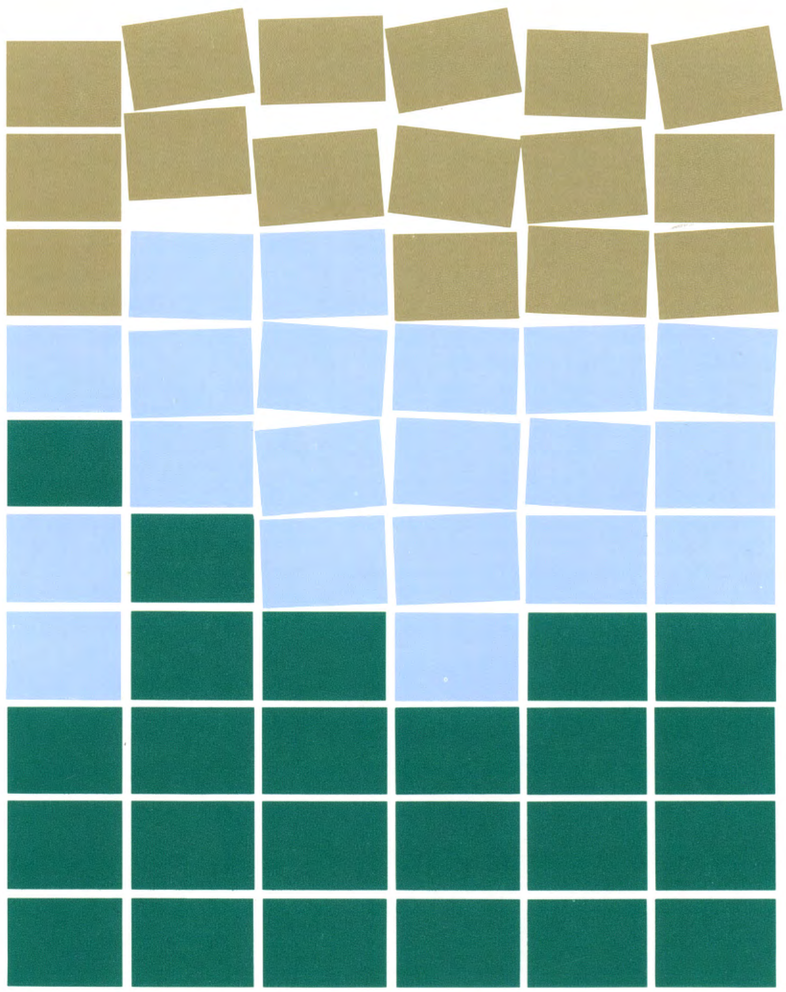
Geohydrology of sandstone aquifers in southwestern Kansas



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Kansas Geological Survey Lawrence, Kansas

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Prepared by the U.S. Geological Survey in cooperation with the Kansas Geological Survey and the Kansas Department of Health and Environment

Kansas Geological Survey

Lawrence, Kansas

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Abstract

Sandstone aquifers in southwestern Kansas are a source of water for irrigation, industrial, municipal, domestic, and stock uses. An appraisal of water resources in sandstone aquifers underlying approximately 17,400 mi^2 in 26 counties of southwestern Kansas shows that in some areas water is still available for additional well development. Additional water is needed to supplement decreasing supplies in the overlying Ogallala aquifer as demand for water increases. Major sandstone aquifers, in order of importance, occur in the Dakota Formation in the Lower Cretaceous Series, in undifferentiated rocks in the Upper Jurassic Series, and in the Cheyenne Sandstone in the Lower Cretaceous Series. Minor sandstone aquifers, in stratigraphic sequence, occur in undifferentiated rocks in the Upper Permian Series, in the Kiowa Formation in the Lower Cretaceous Series, and in the Codell Sandstone Member of the Carlile Shale in the Upper Cretaceous Series. Aquifers in the Dakota Formation occur throughout most of the area, contain fresh to moderately saline water, range from 0 to approximately 150 ft in thickness (average 58 ft in thickness), and yield up to 2,200 gal/water/min to wells. Dissolved-solids concentrations are less than 500 mg/L in water from the aquifers in the southern two-thirds of the area. Sodium bicarbonate and calcium bicarbonate are the most common chemical types of water. In some areas, moderate well development has occurred in the aquifers for irrigation, industrial, municipal, domestic, and stock supplies. The aquifers in rocks of Late Jurassic age occur in the western half of the study area, contain freshwater, and range from 0 to approximately 50 ft in thickness (average 24 ft in thickness). Dissolved-solids concentrations in water from aquifers in Upper Jurassic rocks range from 296 to 517 mg/L. Waters are calcium bicarbonate and sodium bicarbonate chemical types. Moderate development of irrigation, stock, and domestic wells has occurred locally in the aquifers. The aquifers in the Cheyenne Sandstone occur throughout most of the area, contain fresh to briny water, and range from 0 to 190 ft in thickness (average 37 ft in thickness). Dissolved-solids concentrations in water range from 192 to 51,000 mg/L. Sodium sulfate or sodium chloride waters are the common chemical types. Minor development of irrigation, stock, and domestic wells has occurred locally in the aquifers. Aquifers in rocks of Permian age occur throughout the area, reach a maximum depth of approximately 2,100 ft in Wallace County, and generally contain saline to briny water. Dissolved-solids concentrations in water range from 89 to 51,000 mg/L. Sodium chloride and calcium sulfate are the common chemical types of water. A minor amount of stock-well development has occurred in the aquifers. Aquifers in the Kiowa Formation and in the Codell Sandstone Member of the Carlile Shale occur in the northeastern corner of the study area, are thin and discontinuous, and have a minor amount of stock- and domestic-well development. The aquifers in the Kiowa Formation range in thickness from 10 to 35 ft, and the aquifers in the Codell Sandstone range in thickness from 0 to approximately 25 ft.

Introduction

Economic stability and growth in southwestern Kansas depend on the continued availability of ground water for irrigation and other uses. The production of food and fiber from irrigated land in this region is of major significance to the economic well-being of Kansas and the nation. However, ground-water supplies for irrigation from the Ogallala Formation, the principal aquifer in western Kansas, are being depleted because water is being withdrawn at a rate many times faster than it is being replenished by recharge. Sandstone aquifers in underlying consolidated bedrock of Late Jurassic and Early Cretaceous age are being developed to varying degrees for stock, domestic, industrial, and irrigation supplies in certain parts of southwestern Kansas. However, based on present information, the sandstone aquifers have significantly greater potential for additional development.

The study area for this report includes all or parts of 26 counties in southwestern Kansas (fig. 1). The area comprises approximately 17,400 mi^2 and is bounded on the north by the Smoky Hill River, on the west by Colorado, on the south by Oklahoma, and on the east by the Arkansas River and Barton, Clark, and Kiowa counties.

This report presents the results of a geohydrologic study of the sandstone aquifers of Permian, Jurassic, and Cretaceous age in southwestern Kansas conducted in cooperation with the Kansas Geological Survey and the Kansas Department of Health and Environment. The report includes a description of the aquifers and their properties and the chemical characteristics of the ground water from these aquifers. In previous county and state studies, the sandstone units commonly were undifferentiated and were included in a single geohydrologic unit known as the "sandstone aquifer." Because an excessive amount of shale and siltstone also was included in this "aquifer," erroneous conclusions possibly could have been made as to the potential for development of water supplies from this "sandstone aquifer." For a summary of selected reports where the "sandstone aquifer" is addressed, see table 1.

For this study, 15 observation wells were drilled for a total of 6,340 ft, and 20 piezometers were installed (fig. 1). The wells were constructed with plastic or steel pipe and screens. No sand pack was put into the hole. Air lift was used to develop some observation wells.

Data collection included the sampling and description of well cuttings from these wells (table 7), measuring ground-water levels from piezometers (table 8), and collecting water samples from wells for chemical analysis (table 9). Also borehole geophysical logs were run in the completed test holes. Tables 7–9 are given at the end of this report.

Selected electrical and nuclear logs of oil and gas test wells in southwestern Kansas were used to define and correlate geologic formations in the study area. Data from previous studies and logs of water wells were compiled and analyzed.

The geohydrologic data from this study are described in two reports prepared by the U.S. Geological Survey (Kume and Spinazola, 1982; 1983). These data complement and are the documentation for this report.

ACKNOWLEDGMENTS—This report is the product of a cooperative study during 1976–79 conducted by the U.S. Geological Survey in cooperation with the Kansas Geological Survey and the Kansas Department of Health and Environment.

Drillers' well logs were furnished by various commercial drillers, including Layne Western Co., Henkle Drilling and Supply Co., Inc., and Minter-Wilson Drilling Co.

Appreciation is expressed to the landowners who allowed access to their property for test drilling, observation-well construction, hydrologic measurements, and water-sample collection. Special thanks are expressed to the farmers, ranchers, and other individuals who provided information and assistance for this study.

Purpose and scope

The purpose of the investigation was 1) to define the geologic formations in which sandstone aquifers occur, 2) to describe the geohydrology of the sandstone aquifers, and 3) to describe the chemical characteristics of ground water in the sandstone aquifers and the suitability of the water for common uses.

The sandstone aquifers described in this report were limited to those that occur in the Upper Permian Series, the Upper Jurassic Series, and the Lower and Upper Cretaceous Series (table 2). These stratigraphic intervals were selected because they include those sandstones that contain or may contain freshwater. However, the Permian formations that subcrop beneath Jurassic and Cretaceous rocks

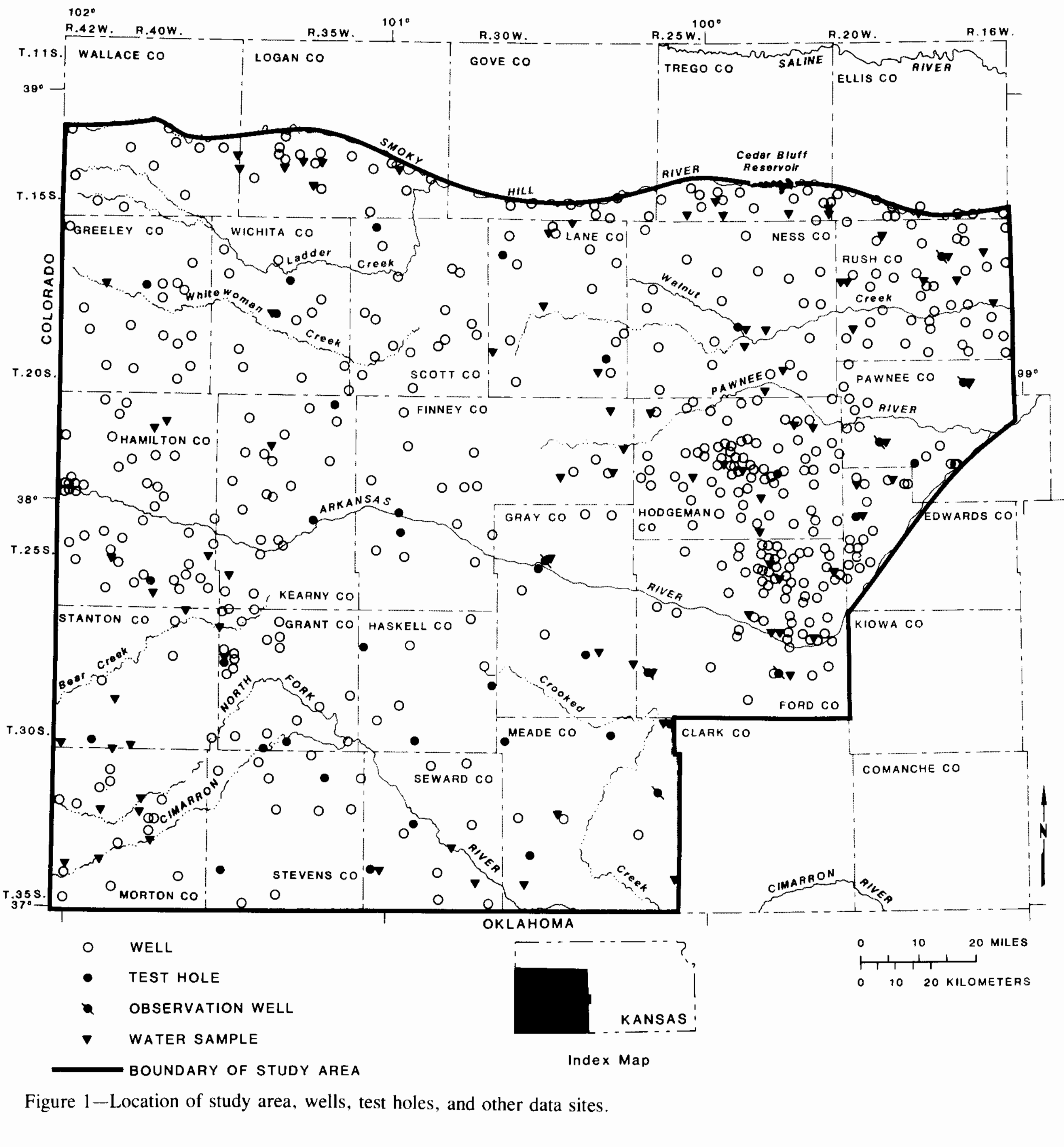


Figure 1—Location of study area, wells, test holes, and other data sites.

may contain moderately saline to briny water in some areas of southwestern Kansas. The classification and nomenclature of the rock units in this report are those of the Kansas Geological Survey and differ somewhat from those of the U.S. Geological Survey.

Well-numbering system

The well-numbering system, as shown in fig. 2, gives the location of a well or test hole according to the U.S. Bureau of Land Management's system of land subdivision. In this system, the first set of digits of a well number indicates the township; the second set, the range east or west of the Sixth Principal Meridian; and the third set, the section in which the well or test hole is located. The first letter after the section number denotes the quarter section or 160-acre tract; the second, the quarter-quarter section or 40-acre tract; and the third, the quarter-quarter-quarter section or 10-acre tract. The 160-, 40-, and 10-acre tracts are designated A, B, C, or D in a counterclockwise direction, beginning in the northeast quadrant. Multiple well or test-hole locations within a 10-acre tract are assigned consecutive numbers, beginning with "1," in the order in which data were collected. When only one well is

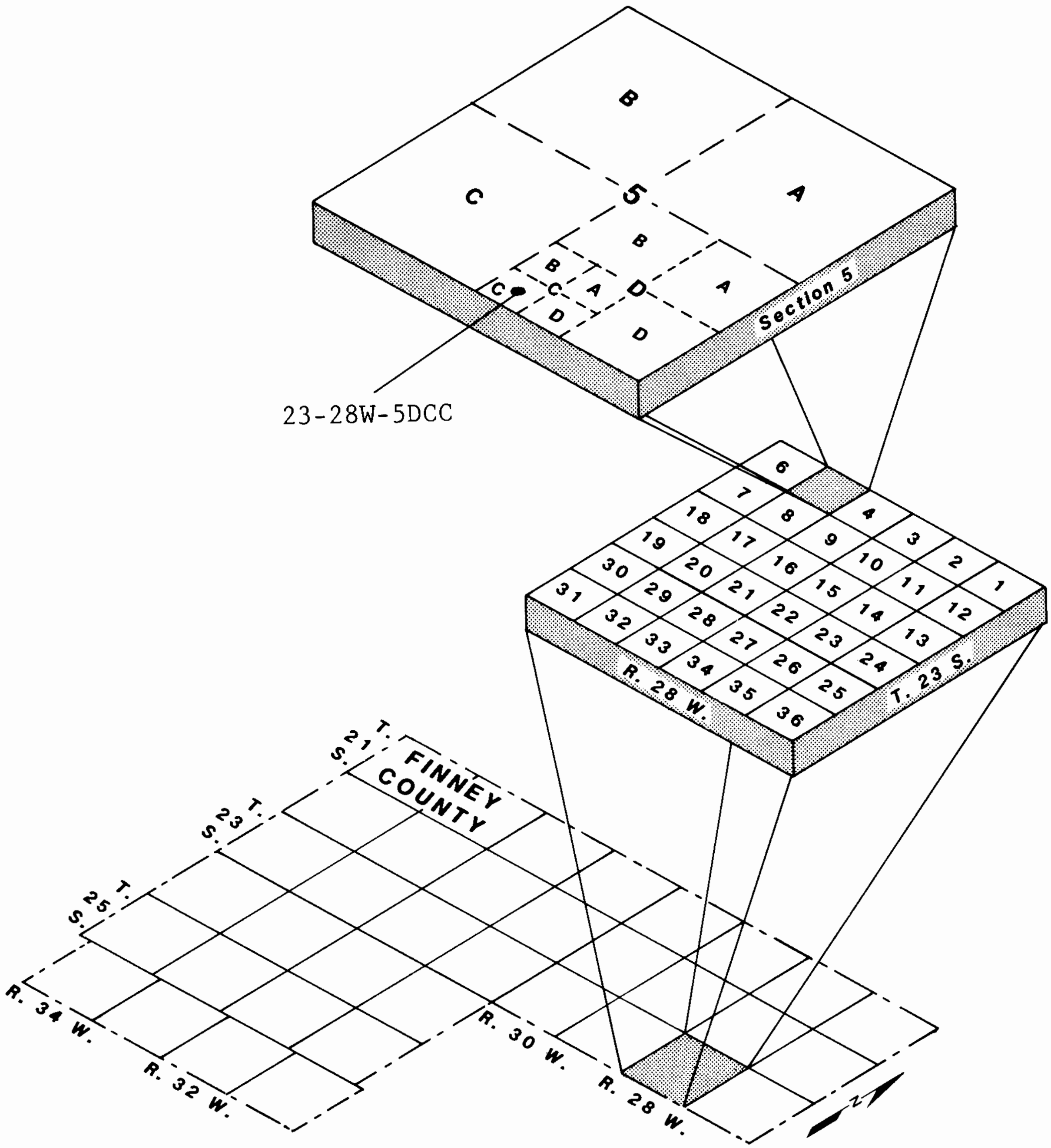


Figure 2—Well-numbering system.

present in a 10-acre tract, that "1" is frequently omitted. Thus, in Finney County, the number 23-28W-5DCC means that the well is in the SW¼SW¼SE¼ sec. 5, T. 23 S., R. 28 W.

Geology

The geologic formations described in this report belong to the Upper Permian Series, the Upper Jurassic Series, and the Lower and Upper Cretaceous Series. Permian formations that are discussed include the Whitehorse and the Big Basin formations. The Jurassic formations are not differentiated. The discussions of Cretaceous formations include the Cheyenne Sandstone, the Kiowa and Dakota formations, and the Codell Sandstone Member of the Carlile Shale. The geology of the pre-Ogallala (Pliocene and Miocene) bedrock surface is shown in fig. 3. This map shows the areal extent of Upper Permian, Upper Jurassic, and Lower and Upper Cretaceous rocks.

TABLE 1—Summary of sandstone-aquifer data from selected previous reports. (Thickness is given in feet and is the stratigraphic unit thickness. Yield is given in gallons per minute. Depth to top of aquifer is given in feet. Asterisks [*] indicate units included in the "sandstone aquifer"; "Yes" indicates that the unit yields potable water to wells, but marginal for most uses; "No" indicates that the unit does not yield potable water to wells.)

Study area	Finney County	Grant and Stanton counties	Gray County	Greeley and Wichita counties	Hamilton County	Haskell County	Hodgeman and northern Ford counties	Kearny County	Lane and Scott counties	Ness County	Rush County	Trego County	Kansas
Reference / **Sandstone aquifers**	Gutentag, Lobmeyer, McGovern, and Long, 1972	Fader Gutentag, Lobmeyer, and Meyer, 1964	McGovern and Long, 1974	Slagle and Weakly, 1976	Lobmeyer and Sauer, 1974	Gutentag and Stullken, 1974	Lobmeyer and Weakly, 1979	Gutentag, Lobmeyer, and McGovern, 1972	Gutentag and Stullken, 1976	Jenkins and Pabst, 1977	McNellis, 1973	Hodson, 1965	Keene and Bayne, 1977
UPPER CRETACEOUS													
Codell Sandstone Member of the Carlile Shale	—	—	—	—	—	—	—	—	—	—	—	—	—
Thickness	—	—	—	—	—	—	—	—	—	—	4	3-5	—
Yield	—	—	—	5-10	—	—	—	—	5-10	—	0	small amount	—
LOWER CRETACEOUS	*	*	*	*	*	*	*	*	*	*	*	*	*
Thickness	120-460	—	300-400	300-500	350	0-260	—	210-380	300-680	260-690	5-500	150-250	0-850
Yield	30-1,000	500	1,000	30-300	—	—	100-2,200	30-300	30-300	20-800	—	—	100-2,000
Dakota Formation	*	*	*	*	*	*	*	*	*	*	*	*	*
Thickness	—	0-135	—	—	—	—	100-450	—	—	150-300	200-300	150-250	2-330
Yields potable water to wells	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Kiowa Formation	*	*	*	*	*	*	*	*	*	—	*	—	*
Thickness	—	0-150	—	—	—	—	160-250	—	—	60-170	100-125	—	100-380
Yields potable water to wells	—	—	—	—	—	Yes	No	—	—	—	No	—	No
Cheyenne Sandstone	*	*	*	*	*	*	*	*	*	*	*	—	*
Thickness	—	0-120	—	—	—	—	20-300	—	—	50-220	25-100	—	33-300
Yields potable water to wells	Yes	Yes	—	Yes	—	Yes	No	Yes	No	No	No	—	No
UPPER JURASSIC	*	*	*	*	*	*	—	*	*	—	—	—	—
Thickness	50-350	0-130	100-200	0-200	130-230	0-160	—	130-230	0-200	—	—	—	—
Yield	30-300	—	—	—	—	—	—	30-300	—	—	—	—	—
UPPER PERMIAN	—	—	—	—	—	—	—	—	—	—	—	—	—
Thickness	200-500	160	500	—	350-500	200-400	—	350-500	—	—	600-700	—	—
Yields potable water to wells	No	No	No	—	No	No	No	No	—	—	—	—	—
"SANDSTONE AQUIFER"													
Depth to top of aquifer	300-800	70-500	—	600-1,500	0-800	300-600	100-350	0-700	530-1,060	100-700	80-530	300-1,000	100-2,600
Thickness, including interbedded shale	300-650	450	400-600	400-550	350-500	0-400	—	350-500	430-710	260-690	70-500	150-250	0-850
Yield	30-1,000	500-1,000	1,000	30-300	10-400	30-1,000	100-2,200	30-300	30-300	20-800	5-500	—	100-2,000

TABLE 2—Generalized section of geologic formations and their hydrologic characteristics (classification and nomenclature used in this report are those of the Kansas Geological Survey and differ somewhat from those of the U.S. Geological Survey).

SYSTEM	SERIES	FORMATION	MEMBER	RANGE OF THICKNESS (FEET)	PHYSICAL CHARACTER	WATER SUPPLY
QUATERNARY	PLEISTOCENE		Loess and dune sand	0–100	Silt and fine sand, mostly eolian. Mantles most of the uplands and masks much of the valley walls.	Most of the deposits are above the water table. Locally aquifer yields from 5 to 10 gal/min to wells.
			Alluvium	0–80	Stream-laid deposits ranging from sand and gravel to silt and clay. Occurs along principal stream valleys.	Generally above the water table. Locally aquifer yields from 10 to 500 gal/min to wells.
			Undifferentiated deposits	0–200	Sand and medium to very coarse gravel, interbedded with clay, silt, fine sand, and caliche.	Principal unconsolidated aquifer in central Scott County. Yields ranged from 250 to 1,500 gal/min to irrigation wells.
TERTIARY	MIOCENE—PLIOCENE	Ogallala Formation		0–350	Sand, gravel, silt, clay, and caliche, commonly unconsolidated. Locally cemented by calcium carbonate (lime) or silica (opal) into mortar beds. Contains freshwater limestone beds.	Principal unconsolidated aquifer in most of study area. Aquifer yields from 100 to 2,500 gal/min to irrigation wells.
CRETACEOUS	UPPER	Niobrara Chalk	Smoky Hill Chalk	0–700	Chalk and chalky shale, gray to yellow, with interbedded shale. Limonitic concretions.	Consolidated aquifer, but not known to yield significant amounts of water to wells in most areas. In southwestern Scott County, where rocks have been fractured, the aquifer yields as much as 1,000 gal/min to wells. In Finney County, where solution cavities are present, the aquifer yields as much as 800 gal/min.
			Fort Hays Limestone	0–65	Limestone, chalky, white and yellow to gray, with chalky light- to dark-gray shale beds.	
		Carlile Shale	Codell Sandstone	0–25	Sandstone, fine-grained, silty. Locally shaly.	Sandstone aquifer that may yield 5–10 gal/min in a few areas.
			Blue Hill Shale	0–200	Shale, clayey, blocky to fissile, dark-gray.	Not known to yield significant amounts of water to wells. In a few areas, the Greenhorn Limestone may yield 5–10 gal/min to wells. Generally considered a confining layer in most of study area.
			Fairport Chalk	0–150	Shale, chalky, bluish-gray to gray, with chalky limestone and thin bentonite beds throughout member.	
		Greenhorn Limestone		0–135	Limestone, chalky, light- to dark-gray, and yellowish-gray to light-gray shale.	
		Graneros Shale		0–65	Shale, calcareous, dark-gray; interbedded with noncalcareous black shale, gray limestone, and silty fine-grained sandstone.	
	LOWER	Dakota Formation		0–580	Sandstone, fine- to medium-grained, white, gray, and brown; interbedded with shale and siltstone. Contains lignite.	Principal sandstone aquifer in study area; yields 30–2,200 gal/min to wells. The Kiowa Formation is generally considered a confining layer in the study area. Water from wells in Cheyenne aquifer may not be potable in some areas. Untested in many places.
		Kiowa Formation		0–190	Shale, light-gray to black, with interbedded thin limestone beds and, locally, sandstones.	
		Cheyenne Sandstone		0–245	Sandstone, very fine to medium-grained, mostly fine-grained, white, brown, and gray, with interbedded dark-gray shale.	
JURASSIC	UPPER	Undifferentiated rocks		0–247	Shale, sandy, calcareous, green, with noncalcareous gray shale, limestone lenses, and fine-grained silty sandstone.	
PERMIAN	UPPER	Big Basin ("Taloga") Formation		0–45	Shale, silty, red, with siltstone, dolomite, and very fine grained feldspathic sandstone.	Sandstone aquifer, but not known to yield potable water to wells. Untested in many places.
		Day Creek Dolomite		0–3	Dolomite, light-gray to pink, dense.	May yield potable water to wells in isolated areas. Untested in many places.
		Whitehorse Formation		0–270	Sandstone, siltstone, and feldspathic red shale. Minor amount of dolomite.	Sandstone aquifer, but not known to yield potable water to wells. Untested in many places.

