Geology and Ground-Water Resources of Baca County, Colorado

By THAD G. McLAUGHLIN

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GEOLOGY AND GROUND-WATER RESOURCES OF BACA COUNTY, COLORADO

By THAD G. McLAUGHLIN

ABSTRACT

The report describes the geology and ground-water resources of Baca County in the southeastern corner of Colorado. The county has an area of 2,577 square miles and, in 1950, had a population of 7,947. It consists largely of relatively flat plains but locally has undulating sand-dune areas, shallow valleys, and, in the northwestern and southwestern parts, deep canyons. The climate is semiarid, the average annual precipitation being about 16 inches. Farming and stockraising are the principal occupations in the county.

Most of the exposed rocks in the county are of Tertiary and Quaternary age, although rocks as old as Permian crop out locally. The Ogallala formation and younger deposits including the Meade(?) formation, alluvium, and dune sand underlie more than three-fourths of the county. The remainder of the county is underlain largely by Mesozoic rocks of Triassic, Jurassic, and Cretaceous age. The Ogallala formation yields water to domestic and stock wells in a large part of the county and locally is capable of yielding large quantities of water. The Dakota sandstone furnishes water for many domestic and stock wells and for a few municipal wells. The Cheyenne sandstone member of the Purgatoire formation yields water to many domestic and stock wells and to a few municipal and industrial wells. In the vicinity of Walsh, flowing wells obtain water from the Cheyenne sandstone member. The report contains a map and diagrammatic cross section showing the distribution of these rock formations.

The report contains a map showing by means of contours the depth to water table in part of the county. The water table ranges in depth from less than 10 feet in the valley of the Cimarron River to more than 300 feet in the southwestern part of the county. The report also contains maps showing by means of contours the shape and slope of the water table in the Ogallala formation and of the piezometric surfaces of water in the Dakota sandstone and the Cheyenne sandstone member of the Purgatoire formation. These maps show that the water in all three aquifers moves generally eastward across the country.

The ground-water reservoir is recharged principally from rain and snow that fall within the area, by percolation from intermittent streams and depressions, and by underground movement from adjacent areas. Ground water is discharged from the ground-water reservoir by movement into adjacent areas to the south and east, by evaporation and transpiration in areas of shallow water table, by seepage into perennial streams, and through wells.

Most of the wells in Baca County are drilled, but a few are dug or driven. Of the more than 400 wells listed in the report, only a few are used for irrigation. These include many small flowing wells and a few large-capacity pumped wells—all in the Walsh area. The areas most favorable for the development of irrigation from wells are in the southeastern and northeastern parts of the county.

Ground water in Baca County generally is hard but is suitable for most ordinary uses. Water from the Ogallala formation is of fairly uniform quality, whereas the quality of the water from the Cheyenne sandstone member of the Purgatoire formation and from the Dakota sandstone may range between wide limits and may contain excessive amounts of iron and fluoride.

The field data upon which most of this report is based are given in tables; they include records of 434 wells and springs and chemical analyses of the water from 60 wells and springs. Logs of 144 test holes, water wells, oil and gas tests, and seismograph shot-holes in the area are given, including 18 test holes drilled as a part of this investigation.

INTRODUCTION

Purpose and scope of the investigation.—An investigation of the geology and ground-water resources of Baca County, Colo., was begun in June 1947 as a part of the program of ground-water investigations being made in Colorado in cooperation between the Colorado Water Conservation Board and the United States Geological Survey. The project was begun with the view of determining the origin, movement, and availability of ground water for domestic, stock, industrial, irrigation, and public supplies. The program is under the general administration of Judge Clifford H. Stone, director of the Colorado Water Conservation Board, and A. N. Sayre, chief of the Ground Water Branch of the U. S. Geological Survey. The investigation in Baca County was under the direct supervision of S. W. Lohman and the writer, successive district geologists in charge of ground-water investigations in Colorado.

Details as to the scope of the investigation were worked out in conferences with Messrs. Stone and Lohman. Mr. Lohman visited the writer in the field and has been in constant touch with the progress of the work.

Ground water is one of the principal natural resources of Baca County, for nearly all water supplies in the area are obtained from wells and springs. There is, therefore, a need for an adequate understanding of ground water in order to facilitate its safe development.

Location and extent of the area.—Baca County is largely in the High Plains section of the Great Plains physiographic province. It is the southeasternmost county in Colorado and lies between 37°00'00'' and 37°38'34'' north latitude and between 102°02'38'' and 103°05'09'' west longitude (fig. 1). The county contains 80 townships, some of which are small, and has an area of 2,577 square miles. The location of Baca County and of other areas in Colorado in which cooperative ground-water studies have been made or are in progress is shown in figure 1.

Previous investigations.—The geology and ground-water resources of part of Baca County were described briefly by Gilbert (1896a) in his report on the Arkansas River Valley in eastern Colorado. Johnson (1901, 1902) later discussed the utilization of the High Plains, including the greater part of Baca County. The northern and northwestern parts of the county were described in Darton's report (1906) of the geology and underground-water resources of the Arkansas River Valley in eastern Colorado, and all of Baca County was discussed in his more comprehensive report on the geology and underground-water resources of the central Great Plains (1905b).

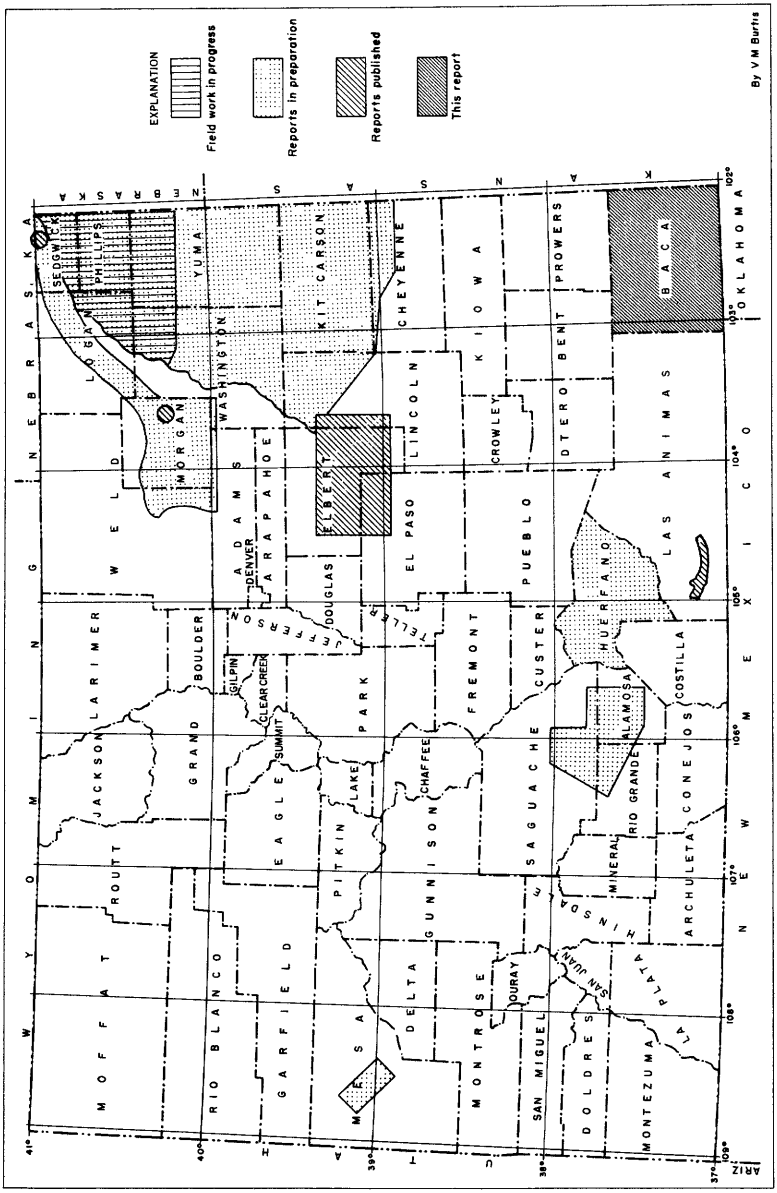

Figure 1. —Index map of Colorado showing area covered by this report and areas in which ground-water studies have been made or are in progress.

No comprehensive report of the geology or ground-water resources of Baca County had been published at the time this investigation was begun, although many petroleum geologists have made detailed studies of several parts of the county. Unfortunately, little of that information is available. Detailed studies have been made of the geology and ground-water resources of several adjoining areas, including Cimarron County, Okla. (Schoff and Stovall, 1943), Texas County, Okla. (Schoff, 1939), Morton and Hamilton Counties, Kans. (McLaughlin, 1942, 1943), and Stanton County, Kans. (Latta, 1941).

Methods of investigation.—The field work upon which this report is based was done from June 1947 to December 1947 and from July 1948 to December 1948. The writer was assisted by William R. Smith from June 1947 to September 1947 and by William M. Chapman during August and part of September 1948. Records of 434 wells and springs were obtained during the investigation. The depths of and the water levels in most of the wells were measured by means of a steel tape, the measurements being made from the top of the casing or some other fixed point. Reported depths and reported water levels of the other wells were obtained from well owners, tenants, and drillers, or from well records compiled in the 1930's by the Works Projects Administration. Data on the character and thickness of water-bearing materials, the yield and drawdown of wells, and the general quality of the water were obtained from the same sources.

Samples of water were collected from 60 wells and springs in the area and were analyzed to determine their mineral content. The samples were analyzed in the chemical laboratory of the Quality of Water Branch of the U. S. Geological Survey at Salt Lake City, Utah.

Information on the geology and ground-water resources of the area was supplemented by the drilling of 18 test holes in strategic areas where few or no data were available. Cuttings from the test holes were collected and were studied by William M. Chapman and by the writer. More than 500 additional logs of wells, test holes, and seismograph shotholes were obtained from well owners, drillers, and oil companies.

Flow tests were made on several of the flowing artesian wells north and northeast of Walsh with the assistance of William R. Smith and William J. Powell in order to determine the coefficients of transmissibility and storage of the artesian aquifer. The method used was that originated by Jacob and Lohman (1952). The pressure heads of the wells were measured with a mercury manometer designed and constructed by Mr. Lohman.

The geologic formations, except dune sand, were mapped by the writer using aerial mosaics and aerial contact prints and the data were then transferred to a base map by means of a Vertical Sketchmaster. The data on distribution of dune sand were taken from soil maps prepared by the U. S. Soil Conservation Service and transferred to the geologic map by W. D. E. Cardwell and V. M. Burtis (pl. 1).

Other field data were compiled on quadrangle highway maps prepared by the State Highway Department. The base map for plate 1 was prepared from two sources: (1) Soil Conservation Service soil maps which were prepared from aerial contact prints and which covered all but the northeast quarter of the county, and (2) State Highway Department quadrangle maps, with some revision of drainage by means of aerial photographs. The wells shown on plate 1 were located within the sections by means of an odometer and their position should be accurate to within 0. 1 mile. The wells are numbered by townships from north to south and by ranges from east to west, and within a township the wells are numbered in the same order as the sections. For each well shown on plate 1 the number above the line corresponds to the number of the well in the well table (table 9) and brackets around this number indicate that an analysis of the water from that well is given in table 6. The number below the line is the depth to water level below the land surface.

The altitudes of wells and test holes were determined by a level crew headed by V. M. Burtis.

Acknowledgments.—The writer extends his thanks to Osa Packard, Wilbur Tolbert, James Thompson, H. McMurtry, and Felix Mondell, who supplied information on their wells and gave permission to run flow tests on their flowing artesian wells. He is grateful also to the city officials of Springfield, Walsh, Pritchett, and Campo who supplied information on the municipal water supplies in the county. The writer was particularly fortunate in obtaining more than 700 logs of wells, test holes, and seismograph shotholes in Baca County. For most of these the writer is indebted to the following drillers and organizations; L. F. Collins, C. F. Robins, and L. C. Williamson (pioneer drillers in Baca County), to R. L. Weeks, and to Western Drilling Co., Atchison, Topeka and Santa Fe Railway Co., U. S. Soil Conservation Service, Skelly Oil Co., California Co., Stanolind Oil and Gas Co., Phillips Petroleum Co., and Shell Oil Co. Thanks are extended to Edward Bloesch, consulting geologist, who spent several days in the field with the writer in the spring of 1947 familarizing him with the geology of the area, to Harry W. Oborne, consulting geologist, for many helpful suggestions, and to B. H. Williams of the U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering for geologic interpretation of the Baca County soils map.

The manuscript of this report has been reviewed critically by Judge Clifford H. Stone, R. M. Gildersleeve, and R. J. Tipton of the Colorado Water Conservation Board, among others.

GEOGRAPHY

Topography and drainage.—Baca County lies entirely within the Great Plains physiographic province. Most of the county is in the High Plains section but parts of southwestern and northwestern Baca County are in the Raton section and some of northwestern and south-central Baca County is in the Colorado Piedmont section. The area ranges in altitude from about 5,175 feet on Carrizo Mesa to about 3,485 feet where the Cimarron River leaves the county. The total relief, therefore, is almost 1,700 feet.

