyenne Sandstone, Kiowa Formation, and Dakota Formation. Genetically related to this erosion surface, rather than to a stratigraphic position within the Cretaceous rocks, is a zone of rounded pebbles and cobbles consisting predominantly of chert, quartz, quartzite, and siliceous and ferruginous quartzose sandstone judged, in Kansas, to have been derived from the north and east (Frye and Leonard, 1952, p. 180-181).

In southwestern Iowa the Dakota was originally extensive but is now present only as scattered remnants partly covered by glacial deposits. In southwestern Iowa the Dakota consists of sandstone, clayey shale, and conglomerate; the conglomerate most often consists of siliceous pebbles in a ferruginous matrix (Hershey and others, 1960, p. 6).

In Johnson County the gravel of possible Cretaceous age consists of scattered rounded pebbles and cobbles of light and dark quartz, quartzite, and subrounded chert. These are lithologically similar to the pebbles and cobbles found in the basal Cretaceous of north-central Kansas. In addition, there are pebbles and cobbles of a subangular siliceous and ferruginous conglomeratic sandstone that weathers dark reddish brown. The siliceous and ferruginous conglomeratic sandstone pebbles are lithologically similar to cemented sandstone found in the Dakota of Saline County, Kans., and are distinctively different from any sandstone in the Pennsylvanian rocks of eastern Kansas.

The gravel, at an altitude of about 1,040 feet, was observed in a new road cut in the NW¼ SE¼ sec. 30, T.14 S., R.23 E., during construction of Interstate Highway 35. The scattered pebbles and cobbles of gravel occur in a red soil developed over the Weston Shale Member and below a thin mantle of loess.

The gravel cannot be of glacial origin because it lies south of the glacial border in the Marais des Cygnes River drainage basin and lacks certain igneous and metamorphic rock types that are characteristic of weathered till or outwash in Kansas (Davis, 1951). The angularity of the siliceous-cemented ferruginous sandstone pebbles precludes their having been transported by streams for any great distance. The high topographic position and the lack of a local source for rocks of this lithology make it unlikely that the gravel is a remnant of a Tertiary or early Pleistocene stream deposit. Therefore, the scattered pebbles and cobbles of lithologically distinctive gravel probably represent a formerly extensive deposit of Cretaceous rocks and a Cretaceous erosional surface. The rocks are not extensive enough to map.

Quaternary System—Pleistocene Series

Deposits of Pleistocene age are at the surface in much of Johnson County and include glacial, fluvial, lacustrine, and eolian deposits. In the general classification of Pleistocene deposits established for northeastern Kansas (table 3), the Pleistocene is divided into eight geologic-time units called stages.

The Recent Stage (age) is the last major subdivision of the Pleistocene and includes the time since the Mankatoan glaciers (uppermost Wisconsinan) retreated from the continental interior of North America and Europe. Studies of Wisconsinan and Recent deposits in the Great Lakes region and the upper Mississippi Valley (Frye and William, 1963), utilizing radiocarbon-dating and pollen-stratigraphy methods, indicate that the Recent Stage comprises about 5,000 years before the present, and the Recent Stage is used in this sense in this report.

The bulk of the Pleistocene sediments in Kansas was deposited during the glacial stages, whereas soil

TABLE 3.—General classification of Pleistocene deposits in northeastern Kansas (adapted from Bayne and O'Connor, 1968).

<table>
<tr><th colspan="3">Time-stratigraphic units</th><th colspan="2">Rock-stratigraphic and soil-stratigraphic units</th></tr>
<tr><td rowspan="17">QUATERNARY SYSTEM</td><td rowspan="17">Pleistocene Series</td><td>Recent Stage</td><td colspan="2">Eolian and fluvial deposits</td></tr>
<tr><td rowspan="4">Wisconsinan Stage</td><td>Bignell Formation</td><td>Fluvial deposits</td></tr>
<tr><td colspan="2">Brady Soil</td></tr>
<tr><td>Peoria Formation</td><td rowspan="2">Fluvial deposits</td></tr>
<tr><td>Gilman Canyon Formation</td></tr>
<tr><td>Sangamonian Stage</td><td colspan="2">Sangamon Soil</td></tr>
<tr><td>Illinoisan Stage</td><td>Loveland Formation</td><td>Fluvial deposits</td></tr>
<tr><td>Yarmouthian Stage</td><td colspan="2">Yarmouth Soil</td></tr>
<tr><td rowspan="5">Kansan Stage</td><td>Loess</td><td>Fluvial and lacustrine deposits[1]</td></tr>
<tr><td colspan="2">Cedar Bluffs Till</td></tr>
<tr><td colspan="2">Fluvial deposits</td></tr>
<tr><td colspan="2">Nickerson Till</td></tr>
<tr><td colspan="2">Atchison Formation[2]</td></tr>
<tr><td>Aftonian Stage</td><td colspan="2">Afton Soil</td></tr>
<tr><td rowspan="3">Nebraskan Stage</td><td>Loess</td><td>Fluvial deposits</td></tr>
<tr><td colspan="2">Iowa Point Till</td></tr>
<tr><td colspan="2">David City Formation</td></tr>
</table>

[1] Locally contains the Pearlette ash bed.
[2] Atchison Formation has been defined as proglacial outwash of early Kansan age. Similar deposits are found between the Nickerson Till and the Cedar Bluffs Till.

development and stability were characteristic of the interglacial stages.

PRE-KANSAN DEPOSITS

Except for the sparse pebbles and cobbles of distinctive rock types in the upland area along the drainage divide between the Kansas and Marais des Cygnes Rivers that may represent remnants of former Cretaceous deposits, no deposits younger than Pennsylvanian or older than Kansan have been recognized in Johnson County. In nearby Leavenworth County (SW¼ sec. 20, T.12 S., R.21 E.), Dufford (1958, pl. 1) mapped deposits of gravel, consisting chiefly of subrounded chert pebbles, which he believed to be Nebraskan or late Tertiary in age. These gravels are at altitudes of 930 to 940 feet above sea level and are about 130 to 140 feet above the flood plain of the Kansas River. O'Connor (1960, p. 48) cited similar gravel deposits in adjacent Douglas County at altitudes of 880 to 900 feet, which are 60 to 80 feet above the modern flood plain. These deposits have not been firmly dated but are judged to be pre-Kansan in age and probably are remnants of stream deposits of late Tertiary and early Pleistocene age. If comparable deposits of chert gravels are present in Johnson County, they are concealed by younger deposits.

KANSAN STAGE

Atchison Formation, Kansan Till, and Undifferentiated Fluvial and Lacustrine Deposits

The Kansan Stage in Johnson County is represented by the Atchison Formation, by undifferentiated deposits of till, and by undifferentiated fluvial and lacustrine deposits. The Atchison Formation consists of clay, silt, sand, and some gravel deposited as early Kansan glacial outwash (table 3). Two tills (Nickerson and Cedar Bluffs) of Kansan age are recognized in northeastern Kansas. The Nickerson Till of early Kansan age is the more extensive of the two. If only one of the Kansan till sheets extends into Johnson County, it is most probably the Nickerson Till. The Cedar Bluffs Till, of middle Kansan age, may also be present in this area (table 3). No exposures were observed in Johnson County in which the presence of two tills could be demonstrated. Because of a lack of adequate criteria for identifying the thin local till deposits south of the Kansas River, the till is identified only as Kansan till. In the Kansas River valley, the Atchison Formation, undifferentiated Kansan till, and late Kansan fluvial deposits locally form a conformable sequence (Frye and Leonard, 1952, p. 103-104). Fluvial and lacustrine sediments comprise the bulk of Kansan sediments south of the Kansas River.

One of the principal effects of Kansan glaciation was the enlargement of the Kansas River basin and the entrenchment of the Kansas River and its tributaries to a considerable depth below their base levels in Pliocene and Nebraskan time. Bayne and Fent (1963) summarized the Pleistocene history of the upper Kansas River basin and showed that the resultant flow of the upper Kansas River drainage system (chiefly the present Solomon River system) was eastward through the Flint Hills in Nebraskan time. Bayne and Fent also report that Kansan age deposits have eastward gradients and occupy the deepest part of the valleys near Salina, Kans., and across parts of Cloud and Clay Counties on the lower reaches of the Republican River. O'Connor and Fowler (1963) reported 150 feet of Kansan till below the Kansas River alluvium at Kansas City and as much as 242 feet of Pleistocene deposits, judged to be chiefly Kansan outwash, in the abandoned Turkey Creek valley, which trends eastward across Kansas City, Mo., about 10 to 12 miles east of the easternmost section of the Kansas River in Johnson County. These findings suggest a possible change in the concept of earlier workers (Frye and Leonard, 1952, p. 90; Davis and Carlson, 1952, p. 227) who believed that the maximum depth of entrenchment of the Kansas River and of glacial scour across eastern Kansas was about 10 to 20 feet above the flood plain. Kansan deposits are at the bottom of the Kansas River valley fill and are overlain by Wisconsinan and Recent deposits, at least locally at Kansas City. A similar relationship probably exists in other parts of the lower Kansas River valley upstream from Kansas City.

A lobe of one of the Kansan glaciers extended south of the Kansas River valley for nearly 10 miles in northwestern Johnson County and northeastern Douglas County, and meltwater from the ice front deposited sand and gravel that locally is preserved in low areas of the preglacial topography. These proglacial deposits are probably the Atchison Formation. As the glacier lobe extended progressively farther southward from the Kansas River valley, the topography became higher, and at the glacier's maximum extent meltwater along the edge of the ice deposited fluvial and lacustrine deposits at altitudes of 950 to 1,000 feet, or some 150 to 200 feet higher than till and outwash along the south bluff of the Kansas River west of DeSoto. Much of the Kansan deposits along the south river bluff rests on Pennsylvanian rocks at an altitude of about 850 feet, but locally, as along Kill Creek road at its intersection with Kansas Highway 10 (near cen. sec. 27, T.12 S., R.22 E.), till rests on Pennsylvanian rocks at an altitude of about 790 feet, or about 5 to 10 feet above the Kansas River flood plain.

Kansan outwash gravel deposits cap a series of hills that trends southeast from Lawrence, Kans. (sec. 30, T.13 S., R.20 E.), to near Clearfield in southeastern Douglas County (secs. 16 and 17, T.14 S., R.21 E.). These deposits represent outwash laid down along or in contact with the ice during the maximum stand of the glacier (O'Connor, 1960, p. 56). From near Clearfield the outwash train is represented by gravel-capped hills that trend northeastward and cross into Johnson County in sec. 26 and 35, T.13 S., R.21 E., and sec. 2, T.14 S., R.21 E., as a linear ridge. The outwash east and northeast of Clearfield is chiefly sand. Part of the sand along the southern edge of the Kansan deposits in northwestern Johnson County (pl. 1) is believed to be lacustrine in origin. During the maximum stand of the glacier, many temporary glacial lakes formed as a result of blockage of the Kansas River and its north-flowing tributaries. Where the lacustrine deposits were thin or were not protected by a cover of till or gravel, they have generally been removed by post-Kansan erosion.

Much of the Kansan deposits in the area west of Kill Creek in northwestern Johnson County is probably outwash deposited during retreatal phases of one of the Kansan glaciers, but sandy till also is present. Test-hole data indicate that both sandy till and outwash comprise these deposits and, in many places in northwest Johnson County, a sandy or gravelly zone occurs just above the bedrock. The Kansan deposits are 30 to 60 feet thick where they have not been appreciably thinned by post-Kansan erosion.

The second largest area of Kansan deposits, herein referred to as the Holliday area, is in T.12 S., R.23 E., just west of Holliday, and is drained principally by Clear Creek. Deposits of till and outwash fill an abandoned valley cut by an ice-marginal stream that existed when the present Kansas River valley was blocked by ice in secs. 34 and 35, T.11 S., R.23 E. The narrow drainage divide between the Kansas River and the headwater area of Clear Creek has deposits of till and outwash as much as 30 feet thick locally along the crest of the divide at altitudes of about 950 to 1,000 feet (secs. 17, 19 and 30, T.12 S., R.23 E.). At several points within the upper part of the area drained by Clear Creek are deposits of red sandy and gravelly silt and pebble, cobble, and boulder gravel. One well-exposed gravel deposit is west of Monticello (fig. 13A). Limestone cobble and boulder gravel, 8 feet or more thick and overlain by red sandy silts estimated to have a thickness of 10 to 15 feet, fills a narrow channel cut into the hillside. The cobbles and boulders are 95 percent or more local rock types, mainly limestone, and are only 5 percent or less pink quartzite, granite, and dark igneous and metamorphic rocks. This gravel probably was deposited by a short, ice-margin stream having a high gradient or was deposited as an ice-contact feature.

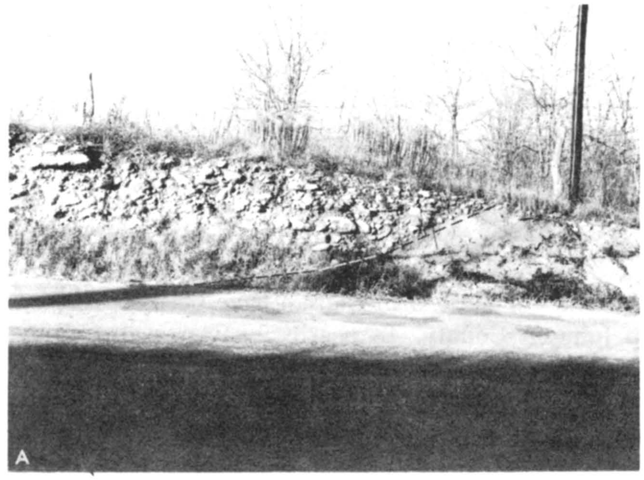

FIGURE 13.—*A*, Kansan deposit of limestone cobble and boulder gravel west of Monticello in the SE¼ SW¼ sec. 16, T.12 S., R.23 E. *B*, Ahlskog gravel pit in the filled and abandoned glacial stream valley near Holliday in the NE¼ NW¼ sec. 11, T.12 S., R.23 E.

The sparse boulders and thin patches of red sandy silts containing glacial erratics, which are found at altitudes as high as 1,000 feet in the south part of the Clear Creek drainage area, may have been deposited partly in temporary ice-margin lakes.

Perhaps the most spectacular deposits made by an ice-margin stream are those exposed in the old Ahlskog gravel pit on the List and Clark Construction Co. property (figs. 13B; 14A,B). About 30 feet of Kansan deposits is exposed in the walls of this gravel pit. Steeply dipping foreset beds of poorly sorted pebble, cobble, and boulder gravel, chiefly limestone, in many parts of the pit overlie almost-flat-lying beds of sand and gravel. Parts of the sand and gravel beds are tightly cemented with calcium carbonate, whereas other parts are uncemented and loose. A variable thickness of red sandy silt overlies all the deposits. The maximum thickness of Kansan deposits in this

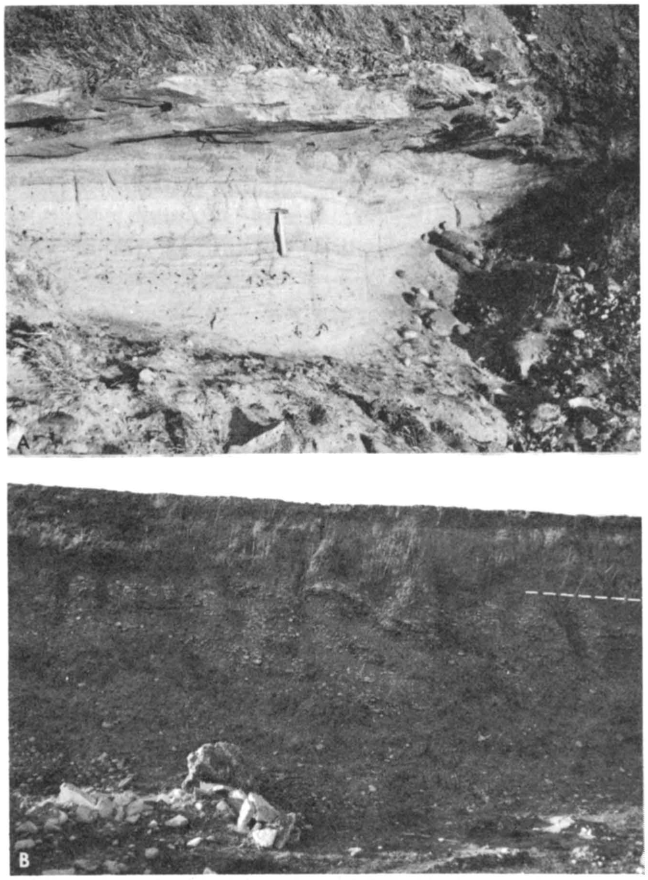

FIGURE 14.—Ahlskog gravel pit in the NE¼ NW¼ sec. 11, T.12 S., R.23 E. *A*, Cemented and uncemented sand and fine gravel. *B*, Red sandy silts overlying steeply dipping beds of poorly sorted gravel.

filled valley is not known, but Newell (1935, p. 83) reported that the thickness exceeds 80 feet and Dufford (1958, p. 46) reported more than 100 feet of glacial outwash in the Holliday area. Part of this filled valley was eroded to an altitude slightly below that of the present Kansas River flood plain for a short distance downstream from Wilder. Whether a narrow and much deeper till or outwash-filled gorge, such as has been found a few miles farther east at Kansas City, underlies a part of this area is not known.

Late Kansan deposits equivalent to the Sappa Formation of central and western Kansas are predominantly silt and sandy silt. The deposits are at the land surface, or below a thin cover of Loveland or Peoria Formation, and they commonly overlie sand and gravel deposits equivalent to the Grand Island Formation of central and western Kansas. The silts and sandy silts are commonly leached and are oxidized to yellowish red or reddish brown where they are in a well-drained topographic position. The Pearlette ash bed, of late Kansan age, is present in the lower part of these silts along the north bluff of the Kansas River valley about 1 mile north of DeSoto, Kans. (NW¼ SW¼ NE¼ sec. 21, T.12 S., R.22 E.), just outside this study area. The Pearlette ash deposit is 0.6 foot thick and the upper half has been altered to clay (Ada Swineford, oral commun., 1965). The ash overlies 10 feet of finely laminated and even-textured silt and clay which, in turn, overlies Kansan sand and gravel. The ash is at an altitude of about 810 feet and is about 23 feet above the surface of the Kansas River alluvium. The Pearlette ash firmly dates the deposits as late Kansan (Swineford, 1963).

Kansan deposits, both till and outwash, occur as much as 200 feet above the Kansas River flood plain in an area 1 to 10 miles south of the valley and as low as the present flood plain at the edge of the valley. A part of the coarse gravel at the bottom of the valley fill, below the Wisconsinan and Recent alluvium, may be Kansan in age.

ILLINOISAN STAGE

During the Illinoisan Stage, continental glaciers approached no closer to northeastern Kansas than eastern Iowa and western Illinois, and the volume of Illinoisan deposits is much less than the volume of deposits of the preceding Kansan glaciation or the succeeding Wisconsinan glaciation. Indirect effects of the Illinoisan glaciation in northeastern Kansas were the erosion of much of the previously deposited alluvium and till occurring in and along the Kansas River valley and its tributaries and the entrenchment of the Kansas River, followed by filling with unnamed sand and gravel deposits and with silt deposits of the Loveland Formation. Illinoisan alluvial deposits were almost completely removed along the Kansas River valley in Johnson County during the Wisconsinan and Recent Stages. The Illinoisan deposits that remain are beneath the dissected Buck Creek terrace (Davis and Carlson, 1952, p. 213) along the major tributaries of the Kansas River. The Buck Creek terrace is in an intermediate position between the prominent Kansan outwash deposits along the Kansas River valley and the Newman terrace and alluvium. It has a prominent Sangamon Soil developed in the upper part of the Loveland. Only three small areas of Illinoisan deposits (Buck Creek terrace) are shown on plate 1. Near the mouth of Cedar Creek, the surface of the Buck Creek terrace is about 20 to 25 feet above the younger and more extensive Newman terrace. The Illinoisan deposits are not differentiated from the more extensive Wisconsinan and Recent alluvial deposits in the tributary valleys but are included with alluvial deposits mapped as Qtu on plate 1.