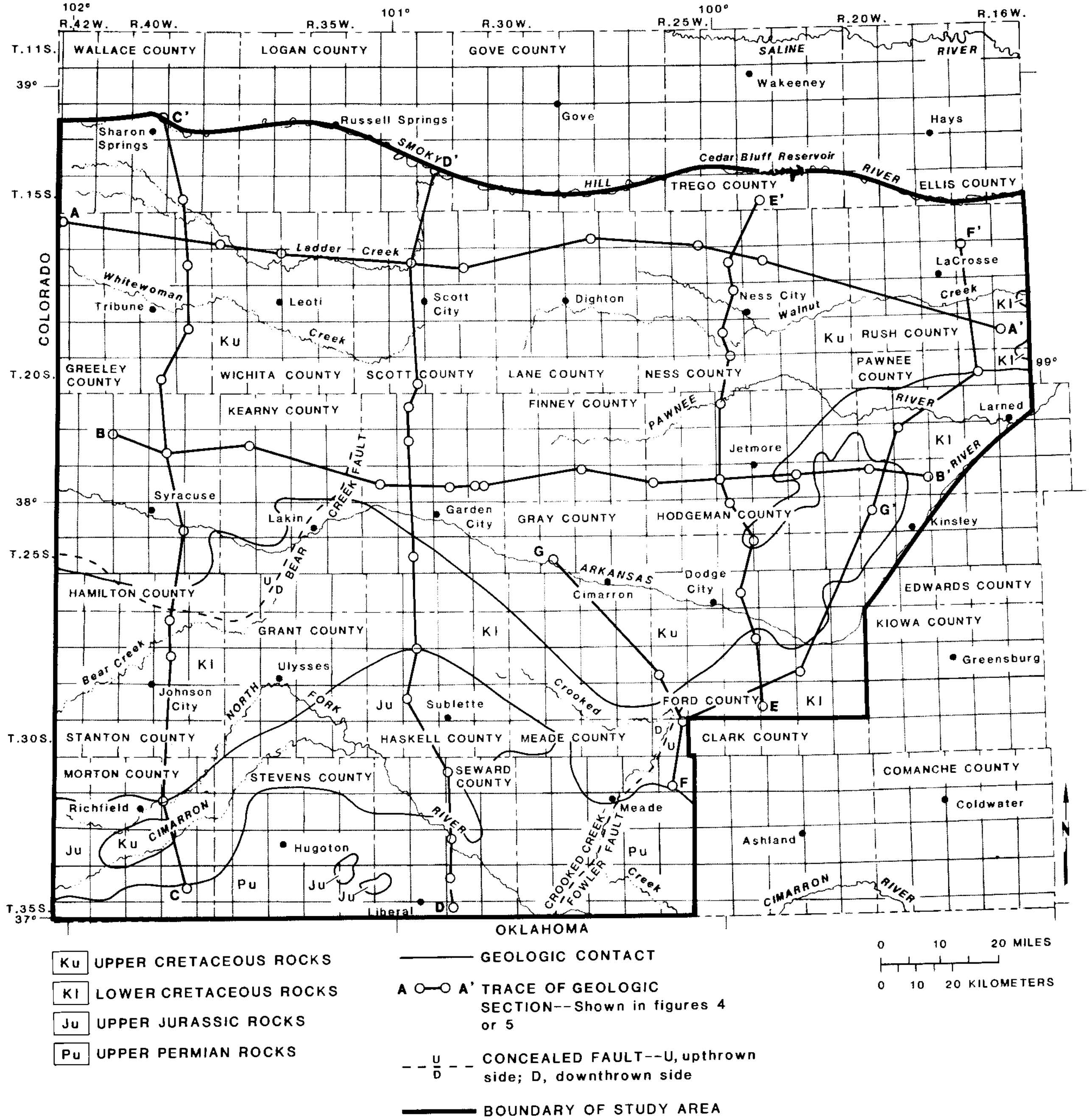


Figure 3—Geology of the pre-Ogallala (Pliocene and Miocene) bedrock surface, southwestern Kansas.

Geologic sections

Geologic sections show the correlation, stratigraphic position, and structure of various formations. Gamma-gamma, neutron, and spontaneous-potential logs, obtained from oil- and gas-exploration tests, were used in the construction of geologic sections A-A' to E-E' (fig. 4). Geologic detail between geophysical logs was transferred from structure maps introduced in later sections of this report.

Some notable geologic features are seen on these geologic sections. In some localities, sections display large differences in formation thicknesses within a few miles. In section C-C', the trace of Bear Creek fault and the approximate amount of bed displacement are shown. The upthrown block is on the north side of the fault. Rocks of Late Jurassic age are shown in geologic sections A-A' through D-D' (fig. 4), and their eastern limit is shown in sections A-A', B-B', and D-D'. At the southern ends of sections C-C' and D-D', the limit of Lower Cretaceous rocks is shown. At this location, the formations have a moderate dip toward the north into the Anadarko Basin (Merriam, 1963). At the southern end of section E-E', the formations appear as synclines and anticlines.

Geologic sections F–F' and G–G' (fig. 5) are based on test drilling conducted in six counties along the eastern border of the study area during this investigation. Formation tops of Permian and Cretaceous rocks and Tertiary and Quaternary deposits were determined from lithologic sample logs (listed in table 7 at the end of this report) and from borehole geophysical logs measuring resistivity, spontaneous potential, and natural gamma-ray response in the test holes.

Sections F–F' and G–G' reflect some of the major structural features that have affected geologic formations from Permian to Tertiary age. The structural depression, as seen on section F–F' in Ford, Edwards, and Pawnee counties, represents part of the Dodge City Basin (also called the Hugoton embayment of the Anadarko Basin; Merriam, 1963). The steep slope of the formations marks the boundary of an adjacent upland in Edwards, Pawnee, and Rush counties that is part of the Central Kansas Uplift (Merriam, 1963). In Rush and Pawnee counties, the Greenhorn Limestone and Carlile Shale have been truncated to the west of the uplift; also, the Ogallala Formation is very thin here. In section G–G', the Crooked Creek–Fowler fault, a normal, tension-type fault, is shown in Ford and Meade counties. Displacement of beds of Permian to Tertiary age is shown. The thickness of the Cretaceous formations on the east side of the fault (upthrown side) is markedly thinner than that on the west side (downthrown side), indicating that the fault was active during the period of Cretaceous deposition. The Big Basin and the Whitehorse formations are shown in geologic sections F–F' and G–G' (fig. 5). The contact between these two formations was determined approximately in the cross section and is shown by dashed lines.

Upper Permian Series

Rocks of Permian age crop out in Meade County and occur in the subsurface throughout the study area. They underlie and are in direct contact with rocks of Jurassic and Cretaceous age and deposits of Tertiary and Quaternary age. Permian formations containing sandstones that immediately underlie Jurassic and Cretaceous rocks are the Whitehorse Formation in the northeastern part of the study area and the Big Basin Formation in the southwestern part of the area (Merriam, 1963). In Morton, Stevens, Seward, and Meade counties, the Big Basin Formation immediately underlies rocks of Tertiary age or deposits of Quaternary age in the area where rocks of Jurassic and Cretaceous age are not present.

The lithology of Permian rocks in Kansas consists of red feldspathic clastic sediments (sandstone, siltstone, and shale), evaporite deposits (gypsum, anhydrite, and salt), limestone, and dolomite (Zeller, 1968). In the study area sandstone units consist of alternating lithologies of reddish-brown clay, shale, and siltstone that are thinly interbedded. The sandstones are commonly very fine grained.

The Whitehorse Formation consists of red fine-grained feldspathic sandstone, coarse-grained siltstone, clay, and shale with a minor amount of dolomite. The Big Basin ("Taloga") Formation consists of red silty shale, siltstone, and dolomitic siltstone. Locally, the formation may contain some fine-grained sandstone.

The depth below land surface to the top of the Permian rocks ranges from zero at the outcrop in Meade County and increases northwestwardly to about 2,100 ft in Wallace County (Kume and Spinazola, 1983). The altitude of the top of the Permian surface ranges from just below 1,300 ft in northwestern Rush County to approximately 3,400 ft in Morton County (fig. 6). The surface is quite irregular and dissected, but it dips to the northeast at approximately 19 ft/mi from Morton to Finney counties and approximately 8 ft/mi from Finney to Rush counties. Two prominent faults are shown in fig. 6 (sheet 1). The Bear Creek fault occurs in Hamilton, Kearny, Stanton, and Grant counties, and the Crooked Creek–Fowler fault complex occurs in Meade and Ford counties.

Upper Jurassic Series

Rocks of Late Jurassic age crop out in Morton County and occur in the subsurface in the western half of the study area. The rocks underlie and are in direct contact with rocks of Cretaceous and Tertiary age. Although rocks of Jurassic age are undifferentiated in this report, the Morrison Formation is discernible in the lithologic logs of some wells (Kume and Spinazola, 1982, p. 25–88).

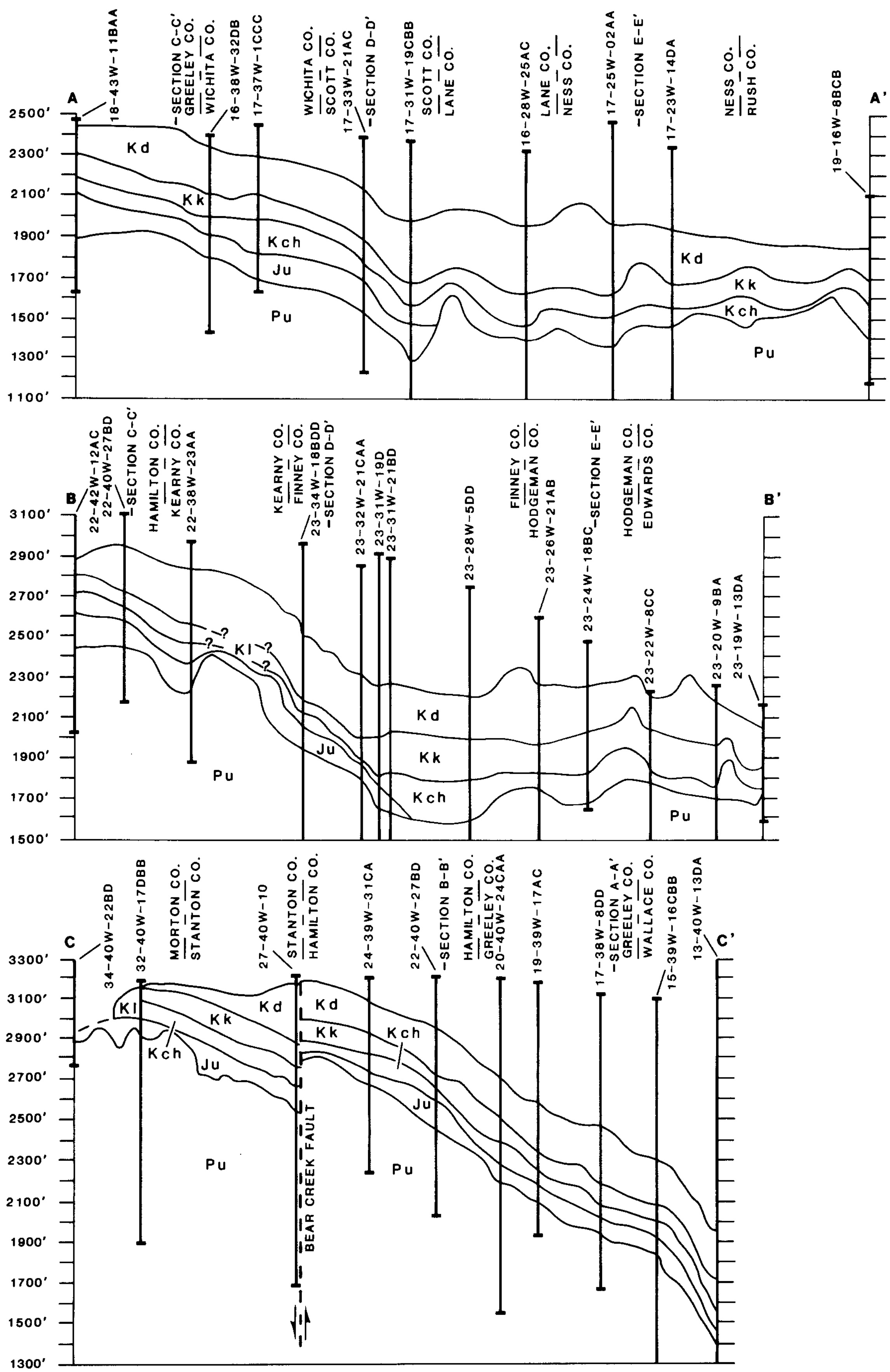
Rocks of Jurassic age in Kansas consist of varicolored shales and red sandstones (Zeller, 1968). Sand, siltstone, and shale were logged in the drill cuttings examined in well 21–35W–09DA, an oil and gas test in Kearny County (Kume and Spinazola, 1982, p. 57). The Morrison Formation in Kansas consists of green sandy shale containing limestone lenses and shales containing chert, anhydrite, and gypsum (Zeller, 1968).

The depth below land surface to the top of the Upper Jurassic rocks ranges from 0 at the outcrop in southwestern Morton County, to approximately 2,000 ft in Wallace County (Kume and Spinazola, 1983). The increase in depth is not uniform. About one-half of the subsurface occurrence of Jurassic rocks in the southwestern part of the study area is less than 600 ft deep.

The top of Upper Jurassic rocks ranges in altitude from just over 1,400 ft in Logan County to approximately 3,500 ft in Morton County (fig. 7, sheet 1). In general, the altitude increases uniformly except near the southwestern corner of the area and along the Bear Creek fault where considerable bed disruption and displacement have occurred.

The thickness of rocks of Late Jurassic age ranges from 0 ft along the eastern limit to a maximum of approximately 250 ft in northwestern Scott County and averages 103 ft. Thickness changes considerably within short distances, and thicknesses of more than 200 ft occur at several scattered sites in Scott, Greeley, Morton, and Stanton counties (Kume and Spinazola, 1983).

The sandstone beds in rocks of Late Jurassic age range in thickness from 0 ft at several scattered locations and along the eastern limit to approximately 50 ft at several sites in Grant, Hamilton, Kearny, Morton, and Stanton counties (fig. 8, sheet 1). The average thickness of the sandstone beds is 24 ft. Sandstone beds may be continuous locally but, because of their lenticular nature, exhibit little regional continuity or uniform thickness in the study area.



A
A'
18-43W-11BAA
SECTION C-C'
GREELEY CO.
WICHITA CO.
16-38W-32DB
17-37W-1CCC
WICHITA CO.
SCOTT CO.
17-33W-21AC
SECTION D-D'
17-31W-19CBB
SCOTT CO.
LANE CO.
16-28W-25AC
LANE CO.
NESS CO.
17-25W-02AA
SECTION E-E'
17-23W-14DA
NESS CO.
RUSH CO.
19-16W-8BCB
2500'
2300'
2100'
1900'
1700'
1500'
1300'
1100'
Kd
Kk
Kch
Ju
Pu
B
B'
22-42W-12AC
22-40W-27BD
SECTION C-C'
HAMILTON CO.
KEARNY CO.
22-38W-23AA
KEARNY CO.
FINNEY CO.
23-34W-18BDD
SECTION D-D'
23-32W-21CAA
23-31W-19D
23-31W-21BD
23-28W-5DD
FINNEY CO.
HODGEMAN CO.
23-26W-21AB
23-24W-18BC
SECTION E-E'
HODGEMAN CO.
EDWARDS CO.
23-22W-8CC
23-20W-9BA
23-19W-13DA
3100'
2900'
2700'
2500'
2300'
2100'
1900'
1700'
1500'
Kl
?
Kd
Kk
Kch
Ju
Pu
C
C'
34-40W-22BD
32-40W-17DBB
MORTON CO.
STANTON CO.
27-40W-10
STANTON CO.
HAMILTON CO.
24-39W-31CA
22-40W-27BD
SECTION B-B'
HAMILTON CO.
GREELEY CO.
20-40W-24CAA
19-39W-17AC
17-38W-8DD
SECTION A-A'
GREELEY CO.
WALLACE CO.
15-39W-16CBB
13-40W-13DA
3300'
3100'
2900'
2700'
2500'
2300'
2100'
1900'
1700'
1500'
1300'
Kl
Kd
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Pu
BEAR CREEK FAULT

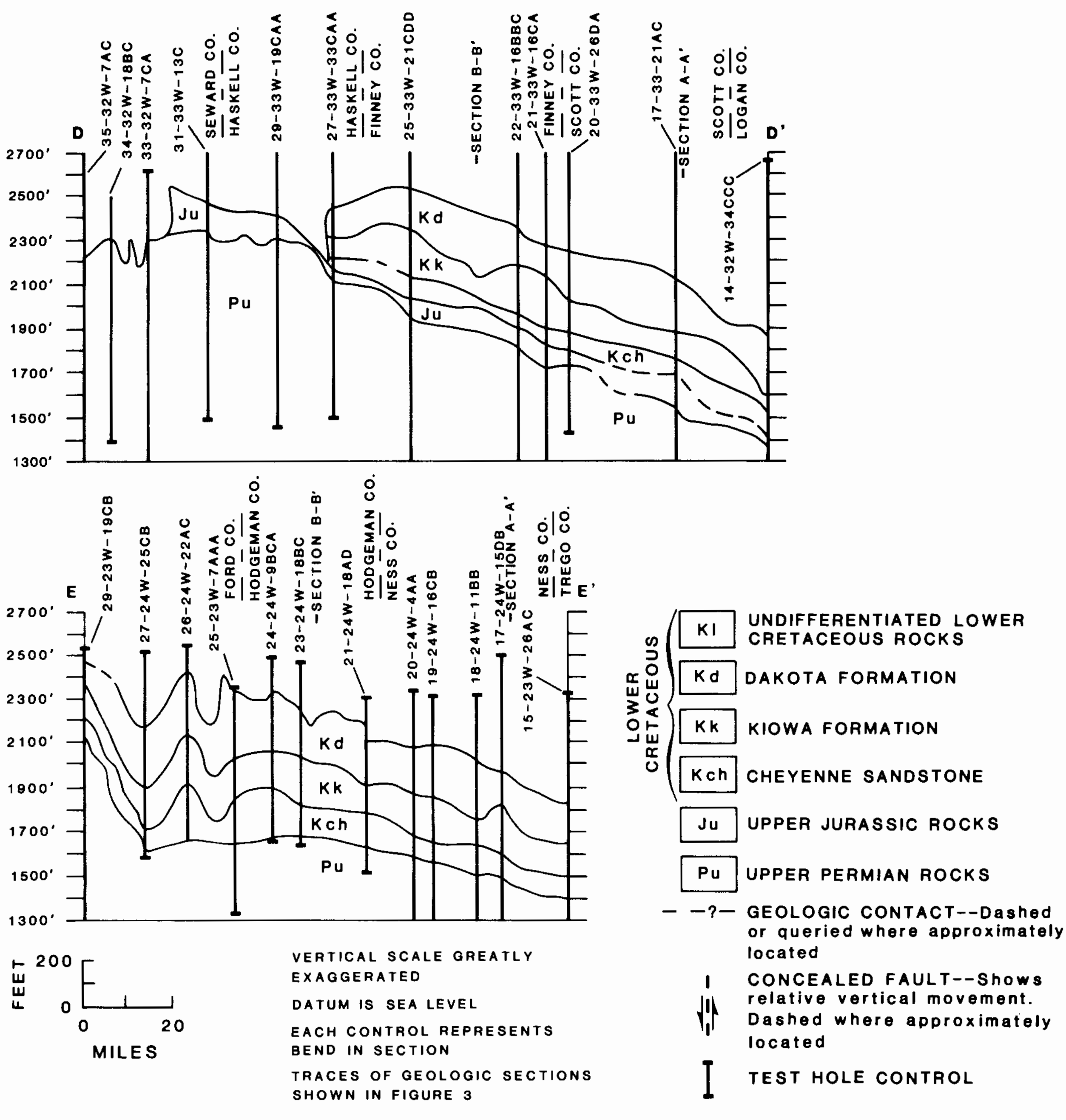


Figure 4—Geologic sections constructed from information obtained from oil- and gas-exploration tests.

Lower Cretaceous Series

Rocks of Early Cretaceous age crop out in Ford, Hamilton, Hodgeman, Kearny, Pawnee, and Stanton counties. The Lower Cretaceous Series is composed of the Cheyenne Sandstone, the Kiowa Formation, and the Dakota Formation. In Kansas these formations consist of interbedded shales, siltstones, and sandstones. The oldest Cretaceous rocks are of a nonmarine and littoral origin, laid down in advance of an encroaching sea. Next, brackish marine sediments were deposited, followed by marine shales and sandstones. Parts of the Cheyenne Sandstone and Dakota Formation are of nonmarine origin (Zeller, 1968).

Lower Cretaceous formations were not differentiated in five local areas in Finney, Grant, Gray, Haskell, Hodgeman, Kearny, Morton, Scott, Stanton, and Wichita counties. In these areas, the geophysical logs examined show no discernible characteristics to distinguish the individual formations from one another.

Cheyenne Sandstone—The Cheyenne Sandstone in Kansas consists of white, buff, and light-gray fine-grained sandstones and gray sandy shales (Zeller, 1968). Based on lithologic samples from test holes, the Cheyenne Sandstone in the study area consists of shale, siltstone, clay, and sandstone. The sandstone is very fine grained, friable to cemented, white to light-gray, silty, shaly, and thin bedded, with minor amounts of carbonaceous material. In the study area, the Cheyenne Sandstone consists mostly of clay or shale, and sandstone beds tend to be local and discontinuous.

The depth below land surface to the top of the Cheyenne Sandstone ranges from approximately 150 ft in northern Morton County to approximately 1,950 ft in Wallace County. The depth increases toward the northwestern corner of the area in an irregular manner (Kume and Spinazola, 1983).

The altitude of the top of the Cheyenne Sandstone ranges from just over 1,400 ft in Gove County to approximately 3,400 ft in Stanton and Morton counties (fig. 9, sheet 1). The surface has been disrupted by the Bear Creek fault, and a depression occurs in Ford County.

The thickness of the Cheyenne Sandstone ranges from approximately 20 ft in Pawnee County to a maximum of 245 ft in Ford County and averages 91 ft (Kume and Spinazola, 1983). In northwestern Lane County, drill cuttings from test wells show that the Cheyenne is about 230 ft thick. The Cheyenne Sandstone was not differentiated from the Kiowa or Dakota formations in several local areas in Finney, Grant, Gray, Haskell, Hodgeman, Kearny, Morton, Scott, Stanton, and Wichita counties because the logged section was mostly shale. The thickness of the sandstone beds in the Cheyenne ranges from 0 in southeastern Wallace County, northeastern Finney County, and along the limit of the Cheyenne Sandstone to 190 ft in southwestern Hodgeman County and averages 37 ft (fig. 10, sheet 2). In southeastern Rush County drill cuttings from test wells show that the sandstone beds in the Cheyenne are about 165 ft thick.

Kiowa Formation—The Kiowa Formation in Kansas consists of light-gray to black illitic shale. Locally, it contains coquinoidal limestone beds and sandstone lenses. Sandstone lenses are most abundant in central and southwestern Kansas (Zeller, 1968).

The lithology of the Kiowa Formation, based on drill cuttings from nine test-hole sites in the study area, consists of shale, clay, and siltstone, with lesser amounts of limestone and sandstone. The shales and siltstones generally are dark gray to black but are occasionally varicolored. A 1-ft-thick limestone bed occurs near the base of the Kiowa Formation. The sandstone is very lenticular, thin bedded, and fine grained. No sandstone was logged from the Kiowa Formation at several of the drilling sites. The Kiowa Formation is considered to be a confining bed.