That part of Baca County lying in the High Plains section is underlain by unconsolidated Tertiary and Quaternary sediments. It consists of a nearly flat plain slightly dissected by small intermittent streams (figs. 4, 5, 6) and rather deeply dissected by the Cimarron River and some of its tributaries (fig. 3). In parts of

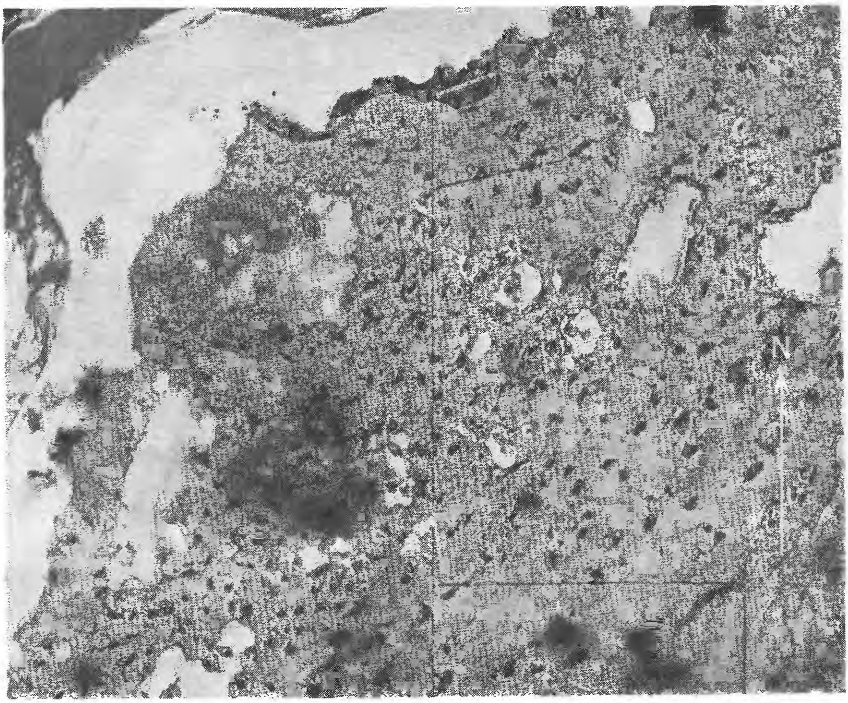

Figure 2.—Aerial photograph of sand-dune area southeast of the Cimarron River. Note lack of development of a drainage system among the dunes. Dark spots are undrained depressions. Photograph by the U. S. Department of Agriculture.

Figure 3.—Aerial photograph showing well-developed drainage in bedrock formations in southeastern Baca County; note the flood plain of Furnish Creek and the steep canyon walls. Photograph by the U. S. Department of Agriculture.

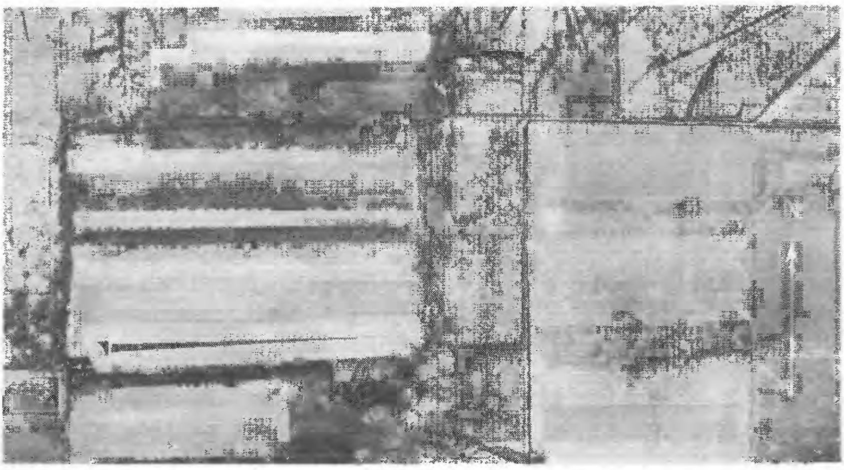

Figure 4.—Flat upland area underlain by the Ogallala formation and having poorly developed drainage system. Photograph by the U. S. Department of Agriculture.

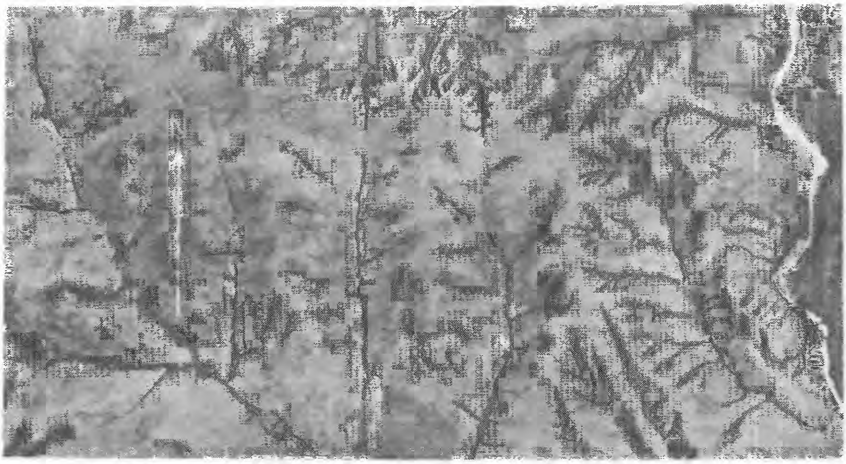

Figure 5.—Well-developed dendritic drainage pattern on the soft rocks of the Ogallala formation near the edge of its outcrop where stream gradients are steep. Photograph by the U. S. Department of Agriculture.

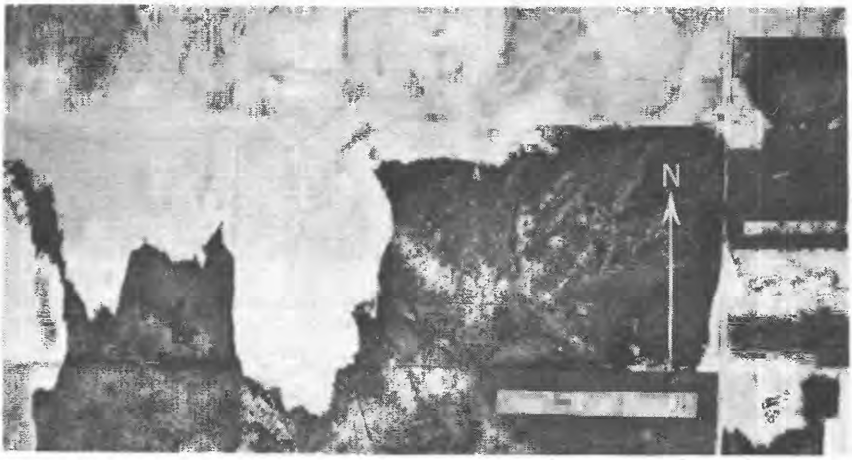

Figure 6.—Poorly developed drainage in an area underlain by old-age dunes. Photograph by the U. S. Department of Agriculture.

the area, particularly in the south half of the county, the relatively flat topography is broken by low, undulating sand dunes (fig. 2). The flat area underlain by the unconsolidated deposits contains numerous broad, shallow depressions which are filled with water after heavy rains to form temporary lakes and ponds.

The Raton section consists of relatively deep (about 300 feet) steep-walled canyons and flat interstream uplands (figs. 3, 4). The canyons have been cut through alternating beds of sandstone and soft shale, the cutting has resulted in nearly vertical cliffs in the massive sandstones and moderate slopes in the intervening shale formations. In a few places there are flat-topped mesas and buttes that generally are capped by hard sandstone, or as at Carrizo Mesa, by basalt.

The relief in the Colorado Piedmont section is greater than that in the High Plains section but not as great as that in the Raton section. The area is drained largely by Two Butte Creek and its tributaries, the valleys of which have been eroded through the unconsolidated sediments and through a series of soft beds of limestone and shale into the underlying sandstone. The main valley is moderately deep but is not steepwalled as are the valleys in the Raton section. There are a few sharp bluffs of sandstone and many small terraces formed on the thin beds of limestone.

The most striking structural feature of the area is Two Buttes dome in north-central Baca and southwestern Prowers Counties, the most prominent topographic expression of which is Two Buttes, a sharp cone-shaped hill culminating in two small flat-topped buttes just north of the Baca-Prowers County line (fig. 46). The altitude of the highest butte is 4,716 feet. Narrow, steepwalled canyons have been formed where Two Butte Creek cuts across the south flank of the dome in northern Baca County.

Baca County is drained by tributaries of the Arkansas River. The Cimarron River, which is the largest tributary of the Arkansas River in this region, flows across the southeastern corner of the county. A few short tributaries of the Cimarron River, such as Bogg Springs Draw and Antelope Springs Arroyo, enter the Cimarron River in the southeastern part of the county, whereas the short tributaries in the Raton section in the southwestern part of the county, such as Carrizo and Gallinas Creeks, flow southward and southeastward and enter the Cimarron in Oklahoma. The longest tributaries of the Cimarron River in Baca County (Sand Arroyo and the North Fork of the Cimarron River) flow eastward across the central part of Baca County and debouch into the Cimarron in western Kansas. Sand Arroyo enters the North Fork of the Cimarron River in western Grant County, Kans., and the North Fork enters the Cimarron in southeastern Grant County.

The northwestern corner of Baca County is drained by Hackberry Creek, which discharges into Rule Creek and thence into the Arkansas River west of Caddoa. The remainder of northwestern Baca County and a small area in north-central Baca County are drained by Two Butte Creek, which enters the Arkansas River near Holly.

Bear Creek and its tributaries drain most of the north-central part and all the northeastern part of the county. Bear Creek flows eastward from Baca County through Stanton County, Kans., and into Grant and Kearny Counties, Kans., where its valley becomes inconspicuous and the flood waters are dissipated in a series of shallow depressions or sinkholes. Flood waters have reached a sinkhole in the sandhills in Kearny County within a mile of the flood plain of the Arkansas River. At times they have overflowed the sinkholes in northwestern Grant County and have discharged into the Cimarron River by way of Lakin Draw and the North Fork.

Climate.—The climate of Baca County is semiarid. The precipitation generally is low to moderate, the heaviest rains falling during May, June, and July, the months which constitute the principal growing season (fig. 7). The mean annual precipitation

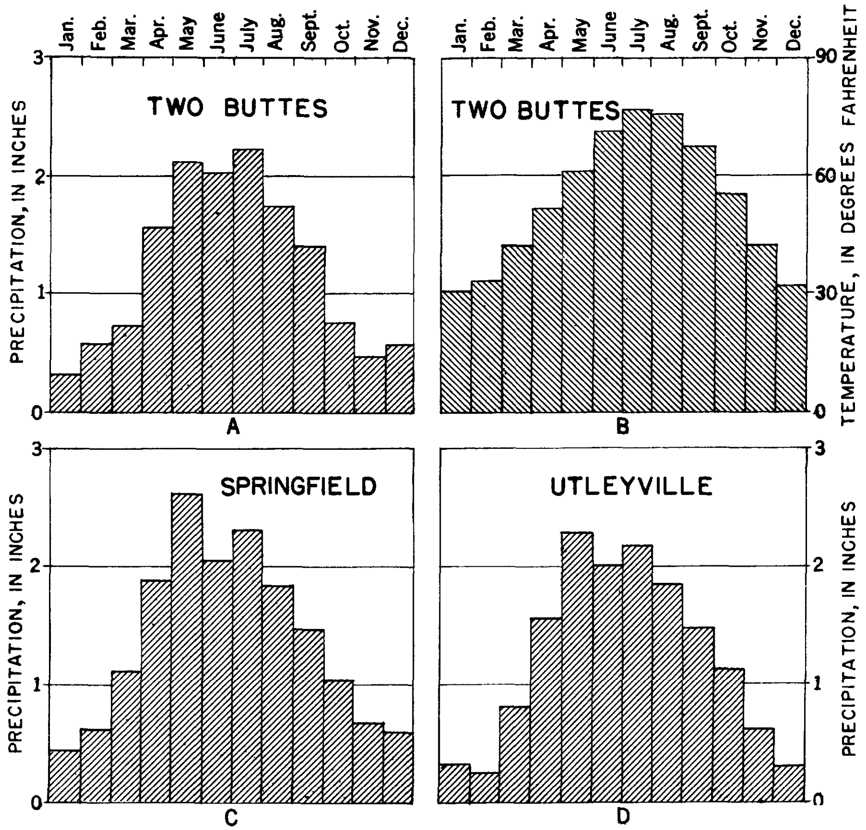

Figure 7.—Normal monthly precipitation and temperature in Baca County. *A*, Normal monthly precipitation at Two Buttes; *B*, Normal monthly temperature at Two Buttes; *C*, Normal monthly precipitation at Springfield; *D*, Normal monthly precipitation at Utleyville.

in Baca County ranges from 14 to 15 inches in the northwestern part of the county to 17 to 18 inches in the southeastern part (fig. 8). The mean annual precipitation in inches at the principal weather stations in Baca County is as follows: Springfield, 16.67;

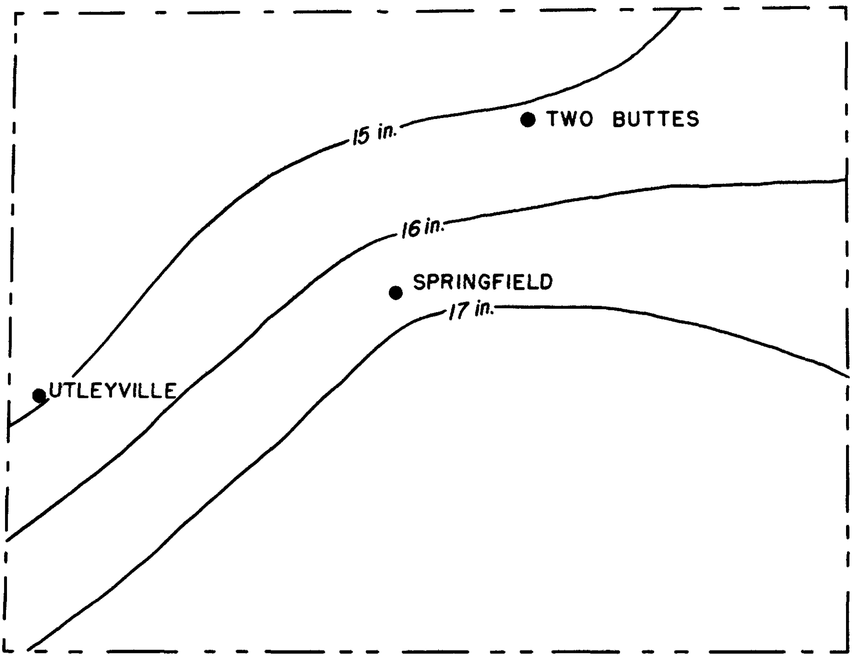

Figure 8. —Distribution of precipitation in Baca County.