Unnamed Sand and Gravel Deposits

Water-laid sand and gravel deposits of Illinoisan age constitute the lower part of the alluvial fill underlying the Buck Creek terrace. No remnants of the Buck Creek terrace remain in the Kansas River valley in Johnson County, but the thickness, character, and position of Illinoisan deposits relative to stratigraphic units older and younger are known from studies in adjacent areas where deposits underlying the Buck Creek terrace have been called Crete Formation (Davis and Carlson, 1952, p. 213 and 229; and Dufford, 1958, p. 25-26). The term "Crete Formation" is now restricted to usage in central and western Kansas (Bayne and O'Connor, 1968). Dufford (1958, p. 47) reported 24 feet of terrace deposits, including 4 feet of silty sand at the base of the terrace, which he judged to represent the Crete Formation, along a small tributary of the Kansas River just outside the area of this report (NW¼ sec. 9, T.12 S., R.21 E.). Similar deposits probably are present along the principal tributaries of the Kansas River in Johnson County.

Loveland Formation

The Loveland Formation occurs in two phases: 1) as alluvial deposits of sandy to clayey silt in the upper part of the alluvial fill below the Buck Creek terrace along the tributary stream valleys of the Kansas River, and 2) locally as thin eolian silt deposits on the uplands along the Kansas River valley.

The alluvial phase of the Loveland Formation, which comprises the upper part of the deposits underlying the Buck Creek terrace, consists of silt and clay, locally sandy; its contact with the underlying unnamed sand and gravel deposits is gradational. The alluvial Loveland has a thickness of 10 to 20 feet, except near the Kansas River where it may be as much as 40 feet thick. In the headwater areas of the tributaries, alluvial Loveland converges with the Wisconsinan and Recent alluvium and may be less than 10 feet thick. Because the upper part of the alluvial Loveland is well drained where it is present along the tributary valleys, it has a well-developed reddish-brown Sangamon Soil at its surface.

The eolian or loess phase of the Loveland Formation forms a thin and discontinuous silt cap on some of the hills along the Kansas River and on the uplands in northeastern Johnson County. The thickness of Loveland loess is less than 8 feet.

The alluvial and eolian Loveland deposits are leached of all carbonates and contain no fossil mollusks in exposures that were studied. The eolian Loveland is entirely within the Sangamon Soil profile.

WISCONSINAN AND RECENT STAGES

Deposits of gravel, sand, silt, and clay that occur as alluvial fill in the stream valleys of Johnson County are predominantly Wisconsinan and Recent in age and comprise much of the deposits mapped as alluvium and Newman terrace deposits on the geologic map (pl. 1). Undifferentiated terrace and colluvial deposits in the tributary stream valleys also are largely of Wisconsinan and Recent age. Thin loess deposits of the Peoria Formation are of early Wisconsinan age.

Although the Wisconsinan glaciers did not extend into Kansas, they repeatedly invaded the Missouri Valley region north of Kansas and had a profound effect on the fluvial and eolian sedimentation in northeastern Kansas. Two or more cycles of downcutting followed by aggradation have occurred in the Kansas River valley as a result of the early and late Wisconsinan glaciations into the Missouri River valley of Iowa, Nebraska, and North and South Dakota.

Peoria Formation

The more extensive of the Wisconsinan loess deposits in Johnson County are of early Wisconsinan age (table 3). These loess deposits are named the Peoria Formation and are found as a widespread but discontinuous blanket of silt on the uplands. The Peoria Formation is thickest along the bluffs of the Kansas River and in the northeastern part of the county. Peoria loess is much thicker along the bluffs south and east of the Missouri River valley than along bluffs of the Kansas River valley, suggesting that the primary source of the silts was the Missouri River valley and that the Kansas River valley was only a secondary source from which the wind-blown silts were derived.

Peoria silts are yellowish brown to yellowish gray, completely leached, and devoid of any observed fauna in Johnson County. The maximum thickness of Peoria is about 15 feet in the northeastern part of the county. Peoria silts thin to the south and west, but even in the southwestern part of the county 0.5 to 3 feet of Peoria loess is present locally. Over much of the upland area 2 to 6 feet of Peoria is common. The Peoria loess is not mapped on plate 1 because the deposits are thin and it is difficult to accurately identify and delimit them.

The Bignell Formation, a loess deposit younger than the Peoria, is recognized along the Missouri River valley of northeastern Kansas. If the Bignell is present in Johnson County, it is so thin that it is included entirely within the A-horizon of the modern soil profile.

Deposits of Newman Terrace

The Newman terrace is a prominent and widespread low surface in the Kansas River valley of eastern Kansas. It is not, however, present in the Kansas River valley in Johnson County. Deposits beneath the Newman terrace constitute a major part of the alluvial valley fill in tributaries such as Captain Creek, Kill Creek, Cedar Creek, and Mill Creek and probably also the eastward-draining tributaries such as the Blue River.

The Newman terrace is flat, poorly drained, and bordered by low natural levees. It is still being raised by slight accretion each time it is covered by floodwaters.

In Cedar Creek valley the Newman terrace is about 30 feet below the Buck Creek terrace and is about 30 feet above the average low-water stream level of Cedar Creek. One test hole (12-22E-26dab) in Newman terrace deposits at the mouth of Cedar Creek valley penetrated more than 70 feet of alluvial fill and probably represents a near-maximum thickness of the deposits. The upper part of the alluvial deposits in this test hole is medium to dark gray and gray brown and is chiefly silt and clay. Descriptions of Newman terrace deposits elsewhere in the Kansas River valley and major tributaries (Davis and Carlson, 1952; Dufford, 1958; and O'Connor, 1960) indicate that the upper 8 to 50 feet of the deposits is typically dark and clayey. The basal part of the alluvial fill beneath the Newman terrace at the mouth of Cedar Creek is sandy and gravelly and includes much silt.

The dark clay that everywhere is found in the upper part of the deposits underlying the Newman terrace is judged to be of late Wisconsinan and Recent age. Both early and late Wisconsinan sediments may be represented, but the deposits have not been dated by fossils or by other means. The sandy and gravelly basal part, likewise, has not been dated but may be of Wisconsinan or Kansan age. The deposits mapped as Qtu on plate 1 are chiefly of Wisconsinan and Recent age, and are equivalent to those underlying the Newman terrace and to alluvium in the Kansas River valley; they also include some older Pleistocene deposits.

The composition of the deposits in the tributary valleys reflects the lithology of the rocks that crop out within the drainage basins. Tributaries draining appreciable areas of sandstone or sandy Kansan glacial and fluvial deposits have sandier fillings than do other valleys. The nature of these fillings is shown by logs of test holes given at the end of this report.

Alluvium

Deposits mapped as alluvium (pl. 1) along the Kansas River and its tributaries are Wisconsinan and Recent in age and underlie an irregular surface about 3 to 20 feet below the Newman surface. In most of the tributary valleys the Wisconsinan and Recent terraces and the deposits that underlie them are not differentiated and are not mapped separately.

In the Kansas River valley the surface of the alluvium is marked by meander scroll patterns and irregularities commonly having a relief of 5 to 10 feet. These irregularities resulted from the gradual downcutting during progressive, nonuniform downstream migration of meanders. Point-bar accretion slopes are so gentle that they may be interpreted as representing one or more minor terraces. Dufford (1958) considered four distinct surfaces below the Newman terrace, but he did not map any of them as terraces. The four surfaces were distinguished on the basis of the degree of soil development, radius of curvature of the meander scrolls, and relative altitude of the different surfaces. Locally the distinctions between surfaces are so subtle that the surfaces cannot be identified with certainty. In this report all the valley surface below the Newman terrace is mapped as alluvium on plate 1.

The surficial deposits of alluvium are generally light colored and sandy, and contrast markedly with the dark silt and clay "backswamp" deposits at the Newman surface. Test-hole data indicate that the upper 35 to 45 feet of sediments in the alluvium is similar to sediments transported by the Kansas River today. Wyman (1935, p. 229-230) indicates that the largest fragments of rock recovered in 34 samples of bed load from the Kansas River collected by the U.S. Army Corps of Engineers did not exceed 64 mm in diameter (pebble gravel).

Very fine, fine, and medium sand comprise much of the upper part of the alluvium. Thin lenses of gray silt and clay occur locally in the upper part of the alluvium and may represent fine-grained sediment deposited on the bottom of meander scrolls. Sediments are coarser in the lower part of the alluvium and are predominantly medium sand to granule gravel (0.2 to 4 mm). The basal part of the alluvium almost everywhere contains gravel in the size range of cobbles and boulders, which is much larger than the rock fragments being transported by the Kansas River today. The basal part of alluvial fill, that part containing cobbles and boulders, may be of Wisconsinan or Kansan age.

The segment of the Kansas River valley in Johnson County that is entrenched into rocks of the Kansas City and Lansing Groups is the narrowest section of the valley between Manhattan and Kansas City. The valley ranges in width from about 1.1 to 1.8 miles, and the alluvial fill ranges in thickness from about 40 to 70 feet.

INTERGLACIAL STAGES

The interglacial stages are represented in northeastern Kansas primarily by buried soils, or paleosols, and represent the time between glacial stages when the continental interior of North America was free of ice caps and the sea level in the coastal areas was essentially stable.

Although the Afton, Yarmouth, and Sangamon Soils are all believed to be represented in Johnson County, in addition to the modern soil, the paleosols were not studied in detail, and only brief comments about their nature and extent are given. The Brady Soil has not been recognized in Johnson County.

The Aftonian Stage, oldest of the Pleistocene interglacial stages, may be represented by a soil developed on Pennsylvanian rocks and locally preserved beneath deposits of Kansan age.

The Yarmouthian Stage is represented by the Yarmouth Soil and is developed extensively on the Kansan deposits in northern Johnson County. Where the Yarmouth Soil is developed on Kansan silts in a well-drained position, it has a thick B-horizon that is red, leached, and enriched with clay. James Thorp (written commun., 1965) has identified the buried Yarmouth Soil in the Ahlskog gravel pit (E½ NW¼ sec. 11, T.12 S., R.23 E.). Thorp measured and described the soil and paleosol above the gravel in the northeastern part of the pit. At this site the modern soil, 4.7 feet thick, is developed on Peoria loess and overlies a dark-reddish-gray and reddish-brown buried A-horizon about 1 foot thick. Thorp estimated that this buried A-horizon contained 30 percent clay, 10 percent sand, and 60 percent silt. It contains many small pockets and streaks of black carbon. The B-horizon, at depths from 5.7 to 14.2 feet, is reddish brown, red, and yellowish red and has a clay content of 35 to 45 percent. Many tubular voids (0.1 inch in diameter) and spheroidal voids (0.5 to 0.8 inch in diameter) in the buried B-horizon are coated or half-filled with illuvial clay derived largely from the buried A-horizon but partly from the modern soil. Thorp considered that the buried A-horizon and part of the B-horizon, from 4.7 to 6.0 feet in depth, might possibly be Loveland loess, and that the Sangamon Soil may have developed on a truncated Yarmouth Soil. In areas where the Yarmouth Soil is developed on Kansan silts in a poorly drained profile, the B-horizon is a heavy gray clay mottled with brown, pink, and red.

The Sangamonian Stage is represented by the widespread Sangamon Soil. Where the soil is developed in a well-drained profile on Illinoisan terrace deposits, it has a thick reddish-brown B-horizon and is leached to a depth of more than 20 feet.

Much of the relatively flat upland, which is underlain at a depth of a few feet by the Stanton Limestone and the lower part of the Stranger Formation, has a thin cover of Peoria loess at the land surface. The modern soil, developed on this Peoria loess in much of the upland, overlies a very sticky tenacious mottled clay, about 5 feet thick, that is believed to be part of the Yarmouth Soil or Sangamon Soil, or both, that developed under conditions of poor drainage.

STRUCTURAL GEOLOGY

A detailed analysis of the structural geology is beyond the scope of this report, but certain aspects of the structural geology are readily discernible and are summarized in the following paragraphs.

Regional Structure

The name "Prairie Plains monocline" (Prosser and Beede, 1904) is applied to the area of eastern Kansas, including Johnson County, and western Missouri where the outcropping Pennsylvanian and Permian rocks dip generally westward and northwestward at about 20 feet per mile. This structure is post-Permian in age. Overstep of Cretaceous rocks, or beveled Permian and Pennsylvanian rocks in eastern Kansas, southeastern Nebraska, and southwestern Iowa, indicates a pre-Cretaceous age for the structure.

Using modern 7½-minute topographic maps having 10-foot contour intervals, many measured geologic sections, and logs of wells and test holes, a map was prepared showing the configuration of the top of the Stanton Limestone (fig. 15). This map indicates that the near-surface rocks dip gently northwestward across Johnson County at an average rate of about 12 feet per mile.

The regional northwesterly dip is modified by a northeast-trending anticline, here named the Gardner anticline, that extends from near Gardner across the central part of the county to near Craig. Much drilling for oil and gas has been on or adjacent to this structure, and the Gardner, Olathe, Olathe North, and Craig-Monticello (in part) fields are on the anticline. There is more than 40 feet of surface closure near the south end of the structure. To the east of the Gardner anticline there is a nearly parallel structural depression. A structure map of the base of the Kansas City Group, not included in this report, shows slightly more closure on the Gardner anticline. Some of the "nosing" structures in the Stilwell and Dallas field areas (fig. 3) appear to have some closure on the base of the Kansas City Group.

Generally, the amount of structural deformation indicated in the surface rocks increases with depth in

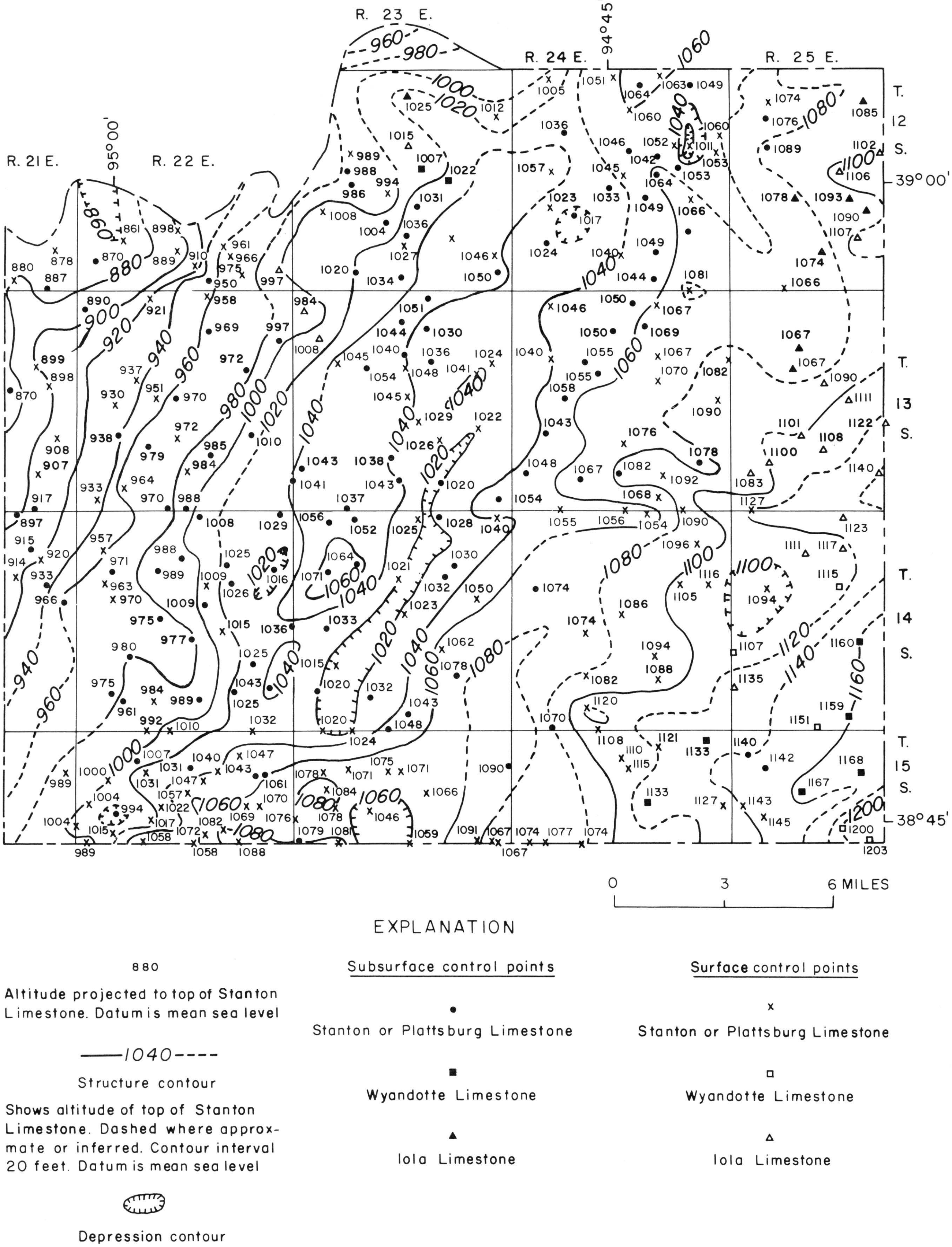

FIGURE 15.—Configuration of the top of the Stanton Limestone. Faults mapped on plate 1 are not shown.

the older Pennsylvanian rocks, and some of the structural "noses" shown in the surface rocks may become closed anticlines in the Marmaton and Cherokee rocks. Differential compaction and recurrent movement of fault blocks in the basement rocks probably account for most of the structures.

Figure 4 shows the post-Mississippian, pre-Pennsylvanian paleotopography on top of the Mississippian rocks. The map is not a structure map because both the St. Louis and Salem Limestones are exposed directly below the basal Pennsylvanian rocks as a result of post-Mississippian, pre-Pennsylvanian uplift and erosion. In some areas where the topography on the post-Mississippian, pre-Pennsylvanian surface is confined to one formational unit, a contour map on this surface approximates a structure map. The location and altitudes of the top of the Arbuckle for all wells of record that have been drilled into the Arbuckle are also shown on figure 4.

Faulting

Faults have been mapped in only two small areas of Johnson County, in the town of Shawnee and near Cedar. One or more faults strike approximately northeast along an intermittent stream to Nieman Road (east side SE¼ SW¼ sec. 11, T.12 S., R.24 E.) and have a throw of as much as 30 feet. Another fault trends south-southeast from Nieman Road (SW¼ SE¼ sec. 11, T.12 S., R.24 E.) across Switzer Road to Interstate Highway 35 at 75th Street (SE¼ NW¼ sec. 24, T.12 S., R.24 E.) and has a throw of as much as 35 feet. Both faults affect the exposed rocks of the Kansas City and Lansing Groups, but little is known about the effects of the faults on older rocks. Rocks exposed along the faults and in nearby areas of secs. 11 and 14, T.12 S., R.24 E., locally have dips of 5 to 10 degrees, and the SW cor. SE¼ sec. 11, T.12 S., R.24 E., seems to be the locus of a structural depression associated with the faulting (fig. 15, pl. 1). Three small faults, across Quivira Road just south of 67th Street (west side NW¼ SW¼ sec. 14, T.12 S., R.24 E.), in Shawnee were first noted by State Highway Commission geologists.

The south-trending fault near Cedar (sec. 25, T.12 S., R.22 E.) is along the east side of Cedar Creek. The Iola Limestone, Lane Shale, and lower Wyandotte Limestone are well exposed in the bluff along the railroad about 1,600 feet east of Cedar Creek; the Iola is just above the track level. About midway between this exposure and Cedar Creek the beds are cut by a fault. In the east bank of Cedar Creek just south of the railroad bridge, the top of the Iola Limestone is in the creek bed and is overlain by good exposures of the Lane Shale and lower Wyandotte beds. Rocks on the west side of the fault are downthrown about 30 feet. Although the trace of the fault is obscure, the difference in altitude of the Wyandotte Limestone along the east and west sides of Cedar Creek valley suggests that the fault may continue southward for a mile or more, but it is concealed by alluvial deposits.