The thickness of the Kiowa Formation ranges from approximately 30 to 190 ft in test holes. Sandstone, where it occurs in the formation, ranges in thickness from 10 to 35 ft, based on geophysical logs. The sandstone is best developed in Gove, Lane, Ness, Rush, and Trego counties (Kume and Spinazola, 1982).

The altitude of the top of the Kiowa Formation ranges from approximately 1,600 ft in the counties along the northern boundary of the study area to approximately 3,500 ft in Morton County (fig. 11, sheet 2). The slope of the surface is fairly regular in the western part of the study area but irregular elsewhere.

Dakota Formation—The Dakota Formation in Kansas is composed of claystone, mudstone, shale, siltstone, and sandstone. The varicolored sediments are white, gray, red, brown, and tan and contain carbonaceous material and lignite (Zeller, 1968). The Dakota Formation crops out in Ford, Hamilton, Hodgeman, Kearny, Pawnee, and Stanton counties.

The Dakota Formation, as indicated by lithologic samples in test holes drilled for this study, consists of interbedded shale, clay, and sandstone, with minor amounts of siltstone and lignite. The sediments vary in color from light to dark gray, red to reddish brown or orange, pink, yellow, buff, tan, and brown. The sandstones are mostly very fine to fine grained but locally are medium to coarse grained. They are friable to cemented, clean to clayey, silty, or shaly. Generally the sandstone beds are lenticular. However, upper and lower sandstone beds in the formation persist throughout most of the area.

The depth to the top of the Dakota Formation and undifferentiated Lower Cretaceous rocks ranges from 0 at the outcrop to approximately 1,650 ft in southwestern Wallace County. Generally, the depth changes markedly over relatively short distances in many areas, except in the northwestern part of the study area (Kume and Spinazola, 1983).

The altitude of the top of the Dakota Formation or the undifferentiated Lower Cretaceous rocks ranges from just less than 1,800 ft in southeastern Trego County to approximately 3,600 ft in southwestern Stanton County (fig. 12, sheet 2). The surface is disrupted by Bear Creek and Crooked Creek–Fowler faults. A noticeable depression of unknown cause also occurs in northern Ford County.

The thickness of the Dakota Formation ranges from approximately 60 ft in northwestern Rush County to about 460 ft in northwestern Ness County and averages 218 ft. Generally, the thickness of the Dakota is not uniform, and locally it may be markedly thicker or thinner than the average thickness (Kume and Spinazola, 1983).

The thickness of the sandstone beds in the Dakota Formation and undifferentiated Lower Cretaceous rocks ranges from 0 in several scattered areas in Finney, Ford, and Kearny counties and along the limit of the Dakota Formation to 150 ft in southwestern Hodgeman County (fig. 13, sheet 2). The sandstone beds average 58 ft in thickness. The thickness is not uniform throughout the study area, and large differences may occur in some areas within a distance of only a few miles. For example, in western Hodgeman County, the thickness varies from 20 to 150 ft in 8 mi.

The presence and thickness of sandstone beds in the Dakota Formation had no relationship to the total thickness of the Dakota Formaiton, based on logs from test wells drilled in the study area. At a drilling site in Rush County almost no sandstone was reported. In contrast, at a drilling site in Ford County 168 ft of sandstone occurred in the Dakota Formation, with 121 ft of the sandstone occurring in a continuous sequence of sandstone beds. At another site in Ford County, the sandstone beds ranged from 1 to 4 ft in thickness and were interbedded with shale throughout an interval of 91 ft.

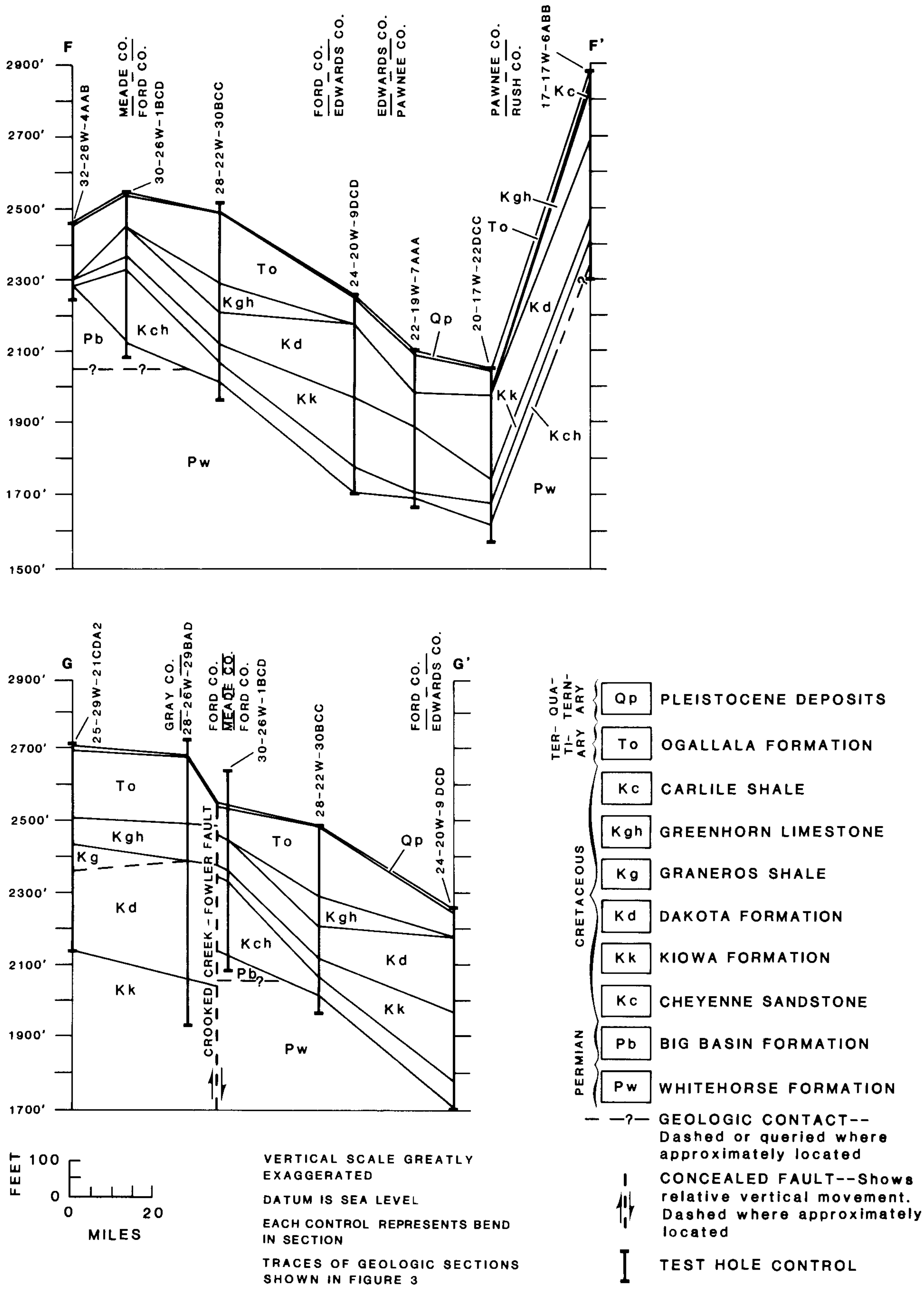


Figure 5—Geologic sections constructed from information obtained from test drilling conducted during this investigation.

Upper Cretaceous Series

The rocks of the Upper Cretaceous Series in Kansas are composed of marine shales and limestones. The formations in this series include the Graneros Shale, the Greenhorn Limestone, the Carlile Shale, and the Niobrara Chalk. The Codell Sandstone Member of the Carlile Shale is the only sandstone unit in the Upper Cretaceous Series and is generally very thin and discontinuous (Zeller, 1968). The Graneros Shale, Greenhorn Limestone, and Carlile Shale truncate and are not present at several of the test-drilling sites.

CODELL SANDSTONE MEMBER OF THE CARLILE SHALE—The Codell Sandstone Member occurs in Ellis, Gove, Ness, Rush, and Trego counties and crops out in northwestern Rush County (McNellis, 1973). In Kansas it is a fine- to very fine grained sandstone that occurs in the upper part of the Carlile Shale. The Codell Sandstone Member has only local significance, with a maximum thickness of approximately 25 ft in northern Ellis County, and thins to 0 in the northeast and south (Zeller, 1968).

Hydrology

The hydrology described in this section includes thickness of the aquifers, properties of the aquifers, water levels in wells, potentiometric surfaces of the aquifers, recharge, and chemical quality of water. Aquifers in rocks of Permian and Late Jurassic age were considered undifferentiated regarding hydrology for most purposes in this report because of the scant data. In some cases, however, limited data exist on specific aquifers. These cases are noted when they appear in following sections. Aquifers in rocks of Cretaceous age in the Cheyenne Sandstone, Kiowa Formation, Dakota Formation, and Codell Sandstone Member of the Carlile Shale were differentiated and are described separately. A hydraulic connection may exist locally between adjacent aquifers, but confining beds separate aquifers in most of the study area.

Aquifer thickness

Aquifer thicknesses, based on sandstone content, should provide a more accurate appraisal of the potential for water-resources development than the broad grouping of entire formations into an undifferentiated "sandstone aquifer" or single geohydrologic unit, as done in previous studies (see table 1). The thickness of a sandstone aquifer given in this report includes the saturated portions, or effective thickness, of the principal water-yielding rocks. However, in many instances, as shown by the test drilling, thinly bedded sandstones are interbedded with thin shales or clay layers. In these instances it was not practical to separate the shale or clay from the sandstone in determining the thickness of the aquifer, although an attempt generally was made to distinguish the thickest sandstone beds. Therefore, segments of the stratigraphic intervals were considered as being beds of either sandstone or shale, even though some thin interbedding of each undoubtedly exists. Average thickness is the average of the values for thickness at the control points where data are available in the study area and where the aquifers occur.

Sandstone thicknesses are shown for Upper Jurassic rocks, the Cheyenne Sandstone, and the Dakota Formation (figs. 8, 10, and 13; sheets 1 and 2), based on interpretation of geophysical logs. The sandstone thicknesses are, for all practical purposes, equivalent to the aquifer thicknesses because the aquifers are under artesian or confined conditions, except in local outcrop areas where the aquifers in Upper Jurassic rocks and the Dakota Formation are under water-table conditions.

Aquifer properties

The storage and movement of water in an aquifer are defined by the physical properties of the aquifer. The volume of water an aquifer is capable of storing is expressed by the storage coefficient and is primarily a function of its porosity. If a hydraulic gradient exists in the aquifer, water will flow through it at a rate governed by the gradient and the lithologic characteristics of the aquifer medium, such as the size and sorting of sand grains, the amount of silt or clay present, and the aquifer thickness. The transmissivity range is from 940 to 7,100 ft^2/d for aquifers in the Dakota Formation (table 3). The range for the aquifer storage coefficient in the Dakota is from 0.0004 to 0.07, representing confined to unconfined conditions, respectively. In Finney County, the aquifer in the Dakota Formation at well 24–33W–19DBD has an average transmissivity of 940 ft^2/d, a storage coefficient of about 0.0004, and an average porosity of 16–18% (Burns and McDonnell, 1977). Data are not available for the other sandstone aquifers. However, information is available for several wells completed in more than one aquifer and is included in table 3. The maximum yield of wells discharging from aquifers in the Dakota Formation and in Ogallala and Pleistocene deposits is 1,200 gal/min. Yields from aquifers in the Dakota Formation in Ford County range from a few gallons per minute to 2,200 gal/min (Lobmeyer and Weakly, 1979). The sandstone aquifers are confined, except in outcrop areas where water-table conditions prevail.

Water-level hydrographs

Hydrographs in this report show water-level fluctuations in observation wells in aquifers in rocks of Late Jurassic and Cretaceous age. The hydrographs of water levels in wells completed in aquifers in rocks of Late Jurassic and Early Cretaceous age are shown in fig. 14. The Upper Jurassic rocks and Cheyenne Sandstone are considered by Fader and others (1964) to be a single hydrologic unit in Grant and Stanton counties because these rock units

TABLE 3—Summary of aquifer properties.

County	Location	Date	Aquifer	Sandstone thickness (ft)	Well depth (ft)	Water level (ft)	Discharge (gal/min) Yield	Discharge (gal/min) Test average	Test duration (min)	Drawdown (ft)	Specific capacity (gal/min/ft of drawdown)	Hydraulic conductivity (ft/d)	Storage coefficient (dimensionless)	Transmissivity (ft^2/d)	Reference (reported by)
Finney	24-33W-19DBD	1977	Dakota	196	714	71	790	600	10,080	117	7.6	4.8	0.0004	940	Burns and McDonnell, 1977
Finney	24-33W-19DBA	1977	Dakota	128	714	90	—	—	10,080	25	—	9.7	.001	1,240	Burns and McDonnell, 1977
Finney	24-34W-3A	1977	Dakota	100	680	114	—	550	2,460	100	5.5	—	—	—	Henkle Drilling Co. (test pump analysis)
Hamilton	north of Arkansas River	1974	Jurassic and Lower Cretaceous	—	—	—	—	—	—	—	—	0.1	.0001	50	Lobmeyer and Sauer, 1974
Hamilton	south of Arkansas River	1974	Jurassic and Lower Cretaceous	—	—	—	—	—	—	—	—	.5	.0001	250	Lobmeyer and Sauer, 1974
Hamilton	25-42W-34CBB	1975	Dakota	100	332	175	—	900	—	69	8.8	—	—	—	Henkle Drilling Co.
Hodgeman	25-23W-35DDB	1969	Dakota	175	320	142	—	950	12,960	44	21.6	41	.07	7,100	Lobmeyer and Weakly, 1979
Hodgeman	25-24W-16ADB	1973	Dakota	125	565	261	—	560	7,200	91	6.2	16	.0005	2,000	Lobmeyer and Weakly, 1979
Stanton	27-39W-13AC	1960	Dakota and Cheyenne	—	508	87	900	—	—	—	—	—	—	6,100	Fader and others, 1964
Stanton	30-40W-24CC	1960	Pleistocene, Ogallala, and Dakota	—	295	105	1,200	—	—	—	—	—	.0013	13,000	Fader and others, 1964
Stanton	30-41W-13CC	1960	Ogallala and Dakota	—	235	168	900	—	—	—	—	—	.044	18,300	Fader and others, 1964

have similar hydrologic characteristics and are stratigraphically adjacent to each other. This hydrologic relationship is described or implied in other reports addressing aquifers in rocks of Late Jurassic and Early Cretaceous age in the region (table 1). As a result of that relationship, wells in southwestern Kansas often are screened in both units, making the determination of respective head differences between aquifers in rocks of Late Jurassic and Early Cretaceous age difficult.

From the hydrographs shown in fig. 14, the average decline in water levels between 1959 and 1975 was calculated to be 21 ft. In Hamilton County stock well 25-42W-20ADA, the water level declined approximately 25 ft during 1962–1976. In Morton County irrigation well 31-41W-31CBB, the water level declined about 25 ft during 1967–1979.

The hydrographs of water levels in wells in aquifers in the Dakota Formation and in rocks of undifferentiated Early Cretaceous age are shown in fig. 15. In Finney County, a hydrograph of irrigation well 22-27W-14ADC shows that between 1970 and 1979 the water level declined about 42 ft. In Ford County, hydrographs of wells 25-22W-7AC, 25-23W-4ADD, and 26-22W-18ACA show a water-level decline that was calculated to average 60 ft in these wells between 1969 and 1979. Most of this decline has occurred since 1974. In Hodgeman County, hydrographs of stock well 22-23W-31ADD and irrigation well 23-26W-7CCC were used to calculate a water-level decline that averaged 52 ft in these wells between 1969 and 1979. Most of this decline has occurred since 1974. The large water-level fluctuations seen in the hydrograph of well 22-23W-31ADD reflect the drawdown and recovery effects of pumping. In Morton County, a hydrograph of an unused water-table well 31-43W-14DDC in aquifers in rocks of Early Cretaceous age shows that very little water-level fluctuation has occurred. The short-term fluctuations in the hydrographs are the result of seasonal pumping of nearby wells.

A hydrograph of the water level in well 12-17W-16AAB in the aquifer in the Codell Sandstone Member of the Carlile Shale is shown in fig. 16. This well in Ellis County is an unused water-table well in which the water level has risen about 34 ft between 1955 and 1974. The large and rapid water-level rises that occur in the spring of most years can be attributed to the percolation of precipitation into the aquifer and runoff directly recharging the aquifer in outcrop areas.

Potentiometric surfaces and water-level measurements

Maps of the potentiometric surface of selected aquifers are shown in figs. 17–20. However none of the maps shows the potentiometric surface for the entire study area nor for a single year. Grouping of years was necessary because of limited data available. The maps are based on measurements of water levels in observation wells penetrating the selected aquifers.

The altitude of the potentiometric surface during 1975–79 in aquifers in rocks of undifferentiated Permian

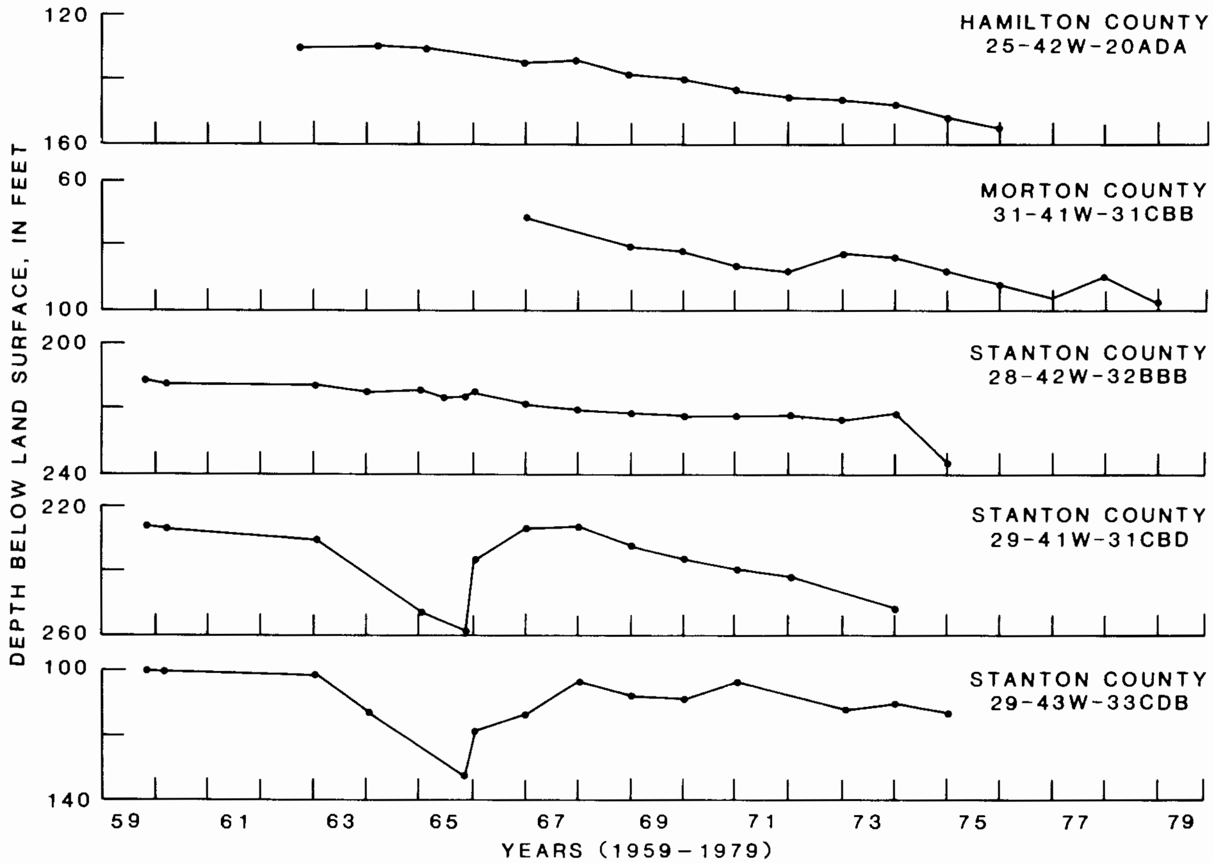


Figure 14—Hydrographs of selected wells in aquifers in rocks of undifferentiated Late Jurassic and Early Cretaceous age.

age in the southeastern part of the area ranged from 2,100 to approximately 2,500 ft (fig. 17). The surface has a hydraulic gradient of about 5 ft/mi or 0.0009 toward the northeast and southeast.

In Ford County, the water level during 1978–79 in observation well 28-22W-30BCC in the aquifer in the Whitehorse Formation ranged from 151.2 to 165.9 ft below land surface. Observation wells 20-17W-22DCC and 22-19W-07AAA2 in Pawnee County are flowing artesian wells in the Whitehorse Formation. The water levels in well 20-17W-22DCC ranged from 32.5 to 35.4 ft above the land surface and in well 22-19W-07AAA2 ranged from 16.6 to 27.3 ft above the land surface during 1978–79. The recorded fluctuations in the water levels in the Whitehorse may be the result of changes in barometric pressure. In Meade County, the water levels during 1978–79 in observation wells in the aquifer in the Big Basin Formation ranged from 118.3 to 125.5 ft below land surface in well 30-26W-01BCD and from 78 to 79.4 ft below land surface in well 32-26W-04AAB.

The altitude of the potentiometric surface during 1975–79 of aquifers in rocks of undifferentiated Late Jurassic and Early Cretaceous age and in Tertiary and Quaternary deposits is shown in fig. 18. Wells in the area shown are completed in more than one aquifer and may be completed in all of the freshwater aquifers present at a given site. The potentiometric surface expressed in these wells represents a common hydraulic head, which ranged from about 2,850 to 3,500 ft in altitude. The hydraulic gradient was about 16 ft/mi or 0.0030 toward the east.

The altitude of the potentiometric surface of the aquifers in the Cheyenne Sandstone during 1978–1981 is shown in fig. 19. The surface ranged from about 3,200 ft in altitude in Hamilton County to about 2,100 ft in Pawnee and Rush counties. The hydraulic gradient was about 8 ft/mi or 0.0015 from west to east (fig. 19).

Upward leakage of ground water from stratigraphically adjacent rocks probably occurs in Pawnee County. Capped observation wells 20-17W-22DCC in the Whitehorse Formation and 20-17W-22DCC2 in the Cheyenne Sandstone are flowing artesian wells and produce briny water when they are uncapped. Similar chemical characteristics of water from these wells suggest a common source of water. Also, the hydraulic head in the Whitehorse Formation is about 5 ft greater than in the Cheyenne Sandstone. A hydraulic connection between formations probably allows the upward movement of water from Permian rocks into the Cretaceous rocks.

In Hamilton County, flowing artesian wells in the Cheyenne Sandstone were reported by Haworth (1913) and McLaughlin (1943) who indicated that flow had decreased by more than 60% by 1943.

Sufficient data are not available for making a potentiometric-surface map of the aquifer in the Kiowa Formation. Depth to water in the aquifer in the Kiowa, as measured in observation well 25-29W-21CDA2 in Gray

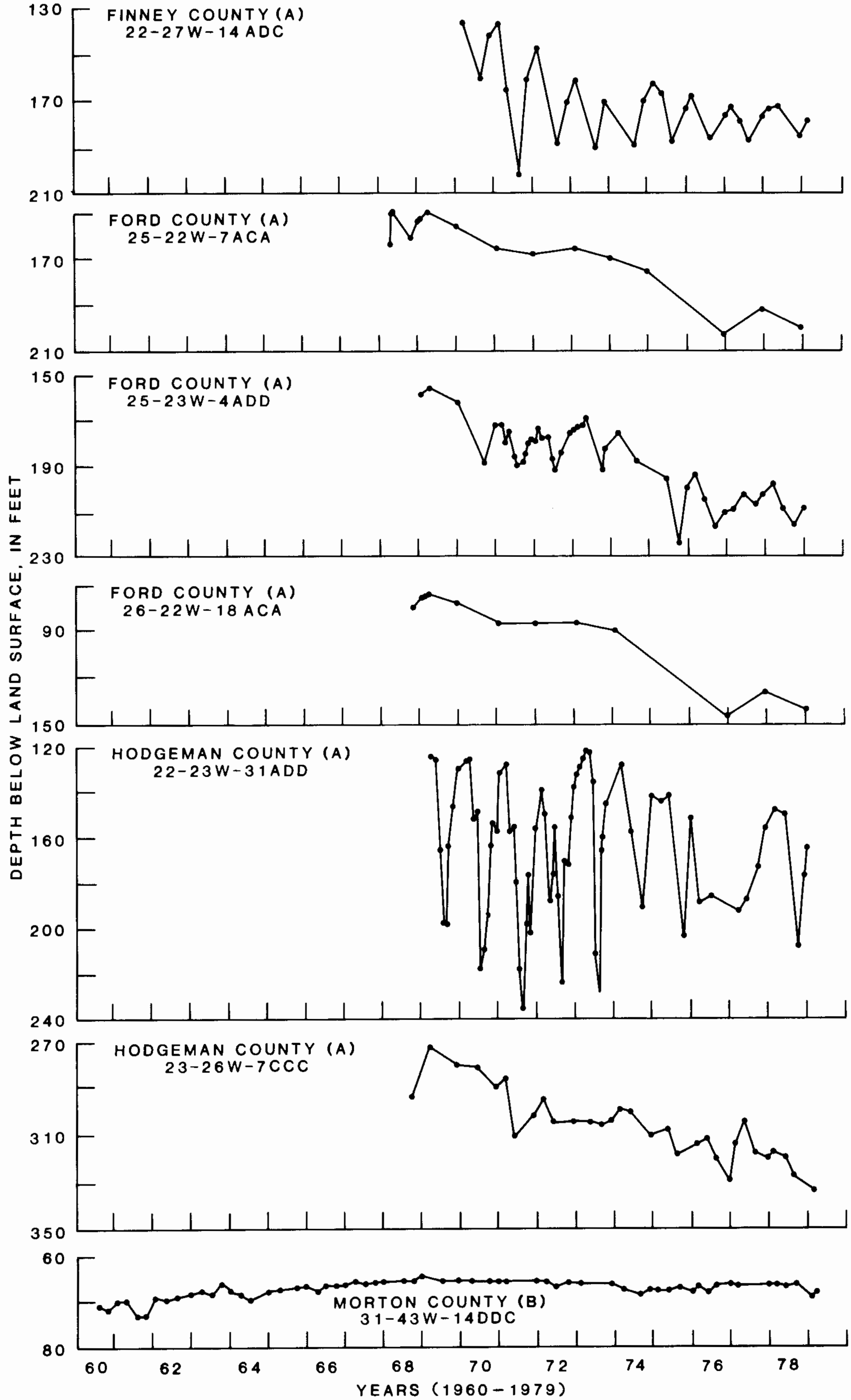


Figure 15—Hydrographs of selected wells in aquifers in the Dakota Formation or in undifferentiated rocks of Early Cretaceous age. **A** indicates that the well is screened in the Dakota Formation, and **B** indicates that the well is screened in undifferentiated rocks of Early Cretaceous age.