Utleyville, 14.99; and Two Buttes, 15.12. The annual precipitation at these stations is shown in figure 9.

The temperature in Baca County generally is high during summer days but, owing to the altitude, the relatively low humidity, and the moderate to strong winds, the summer nights generally are cool. The winters in this area are moderate, the snowfall being relatively small. The mean annual temperature, as recorded at the Two Buttes station, is 53.4°F. The highest normal monthly temperature is 77.0°F in July and the lowest is 31.1°F in January.

Mineral resources.—The principal mineral resources in Baca County, aside from ground water, are sand and gravel, caliche, and building stone. Sand, gravel, and caliche (locally called "gyp"

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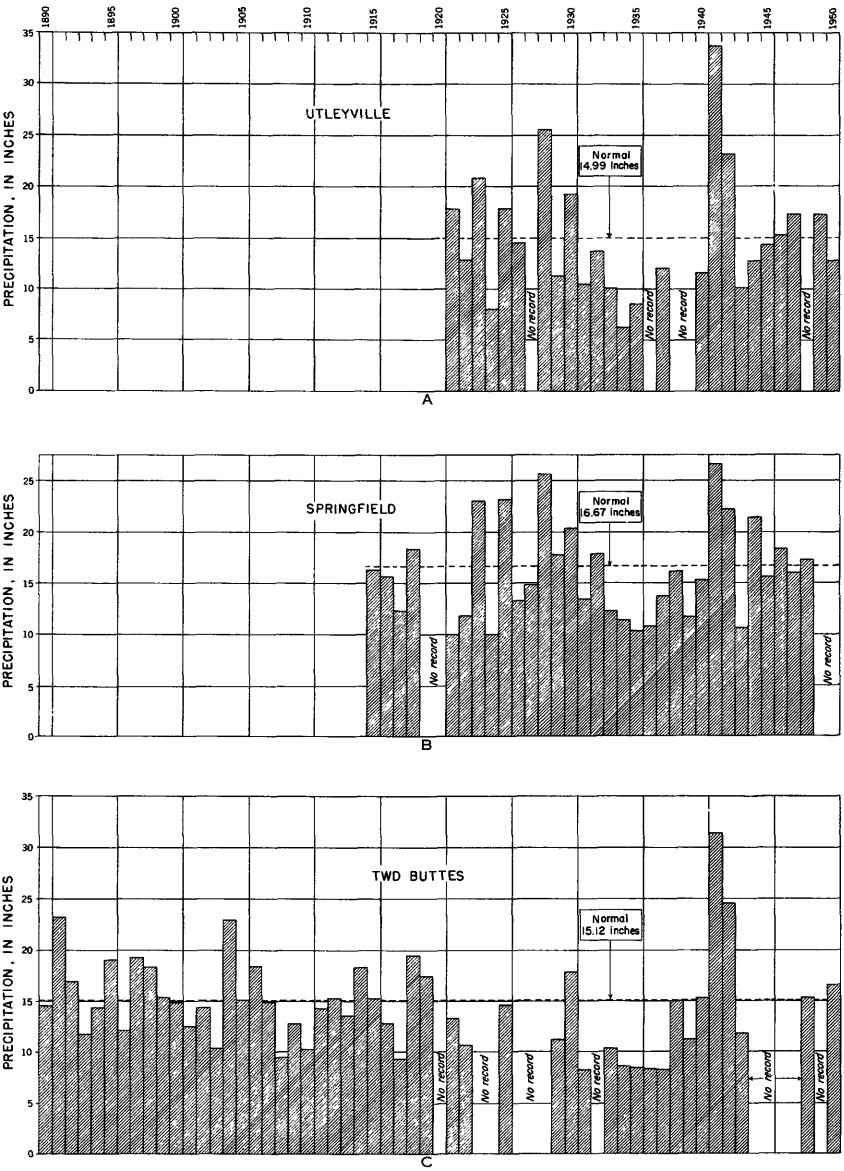

Figure 9. —Annual precipitation in Baca County. *A*, Annual precipitation at Utleyville; *B*, Annual precipitation at Springfield; *C*, Annual precipitation at Two Buttes.

or "gyp rock") are quarried extensively in the area for use as road metal. Building stone, particularly sandstone from the Dakota sandstone, has been quarried locally for the construction of bridges, homes, barns, and schoolhouses. A few small buildings have been constructed from limestone quarried from beds in the Greenhorn limestone.

Copper, gold, and silver have been mined locally in the Entrada sandstone in Skull Canyon but these mines are no longer in operation.

While several unsuccessful oil testholes have been drilled in Baca County, the area has not been tested thoroughly and additional drilling may be expected.

Population.—The density of population of Baca County has been influenced greatly by the precipitation. The semiarid climate of the county is suitable for crop production during periods of above-normal precipitation but crop failures are common during droughts. When the precipitation is high and crops are good the population increases, but when the precipitation is low and crops fail many people are forced to leave the county. Baca County's population increased during the 1920's, declined sharply during the 1930's, and increased again in the 1940's during a period of high precipitation and high crop prices. Recent improvements in farming techniques and soil conservation have tended to reduce the impact of below-average precipitation upon agriculture and population.

According to the 1950 census, Baca County's population was 7,947. Springfield, the county seat and largest city in the county, had a population of 2,026, an increase of 87 percent since the 1940 census. Other settlements in the area include the towns of Walsh (population 898), Pritchett (population 282), Vilas (population 131), Two Buttes (population 121), and Campo (population 265) and the smaller communities of Stonington and Bartlett.

Agriculture.—For many years livestock was the principal agricultural product of Baca County, but because of recent rapid developments of farm machinery, farming practices, and drought-resistant plants the land of the county is now devoted largely to the growing of crops. In 1950 Baca County had more cropland than at any other time in its history (table 1).

Table 1.—*Cropland in Baca County in 1940, 1945, and 1950*[1]

	Acreage		
	1940	1945	1950
Cropland harvested	164,548	355,802	(2)
Cropland lying fallow	177,951	132,668	(2)
Cropland used only for pasture	341,385	27,442	(2)
Crop failure	188,683	22,974	(2)
Total cropland	872,567	538,886	1,109,520

[1] Data for 1940 and 1945 from U. S. Census Bureau. Data for 1950 from Edd Hughes, county agent of Baca County.
[2] No data available.

More than 95 percent of the cropland in Baca County is now used for the growing of wheat and sorghums. Between 1940 and 1950 the acreage of wheat increased from about 24,000 to about 630,000 and the acreage of sorghums increased from about 77,000 to about 445,000 (table 2). Broomcorn, the principal sorghum crop, is grown extensively in the sandy areas in the southern half of the county. About 350,000 acres of cropland were used for growing broomcorn in 1950.

Table 2.—*Acreage of principal crops grown in 1940, 1945, and 1950* [1]

Crop	1940	1945	1950
Wheat	24,172	121,361	650,000
Sorghums	77,142	92,579	[2] 445,000
Corn	6,566	15,257	(3)
Barley	2,695	16,099	(3)

[1] Data for 1940 and 1945 from U. S. Census Bureau. Data for 1950 from Edd Hughes, county agent of Baca County.
[2] Includes 350,000 acres of broomcorn.
[3] No data available.

Transportation.—Baca County is served by the Atchison, Topeka and Santa Fe Railway Co., which has a branch line extending from the main line at Dodge City, Kans., westward to Pritchett. In addition to Pritchett, the line serves Barlett, Walsh, Vilas, and Springfield. The company also has a branch line connecting Las Animas, Colo., with Amarillo, Tex., which serves Springfield and Campo.

Baca County has several State and Federal highways, of which only a few are hard surfaced. U. S. Highway 287 is an oiled road extending north and south through Baca County and serving Springfield and Campo. U. S. Highway 160 is partly graveled and partly oiled and extends generally east and west through the county. It serves Two Buttes, Springfield, and Pritchett. The principal State highways in the county are nos. 100 and 101. Highway 100 extends from Pritchett eastward and northeastward to the Colorado-Kansas State line. The highway is paved from Pritchett to Walsh and is graveled the remainder of the way. Highway 101 is a graveled road extending north and northwest from a point south of Pritchett to Las Animas in Bent County. Other State highways in the county are nos. 51, 59, 89, 116, 118, 197, 198, and 199.

GENERAL GEOLOGY

SUMMARY OF STRATIGRAPHY

Most of the rocks that crop out in Baca County are of sedimentary origin but some are igneous. The exposed sedimentary rocks range in age from Permian to Quaternary and the igneous rocks (dikes and lava flows) are of Tertiary age. The areas of outcrop of the sedimentary and igneous formations are shown on plate 1. The oldest rocks exposed in the county are of Permian age and are a part of the Taloga formation of Cragin (Cragin, 1897). The Triassic rocks include the Dockum group, which crops out in the southwestern part of the county, along the Cimarron River in the southeastern part of the county, and along Two Butte Creek in the northwestern part of the county. The Jurassic formations are the Entrada and Morrison; the Cretaceous formations are the Purgatoire, Dakota, Graneros, Greenhorn, Carlile, and Niobrara; the Tertiary formations are the Ogallala and the igneous rocks; and the Quaternary formations are the Pleistocene Meade (?) formation and terrace deposits and the Recent alluvium and dune sand.

A generalized section of the geologic formations exposed in Baca County is given in table 3 and a geologic time scale is shown in table 4. A brief summary of the geologic history of the area is given in the following pages; more detailed discussions of the geologic formations and their water-bearing properties may be found on pages 81 to 141.

Table 3.—*Generalized section of the geologic formations*

System	Series	Subdivision	Member	Thickness (feet)	Physical character	Water supply
Quaternary	Recent	Dune sand		0-50±	Very fine to coarse poorly sorted sand.	Lies above water table and, hence, yields no water to wells. The dunes are important catchment areas for recharge from precipitation.
		Alluvium		0-75±	Sand and gravel containing considerable silt and clay, particularly in small valleys.	Yields adequate quantities of water to domestic and stock wells in many stream valleys. Alluvium in Cimarron Valley might yield moderate to large quantities of water in some places.
	Pleistocene and Recent	Terrace deposits		0-25±	Very coarse gravel, small to large cobbles, and small boulders. Lesser amounts of sand and fine to coarse gravel.	Lie above water table and, hence, yield no water to wells.
	Pleistocene	Meade(?) formation		0-50	Sand and gravel. Contains volcanic ash in a few places.	Do.
Tertiary	Pliocene	Extrusive rocks		20-110	Dense olivine basalt.	Do.
		Ogallala formation		0-260	Sand, gravel, silt, caliche, and algal limestone.	Yields small to moderate quantities of water to domestic and stock wells in many parts of the county.
	Miocene(?)	Intrusive rocks		0-20	Basalt and porphyry dikes.	Yields no water to wells in Baca County.
		Niobrara formation	Fort Hays limestone	20	Thick-bedded chalky limestone and thin shale partings.	Yields small quantities of water to a few springs in northwestern Baca County.
		Carlile shale	Codell sandstone		Finely crystalline fossiliferous bituminous limestone underlain by fine-grained sandstone and sandy shale.	Do.
			Blue Hill shale	85	Platy to fissile black shale containing large septarian concretions in upper part.	Yields no water to wells in Baca County.

Cretaceous	Upper Cretaceous		Fairport chalky shale		Thin-bedded chalky limestone and chalky shale.	Lower part may yield small quantities of water to a few springs and seeps in northwestern Baca County
		Greenhorn limestone	Bridge Creek limestone	62	Thin-bedded chalky limestone and calcareous shale.	Yields small quantities of water to springs, seeps, and a few dug wells in northwestern Baca County.
			Hartland shale	30	Platy to fissile chalky shale and thin layers of bentonite.	Yields no water to wells in Baca County.
			Lincoln limestone	25	Hard platy crystalline bituminous limestone and calcareous shale.	Yields small quantities of water to a few wells in Baca County. May yield water to a few springs in the northwestern part of the county.
		Graneros shale		86	Gray to black platy and fissile shale containing thin beds of bentonite. Contains thin-bedded rusty limestone in lower part.	Yields no water to wells in Baca County.
	Lower Cretaceous	Dakota sandstone		85-150	Fine-grained thin-bedded to massive sandstone containing clayey to sandy shale. Color ranges from white to dark brown.	Yields adequate water for domestic and stock use in large part of county. In some areas it yields enough water for municipal and industrial supplies.
		Purgatoire formation	Kiowa shale	40-90	Gray to black platy calcareous clayey shale. Thin-bedded fine-grained sandstone in upper part.	Yields no water to wells in Baca County.
			Cheyenne sandstone	35-135	Massive white to buff fine-grained sandstone.	Yields small to large quantities of water for domestic, stock, industrial, municipal, and irrigation use.
Jurassic	Upper Jurassic	Morrison formation		125-325	Varicolored marl containing thin beds of hard sandstone and conglomerate and platy limestone.	Not known to yield water to wells in Baca County.
		Entrada sandstone		0-380	Massive white to buff crossbedded fine- to medium-grained sandstone.	Yields water to well 23 in north-central Baca County.
					Southwestern Baca County: Variegated shale, clay, and marl containing conglomerate and fine-grained sandstone.	Yields small quantities of water for domestic and stock use in southwestern part of county.