At one other locality along the south county boundary in the valley of Sweetwater Creek (sec. 13, T.15 S., R.23 E.) just east of Spring Hill, the Plattsburg, Vilas, and Stanton beds are about 20 to 25 feet higher in the west valley wall than in the east valley wall. This relationship may result from a sharp reversal of dip or from a small north-trending fault, located along Sweetwater Creek, that has a throw of about 25 feet.

Sinks and Depression Structures

Some of the depressions shown on figure 15 may be related to sink holes or collapse structures that have developed in the Mississippian and older Paleozoic rocks. Clair (1943) has indicated a large number of similar depressions on structural maps that he prepared for adjacent Jackson and Cass Counties, Mo. He considered some of these features to be sinks that originated in the pre-Pennsylvanian carbonate rocks and affected the younger Pennsylvanian rocks. Miller (1966) has reported structural features in the surface rocks of Miami County that also may have resulted from solution and collapse.

For the most part, the structures depicted on figure 15 are simpler than those described by Clair in Jackson and Cass Counties, Mo. Two factors account for part of the apparent greater complexity of the geology in Missouri. The first is the greater number of data points, chiefly wells, and the second is the deeper (older) geologic unit on which Clair prepared his maps. The complexity of the structures contoured is greater on the base of the Myrick Station Limestone Member of the Pawnee Limestone as drawn by Clair than on the younger Stanton Limestone in this report. Sink holes in Mississippian and older rocks probably are reflected to a greater degree in the Cherokee and Marmaton rocks than in the younger Lansing rocks.

The thickening and thinning of some of the limestones and shales at shallow depths probably affect the structure in the Stanton Limestone to some degree also. As an example, where the intervals of Lane Shale and Bonner Springs Shale are thick and the Wyandotte Limestone is thin, the sequence of sediments probably has compacted to a greater degree than where the compactable shale units are thin and the more competent Wyandotte Limestone is relatively thick (figs. 6, 7, 10).

GROUND-WATER RESOURCES

Ground-Water Recharge and Discharge

The addition of water to the underground reservoir is called recharge. The most important source of recharge in Johnson County is local precipitation; for shallow upland wells, local precipitation is the only source of recharge. Lesser amounts are contributed elsewhere by influent seepage from streams and ponds and by subsurface inflow from adjacent areas.

Recharge is seasonal in Johnson County. Generally, water levels in wells are lowered by natural drainage into streams or valley areas during the winter when the soil is frozen and precipitation is slight. During the spring months frost leaves the ground, precipitation is more abundant, temperatures are moderately cool, and transpiration and evaporation demands are low, resulting in considerable recharge. Seasonal effects are most noticeable in shallow water-table aquifers and least apparent in deeper artesian aquifers. Recharge occurs, however, anytime that the infiltration of precipitation exceeds soil-moisture requirements.

Ground water moves downward through permeable rocks under the influence of gravity. The direction and rate of movement of the water may be affected by the character and structure of the rocks. Ground water may discharge directly to a stream or to a spring or seep, or it may evaporate or be transpired by plants. Part of the ground water is discharged from wells, but except for the municipal, industrial, and irrigation pumpage in the Kansas River valley, the amount discharged by wells is small compared with that discharged by other means. Over a long period of time, approximate equilibrium generally exists between the amount of water that is added annually to ground-water storage and the amount that is discharged.

Chemical Character of Ground Water

Water is commonly referred to as the universal solvent. Various gases and minerals are taken into solution by water as it is precipitated and as it percolates through the earth materials. The kind and amount of impurities in ground water may be determined by chemical analysis. The corrosiveness, encrusting tendency, palatability, and other objectionable or desirable properties also can be predicted from the results of a quantitative chemical analysis. Ordinarily, greater amounts of dissolved mineral constituents are found in ground water than in surface water in eastern Kansas because ground water has been in contact with soluble materials in the geologic strata for a longer time.

The chemical character of ground water in Johnson County is indicated by chemical analyses of 54 water samples from selected wells, test holes, and springs. The analyses are listed in tables 4 and 9. The mineral constituents are reported in milligrams per liter (mg/l). Factors for converting milligrams per liter to milliequivalents per liter are given in table 5. Even though the analyses were made several years ago, they should still be representative of the chemical quality of ground water in Johnson County.

QUALITY IN RELATION TO USE

Water for domestic use should not contain excessive amounts of hardness, iron, magnesium, chloride, sulfate, nitrate, fluoride, or dissolved solids. The maximum concentrations of various constituents in drinking water recommended by the U.S. Public Health Service are summarized in table 6.

The suitability of ground water for irrigation depends upon the effects of the mineral constituents in the water on both the plants and the soils being irrigated. Water used for irrigation should not contain excessive amounts of dissolved solids, boron, or bicarbonate, and should not have a high calcium magnesium to sodium ratio.

Water-quality requirements for industrial processes vary widely. Some industrial uses require water of extremely high quality, whereas others satisfactorily use water of low quality. The concentrations of dissolved solids, hardness, iron, and hydrogen ion (pH), and the alkalinity and temperature of the ground water are some of the more important factors in determining the usability of the water.

The discussion of the various dissolved constituents that affect the chemical quality and use of ground water has been adopted from various sources including the American Public Health Association and others (1955), California State Water Pollution Control Board (1952), Hem (1959), Rainwater and Thatcher (1960), U.S. Salinity Laboratory Staff (1954), and U.S. Public Health Service (1962).

In this report, water is classified from fresh to briny according to its dissolved-solids content and specific conductance as given in table 7.

Dissolved solids.—When water is evaporated, the residue consists mainly of the mineral constituents listed in table 4, except bicarbonate. The residue may include a small quantity of organic material or water of crystallization. Water containing less than 500 mg/l dissolved solids generally is satisfactory for domestic use, except for difficulties resulting from its hardness or iron content. Water containing more than 1,000 mg/l dissolved solids may have certain constituents in

TABLE 4.—Chemical analyses of water from selected wells, test holes, and springs.
[Dissolved constituents and hardness in milligrams per liter.[1]]

Well number[2]	Depth (feet)	Geologic source[3]	Date of collection	Temperature (°C)	Dissolved solids (evaporated at 180° C)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate[4] (NO_3)	Hardness as $CaCO_3$ Total	Hardness as $CaCO_3$ Non Carbonate	Specific conductance (micromhos at 25° C)	pH
11-23E-28dcc	55	Alluvium	6-27-44	16	489	----	16	----	140	14	18	425	72	14	0.2	2.4	407	59	----	----
33abb	55	do	6-28-44	16	408	----	12	----	108	13	24	368	51	14	.2	1.5	323	21	----	----
33abc	52	do	6-29-44	14	442	----	25	----	127	11	14	377	62	12	.2	1.8	362	53	----	----
33acb	56	do	7- 1-44	13	436	----	10	----	129	13	8.3	337	91	15	.1	1.5	376	100	----	----
33acc	51	do	7- 1-44	15	365	----	10	----	102	14	6.7	265	82	16	.1	1.3	312	94	----	----
33caa	41	do	7- 3-44	16	413	----	4.2	----	128	14	3.2	348	73	15	.1	1.5	377	91	----	----
12-21E-36ccc	236	Chanute Sh	6- 9-55	----	5,090	8.5	.16	----	31	21	1,950	625	24	2,730	6.0	9.7	164	0	----	----
12-22E-23cad	33	Alluvium	2- 1-53	----	553	36	.08	----	145	13	10	314	65	14	.3	115	416	158	----	----
25cdb	40	Newman terrace deposits	10- 1-52	----	----	----	.40	.00	----	----	----	----	----	56	----	80	568	----	----	----
26add	37	Alluvium	8-19-62	----	----	----	4.7	.49	195	23	----	----	72	15	.2	.7	581	----	----	7.7
26bda	17	do	10- 1-52	----	----	----	1.2	.00	----	----	----	----	----	22	----	11	412	----	----	----
28abc1	46	do	11-15-57	----	----	----	8.0	.24	----	----	----	----	24	9.0	.2	1.2	436	----	----	----
28abc2	46	do	11-15-57	----	----	----	7.7	.57	----	----	----	----	26	12	.2	1.2	440	----	----	----
12-23E- 1bdc	24	do	6- 2-55	13	540	18	1.6	----	155	15	18	437	87	20	.2	12	448	90	----	----
5ca	32	do	2- 7-53	----	444	23	17	----	120	21	14	448	37	6.0	0	1.8	386	18	----	----
11bb1	25	Kansan Stage	6- 2-55	----	328	18	1.6	----	94	7.2	12	288	12	10	.1	33	264	28	----	----
27bcb	109	Farley Ls Member of Wyandotte Ls	5-19-55	----	1,370	6.0	.39	----	13	8.6	485	600	444	105	6.0	4.3	68	0	----	----
12-24E- 5cda	55	Drum Ls	5-19-55	14	517	13	1.2	----	95	14	80	427	76	25	.5	3.8	294	0	----	----
20abb	40	Iola Ls	6- 2-55	----	407	12	.16	----	128	10	7.6	368	46	14	.2	8.4	360	58	----	----
12-25E-18bad	48	Stanton Ls	6- 8-55	----	247	8.5	4.9	----	58	7.2	19	163	41	18	.3	15	174	40	----	----
13-21E-23cbd	25	do	6- 9-55	----	450	21	.12	----	81	14	54	276	119	9.5	.2	15	260	34	----	----
26ccd1	35	Kansan Stage	6- 9-55	14	245	26	.36	----	46	7.3	31	229	10	7.0	.1	4.2	145	0	----	----
13-22E-33ddd	93	Farley Ls Member of Wyandotte Ls	6- 8-55	----	462	19	.26	----	65	57	26	464	55	10	.2	1.2	396	16	----	----
13-23E-30ccc	20	Stanton Ls	6- 8-55	----	546	18	.20	----	62	24	116	527	37	15	.3	15	253	0	----	----
13-24E- 3acb	23	do	6- 2-55	13	278	8.5	.08	----	51	6.6	34	120	91	19	.3	8.8	154	56	----	----
17bba	Spring	Plattsburg Ls	6- 2-55	13	329	10	.04	----	95	6.6	11	249	41	10	.2	32	264	60	----	----
13-25E-23ccb	10	Colluvium	5-17-55	14	403	16	.12	----	88	14	41	372	20	11	.3	30	277	0	----	----
32bcc	95	Chanute Sh	5-31-55	----	375	15	.44	----	77	20	37	376	34	6.5	.2	.4	274	0	----	----
14-21E-12ada	50	Kansan Stage	6- 9-55	14	328	21	2.7	----	55	8.5	43	210	48	5.5	.2	44	172	0	----	----
25baa	41	Ireland Ss Member of Lawrence Fm	6- 9-55	13	124	21	.62	----	12	4.9	19	78	7.0	5.0	.2	17	50	0	----	----
36ccb	30	do	5-18-55	----	119	24	.36	----	12	7.3	16	102	2.5	4.0	.4	3.0	60	0	----	----
14-22E- 9cbb	15	Rock Lake Sh Member of Stanton Ls	6- 9-55	13	352	20	.28	----	71	15	26	224	82	6.0	.2	22	238	54	----	----
21bcb	55	Ireland Ss Member of Lawrence Fm	2- 1-46	----	337	16	.30	.13	44	21	30	239	55	4.5	.3	2.7	196	0	----	7.0

21cbb1	36	do	7- 44	----	336	15	1.7	----	50	24	37	310	41	4.5	.4	1.5	224	0	----	----
21cbb2	42	do	7- 44	----	326	14	1.8	----	48	23	38	300	43	3.5	.4	1.5	214	0	----	----
14-23E-11bcc1	12	Stanton Ls	6- 9-55	----	358	13	.15	----	77	15	27	271	39	10	.3	44	254	32	----	----
11bcc2*	115	Wyandotte Ls	1- 9-53	----	4,000	----	----	----	----	----	----	----	1,320	945	----	----	----	----	----	----
15daa*	84	Bonner Springs Sh	7- 6-59	----	1,890	----	----	----	----	----	----	----	460	700	----	----	----	----	----	----
14-24E-18aba	21	Rock Lake Sh Member of Stanton Ls	5-19-55	----	442	20	.05	----	83	12	65	417	7.4	15	.2	34	256	0	----	----
14-25E- 3ccc	15	Iola Ls	5-31-55	14	326	6.5	.39	----	44	6.3	58	116	126	21	.4	6.6	136	41	----	----
22baa	200	Stark Sh Member of Dennis Ls	2-28-57	----	1,310	7.5	.11	.00	3.3	1.5	545	883	1.6	240	14	.7	14	0	2,370	----
15-21E-14cbb	40	Ireland Ss Member of Lawrence Fm	6- 9-55	----	399	20	.26	----	57	15	67	329	16	18	.3	44	204	0	----	----
15-22E- 5ddd	26	Recent Stage Wisconsinan Stage	5-18-55	12	528	17	.10	----	152	10	19	351	112	34	.2	11	420	132	----	----
15-23E- 2ddd	32	Stanton Ls	6- 3-55	13	1,050	18	.26	----	167	37	125	284	304	130	.3	133	568	335	----	----
15-24E- 2dda	9	Colluvium	6- 3-55	----	217	15	.24	----	49	7.3	8.5	110	33	9.0	.2	41	152	62	----	----
15-25E- 4bab	Spring	Argentine Ls Member of Wyandotte Ls	6- 3-55	15	345	11	.14	----	102	8.6	9.0	277	55	11	.2	12	290	63	----	----
4dcd	15	Colluvium	6- 3-55	13	231	16	.12	----	61	4.9	13	183	33	9.0	.2	3.9	172	22	----	----

[1] One milligram per liter is equivalent to 8.33 pounds of substance per million gallons of water.
[2] Analyses with asterisk after well number are by State Geological Survey of Kansas. All other analyses are by Kansas State Department of Health.
[3] *Ls*, Limestone; *Sh*, Shale; *Ss*, Sandstone; *Fm*, Formation.
[4] In areas where the nitrate content of water is known to exceed 45 mg/l, the public should be warned of the potential dangers of using the water for infant feeding (U.S. Public Health Service, 1962, p. 7).

TABLE 5.—Factors for converting milligrams per liter to milliequivalents per liter.

Mineral constituents	Chemical symbol	Multiply by
Cations		
Calcium	Ca^{++}	0.04990
Magnesium	Mg^{++}	.08226
Sodium	Na^{+}	.04350
Potassium	K^{+}	.02558
Anions		
Carbonate	CO_3^{--}	.03333
Bicarbonate	HCO_3^{-}	.01639
Sulfate	SO_4^{--}	.02082
Chloride	Cl^{-}	.02821
Fluoride	F^{-}	.05264
Nitrate	NO_3^{-}	.01613

sufficient quantity to produce a noticeable taste or to make it unsuitable in some other respect.

Smith and others (1942) and Heller (1933) have described experiments with livestock using known concentrations of salts in the animals' drinking water. They conclude that sheep have a greater tolerance than cattle and cattle have a greater tolerance than hogs to mineralized drinking water. In general, the experiments indicate that about 10,000 mg/l is the upper limit of dissolved solids that can be tolerated by livestock. Cattle on some farms in eastern Kansas are drinking water with 3,000 to 5,000 mg/l dissolved solids (chiefly sodium chloride and sodium bicarbonate) with no apparent ill effects.

The concentrations of dissolved solids in 42 samples of ground water collected in Johnson County from wells, test holes, and springs are given in table 4. The dissolved-solids concentration ranged from 119 to 5,090 mg/l.

Specific conductance.—The specific conductance is a measure of the ability of water to conduct an electric current and is an indication of the ionic strength of the solution. Because conductance is the reciprocal of resistance, the units in which specific conductance is reported are reciprocal ohms or "mhos." Natural waters have specific conductance values much less than 1 mho and, therefore, are reported in millionths of mhos or micromhos at a standard temperature of 25°C (77°F). For practical purposes the relation between specific conductance and concentration of dissolved solids is linear for dilute solutions, such as the water used for domestic and stock purposes in Johnson County. Specific conductance is conveniently determined with a Wheatstone bridge using a standardized conductivity cell, and the results are converted to the approximate value of the dissolved-solids concentration.

TABLE 6.—Recommended maximum amounts of various constituents in drinking water (adapted from U.S. Public Health Service, 1962).

Constituent	Concentration (milligrams per liter)
Chloride (Cl)	250.
Fluoride (F)	1.2
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45.
Sulfate (SO_4)	250.
Dissolved solids	500.

The relationship between specific conductance and dissolved solids is expressed as:

Specific conductance (micromhos at 25°C) x A = Dissolved solids (mg/l).

The factor A has a value ranging from 0.5 to 1.0 but A commonly has a value between 0.55 and 0.75 (Hem, 1959, p. 40).

Hardness.—Calcium and magnesium cause nearly all the hardness of water and are the active agents in the formation of most of the scale in steam boilers and other vessels in which water is heated or evaporated. Dissolved calcium and magnesium react with soap to form a sticky curd that is difficult to remove from containers and fabrics. Soap will not cleanse or lather until the hardness-causing constituents have been removed.

TABLE 7.—Classification of water according to dissolved-solids content and specific conductance (from Winslow and Kister, 1956, p. 5; Robinove and others, 1958, p. 3).

Quality description	Dissolved solids (milligrams per liter)	Specific conductance (micromhos per cm at 25°C or 77°F)
Fresh	less than 1,000	less than 1,400
Slightly saline	1,000 to 3,000	1,400 to 4,000
Moderately saline	3,000 to 10,000	4,000 to 14,000
Very saline	10,000 to 35,000	14,000 to 50,000
Briny	more than 35,000	more than 50,000

Total hardness (carbonate plus noncarbonate hardness) and noncarbonate hardness of water in Johnson County are given in table 4. Carbonate, or temporary, hardness can be removed almost entirely by boiling. Noncarbonate hardness is due to the presence of calcium and magnesium from salts of sulfate and chloride. It cannot be removed by boiling and, therefore, is sometimes reported as permanent hardness. The two types of hardness have the same reaction with soap.

The hardness of water is arbitrarily classified as follows: 60 mg/l or less, soft; 61-120 mg/l, moderately hard; 121-180 mg/l, hard; and 181 mg/l or more, very hard (Durfor and Becker, 1964). Soft water used for domestic or municipal purposes is seldom treated to remove hardness. Very hard water, when used for municipal or domestic supplies, commonly is softened. Municipalities decrease the hardness by the addition of lime and soda ash. Individual domestic water supplies are commonly softened with zeolite-type softeners. Cisterns may be installed to collect soft rainwater for laundry and washing purposes.

The tolerance to hardness of water used for industrial processes varies greatly, ranging from 2 mg/l or less for high pressure steam boilers to several hundred milligrams per liter for other process waters. Hard water is generally more suitable for irrigation than soft water due to a favorable calcium magnesium to sodium ratio.

The total hardness of 45 samples of ground water collected in Johnson County ranged from 14 to 581 mg/l (table 4).

Iron and manganese.—Iron, in the ferrous state, is generally present in small quantities in most natural ground water. If water containing more than 0.1 mg/l iron is exposed to the air, some of the iron may oxidize and precipitate as a reddish sediment. Iron in concentrations in excess of 0.3 mg/l is undesirable as it may stain cooking utensils, plumbing fixtures, and clothing being laundered, or give a disagreeable taste to the water. Dissolved manganese also causes objectionable staining and taste problems, but is less commonly present. In water treatment plants, iron and manganese are commonly removed by aeration or chlorination, or both followed by sedimentation and filtration.

The concentration of iron in 45 samples of ground water collected in Johnson County ranged from 0.04 to 25 mg/l (table 4). Iron in concentrations of 0.3 mg/l or more was found in 26 of the samples.

Fluoride.—Fluoride in concentrations of about 1 mg/l in drinking water used by children during the period of tooth calcification prevents or lessens the incidence of tooth decay; concentrations greater than 1.5 mg/l may cause mottling of the enamel (Dean, 1936, 1938). The U.S. Public Health Service (1962) recommends 1.2 mg/l as the maximum concentration of fluoride in drinking water used in Johnson County. The concentration of fluoride in 43 samples of ground water collected in Johnson County ranged from 0.0 to 14 mg/l. The fluoride concentration exceeded 1.5 mg/l in three samples.