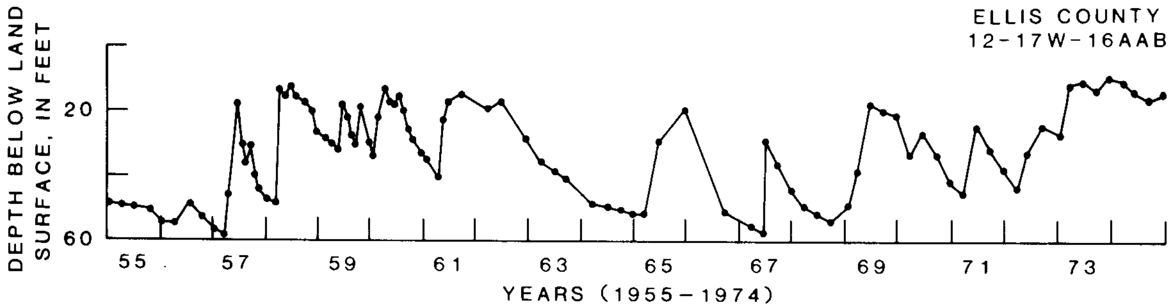


Figure 16—Hydrograph of a selected well in aquifers in the Codell Sandstone Member of the Carlile Shale.

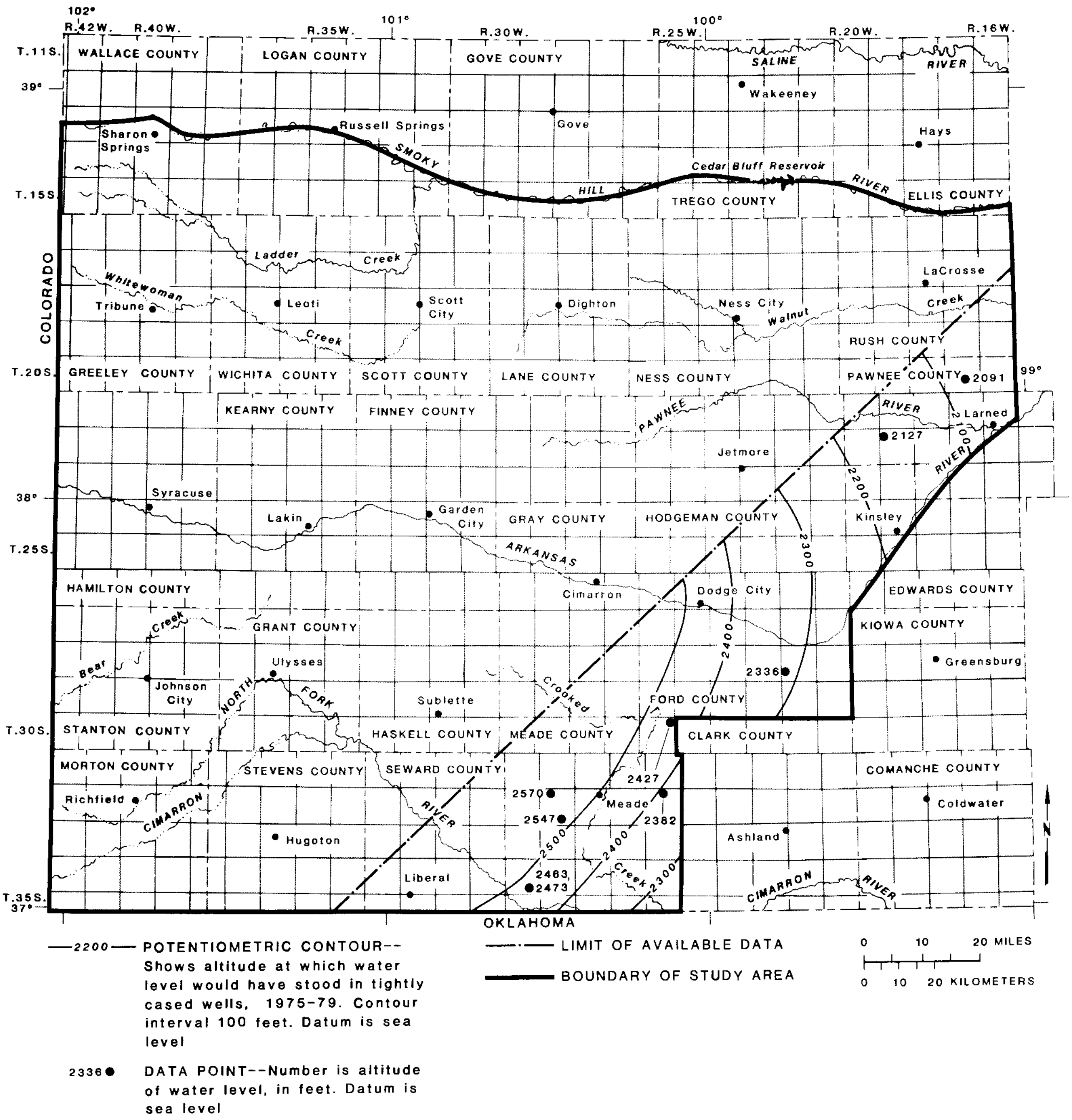


Figure 17—Potentiometric surface of aquifers in rocks of Permian age, 1975-79.

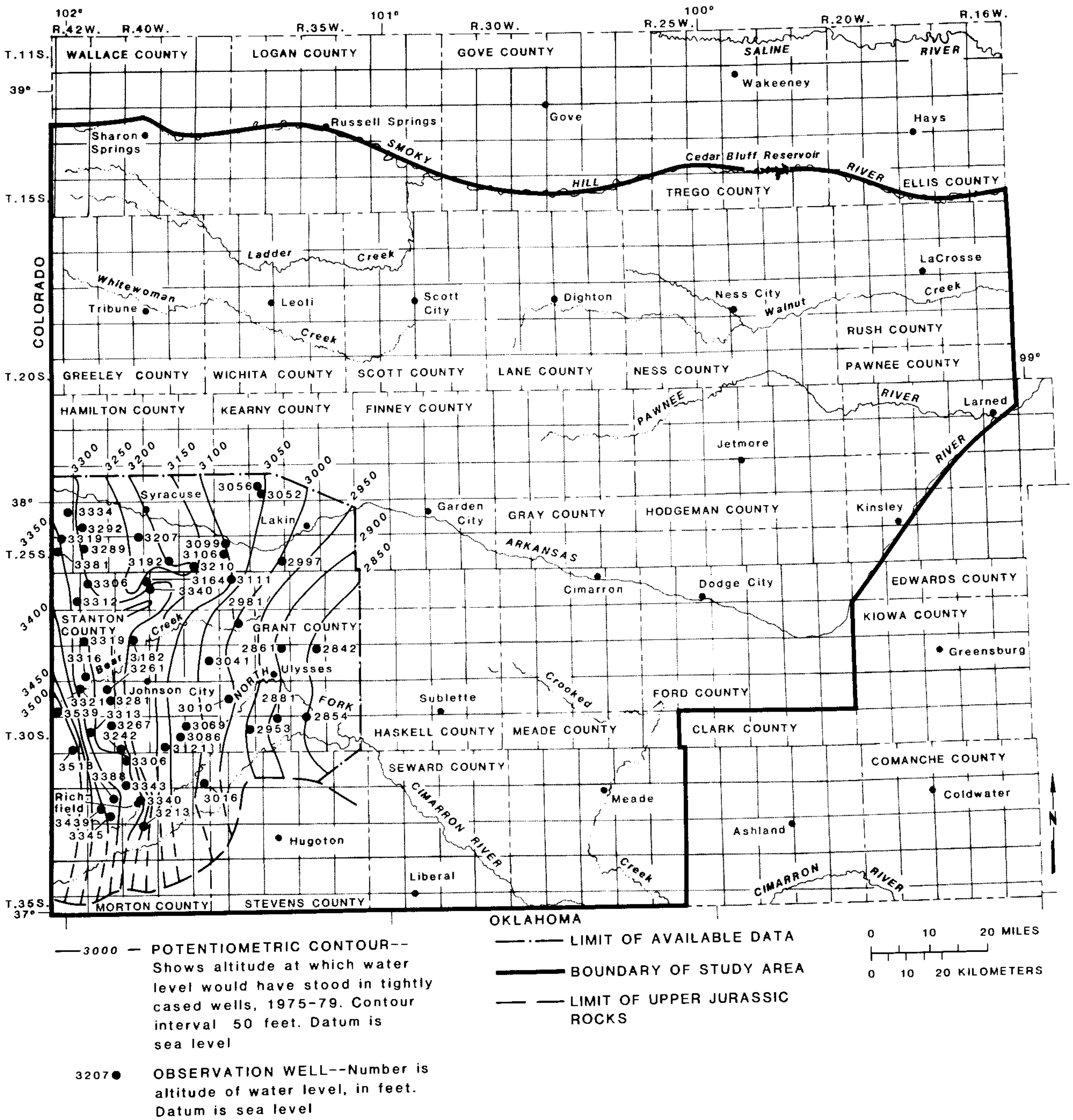


Figure 18—Potentiometric surface of aquifers in rocks of undifferentiated Late Jurassic and Early Cretaceous age and Tertiary and Quaternary deposits, 1975–79.

County, was 168 ft below land surface in 1979. The altitude of this water level is 2,539 ft.

The altitude of the potentiometric surface of the aquifers in the Dakota Formation during 1975–1981 ranged from about 1,900 ft in Rush County to about 3,300 ft in Greeley, Hamilton, Stanton, and Morton counties (fig. 18). The hydraulic gradient was about 9 ft/mi or 0.0017 sloping to the east. The direction and slope of the potentiometric surface in the eastern part of the study area have been affected by ground-water withdrawals in Hodgeman and Ford counties. The hydraulic gradient from Gray to Pawnee counties was about 6 ft/mi or 0.0011 sloping to the northeast.

Recharge

Recharge to the sandstone aquifers is from 1) precipitation and runoff percolating into numerous sandstone outcrops in eastern Colorado and into scattered outcrop areas in southwestern Kansas, 2) underflow from adjoining areas, and 3) vertical flow between adjacent permeable

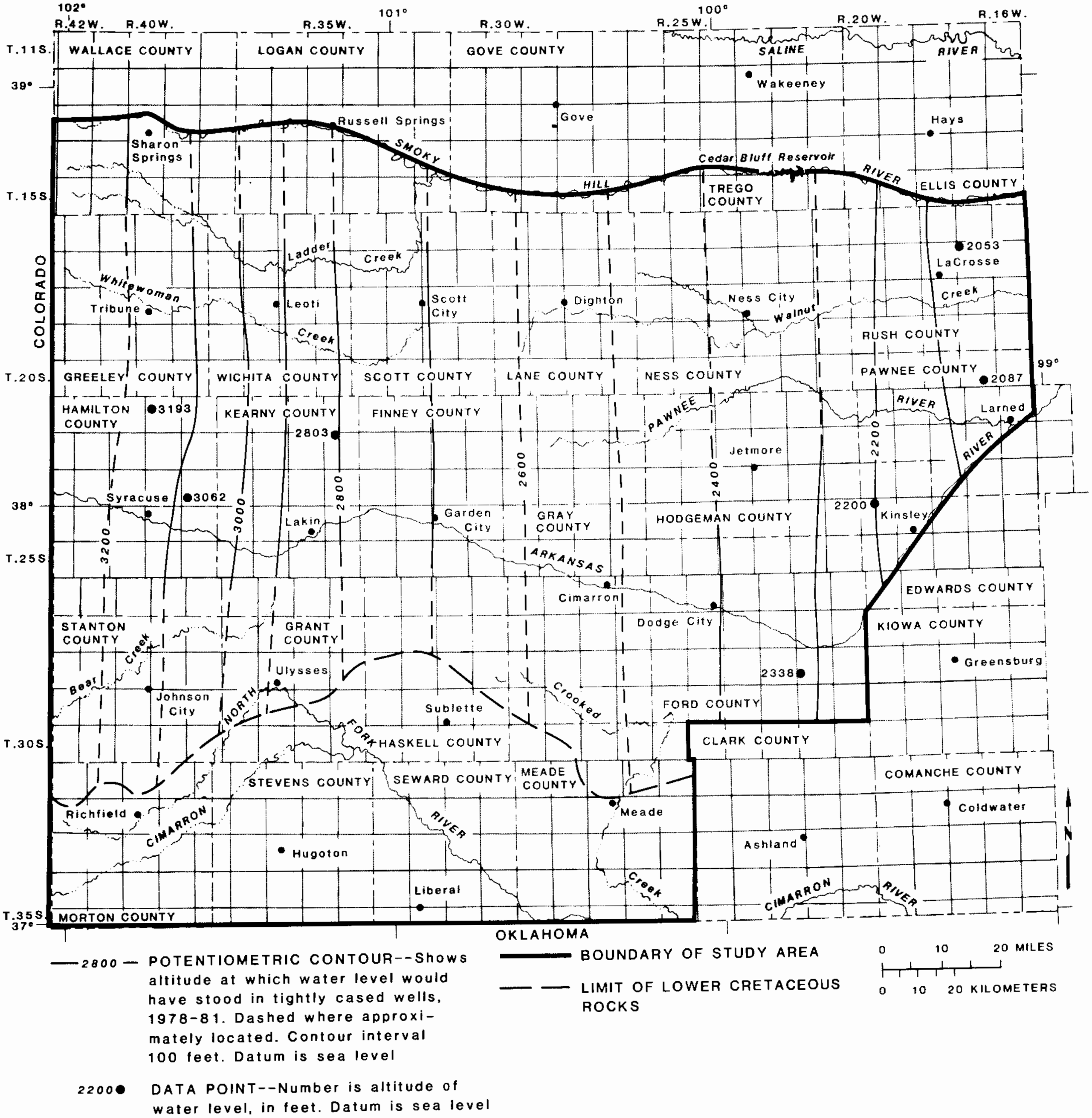


Figure 19—Potentiometric surface of aquifers in the Cheyenne Sandstone, 1978–1981.

formations, such as the overlying aquifers in Ogallala and Pleistocene deposits and the underlying aquifers in rocks of Permian and Late Jurassic age, or through semipermeable confining beds, such as siltstone, silty clay, and clay. Vertical flow is probably the most important source of recharge.

Part of the recharge in the study area is by underflow from adjoining areas to the west. The altitude of the potentiometric surfaces of the sandstone aquifers is highest in the western part and lowest in the eastern part of the study area. This ground-water gradient indicates that the major direction of ground-water flow is from Colorado eastward through southwestern Kansas.

Because of higher hydraulic heads in the aquifers in Ogallala and Pleistocene deposits, flow of water is downward into aquifers in rocks of Early Cretaceous and Late Jurassic age in Finney and Haskell counties (Gutentag and others, 1972), in southwestern Hamilton and northern Stanton counties (Lobmeyer and Sauer, 1974), and in Kearny and Grant counties (Gutentag and others, 1972).

The hydraulic heads in aquifers in rocks of Permian age are generally higher than those of the aquifers in rocks of Early Cretaceous age in the eastern part of the area. For example, artesian flow from aquifers in rocks of Permian age occurs in Pawnee County in observation wells 20-17W-22DCC and 22-19W-7AAA2 and in wells near

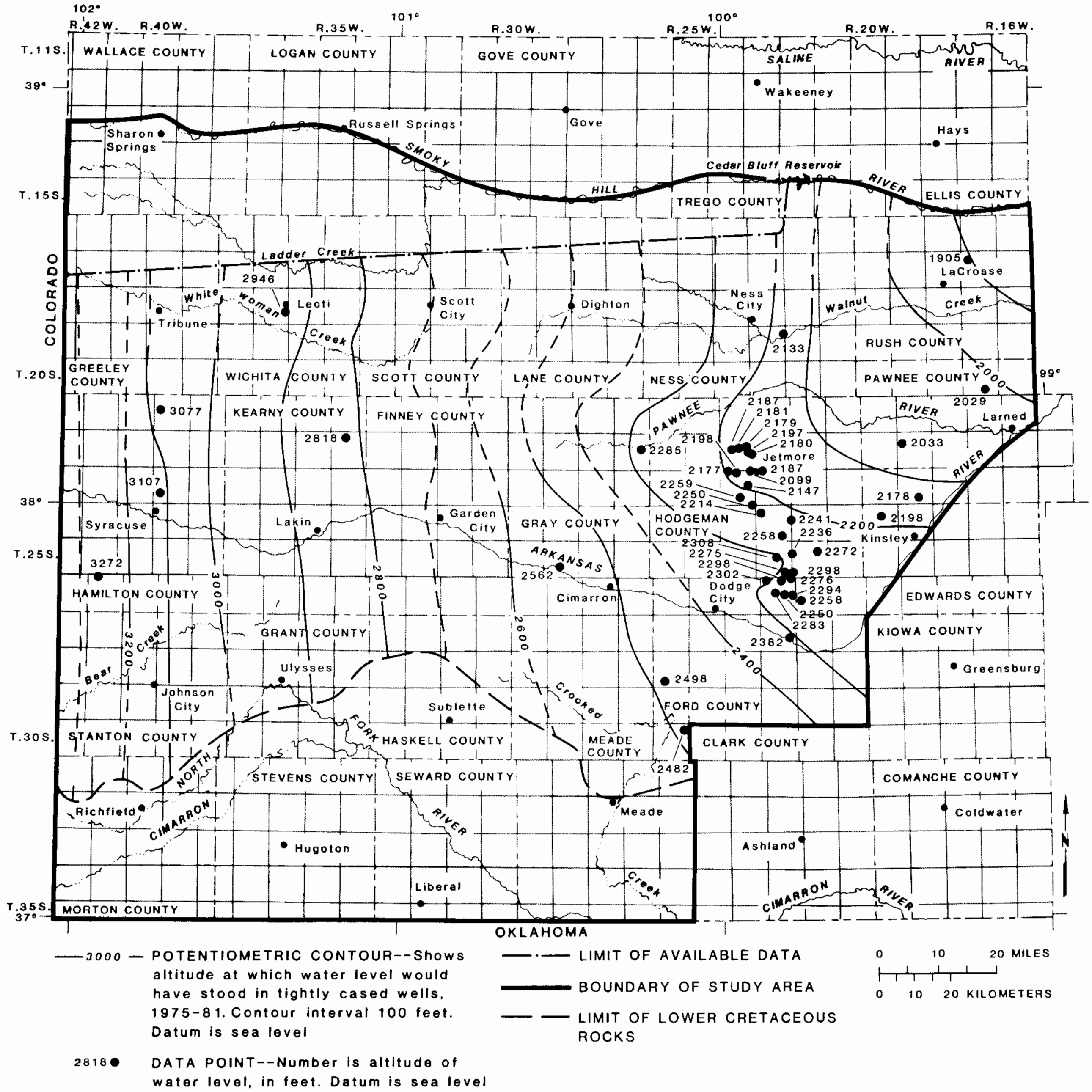


Figure 20—Potentiometric surface of aquifers in the Dakota Formation, 1975–1981.

Frizell and at Larned, as reported by McLaughlin (1949). Vertical flow upward from aquifers in rocks of Permian age into aquifers in rocks of Early Cretaceous age may occur in certain areas where hydraulic connections are present.

Chemical quality of water

Selected chemical analyses of ground water from aquifers in rocks of Permian and Late Jurassic age and in the Cheyenne Sandstone, the Dakota Formation, and the Codell Sandstone Member of the Carlile Shale are summarized in table 4. For each constituent or property, the number of analyses and the minimum and maximum values are given. Of the total number of analyses listed, most are for water samples collected from the aquifers in the Dakota Formation. The least number of water samples collected are from the aquifers in rocks of Late Jurassic age and in the Cheyenne Sandstone and the Codell Sandstone Member.

The procedures for sample preparation and pretreatment and the methods for determination of inorganic substances in water are described by Skougstad and others (1979) and Wood (1976). The water samples were collected from flowing wells and by air lifting water from other wells. The samples were filtered, acidified, and chilled following collection. They were sent to the laboratory under chilled conditions.

TABLE 4—Summary of selected chemical analyses of ground water from sandstone aquifers. Values are given in milligrams per liter (mg/L); μg/L, micrograms per liter; μmho/cm at 25°C, micromho per centimeter at 25°C; meq/L, milliequivalents per liter. The recommended maximum for public supply is from the Kansas Department of Health and Environment (Kansas State Board of Health, 1973).

Constituent or property	Recommended maximum for public supply	Aquifers in rocks of Permian age			Aquifers in rocks of Late Jurassic age			Aquifers in the Cheyenne Sandstone			Aquifers in the Dakota Formation			Aquifers in the Codell Sandstone Member of Carlile Shale		
		Number of analyses	Minimum	Maximum	Number of analyses	Minimum	Maximum	Number of analyses	Minimum	Maximum	Number of analyses	Minimum	Maximum	Number of analyses	Minimum	Maximum
Calcium, Ca (mg/L)	—	13	8	3,600	3	29	70	4	5.3	796	95	1.6	144	4	62	121
Magnesium, Mg (mg/L)	—	13	1	1,800	3	23	40	4	1.8	709	95	.5	120	4	14	25
Sodium, Na (mg/L)	—	13	14	17,400	3	32	63	4	16	17,400	95	9.2	1,300	4	9.2	38
Potassium, K (mg/L)	—	11	4	680	1	3.2	3.2	4	5.6	60	45	2.8	48	0	—	—
Bicarbonate, HCO_3 (mg/L)	—	13	61	370	3	188	301	4	120	350	95	51	930	4	215	300
Sulfate, SO_4 (mg/L)	250	13	9	3,700	3	46	177	4	17	3,700	95	.8	382	4	12	239
Chloride, Cl (mg/L)	250	13	7	28,200	3	10	15	4	15	28,200	95	4.5	1,800	4	11	64
Fluoride, F (mg/L)	1.5	10	0.1	3.2	3	0.5	2.8	3	.9	3.2	89	.2	8	4	.3	.7
Nitrate, NO_3 (mg/L)	45	13	.1	8	3	7.5	15	3	.1	4.7	93	0	41	4	10	80
Iron, Fe (μg/L	300	8	20	1,800	3	790	1,300	2	30	170	87	10	9,300	4	30	890
Manganese, Mn (μg/L)	50	6	0	220	1	0	0	2	0	100	58	0	200	1	0	0
Silica, SiO_2 (mg/L)	—	11	8.3	33	1	29	29	4	8	30	74	0	45	4	16	25
Hardness, total (mg/L)	—	13	28	5,800	3	154	326	4	24	4,900	93	6	483	4	212	400
Hardness, noncarbonate (mg/L)	—	13	0	16,300	3	0	115	3	12	4,610	90	0	1,240	4	22	224
Sodium-adsorption ratio, SAR (meq/L)	—	13	0.4	108	3	0.9	1.5	4	.7	108	93	.3	73	4	.3	.6
Specific conductance (μmho/cm at 25°C)	—	9	115	60,000	1	660	660	4	325	60,000	63	470	6,740	4	465	915
Dissolved solids (mg/L)	500	13	89	51,000	3	296	517	3	192	51,000	94	201	3,660	4	264	564
pH	—	7	7.1	8.0	1	8.4	8.4	4	7.1	8.4	44	6.8	8.7	0	—	—
Temperature (°C)	—	10	14	18.9	3	15	16.7	3	14	20.2	72	14	22	3	12	15.5

The wide range in values of the constituents or properties shown in table 4 indicates an extreme diversity in the chemical quality of water in the sandstone aquifers. Therefore, precisely characterizing the chemical quality of water from any given aquifer is difficult. Quality may vary in different areas of an aquifer from excellent to extremely poor.