Table 3.—*Generalized section of the geologic formations*—Continued

System	Series	Subdivision	Member	Thickness (feet)	Physical character	Water supply
Triassic		Dockum group		0-570	Southeastern Baca County: Red siltstone and red to buff and cream fine- to coarse-grained sandstone.	Probably the source of water in two flowing wells. Yields small quantities of water to a few domestic and stock wells in southeastern part of county.
					Northwestern Baca County; Red and maroon siltstone and quartzitic sandstone and hard gray limestone.	The limestone yields water to one stock well (109) in northwestern part of county.
Permian		Taloga formation (of Cragin)		90-200	Redsiltstone and fine-grained sandstone.	Yields no water to wells in Baca County.

Table 4.—*The geologic time scale*[1]

Eras	Periods	Epochs	Estimated duration, in millions of years	Time since beginning of period, in millions of years
Cenozoic	Quaternary	Recent Pleistocene	2	2
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	58	60
Mesozoic	Cretaceous		65	125
	Jurassic		32	157
	Triassic		28	185
Paleozoic	Permian		38	223
	Carboniferous			
	Pennsylvanian		48	271
	Mississippian		38	309
	Devonian		45	354
	Silurian		27	381
	Ordovician		67	448
	Cambrian		105	553
Proterozoic	Pre-Cambrian rocks.		1,450	2,003

[1] Modified from Moore (1933, p. 52).

GEOLOGIC HISTORY

Baca County is underlain by deposits of limestone, shale, sandstone, sand, and gravel ranging in thickness from about 2,000 feet over the Las Animas arch in the western part of the county to about 7,000 feet in the southeastern part. The studies of well cuttings and of outcrops by many geologists have revealed much of the geologic history of the area. The following discussion of the geologic history of the area is taken largely from Maher (1946, 1948), Buehler (1947), Maher and Collins (1949), and the writer's observations.

Paleozoic era.—The area of present Baca County was being eroded at the beginning of the Paleozoic era but before the end of the Cambrian period (see geologic time scale in table 4) the area was invaded by a widespread sea which deposited a thick sequence of limestone and dolomite (the Arbuckle limestone) during the remainder of the Cambrian period and during part of the Ordovician period. Sediments of Silurian and Devonian age have not been found in Baca County and probably were never deposited in this area. After the Devonian period this area was again submerged and more than 3,000 feet of marine depostis were laid down during Carboniferous and early Permian time. The sea withdrew during the Permian period and late Permian deposits in the area consist largely of nonmarine red beds.

The principal structural feature developed during the Paleozoic era was the Freezeout Creek fault along the east flank of the Las Animas arch in northwestern Baca County. The fault is estimated to have a throw of about 1,900 feet (Buehler, 1947). Movement along the fault is thought to have begun in early Pennsylvanian time and has subsequently displaced beds of lower and middle Pennsylvanian age.

Mesozoic era.—Erosion and the deposition of continental sediments characterized the geologic history of the early part of the

Mesozoic era. Variegated shale and sandstone and a little fresh-water limestone were deposited during the Triassic period. During the first part of the Jurassic the area was eroded and during the last part of the period continental sediments comprising the Entrada and Morrison formations were deposited throughout most of Baca County.

The Lower Cretaceous is represented in this area by the Purgatoire formation, consisting of the continental Cheyenne sandstone member and the marine Kiowa shale member, and by the Dakota sandstone. Near the end of Early Cretaceous time the sea withdrew and the sandstone and sandy shale constituting the Dakota sandstone was deposited throughout most or all of Baca County. The Upper Cretaceous formations in the area, the Graneros, Greenhorn, Carlile, and Niobrara. were deposited by a widespread sea. Upper Cretaceous formations such as the Pierre and Fox Hills do not crop out in or near Baca County. If they were deposited in the area they were later removed by erosion.

Cenozoic era.—The Cenozoic era was marked in this area by erosion, by deposition of continental deposits derived largely from the erosion of the rising Rocky Mountains, by intrusion and extrusion of igneous rocks, and by folding and faulting of the sedimentary rocks. The area probably was being eroded during most of Tertiary time until the middle of the Pliocene epoch, when the silt, sand, gravel, and caliche of the Ogallala formation was deposited over all the county. Early in a new cycle of erosion a small area in the southwestern part of the county was covered by basaltic lava flows.

The principal structure developed during this era was the Two Buttes dome, probably as the result of the intrusion of igneous rocks. The igneous rocks were intruded and the dome was developed after the withdrawal of the Cretaceous sea and largely before the deposition of the middle Pliocene Ogallala formation—probably during the Miocene epoch.

The Quaternary period has been largely one of erosion in this area. In the early part of the period thin deposits of sand and gravel were laid down in the northern part of the county. Since then most of the present topography of Baca County has been developed. Near the end of the Pleistocene epoch the Cimarron River began cutting its valley and a very broad flood plain was developed. During the Recent epoch further valley-cutting was done, the alluvium in the present flood plain was deposited, and large areas in the southern part of the county were covered with dune sand. Other streams in the area probably were developed at the same time as the Cimarron, with the exception of Two Butte Creek, which may be considerably older.

GROUND WATER

PRINCIPLES OF OCCURRENCE

The following discussion on the occurrence of ground water is adapted in part from Meinzer (1923a, p. 2-102), and the reader is referred to his report for a more detailed discussion of the subject.

The rocks that form the outer crust of the earth generally contain many open spaces called voids or interstices. These open spaces are the receptacles that hold the water which is found below the surface of the land and is recovered in part through wells and springs. The amount of water that can be stored in any rock depends upon the volume of the rock that is occupied by open spaces—that is, the "porosity" of the rock. The capacity of a rock to hold water is determined by its porosity, but its capacity to yield water is determined by its permeability. The "permeability" of a rock may be defined as its capacity for transmitting water under hydraulic head, and it is measured by the rate at which the rock will transmit water through a given cross section under a given difference of head per unit of distance. Rocks that will not transmit water are said to be impermeable. Some deposits, such as dense silt or clay, may have a high porosity but, because of the small size of the pores, transmit water slowly. Other deposits, such as well-sorted gravel containing large openings that are freely interconnected, transmit water readily. Part of the water in any deposit is not available to wells because it is held against the force of gravity by molecular attraction—that is, by the cohesion of the molecules of the water itself and by their adhesion to the walls of the pores. The ratio of the volume of water that a rock will yield by gravity, after being saturated, to its own volume is known as the "specific yield" of the rock.

Below a zone, which in Baca County ranges in depth from almost zero to about 250 feet below the land surface, the permeable rocks are saturated with water. These saturated rocks are said to be in the "zone of saturation," and the upper surface of this zone is called the "water table." Wells dug or drilled into the zone of saturation will become filled with ground water to the level of the water table.

The rocks that lie above the zone of saturation are said to be in the "zone of aeration." As water from the surface percolates slowly downward to the zone of saturation, part of it is held in the zone of aeration by the molecular attraction of the walls of the open spaces through which it passes. In granular material there is invariably a moist belt in the zone of aeration just above the water table, ranging in thickness from a fraction of an inch in coarse gravel to several feet in silt or clay; this moist belt is known as the "capillary fringe". Although water in the zone of aeration is not available to wells, much of the water in the soil may be withdrawn by plants and by evaporation from the soil. Most of the rocks penetrated by wells in Baca County are sedimentary, and they include several types that differ greatly in character and in their ability to store and transmit water. The chief types of sedimentary tocks in this area are sand, gravel, sandstone, shale, and limestone.

Water in sand and gravel.—Baca County is underlain by thick deposits of stream-laid sand, gravel, silt, and clay constituting the Recent alluvium and the Ogallala and Meade(?) formations. Some of the beds contain well-sorted sand and gravel having a moderately uniform texture and a relatively high specific yield and permeability. Wells in this type of material yield adequate quantities of water to many domestic and stock wells in Baca County. In a few parts of the county where there are thick deposits of uniform saturated sand and gravel, properly constructed wells would yield large quantities of water.

In many parts of the county the sand and gravel of the Ogallala and alluvium is thin or is poorly sorted and contains silt and clay which tend to fill the pore spaces and reduce the permeability. Wells in this type of material generally yield only small to moderate quantities of water for domestic and stock use.

Water in sandstone.—Most of the beds of sandstone in Baca County are fine grained and have a relatively low permeability owing to the adhesion of the water to the walls of the very small pore spaces. In those sandstones in which the grains are held together firmly by cementing material (as in the Morrison formation) the pore spaces are partly or mostly filled with the cementing material and little space is left for the movement of ground water. Conversely, some saturated sandstones are in part uniform-grained and poorly cemented (such as the Cheyenne sandstone member of the Purgatoire formation) and, in some places, will yield large quantities of water to properly constructed wells. The principal sandstone aquifers in Baca County are the Cheyenne sandstone member of the Purgatoire formation and the Dakota sandstone.

Water in shale.—Shale is formed by the induration of clay or clayey mixtures and generally has a very low specific yield and permeability. In some places, however, shale may have sufficient open joints and bedding planes to permit moderately free movement of water. In other places the shale may contain sand grains in sufficient quantity to make it moderately permeable. In this area many of the formations contain shale but only in the Dakota sandstone is the shale sufficiently permeable to yield water to wells.

The impermeability of shale is of value to some areas. The Kiowa shale member of the Purgatoire formation overlies the Cheyenne sandstone member in much of Baca County, thus confining the water in the Cheyenne under artesian pressure and greatly reducing the pumping lifts of most wells drilled into the Cheyenne. In the area north of Walsh the artesian pressure is sufficient to cause the wells to flow (pl. 1).

Water in limestone.—The limestones in Baca County are dense, compact rocks having very few open spaces and, hence, very low specific yields and permeabilities. In some places the thin beds of limestone contain sufficient open joints to permit the flow of ground water but they generally will yield only small quantities of water to wells. In Baca County water has been obtained from wells penetrating beds of limestone in Triassic rocks and in the Cretaceous Greenhorn limestone.

ARTESIAN CONDITIONS

GENERAL PRINCIPLES

The "head" of water has been defined as the height that a column of water will rise in a tightly cased well that has no discharge. Ground water that rises in wells above the level at which it is first encountered is said to be "artesian" or "piestic" water (Meinzer and Wenzel, p. 451). If the water rises high enough to flow at the surface the well is termed a flowing artesian well.

In many of the rock formations in Baca County there are strata of relatively permeable rock, principally sandstone, that alternate with strata of relatively impermeable rock, such as shale or clay. In Baca County the strata dip generally eastward so that water entering the more permeable beds in their areas of outcrop in the western part of the county moves eastward down the dip of the beds between the confining layers of relatively impermeable strata and saturates the permeable strata. Under such conditions the water in the permeable beds between the confining layers is under artesian pressure.

The principal artesian aquifers in Baca County are the Cheyenne sandstone member of the Purgatoire formation, the Dakota sandstone, and the Triassic red beds. The Cheyenne is underlain by the relatively impermeable marl, shale, and clay of the Morrison and is overlain by the Kiowa shale member of the Purgatoire. Water in the Cheyenne sandstone member is under artesian pressure in all of Baca County except the southeastern corner (fig. 27), where the Cheyenne is absent and the southwestern, northwestern, and north-central parts, in and near the areas where the member is recharged. North of Walsh, along Bear

Creek and its tributaries, the water is under sufficient pressure to flow at the surface.

The Dakota sandstone is underlain by the Kiowa shale member of the Purgatoire formation in most of the county and is overlain by the Graneros shale in the northwestern part of the county. Water in the Dakota sandstone is under artesian pressure throughout northwestern Baca County except near the areas of outcrop. Where the Dakota is overlain by the relatively permeable Ogallala formation the water in the upper part of the formation generally is under little or no pressure, but, inasmuch as the Dakota consists of a series of relatively permeable sandstones separated by relatively impermeable sandy shale, the water in the sandstones in the lower part of the formation may be locally confined under artesian pressure by beds of sandy shale within the formation. Most wells, therefore, that are drilled to the base of the Dakota sandstone encounter water under artesian pressure, except near the areas of outcrop of the lower part of the formation. The pressure of the water in the Dakota sandstone is sufficient to reduce materially the pumping lift in a large part of the county.

The Triassic red beds in the southeastern part of the county consist of a series of beds of relatively impermeable shale and siltstone alternating with relatively permeable sandstone. In the topographically low areas along the Cimarron River the pressure of the water in some of the sandstones is sufficient to cause the water to flow at the surface.

CIMARRON VALLEY AREA

The Cimarron River valley in the southeastern part of Baca County is part of a much larger area of artesian flow from sandstones within the red bed series, which is probably in part of Triassic age but which toward the east may be of Permian age. The area of flow extends eastward along the Cimarron River valley at least as far as central Morton County, Kans., and thence northward to the North Fork of the Cimarron River near Richfield. The flowing wells in the Cimarron River valley generally are about 200 feet deep, whereas those on the uplands near Richfield are 600 to 750 feet deep. Inasmuch as the upland areas near Richfield are less than 100 feet above the flood plain of the Cimarron River, the flowing wells in the uplands probably tap deeper-lying aquifers of Permian age.