Fluoride, unlike chloride, is only sparingly soluble in water and usually is present in only small amounts. It is often characteristic of waters from deep strata and of salt water from oil and gas wells. In Johnson County fluoride is commonly more abundant in water from sandstone and black shale aquifers than from aquifers of other rock types.

Nitrate.—Nitrate is highly soluble, but ground water in Kansas generally contains only small amounts, usually less than 10 mg/l (Metzler and Stoltenberg, 1950, table 3). Concentrations of 90 mg/l of nitrate in drinking water may cause cyanosis, or oxygen starvation, if used in the preparation of a baby's formula (Metzler and Stoltenberg, 1950), and some authorities (Comly, 1945) recommend that water containing more than 45 mg/l should not be used for preparation of infants' formulas. Drinking water standards established by the U.S. Public Health Service (1962) recommend 45 mg/l as the maximum concentration. Of the 45 samples of ground water collected from Johnson County and analyzed for nitrate, three contained concentrations of more than 45 mg/l.

Nitrate from natural sources generally is attributed to the oxidation of nitrogen of the air by bacteria and to the decomposition of organic material in the soil. In general, shallow water-table aquifers having a significant range in fluctuation of the water table appear to have more nitrate attributable to natural sources than do other aquifers. Fertilizers and animal wastes may also contribute nitrates directly to water resources.

Sulfate.—The concentration of sulfate is not very critical for domestic or irrigation uses or for many industrial processes. Sulfate in ground water is derived chiefly from the solution of gypsum and the oxidization of pyrite. Most of the sulfate in the domestic and irrigation water supplies of Johnson County probably results from the oxidization of small amounts of pyrite disseminated through the limestones, shales, and sandstones through which the water percolates. Sulfate in ground water in concentrations in excess of about 500 mg/l may have a laxative effect on persons not accustomed to drinking such water. The concentration of sulfate in 45 samples analyzed ranged from 1.6 to 1,320 mg/l.

Chloride.—Most naturally occurring chlorides are very soluble. Chloride concentrations in ground water are known to range from less than 1 mg/l in some shallow aquifers to many thousand milligrams per liter in some of the deep strata. Sodium and chloride are the chief dissolved constituents in the ground water in some of the deeper aquifers. A sodium chloride water with a chloride concentration of 150 to 200 mg/l can be detected by persons having a sensitive taste. Water with a high chloride content is corrosive to many metal surfaces, and many crops may be injured by waters containing excessive quantities of chloride.

Chloride in ground water may be derived from connate marine water in the sediments, from sewage and animal wastes, or from solution of minerals containing chloride. It has little effect on the suitability of water for ordinary use unless the quantity is enough to give the taste of salt.

The concentration of chloride in 47 water samples from Johnson County (table 4) ranged from 3.5 to 2,730 mg/l.

Sanitary considerations.—The analyses of water (table 4) show only the amount of dissolved minerals and do not indicate the sanitary quality of the water. Well water may contain mineral matter that gives the water an objectionable taste, but still be free from harmful bacteria and, consequently, safe for drinking. Other well water, good-tasting and seemingly pure, may contain harmful bacteria. Water supplies obtained from wells that are properly constructed and located away from sources of pollution are almost always free of harmful bacteria. Because human and animal wastes are high in chloride and nitrogenous material, the presence of abnormal concentrations of both chloride and nitrate can be indicative of pollution from these sources.

Recommendations for well locations and for sanitary well construction and pump installation can be obtained from the Kansas State Department of Health. A bacteriological analysis of water from individual wells may be obtained at little or no cost to the well owner from the Division of Environmental Health of the Kansas State Department of Health. The County Health Officer can explain the procedure for obtaining this analysis.

Temperature.—The temperature of the earth at a depth of 30 feet may be expected to vary less than 1°F annually (Collins, 1925). Ground water at depths of 30 to 60 feet, likewise, has only a small variation in temperature and generally exceeds the mean annual air temperature by 2° to 3°F. Ground-water temperature in Johnson County, therefore, should range from about 57° to 59°F in aquifers at a depth of about 30 feet. At very shallow depths the ground water has a slightly greater temperature variation, as shown in table 4. Water samples from Wisconsinan and Recent alluvium ranged in temperature from 53° to 60°F (12° to 16°C). Wells pumping near a stream may induce recharge from the stream, and thus cause an increase or decrease in the ground-water temperature. The temperature of the Kansas River ranges from 32° to about 80°F (Fishel and others, 1953, p. 23).

Temperature of ground water in deeper aquifers increases about 1°C (1 4/5°F) for each 100 feet of depth. Ground water from Mississippian rocks at a depth of 1,100 feet below land surface would have a temperature of about 78°F and water from Arbuckle rocks at a depth of 1,900 feet below land surface would have a temperature of about 92°F.

Aquifer Properties

An aquifer is a geologic formation, a part of a formation, or a group of formations that will yield significant quantities of water to wells and springs. The properties of an aquifer that determine its capacity to transmit water and to release water from storage are its permeability, transmissibility, and storage. These factors depend in part on the thickness, extent, continuity, and homogeneity of an aquifer and on the size and nature of the pore spaces in the aquifer.

The field coefficient of permeability (P) is defined as the number of gallons of water per day, at the prevailing water temperature, that will move in 1 day through a vertical section of the aquifer 1 foot square under a hydraulic gradient of 100 percent or 1 foot per foot (Stearns, 1928). Coefficients of permeability of less than 100 gpd (gallons per day) per sq ft (square foot) are considered low, coefficients of 100 to 1,000 are medium, and those of more than 1,000 are considered high. The coefficient of transmissibility (T) is equal to the field coefficient of permeability multiplied by the saturated thickness (m), in feet, of the aquifer (Theis, 1935, p. 520).

The coefficient of storage (S) is defined as the volume of water, measured in cubic feet, released from storage in each column of the aquifer having a base 1 foot square and a height equal to the thickness of the aquifer, when the water table or other piezometric surface is lowered 1 foot. In water-table aquifers the coefficient of storage for long periods of pumping is approximately equal to the specific yield and has a range of about 0.1 to 0.3. The specific yield is defined as the ratio of the volume of water a saturated material will yield by gravity to its own volume. For artesian aquifers the coefficient of storage generally is very small, ranging from about 10^{-5} to 10^{-3}.

Drawdown in a well is the lowering of the water table by pumping or of the piezometric surface by artesian flow. The specific capacity of a well is the discharge expressed as rate of yield per unit of drawdown, generally gallons per minute (gpm) per foot of drawdown. Specific capacity is a better measure of an aquifer's capacity to yield water than is the actual yield of a well, because it relates yield to drawdown in the well.

Hydrologic data for aquifers in Johnson County and the source of the data are summarized in table 8. The availability of ground water in the unconsolidated and consolidated rock aquifers and the important aquifer properties known or inferred are described in the following pages.

TABLE 8.—Summary of hydrologic data for aquifers.

Well or test hole number	Date of aquifer test	Principal aquifer	Dis-charge (gpm)	Draw-down (feet)	Duration of test (minutes)	Specific capacity (gpm per ft)	Thick-ness of aquifer (feet)	Remarks[1]
12-22E-19cbc	-42	Alluvium	650	13.5	60	48	36.1	SOW 131-1. Data from Layne-Western Co. and Sunflower Ordnance Works
do	1- 1-44	do	450	8	----	56	----	SOW 131-1. Actual operating conditions
12-22E-19cca	-42	do	750	18.5	60	41	37.3	SOW 131-2. Data from Layne-Western Co. and Sunflower Ordnance Works
do	1- 1-44	do	450	12.5	----	36	----	SOW 131-2. Actual operating conditions.
12-22E-20cac	-42	do	770	15.8	120	49	40.1	SOW 131-4.
do	1- 1-44	do	150	----	----	----	----	SOW 131-4. Actual operating conditions, before well was acidized
do	1-15-44	do	630	9	----	70	----	SOW 131-4. Actual operating conditions, about 10 days after well was acidized
12-22E-20cbc2	-42	do	800	14	60	57	34.6	SOW 131-3. Data from Layne-Western Co. and Sunflower Ordnance Works
do	1- 1-44	do	240	17.5	----	14	----	SOW 131-3. Actual operating conditions, before well was acidized
do	1-10-44	do	610	10	----	61	----	SOW 131-3. Actual operating conditions, 6 days after well was acidized
12-22E-20cdd	-42	do	695	26.5	180	26	39.8	SOW 131-6 Data from Layne-Western Co. and Sunflower Ordnance Works
do	1- 1-44	do	500	16	----	31	----	SOW 131-6. Actual operating conditions
12-22E-20dcb	-42	do	750	13	60	58	32.4	SOW 131-5. Data from Layne-Western Co. and Sunflower Ordnance Works
do	1- 1-44	do	500	8	----	62	----	SOW 131-5. Actual operating conditions
12-22E-24ccc1	6- 3-64	do	1,080	11.0	1,349	98	35.7	Olathe well #3. Data from Layne-Western Co. and Van Doren-Hazard-Stallings-Schnacke, Engineers
12-22E-24ccc2	6- 1-64	do	1,000	17.1	1,470	58	34.4	Olathe well #4. Data from Layne-Western Co. and Van Doren-Hazard-Stallings-Schnacke, Engineers
12-22E-25bbc1	6-15-64	do	1,080	9.3	1,453	116	44.5	Olathe well #1. Data from Layne-Western Co. and Van Doren-Hazard-Stallings-Schnacke, Engineers
12-22E-25bbc2	6- 9-64	do	1,010	12.7	720	80	40.7	Olathe well #2. Data from Layne-Western Co. and Van Doren-Hazard-Stallings-Schnacke, Engineers
14-22E-21cbb2	6-26-44	Ireland Sandstone Member of Lawrence Formation	12	14.5	1,265	0.8	18	Gardner new well #5. Open-file data

[1] SOW 131-1, Sunflower Ordnance Works (now Sunflower Army Ammunition Plant) well number.

Availability of Ground Water

Ground water for stock and domestic purposes may be obtained in Johnson County from unconsolidated Pleistocene rocks locally to a maximum depth below land surface of about 70 to 100 feet and in consolidated Pennsylvanian rocks locally to a depth of about 250 feet.

The Pleistocene aquifers are all unconsolidated, except for parts of some Kansan glaciofluvial deposits that are cemented with calcium carbonate. Pleistocene aquifers have a wide range of geologic and hydrologic characteristics and occur beneath the upland areas, beneath terraces, and as valley fillings. The texture of the deposits ranges from well-sorted sand and gravel to unsorted boulder clay. Yields from wells drilled into the unconsolidated deposits range from zero, where the deposits are thin and do not contain a saturated zone, to more than 1,000 gpm in the Kansas River valley alluvium.

The consolidated Pennsylvanian rock aquifers that contain ground water of suitable quality for livestock or domestic use consist chiefly of limestone and shale, together with a minor amount of fine-grained sandstone. Yields of wells drilled into the Pennsylvanian rocks cannot be accurately predicted, but generally are less than 50 gpm. Probably 90 percent or more of the wells drilled in consolidated rocks have sustained yields less than 10 gpm, and 50 percent or more of the wells probably have sustained yields less than 3 gpm. An estimate of well yield at a particular site can be made from the records of nearby wells listed in table 10 (p. 54), which contains information about 139 wells, test holes, and springs in Johnson County.

UNCONSOLIDATED ROCK AQUIFERS

The principal unconsolidated rock aquifers in Johnson County are shown on the geologic map (pl. 1) as alluvium (Qal), Newman terrace deposits (Qtn), and undifferentiated fluvial deposits in tributary valleys (Qtu).

Kansan fluvial and lacustrine deposits (Qd) yield small supplies of ground water locally in northwestern Johnson County and near Holliday.

In addition to the unconsolidated rock aquifers described above and shown on the geologic map, there are unmapped deposits of residuum that cover much of the upland interstream areas and locally derived colluvium that occurs along the sides of many intermittent stream valleys. These deposits are locally 20 feet or more thick and are the chief aquifer for many of the older large-diameter stock and domestic dug wells.

Kansas River Valley Alluvium

Large quantities of ground water are available from wells in the alluvium in the Kansas River valley. The extent of the alluvium is shown on plate 1. Logs of wells and test holes (at the end of this report) indicate that the alluvium has a thickness of about 40 to 70 feet. The thickness of saturated water-bearing material ranges from about 30 to 60 feet, but commonly is 35 to 40 feet. The average hydraulic gradient of the water table in this part of the Kansas River valley is about 2.5 feet per mile (Dufford, 1958, fig. 3). The specific capacities of alluvial wells reported in table 8 range from 14 to 116 gpm per ft of drawdown and probably are representative of specific capacities for alluvial wells in Johnson County. However, the specific capacities are less than those reported for alluvial wells in adjacent Douglas County.

Permeability and transmissibility values for alluvium in this part of the Kansas River valley have not been determined by aquifer tests, but they are probably similar to values obtained in adjacent parts of the valley in Douglas County. Most of the alluvium in Douglas County has a permeability of 1,000 gpd per sq ft or more and, in places, a permeability greater than 12,000 gpd per sq ft (Lohman, 1941, p. 36; O'Connor, 1960, table 6). Coefficients of transmissibility of the aquifer in Johnson County, inferred from similarities of geology and hydrology in Douglas County and the specific capacities of inventoried wells, are estimated to range from about 30,000 to 200,000 gpd per ft. Yields of wells in the alluvium generally range from 150 to 1,000 gpm, and yields of more than 1,000 gpm are probably obtainable.

Industrial and municipal pumping in the Kansas River valley alluvium is chiefly in the vicinity of DeSoto and Cedar.

The water table in the Kansas River valley, at distances more than about 0.5 mile from the river and in areas not affected by industrial, irrigation, or municipal pumping, may fluctuate as much as 15 to 20 feet through a cycle of wet and dry years. This fluctuation is an important factor to consider in planning large-capacity wells to ensure that the capacity of a pump and the design of a well correspond to the capacity of the aquifer to yield water in periods of both high and low water-table conditions. The water-level fluctuations in four observation wells near Cedar and Wilder (pl. 1) are shown graphically on figure 16. Only one of the three observation wells in the valley near Wilder is noticeably affected by river stage. Observation well 11-23E-33bba is on the south bank of the Kansas River and, depending on the stage of the river, is about 50 to 300 feet from the river's edge.

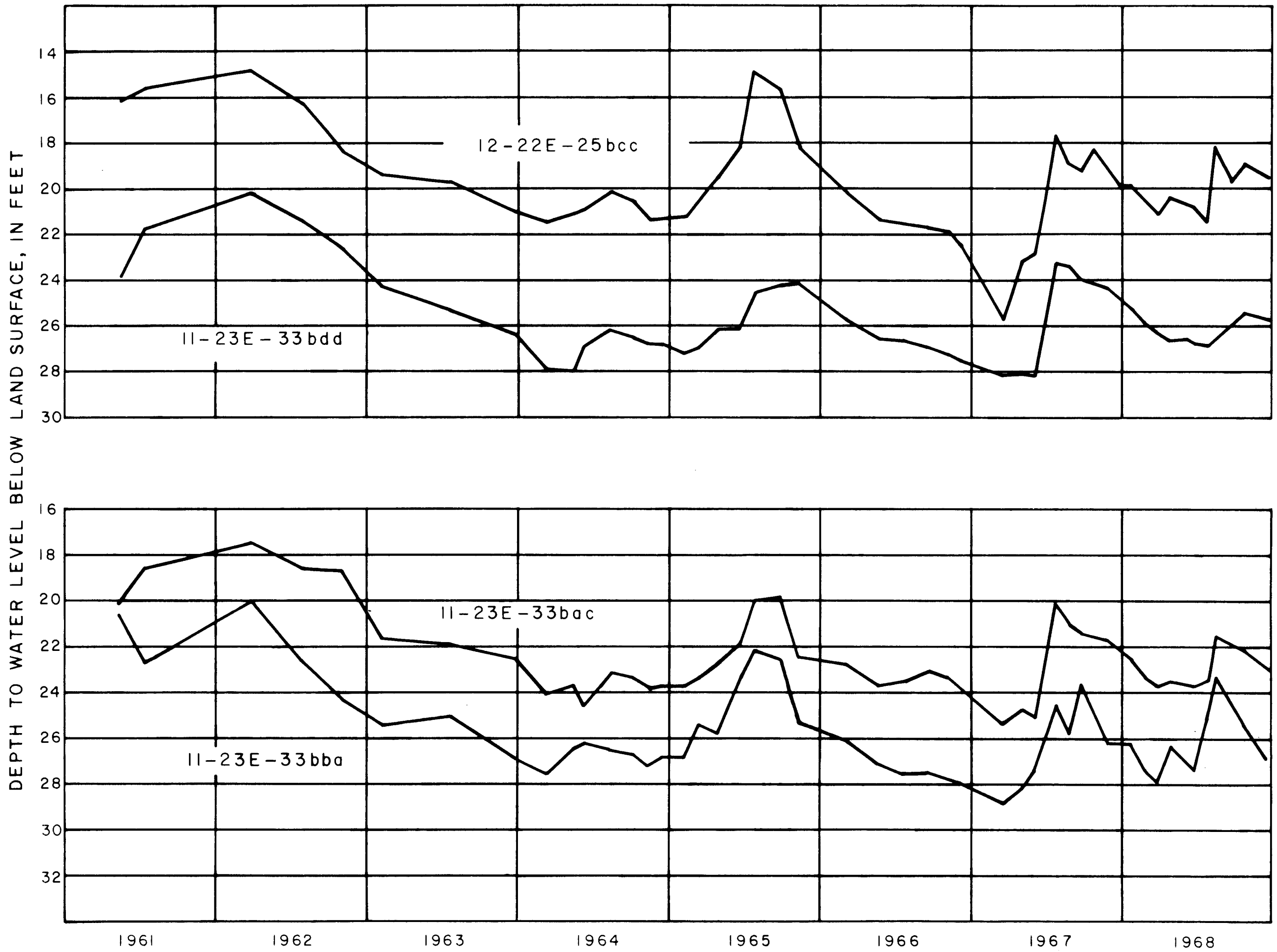

FIGURE 16.—Hydrographs for four selected wells.

Records of wells and test holes in this aquifer are given in table 10.

The chemical character of ground water in the aquifer is indicated by the water analyses in table 4. In general, the ground water can be characterized as a very hard calcium bicarbonate water that generally contains much iron. A few wells pump ground water having less than 0.1 mg/l iron.

Tributary Valley Alluvium of the Kansas, Missouri, and Marais des Cygnes Rivers

Only small quantities of ground water are available from wells in the alluvial deposits (pl. 1) in the tributary valleys of the Kansas, Missouri, and Marais des Cygnes Rivers. The alluvial material in these valleys ranges in thickness from about 20 to 75 feet in the lower reaches of the larger tributaries, but commonly is only 10 to 30 feet thick in the upper reaches. In the thicker alluvial deposits the saturated thickness of the alluvium may be as much as 60 feet thick.

The water-bearing material in these valleys is derived chiefly from rocks in the drainage area of the individual tributary. Because of the large amount of shale in the area and the thin loess deposits on the uplands, most of the valley-fill sediments are clays and silts. The coarse fraction of the alluvium is chiefly poorly sorted limestone and chert gravel in a silt or clay matrix. Captain Creek and Spoon Creek, which drain areas of the Ireland Sandstone Member of the Lawrence Formation and areas of extensive sandy glaciofluvial deposits, are exceptions, and the alluvial deposits of these streams locally are sandy.

Because the aquifers in most tributary valleys are composed predominantly of silt and clay, the transmissibilities are low. Well yields of 25 to 100 gpm probably can be obtained in the lower part of Cedar Creek valley and in parts of Captain Creek valley; however, in 1960 there were no wells of this capacity in operation. Yields of 1 to 10 gpm are more representative of wells in most of the tributary valleys.