The suitability of water for public supply and domestic use are judged by the recommended maximum constituent or property value for public supply as determined by the Kansas Department of Health and Environment (Kansas State Board of Health, 1973), based on standards that have been established by the U.S. Environmental Protection Agency (1976, 1979) for drinking water.

The chemical quality of water from aquifers in rocks of undifferentiated Permian age was quite varied. Sodium chloride and calcium sulfate were the most common chemical types of water for samples analyzed during this study, but calcium bicarbonate type water also was present. Dissolved-solids concentrations ranged from 89 to 51,000 mg/L (milligrams per liter). The temperature of the water ranged from 14 to 18.9°C. The maximum concentrations of sulfate (3,700 mg/L), chloride (28,200 mg/L), fluoride (3.2 mg/L), iron (1,800 μg/L, micrograms per liter), and dissolved solids (51,000 mg/L) exceeded the recommended maximum for public supply. The water was very hard.

Generally, the water from rocks of Permian age is saline to briny and not potable, but lenses of freshwater may be present in small areas where precipitation infiltrates the sandstone outcrops. In Pawnee County, natural discharge of saline water to springs may occur in some outcrops where the potentiometric surface is above the land surface. Upward migration of saline water through overlying permeable strata, whether natural or induced by pumpage, is a factor in the contamination of fresh ground water and surface water. Such contamination appears to have happened in some areas of the Cheyenne Sandstone and the Dakota Formation in Pawnee County.

The water from aquifers in rocks of Late Jurassic age is fresh where it has been sampled in southwest Kansas. Dissolved-solids concentrations ranged from 296 to 517 mg/L. The maximum concentrations of dissolved iron (1,300 μg/L) and fluoride (2.8 mg/L) exceeded the recommended maximum for drinking water. Calcium or sodium bicarbonate were the most common chemical types of water. The water was very hard.

The chemical quality of the water in the aquifer in the Cheyenne Sandstone is considerably varied. Sodium sulfate or sodium chloride were the common chemical types of water. Dissolved-solids concentrations ranged from 192 to 51,000 mg/L. The maximum concentrations of sulfate (3,700 mg/L), chloride (28,200 mg/L), fluoride (3.2 mg/L), and dissolved solids (51,000 mg/L) exceeded the recommended maximums for public supply. The water is soft to very hard. Hardness concentrations range from 24 to 4,900 mg/L. Generally, the water is saline to briny, except where a hydraulic connection exists with the underlying aquifers in rocks of Late Jurassic age or overlying aquifers in the Ogallala Formation or where the sandstone crops out at the land surface. Briny waters generally occurred in areas where a hydraulic connection exists with aquifers in rocks of Permian age.

The quality of water from aquifers in the Dakota Formation was well defined by the 95 available analyses (table 4). The data indicate that the water was fresh to moderately saline. Dissolved-solids concentrations ranged from 201 to 3,660 mg/L (fig. 21 and table 4). The aquifers in most of the southern part of the study area contained water with dissolved-solids concentrations of less than 500 mg/L. North of this area, except for two isolated areas, the dissolved solids increased progressively. Dissolved-solids concentrations reached a high of 3,660 mg/L in central Rush County. In this area the water from the aquifer in the Dakota Formation is of the sodium chloride type.

The sodium chloride type water in the aquifers in the Dakota probably originated from the underlying aquifers in rocks of Permian age by natural upward migration. Upward movement of saline water also can be induced by withdrawals of water from the aquifers by pumping of wells. Natural discharge of saline water by springs occurs in the outcrop area. Contamination of streams by saline water from the Dakota Formation in Ellis and Russell counties was reported by Hargadine and Luehring (1978, p. 103).

The lowest concentrations of dissolved solids—201-232 mg/L—in the aquifers in the Dakota occurred in Morton and Stanton counties. The water was of the calcium bicarbonate type and probably originated from downward migration of freshwater recharge from overlying Ogallala and Pleistocene aquifers or from precipitation on scattered Dakota sandstone outcrops.

Sodium bicarbonate was the most common chemical type in the aquifers in the Dakota Formation and occurred throughout the largest area (fig. 22). Calcium bicarbonate water was the second most common chemical type. Other chemical types present included sodium chloride, sodium sulfate, and calcium sulfate.

Water from the Dakota aquifers was soft to very hard. The total hardness ranged from 6 to 483 mg/L. The water was potable, but the maximum concentrations of iron (9,300 μg/L), fluoride (8 mg/L), and dissolved solids (3,660 mg/L) exceeded the recommended maximum concentrations for public supply.

Calcium bicarbonate or calcium sulfate were the most common chemical types of water in samples from aquifers in the Codell Sandstone Member of the Carlile Shale. The water was fresh. Dissolved solids ranged from 264 to 564 mg/L, which is less than the recommended maximum for drinking water. However, the maximum concentrations of nitrate (80 mg/L), dissolved iron (890 μg/L), and dissolved solids (564 mg/L) exceeded the recommended maxima for drinking water. The water was very hard.

Suitability of water for irrigation

The chemical characteristics of water that are most important in determining its suitability for irrigation are 1) the total concentration of soluble salts (salinity), 2) the relative proportion of sodium to other cations (alkalinity), 3) the concentration of boron or other elements that may be toxic, and, under some conditions, 4) the bicarbonate concentrations (U.S. Salinity Laboratory Staff, 1954).

Water quality for irrigation can be ranked from most suitable to least suitable based on available analyses as

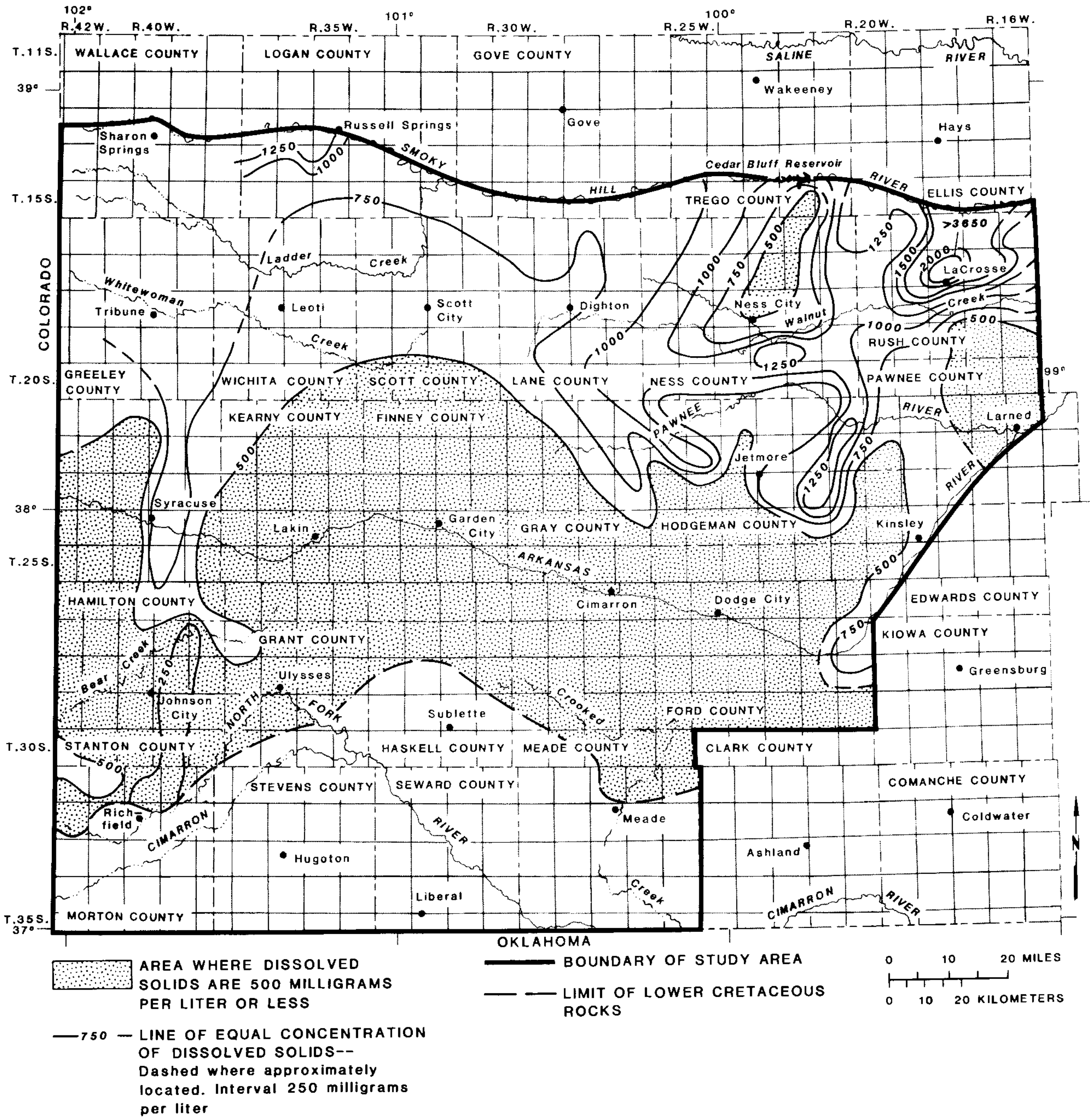


Figure 21—Concentrations of dissolved solids in water from aquifers in the Dakota Formation.

follows: 1) water from aquifers in the Codell Sandstone Member of the Carlile Shale, 2) water from aquifers in the Dakota Formation, 3) water from aquifers in rocks of Late Jurassic age, 4) water from aquifers in the Cheyenne Sandstone, and 5) water from aquifers in rocks of Permian age.

The potential for water containing a high concentration of dissolved solids to cause the soil salinity to increase is called the "salinity hazard" of the water. Increases in soil salinity are undesirable side effects when irrigating crops with high-salinity-hazard water. Soil types, drainage, the amount of water used, and other factors determine whether use of a given water for irrigation will cause a buildup in soil salinity.

A high concentration of sodium in irrigation water has an undesirable effect on the soil through the process of ion exchange. Sodium in the water is exchanged for calcium and magnesium in the soil. This produces an "alkali soil" in which the soil particles have deflocculated and impaired the soil texture. The soil becomes difficult to till and to drain. The potential for water to deflocculate the soil particles is called the "sodium (alkali) hazard" of the water. The potential for irrigation water to produce these conditions depends on the sodium content in relation to the calcium and magnesium content. This is expressed as a sodium-adsorption ratio (SAR). Low SAR values are desirable for irrigation water.

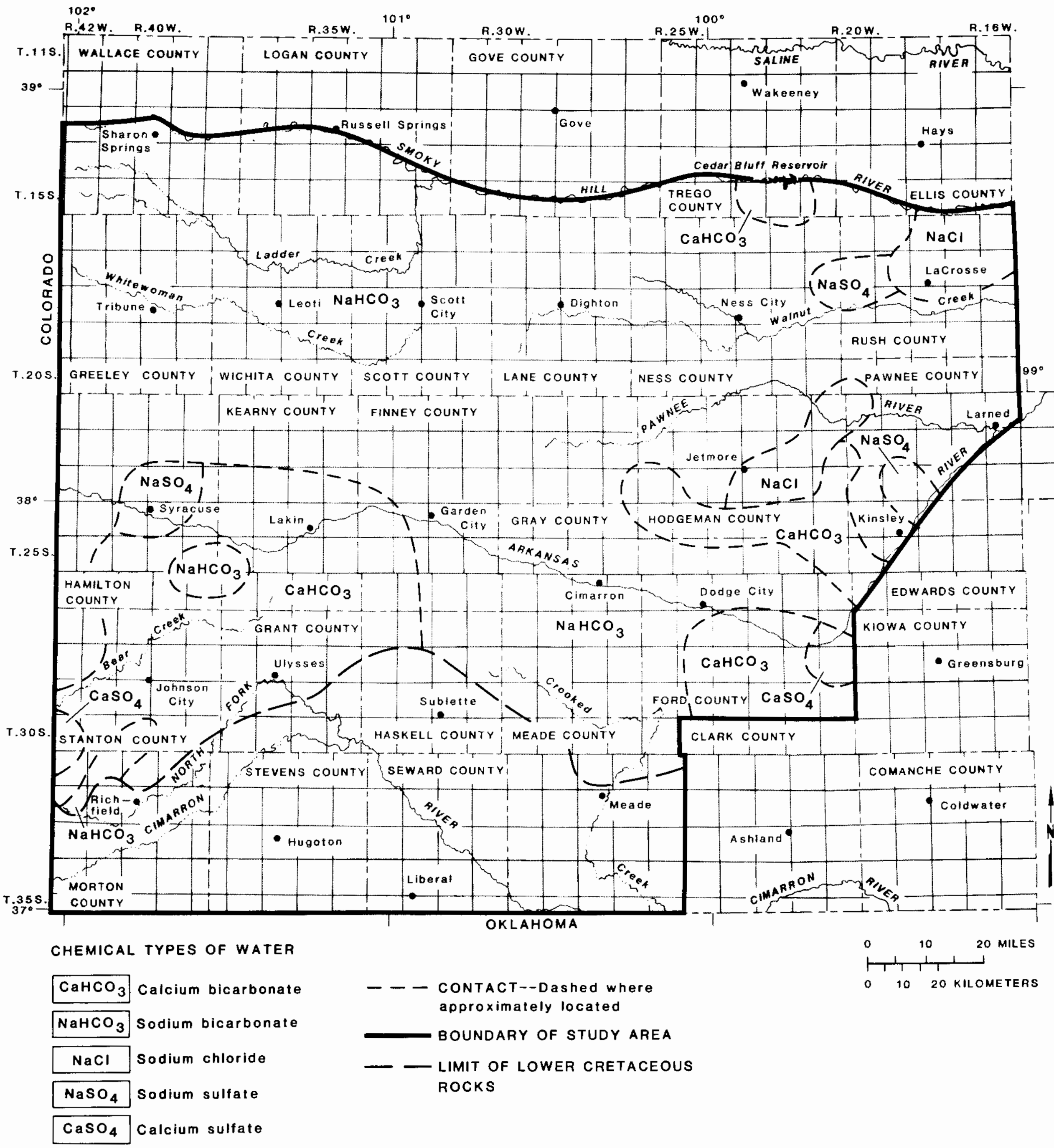


Figure 22—Occurrence of chemical types of water from aquifers in the Dakota Formation.

A classification of water (U.S. Salinity Laboratory Staff, 1954), based on the SAR and specific conductance of water, shows the suitability for irrigation water from 30 selected wells in aquifers in the Dakota Formation (fig. 23). A list of the sample numbers, county names, well numbers, SAR, and specific-conductance values is given in table 5. Water from the Dakota aquifers ranged from a medium to very high salinity hazard and from a low to very high sodium (alkali) hazard. The SAR ranged from 0.4 to 28.0 (table 5). Specific conductance ranged from 470 to 6,740 μmho/cm at 25°C (micromho per centimeter at 25°C; table 4). The wide range in SAR and specific conductance and the scattered points plotted in fig. 23 illustrate the diverse chemical character of the water in the Dakota. Although not shown in fig. 23, the SAR ranged from 35 to 47 and the specific conductance from 1,250 to 2,180 μmho/cm at 25°C in Logan County. For two samples in Wallace County, the SAR ranged from 57 to 73, and the specific conductance ranged from 1,670 to 2,140 μmho/cm at 25°C. Because the water from Logan and Wallace counties has a very high sodium (alkali) hazard and a high salinity hazard, the water would not be suitable for irrigation use.

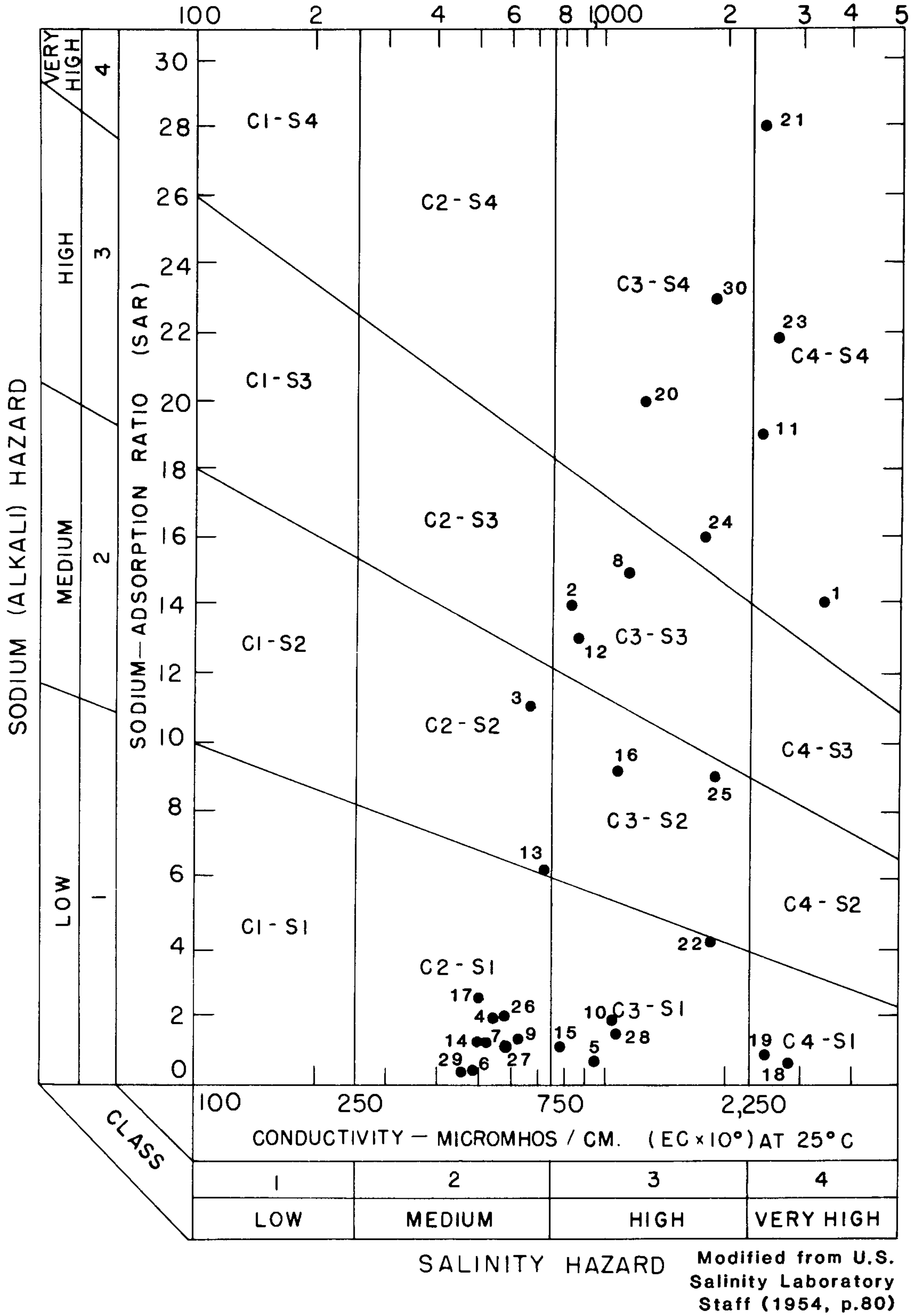


Figure 23—Classification of water from aquifers in the Dakota Formation, describing suitability for irrigation (number is sample number used in table 5).

TABLE 5—Sodium-adsorption ratios and specific-conductance values for water from selected wells drilled into aquifers in the Dakota Formation.

Sample number (shown in fig. 23)	County name	Well number	Sodium-adsorption ratio (SAR)	Specific conductance (micromho/centimeter at 25°C)
1	Ellis	15-18W-33BAA	14	3,200
2	Finney	22-27W-14BD	14	820
3	Finney	23-29W-12CCC	11	670
4	Ford	25-23W-25CCC	2	540
5	Ford	26-21W-11CCB	.8	940
6	Ford	27-22W-19CCC	.5	480
7	Ford	27-23W-24BCB	1.3	520
8	Hamilton	21-40W-28DCC	15	1,200
9	Hamilton	25-39W-22DCC	1.4	610
10	Hamilton	26-41W-24CDC	1.9	1,080
11	Hodgeman	21-21W-31DDA	19	2,440
12	Hodgeman	21-24W-27BCC	13	850
13	Hodgeman	23-25W-11ADA	6.3	720
14	Hodgeman	23-26W-07CCC	1.2	500
15	Hodgeman	24-23W-34AAD	1.1	780
16	Lane	18-29W-15D	9.1	1,050
17	Meade	30-26W-01BCD2	2.5	510
18	Morton	32-41W-28DB	.6	2,920
19	Morton	34-42W-05BD	.9	2,520
20	Ness	19-23W-01CCB	20	1,280
21	Ness	19-23W-21DA	28	2,470
22	Pawnee	20-27W-22DCC3	4.2	1,850
23	Rush	16-16W-32CCB	22	2,650
24	Rush	16-19W-17BAB	16	1,800
25	Rush	17-20W-29CDD	9	1,900
26	Rush	19-17W-27ADD	2	570
27	Stanton	29-42W-24CCC	1.1	570
28	Stanton	30-43W-28DD	1.5	1,070
29	Trego	15-22W-35ABA	.4	470
30	Trego	15-24W-15CCC	23	1,930

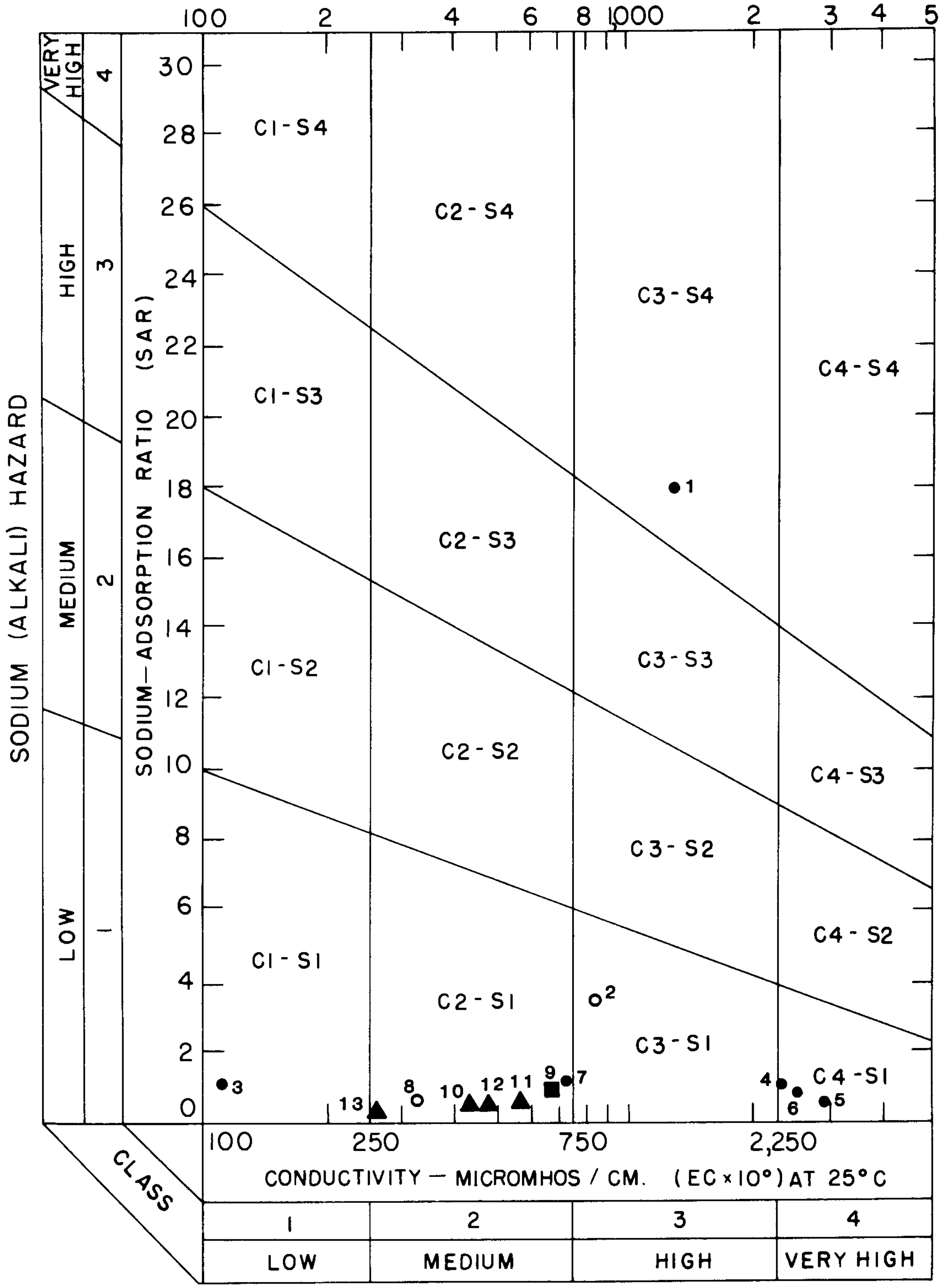
Suitability for irrigation of water from the sandstone aquifers other than the aquifers in the Dakota Formation is shown in fig. 24. A list of the sample numbers, county names, well numbers, aquifers, SAR, and specific-conductance values is given in table 6.