There are only two wells (373 and 374) in the Baca County part of the artesian-flow area of the Cimarron River valley—both in sec. 22, T. 34 S., R. 42 W. Well 374 was drilled many years ago for domestic and stock use at an old cattle camp known as Miles Camp. Its depth is not known but is believed to be about

200 feet. The flow in 1948 was less than 1 gpm. Well 373 was completed in 1931 at a depth of 4,967 feet as a dry oil test. It has since been utilized as a stock well, the flowing water coming from sandstone between the depths of 190 and 200 feet.

The pressure head of the water in these wells is not known but probably is not great. It is believed that flowing wells could be developed throughout the flood plain of the Cimarron River in Baca County. The water would be satisfactory for stock use but the analysis of water from well 373 indicates that the water is too highly mineralized for domestic use, and it would be usable for irrigation only of permeable, well-drained soils.

WALSH AREA

GENERAL FEATURES

The area of artesian flow along Bear Creek and its tributaries north of Walsh is much larger than the Baca County part of the Cimarron River valley area. Flowing wells have been developed along Bear, Buffalo, Horse, Little Horse, and Antelope Creeks and along some of the interstream areas. The water is obtained from the Cheyenne sandstone member of the Purgatoire formation, which here dips northeastward. The sandstone was formerly believed to be a part of the Dakota sandstone, hence, the term "Lower Dakota" is used almost universally by the drillers and laymen of this area.

According to L. W. Collins, pioneer driller in Baca County, the first flowing well in the Walsh area was drilled in 1908 in SW1/4 sec. 24, T. 29 S., R. 43 W. The well failed to encounter sufficient water for domestic and stock use in the Dakota sandstone and was drilled through the Kiowa shale member into the Cheyenne sandstone member of the Purgatoire formation. The second flowing well was drilled in the NW$\frac{1}{4}$ sec. 3, T. 30 S., R. 43 W. Mr. Collins drilled his first flowing well in 1910 and has since drilled most of the flowing wells in the Walsh area. Most of the flowing wells were drilled during the 20-year period from 1910 to 1930. Since 1930 a few new wells have been drilled and several of the old wells have been recased. When records of the wells in the Walsh area were obtained in 1947 there were 32 wells that flowed continuously and 2 that flowed intermittently. Two of the wells are shown in figures 10 and 11.

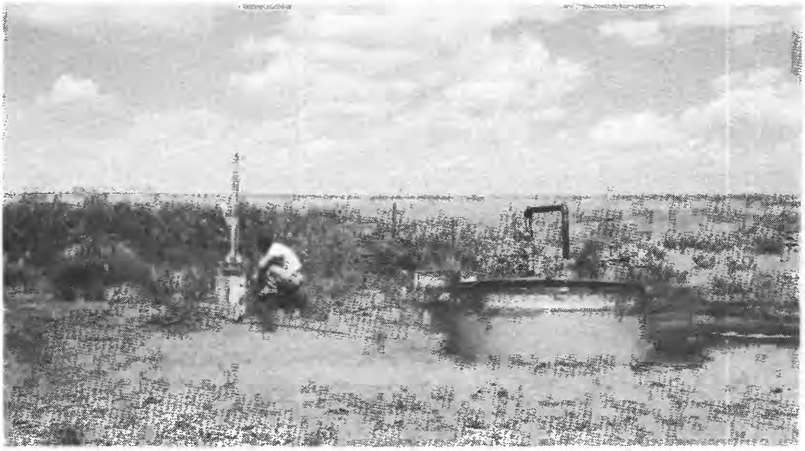

Figure 10.—Flow test of well 124. Discharge is measured in calibrated barrel behind stock tank, and pressure head is recorded by mercury-manometer pressure gage at left.

Figure 11.—Well 117 discharging at the rate of about 100 gallons per minute during a flow test.

Construction and yields of wells.—Nearly all the flowing wells in the Walsh area were constructed in the same manner. A 4- to 6-inch hole was drilled into the Kiowa shale member and the casing was set tightly in the shale. A slightly smaller hole was then drilled into the underlying Cheyenne sandstone member and left uncased. Many of the wells were then equipped with valves to regulate the flow. This method of well construction has been moderately satisfactory. The Cheyenne and Kiowa members generally are sufficiently indurated and resist caving and the Kiowa generally contains beds that are satisfactory for seating the casing. After many years of service, however, most of the casings were corroded and water from the Cheyenne discharged into the overlying Dakota sandstone and, in a few instances, reached the surface outside the casing. Several of the wells drilled or reconditioned recently have been cement-grouted to prevent leakage of the artesian water into overlying formations. The flow of one reconditioned well was increased from 2.5 to 37.3 gpm.

The yields of the flowing wells in the Walsh artesian area range from a trickle to an estimated 100 gpm, although some of the wells were reported to have had an initial flow of several hundred gallons a minute. The largest sustained flow measured during this investigation was 60.9 gpm. Most of the wells in this area having a small flow are either old wells in which the casings probably are badly corroded or are wells near the edge of the area of flow where the pressure head is barely sufficient to raise the water to the ground surface. The flow tests made during this investigation were all of newly reconditioned or recently drilled wells. The sustained flows of these wells ranged from 22.7 to 60.9 gpm and averaged 41.8 gpm.

The yields of most of the wells probably have declined considerably. Many of the wells have been allowed to flow continuously without restriction, causing a decline in pressure head and a resultant decline in yield. The casings of many of the older wells have been corroded and, although these wells generally have a small flow, considerable quantities of water escape from the artesian aquifer into the overlying formations, causing additional declines in pressure head and in yield.

Pressure head and piezometric surface.—The "pressure head" of water at a given point in an artesian aquifer is its hydrostatic pressure expressed as the height of a column of water, above some fixed datum, that can be supported by the pressure. It is the height that a column of water rises in a tightly cased well that has no discharge. In areas of artesian flow it generally is expressed in terms of feet above land surface or above some fixed measuring point such as the top of the casing. The piezometric surface of any aquifer is an imaginary surface that everywhere coincides with the head of the water in the aquifer. In areas of artesian flow it is above the land surface.

The pressure head of the artesian water in flowing wells in the Walsh area ranges from a few inches above the land surface near the boundary of the area of flow to nearly 70 feet above the land surface along Horse Creek in the central part of the area. Wells 55 and 67 are so near the edge of the artesian area that they flow intermittently over the tops of their casings, which are about 6 inches above the ground surface. The pressure head of well 75 in the Horse Creek valley was 66.5 feet above the ground surface when measured on September 8, 1947.

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No records are available as to the pressure head of water in the artesian aquifer when the first flowing wells were drilled in this area, and there is no direct method by which the decline in pressure head can be determined. There is no doubt, however, that the pressure head has declined for, although the discharge of individual wells generally is small, the combined discharge and leakage of all the wells in the area is considerable. As shown by figure 13 in the following section on Permeability of water-bearing materials, a well in the Cheyenne sandstone member having a flow of 100 gpm will lower the pressure head of the artesian water about 11 feet at a distance of 10,000 feet from the flowing well after 1,000 days of continuous flow and about 15.5 feet after 10,000 days of continuous flow (assuming that the transmissibility and storage coefficient of the aquifer are equal to the averages of the transmissibilities and storage coefficients determined by the five flow tests). Although it is not possible to determine the average discharge from the aquifer, it is certain that it amounts to several hundred gallons per minute and has therefore lowered the pressure head appreciably over the years.

The best indication of lowering of the pressure head in this area is the shape of the piezometric or pressure-indicating surface as shown in figure 17. The contour lines join points of equal pressure head. In general they are smooth lines except for the sharp westward flexures in the Walsh artesian area. Before flowing wells were drilled in that area the piezometric surface was relatively undisturbed and the contour lines representing the original piezometric surface must have been smooth lines having no sharp flexures. The present deviation of the contour lines from the original position is a measure of the amount of lowering of the pressure head. The map indicates that in part of the artesian area the contours now lie between one-third and one-half contour interval (contour interval is 100 feet) west of their probable original position, indicating a decline in pressure head of 30 to 50 feet. Even though the pressure head has declined considerably in the area of greatest development, the area of artesian flow probably is nearly as great as ever. Near the edges of the area of flow the pressure head is very low, the discharges of the flowing wells are very small, and the resulting decline of pressure head probably has been negligible.

PERMEABILITY OF WATER-BEARING MATERIALS

The rate of movement of ground water is determined by the size, shape, number, and degree of interconnection of the interstices in the aquifer, by the density and viscosity of the water, and by the hydraulic gradient. The capacity of a water-bearing material for transmitting water under a hydraulic gradient is known as its "permeability". Meinzer's "coefficient of permeability" is the rate of flow, in gallons a day, through a cross section 1 foot square, under a hydraulic gradient of 100 percent, at a temperature of 60°F. It may be expressed as the number of gallons of water per day, at 60°F, that is conducted laterally through each mile of the water-bearing bed under investigation (measured at right angles to the direction of flow), for each foot per mile of hydraulic gradient (Stearns, 1927). The "field coefficient of permeability" is the same unit (expressed in either of the ways given above), except that it is adjusted for the prevailing ground-water temperature in the area concerned. The "coefficient of transmissibility" is a similar measure for the entire thickness of the water-bearing formation and may be expressed as the number of gallons of water per day transmitted through each 1-foot strip extending the height of the aquifer at the existing temperature, under a hydraulic gradient of 100 percent (or through a mile-wide section of the aquifer under a gradient of 1 foot per mile)—it is the field coefficient of permeability multiplied by the thickness of the aquifer in feet.

The term "coefficient of storage" expresses the quantity of water released from storage in a vertical column of the aquifer of unit cross section as the result of a unit decline in head. Under water-table conditions this quantity is essentially equal to the "specific yield," which expresses the quantity of water that a given volumn of the aquifer will yield to wells under the pull of gravity if it is first saturated and then allowed to drain. The ratio, expressed in percent, of the volume of this water to the total volume of the material that is drained is the specific yield. Under artesian conditions, in which aquifers are not dewatered by the withdrawal of water through wells, the "coefficient of storage" represents the water released from storage by the compression of the aquifer and by expansion of the water itself, and it is proportional to the thickness of the aquifer. It is defined as the quantity of water, expressed as a decimal fraction of a cubic foot, discharged from each vertical column of the aquifer having a basal area of 1 square foot as the water level or pressure head declines 1 foot.

During the investigation in Baca County flow tests were run on wells 56, 59, 75, 117, and 129 in the Walsh artesian area in order to determine the coefficients of transmissibility and storage of the artesian aquifer there—the Cheyenne sandstone member of the Purgatoire formation. The flow tests were made in 1948 and 1949 using a mercury manometer designed and constructed by S. W. Lohman (fig. 10). Each well was shut off for a period sufficiently long to permit the pressure head to return approximately to its normal position, generally 10 to 15 hours, and the static pressure head was determined by means of the mercury gage. The well was then turned on and allowed to flow freely for a period of several hours until the discharge had ceased to decline appreciably.

During this period the discharge was measured periodically in order to determine its rate of decline. The well was again shut off and the pressure head allowed to return nearly to its original position. During this period the rate of recovery of the pressure head was determined by periodic measurements of the pressure head by means of the mercury gage. The coefficient of transmissibility was determined by means of the Theis equation (Theis, 1935) which is based on the rate of recovery of the pressure head, and the coefficients of both transmissibility and storage were determined by means of equations developed by Jacob and field-tested by Lohman (Jacob and Lohman, 1952) which are based on the rate of decline of the discharge.

The coefficients of transmissibility as determined by the recovery and discharge methods ranged from 950 to 22,000 and averaged 6,000 gpd per foot. The coefficients of storage as determined by the discharge method ranged from 4.0×10^{-6} to 3.7×10^{-4} and averaged 5.0×10^{-5} Considerable variations in the coefficients of transmissibility and storage are indicated by the five tests and by the yields and drawdowns of wells drilled into the artesian aquifer. Some wells flow less than 50 gpm with a decline of pressure head of more than 60 feet, whereas a few large irrigation wells discharge more than 1,000 gallons a minute with a drawdown of less than 60 feet and well 83 discharges more than 3,000 gpm with a drawdown of less than 80 feet. The wide variation in productivity of the sandstone probably is influenced in part by the size and degree of sorting of the sand grains in the sandstone but largely by the degree of cementation of the grains. Where the sandstone is well cemented the water will not enter wells freely. Local drillers report that the most abundant supplies of water generally are obtained at places where the sandstone is easily drilled and appears to be soft, indicating a relatively small amount of cement. Some of the larger irrigation wells pump a large amount of sand, also indicating a relatively small amount of cement in the sandstone.

It is believed that the average coefficients of transmissibility and storage (6,000 gpd per foot and 5.0×10^{-5}), as determined in the five tests, are of the right order of magnitude. The average coefficients as determined by the flow tests probably are within the limits of the actual maximum and minimum coefficients because measured drawdowns in some wells tapping the artesian aquifer are larger and in others, smaller than the calculated drawdowns (calculations based on the assumption that the coefficients of transmissibility and storage are equal to the averages as determined by the five flow tests).