Because of low aquifer transmissibility and low well yields, large-diameter dug wells that provide considerable storage in the well itself have been more satisfactory than small-diameter drilled wells. Well 15-22E-5ddd along Bull Creek (tables 4, 10) is representative of the water supplies available from these deposits.

The chemical quality of ground water from deposits in tributary valleys generally is satisfactory for domestic and stock use. However, some of the water is hard and, in some instances, contains high concentrations of iron (table 4).

Kansan Deposits

Kansan deposits, exclusive of those that may be present in the Kansas River valley, are significant sources of ground water in only two relatively small areas. The larger of these areas is west of Kill Creek and extends south of the Kansas River valley for about 10 miles (pl. 1). The area is an eastward continuation of extensive Kansan deposits in the Hesper vicinity of Douglas County. The Kansan deposits along the Douglas County-Johnson County boundary are as much as 52 feet thick (test hole 13-21E-26ccd2) and consist of outwash, lacustrine deposits, and till. The basal part of the deposits commonly is sand, or sand and gravel. Except where the deposits have been dissected and removed by post-Kansan stream erosion, or where the deposits are thin, they generally contain a thin saturated zone that yields water readily. Wells yielding 50 to 100 gpm probably can be obtained from Kansan deposits in parts of this area, although no wells with yields this large were inventoried. Several test holes that were drilled during this investigation penetrated 10 to 20 feet of saturated sand and gravel. Other test holes, however, penetrated little or no sand (12-22E-31dcb), or have little or no water-bearing material (13-21E-2abb). Because of the wide range in the lithology and saturated thickness of the Kansan deposits, the amount of ground water obtained from wells varies greatly from one locality to another.

Although no aquifer tests were made, some of the Kansan deposits consist of well-sorted sand and gravel that probably have permeabilities greater than 1,000 gpd per sq ft. Conversely, the deposits of sandy clay that comprise parts of the aquifer probably have very low permeabilities.

Most of the ground water is discharged naturally from the aquifer through springs and seeps. Captain Creek and some of its small tributaries have perennial flow maintained by ground-water discharge from the Kansan deposits.

The second area in which Kansan deposits are significant as an aquifer is south of the Kansas River near Wilder, bounded on the east by Mill Creek and on the south by Clear Creek (pl. 1). In this area, the deposits are similar in character to those previously described west of Kill Creek, but they probably have a greater range in thickness. Jewett and Williams (1935, p. 198) reported about 80 feet of drift in this area, and Newell (1935, p. 83) subsequently measured and described about 71 feet of Kansan deposits that consist mostly of sand and gravel and locally contain zones of cemented conglomerate. Dufford (1958, p. 46) reported more than 100 feet of glacial outwash in the area. The thickness of the deposits reported by Newell (1935) in the vicinity of the Ahlskog gravel pit (NE cor. sec. 11, T.12 S., R.23 E.) and the altitude of the water table in the pit indicate that locally there are 50 feet or more of saturated Kansan deposits consisting of sand and gravel. Jewett and Williams (1935) reported that a spring flowed about 60 gpm from the lower part of the aquifer. According to J. M. Jewett (oral commun., 1964) the spring is north of the Ahlskog pit in the SW¼ sec. 2, T.12 S., R.23 E.

Yields of 50 gpm or more probably could be obtained from wells completed in these deposits, but no wells were inventoried that had yields of this magnitude. Because most of the deposits consist of sandy silts or silty sand, wells completed in these materials have small yields. Along the outcrop margins, the Kansan deposits yield little or no water to wells, because they are drained or are thin with an intermittent saturated zone.

The chemical quality of ground water from wells in Kansan deposits is indicated by the analyses in table 4. The water can be characterized as hard to very hard calcium bicarbonate water that contains high concentrations of iron. The water is satisfactory for most domestic uses except for its hardness and iron content.

Other Aquifers

Much of the upland and slope area of Johnson County is covered by relatively thin but areally extensive deposits of weathered surficial material that overlies the Pennsylvanian bedrock. This material includes unmapped colluvium, slopewash, residual soil, and, in much of the upland area, a thin cap of loess. Collectively these deposits comprise the regolith, or mantle rock, and are of hydrologic importance in two respects: as a source locally of very small domestic and stock water supplies, and as the surficial material through which much of the recharge to the underlying limestone, sandstone, and shale must move.

In addition to the regolith, thin, narrow patches of fluvial deposits in the upland and slope areas locally yield ground water to wells along the tributary streams. The fluvial deposits shown on plate 1 are arbitrarily terminated along the headward parts of the streams. However, there are patches of thin water-yielding fluvial deposits of variable thickness and width along the streams beyond the mapped deposits. Because ground water moves from the superjacent interstream areas toward the streams, these thin fluvial deposits frequently receive seepage from adjacent bedrock and, in wet years, from the regolith.

CONSOLIDATED ROCK AQUIFERS

The consolidated rock, or bedrock, aquifers are the limestones, sandstones, and shales of Pennsylvanian and older age that underlie Johnson County. The chemical quality of ground water pumped by domestic and stock wells from bedrock aquifers ranges from excellent to poor. Many of the bedrock wells yield water that is more mineralized than ground water pumped from the unconsolidated Pleistocene deposits. Wells obtain fresh or slightly saline water (table 7) at depths of 100 feet or less, and no area of the county is known where fresh or slightly saline water occurs at depths greater than about 250 feet. Locally, ground water at depths of less than 100 feet is moderately saline. Ground water from Pleasanton Group and older rocks is believed to have more than 10,000 mg/l dissolved solids throughout Johnson County.

The yields of wells in the bedrock aquifers generally are less than 10 gpm. A few wells have yields of 10 to 50 gpm, but these are restricted chiefly to areas where the Wyandotte Limestone has greater than average permeability and to part of the area underlain by the Ireland Sandstone Member of the Lawrence Formation. The water-bearing characteristics of Pennsylvanian and older rocks in Johnson County are summarized in figure 17.

Shale Aquifers

The shales in Johnson County that contain fresh to moderately saline water probably have porosities that range from 5 to 20 percent (Hedberg, 1926; Athy, 1930). The shales have such extremely low coefficients of permeability that, for practical purposes, they will not yield water to wells. There are two exceptions to this general statement.

The first group of shales that may be considered as aquifers is the black or very dark gray fissile shales that comprise parts of the Hushpuckney, Stark, Muncie Creek, and Eudora Shale Members and, locally, the Quivira. These black shales have nearly vertical open fractures that have been developed partly by shrinkage of colloidal material in the black sediments and partly by deep-seated stresses. Wells that intersect these open fractures obtain small supplies of water. The Stark Shale Member of the Dennis Limestone and the Hushpuckney Shale Member of the Swope Limestone yield fresh to slightly saline water to wells in eastern Johnson County in most of R.25 E.; in parts of T.12 S. the water is moderately saline. Six wells in these shales in R.25 E. have yields ranging from about 0.5 to 5 gpm. An analysis (table 4) of a water sample from well 14-25E-22baa, completed in the Stark Shale Member at a depth of 200 feet, indicates that the water is a very soft (hardness, 14 mg/l) sodium bicarbonate type, is high in fluoride concentration (14 mg/l), and has a dissolved-solids concentration of about 1,300 mg/l. The water would be classified as slightly saline and would be usable for livestock. However, in spite of its undesirably high dissolved-solids and fluoride content, the water is used for domestic purposes. The Earl Caddell well (12-25E-35bbd) is reported to yield 3 gpm of good-tasting "fresh" water from the Stark Shale Member at a depth of 127 to 131 feet. Other wells in the Stark and Hushpuckney are reported to obtain water ranging in quality from fresh to slightly saline, which is used for stock and domestic water supplies. Elsewhere in central and western Johnson County at depths of 200 to 400 feet, water in the black shales in the lower part of the Kansas City Group is believed to be moderately saline to very saline (12-24E-4dad, 12-24E-4ddc, table 9).

About 10 to 20 percent of the drillers' logs of wells drilled in central and western Johnson County note "salty" water in the lower Kansas City Group black shales, generally in amounts less than 20 gpm.

Locally black shale in the Quivira Shale Member of the Cherryvale Shale yields very small amounts of fresh to slightly saline water to wells at depths of 250 feet or less.

The Muncie Creek Shale Member of the Iola Limestone includes 1 to 2 feet of black shale in the northwest and north-central parts of the county. This black shale yields small quantities of fresh to slightly saline water to a few wells. Well 13-21E-3ddd, in adjacent Douglas County about 150 feet west of the Johnson County-Douglas County boundary, yields 35 gph (gallons per hour) from the Muncie Creek at a depth of 198 to 200 feet. The water is slightly saline but, because water of better quality is not available, it is used as a domestic supply.

The second group of shales that may be considered as aquifers is the near-surface shales in the zone of weathering. Various weathering processes and biological activities tend to enlarge and increase the number of secondary openings in the shales. As a result, the shale beds at or near land surface have a much greater permeability than do similar shale beds at

DEPTH, IN FEET BELOW LAND SURFACE: 0, 500, 1000, 1500, 2000

Stratigraphic unit	Water quality	Estimated well yield (gpm)
Douglas, Lansing, and Kansas City Groups	Fresh or slightly saline at depths less than 100 feet, locally to depths of 250 feet. Moderately to very saline at depths greater than 250 feet.	0-50, commonly less than 10
Pleasanton Group	Very saline	0-20
Marmaton Group	Very saline	0-150
Cherokee Group	Very saline or briny	0-200
Mississippian rocks	Very saline	50-500
Chattanooga Shale	------------	----
"Hunton Group" and Viola Limestone	Very saline or briny	0-100
Simpson Group	Very saline or briny	0-300
Arbuckle Group and Lamotte Sandstone	Very saline or briny	200-1,000

FIGURE 17.—Water-bearing characteristics of Pennsylvanian and older rocks.

depths of 50 feet or greater. Many of the shale beds will yield a few hundred gallons of water per day to large-diameter (greater than 3 feet) wells that intersect one or more fractures or other openings. Fractures in the shale decrease in size and number downward, and, except in the black fissile shales, are few below depths of about 50 feet.

LIMESTONE AQUIFERS

Most of the limestones that are within the zone of fresh to slightly saline water are relatively uniform in thickness and composition, are laterally continuous, and are nearly flat lying. Except where weathered, they are relatively impermeable and generally yield little or no water to wells. At or near land surface, however, weathering processes have increased and enlarged the interconnected open spaces within the rocks, especially along joints, fractures, and within any zones that originally had a significant primary permeability. The carbonate rocks are especially susceptible to solution in the vadose water zone, within the zone of fluctuation of the water table, and just above less permeable strata, such as shale beds, within the zone of saturation. Much of the fresh or slightly saline water obtained from wells in limestones in Johnson County is obtained from widely spaced solution-enlarged fractures at relatively shallow depths (less than 100 feet), but some of the wells may obtain water from limestones at depths as great as 240 feet.

Wyandotte Limestone.—The Wyandotte is the most important limestone aquifer in Johnson County, but wells tapping this aquifer have a great range in yields. The largest well yield reported during this investigation was about 40 gpm (Marvin Rankin No. 1 gas well, NW¼ SW¼ sec. 9, T.14 S., R.22 E.). The Wyandotte is 74 feet thick at this location, and the permeable zone that yielded fresh water was found at a depth of 163 feet in the lower part of the formation. There apparently is a zone of significant solution permeability in the Wyandotte in this general area inasmuch as many oil and gas wells have found ground water in amounts sufficient for stock or domestic supplies.

The Wyandotte is more likely to yield water from fractures or solution cavities in those areas where the thickness of the formation is greatest (areas A and B, fig. 7). In areas where the Wyandotte is overlain by younger Pennsylvanian strata, the ground water generally is under artesian pressure and will rise in a well some distance above the point at which it was encountered.

Numerous springs discharge from the Wyandotte in southeastern Johnson County (area B, fig. 7). One of the larger springs (15-25E-4bab) was estimated to flow 100 gpm from a solution cavern near the base of the formation. This spring, and several others in this area, becomes turbid after heavy rains due to the flushing of the solution-enlarged joints, solution galleries, and sink holes through which surface water may enter and move through the formation.

Wells in the Wyandotte that do not penetrate saturated cavernous zones or open fractures yield little or no water. It is not unusual to have one well in this aquifer yield enough water for a small domestic supply and a nearby well, penetrating the same sequence and thickness of rocks, yield so little water that it is considered a "dry hole," the differences in yields being due to the size and number of fracture or solution openings penetrated in the zone of saturation by the well. About half of the wells drilled into this aquifer have yields of 0.5 gpm or more, but the range in yields is from 0 to 40 gpm. The localized character of the permeable zones is illustrated by the ground-water discharge and ice formation on a quarry face during wintertime (fig. 8B). The yield of many Wyandotte and other limestone aquifer wells probably could be increased appreciably by pressure acidization, but this method of stimulation, or development, has been utilized very little by the local drillers.

The chemical quality of ground water from the Wyandotte at depths of 200 feet or less is variable, but generally the water can be characterized as a very hard calcium bicarbonate type that is satisfactory for domestic water supplies (13-22E-33ddd, 15-25E-4bab, table 4). The chemical quality may be poor (slightly to moderately saline) and yields may be very low at depths of 115 feet or less where the formation has little solution or fracture permeability and ground-water circulation is poor (12-23E-27bcb, 14-23E-11bcc2, tables 4 and 10). At depths greater than about 200 feet any ground water obtained from the Wyandotte is likely to be moderately saline to very saline.

Other limestones.—All the limestones that crop out in Johnson County have, at one place or another, open fractures, joints, and bedding planes that yield ground water to shallow wells in the zone of weathering. Below a depth of 30 to 50 feet, however, few of the limestones have adequate permeability to be considered significant aquifers. Wells in the shallow limestone aquifers may go dry in drouth years.

The chemical quality of water from the limestones generally is satisfactory for domestic use, except for excessive hardness and possibly high concentrations of iron. The sanitary quality of ground water from shallow wells in the limestones may be poor; it should be tested regularly because many such wells are not properly constructed and are near sources of pollution. Testing of the water will be performed at little or no cost to the owner by the Division of Environmental Health of the Kansas State Department of Health. The local County Health Officer can explain the procedure.

Sandstone Aquifers

Several of the shale and limestone formations include thin beds of sandstone that locally yield water to wells. Stratigraphic units that contain sandstone beds are the Cherryvale, Chanute, Lane, Bonner Springs, and Vilas Shales, the Lawrence Formation, and the Rock Lake Shale Member of the Stanton Limestone. Sandstones in each of these units yield water to domestic and stock wells somewhere in the county. Except for the Ireland Sandstone Member of the Lawrence Formation, no sandstones are thick or permeable enough to yield more than about 5 gpm to wells. Many wells, in which 1 to 25 feet of sandstone was indicated by the driller's log, have reported yields of as much as 3 gpm. Numerous well logs report so little water that the sandstones are considered "dry." These "dry sandstones" may be siltstone, cemented sandstone, or impure shaly sandstone with very low permeability.

The sandstones in the Kansas City and Lansing Groups are chiefly very fine grained, micaceous, and quartzose, and have permeabilities generally less than 100 gpd per sq ft. The Lawrence Formation contains very fine to medium-grained quartzose micaceous sandstone that may range in permeability from 200 to 400 gpd per sq ft locally.

Sandstone identified as the "Belton sand" by Clair (1943, p. 20 and pl. 1) is considered to replace stratigraphically the Westerville Limestone Member of the Cherryvale Shale and all or parts of the underlying Wea Shale Member and overlying Quivira Shale Member in a part of Cass County, Mo., just east of the area between Stilwell and Stanley, Kans. Clair reports that the sand is as much as 34 feet thick, light gray, and quartzose to micaceous in character in the Belton area where the town of Belton has municipal wells that obtain water from this sandstone. Clair's studies indicate that the sands are narrow elongate bodies that trend southwesterly, have convex upper surfaces, and probably represent "offshore bar" type deposits. In southeastern Johnson County a few wells obtain fresh to slightly saline water, thought to come from sandstone in the stratigraphic position of the "Belton sand." The sandstone is believed to be restricted to southeastern Johnson County, chiefly in parts of Tps. 14 and 15 S., and probably only in a part of this area does the sandstone yield water suitable for domestic and stock supplies. Well 14-24E-32ccc is reported to yield about 150 gpd from 8 feet of sand in the Quivira or Westerville, which probably is equivalent to Clair's "Belton sand." The water is reportedly too mineralized for domestic drinking but is satisfactory for livestock use.

The Chanute Shale contains about 4 feet of very fine grained micaeous sandstone in eastern Johnson County, and, even where the sandstone is absent, the interval commonly is represented by sandy and silty shale. Ground water from wells in the Chanute generally is hard, but is satisfactory for domestic use. In northwestern Johnson County, well 12-21E-36ccc yields about 3 gpm of moderately saline water (table 4) from depths of 207 to 216 and 220 to 236 feet, which are intervals of gray sandy shale and sandstone. The water from this well can be characterized as a sodium chloride type that is hard and contains a high concentration of fluoride. The water is used for livestock and domestic purposes other than drinking. Except for a few wells in the eastern part of the county, sandstone beds in the Chanute yield water that is too poor in quality for any use.

The Lane Shale contains sandstone and sandy shale beds in areas where the formation is thick. Well 15-23E-18ccc is 157 feet deep and is reported to yield about 100 gph from 12 feet of sandstone at a depth of 114 to 126 feet. The owner reports that this water is used for domestic and livestock purposes, is "soft," and has a slight "sodium bicarbonate taste." Only a few wells obtain water from sandstone in the Lane Shale in Johnson County.

Sandstone in the Bonner Springs Shale probably is more widely distributed in the county than any of the other sandstone aquifers described, and, locally, it is the principal aquifer in the southeastern part of the county. In parts of Tps. 13, 14, and 15 S., Rs. 24 and 25 E., the sandstone is 15 to 25 feet thick and yields fresh water supplies of 1 to 3 gpm from depths of 100 feet or less. In parts of the county ground water from Bonner Springs sandstone may be slightly saline (well 14-23E-15daa, table 4) at depths of less than 100 feet.

Although the Vilas Shale locally includes as much as 11 feet of very fine grained sandstone and siltstone, very few wells obtain water supplies from the unit. Most of the wells in the Vilas have low yields, are shallow, and have large diameters.

The Rock Lake Shale Member of the Stanton Limestone generally contains 5 to 10 feet of very fine to fine-grained micaceous sandstone. Shallow wells tapping the sandstone at several localities in Johnson County commonly yield from 20 to 300 gph. Chemical analyses of water from two wells indicate that the water is a very hard calcium bicarbonate type (table 4).

The Lawrence Formation, which contains the Ireland Sandstone Member, yields water of good quality to stock and domestic wells in part of southwestern Johnson County and formerly was the source of water supplies for the towns of Gardner and Edgerton.

Pre-Kansas City Group Aquifers

Rocks older than those of the Kansas City Group in Johnson County are not known to contain water having less than 10,000 mg/l dissolved solids; therefore, pre-Kansas City Group aquifers have not been utilized for any domestic, stock, industrial, or irrigation purposes. Figure 17 shows the quality of ground water and estimated yield that are obtainable from Pennsylvanian and older rocks in Johnson County. Analyses of water samples from several oil and gas wells are given in table 9.

Utilization of Ground Water

PUBLIC SUPPLIES

Public water supplies for DeSoto, Olathe, and Rural Water District No. 1 are obtained from wells in Johnson County. Two additional public water supplies, Johnson County Water District No. 1 and Rural Water District No. 3, obtain ground water from wells in the Kansas River valley in adjacent Wyandotte

TABLE 9.—Chemical analyses of water from selected wells yielding moderately saline to briny water.
[Dissolved constituents and hardness given in milligrams per liter.]