The water samples from aquifers in rocks of Permian age had a low to very high sodium hazard and a low to very high salinity hazard (fig. 24). The SAR ranged from 0.6 to 18. The specific conductance ranged from 115 to 60,000 μmho/cm at 25°C. Generally, the water from the aquifers is not suitable for irrigation. However, near outcrop areas where freshwater can recharge the aquifer, water quality in the aquifer may be more suitable for irrigation than in areas further from freshwater recharge.

The only well sampled from an aquifer in rocks of Late Jurassic age had water with a low sodium hazard and a medium salinity hazard. The SAR was 0.9, and specific conductance was 660 μmho/cm at 25°C. The water from the aquifer was suitable for irrigation at the sampled location.

Water from wells in aquifers in the Cheyenne Sandstone had a low sodium hazard and a medium to high salinity hazard. The SAR ranged from 0.7 to 3.5. The specific conductance ranged from 325 to 60,000 μmho/cm at 25°C. The suitability for irrigation of water from the aquifers is variable in the study area.

The water from wells in the aquifers in the Codell Sandstone Member of the Carlile Shale had a low sodium hazard and a medium to high salinity hazard. The SAR ranged from 0.3 to 0.6. The specific conductance ranged from 465 to 915 μmho/cm at 25°C. The water was suitable for irrigation.



Modified from U.S. Salinity Laboratory Staff (1954, p.80)

EXPLANATION

WATER SAMPLE FROM AQUIFERS IN THE FOLLOWING ROCKS:

- ● Permian
- o Cheyenne Sandstone
- ■ Upper Jurassic
- ▲ Codell Sandstone Member

Figure 24—Classification of water from aquifers in rocks of Permian and Late Jurassic age, in the Cheyenne Sandstone, and in the Codell Sandstone Member of the Carlile Shale, describing suitability for irrigation (number is sample number used in table 6).

TABLE 6—Sodium-adsorption ratios and specific-conductance values for water from selected wells drilled into aquifers in rocks of Permian and Late Jurassic age, in the Cheyenne Sandstone, and in the Codell Sandstone Member of the Carlile Shale.

Sample number (shown in fig. 24)	County name	Well number	Aquifer	Sodium-adsorption ratio (SAR)	Specific conductance (micromho/centimeter at 25°C)
1	Edwards	24-20W-09CDD2	Permian	18	1,350
2	Grant	28-38W-07AB	Cheyenne	3.5	830
3	Meade	30-26W-01BCD	Permian	1.1	115
4	Meade	32-29W-27AAB	Permian	1.1	2,300
5	Morton	32-41W-28DB	Permian	.6	2,920
6	Morton	24-42W-05DB	Permian	.9	2,520
7	Pawnee	22-19W-07AAA2	Permian	1.2	725
8	Rush	17-17W-06ABBA	Cheyenne	.7	325
9	Seward	34-34W-17DDD	Jurassic	.9	660
10	Trego	15-21W-36DDD	Codell	.5	434
11	Trego	15-23W-04BCB	Codell	.6	564
12	Trego	15-24W-35CCC	Codell	.5	488
13	Trego	15-25W-35CDC	Codell	.3	264

Ground-water development

The number of wells completed in each of the sandstone aquifers is difficult to determine for various reasons. Many wells are completed in several aquifers, including both unconsolidated deposits and consolidated rocks. Classifying these wells as to principal aquifer is difficult if the screened interval of the well or a lithologic description of the well bore is not available. The total number of applications to appropriate ground water by large-capacity wells (yields of more than 100 gal/min) from sandstone aquifers also is difficult to determine. According to the Division of Water Resources, Kansas State Board of Agriculture, early applications for water rights were not reported or granted on the basis of any particular sandstone aquifer.

A partial listing of selected wells drilled into the sandstone aquifers is given in a table of wells in Kume and Spinazola (1982). The table lists about 374 wells in 20 counties in southwestern Kansas, which is an average density of approximately 19 wells per county. Eighty percent of these wells were completed in aquifers in the Dakota Formation, and every county has wells in these aquifers. The water from sandstone aquifers is used primarily for domestic and stock purposes, with 54% of the wells in this list in that category. A secondary use is for irrigation, with 23% of the wells in that category. Generally, the sandstone aquifers are underdeveloped.

Aquifers in the Dakota Formation

The aquifers in the Dakota Formation are the most widely used sandstone aquifers for ground water in the study area. Irrigation-well construction in the Dakota aquifers has occurred in two main areas shown in fig. 20—1) northeastern Ford County in the vicinity of Spearville and Ford (about 46 irrigation wells) and 2) central Hodgeman County in the vicinity of Jetmore (about 19 irrigation wells).

Other well construction in Ford and Hodgeman counties has been for public supplies for Jetmore and Spearville, industrial supplies for several cattle feedlots and a beef-packing plant near Dodge City, and numerous stock and domestic supplies. The annual withdrawal of water from the aquifers in the Dakota Formation during 1973 was estimated to range from 7,700 to 15,000 acre-ft/yr in Hodgeman and northern Ford counties (Lobmeyer and Weakly, 1979).

Other areas of large-capacity well construction in the Dakota aquifers include: 1) Edwards County—15 irrigation and public-supply wells, 2) Finney County—irrigation supplies and industrial supplies at a coal-fired electric-generation plant near Holcomb, 3) Kearny County—irrigation supplies and public supplies at Lakin, 4) western Stanton County near Manter—irrigation supplies, 5) Wichita County—irrigation supplies, and 6) Grant and Ness counties—irrigation supplies.

Aquifers in rocks of Late Jurassic age

The aquifers in rocks of Late Jurassic age are the second most widely used source of ground water from sandstone aquifers in the study area. However, the aquifers occur only in the western one-fourth of the study area, and the aquifer thicknesses are quite limited in some areas. Most of the well development has occurred where the aquifers are less than 550 ft deep. The aquifers are developed extensively in Stanton and Grant counties, southern Hamilton and Kearny counties, and northern Morton and Stevens counties. These are important areas of ground-water use for irrigation, domestic, and stock supplies.

However, the wells are completed not only in the aquifers in rocks of Late Jurassic age but in aquifers in the rocks of Early Cretaceous age and in Tertiary and Pleistocene deposits as well.

Other sandstone aquifers

Other sandstone aquifers occur in rocks of Permian age, the Cheyenne Sandstone, the Kiowa Formation, and the Codell Sandstone Member of the Carlile Shale. They are the least-used sources of ground water from sandstone aquifers in the study area. Only minor stock- and domestic-well use occurs in these aquifers. Very little well construction has occurred in the aquifers in rocks of Permian age because they may contain very poor quality water and are generally deeper than the other sandstone aquifers. The aquifers in the Cheyenne Sandstone are used in Hamilton, Grant, and Stanton counties. In Stanton County, these aquifers are hydraulically connected with the aquifers in rocks of Late Jurassic age, and both aquifers are screened together for irrigation supplies. Just east of the study area in Russell County, Swineford and Williams (1945) reported that the Cheyenne Sandstone was used as a legal shallow-disposal zone for oil-field brine and that the water in the sandstone is not potable. In some areas, the "poor-quality" water in these aquifers has curtailed well construction. Very little well construction has occurred in the aquifers in the Kiowa Formation because the sandstone in this formation is very localized. The aquifers in the Codell Sandstone Member are used in Trego, Ellis, and Gove counties.

Future investigations

Additional studies are needed to provide the detailed data for a better understanding of the geohydrology and chemical quality of water in sandstone aquifers. Suggestions include

1. Additional test drilling is required, especially in the deep-aquifer areas. The study area needs test-hole data; where data are sparse, units from the land surface down to the Permian need describing.
2. Borehole geophysical logs need to be run in each test hole drilled. The lithology and hydraulic characteristics of the well bore also need to be described.
3. Construction of test wells is necessary. Steel-cased (inside diameter, 5 inches) and screened wells capable of being pumped need to be constructed. A pump and power plant also need to be installed in each test well to check yield and to facilitate collection of water samples.
4. Aquifer tests are essential. Water discharge and drawdown data need to be collected. Water-velocity surveys inside the well casing could be run along the well screen during discharge tests.
5. Collection of samples need to be made for chemical analysis from selected privately owned wells in the significant sandstone beds in aquifers in rocks of Jurassic age, the Cheyenne Sandstone, and the Kiowa Formation throughout the study area.
6. Piezometers need to be established in each aquifer throughout the study area in test holes or privately owned wells.
7. Water levels in observation wells need to be monitored quarterly or at least annually in January.
8. Annual water-level maps for each aquifer need to be made from the project measurements and from January mass measurements in western Kansas.
9. Maps of formation thickness and depth, structural contours, and sandstone-bed thicknesses need to be updated as new data become available.
10. Interpretation of geophysical logs from oil and gas wells needs to be continued. New logs are continually available as more wells are drilled. Geologic sections need to be updated as new data are available.
11. The current status of water-well construction in sandstone aquifers is needed. All unlisted sandstone-aquifer wells need to be entered into the computer data base. Previously listed wells need to be updated if new data are available.
12. Measurements of well discharge and time-of-pump operation need to be made to determine the water use from sandstone aquifers for each year.
13. Digital computer models of ground-water-flow systems in the sandstone aquifers need to be prepared.

Summary

Sandstone aquifers occur in Upper Permian, Upper Jurassic, and Lower and Upper Cretaceous rocks in southwestern Kansas. Information regarding sandstone aquifers compiled in this report included extent of formations, lithologies, altitude of formation surface, depth below land surface, formation thickness, thickness of sandstone beds, altitude of potentiometric surface, aquifer properties, water types, suitability for irrigation, chemical characteristics, and use of water during 1980.

Rocks of Permian age crop out in Meade County and are present in the subsurface throughout the study area. These rocks are characterized by sandstones, siltstones, shales, evaporites, limestones, and dolomites. The altitude of the top of the Permian surface increases southwestwardly from below 1,300 ft in northwestern Rush County to approximately 3,400 ft in Morton County. Depths below land surface to the top of the Permian increase northwestwardly from 0 at the outcrop to 2,100 ft in Wallace County. Altitude of the potentiometric surface during 1975–79 ranged from approximately 2,500 ft in the west to 2,100 ft in the east along the eastern edge of the study area.

Water from aquifers in rocks of Permian age was generally saline to briny. The water was of the sodium chloride or calcium sulfate types, but calcium bicarbonate type also was present. Dissolved-solids concentrations in samples ranged from 89 to 51,000 mg/L. The results of chemical analysis showed a low to very high sodium hazard and a low to very high salinity hazard. Specific conductance ranged from 115 to 60,000 μmho/cm at 25°C. Water from rocks of Permian age generally was not suitable for irrigation but may be used in isolated areas because of local recharge. Water from Permian sandstone aquifers is used for stock and domestic supplies.

Rocks of Late Jurassic age crop out in Morton County and occur in the subsurface of the western half of the study area. Rocks of Late Jurassic age overlie rocks of Permian age in the study area and underlie rocks of Early Cretaceous age in most of the study area. Rocks of Late Jurassic age underlie Tertiary deposits south of the limit of rocks of Cretaceous age in Grant, Haskell, Morton, Seward, and Stevens counties. Rocks of Late Jurassic age consist of varicolored shales and red sandstones. The altitude of the top of Upper Jurassic rocks decreases from approximately 3,500 ft in Morton County to just over 1,400 ft in Logan County. Depth below land surface ranges from 0 at the outcrop to about 2,000 ft in Wallace County. The thickness of the rocks ranges from 0 along the eastern limit to about 250 ft in northwestern Scott County and averages 103 ft. Sandstone beds range in thickness from 0 to about 50 ft and average 24 ft but exhibit little regional continuity.

Rocks of Late Jurassic age and the Cheyenne Sandstone comprise a single hydrologic unit in parts of Grant, Stanton, and neighboring counties in southwestern Kansas. The potentiometric surface in this hydrologic unit ranged from 3,500 ft in the west to about 2,850 ft in the east. Hydrographs show an approximate 25-ft decline in water levels between 1959 and 1979. Water samples from the unit were classified as fresh. Dissolved-solids concentrations ranged from 296 mg/L to 517 mg/L. Calcium or sodium bicarbonate were the most common chemical types. Water exclusively from rocks of Late Jurassic age was suitable for irrigation at the one well for which a chemical analysis was made. The water at this site had a low sodium hazard and a medium salinity hazard. Specific conductance was 660 μmho/cm at 25°C. Water from rocks of Late Jurassic age is used for irrigation, stock, and domestic supplies in the study area.

Geophysical logs were used to differentiate rocks of Early Cretaceous age into the Cheyenne Sandstone, Kiowa Formation, and Dakota Formation in most of the study area. In parts of Finney, Grant, Gray, Haskell, Hodgeman, Kearny, Scott, Stanton, and Wichita counties, the three formations comprising the Lower Cretaceous Series in the study area were not differentiated. Facies changes within each formation make the correlation of formation tops impractical in some areas, using available information. Rocks of Early Cretaceous age crop out in Ford, Hamilton, Hodgeman, Kearny, Pawnee, and Stanton counties.

The Cheyenne Sandstone consists of light-colored, fine-grained sandstone, gray and sandy shale, shale, siltstone, and clay in the study area. The altitude of the top of the Cheyenne Sandstone decreases northward from approximately 3,400 ft in Stanton and Morton counties to just over 1,400 ft in Gove County. Depth below land surface to the top of the Cheyenne Sandstone increases northward from 150 ft in Morton County to about 1,950 ft in Wallace County. The thickness of the formation ranges from about 20 ft in Pawnee County to 245 ft in Ford County and averages 91 ft. Thickness of sandstone beds ranges from 0 in southeastern Wallace County and northeastern Finney County to 190 ft in southwestern Hodgeman County and averages 37 ft. Sandstone beds tend to be local and discontinuous. The potentiometric surface in the Cheyenne decreased easterly from about 3,200 ft in Hamilton County to about 2,100 ft in Pawnee and Rush counties during 1975–1981. Vertical movement of water between rocks of Permian age and the Cheyenne Sandstone occurs through a hydraulic connection in Pawnee County where the hydraulic head is about 5 ft greater in the rocks of Permian age than in the Cheyenne rocks.

Water from the Cheyenne is generally saline to briny. Water with lower dissolved-solids concentrations may be available where the Cheyenne is hydraulically connected with rocks of Late Jurassic age or near outcrop areas. Dissolved-solids concentrations in samples ranged from 192 to 51,000 mg/L. Sodium sulfate or sodium chloride were the common water types. The suitability of water for irrigation from the Cheyenne is variable. Samples had a low sodium hazard and a medium to high salinity hazard. Specific conductance ranged from 325 to 60,000 μmho/cm at 25°C. In Grant, Hamilton, and Stanton counties, water from the Cheyenne Sandstone is used for irrigation.

The Kiowa Formation consists of light-gray to black illitic shale. Limestone beds and sandstone lenses occur locally. The altitude of the top of the Kiowa ranges from approximately 3,500 ft in Morton County to approximately 1,600 ft in the counties along the northern boundary of the study area. The Kiowa generally is considered to be a confining layer in the study area, but sandstone lenses found mainly in the northeast part of the study area yield minor amounts of water for domestic and stock uses.

The Dakota Formation is composed of varicolored claystone, mudstone, shale, siltstone, and sandstone. The altitude of the top of the Dakota decreases northward from approximately 3,600 ft in Stanton County to just less than 1,800 ft in Trego County. Depth below land surface to the top of the Dakota ranges from 0 at the outcrop to about 1,650 ft in Wallace County. Thickness of the formation ranges from about 60 ft to about 460 ft and averages 218 ft. Thickness of sandstone beds ranges from 0 to 150 ft and averages 58 ft. Large variations in formation and sandstone thicknesses are apparent within short distances in the study area. Transmissivity values in aquifers in the Dakota Formation range from 940 to 7,100 ft^2/d, and storage coefficients range from 0.0004 to 0.07. Well yields range from a few gallons per minute to 2,200 gal/min. The maximum decline of water levels in wells in the Dakota for the period between 1969 and 1979 averaged 60 ft. The potentiometric surface in the Dakota Formation ranged from about 3,300 ft in the west to about 1,900 ft in the east during 1975–1981. Higher hydraulic heads in the Ogallala and Pleistocene aquifers in Finney, Grant, Hamilton, Haskell, and Stanton counties induce downward flow of water to the stratigraphically adjacent Dakota Formation through a hydraulic connection in these areas.

Water from the Dakota Formation was fresh to moderately saline. Dissolved-solids concentrations in samples ranged from 201 to 3,660 mg/L. Sodium bicarbonate was the predominant water type among calcium bicarbonate, sodium chloride, sodium sulfate, and calcium sulfate types. Sodium chloride type water found in Ellis and Russell counties probably migrated upwards from underlying Permian rocks. The suitability of water from the Dakota Formation for irrigation is variable. Samples ranged from a medium to very high salinity hazard and from a low to very high sodium hazard. Specific conductance ranged from 470 to 6,740 μmho/cm at 25°C. Water from the Dakota is used for stock, domestic, irrigation, and municipal supplies in the study area.

The Codell Sandstone Member of the Carlile Shale in the Upper Cretaceous Series occurs in Ellis, Gove, Ness, Rush, and Trego counties and crops out in Rush County. The Codell is a fine- to very fine grained sandstone that occurs in the upper part of the Carlile Shale. The Codell reaches a maximum thickness of about 25 ft in Ellis County and thins to 0 in the northeast and south. Water from the Codell Sandstone Member is fresh. Calcium bicarbonate and calcium sulfate were the most common chemical types of water. Dissolved-solids concentrations ranged from 264 to 564 mg/L. The water was suitable for irrigation with a low sodium hazard and a medium to high salinity hazard. Specific conductance ranged from 465 to 915 μmho/cm at 25°C. The Codell Sandstone Member is used in Trego, Ellis, and Gove counties as a source of irrigation, stock, and domestic water.

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Tables 7-9 and appendices A and B follow

TABLE 7—Logs of observation wells (altitudes are in feet above sea level).

EDWARDS COUNTY

24–20W–9DCD—Drilled May 11, 1978. Altitude 2,260 ft. Depth to water 53 ft (Dakota Formation, 1978) and 50 ft (Cheyenne Sandstone, 1978).

	Thickness (ft)	Depth (ft)
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Clay (topsoil), dark-brown	5	5
Clay, reddish-brown	5	10
Clay, limy, light-brown	1	11
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Caliche, with light reddish-brown clay	4	15
Clay, limy, light reddish-brown	6	21
Clay, reddish-brown	3	24
Clay, limy, reddish-brown	32	56
Caliche, brittle, reddish-brown	1	57
Clay, very sandy, light reddish-brown	13	70
Caliche and mortar bed	11	81
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, hard, light-gray	1	82
Clay, light-gray, some weathered yellow layers	14	96
Ironstone, black	1	97
Clay, gray, with hard sandstone layer and lignite	4	101
Clay, gray, with dark-gray clay	6	107
Sandstone, fine-grained	1	108
Clay, gray with thin sandstone layers	11	119
Sandstone, light-gray	1	120
Sandstone, very fine grained, light-gray	1	121
Clay, gray, with thin sandstone layers	9	130
Sandstone, silty, brown	7	137
Sandstone, fine-grained, silty, brown, and gray clay layers	15	152
Ironstone, with dark-gray clay, brown sandstone, and lignite	6	158
Clay, gray, and very fine grained, light brownish-yellow sandstone	7	165
Clay, gray, with thin black to dark-brown translucent fragments	16	181
Clay, gray, and light-brown, silty very fine grained sandstone	43	224
Sandstone, medium-grained, brown	2	226
Clay, light-gray to yellowish-brown, with thin sandstone layers	14	240
Clay, light-gray to gray and red, with a few thin hardened layers	47	287
Kiowa Formation		
Siltstone, with gray layers	13	300
Shale, gray, with hard siltstone layers	48	348
Shale, black to gray, very hard layer	59	407
Shell material, thin layer	1	408
Shale, black, with thin hard layers	73	481
Cheyenne Sandstone		
Shale, black to dark-gray, with gray sandy shale and very fine, white sandstone	14	495
Shale, sandy, dark grayish-brown, with hard streaks, lignite	14	509
Siltstone, gray, moderately hard, with some soft layers	31	540
Siltstone, gray, with brown shale, lignite, and sandstone layers	10	550
PERMIAN SYSTEM		
Upper Permian Series		
Whitehorse Formation		
Siltstone, pale green, with some red layers	2	552
Shale, red, with some sandy shale	4	556

FORD COUNTY

28–22W–30BCC—Drilled September 12, 1978. Altitude 2,490 ft. Depth to water 123 ft (Ogallala Formation, 1978), 147 ft (Cheyenne Sandstone, 1978), and 166 ft (Upper Permian rocks, 1978); Everette Copeland, landowner.

	Thickness (ft)	Depth (ft)
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Topsoil, clayey and silty, dark-brown	2	2

	Thickness (ft)	Depth (ft)
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Clay, very silty, light reddish-brown, with occasional caliche streaks	13	15
Silt, slightly clayey, very light brown, with some caliche	15	30
Silt, very light brown, with some caliche	48	78
Silt, clayey, medium-brown	23	101
Silt, with caliche streaks	12	113
Sand, very fine to fine silty, medium-brown	3	116
Sand and gravel, fine to medium, reddish-brown, with particles of quartz, orthoclase, and basalt	3	119
Gravel, fine to medium, reddish-brown	26	145
Gravel, coarse, reddish-brown	2	147
Gravel, fine to medium	1	148
Gravel, medium to coarse	3	151
Clay, yellow-brown to pinkish-gray, with fine to medium sand	2	153
Clay, grayish-white, and very fine sand	18	171
Gravel, medium, reddish-brown	2	173
Clay, grayish-white, and medium, reddish-brown gravel	2	175
Gravel, medium to coarse, and grayish-white clay	6	181
Clay, grayish-white	17	198
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn (?) Limestone		
Shale, soft, olive-gray	11	209
Limestone, light-gray, indurated	2	211
Shale, firm, olive-gray, with a few indurated thin beds of limestone	14	225
Shale, hard, dark-gray, with local hard thin streaks of very thin limestone	15	240
Graneros (?) Shale		
Shale, hard, dark-gray	38	278
Lower Cretaceous Series		
Dakota Formation		
Siltstone, light-gray, and very fine grained, light-gray sandstone	2	280
Shale, hard, dark-gray	1	281
Sandstone, very fine grained, light-gray	1	282
Shale, hard, dark-gray	3	285
Sandstone, very fine grained, light-gray	2	287
Shale, hard, dark-gray, and interbedded very fine grained, thin light-gray sandstone	6	293
Shale, hard, dark-gray	7	300
Sandstone, very fine grained, light-gray, and hard dark-gray shale	4	304
Shale, hard, dark-gray	3	307
Sandstone, very fine grained, light- to medium-gray	1	308
Shale, dark-gray	3	311
Sandstone and shale, interbedded	2	313
Shale, dark-gray	4	317
Sandstone, very fine grained, light- to medium-gray	3	320
Shale, dark-gray	5	325
Sandstone, very fine grained, light- to medium-gray	1	326
Shale, dark-gray	3	329
Sandstone and shale, interbedded	14	343
Sandstone, very fine grained, light- to medium-gray	2	345
Shale, dark-gray, and dark-gray silty shale	22	367
Sandstone, very fine grained, light- to medium-gray	1	368
Shale, dark-gray	2	370
Kiowa Formation		
Shale, smooth, very dark gray	47	417
Limestone, white, and very dark gray shale	1	418
Shale, very dark gray	2	420
Cheyenne Sandstone		
Shale, very dark gray, and very fine grained, mostly friable to thinly indurated, thin light-gray sandstone	3	423
Sandstone, very fine grained, light-gray, friable, and black carbonaceous shale	10	433
Sandstone, very fine grained, light-gray, cemented	1	434
Sandstone, very fine grained, light-gray, mostly friable, with thin cemented layers, and black carbonaceous shale splinters	13	447
Shale, friable, medium-gray, with very fine grained sandstone	11	458
Sandstone, very fine grained, friable, light-gray, few thin cemented streaks	8	466

	Thickness (ft)	Depth (ft)
Sandstone, very fine grained, friable, very light gray and yellow-brown streaks, and minor amount of very light gray, soft shale	7	473
PERMIAN SYSTEM		
Upper Permian Series		
Whitehorse Formation		
Shale, soft, dark reddish-brown	8	481
Shale, soft, dark reddish-brown and black brittle splintery shale, with a few hard siltstone streaks	2	483
Shale, soft, dark reddish-brown, and dark reddish-brown siltstone, with few hard siltstone streaks	20	503
Siltstone, dark reddish-brown, indurated	2	505
Shale, dark reddish-brown, and dark reddish-brown siltstone	5	510
Siltstone, dark reddish-brown, and dark reddish-brown shale	15	525

28–26W–29BAD—Drilled July 13, 1977. Altitude 2,680 ft. Depth to water 180 ft and 171 ft (Dakota Formation at well depths 593 and 455 ft, respectively, 1978). Austin Bentzer, landowner.