Figures 12 and 13 have been prepared in order to indicate the magnitude of decline in pressure head that may be expected in parts of the artesian aquifer where the coefficients of trans-

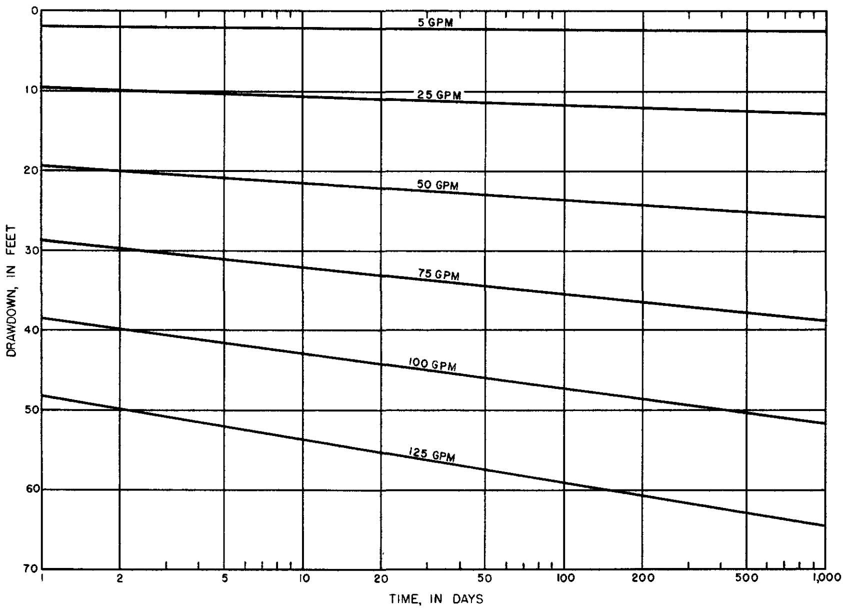

Figure 12.—Theoretical declines in pressure head in a well discharging at the rates of 5, 25, 50, 75, 100, and 125 gpm for periods ranging from 1 to 1,000 days. (Assumptions: T = 6,000 gpd per foot and S = 5.0 x 10^{-5}.)

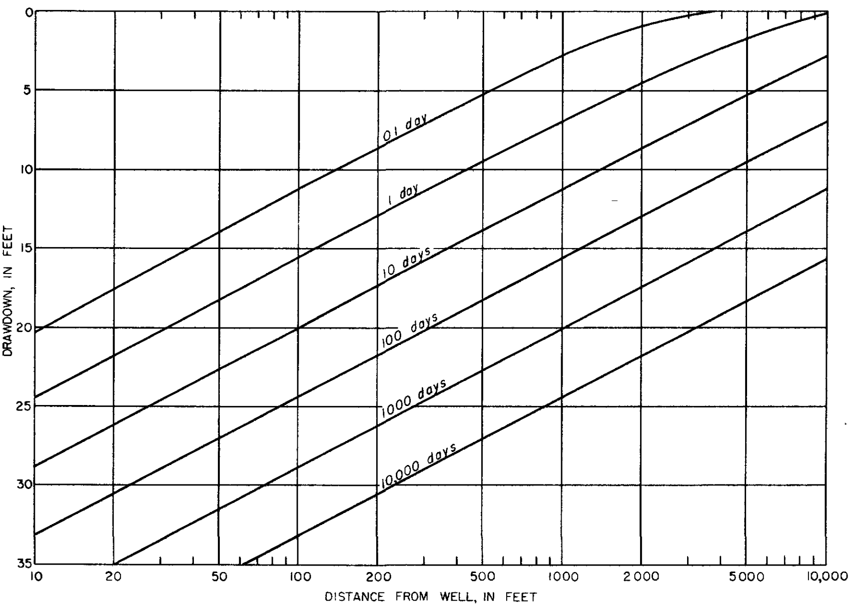

Figure 13.—Theoretical declines in pressure head caused by a well discharging 100 gpm for 0.1, 1, 10, 100, 1,000 and 10,000 days at distances ranging from 10 to 10,000 feet from the discharging well. (Assumptions: T = 6,000 gpd per foot and S = 5.0 x 10^{-5}.)

missibility and storage are equal to the computed averages and where the distance to boundaries of the aquifer is great. The discharge and leakage from flowing wells in the Walsh artesian area probably amounts to several hundred gallons a minute and has caused a noticeable but not a serious decline in pressure head in the area of greatest development. In 1949-50, however, several large irrigation wells were developed in the artesian aquifer in and near the area of artesian flow. Each of these wells, when pumping, probably discharges more water from the artesian aquifer than the combined discharge and leakage of all the flowing wells in the Walsh area. That area therefore is threatened with a large decline of pressure head with the extensive development of large irrigation supplies from wells in the artesian aquifer.

The determination of the coefficient of transmissibility of an aquifer in any area makes possible the determination of the underflow in a given section of the aquifer, provided that the gradient of the piezometric surface is known. The underflow, in gallons per day, is equal to the coefficient of transmissibility of the aquifer, as defined, times the gradient of the piezometric surface, in feet per mile, times the width of the given section, in miles. To determine the underflow in a 1-mile section of the aquifer at right angles to the direction of flow the equation used is simply the coefficient of transmissibility times the hydraulic gradient, which in most of the Walsh artesian area is about 30 feet per mile. Determinations of underflow through a 1-mile section of the artesian aquifer in the Walsh area are listed in table 5. They are based on the assumptions that the coefficient of transmissibility of the artesian aquifer is equivalent to the maximum, minimum, and average coefficients as determined by the five flow tests. They indicate that the amount of water moving through the aquifer is relatively small and that the aquifer cannot be developed extensively by means of large-capacity wells without a great lowering of the pressure head of the water in the aquifer, inasmuch as a single large-capacity well may yield more water than is transmitted by a 1-mile section of the aquifer.

Table 5.—*Rate of underflow*[1]

Coefficient of transmissibility (gpd per foot)	Gradient (feet per mile)	Approximate underflow	
		Gallons per day	Gallons per minute
22,000[2]	30	660,000	460
950[3]	30	28,500	20
6,000[4]	30	180,000	125

[1] Figures rounded.
[2] Maximum coefficient of transmissibility determined by flow tests.
[3] Minimum coefficient of transmissibility determined by flow tests.
[4] Average coefficient of transmissibility determined by flow tests.

WATER TABLE

The upper surface on the zone of saturation in ordinary permeable soil or rock has been defined as the ground-water table, or simply the "water table". Where the aquifer is confined by overlying materials that are relatively impermeable, the water table is absent, and the imaginary surface to which water in the confined aquifer will rise is known by the general term pressure-indicating surface or "piezometric surface". In Baca County the water in the Ogallala formation generally is unconfined, whereas the water in the Dakota sandstone and the Cheyenne sandstone member of the Purgatoire formation generally is confined. The statements on the following pages concerning the water table apply primarily to water in the Ogallala formation and the statements concerning the piezometric surfaces apply largely to water in the Dakota sandstone and the Cheyenne sandstone member.

The water table is not a plane surface in all parts of the area but in places has irregularities comparable with and related to those of land surface, although it is much less uneven. It does not remain stationary but fluctuates up and down. The irregularities are caused chiefly by local differences in gain or loss of water, and the fluctuations are caused by variations from time to time in gain or loss of water. The water-table contours shown in figure 14 are based on water-level measurements made during the summer of 1947 and represent the approximate shape and slope of the water table at the time the measurements were made. Fluctuations in water level, particularly in the areas of shallow water, might cause some change in the shape and slope.

Shape and slope.—The shape and slope of the water table in the Ogallala formation in Baca County are shown on the map (fig. 14) by contours drawn on the water table. Each point on the water table along a contour has the same altitude. The water-table contours show the configuration of the water surface just as topographic contours show the shape of the land surface. The direction of movement of the ground water is at right angles to the contours in the direction of downward slope. The map (fig. 14) shows that the general movement of the ground water in the Ogallala formation in Baca County is toward the east, but that the slope and the direction of movement differ from place to place. The maximum slope is about 54 feet per mile in the western part of the county near Utleyville and the minimum slope is about 14 feet per mile in the southeastern part of the county near Stonington. The average slope of the water table through the county is about 25 feet per mile.

The shape and slope of the water table determine the rate and direction of movement of ground water and are controlled by several factors. Irregularities in the shape and slope may be caused by: (1) configuration of the bedrock floor; (2) discharge of ground water into streams; (3) recharge of the ground-water reservoir

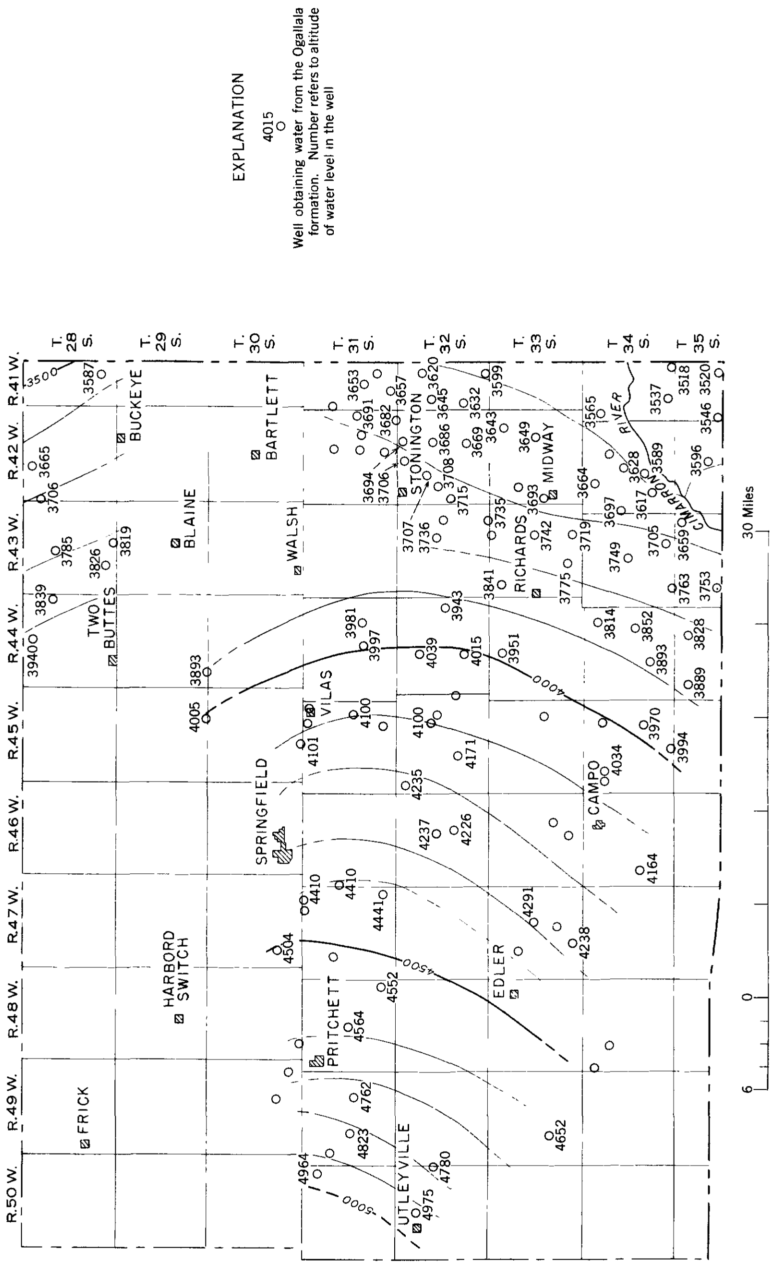

Figure 14. —Contours of the water table in the Ogallala formation. Altitudes are in feet above mean sea level. Contour interval is 100 feet.

by ephemeral streams; (4) unequal additions of water to the ground-water reservoir; (5) local differences in the thickness and permeability of the aquifer; and (6) discharge of water from wells, seeps, or springs.

The shape of the underlying bedrock floor of older rocks in Baca County appears to have considerable influence upon the shape and slope of the water table. The surface of the bedrock floor slopes generally eastward but there are moderate north and south slopes away from the ridge of bedrock extending east-west through the northern half of the county (pl. 2). The water table slopes eastward, as does the bedrock surfaces. It slopes southeastward away from the bedrock ridge in the southeastern part of the county and slopes northeastward away from the ridge in the northeastern part of the county (fig. 14).

The shape and slope of the water table generally are affected by the position of the water table in relation to the streams. The water table may slope toward or away from a stream, depending upon whether the stream is a "gaining" (effluent) stream or "losing" (influent) stream. The diagrammatic sections in figure 15 show the relations between the water table and stream channels. Most of the streams in Baca County are losing streams and contribute water to the underlying water table during periods of flow. These contributions of water probably form small ridges and mounds on the water table but the water-table contour map is not sufficiently detailed to show them. The Cimarron River, a gaining stream in this area, has cut its valley to a level below that of the water table in the adjacent upland areas, thus causing

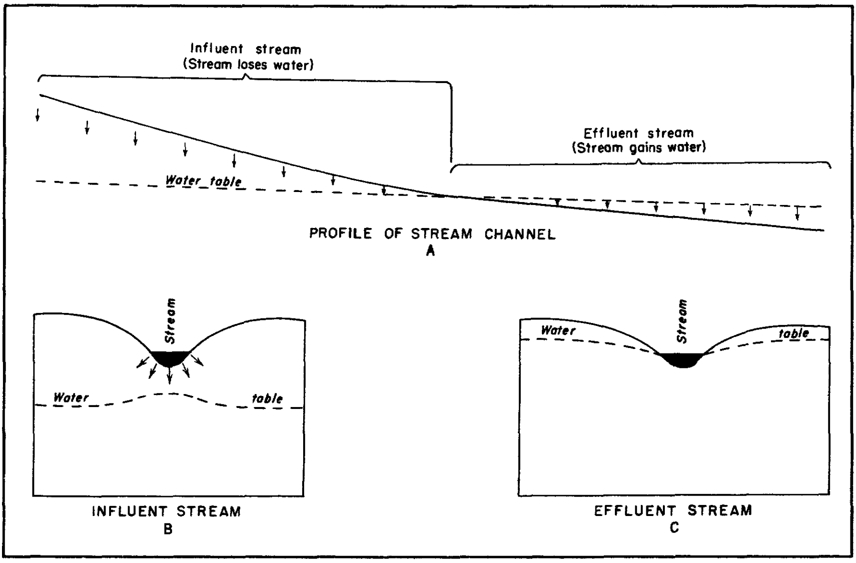

Figure 15.—The relations between a stream and the water table. *A*, Longitudinal section showing how a stream loses and gains water; *B*, Transverse section across influent or losing part of stream; *C*, Transverse section across effluent or gaining part of stream.

the water table to slope toward the river. This is shown clearly by the upstream flexure of the 3,600-foot contour in figure 14.