Well number	Depth (feet)	Geologic source	Date of collection	Dissolved solids (evaporated at 180°C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as $CaCO_3$ Total	Hardness as $CaCO_3$ Noncarbonate	Analyst[1]
12-24E- 4dad	205	Stark Shale Member of Dennis Limestone	7- 6-40	7,346	13	----	46	25	2,635	565	13	3,886	218	0	c
4dad	485	Marmaton Group	7-20-40	18,357	10	----	257	117	6,073	405	6.2	9,803	1,123	791	c
4ddc	230	Ladore Shale	10- 1-40	10,015	1.6	----	94	44	3,757	441	6.0	5,484	414	52	c
14-22E-25c	1,698	Arbuckle Group	3- 4-40	39,800	----	----	----	----	----	----	1,550	17,100	----	----	d
14-24E-15bcb	230	Stark Shale Member of Dennis Limestone	-54	----	----	----	----	----	----	----	----	5,690	----	----	b
15-22E- 3ccc	816	Krebs Formation	11- -58	33,000	----	34	850	365	11,500	146	14	20,200	3,621	3,501	a
3ccc	1,042	St. Louis Limestone	11- -58	24,160	----	----	800	337	8,120	353	23	14,700	3,381	3,091	a

[1] Analyst
a. Kansas State Department of Health.
b. State Geological Survey of Kansas.
c. Missouri Geological Survey and Water Resources, R. T. Rolufs.
d. Morgan Acid Company, Wichita, Kansas.

County, Kans. The village of Sunflower purchases ground water from the Sunflower Army Ammunition Plant.

Data on the public water supplies were obtained from water superintendents, the Kansas State Department of Health, and the U.S. Public Health Service 1963 inventory of municipal water facilities (U.S. Public Health Service, 1964). Representative water analyses are given in table 4.

DeSoto

The water supply of DeSoto is obtained from two drilled wells, each 46 feet deep, in the Kansas River valley. The wells are each reported to have a capacity of 200 gpm and are equipped with electrically powered turbine pumps. An average of 160,000 gpd is pumped from the well field. The raw water is hard and high in iron and manganese content. Treatment consists of removal of iron and manganese, softening, filtering, and chlorination. There are 200,000 gallons of ground-level storage and 50,000 gallons of elevated storage provided for the treated water.

Olathe

Olathe obtains water from two surface reservoirs and from four wells. The older of the reservoirs, called Olathe Lake, is a 77-acre lake southwest of the city that impounds about 720 acre-feet of water. New Olathe Lake, west of the city, is a 190-acre lake that impounds 3,380 acre-feet of water.

The well field consists of four wells in the Kansas River valley alluvium near the mouth of Cedar Creek. Each well is 16 inches in diameter; they range from 56 to 66 feet in depth. Well yields range from 500 to 1,000 gpm. Water is pumped from the well field to a 4-mgd (million gallons per day)-capacity treatment plant on the Cedar Creek bluff above the well field. At the treatment plant the water is chlorinated, softened, and dissolved iron is removed prior to pumping the water into Olathe.

Rural Water District Number 1

Rural Water District No. 1 serves about 325 people between Cedar Creek and Mill Creek, chiefly along and near Kansas Highway 10. Originally the district water supply was obtained from one drilled well (12-22E-26add) equipped with a 60-gpm-capacity turbine pump in the Kansas River valley near the mouth of Cedar Creek. The water was chlorinated and treated to reduce the amount of iron and manganese. In May 1967 the district began purchasing softened water from the city of Olathe at its Cedar Creek treatment plant. Monthly purchases in 1967 ranged from 574,000 to 895,000 gallons.

Rural Water District Number 3

Rural Water District No. 3 serves about 900 persons in an area between Olathe and Bonner Springs, chiefly along Mill Creek and Clear Creek drainages. Water for the district is purchased from the city of Bonner Springs, Kans. The Bonner Springs water supply is obtained from wells in the Kansas River valley alluvium on the north side of the Kansas River in Wyandotte County. The water is chlorinated and fluoridated before being distributed. In 1967 the water district purchased and distributed 21.6 million gallons of water.

Sunflower

Sunflower, a community along Kansas Highway 10 just north of the Sunflower Army Ammunition Plant, has a population of about 1,200 persons and is served with ground water purchased from the Sunflower plant.

Johnson County Water District Number 1

Johnson County Water District Number 1 serves nearly all the metropolitan area of northeastern Johnson County. The water district serves about 140,000 persons, including 1,000 in Wyandotte County. The city of Lenexa purchases about 11 million gallons of water per month from the district. The water district, in 1967, had an average daily use of about 13 mgd and a maximum daily use of 25 mgd. About 5.5 million gallons of ground water is pumped daily and the remainder of the water supply is obtained from the Kansas River. The ground water is obtained from a series of 21 wells that are 65 to 70 feet deep. The wells are in the Kansas River valley alluvium northeast of Quivira Lake near Morris in Wyandotte County. The water obtained from the 21 wells ranges in hardness from 450 to 600 mg/l. The water is treated to remove iron and manganese, softened, fluoridated, filtered, and chlorinated before being distributed.

Other Public Water Supplies

Water is purchased from the Kansas City, Mo., municipal water system by the J. C. Nichols Water Co. and the Westport Annex Water Co. These companies serve that part of metropolitan northeast Johnson County not served by Johnson County Water District No. 1.

The towns of Edgerton, Gardner, and Spring Hill utilize surface water for their municipal water systems. Edgerton obtains water from Santa Fe Lake, a small reservoir having a capacity of about 120 acre-feet. Prior to 1960 Edgerton utilized six low-yielding wells, each about 80 feet deep, in sec. 30, T.14 S., R.22 E., north of town. The wells yielded about 5 gpm each.

Gardner obtains water from Gardner Lake 2 miles north of town. This lake is a 131-acre impoundment having a capacity of about 2,350 acre-feet of water. Gardner formerly used one dug and five drilled wells, ranging from 35 to 65 feet in depth, about 3½ miles northwest of town. The wells had capacities of about 5 gpm each and were abandoned in 1957 when the surface-water supply was developed. The Edgerton and Gardner wells each obtained water from the Ireland Sandstone Member of the Lawrence Formation.

INDUSTRIAL SUPPLIES

The Hercules Powder Co., operator of the Sunflower Army Ammunition Plant (Sunflower Ordnance Works), is the only industrial user that has developed a large ground-water supply in Johnson County. According to Mr. Hugh Jackson, utilities supervisor for Hercules, about 7 mgd was pumped during the early 1940's for use at the ordnance plant from a well field in the Kansas River valley partly in Johnson County and partly in adjacent Leavenworth County west of DeSoto. In addition about 50 mgd was pumped from the Kansas River. In 1967 six wells south of the Kansas River in Johnson County and six wells north of the Kansas River in Leavenworth County pumped 529.8 million gallons or 1,621 acre-feet of water. Hercules furnishes about 3 million gallons per month to the U.S. Industrial Chemical Co., located on the ordnance property, chiefly for the production of acid. The location of the well field is shown on plate 1 and pertinent data on the individual wells are given in tables 8 and 10.

IRRIGATION SUPPLIES

According to the Division of Water Resources of the Kansas State Board of Agriculture (written commun., Jan. 1, 1971), water rights have been perfected or are in the process of being perfected to irrigate 210.6 acres of land with ground water and 388 acres of land with surface water. All the land irrigated with ground water is in the Kansas River valley in the vicinity of Cedar and Wilder. An additional 70 acres or more is irrigated by ground water in the Kansas River valley by farmers who are not yet perfecting water rights. Irrigation water is most commonly distributed by sprinkler systems, and the wells are pumped at rates of 250 to 600 gpm. There is no ground-water irrigation outside the Kansas River valley. Surface water for irrigation is obtained from Kill Creek, Little Bull Creek, Blue River, and Indian Creek.

The principal crops irrigated in the Kansas River valley are field corn, sweet corn, sweet potatoes, milo, watermelons, pumpkins, cantaloupes, turnips, and radishes. Much of the fruit and vegetable crop is sold in the metropolitan Kansas City market.

Chemical analyses indicate that ground water from wells in the Kansas River valley alluvium is satisfactory for crops most commonly irrigated. The water generally had a low sodium (alkali) hazard and a medium or high salinity hazard. The soils irrigated generally are characterized by good drainage. For a more thorough discussion of the suitability of water for irrigation, the interested reader is referred to Agriculture Handbook No. 60 (U.S. Salinity Laboratory Staff, 1954).

DOMESTIC AND STOCK SUPPLIES

Several hundred domestic and stock water supplies are obtained from wells and springs in Johnson County. Exclusive of water from public-water-supply facilities, about 225,000 gpd was obtained from wells and springs in 1967. With the increasing urbanization of the county and the growth of public water supplies, the amount of ground water obtained from individually owned wells and springs is declining in relation to total use. The total use of ground water obtained from individual domestic and stock supplies in 1967 was estimated to be 82 million gallons or 252 acre-feet.

SUMMARY

The use of ground water for public, irrigation, and industrial water supplies will increase and will be obtained chiefly from wells in the Kansas River valley alluvium. Ground-water supplies for domestic and stock use will continue to be developed from the other Pleistocene aquifers and from the Pennsylvanian aquifers to serve the suburban and rural users not served by public water supplies.

RECORDS OF WELLS, TEST HOLES, AND SPRINGS

Information pertaining to 139 water wells, test holes, and springs in Johnson County is given in table 10. Much of the data was obtained from well owners, well users, and well drillers. The depth to water and the depth of the well were measured by the author when possible. The locations of the wells, test holes, and springs are shown on plate 1.

TABLE 10.—Records of wells, test holes, and springs.

Well number[1]	Owner or user	Depth of well[2] (feet)	Diameter of well (inches)	Type of casing[3]	Principal water-bearing unit: Character of material[4]	Principal water-bearing unit: Geologic source[5]	Method of lift,[6] type of power[7]	Use[8]	Water level: Depth below land surface[2] (feet)	Water level: Date of measurement	Altitude of land surface above mean sea level (feet)	Yield[9]
11-23E-28dcc*	State Geol. Survey	56	4	N	Sd, Gr	Alluvium	N	T	15.0	6-44	768	
33abb*	do	55	4	N	Sd, Gr	do	N	T	14.2	6-44	766	
33abc*	do	55	4	N	Sd, Gr	do	N	T	13.8	6-44	770	
33acb*	do	58	4	N	Sd, Gr	do	N	T	19.3	7-44	775	
33acc*	do	52	4	N	Sd, Gr	do	N	T	15.1	7-44	771	
33bac	do	37	1	G	Sd, Gr	do	N	T, O	20.1	5-61	770	
33bba	do	38	1	G	Sd, Gr, St	do	N	T, O	20.7	5-61	772	
33bcd	Otto Wendt	60 R	6		Sd, Gr	do	T, G	I				350 gpm
33bdd	State Geol. Survey	39	1	G	Sd, Gr, St	do	N	T, O	23.8	5-61	773	
33caa*	do	42	4	N	Sd, Gr	do	N	T	16.5	7-44	769	
33dbc	do	18	4	N	Sd, Gr	do	N	T	9.7	7-44	770	
35dcd	E. Daniels	85 R	6	G	Sd, Gr	Kansan Stage	J, E	D	58 R	8-56	838	2 gpm R
12-21E-24ddd	Sunflower Army Amm. Plant	68	4	N	Sd, Gr	Alluvium	N	T			798	
25daa	do	39	4	N	Sd, Gr	do	N	T	13.6	7-42	798	
25dba	do	45	4	N	Sd, Gr	do	N	T	19.0	7-42	799	
25dbc	do	39	4	N	Sd, Gr	do	N	T	14.8	7-42	796	
36ccc*	Ted Weeks	236 R	6	G	Sh	Chanute Sh Vilas Sh	Cy, E	D, S	121 R	52	885	3 gpm R
12-22E-19acd	Sunflower Army Amm. Plant	50	4	N	Sd, Gr	Alluvium	N	T	14.1	8-42	792	
19bdc	do	42	4	N	Sd, Gr	do	N	T	6.0	8-42	782	
19cbb	do	70	4	N	Sd, Gr	do	N	T	29.7	7-42	805	
19cbc	do	65 R	18	S	Sd, Gr	do	T, E	Id	23 R	10-42	802	650 gpm R
19cca	do	60 R	18	S	Sd, Gr	do	T, E	Id	20 R	10-42	802	750 gpm R
19cdc	do	57	4	N	Sd, Gr	do	N	T	19.1	7-42	799	
19dbb	do	46	4	N	Sd, Gr	do	N	T	14.3	8-42	791	
19dcc	do	58	4	N	Sd, Gr	do	N	T	16.3	7-42	796	
19ddc	do	50	4	N	Sd, Gr	do	N	T	14.4	7-42	794	
20bcc	do	51	4	N	Sd, Gr	do	N	T	19.0	8-42	793	
20cab	do	55	4	N	Sd, Gr	do	N	T	14.6	8-42	787	
20cac	do	48 R	18	S	Sd, Gr	do	T, E	Id	7.9	5-42	786	770 gpm R
20cbc1	do	44 R	4	N	Sd, Gr	do	N	T	9.5	4-42	787	
20cbc2	do	46 R	18	S	Sd, Gr	do	T, E	Id	11 R	10-42	786	800 gpm R
20cca	do	41	4	N	Sd, Gr	do	N	T	6.1	7-42	784	
20cdd	do	51 R	18	S	Sd, Gr	do	T, E	Id	11 R	10-42	780	695 gpm R
20dcb	do	41 R	18	S	Sd, Gr	do	T, E	Id	8 R	9-42	784	750 gpm R
23cad*	Unknown	35 R			Sd, Gr	do	N	D			783	
23cdd	Sunflower Army Amm. Plant	60	4	N	Sd, Gr	do	N	T			782	
23daa	do	47	4	N	Sd, Gr	do	N	T			778	
23dab	do	50	4	N	Sd, Gr	do		T			782	
23dac	W. and H. Caldwell	46 R	24	S	Sd, Gr	do	T, G	I	25.0	9-57	788	330 gpm
23dad	Sunflower Army Amm. Plant	48	4	N	Sd, Gr	do	N	T			779	
23dca	do	53	4	N	Sd, Gr	do	N	T	16.0	8-42	783	
23dcd	do	55	4	N	Sd, Gr	do	N	T	13.1	8-42	780	
24ccc1	City of Olathe	60 R	16	S	Sd, Gr	do	T, E	P	24 R	6-64	783	750 gpm R
24ccc2	do	56 R	16	S	Sd, Gr	do	T, E	P	21 R	6-64	780	500 gpm R
25bbc1	do	66 R	16	S	Sd, Gr	do	T, E	P	21 R	6-64	781	1,000 gpm R
25bbc2	do	63 R	16	S	Sd, Gr	do	T, E	P	22 R	6-64	781	800 gpm R
25bcc	State Geol. Survey	33	1	G	Sd, Gr	do	N	T, O	16.2	5-61	780	
25cbb	R. Frisbie	65 R	5	G	Sd, St, Cl	Terrace deposits		D	25.1	11-52	795	
25cdb*	A. C. Kramsch	44 R			Sd, St, Cl	do		D, S	26 R	10-52	795	10 gpm R

26add*	Rural Water District 1	37 R	8	S	Sd, Gr	Alluvium	T, E	P	21 R	2-61	778	60 gpm R
26bac	Sunflower Army Amm. Plant	63	4	N	Sd, Gr	do	N	T			783	
26bad	do	66	4	N	Sd, Gr	do	N	T			779	
26bda*	W. D. Masterson	18 R	2	G	Sd, Gr	do	Cy, H	D			782	
26bdb	B. E. Hodgton	58 R	18	C	Sd, Gr	do	T, LPG	I	18.7	9-57	783	400 gpm R
28abc1*	City of De Soto	46	24	S	Sd, Gr	do	T, E	P	18.5	1-64	783	235 gpm R
28abc2*	do	46 R	24	S	Sd, Gr	do	T, E	P	18.8	3-67	783	234 gpm
29bad	Sunflower Army Amm. Plant	44	4	N	Sd, Gr	do	N	T	5.2	7-42	785	
30bbc	do	55	4	N	Sd, Gr	do	N	T	17.4	7-42	798	
12-23E- 1acc	Holliday School	61 R	6	S	Sh	Stark Sh Member of Dennis Ls		D			780	3 gpm R
1bdc*	Lorine Clouse	24	8	T	Sd, Gr	Alluvium	Cy, H	D	13.3	6-55	768	5 gpm R
5ca*	W. Knipp	36	6	I	Sd, Gr	do		D, S	24.6	2-53	777	
8bdb	Jim Coleman	56 R	18	C	Sd, Gr, St	do	T, G	I	26.8	9-57	780	600 gpm R
11bb1*	Round Prairie School	25 R	1	G	Sd, Gr	Kansan Stage	Cy, H	D			854	
11bb2	do	70 R	6	S	Sd, Gr	do	J, E	D	34 R		857	
20aba	Mr. Hodges	125 R	6	G	Ls	Wyandotte Ls		D			924	168gpd R
27bcb*	E. D. Garnett	190 R	5	G	Ls	Farley Ls Member of Wyandotte Ls	J, E	D	46 R	7-55	1,020	18 gph R
32acc	Thomas Anderson	260 R	8			Upper Pennsylvanian Series	N	N			994	30 gpd R
12-24E- 5cda*	O. R. Dunham	100 R	5	S	Ls	Drum Ls	S, E	D	24 R	3-55		12 gph R
14bdc	G. Fickle	95 R	5	G	Sh	Eudora Sh Member of Stanton Ls		D			1,040	6 gph R
15bb	E. L. Cook		6		Ls, Sh	Farley Ls Member of Wyandotte Ls Plattsburg Ls	N	T	23 R	8-56		15 gpd R
18ac	Alex Osipac	41	36	R	Ls	do	J, E	D	40.5	9-59	1,005	
20abb*	W. E. Lyda	40 R	8	S	Sh	Iola Ls	J, E	D, S	3 R	6-49	880	7 gpm R
12-25E- 8bba	Walter Moore	136 R	6	I		Lane Sh		D	9 R	8-52	1,052	3 gpm R
10dad	Dr. Sam Roberts	113 R			Sh	Wea Sh Member of Cherryvale Sh Stark Sh Member of Dennis Ls		D			900	
18bad*	C. B. Crowther	48 R	6	S	Ss, Ls	Vilas Sh Stanton Ls	N	D	5.6	6-55	1,050	
20add	E. Brown	196 R	5	G	Ls	Bethany Falls Ls Member of Swope Ls		D	118 R	36	955	28 gpm R
22adc	A. D. Hobart	300 R	6		Sh	Hushpuckney Sh Member of Swope Ls		N			1,050	42 gph R
22cba	Mr. Vaughn	295 R	6		Sh	do		N	200 R	36	1,005	
35bbd	Earl Caddell	152 R	6	S	Sh	Stark Sh Member of Dennis Ls		D	44.4	5-55	912	3gpm R
13-21E-14cbb	Gus Koch	227 R	8		Ls	Wyandotte Ls		D			875	30 gpd R
23cbc	Fred Neis	82 R	10	S	Ls	Stoner Ls Member of Stanton Ls	J, E	D, S	3 R	8-57	890	
23cbd*	do	25 R	48	R	Ss	Stanton Ls	Cy, E	D, S			895	
26ccd1*	Fred Howard	43 R	36	R	Sd, Gr	Kansan Stage	Cy, E	D, S	35 R	6-55	938	
13-22E-16dca	A. L. Ryan	100 R	6	S		Stanton Ls Plattsburg Ls	J, E	D	12 R	2-58	946	30 gph R
23ddc	Mr. Eddington	166 R	8					T			982	0 gpm R
33ddd*	Ralph Holey	181 R	6	S	Ls	Farley Ls Member of Wyandotte Ls	S, E	D, S	40 R	6-55	987	30 gph R
13-23E-10ddc	School District 108	76 R	7				N	T			1,042	0 gpm R

TABLE 10.—Records of wells, test holes, and springs (*concluded*).