	Thickness (ft)	Depth (ft)
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Topsoil	1	1
Clay, light reddish-brown, with caliche	6	7
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Clay, light-brown, with caliche	8	15
Clay, brown to light-brown	30	45
Clay, brown, with caliche	13	58
Clay, brown, with caliche and reddish-brown clay layers	17	75
Clay, reddish-brown to light reddish-brown, with caliche	25	100
Sand, fine to coarse, and fine gravel	15	115
Sand, fine to coarse, slightly cemented, and fine gravel	11	126
Caliche, hard	1	127
Sand, fine to coarse, slightly cemented, and fine gravel	8	135
Caliche, hard	1	136
Sand, fine to coarse, slightly cemented, and fine gravel with thin clay and caliche layers	14	150
Clay, light-brown, and caliche, with a few thin sand layers	15	165
Clay, light-gray to light-yellow, with hard caliche and mortar-bed streaks	25	190
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Clay, light-yellow to gray, with thin limestone streaks	4	194
Clay, black to light-gray, with thin hard limestone streaks	31	225
Shale, black, with light-gray shale and thin hard limestone layers	10	235
Graneros Shale		
Shale, black, with a thin green clay layer and white bentonite layers	5	240
Shale, dark brownish-gray, with thin hard cemented layers	50	290
Lower Cretaceous Series		
Dakota Formation		
Clay, dark-gray, and very fine grained, light-gray sandstone	9	299
Clay, dark-gray, with hard streaks	31	330
Clay, dark-gray to very light gray	16	346
Clay, very light gray	17	363
Clay, light-brown to grayish-brown, and lignite	7	370
Clay, very light gray, with brownish-gray clay and lignite streaks	36	406
Sandstone, very fine grained, silty, light-gray, some hard layers, and light brownish-gray clay with lignite layers	29	435
Sandstone, silica-cemented (orthoquartzite), very hard, brown	1	436
Sandstone, very fine grained, very silty, light-gray	9	445
Sandstone, very silty, gray	47	492
Sandstone, hard, brown	1	493
Sandstone, very fine grained, gray, and red mottled-gray clay	27	520
Sandstone, very fine grained, hard, gray	7	527
Clay, gray, with hard streaks	8	535
Sandstone, hard, gray	5	540
Clay, gray, with hard streaks	8	548
Sandstone, hard, gray, and gray clay in thin layers	25	573
Clay, gray, with hard streaks	12	585
Clay, light-gray, and very fine grained silty sandstones with red clay	18	603

	Thickness (ft)	Depth (ft)
Sandstone, very fine grained, light-gray	16	619
Sandstone, hard	1	620
Kiowa Formation		
Shale, gray to black, with hard streaks	130	750

GRAY COUNTY

25-29W-21CDA—Drilled October 31, 1977. Altitude 2,707 ft (Dakota Formation, 1977), Carl Strawn, landowner.

	Thickness (ft)	Depth (ft)
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Silt, sandy, clayey, dark-brown; contains plant roots and partly decayed organic matter	2	2
Silt, sandy, light reddish-brown, with caliche	3	5
Sand, fine to medium, silty, light reddish-brown	4	9
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Sand, fine to coarse, and fine gravel; contains caliche pebbles	7	16
Clay, very sandy, light-brown to light grayish-brown	14	30
Sand, fine to medium, with light reddish-brown clay streaks and caliche streaks	29	59
Clay, light reddish-brown, and caliche with agate	16	75
Clay, compact, brittle, light yellowish-brown	15	90
Sand, yellowish-brown to brown	3	93
Sand, fine to medium, light-brown, with light-brown clay and caliche layers	25	118
Sand, fine to medium, light-brown to yellowish-brown, with light-brown, grayish-green, and yellowish-brown clay	17	135
Sand, fine, silty, light-brown, with caliche and clay layers	18	153
Sand, fine to coarse	13	166
Sand, fine to coarse, silty, with loose sand layers	15	181
Sand, fine to coarse, with a few very loose streaks	19	200
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Limestone, weathered, light-gray to yellow, and gray to yellow shale	5	205
Shale, black, and limestone streaks	20	225
Limestone, hard, gray to black, and black shale	52	277
Graneros Shale		
Shale, black; contains bentonite layers	64	341
Shale, hard, black	12	353
Lower Cretaceous Series		
Dakota Formation		
Shale, black to light-gray, with hard streaks; contains lignite layers	14	367
Sandstone, very fine grained, white	8	375
Siltstone, light-gray, and very fine grained sandstone	17	392
Sandstone, very fine grained, white	4	396
Clay, gray, red-mottled, and clay with very fine grained sandstone layers	9	405

25-29W-21CDA2—Drilled October 4, 1978. Altitude 2,707 ft. Depth to water 168 ft (Kiowa Formation, 1978). Carl Strawn, landowner.

	Thickness (ft)	Depth (ft)
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Topsoil, light gray-brown	2	2
Sand, fine to medium, and light-tan silt	4	6
Sand, fine to coarse, reddish-orange-brown	7	13
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Sand and silt, some caliche	2	15
Sand and silt layers, clayey, light brownish-orange	13	28
Sand, fine, and medium to coarse gravel, light brownish-orange, with abundant caliche	4	32
Silt, clayey, light-brown	8	40
Silt, light-brown, with hard caliche streaks and cemented fine to medium silty light brownish-orange sand	5	45
Sand, fine to medium, with light brownish-orange caliche streaks	11	56
Sand, fine to medium, light brownish-orange	3	59
Sand, fine to medium, light brownish-orange, with caliche streak	1	60
Clay, silty, very calcareous, very light brown and light-brown	7	67
Clay, silty, very calcareous, light-brown, with fine gravel and caliche	5	72
Clay, silty, very calcareous, light-brown, with abundant caliche	3	75

	Thickness (ft)	Depth (ft)
Clay and caliche, very light brown, brittle, and very calcareous clay	15	90
Sand, fine to medium, brown, with minor clay	12	102
Clay, very calcareous, buff, and much caliche	3	105
Sand, medium to coarse, and clay, brown to buff, with some caliche	11	116
Sand, medium to coarse, and clay, with abundant caliche	4	120
Sand, medium to coarse, brown	13	133
Clay and caliche, buff to tan	2	135
Sand, fine to very coarse, mostly medium, brown	13	148
Caliche and clay	1	149
Sand, medium, brown	1	150
Sand, fine to very coarse, mostly medium to coarse, very clean	29	179
Caliche and clay	1	180
Clay, buff to tan	4	184
Sand, medium to coarse, brown, with minor caliche	17	201
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Limestone and clay, soft to brittle	5	206
Shale, soft, very dark gray	3	209
Shale, soft, very dark gray, with cemented layer	1	210
Shale, hard, very dark gray	3	213
Cemented layer	1	214
Shale, very dark gray, with scattered hard streaks	9	223
Cemented layer	1	224
Shale, very dark gray, and medium-gray thin cemented layers of shale	6	230
Shale, very dark gray, and medium light-gray cemented limy shale	9	239
Shale, medium-brown, calcareous, brittle	1	240
Shale, cemented, limy, medium light-gray, and minor amounts of very dark gray shale	29	269
Graneros Shale		
Shale, hard streaks, light-gray and medium light-gray bentonite	15	284
Shale, very dark gray, with minor amount of light-gray bentonite	15	299
Shale, very dark gray, with a few hard streaks	23	322
Shale, very dark gray, with minor amount of light-gray bentonite	7	329
Shale, very dark gray, with many hard streaks	15	344
Lower Cretaceous Series		
Dakota Formation		
Shale, dark-gray, and tan orangish-yellow shale	9	353
Cemented layer, probably sandstone	3	356
Cemented layer, gray and tan shale	3	359
Cemented layer, whitish-gray shale and lignite	15	374
Shale, tan, light-gray, and gray	10	384
Shale, tan, light-gray, and gray, with some thin lignite beds and whitish-gray shale	5	389
Sandstone, very fine grained, dark-gray, and silty, gray shale	6	395
Shale and siltstone, medium to dark-gray, and some tan shale	4	399
Shale, tan, and cemented, quartzitic, red sandstone	5	404
Shale, dark-gray, and silty light- to medium-gray and tan shale, with hard streak at 411 ft	17	421
Sandstone, fine-grained, and reddish-brown-yellow cemented and hard shale	9	430
Shale, light- to dark-gray and tan, and silty shale	6	436
Shale, dark-gray	3	439
Shale, dark-gray and light-tan	7	446
Shale, dark- and light-gray	3	449
Shale, light-gray and tan, with trace of lignite	3	452
Shale, light-gray and tan	9	461
Shale, dark-gray, with trace of lignite at 464 ft	8	469
Shale, dark-gray, with trace of friable, red quartz sandstone	1	470
Lignite	3	473
Shale, light-gray, and lignite	2	475
Shale, light- to dark-gray	1	476
Shale, silty, dark-gray, with trace of calcite	3	479
Shale, dark-gray and light-tan	2	481
Shale, light- to dark-gray and tan	6	487
Shale, sandy, soft, buff, and dark-gray shale	3	490
Shale, light- to dark-gray and tan, with trace of lignite	12	502
Shale, light- to dark-gray and tan, with trace of red-maroon shale	2	504
Shale, light- to dark-gray and tan	3	507
Shale, light- to dark-gray and tan, with trace of red-mottled and light-gray shale	4	511

	Thickness (ft)	Depth (ft)
Shale, dark-gray, some light-gray, tan, and red-maroon	3	514
Shale, dark-gray, some light-gray, tan, and red-maroon, with trace of friable, medium-grained sandstone	6	520
Shale and sand, dark-gray, light-gray, tan, and red-maroon, with trace of gray shale with red mottling	2	522
Shale, light- to dark-gray, tan, and red-mottled, with hard sandstone layer at 528 ft	9	531
Shale, light- to dark-gray, tan, and maroon	3	534
Shale, light- to dark-gray, tan, red-mottled, and friable, medium to coarse sandstone, with hard sandstone streak at 538 ft	9	543
Sandstone, hard, reddish-brown, and light- to dark-gray, tan, and red-mottled shale	4	547
Sandstone and shale, reddish-brown, with granules at 547 ft	2	549
Shale, light-gray, with red mottling and hard streaks	1	550
Shale, light-gray, with red mottling and fine-grained, cemented red sandstone	6	556
Shale and sandstone, light-gray, with red mottling; contains bright red shale	2	558
Shale and sandstone, light-gray with red mottling, hard	5	563
Shale, light-gray, red-mottled, and trace of yellow shale	4	567
Shale, light-gray with red mottling, and thin, cemented, very hard red sandstone	4	571
Kiowa Formation		
Shale, dark-gray to black	30	601
Shale, light-gray to black, with traces of red mottling	9	610
Shale, light-gray to black, bright blue-green, and pale blue-gray, silty	6	616
Shale, light-gray, and thin, cemented brownish-red sandstone	7	623
Shale, light-gray	5	628
Sandstone, thin, well-cemented, brown	2	630
Ironstone and quartz, red-stained	1	631
Shale, light- to dark-gray, occasional hard sandstone streak	25	656

MEADE COUNTY

30-26W-1BCD—Drilled September 28, 1978. Altitude 2,545 ft. Depth to water 121 ft (undifferentiated Permian rocks, 1978) and 63 ft (Dakota Formation, 1978). Norman Hatfield, landowner.

	Thickness (ft)	Depth (ft)
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Topsoil	1	1
Silt and very fine to fine sand, with caliche	9	10
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Caliche and fine to coarse sand, calcium-carbonate cemented, with small gravel	5	15
Clay, dark-tan, with very fine sand, silt, and caliche	15	30
Sand, medium to coarse, with small gravel and light-tan, sandy clay	12	42
Clay, stiff, white, slightly calcareous	3	45
Sand, cemented, very fine, light tannish-white and pinkish-tan, and tan sandy clay	7	52
Clay, sandy, light pinkish-tan to salmon-pink	8	60
Sand, fine, carbonate-cemented, and sandy tannish-pinkish-white clay	23	83
Mortar bed	1	84
Sand, carbonate-cemented, fine, light-tan, and cemented pale-yellow sand	6	90
Sand, very fine, cemented, light-yellow to tan	5	95
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, well-cemented, reddish-brown	1	96
Shale, sandy, light- to medium-dark-gray, and very fine, light-gray sandstone	2	98
Sandstone, light-gray, and whitish-gray to dark-gray shale	7	105
Shale, light- to medium-dark-gray	7	112
Sandstone, very fine grained, well-cemented, pale orangish-yellow	1	113
Shale, dark- to medium-gray, and light-gray shale	2	115
Sandstone, fine-grained, cemented, pinkish-tan	1	116
Shale, sandy, light-gray	1	117
Clay, light-gray to pinkish-tan, and silty light-gray sandstone	2	119
Shale, sandy, soft, with less than 5% pea-size gravel and light-gray shale	1	120
Shale, light- to dark-gray	10	130
Sandstone, very fine, brownish-yellow, and gray clay	4	134
Shale, medium-gray	4	138
Sandstone, fine-grained, reddish-brown	1	139
Shale, light-gray	6	145
Sandstone, fine-grained, brownish-rust	1	146

	Thickness (ft)	Depth (ft)
Shale, silty, medium- to dark-gray	31	177
Kiowa Formation		
Shale, dark- to light-gray, and less than 1 ft of sandy siltstone	3	180
Shale, silty, light- to medium-gray	34	214
Shale, silty, light- to medium-gray, with white limestone and limy sandstone	1	215
Cheyenne Sandstone		
Shale, gray, with thin siltstones and very fine grained sandstone (siltstone and sandstone less than 5%)	78	293
Sandstone, well-cemented, very fine grained, gray	1	294
Shale, silty, gray, with thin siltstones and very fine grained sandstones (10% siltstone and sandstone between 310–315 ft)	21	315
Shale, gray, and thin siltstones	96	411
Shale, gray, with brown mottling	4	415
Shale, light-gray, and silty, light greenish-gray shale	3	418
PERMIAN SYSTEM		
Upper Permian Series		
Big Basin Formation		
Shale, silty, reddish-brown	2	420
Siltstone, reddish-brown	37	457
Shale, reddish-brown	8	465
30–27W–17DDD—Drilled November 14, 1974. Altitude 2,558 ft.		
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Topsoil, drifted, black	3	3
Clay, light-brown, and caliche	7	10
Caliche, with some light-brown clay	5	15
Clay, light grayish-brown to light grayish-green, with caliche and thin, yellowish-brown, fine sand streaks	18	33
Clay, light-green, with a few hard layers	11	44
Clay, gray	31	75
Clay, dark olive-green	10	85
Sand, fine, gray, with grayish-yellow clay streaks	5	90
Sand, fine to medium, brown	11	101
Clay, sandy, light-brown, and caliche	17	118
Sand, fine to medium, brown	15	133
Sand, fine, silty, cemented, brown	5	138
Sand, fine to coarse, light-brown, with caliche layers and light-brown to light-gray clay layers	42	180
Sand, fine to coarse, light-brown, with cemented layers	22	202
Sand, fine to coarse	29	231
Sand, fine to coarse, and fine gravel, with cemented streaks	11	242
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Clay, sandy, light-brown, and caliche	14	256
Sand, fine to coarse, light-brown, with thin cemented layers	29	285
Clay, very sandy	7	292
Sand, fine to coarse	8	300
Clay, sandy, light-brown, with caliche and cemented streaks	25	325
Sand, fine to coarse, cemented	16	341
Clay, light-brown, with caliche and thin cemented sand streaks	33	374
CRETACEOUS SYSTEM		
Lower Cretaceous Series, undifferentiated		
Ironstone	1	375
Clay, yellow, light-gray, and light-brown, with some thin, hard, clay layers	25	400
Clay, very dark gray, with very hard streaks	80	480
Clay, light-gray, with hard clay streaks	30	510
Siltstone, hard, gray	4	514
Clay, dark-gray, with a few hard clay streaks	61	575
Clay, light-green	5	580
PERMIAN SYSTEM		
Upper Permian Series		
Big Basin Formation		
Sand, very fine, silty, reddish-brown	5	585
Sandstone, hard, reddish-brown, with a few thin reddish-brown clay layers	9	594

	Thickness (ft)	Depth (ft)
30-30W-19BAA—Drilled December 6, 1974. Altitude 2,815 ft.		
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Clay, silty, sandy, brown	5	5
Clay, light reddish-brown	5	10
Clay, light reddish-brown, with caliche	35	45
Clay, very sandy, gravelly, light reddish-brown, with caliche	21	66
Sand, fine to coarse, and fine gravel	7	73
Clay, sandy, light-brown, and caliche	6	79
Sand, fine to coarse, and fine gravel	7	86
Clay, sandy, light reddish-brown, with sand and caliche streaks	40	126
Clay, sandy, light-brown	27	153
Sand, fine, cemented, brown, with loose streaks	3	156
Sand, fine to coarse, silty, with a few clay streaks and hard-cemented sand streaks	70	226
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Caliche, hard	1	227
Sand, fine to coarse, and fine gravel	26	253
Clay, limy, varved, brown and white	2	255
Sand, fine	15	270
Sand, fine to coarse, and fine gravel	86	356
Sand, cemented, white, with gray clay	1	357
Sand, fine to coarse, and fine gravel	13	370
Clay, gray, with a little lignite	23	393
Sand, fine to coarse, and fine gravel, with a few thin lime-cemented streaks	7	400
Clay, gray	4	404
Sand, fine to coarse, and fine gravel, with a few thin lime-cemented streaks	26	430
Sand, fine to coarse, and fine gravel, with caliche and light-brown clay layers	65	495
Sand, fine to medium, silty, with clay and caliche streaks	20	515
Sand, fine to coarse, and ironstone	9	524
CRETACEOUS SYSTEM		
Lower Cretaceous Series, undifferentiated		
Clay, sticky, dark-gray	16	540
Clay, firm, silty, gray	9	549
Clay, firm, silty, light greenish-gray	16	565
PERMIAN SYSTEM		
Upper Permian Series		
Big Basin Formation		
Clay, firm, dark reddish-brown	20	585
Clay, firm, dark reddish-brown, and very fine grained, silty sandstone	15	600
32-26W-4AAB—Drilled August 3, 1977. Altitude 2,460 ft. Depth to water 88 ft (Ogallala Formation, 1978) and 79 ft (Upper Permian Series, 1978). Clarence Williams, landowner.		
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Topsoil	4	4
Clay, limy, light reddish-brown	1	5
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Caliche, white	3	8
Clay, light reddish-brown to reddish-brown, and caliche with hard streaks	15	23
Caliche and clay, light-brown, sandy, with gravel	9	32
Sand, fine to coarse, black and light-brown, and fine to coarse gravel	11	43
Caliche, soft, and brown to green clay	10	53
Sand, fine to coarse, and fine gravel	3	56
Clay, brown	1	57
Caliche, sandy to very sandy, white to brown ("mortar bed")	15	72
Caliche and clay, light reddish-brown	9	81
Caliche, hard	1	82
Caliche, soft, white, with light-brown clay streaks	35	117
Sand, fine to coarse; contains fine gravel	7	124
Sand, fine to coarse; contains ironstone and ironstone gravel with clay layers	32	156
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Kiowa Formation		

	Thickness (ft)	Depth (ft)
Clay, gray, with yellow clay streaks	3	159
Clay, dark-gray	2	161
Clay, black	3	164
Clay, very dark reddish-brown	8	172
Clay, gray	3	175
PERMIAN SYSTEM		
Upper Permian Series		
Big Basin Formation		
Clay, reddish-brown, and very sandy reddish-brown clay	12	187
Clay, dark reddish-brown, with hard sandstone streaks	8	195

PAWNEE COUNTY

20-17W-22DCC—Drilled April 4, 1978. Altitude 2,053 ft. Water levels 24 ft (Dakota Formation, 1978), +33 ft (Cheyenne Sandstone, 1978), and +35 ft (Upper Permian rocks, 1978). Bruce Wiessensee, landowner.

	Thickness (ft)	Depth (ft)
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Soil, caliche at base	6	6
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		
Clay, silty, yellowish-brown, with caliche	10	16
Clay, silty, light-brown, and very pale orange limestone	15	31
Clay, silty, light-brown, dark yellowish-orange, and very pale orange	25	56
Clay, pale yellowish-brown	16	72
Clay, dark reddish-brown	4	76
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, yellowish-brown, light olive-gray, and red mottled with gray	27	103
Clay, dark reddish-brown, light olive-gray, with a thin sandstone bed at about 108 ft	20	123
Clay, silty, red, yellow, and mottled-gray	3	126
Clay, dark brownish-gray	10	136
Sandstone, very fine grained, siliceous-cemented, dark yellowish-orange	1	137
Clay, olive-gray	13	150
Clay, moderate dark-gray	46	196
Clay, red with olive-gray mottles and olive-gray with dusky yellow	15	211
Clay, moderate dark-gray, and lignite (?)	13	224
Sandstone, very fine grained, brown	2	226
Clay, grayish-blue (possible shale), and some cemented, brown sandstone	11	237
Shale, stiff, grayish-blue	6	243
Shale, very stiff, moderate dark-gray	6	249
Shale, moderate dark-gray, with interbedded thin, brown sandstone layers	58	307
Sandstone, cemented, micaceous, very fine grained	2	309
Kiowa Formation		
Shale, medium dark-gray	66	375
Cheyenne Sandstone		
Shale, olive-gray and moderate dark-gray, and very fine grained well-cemented sandstone	2	377
Shale, moderate dark-gray, some pyrite near 387 ft	32	409
Sandstone, silty, very fine to fine-grained, some pyrite	10	419
Shale, pale bluish-green, and some silty shale	15	434
PERMIAN SYSTEM		
Upper Permian Series		
Whitehorse Formation		
Sandstone, very fine grained, silty, medium-brown, with some pyrite	2	436
Shale, silty, red to medium-brown	47	483

22-19W-7AAA—Drilled June 16, 1977. Altitude 2,100 ft. Water levels 64 ft (Dakota Formation, 1978) and +19 ft (Upper Permian rocks, 1978). Raymond Polson, landowner.

	Thickness (ft)	Depth (ft)
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Silt, sandy, clayey, dark-brown	6	6
Clay, light-brown	1	7
Clay, brown to light reddish-brown, with sandy clay	6	13
TERTIARY SYSTEM		
Pliocene and Miocene Series		
Ogallala Formation		

	Thickness (ft)	Depth (ft)
Clay, silty, light-brown to very light brown, with thin, fine to coarse, sand streaks	32	45
Clay, light-brown, with limy layers	40	85
Sand, coarse, and fine to medium gravel; contains ironstone chips	19	104
Clay, light reddish-brown	10	114
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, red to light-gray	6	120
Clay, red to gray, with yellow clay and silty sandstone	32	152
Sandstone, medium-grained, light- to dark-brown	40	192
Shale, hard, dark-gray, and light-gray hard siltstone	6	198
Clay, light-gray, with red clay; contains hard siltstone streaks	12	210
Clay, dark-gray, with lignite streaks	9	219
Kiowa Formation		
Clay, light-gray, dark-gray, and black, with hard siltstone and very fine grained sandstone layers	31	250
Cheyenne Sandstone		
Clay, light-gray to black, with thin, hard layers	150	400
Clay, dark-gray, with light greenish-gray clay	15	415
PERMIAN SYSTEM		
Upper Permian Series		
Whitehorse Formation		
Clay, light reddish-brown	5	420
Clay, dark reddish-brown, with sandstone streaks	14	434
Sandstone, silty, dark reddish-brown	4	438
Clay, dark reddish-brown	3	441
Sandstone, silty, dark reddish-brown	3	444
Clay, dark reddish-brown	1	445

RUSH COUNTY

17-17W-6ABB—Drilled April 25, 1978. Altitude 2,877 ft. Depth to water 183 ft (Dakota Formation, 1978) and 35 ft (Cheyenne Sandstone, 1978). Van Lippert, landowner.

QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Clay, silty, light-brown	3	3
Clay, very light brown to yellow, some white calcareous limestone	3	6
Clay, firm, calcareous, yellowish-brown	6	12
Clay, yellowish-brown, some white limestone	3	15
Clay, firm, chalky, light-yellow, and some orangish-brown limestone	5	20
Clay, firm, light-yellow, white limestone and clear "gypsum" crystals (?)	3	23
Sand, very fine, orangish-brown, cemented, and "ironstone"	2	25
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, very firm, calcareous, light-gray	3	28
Shale, loose, calcareous, black	7	35
Shale, silty, loose, black, with some firm "lignite"	1	36
Shale, silty, firm, black	7	43
Shale, silty, calcareous, black, with medium-firm shale	15	58
Shale, silty, firm, dark-gray	8	66
Shale, silty, dark-gray, with grayish-white noncalcareous chalky "bentonite" (?)	4	70
Shale, silty, grayish-black, firm	1	71
Greenhorn Limestone		
Shale, grayish-black, some chalky yellowish-brown limestone	4	75
Shale, silty, firm, calcareous, grayish-black	3	78
Shale, very firm, grayish-black, with grayish-white bentonite	3	81
Shale, calcareous, silty, very firm, grayish-black	9	90
Shale, clayey, medium-firm, calcareous, grayish-black	9	99
Graneros Shale		
Shale, clayey, firm, grayish-black, with bentonite	6	105
Shale, silty, very firm, grayish-black, calcareous; 50% light-gray bentonite	2	107
Shale, grayish-black, with some bentonite	3	110
Shale, silty, very firm, grayish-black and gray, with noncalcareous gray shale and some bentonite	1	111
Shale, clayey, loose, grayish-black	1	112
Shale, clayey, medium-firm, grayish-black, with bentonite	3	115

	Thickness (ft)	Depth (ft)
Shale, clayey, loose, grayish-black	8	123
Shale, clayey, firm, grayish-black	3	126
Shale, clayey, medium-firm, grayish-black, with bentonite	9	135
Shale, clayey, firm to loose, grayish-black, with bentonite	15	150
Shale, clayey to silty, firm to loose, grayish-black, with some bentonite	15	165
Shale, clayey to silty, firm to loose, grayish-black, and hard (possibly fractured) shale	15	180
Shale, clayey to silty, loose, calcareous, grayish-black	2	182
Shale, clayey, loose, grayish-black, with bentonite	8	190
Shale, grayish-black, no bentonite	5	195
Shale, grayish-black, with a few pieces of yellowish-brown loose, chalky shale	24	219
Lower Cretaceous Series		
Dakota Formation		
Shale, clayey, loose, grayish-black, with light-gray bentonite and firm lignite	21	240
Clay, sticky, gray, with small amount of lignite and bentonite	12	252
Clay, sticky, gray and reddish-orange, and lignite	3	255
Clay, loose, gray to yellowish-brown, and lignite	10	265
Shale, loose to firm, light- to dark-gray, with some loose, yellowish-brown clay and reddish-pink clay	5	270
Shale, clayey, loose to firm, light- to dark-gray, and yellowish-brown, medium-firm, noncalcareous clay	3	273
Clay, light-gray, with clayey dark-gray shale and some yellowish-brown and reddish-pink clay	9	282
Clay, light-gray, with clayey, dark-gray shale and reddish-pink, loose, noncalcareous clay	20	302
Clay, light-gray, with dark-gray, firm shale, reddish-pink clay, lignite, and a few light-tan, noncalcareous sandstone fragments	1	303
Clay, light-gray and pinkish-red, and dark-gray shale	7	310
Clay, light-gray, pinkish-red, and light-tan, and clayey, dark-gray loose to firm shale	5	315
Clay, light-gray, pinkish-red, and light-tan, and clayey, dark-gray loose shale	15	330
Clay, silty, light-gray, medium-gray, and red	15	345
Clay, silty, light- and medium-gray, with lignite and some hard chips of shale	15	360
Clay, silty, gray and reddish-pink, and medium-gray, firm shale	15	375
Clay, gray, silty, and dark-gray, firm to very firm shale	15	390
Clay, silty to sandy, gray, and dark-gray, friable shale	8	398
Clay, silty to sandy, gray and reddish-orange, and dark-gray, friable shale	2	400
Clay, silty to sandy, gray, with off-white bentonite, lignite, and light- to dark-gray, medium-firm, silty to clayey shale	5	405
Clay, silty and sandy, light-gray, light-tan, and reddish-pink, and clayey, dark-gray friable shale	1	406
Kiowa Formation		
Shale, clayey, light- to dark-gray, and firm to loose, very light tan and gray clay	4	410
Shale, light- to dark-gray	5	415
Clay, gray, and friable shale	5	420
Clay, light-gray and light-tan	5	425
Clay, silty, light-gray, with dark-gray, very firm to hard shale and some very hard and very fine, noncalcareous sandstone chips	5	430
Clay, silty, light-gray, red, green, and light-tan	5	435
Clay, silty, gray, and very firm gray shale	3	438
Clay, silty, gray, with chalky, light-tan clay and silty, gray, very firm shale	2	440
Clay, light-gray and red, and gray, very firm shale	5	445
Clay, gray, with clayey, gray, medium-firm shale and occasional hard, buff, fine-grained sandstone	5	450
Clay and shale, silty, firm to medium-firm, slightly sandy; contains light-gray clay and firm, noncalcareous shale	12	462
Clay, light-gray, and firm, noncalcareous shale	3	465
Cheyenne Sandstone		
Clay, light-gray, with silty, very hard, very fine grained, buff sandstone and black, firm shale	3	468
Shale, clayey, light-gray	12	480
Shale, gray, with hard shell streaks	15	495
Shale, gray; contains very fine grained, soft-white sandstone and hard, dark-gray sandstone	15	510
Shale, gray, and lesser amounts of very fine grained, soft-white and dark-gray, hard sandstone	32	542

TABLE 8—Water levels in observation wells. Measurements made in wells constructed by the U.S. Geological Survey and drilled by the Kansas Geological Survey. Altitudes are given in feet above sea level. Depths of wells are given in feet; water levels to the nearest 0.1 ft above (+) or below (−) land surface; specific conductance in micromho per centimeter at 25°C (μmho/cm at 25°C); and flow in gallons per day (gal/d).

EDWARDS COUNTY

24-20W-9DCD—Mrs. L. J. Lanfenberg, artesian observation well in a sandstone in the Dakota Formation, diameter 2 inches, screened interval 128–132 ft, casing depth 136 ft. Measuring point—top of casing at land-surface altitude of 2,250 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Aug. 17, 1978	−52.7	—	—	—	—
Dec. 14	−52.8	—	—	—	—
May 22, 1979	−52.2	—	—	—	—
Sept. 12	−52.1	—	—	—	—
Sept. 27	−52.3	—	—	—	—

24-20W-9DCD2—Mrs. L. J. Lanfenberg, artesian observation well in a sandstone in the Cheyenne Sandstone, diameter 2 inches, screened interval 535–539 ft, casing depth 556 ft. Measuring point—top of casing at land-surface altitude of 2,250 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
May 24, 1978	−50.4	—	—	—	—
Dec. 14	−50.4	—	—	—	—
May 22, 1979	−49.9	—	—	—	—
Sept. 27	−49.9	—	—	—	—

FORD COUNTY

28-22W-30BCCA—Everette Copeland, artesian observation well in a siltstone in Permian rocks, diameter 2 inches, screened interval 517–520 ft, casing depth 525 ft. Measuring point—top of casing 0.5 ft above land-surface altitude of 2,490 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Dec. 14, 1978	−165.9	—	—	—	—
May 23, 1979	−153.9	—	—	—	—
Sept. 10	−151.2	—	—	—	—
Sept. 27	−150.9	—	—	—	—

28-22W-30BCCA2—Everette Copeland, artesian observation well in a sandstone in Cheyenne Sandstone, diameter 1 inch, screened interval 425–445 ft, casing depth 445 ft. Measuring point—top of casing 1.1 ft above land-surface altitude of 2,490 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Dec. 14, 1978	−147.4	—	—	—	—
May 23, 1979	−151.9	—	—	—	—

28-26W-29BAD—Austin Bentzer, artesian observation well in a sandstone in the Dakota Formation, diameter 2 inches, screened interval 569–573 ft, casing depth 593 ft. Measuring point—top of casing at land-surface altitude of 2,680 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Aug. 17, 1978	−180.4	—	—	—	—
Dec. 15	−181.1	—	—	—	—
May 23, 1979	−181.6	—	—	—	—
Sept. 11	−181.8	—	—	—	—
Oct. 3	−182.0	—	—	—	—

28-26W-29BAD2—Austin Bentzer, artesian observation well in a sandstone in the Dakota Formation, diameter 2 inches, screened interval 451–455 ft, casing depth 455 ft. Measuring point—top of casing at land-surface altitude of 2,680 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Aug. 17, 1978	−170.5	—	—	—	—
Dec. 15	−171.2	—	—	—	—
May 23, 1979	−171.9	—	—	—	—
Sept. 11	−172.2	—	—	—	—
Oct. 3	−172.4	—	—	—	—

GRAY COUNTY

25-29W-21CDA—C. L. and A. Strawn, artesian observation well in a sandstone in the Dakota Formation, diameter 2 inches, screened interval 370–371 ft, casing depth 405 ft. Measuring point—top of pipe at land-surface altitude of 2,707 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Oct. 4, 1978	−141.0	—	—	—	—
Dec. 14	−142.5	—	—	—	—
May 27, 1979	−145.0	—	—	—	—
Sept. 11	−146.3	—	—	—	—
Oct. 2	−146.4	—	—	—	—

25-29W-21CDA2—C. L. and A. Strawn, artesian observation well in a sandstone in the Kiowa Formation, diameter 2 inches, screened interval 551-555 ft, casing depth 655 ft. Measuring point—top of casing 0.4 ft above land-surface altitude of 2,707 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Dec. 14, 1978	−167.8	—	—	—	—
May 23, 1979	−168.0	—	—	—	—
Sept. 11	−167.5	—	—	—	—
Oct. 2	−167.5	—	—	—	—

MEADE COUNTY

30-26W-1BCD—Norman Hatfield, artesian observation well in a siltstone in the Permian rocks, diameter 2 inches, screened interval 455-457 ft, casing depth 465 ft. Measuring point—top of casing 0.3 ft above land-surface altitude of 2,545 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Dec.15, 1978	−121.4	—	—	—	—
May 23, 1979	−118.3	—	—	—	—
Sept. 18	−125.4	—	—	—	—
Sept. 28	−125.5	—	—	—	—

30-26W-1BCD2—Norman Hatfield, artesian observation well in a sandstone in the Dakota Formation, diameter 1 inch, screened interval 275-290 ft, casing depth 290 ft. Measuring point—top of casing 0.2 ft above land-surface altitude of 2,545 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Dec. 15, 1978	−63.4	—	—	—	—
May 23, 1979	−63.3	—	—	—	—
Sept. 18	−64.2	—	—	—	—
Sept. 27	−64.2	—	—	—	—

32-26W-4AAB—Clarence Williams, artesian observation well in a shale in the Permian rocks, diameter 2 inches, screened interval 191-195 ft, casing depth 195 ft. Measuring point—top of casing 0.6 ft above land-surface altitude of 2,460 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Dec. 15, 1978	−79.4	—	—	—	—
May 23, 1979	−78.3	—	—	—	—
Sept. 18	−78.0	—	—	—	—
Oct. 3	−78.9	—	—	—	—

PAWNEE COUNTY

20-17W-22DCC—Bruce Wiessensee, artesian observation well in a siltstone in Permian rocks, diameter 2 inches, screened interval 464-465 ft, casing depth 480 ft. Measuring point—top of pipe at land-surface altitude of 2,053 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Apr. 4, 1978	flow	—	—	—	—
Dec. 13	+35.4	12.5	—	41,000	420
May 22, 1979	+37.5	15.0	7.5	51,000	550
Aug. 17	+35.4	18.5	7.4	60,000	520
Sept. 26	+35.5	21.5	7.5	50,000	—

20-17W-22DCC2—Bruce Wiessensee, artesian observation well in a sandstone in the Cheyenne Sandstone, diameter 2 inches, screened interval 409-410 ft, casing depth 410 ft. Measuring point—top of casing at land-surface altitude of 2,053 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Apr. 13, 1978	flow	—	—	—	—
Dec. 13	+33.1	13.0	—	53,000	820
May 22, 1979	+32.9	13.0	7.15	55,000	1,070
Aug. 17	+35.4	14.0	7.10	60,000	950
Sept. 26	+32.3	21.0	7.10	53,000	—

20-17W-22DCC3—Bruce Wiessensee, artesian observation well in a sandstone in the Dakota Formation, diameter 2 inches, casing depth 110 ft. Measuring point—top of casing at land-surface altitude of 2,053 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Aug. 17, 1978	−23.6	—	—	—	—
Dec. 13	−24.4	—	—	—	—
May 22, 1979	−24.3	—	—	—	—
Aug. 17	−24.5	—	—	—	—
Sept. 26	−24.5	—	—	—	—

22-19W-7AAA—Raymond Polson, artesian observation well in a sandstone in the Dakota Formation, diameter 1.5 inches, screened interval 159–165 ft, casing depth 165 ft. Measuring point—top of casing at land-surface altitude of 2,100 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
June 14, 1977	−60.4	—	—	—	—
Dec. 13, 1978	−64.5	—	—	—	—
May 22, 1979	−67.4	—	—	—	—
Aug. 17	−100.1	—	—	—	—
Sept. 27	−92.0	—	—	—	—

22-19W-7AAA2—Raymond Polson, artesian observation well in a siltstone in Permian rocks, diameter 2 inches, screened interval 421–425 ft, casing depth 435 ft. Measuring point—top of casing at land-surface altitude of 2,100 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
June 16, 1977	flow	—	—	—	Trace
Dec. 14, 1978	+19.2	9.0	—	835	Trace
May 22, 1979	+27.3	28.0	7.15	640	9
Aug. 17	+19.2	30.0	7.60	2,250	Trace
Sept. 27	+16.6	—	—	—	—

RUSH COUNTY

17-17W-6ABBA—Van Lippert, artesian observation well in a sandstone in the Cheyenne Sandstone, diameter 2 inches, screened interval 509–510 ft, casing depth 510 ft. Measuring point—top of casing at land-surface altitude of 2,089 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Aug. 17, 1978	−35.3	—	—	—	—
Dec. 14	−35.5	9.0	—	1,130	—
May 22, 1979	−35.6	—	—	—	—
Aug. 17	−32.6	—	—	—	—
Sept. 27	−35.9	—	—	—	—

17-17W-6ABBA2—Van Lippert, artesian observation well in a sandstone in the Dakota Formation, diameter 1 inch, casing depth 220 ft. Measuring point—top of casing at land-surface altitude of 2,089 ft.

Date	Water level (ft)	Temperature (°C)	pH	Specific conductance (μmho/cm at 25°C)	Flow (gal/d)
Aug. 17, 1978	−183.2	—	—	—	—
Dec. 14	−183.8	—	—	—	—
May 22, 1979	−183.4	—	—	—	—
Aug. 17	−183.5	—	—	—	—
Sept. 27	−183.5	—	—	—	—

TABLE 9—Chemical analyses of water from selected wells. Analyses by Kansas Department of Health and Environment, except as indicated. Dissolved constituents and hardness given in milligrams per liter (mg/L) or micrograms per liter (μg/L); specific conductance in micromho per centimeter at 25°C (μmho/cm at 25°C); depth of well given in ft below land surface. Geologic source—**Kd**, Dakota Formation; **Kch**, Cheyenne Sandstone; and **Pu**, undifferentiated Permian rocks. SAR, sodium-adsorption ratio.

Well number	Depth (ft)	Geologic source	Date of collection	Temperature (°C)	Dissolved solids (evaporated at 180°C; mg/L)	Silica (SiO_2; mg/L)	Iron (Fe; μg/L)	Manganese (Mn; μg/L)	Calcium (Ca; mg/L)	Magnesium (Mg; mg/L)	Sodium (Na; mg/L)	Potassium (K; mg/L)	Carbonate (CO_3; mg/L)	Bicarbonate (HCO_3; mg/L)
EDWARDS COUNTY														
24-20W-9DCD2	556	Kch	9-27-79	16	734	16	—	—	8.0	2.9	240	27	0	450
ELLIS COUNTY														
15-10W-33BAA	154	Kd	7-13-78	21	—	9.2	60	40	30	120	740	13	0	310
FINNEY COUNTY														
24-33W-19DBD[1]	700	Kd	2-2-77	—	252	14	150	50	43	12	43	2.8	—	—
HODGEMAN COUNTY														
22-24W-34CDC	416	Kd	8-25-78	20	509	2.3	40	10	19	8.9	160	8.0	0	280
24-23W-34AAD	120	Kd	10-28-77	16	423	32	70	140	57	32	43	7.0	0	320
HAMILTON COUNTY														
21-40W-31CCC	902	Kd	8-31-78	20	428	3.3	—	—	6.4	2.0	150	5.0	7	270
MEADE COUNTY														
30-26W-1BCD	465	Pu	9-28-79	16.5	89	14	—	—	9.6	1.0	14	4.0	0	61
30-26W-1BCD2	290	Kd	9-28-79	15.5	265	30	—	—	24	2.0	47	11	0	51
NESS COUNTY														
19-23W-1CCB	450	Kd	9-8-78	19	677	3.8	—	—	8.0	2.0	240	6.0	0	250
PAWNEE COUNTY														
20-17W-22DCC	480	Pu	8-17-79	18.5	47,400	11	—	—	776	838	16,200	64	0	327
20-17W-22DCC2	410	Kch	8-17-79	14	51,000	9.0	—	—	796	709	17,400	60	0	349
20-17W-22DCC3	110	Kd	9-26-79	14.5	685	7.0	—	—	61	23	150	7.0	0	290
22-19W-7AAA2	435	Pu	9-27-79	15.5	417	26	—	—	85	15	44	6.0	0	370
RUSH COUNTY														
17-17W-06ABBA	510	Kch	9-27-79	14.5	192	8.0	—	—	42	1.8	16	9.0	0	120
17-20W-30CCB	325	Kd	7-6-78	22	—	—	—	—	66	52	430	14	0	270
STANTON COUNTY														
27-39W-13ACB	508	Kd	8-10-78	20	577	13	10	0	94	34	48	5.0	0	260
29-42W-24CCC	515	Kd	9-14-78	17	355	9.2	10	0	53	22	37	5.0	0	200
WICHITA COUNTY														
18-37W-24CCCA[2]	1,050	Kch	5-12-78	—	—	13	170	100	5.3	2.6	365	5.8	14	350

Well number	Sulfate (SO_4; mg/L)	Chloride (Cl; mg/L)	Fluoride (F; mg/L)	Nitrate (NO_3; mg/L)	Hardness as $CaCO_3$ (mg/L) Total (Ca, Mg)	Hardness as $CaCO_3$ (mg/L) Noncarbonate	SAR	Specific conductance (μmho/cm at 25°C)	pH
EDWARDS COUNTY									
24-20W-9DCD2	29	190	—	—	32	0	18	1,350	8.0
ELLIS COUNTY									
15-10W-33BAA	270	850	4.4	2.7	120	0	14	3,200	7.7
FINNEY COUNTY									
24-33W-19DBD[1]	81	8.8	—	0.02	—	—	—	—	8.5
HODGEMAN COUNTY									
22-24W-34CDC	120	55	2.8	0.4	84	0	7.6	890	7.9
24-23W-34AAD	67	30	2.6	0.9	270	20	1.1	780	7.2
HAMILTON COUNTY									
21-40W-31CCC	110	13	2.1	0.4	24	0	13	710	8.4
MEADE COUNTY									
30-26W-1BCD	9.0	7.0	—	0.1	28	0	1.1	115	7.1
30-26W-1BCD2	58	55	—	2.9	68	26	2.5	510	10.2
NESS COUNTY									
19-23W-1CCB	130	160	3.4	0.4	28	0	20	1,280	8.0
PAWNEE COUNTY									
20-17W-22DCC	3,360	26,200	3.2	0.1	4,560	268	104	60,000	7.4
20-17W-22DCC2	3,700	28,200	3.2	0.1	4,900	286	108	60,000	7.4
20-17W-22DCC3	145	145	—	0.1	250	11	4.2	1,850	7.7
22-19W-7AAA2	21	40	—	0.1	270	0	1.2	725	7.9
RUSH COUNTY									
17-17W-06ABBA	17	28	—	2.2	110	12	0.7	325	7.5
17-20W-30CCB	650	—	—	—	380	160	9.6	2,340	6.8
STANTON COUNTY									
27-39W-13ACB	230	21	1.2	6.6	370	160	1.1	870	7.4
29-42W-24CCC	93	18	1.6	7.5	220	41	1.1	570	7.5
WICHITA COUNTY									
18-37W-24CCCA[2]	500	63	3.0	—	24	—	184	1,790	8.4

[1]Analysis by Burns and McDonnell, Kansas City, Missouri
[2]Analysis by Wilson Laboratories, Salina, Kansas.

Appendix A

Conversion factors

For those readers who may prefer to use metric rather than the inch-pound units used in this report, the factors for converting to the International System of Units (SI) and abbreviations are listed below:

Multiply inch-pound unit	by	To obtain SI unit
	Length	
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
acre-foot	1,233	cubic meter (m^3)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
	Flow	
gallon per minute (gal/min)	0.000063	cubic meter per second (m^3/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
	Temperature	
degree Fahrenheit (°F)	5/9 (°F − 32)	degree Celsius (°C)
	Specific conductance	
micromho per centimeter at 25° Celsius (μmho/cm at 25°C)	1.000	microsiemens per centimeter at 25° Celsius (μS/cm at 25°C)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. "NGVD of 1929" is referred to as sea level in this report.

Appendix B

Definition of terms

Anticline—A structural fold in rocks where strata are convex upward.

Aquifer—A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Artesian aquifer—An aquifer containing ground water under pressure significantly greater than atmospheric. Its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the material in which the artesian ground water occurs.

Artesian well—A well deriving its water from an artesian aquifer. The water level stands above the top of the artesian water body in an artesian well.

Borehole geophysics—All techniques of lowering sensing devices down a well or test hole and recording some physical measurement that may be interpreted in terms of the physical characteristics of the rocks, the fluid contained in the rocks, and the construction of the well.

Classification of water for irrigation—(definitions were developed by the U.S. Salinity Laboratory Staff, 1954).

Low-salinity water (C1)—Water can be used for irrigation with little likelihood that soil salinity will develop.

Medium-salinity water (C2)—Water can be used if a moderate amount of leaching occurs.

High-salinity water (C3)—Water cannot be used on soils with restrictive drainage; special management for salinity control may be required; and plants with good salt tolerance should be selected.

Very high salinity water (C4)—Water is not suitable for irrigation purposes under ordinary conditions.

Low-sodium water (S1)—Water can be used for irrigation with little danger of the development of harmful levels of exchangeable sodium in the soil.

Medium-sodium water (S2)—Water will present an appreciable sodium hazard in fine-textured soil that has a high cation-exchange capacity, unless gypsum is present in the soil. This water can be used on coarse-textured or organic soils with good permeability.

High-sodium water (S3)—Water may produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching, and organic conditions.

Very high sodium water (S4)—Water is generally unsatisfactory for irrigation purposes except at low and perhaps medium-salinity levels.

Confining bed—A body of "impermeable" material stratigraphically adjacent to one or more aquifers.

Deflocculate—To convert into very fine particles.

Digital model—A simplified mathematical representation of a complex system, in which a computer program is used to solve ground-water-flow equations.

Formation—A body of rock that can be mapped or traced and is generally characterized by some degree of internal lithologic homogeneity or distinctive lithologic features.

Freshwater—For the purpose of this report, water containing less than 1,000 milligrams per liter of dissolved solids.

Geohydrologic unit—An aquifer, a confining bed, or a combination of aquifers and confining beds that comprise a framework for a reasonably distinct hydraulic system.

Hardness of water—A property of water generally related to its soap-consuming capacity; it is caused by the presence of polyvalent cations in the water that form insoluble compounds with soap. Hardness is reported in terms of an equivalent concentration of calcium bicarbonate.

Hardness classification (from Hem, 1970)	*Hardness range (milligrams per liter of calcium carbonate)*
soft	0–60
moderately hard	61–120
hard	121–180
very hard	more than 180

Hydraulic conductivity—The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic gradient—The change in static head per unit of distance in a given direction.

Hydraulic head—Height of the potentiometric surface of an aquifer above a given subsurface point.

Hydrograph—A graph showing some property of water with respect to time, such as the hydraulic head measured in a well.

Lenticular—Shaped like a double convex lens, thick in the middle and thinning at the edges.

Piezometer—A special well in a selected location for observing fluid level and pressure changes.

Porosity—The ratio of the aggregate volume of interstices or voids in a rock or soil to its total volume, usually stated as a percentage.

Potable water—Water that is palatable and fit for human use; water that has been treated so as to be tolerably low in objectionable taste, odor, color, and turbidity, and of a temperature suitable for the intended use.

Potentiometric surface—A surface that represents the static head. It is defined by the levels to which water will rise in tightly cased wells.

Recharge—Amount of water added to the zone of saturation.

Resistivity—The resistance to the flow of electrical current through material. The electrical resistivity of a rock depends on physical properties of the rock and the fluids it contains.

Saline water—Water containing 1,000 milligrams per liter or more of dissolved solids.

Classification of saline water (from Hem, 1970)	*Dissolved solids (milligrams per liter)*
slightly saline	1,000–3,000
moderately saline	3,000–10,000
very saline	10,000–35,000
briny	more than 35,000

Saturated thickness—That amount of a water-bearing material in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

Semiconfined aquifer—Aquifer in which semiartesian conditions exist. Confining beds leak water either to or from the aquifer.

Sodium-adsorption ratio (SAR)—Related to the adsorption of sodium from water by the soil to which the water has been added. It is determined by the following relation where ion concentrations of sodium (Na^{+}), calcium (Ca^{+2}), and magnesium (Mg^{+2}) are expressed in milliequivalents per liter:

$$SAR = \frac{(Na^{+})}{([(Ca^{+2}) + (Mg^{+2})]/2)^{1/2}}$$

Specific conductance—The ability of a substance to conduct an electric current. It is the conductance of a body of unit length and unit cross section at a specified temperature. Specific conductance can be used as a measure of the concentration of dissolved solids in a water sample.

Spontaneous potential—An electrical method in which a spontaneous electrical field is developed between the borehole fluid and the surrounding rock material.

Storage coefficient—Volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Syncline—A structural fold in rocks where strata are concave upward.

Transmissivity—The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Unconfined aquifer—An aquifer having a water table.

Water table—The potentiometric surface in an unconfined aquifer at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the aquifer enough to hold standing water.

Sheets 1 and 2

(in back pocket)