Unequal additions of water to the ground-water reservoir may have caused some minor irregularities in the water table but these are not indicated by the water-table contour map. There are many small sinks and depressions in Baca County that fill with water after heavy rains and that become dry again during periods of low precipitation. Much of the water is discharged by transpiration and evaporation but some probably reaches the water table, causing small and temporary changes in its shape.

Local differences in the thickness and permeability of the saturated part of the Ogallala formation are two of the principal factors affecting the shape and slope of the water table in Baca County. Where the upper part of the zone of saturation is in material of low permeability, the water table is steep, and where it is in material of high permeability, the water table is flat. The effect of thickness and permeability upon the shape and slope of the water table is indicated by the closely spaced contours in the western part of the county and by the more widely spaced contours in the southeastern part of the county (fig. 14).

There has not been sufficient pumping of water from wells in the Ogallala formation to have a noticeable effect on the shape and slope of the water table. A pronounced effect, however, has been produced by seeps and springs in the southwestern part of the county where the streams have cut through the Ogallala formation into the underlying bedrock formations. The seeps and springs issuing from the Ogallala in this area have drained the Ogallala of most of its water, causing the westward flexure of some of the contour lines in that part of the county (fig. 14).

Relation to topography.—The depth to the water table below the land surface is controlled largely by the configuration of the land surface. A map (pl. 1) has been prepared showing by isobath lines the depths to water level in the eastern part of the county. Isobath lines connect points of equal depth to water level. The depths to water level are shown only in the easternmost part of the county where adequate data are available. The depths refer primarily to water in the Ogallala formation but in part of the area they refer also to unconfined water in the upper part of the Dakota sandstone. There are a few minor discrepancies in the map because the depth to water in a few wells in the easternmost part of the county differs from the depths in nearby wells. These wells generally obtain water from a different aquifer—usually an underlying artesian aquifer.

The depth to water level is less than 50 feet in a large area along the Cimarron River valley and in the upland areas adjacent to Sand Arroyo. It is also less than 50 feet in part of the valleys of Bear Creek and two of its tributaries. The depth to water level increases northwestward and southeastward away from the Cimarron River valley and westward from the shallow-water areas along Sand Arroyo and Bear Creek. The greatest depths to water in the areas outlined by the isobath lines (pl. 1) are 150 to 200 feet.

PIEZOMETRIC SURFACES

The term "piezometric surface" is used for the imaginary surface to which water in a confined aquifer will rise. It is not a plane surface but, like the water table, has irregularities and variations in slope. It does not remain stationary but fluctuates up and down much like the water table. The piezometric-surface contours shown in figures 16 and 17 are based on water-level measurements made during the summer of 1947 and represent the approximate shape and slope of the piezometric surfaces at that time.

Shape and slope.—The shape and slope of the piezometric surfaces in Baca County are shown on the maps (figs. 16, 17) by contours drawn on the piezometric surfaces. Each point on a piezometric surface along a contour has the same altitude. The piezometric-surface contours show the configuration of the pressure-indicating surface just as water-table contours show the shape and slope of the water table. The direction of movement of water in the confined aquifers is at right angles to the contours in the direction of the downward slope.

The maps (fig. 16, 17) show that the water in the Dakota sandstone and the Cheyenne sandstone member in Baca County moves generally eastward but that there are local differences in the rate and direction of movement. The slope of the piezometric surface of the water in the Dakota sandstone ranges from about 60 feet per mile north of Utleyville in the west-central part of the county to about 15 feet per mile north of Campo and in the vicinity of Vilas. The average slope across the county is about 25 feet per mile.

The slope of the piezometric surface of water in the Cheyenne sandstone member is greatest in the western part of the county where it is as much as 60 feet per mile. The least slope is less than 10 feet per mile in the area north of Campo. The slope is also small in the area northwest of Walsh. The average slope across the county is between 25 and 30 feet per mile—a little more than the slope of the water table and of the piezometric surface of water in the Dakota sandstone.

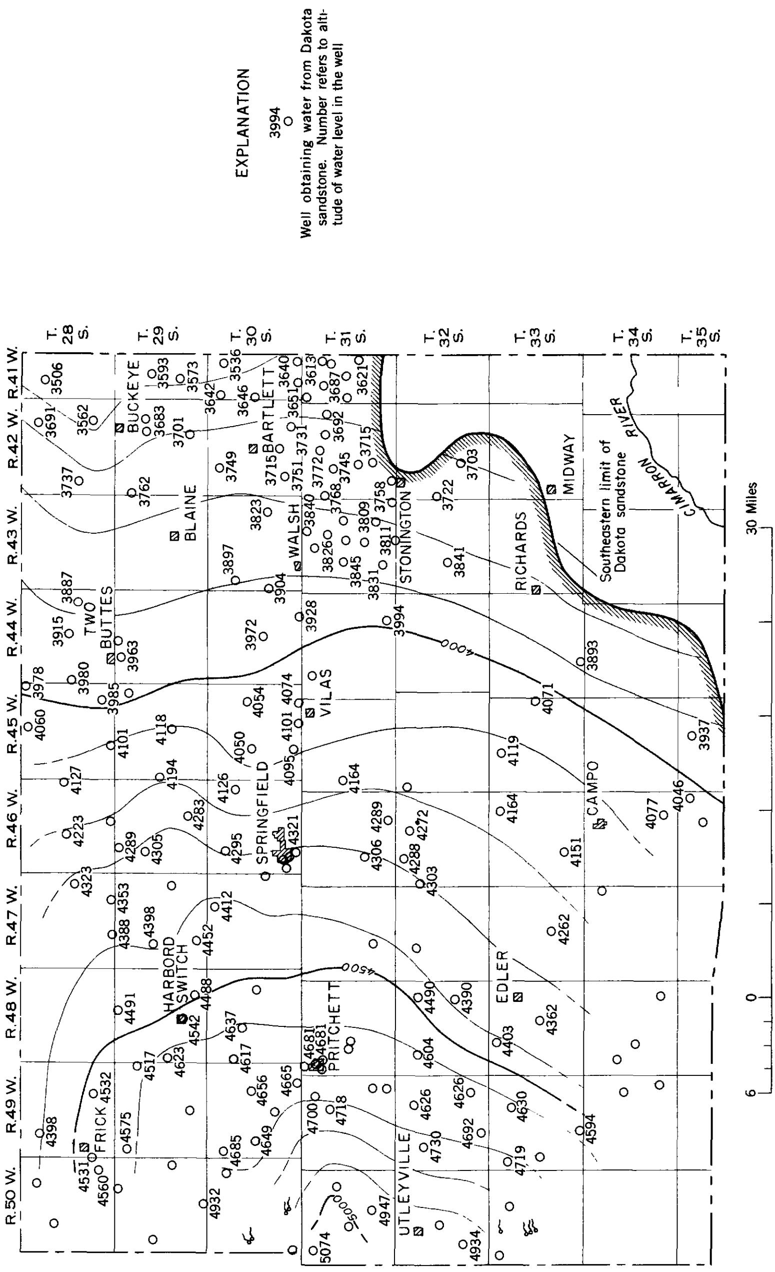

Figure 16.—Contours of the piezometric surface of water in the Dakota sandstone. Altitudes are in feet above mean sea level. Contour interval is 100 feet.

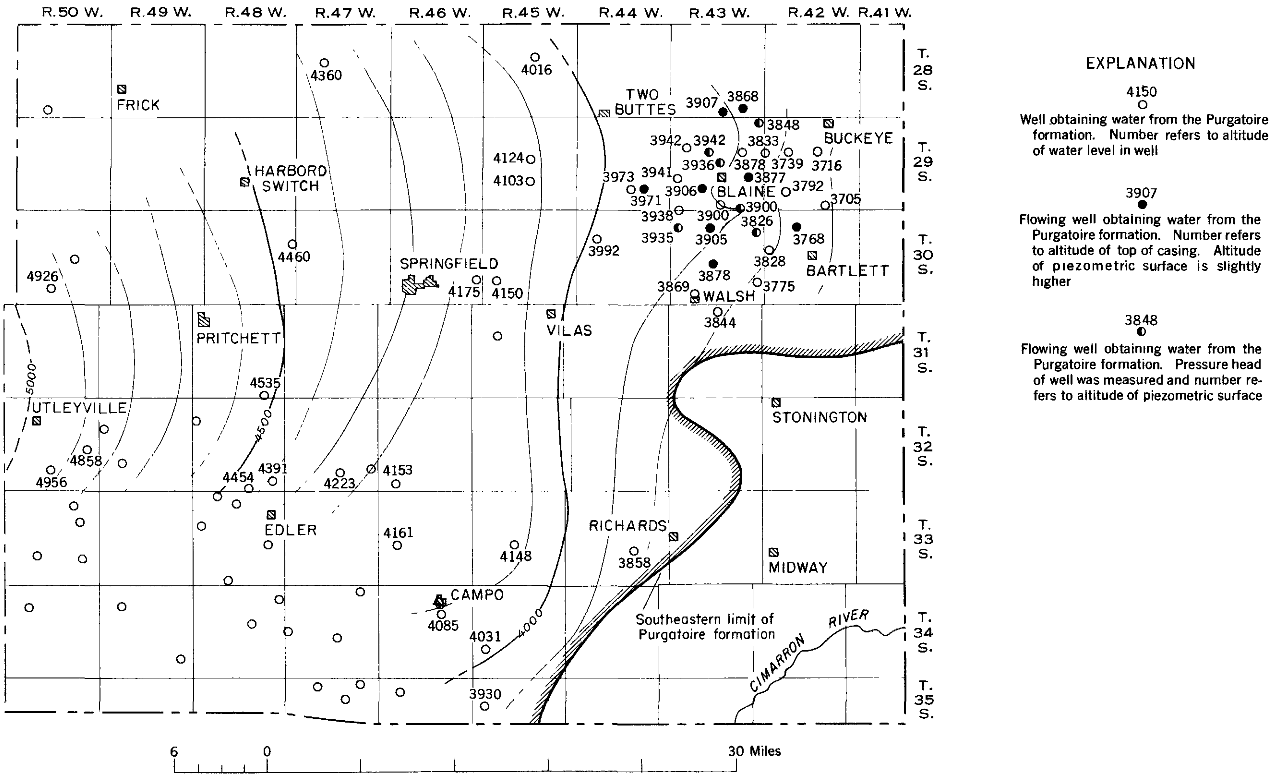

Figure 17.—Contours of the piezometric surface of water in the Cheyenne sandstone member of the Purgatoire formation. Altitudes are in feet above mean sea level. Contour interval is 100 feet.

The shape and slope of the piezometric surfaces determine the rate and direction of movement of ground water in the artesian aquifers and are controlled by several factors. Irregularities in the shape and slope may be caused by: (1) structure of the aquifer; (2) local differences in the permeability and thickness of the aquifer; and (3) discharge of ground water by springs, seeps, and wells.

The general shape and slope of the piezometric surfaces is controlled to a large extent by the structure of the aquifers. Both the Dakota sandstone and the Cheyenne sandstone member dip toward the east but also dip northward and southward from the bedrock ridge extending east-west across the central part of the county (pl. 2). This structure has caused a similar slope of both piezometric surfaces as shown by the contours in figures 16 and 17.

Local differences in permeability and thickness of the aquifers appear to have considerable influence on the shape and slope of the piezometric surfaces in Baca County. Where the aquifers are thinner and less permeable the contours on the piezometric surfaces are more closely spaced than they are in areas where the aquifers are thicker and more permeable. Differences in thickness and permeability probably are the principal causes of the great differences in spacing of the contours in figures 16 and 17. The most productive wells that have been developed in the Cheyenne sandstone member are in the area of widely spaced contours northwest of Walsh, indicating that the Cheyenne sandstone member has a relatively great thickness and permeability in that area.

The discharge of water from springs and seeps in the Dakota sandstone and Cheyenne sandstone member has significant local effects on the shape and slope of the piezometric surfaces. In the canyon area in southwestern Baca County the discharge has drained locally the Dakota and Cheyenne, causing the sharp westward flexures of the contours on the piezometric surfaces (figs. 16, 17). The same is true of the water in the Dakota sandstone in northwestern Baca County, where the deeper canyons have been cut through the Dakota and Cheyenne. This is reflected in the shape of the piezometric surface of the water in the Dakota (fig. 16), but there were not sufficient data to determine the effect of discharge by seeps and springs upon the shape of the piezometric surface of the water in the Cheyenne (fig. 17).

Most of the wells that obtain water from the Dakota and Cheyenne are small domestic and stock wells that discharge only small quantities of water and that have had no noticeable effect on the shape and slope of the piezometric surfaces. The extensive local development of flowing wells in the area north of Walsh, however, has caused local changes in the shape and slope of the piezometric surface in the Cheyenne sandstone member because of the considerable local lowering of the artesian-pressure head of the wells. The change in shape and slope is indicated by the sharp westward flexure of the contours in T. 29 S., Rs. 42 and 43 W. (fig. 17). The amount of lowering of the piezometric surface in the most heavily developed area probably is between 30 and 50 feet.