Well number[1]	Owner or user	Depth of well[2] (feet)	Diameter of well (inches)	Type of casing[3]	Principal water-bearing unit: Character of material[4]	Principal water-bearing unit: Geologic source[5]	Method of lift,[6] type of power[7]	Use[8]	Water level: Depth below land surface[2] (feet)	Water level: Date of measurement	Altitude of land surface above mean sea level (feet)	Yield[9]
30ccc*	Moonlight School 65	20	96	R		Stanton Ls	Cy, H	D	13.6	6-55	1,041	1 gpm R
13-24E- 3acb*	Bryce Adams	24	48	R	Ls	do	Cy, H	D, S	14.9	6-55	1,064	30 gph R
17bba*	Ella Voights	Spring		E	Ls	Plattsburg Ls		S			970	7 gpm R
17cdc	Charles S. Anderson	44	72	R		Stanton Ls	Cy, E	D	18.6	9-59	1,051	30 gph R
19ddc	Mr. Reedvele	114 R	6	S	Ss, Sh	Bonner Springs Sh Eudora Sh Member of Stanton Ls		C	25 R	5-55	1,060	18 gph R
25cba	Tom Wilson	193 R	6			Bonner Springs Sh	N	N			1,040	288 gpd R
28ddd	Phillips Petroleum Co.	352 R	6			Upper Pennsylvanian Series	N	N			1,075	125 gpd R
13-25E-23ccb*	Weldon Royce	12	60	B		Colluvium	J, E	D	5.5	5-55	960	1 gpm R
32bcc*	Reno Construction Co.	95 R	6	G		Chanute Sh	J, E	D, S			972	42 gph R
32ccc	A. E. Tanquary	34 R	108	B	Ss	Bonner Springs Sh	J, E	D			1,040	2 gpm R
14-21E-12ada*	D. S. Land	50 R	36	R	Sd	Kansan Stage Fluvial deposits	Cy, E	D, S			995	3 gpm R
25baa*	Round Oak School	41	5	G	Ss	Ireland Ss Member of Lawrence Fm	Cy, H	D	11.6	6-55	1,063	
36ccb*	Francis McKaughan	30 R	48	R	Ss	do	Cy, W	D, S	19.4	5-55	1,054	3 gpm R
14-22E- 9cbb*	Marvin Rankin	16	120	R	Ss	Rock Lake Sh Member of Stanton Ls	Cy, W	D, S	5.5	6-55	990	3 gpm R
21bbc	Art Squires	14	60	R	Ss, Sd	Ireland Ss Member of Lawrence Fm	Cy, E	S	3.0	4-44	1,050	2 gpm R
21bcb*	City of Gardner	55 R	96	C	Ss	Colluvium Ireland Ss Member of Lawrence Fm	T, E	P			1,054	15 gpm R
21bd	Joe Squires	53 R	6	S	Ss	do	N	N	6 R	4-44	1,050	7 gpm R
21cbb1*	City of Gardner	36 R	10	S	Ss, Gr	do		P	8.5	6-44	1,035	20 gpm R
21cbb2*	do	42 R	10	S	Ss	do		P	6.5	6-44	1,030	12 gpm
32bbd	Wendell Knabe	200 R	6	S	Ss	Bonner Springs Sh	S, E	D, S	75 R	1-56	1,047	1,800 gpd R
34bab	William Voights	175 R	6	S	Ss	do	J, E	D	105	7-59	1,029	1,920 gpd R
14-23E-11bcc1*	Elmer Brunker	15	60	R		Stanton Ls	J, E	D, S	3.9	6-55	1,029	5 gpm R
11bcc2*	do	115 R	6			Colluvium Wyandotte Ls	N	N			1,028	120 gpd R
15daa*	Dean Parks	167 R	7	S	Ss	Bonner Springs Sh do	Cy, H	D			1,044	240 gpd R
20baa1	George Hedrick	40	60	R		Colluvium Stanton Ls	Cy, H	S	2.7	6-48	1,039	1 gpm R
20baa2	do	22	30	R		Colluvium Stanton Ls	Cy, H	S	2.6	6-48	1,046	1 gpm R
22cdd	William Hedrick	34	48	R		Weston Sh Member of Stranger Fm	Cy, H	D	18.6	6-48	1,073	
34bcc	Carl Hanser	160 R	7	S	Ss	Stanton Ls Lane Sh Eudora Sh Member of Stanton Ls	J, E	D, S	33 R	3-56	1,043	2 gpm R
14-24E-13bcb	V. V. Ashwell	125 R	6	G	Ss, Sh	Bonner Springs Sh Wyandotte Ls	S, E	D			1,014	5 gpm R
15bcb	E. A. Young	220 R	6	S	Sh	Bonner Springs Sh	Cy, H	D			1,018	250 gpd R

18aba*	R. Brown	21	48	R	Ss	Rock Lake Sh Member of Stanton Ls	Cy, E	D, S	17.0	5-55	1,086	30 gph R
19ccc	Nevenka Burgesen	27	60	R	Ss	do	Cy, H	D	20.8	9-54	1,101	12 gph R
23dcc1	Bert Brooks	120 R	6	N	Ls	Farley Ls Member of Wyandotte Ls	N	T			1,030	200 gpd R
23dcc2	do	20 R	72	B		Colluvium	S, E	D, S	10 R	7-59	1,034	18 gph R
32ccc	W. C. Jones	285 R	6	S	Ss	Cherryvale Sh	Cy, E	S			1,060	150 gpd R
14-25E- 3ccc*	L. S. Bailey	15	72	R	Ls, Sh	Iola Sh Lane Sh	Cy, H	D	6.5	5-55	937	
22baa*	W. O. Cox	225 R	6		Sh	Hushpuckney Sh Member of Swope Ls		D			980	5 gpm R
22bdd	V. J. Stepanick	209 R	6		Ss, Sh	Cherryvale Sh Stark Sh Member of Dennis Ls	S, E	D, S	109 R	8-56	1,022	1 gpm R
28aab	Lee Coleman	155 R	6	G	Ls, Sh	Dennis Ls Cherryvale Sh		D, S			918	6 gpm R
28add	do	Spring			Ls	Argentine Ls Member of Wyandotte Ls	N	D			975	18 gph R
31cdc	A. G. Dunbar	115 R	6	S	Ls	Wyandotte Ls	J, E	D	35 R	7-59	1,067	12 gph R
31cdd	do	105 R	6	S	Ls	do	Cy, H	S			1,053	80 gpd R
15-21E-14cbb*	J. Linnholtwick	40	48	R	Ss	Ireland Ss Member of Lawrence Fm	Cy, E	D, S	26.5	6-55	1,073	1 gpm R
15-22E- 5ddd*	Johnson County	27	120	B	Sd, Gr, Cl	Recent Stage Wisconsinan Stage Fluvial deposits	Cy, H	P	4.5	5-55	955	5 gpm R
17bbc	John Erskin estate	235 R	6	S	Sh	Upper Pennsylvanian Series		S	125 R	11-57	1,033	2 gpm R
15-23E- 2ddd*	Johnson County	35	48	R		Stanton Ls	Cy, H	P	13.5	6-55	1,090	1 gpm R
18ccc	L. A. Butts	157 R	7	S	Ss	Lane Sh	Cy, E	D, S	35 R	3-56	1,065	2,400 gpd R
15-24E- 2dda*	J. B. Baker	10	72	R	Gr, St, Cl	Colluvium	Cy, H	D, S	3.4	6-55	1,035	2 gpm R
4aba	Arthur Van Daele	200 R	6	S	Ls	Wyandotte Ls		D, S			1,023	30 gph R
15-25E- 4bab*	M. J. Nixon	Spring		U	Ls	Argentine Ls Member of Wyandotte Ls	N	S			980	100 gpm R
4dcd*	Johnson County	15	120	R	Gr, St, Cl	Colluvium	Cy, H	P	2.4	6-55	1,040	
6caa	Francis Hodge	227 R	6	S	Ss, Sh	Bonner Springs Sh Cherryvale Sh	Cy, H	D, S	29.3	7-59	1,092	3 gpm R

[1] Asterisk following well number indicates analysis of water is given in table 4.
[2] *R*, reported.
[3] *B*, brick; *C*, concrete; *E*, contact spring; *G*, galvanized; *I*, iron; *N*, none; *R*, rock; *S*, steel; *T*, tile; *U*, solution spring.
[4] *Cl*, clay; *Gr*, gravel; *Ls*, limestone; *Sd*, sand; *Sh*, shale; *Ss*, sandstone; *St*, silt.
[5] *Ls*, Limestone; *Sh*, Shale; *Ss*, Sandstone; *Fm*, Formation.
[6] *Cy*, cylinder; *J*, jet; *N*, none; *S*, submersible; *T*, turbine.
[7] *E*, electric; *G*, gasoline; *H*, hand; *LPG*, liquefied petroleum gas; *W*, wind.
[8] *C*, commercial; *D*, domestic; *I*, irrigation; *Id*, industrial; *N*, none; *O*, observation; *P*, public supply; *S*, stock; *T*, test.
[9] *gpd*, gallons per day; *gph*, gallons per hour; *gpm*, gallons per minute; *R*, reported.

LOGS OF WELLS AND TEST HOLES

Given on the following pages are logs of 15 test holes drilled by the State Geological Survey of Kansas and logs of 22 wells and test holes obtained from drillers and other sources. Additional logs of test holes are on file at the State and U.S. Geological Survey offices, Lawrence, Kans., and may be consulted there.

12-21E-36ccc.—Driller's log of well in the SW¼ SW¼ SW¼ sec. 36, T.12 S., R.21 E.; drilled by W. D. Wilson for Ted Weeks, 1952. Altitude of land surface, 885± feet; reported depth to water, 121 feet.

	Thickness, feet	*Depth, feet*
Soil	3	3
Clay	13	16
Clay and sand	4	20
Limestone, brown	20	40
Shale, dark	6	46
Limestone	7	53
Shale, light	12	65
Shale, sandy (very little water)	12	77
Limestone	20	97
Shale, sandy	15	112
Limestone, light	11	123
Shale, gray	3	126
Limestone	28	154
Shale, dark gray	30	184
Limestone	19	203
Shale, dark	2	205
Limestone	2	207
Shale, sandy, dark (water)	9	216
Red bed	4	220
Shale, sandy, light gray (water)	16	236

12-22E-20cac.—Driller's log of Sunflower Ordnance Works well No. 4 in the SW¼ NE¼ SW¼ sec. 20, T.12 S., R.22 E.; drilled by Layne-Western Co., 1942. Altitude of land surface, 786.1 feet; depth to water, 7.9 feet.

	Thickness, feet	*Depth, feet*
Soil	2	2
Soil, sandy	10	12
Sand, fine, brown	10	22
Sand, fine, gray	8	30
Sand, coarse; gravel and rock	18	48
Limestone	----	48

12-22E-24ccc1.—Driller's log of city of Olathe well No. 3 in the SW¼ SW¼ SW¼ sec. 24, T.12 S., R.22 E.; drilled by Layne-Western Co., April 1964. Altitude of land surface, 782.8 feet.

	Thickness, feet	*Depth, feet*
Topsoil	1.5	1.5
Silt, clayey, brown	8.5	10
Sand, fine to very fine, dense, brown	15	25
Sand, fine to medium, dense, brown	2	27
Sand, fine to medium, dense, brown; trace coarse sand	3	30
Sand, medium to coarse, brown; trace fine sand and loose gravel	5	35
Sand, coarse to medium, gray; trace fine sand and loose gravel	24	59
Shale, hard, green and gray	1	60

12-22E-24ccc2.—Driller's log of city of Olathe well No. 4 in the SW¼ SW¼ SW¼ sec. 24, T.12 S., R.22 E.; drilled by Layne-Western Co., 1964. Altitude of land surface, 780.0 feet.

	Thickness, feet	*Depth, feet*
Topsoil	1	1
Silt, sandy, brown; trace medium clay	2	3
Clay, silty, medium, brown	10	13
Silt, clayey, brown; trace soft sand	5	18
Sand, very fine to fine, dense, brown	2	20
Sand, fine to medium, dense, brown	3	23
Sand, fine to medium, gray; trace dense coarse sand	6	29
Sand, medium to coarse, gray; contains some dense fine sand	3	32
Sand, medium to coarse, gray; trace dense fine sand	1	33
Sand, medium to coarse, brown and gray; trace fine sand and dense gravel	5	38
Sand, medium to coarse, gray and brown; trace fine sand and loose gravel	5	43
Sand, medium to coarse, gray; trace fine sand and loose gravel	4	47
Sand, medium to coarse, gray; trace medium dense fine sand and gravel	3	50
Sand, medium to coarse, gray; and medium dense gravel	5.5	55.5
Limestone, solid	0.5	56

12-22E-25bbc1.—Driller's log of city of Olathe well No. 1 in the SW¼ NW¼ NW¼ sec. 25, T.12 S., R.22 E.; drilled by Layne-Western Co., April 1964. Altitude of land surface, 780.7 feet.

	Thickness, feet	*Depth, feet*
Topsoil	1	1
Silt, clayey, moist, medium, brown	9	10
Silt, sandy, moist, soft, brown	3	13
Sand, fine to medium, very dense, brown	8	21
Sand, very fine to fine, very dense, gray	8	29
Sand, very fine to fine, gray; trace very dense medium sand	3	32
Sand, medium to coarse, gray; trace fine sand and loose gravel	2	34
Sand, medium to coarse, gray; trace fine sand, gravel, and boulders	2	36
Sand, medium to coarse, gray; trace loose fine sand, gravel, and boulders	8	44
Sand, medium to coarse, gray; trace clay, fine sand, gravel, and loose boulders	3	47
Sand, medium to coarse, gray; gravel and loose boulders	4	51
Sand, medium to coarse, gray; gravel and medium dense boulders	15	66
Shale, medium, gray	0.5	66.5

12-22E-25bbc2.—Driller's log of city of Olathe well No. 2 in the SW¼ NW¼ NW¼ sec. 25, T.12 S., R.22 E.; drilled by Layne-Western Co., April 1964. Altitude of land surface, 780.9 feet.

	Thickness, feet	*Depth, feet*
Topsoil	1	1
Silt, sandy, brown; trace medium clay	4	5
Clay, silty, stiff, brown	5	10
Clay, silty, brown; trace medium sand	8	18
Sand, very fine to fine, very dense, brown	11	29
Sand, very fine to fine, very dense, gray	9	38
Sand, medium to coarse, gray; trace medium dense fine sand	6	44
Sand, fine to medium, gray; trace very dense coarse sand	4	48
Sand, medium to coarse, gray; trace fine sand, gravel, and medium dense boulders	14	62
Limestone, solid	1	63

12-22E-26dab.—Sample log of test hole in the NW¼ NE¼ SE¼ sec. 26, T.12 S., R.22 E., about 16 feet south of center line of Kansas Highway 10; augered August 1954. Altitude of land surface, 796± feet; depth to water, 30± feet.

	Thickness, feet	*Depth, feet*
Roadfill	5	5
QUATERNARY SYSTEM		
PLEISTOCENE SERIES		
RECENT AND WISCONSINAN STAGES		
Newman terrace deposits		
Silt and clay, slightly sandy, grayish-black	7	12

	Thickness, feet	*Depth, feet*
Clay, silty, grayish-brown	10	22
Clay, silty, dark-gray	5	27
Silt, clayey, sandy, gray	22	49
Silt, sandy, brownish-gray	9	58
Silt and sand, gray; contains small amount of limestone and chert gravel	17.5	75.5
PENNSYLVANIAN SYSTEM		
UPPER PENNSYLVANIAN SERIES		
MISSOURIAN STAGE		
Shale, hard, gray	3	78.5

12-22E-31dcb.—Sample log of test hole in the NW¼ SW¼ SE¼ sec. 31, T.12 S., R.22 E., on road shoulder at crest of hill; augered August 1954. Altitude of land surface, 924± feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
PLEISTOCENE SERIES		
WISCONSINAN STAGE		
Peoria(?) Formation		
Silt, grayish-black	1.5	1.5
Silt, clayey, grayish-tan	5.5	7
KANSAN STAGE		
Kansan till(?)		
Silt and clay, slighty sandy, noncalcareous, red to brownish-tan	13	20
Silt and clay, sandy, calcareous, reddish-tan	1.5	21.5
PENNSYLVANIAN SYSTEM		
UPPER PENNSYLVANIAN SERIES		
MISSOURIAN STAGE		
Limestone	----	21.5

12-23E-10aab.—Sample log of test hole in the NW¼ NE¼ NE¼ sec. 10, T.12 S., R.23 E.; augered August 1954. Altitude of land surface, 866± feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
PLEISTOCENE SERIES		
WISCONSINAN STAGE		
Peoria(?) Formation		
Soil, silty, black	1.5	1.5
Silt, noncalcareous, grayish-tan; contains a few grains of fine and medium sand	5.5	7
KANSAN STAGE		
Undifferentiated fluvial deposits		
Silt, slightly sandy, noncalcareous, light-reddish-tan	5	12
Silt, clayey, slightly sandy, noncalcareous, moderate-reddish-tan	5	17
Silt and clay, slightly sandy, tannish-red	5	22
Silt, very sandy, tannish-red	7.5	29.5
Sand and gravel, arkosic, silty, calcareous, grayish-brown (could not auger below 39 feet)	9.5	39

12-23E-14acd.—Sample log of test hole in the SE¼ SW¼ NE¼ sec. 14, T.12 S., R.23 E., about 40 feet east of railroad and 20 feet north of road; augered August 1954. Altitude of land surface, 794± feet; depth to water, 10.5 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
PLEISTOCENE SERIES		
Terrace deposits, undifferentiated		
Topsoil and silt, grayish-black	5	5
Silt and clay, tannish-brown	5	10
Silt and clay, sandy, tannish-brown	3	13
Silt and clay, sandy, gray	7	20
Silt and clay, sandy and gravelly, gray	6.5	26.5
PENNSYLVANIAN SYSTEM		
UPPER PENNSYLVANIAN SERIES		
MISSOURIAN STAGE		
Shale, gray	1	27.5

12-23E-14daa.—Sample log of test hole in the NE¼ NE¼ SE¼ sec. 14, T.12 S., R.23 E.; augered August 1954. Altitude of land surface, 768± feet; depth to water, 18.5 feet.

	Thickness, feet	*Depth, feet*
Roadfill	2	2
QUATERNARY SYSTEM		
PLEISTOCENE SERIES		
Terrace deposits, undifferentiated		
Silt and clay, tannish-brown	7	9
Silt and clay, sandy, grayish-tan	10	19
Silt and clay, sandy and gravelly, grayish-tan	1.3	20.3

12-23E-19dad.—Sample log of test hole in the SE¼ NE¼ SE¼ sec. 19, T.12 S., R.23 E.; augered August 1954. Altitude of land surface, 994± feet; depth of water, 28± feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
PLEISTOCENE SERIES		
WISCONSINAN STAGE		
Peoria(?) Formation		
Soil, black, and tannish-gray silt	5	5
KANSAN STAGE		
Undifferentiated fluvial and lacustrine deposits		
Clay, compact, stiff, brownish-red	1	6
Silt, clayey, reddish-tan	9	15
Clay, silty, slightly sandy, light-gray	10	25
Sand, fine to medium, clayey in upper part, tan	5	30
PENNSYLVANIAN SYSTEM		
UPPER PENNSYLVANIAN SERIES		
MISSOURIAN STAGE		
Limestone	----	30

12-23E-27bcb.—Driller's log of well in the NW¼ SW¼ NW¼ sec. 27, T.12 S., R.23 E.; drilled by W. L. Hendee, Jr., for E. D. Garnett, July 1948. Altitude of land surface, 1,020± feet.

	Thickness, feet	*Depth, feet*
Soil and clay	16	16
Limestone	10	26
Shale, blue	5	31
Shale, gray	8	39
Limestone	27	66
Shale	4	70
Limestone	3	73
Shale	3	76
Limestone	33	109
Shale	1	110
Limestone	36	146
Shale	23	169
Limestone	9	178
Shale and slate, black	3	181
Limestone	9	190

12-23E-32acc.—Driller's log of well in the SW¼ SW¼ NE¼ sec. 32, T.12 S., R.23 E.; drilled by Breuer Drilling Co. for Thomas Anderson, February 1956. Altitude of land surface, 994± feet.

	Thickness, feet	*Depth, feet*
Soil	2	2
Clay	8	10
Rock, broken	7	17
Slate	4	21
Lime	6	27
Shale	18	45
Lime	13	58
Shale	18	76
Lime	7	83
Shale	2	85
Lime	20	105
Shale	1	106
Lime	28	134
Shale	24	158
Shale, sandy	16	174
Shale	9	183

	Thickness, feet	*Depth, feet*
Lime	11	194
Slate	2	196
Shale	13	209
Lime	6	215
Slate	4	219
Shale	11	230
Lime	9	239
Shale	10	249
Lime	3	252
Shale	6	258
Lime	2	260
(yields about 30 gallons per day; called dry hole)		

12-24E-16bcb.—Sample log of test hole in the NW¼ SW¼ NW¼ sec. 16, T.12 S., R.24 E., on edge of right-of-way at crest of hill; augered August 1954. Altitude of land surface, 1,045± feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria(?) and Loveland(?) Formations		
Soil, silty, grayish-black, and yellowish-brown silt	6.5	6.5
Silt, noncalcareous, yellowish-brown	3.5	10
Silt, noncalcareous, light-brown	12	22
PENNSYLVANIAN SYSTEM		
Upper Pennsylvanian Series		
Missourian Stage		
Shale, calcareous, yellowish-gray to gray	5	27

12-25E-22adc.—Driller's log of well in the SW¼ SE¼ NE¼ sec. 22, T.12 S., R.25 E.; drilled for A. D. Hobart, 1936. Altitude of land surface, 1,050± feet.

	Thickness, feet	*Depth, feet*
Soil and clay	14	14
Limestone, hard, gray	3	17
Shale, soft, gray	27	44
Limestone, soft, shelly, gray (little water)	3	47
Shale, soft	14	61
Limestone	5	66
Shale	14	80
Shale, sandy	45	125
Shale, gray and black	14	139
Limestone	7	146
Shale	1	147
Limestone	9	156
Shale, gray	14	170
Red bed	4	174
Shale, light	4	178
Limestone	7	185
Shale	5	190
Limestone	1	191
Slate, black	2	193
Shale, dark	7	200
Shale, light	13	213
Sandstone	2	215
Limestone	6	221
Shale	4	225
Limestone	3	228
Slate, black	1	229
Limestone	25	254
Shale	1	255
Limestone	7	262
Shale	4	266
Limestone	20	286
Slate, black (yields 40 gallons per hour; "salty water")	2	288
Limestone	11	299
Shale	1	300

12-25E-35bbd.—Driller's log of well in the SE¼ NW¼ NW¼ sec. 35, T.12 S., R.25 E.; drilled by Young and Brown Drilling Co. for Earl Caddell, April 1955. Altitude of land surface, 912± feet; reported depth to water, 45 feet.

	Thickness, feet	*Depth, feet*
Soil	15	15
Limestone	3	18
Shale, gray	4	22
Limestone	10	32
Shale, sandy, and gray slate	8	40
Limestone	6	46
Sandstone and slate (water)	6	52
Limestone	16	68
Shale, blue	16	84
Limestone	9	93
Shale	4	97
Limestone	30	127
Slate, black	4	131
Shale	4	135
Limestone	17	152
Slate, black (gas and fresh water)	4	156
Limestone	2	158
Sandstone	6	164
(well plugged back to depth of 152 feet)		

13-21E-2abb.—Sample log of test hole in the NW¼ NW¼ NE¼ sec. 2, T.13 S., R.21 E., 12 feet south of center line of road at crest of hill; augered August 1954. Altitude of land surface, 898± feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan stage		
Peoria(?) Formation		
Silt, grayish-black	1	1
Silt, grayish-tan; contains a little sand	4	5
kansan stage		
Undifferentiated fluvial deposits		
Silt and clay, slightly sandy, tan and reddish-tan	4	9
Silt and clay, light-grayish-tan; contains about 30 to 40 percent sand	5	14
Sand, fine to medium; contains about 40 percent noncalcareous grayish-tan silt and clay	5	19
Sand, fine to medium; contains about 25 percent noncalcareous grayish-tan silt and clay	5.7	24.7
Sand, fine to medium, silty, yellowish-brown	0.3	25

13-21E-14cbb.—Driller's log of well in the NW¼ NW¼ SW¼ sec. 14, T.13 S., R.21 E.; drilled by W. D. Wilson for Gus Koch, July 1955. Altitude of land surface, 875 feet.

	Thickness, feet	*Depth, feet*
Soil	1	1
Clay, red	4	5
Sandstone	6	11
Shale, gray	2	13
Limestone	15	28
Shale, gray	6	34
Limestone	7	41
Shale, light	17	58
Shale, dark gray	2	60
Sandstone, dark	6	66
Limestone	12	78
Shale	22	100
Limestone, little water	20	120
Shale	3	123
Limestone	37	160
Shale, light	27	187
Limestone	5	192
Shale, light	2	194
Limestone	9	203
Shale, dark, sandy	15	218
Sandstone, gray	9	227

13-21E-26ccd2.—Sample log of test hole in the SE¼ SW¼ SW¼ sec. 26, T.13 S., R.21 E., at high point along ridge in pasture; augered 1955. Altitude of land surface, 941± feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
KANSAN STAGE		
Undifferentiated fluvial deposits		
Silt and clay, tan; contains about 50 percent sand	3	3
Sand, fine to medium; contains about 40 percent reddish-brown silt and clay	1.5	4.5
Sand, fine to medium; contains about 40 percent brown silt and clay	5.5	10
Sand, fine to medium; contains about 40 percent brownish-red silt and clay	12	22
Clay and sand, grayish-tan; contains about 40 percent fine to medium sand	4	26
Sand, fine to coarse, tan; contains about 30 percent tan silt and clay; sand is 85 percent clear quartz, 10 percent white chert and white quartz, and 5 percent dark metamorphics, feldspar, and quartzite	12	38
Sand, fine to coarse, and tan fine gravel; contains about 10 percent silt	14	52
PENNSYLVANIAN SYSTEM		
Upper Pennsylvanian Series		
Missourian Stage		
Limestone	----	52

13-22E-10cbb.—Sample log of test hole in the NW¼ NW¼ SW¼ sec. 10, T.13 S., R.22 E., along south side of road at crest of hill; augered August 1954. Altitude of land surface, 965± feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN STAGE		
Peoria(?) Formation		
Soil, black	1.5	1.5
Silt, tan	5	6.5
KANSAN STAGE		
Kansan till(?)		
Clay, compact, sandy and gravelly, light-gray	8.5	15
Clay, light-gray, with limestone, chert, and quartzite gravel	3	18
PENNSYLVANIAN SYSTEM		
Upper Pennsylvanian Series		
Missourian Stage		
Limestone	----	18

13-22E-33ddd.—Driller's log of well in the SE¼ SE¼ SE¼ sec. 33, T.13 S., R.22 E.; drilled by Carl Moore and Son for Ralph Holey, 1954. Altitude of land surface, 987± feet; reported depth to water, 40 feet.

	Thickness, feet	*Depth, feet*
Soil	3	3
Sandstone, clayey	5	8
Shale	12	20
Limestone	10	30
Shale, dark	7	37
Limestone	7	44
Shale	11	55
Limestone	15	70
Shale	16	86
Limestone	5	91
Limestone, soft (water)	2	93
Limestone	62	155
Shale	26	181

13-24E-25cba.—Driller's log of well in the NE¼ NW¼ SW¼ sec. 25, T.13 S., R.24 E.; drilled by W. L. Hendee, Sr., for Tom Wilson, July 1959. Altitude of land surface, 1,040± feet.

	Thickness, feet	*Depth, feet*
Dirt, dark	4	4
Clay, yellow	3	7
Limestone	19	26
Shale, gray	11	37
Sandstone, brown	11	48
Shale, sandy	8	56
Limestone	5	61
Shale, gray	27	88
Limestone (with two breaks)	10	98
Shale	39	137
Limestone	9	146
Shale, dark gray	5	151
Shale, gray	14	165
Shale, green and red	4	169
Limestone	5	174
Shale, gray	4	178
Limestone	6	184
Shale, gray	9	193

13-24E-28ddd.—Driller's log of well in the SE¼ SE¼ SE¼ sec. 28, T.13 S., R.24 E.; drilled by Hazen Sears for Phillips Petroleum Co., February 1950. Altitude of land surface, 1,075± feet.

	Thickness, feet	*Depth, feet*
Soil	3	3
Clay	10	13
Lime shells	4	17
Shale	8	25
Limestone	9	34
Shale	6	40
Limestone	16	56
Shale	2	58
Red bed	3	61
Shale	14	75
Limestone	11	86
Shale	13	99
Limestone	18	117
Shale	55	172
Limestone	17	189
Shale	19	208
Limestone	8	216
Shale	6	222
Limestone	4	226
Shale	36	262
Limestone	2	264
Shale	9	273
Limestone	25	298
Slate, black	2	300
Shale	4	304
Limestone	20	324
Shale, dark	4	328
Limestone	2	330
Shale	7	337
Limestone	6	343
Shale	9	352

14-21E-12aba.—Sample log of test hole in the NE¼ NW¼ NE¼ sec. 12, T.14 S., R.21 E., about 15 feet south of centerline of road at crest of hill; augered August 1954. Altitude of land surface, 983± feet; depth to water, 38± feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN STAGE		
Peoria(?) Formation		
Topsoil, black	1.5	1.5
KANSAN STAGE		
Undifferentiated fluvial deposits		
Clay, sandy, tannish-gray	8.5	10
Clay, sandy, gray	5	15
Clay, sandy, tan; contains small caliche nodules	6	21
Clay, very sandy, tan	7	28
Sand, fine to coarse, and tan gravel	21	49

14-21E-25aaa.—Sample log of test hole in the NE¼ NE¼ NE¼ sec. 25, T.14 S., R.21 E., on road shoulder about 400 feet west of NE corner; augered October 1955. Altitude of land surface, 1,072± feet; depth to water, 29.3 feet.

	Thickness, feet	*Depth, feet*
Roadfill	1	1
PENNSYLVANIAN SYSTEM		
Upper Pennsylvanian Series		
VIRGILIAN STAGE		
Douglas Group		
Lawrence Formation		
Ireland Sandstone Member		
Sand, silty, very fine to fine, quartzose, tannish-brown	2	3
Sand, silty, very fine to fine, micaceous, reddish-brown	3	6
Sand, silty, fine, noncalcareous, micaceous, tan	13	19
Sand, silty, fine, noncalcareous, grayish-tan	12	31
Siltstone and silty sandstone, interbedded, noncalcareous, green and grayish-tan	10	41
Sandstone, silty, fine, noncalcareous, partly carbonaceous, gray; contains coal fragments in lower part	9	50

14-22E-9baa.—Sample log of test hole in the NE¼ NE¼ NW¼ sec. 9, T.14 S., R.22 E., about 200 feet west and 6 feet south of N¼ corner; augered August 1954. Altitude of land surface, 1,012± feet; depth to water, 27.5 feet.

	Thickness, feet	*Depth, feet*
Roadfill	2	2
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN STAGE		
Peoria(?) Formation		
Silt, clayey, grayish-tan to brownish-tan; contains sparse grains of fine sand	4.5	6.5
KANSAN STAGE		
Undifferentiated fluvial(?) deposits		
Clay, compact, stiff, mottled gray and reddish-brown; contains sparse grains of fine sand	0.5	7
Clay, silty, moderately stiff, light-grayish-tan	2	9
Clay, compact, tannish-gray	3	12
Clay, compact, light-yellowish-tan; contains clay ironstone fragments	3	15
Clay, compact, yellow; contains manganese-shot	4	19
Clay, sandy, compact, stiff, light-tannish-gray; contains abundant manganese-shot	0.5	19.5
Clay and silt, sandy, greenish-tan to yellowish-tan	5.5	25
Clay and silt, very sandy, olive-green	2	27
Sand, silty, light-olive to yellowish-green	4	31
Gravel, silty, and very fine to medium sand	1.5	32.5
PENNSYLVANIAN SYSTEM		
Upper Pennsylvanian Series		
Missourian Stage		
Limestone	----	32.5

14-22E-32bbd.—Driller's log of well in the SE¼ NW¼ NW¼ sec. 32, T.14 S., R.22 E.; drilled by Carl Moore and Son for Wendell Knabe, January 1956. Altitude of land surface, 1,047± feet; reported depth to water, 75 feet.

	Thickness, feet	*Depth, feet*
Soil	4	4
Clay, sandy	11	15
Limestone, sandy	4	19
Clay, sandy	2	21
Shale	45	66
Limestone	4	70
Shale	3	73
Limestone	15	88
Shale	8	96
Limestone	8	104
Shale	9	113
Limestone	20	133
Shale	16	149
Sandstone (water)	7	156
Limestone	27	183
Shale	7	190
Limestone	10	200

14-23E-34bcc.—Driller's log of well in the SW¼ SW¼ NW¼ sec. 34, T.14 S., R.23 E.; drilled by Carl Moore and Son for Carl Hanser, March 1956. Altitude of land surface, 1,043± feet; reported depth to water, 33 feet.

	Thickness, feet	*Depth, feet*
Soil	2	2
Clay	7	9
Limestone boulders	3	12
Limestone	13	25
Shale	6	31
Limestone	9	40
Shale	8	48
Limestone	17	65
Red bed	2	67
Shale	11	78
Limestone	15	93
Shale	12	105
Limestone	2	107
Sandstone (water)	21	128
Shale	32	160

14-24E-15bcb.—Driller's log of well in the NW¼ SW¼ NW¼ sec. 15, T.14 S., R.24 E.; drilled by J. W. Pinkerson for E. A. Young, 1954. Altitude of land surface, 1,018± feet.

	Thickness, feet	*Depth, feet*
Yellow clay and shale (water at 35 feet; 250 gallons per day)	80	80
Limestone, gray	22	102
Shale, brown	3	105
Limestone, gray	7	112
Shale, brown	13	125
Shale, red	14	139
Limestone	3	142
Shale, blue and black	8	150
Limestone, gray	3	153
Shale, blue	37	190
Limestone	5	195
Shale, blue	5	200
Limestone, gray	2	202
Limestone, white	13	215
Limestone, gray	3	218
Limestone, dark	9	227
Shale, brown and gray (moderately saline water; 3 gallons per minute)	6	233
Limestone, white	2	235
(well cemented back to depth of 220 feet)		

14-25E-10dcc.—Sample log of test hole in the SW¼ SW¼ SE¼ sec. 10, T.14 S., R.25 E.; augered August 1954. Altitude of land surface, 878± feet; depth to water, 12.1 feet.

	Thickness, feet	*Depth, feet*
Roadfill	2	2
QUATERNARY SYSTEM		
Pleistocene Series		
Terrace deposits, undifferentiated		
Silt and clay, grayish-black	4	6
Silt and clay, dark-grayish-brown	4	10
Silt and clay, medium-grayish-brown	3	13
Silt and clay, sandy, grayish-brown	7.5	20.5
Gravel and sand, silty, clayey	5	25.5
PENNSYLVANIAN SYSTEM		
Upper Pennsylvanian Series		
Missourian Stage		
Shale, gray	2.5	28

14-25E-22bdd.—Driller's log of well in the SE¼ SE¼ NW¼ sec. 22, T.14 S., R.25 E.; drilled by Boten Drilling Co. for V. J.

Stepanick, August 1956. Altitude of land surface, 1,022± feet; reported depth to water, 109 feet.

	Thickness, feet	*Depth, feet*
Soil	7	7
Limestone, hard	5	12
Limestone, medium hard	18	30
Limestone, very hard	3	33
Limestone, hard	9	42
Shale, gray	24	66
Limestone, hard	8.5	74.5
Shale (water)	5.5	80
Limestone	1	81
Shale	1	82
Limestone	1	83
Shale, sandy, gray	7	90
Shale, red and green	2	92
Limestone, sandy, red	2	94
Shale, green	8.5	102.5
Limestone	2	104.5
Shale	0.5	105
Limestone	6	111
Shale, gray	15	126
Limestone	7	133
Sandstone and limestone	2	135
Sandstone, soft (water)	10	145
Limestone, hard	8	153
Shale, gray	6	159
Limestone	5	164
Shale, gray	9	173
Limestone, very hard	7	180
Limestone, hard	13	193
Limestone	6	199
Slate and coal (water)	2	201
Shale, gray	5	206
Limestone	3	209

15-22E-16ddb.—Sample log of test hole in the NW¼ SE¼ SE¼ sec. 16, T.15 S., R.22 E., on road shoulder about 280 feet west of creek; augered August 1954. Altitude of land surface, 924± feet.

	Thickness, feet	*Depth, feet*
Roadfill	1	1
QUATERNARY SYSTEM		
Pleistocene Series		
Terrace deposits, undifferentiated		
Silt, sandy, tannish-brown	3	4
Silt and clay, very sandy, dark-grayish-brown	8	12
Silt and clay, grayish-brown; contains about 50 percent chert, limestone, and quartz sand and gravel	8	20
PENNSYLVANIAN SYSTEM		
Upper Pennsylvanian Series		
Missourian Stage		
Shale, clayey, calcareous, bluish-gray	2	22

15-22E-17bbc.—Driller's log of well in the SW¼ NW¼ NW¼ sec. 17, T.15 S., R.22 E.; drilled by Carl Moore and Son for John Erskin estate, November 1957. Altitude of land surface, 1,033± feet; reported depth to water, 125 feet.

	Thickness, feet	*Depth, feet*
Soil	2	2
Clay	19	21
Limestone	22	43
Shale	5	48
Limestone	11	59
Shale	8	67
Limestone	17	84
Shale	66	150
Sandy shale (water)	30	180
Limestone	5	185
Shale	12	197
Limestone	8	205
Shale	17	222
Limestone	13	235

15-23E-18ccc.—Driller's log of well in the SW¼ SW¼ SW¼ sec. 18, T.15 S., R.23 E.; drilled by Carl Moore and Son for L. A. Butts, March 1956. Altitude of land surface, 1,065± feet; reported depth to water, 35 feet.

	Thickness, feet	*Depth, feet*
Soil	3	3
Clay	6	9
Boulders	2	11
Sandy clay	5	16
Limestone	10	26
Shale	3	29
Limestone	2	31
Shale	2	33
Limestone	19	52
Shale	7	59
Red bed	3	62
Shale	2	64
Limestone	3	67
Shale	2	69
Limestone	16	85
Shale	24	109
Limestone	1	110
Sandy shale	4	114
Sandstone (water)	12	126
Sandy shale	4	130
Shale	27.5	157.5

15-24E-4aba.—Driller's log of well in the NE¼ NW¼ NE¼ sec. 4, T.15 S., R.24 E.; drilled by Carl Moore and Son for Arthur Van Daele, August 1956. Altitude of land surface, 1,023± feet.

	Thickness, feet	*Depth, feet*
Topsoil	2	2
Clay	5	7
Boulders	3	10
Shale	12	22
Lime (water at 40 feet)	64	86
Shale	20	106
Lime	9	115
Shale	2	117
Lime, soft	3	120
Shale	3	123
Lime, sandy	4	127
Shale	6	133
Rock, red	2	135
Shale	15	150
Lime	5	155
Slate, black	1	156
Shale	23	179
Lime	1	180
Shale	15	195
Lime	1	196
Shale	4	200

15-25E-6caa.—Driller's log of well in the NE¼ NE¼ SW¼ sec. 6, T.15 S., R.25 E.; drilled by J. D. Judd and Son for Francis Hodge, 1943. Altitude of land surface, 1,092± feet; reported depth to water, 27 feet.

	Thickness, feet	*Depth, feet*
Soil	4	4
Clay	6	10
Lime shells	8	18
Red bed	10	28
Sandstone (water)	6	34
Shale	8	42
Limestone	82	124
Shale	29	153
Limestone	9	162
Sandy shale	16	178
Limestone	1	179
Red bed	6	185
Shale	7	192
Limestone	5	197
Shale and slate (water)	8	205
Shale	4	209
Sandstone	8	217
Shale	5	222
Limestone	5	227

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