WATER-LEVEL FLUCTUATIONS

The water table and piezometric surfaces in any area are not stationary but fluctuate, much like the surface of the water in a reservoir. The rise or fall of the water table and piezometric surfaces depend upon the amount of recharge into the ground-water reservoir and the amount of discharge. If the inflow exceeds the draft, the surfaces will rise; conversely, if the draft exceeds the inflow into the ground-water reservoir, they will fall. The water table and piezometric surfaces fluctuate more by the addition and depletion of a certain quantity of water than does the level of a surface reservoir, because ground water occupies only part of the volume of a ground-water reservoir. If the sand and gravel of an unconfined aquifer have an average specific yield (definition on p. 29) of 25 percent, the addition of 1 foot of water to the aquifer will raise the water table about 4 feet. The storage coefficient (definition on p. 29) of artesian aquifers generally is much smaller than the specific yield of unconfined aquifers, and the fluctuations of water level caused by additions and depletions of water in artesian aquifers generally are greater than fluctuations caused by equal additions and depletions in unconfined aquifers. Changes of water levels record the fluctuations of the water table and the piezometric surfaces and hence the recharge and discharge of the ground-water reservoirs.

The principal factors that control the rise of the water table (ground-water recharge) in Baca County are: (1) the amount of precipitation that, after penetrating the soil, descends to the zone of saturation, (2) infiltration from streams and depressions, and (3) the quantity of water that moves from the confined aquifers to the unconfined aquifers in places where they are connected and where the pressure of the water in a confined aquifer is greater than the pressure of the water in an unconfined aquifer. This type of movement is possible where the confining layer overlying the artesian aquifer has been removed locally by erosion or is sufficiently permeable to allow the upward movement of water. The principal factors that control the rise of the piezometric surfaces in Baca County are: (1) the amount of water that enters the artesian aquifers in areas where they crop out, either by downward percolation from rainfall or by infiltration from streams, (2) the amount of water that moves from the unconfined aquifers into the artesian aquifers in areas where the confining bed is somewhat permeable or has been removed by erosion and where the pressure of the water in the unconfined aquifer is greater than the pressure of the water in the confined aquifer, (3) the amount of water that moves from the lower artesian aquifer (Cheyenne sandstone member of the Purgatoire formation) into the upper artesian aquifer (Dakota sandstone) in areas where the pressure of the water in the Cheyenne exceeds the pressure of the water in the Dakota, and (4) the amount of water moving into the county from the west.

The principal factors causing declines in the water table (ground-water discharge) in this area are: (1) movement into areas toward the east and south, (2) evaporation and transpiration, (3) discharge by seeps and springs, and (4) pumping from wells. Factors causing declines in the piezometric surfaces in this area are: (1) movement of water into areas to the east, (2) movement of water out of the aquifers either through the confining layers or at places where the confining layers have been removed by erosion (provided that the water in the aquifers is under sufficient pressure), (3) discharge of seeps and springs, and (4) discharge of wells.

If the quantity of ground water discharged from a ground-water reservoir during a year is greater than the recharge during that year, the water table or piezometric surface will decline. During a period of dry years the water table and piezometric surfaces may decline even though there has been very little pumping from wells, but in a later period of wet years they may rise. The decline of the water table and piezometric surfaces during a dry year, therefore, does not necessarily mean that there has been an excessive withdrawal of water from the ground-water reservoirs, for during dry years there is less recharge of the ground-water reservoirs because of the decreased precipitation. At the same time the discharge of ground water is increased by greater evaporation and transpiration and, generally, by increased pumping from wells. Conversely, during wet years the recharge to the reservoirs by precipitation is greater and the loss of water by evaporation, transpiration, and pumping is reduced.

The fluctuations of the water table and the piezometric surfaces in Baca County were determined by observing the water levels in wells tapping the principal aquifers. Periodic measurements of water level were begun in the spring of 1947 and are still being made. The measurements have been made every month by W. R. Smith, V. M. Burtis, and the writer. Water-level measurements made in 1947-50 have been published in the annual water-level reports of the U. S. Geological Survey (Water-Supply Papers 1100, 1130, 1160, and 1169) and subsequent measurements will be published in later reports of the series.

RECHARGE OF GROUND WATER

Recharge, the addition of water to a ground-water reservoir, may be accomplished in several ways. All ground water in Baca County within a practical drilling depth is derived from precipitation either within the county or in nearby areas to the west. Once the water becomes a part of the ground-water body it moves in the direction of the downward slope of the water table or piezometric surface, later to be discharged at some point farther down gradient.

In nature a ground-water reservoir as a hydraulic system is in balance; on the average, the recharge is equal to the discharge and the water table is fixed in position. Of course, as discussed above, the recharge and discharge and the position of the water table do fluctuate from season to season and from year to year. Discharge by wells is a new discharge superimposed on the system. Before a new equilibrium can be established water levels must fall throughout the aquifer to an extent sufficient to increase the natural recharge or decrease the natural discharge, or both, by an amount equal to the amount being discharged by the wells. Until this new equilibrium is established water must be withdrawn from storage in the aquifer, and, conversely, the new equilibrium cannot be established until an amount of water is withdrawn from storage by the wells sufficient to depress the water table enough to change the recharge or natural discharge, or both, by the proper amount. These are the fundamental laws upon which must be based all investigations to determine the potential perennial yield or so-called safe yield of aquifers.

The ground-water reservoirs in Baca County are recharged mainly by local precipitation. Other important factors affecting recharge in this area are seepage from streams and depressions, inflow from the west, and movement from one aquifer to another.

Recharge from precipitation.—The average annual precipitation in Baca County is about 16 inches, but, owing to several factors, only a small part of the water reaches the ground-water reservoirs. Of the precipitation that falls in this area, part is lost by evaporation and transpiration, part is lost by runoff, and the remainder reaches the ground-water reservoirs.

The quantity of water lost by evaporation depends upon the temperature, humidity, vegetative covering, depth to water level below land surface, and length of time the processes of evaporation have access to the moisture. The topography of a large part of Baca County is characterized by relatively flat uplands containing numerous shallow sinkholes and undrained depressions and by areas of dune sand having little or no surface drain-

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age. A large part of the precipitation in the upland areas is held in these undrained areas until it evaporates or moves downward to the water table. The water may be held in the sinkholes and undrained depressions or uplands for long periods, until most of it disappears by evaporation. In some sinkholes and depressions, however, the water disappears at a rate greater than the rate of evaporation, indicating that considerable water is moving downward to the water table. The water that accumulates in the poorly drained dune-sand areas as small temporary lakes generally disappears rapidly through infiltration into the relatively permeable sandy soil. A large part of the precipitation in Baca County is lost by evaporation, but also some of the precipitation is lost by transpiration from plants, particularly from May through August when precipitation generally is greatest and plant growth is most abundant.

Because of the poorly developed drainage in the large areas of upland in Baca County, only a small percent of the water that falls in the area is runoff, water that is immediately carried away by the streams. The drainage is well developed in the canyon areas in the southwestern and northwestern parts of the county and is moderately well developed in the southernmost part of the county on the north side of the Cimarron River, but these areas make up only a small part of the total area of the county.

Water that is not lost by evapotranspiration and runoff percolates downward through the soil. The soil will absorb moisture until the amount of water it contains is greater than can be held against the pull of gravity; then part of the water moves downward to the zone of saturation. The downward movement may be prevented by transpiration which during the growing season, may deplete the soil moisture as rapidly as it can be replenished by precipitation. At the end of the growing season the moisture in the soil may have been depleted. Water that enters the soil during the fall and winter tends first to replenish the soil moisture, because there is comparatively little transpiration and evaporation during these seasons, and then to move downward to the water table. From the first killing frost in the fall to the last killing frost in the spring, considerable water moves downward through the soil and to the water table. The high rates of evaporation and transpiration during the growing season probably permit very little recharge except where the water table is relatively near the land surface.

Figure 18 is a hydrograph covering the years 1947 through 1951 which shows the fluctuations of water levels in nine wells in Baca County, and precipitation at Springfield.

Recharge from streams.—One of the important sources of recharge to ground-water reservoirs in this area is the loss of water from channels of intermittent streams during periods of flow. Most of the small streams in the upland areas are intermittent because their channels lie above the water table. During

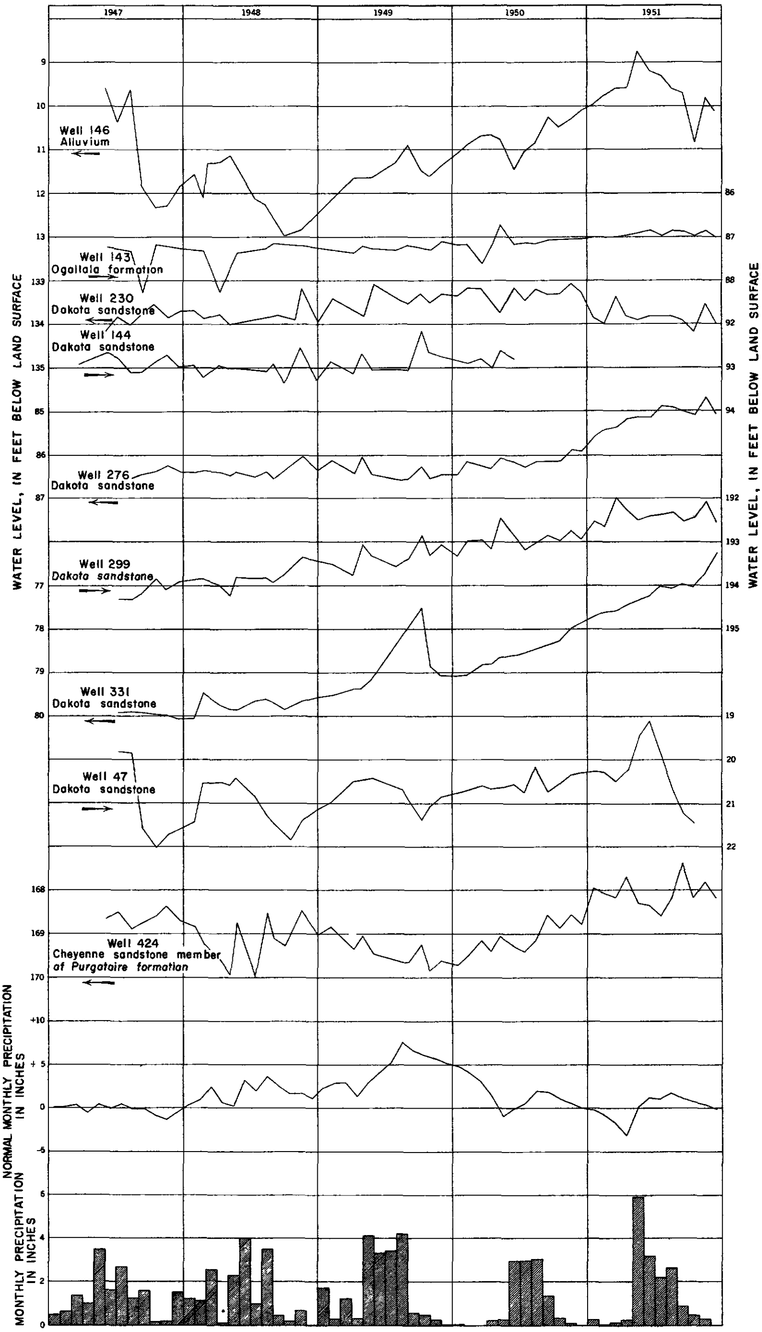

Figure 18. —Fluctuations of water levels in nine wells in Baca County, cumulative departure from normal monthly precipitation at Springfield, and monthly precipitation at Springfield.

periods of flow, much of the water may percolate downward through the sandy stream bed and eventually reach the water table. In those places where the intermittent streams flow across the outcrops of the artesian aquifers, part of the water in the streams is absorbed by the aquifer and moves in the direction of the downward slope of the piezometric surface. At other places water from the stream may percolate downward into the underlying valley fill and, in those places where the valley fill lies on permeable beds of an artesian aquifer, part of the water may then enter the artesian aquifer.

Recharge from undrained depressions.—The surface of the area underlain by the Ogallala formation (pl. 1) is marked by many shallow sinkholes or depressions which catch and hold rainwater and reduce surface runoff. Water that accumulates in these depressions after heavy rains may disappear quickly or may stand for days or even weeks before being dissipated by evaporation or percolation. Studies of recharge from shallow depressions in the High Plains of Texas (White, Broadhurst, and Lang, 1946, p. 386-387) show that the recharge from some ponds in that area was rapid, whereas, from other ponds it was negligible. Gages placed in several of the ponds recorded a decline of water level about equivalent to that which would be caused by evaporation alone. The water levels in other ponds declined at the rate of 2 inches or more a day for 10 days or more, indicating that much of the water was being lost by percolation. Some of the temporary ponds formed in the sinkholes and depressions in the upland areas of Baca County after heavy rains probably lose considerable water by percolation, thus recharging the ground-water reservoir.

The large areas of dune sand (pl. 1) in the southern part of the county are so poorly drained that temporary ponds are formed after heavy rains. These ponds generally are short lived because of the rapid downward percolation through the porous soil developed on the dune sand. The temporary ponds developed in the dune-sand areas probably constitute one of the principal sources of recharge to the ground-water reservoir in the county.

Recharge from subsurface inflow.—It was not practicable during this investigation to measure the amount of recharge to the ground-water reservoirs of Baca County. The amount of water added to the reservoirs probably is large because of the large area of the county, but probably is only a small percent of the total precipitation. The loss of water from some of the intermittent streams and the relatively rapid disappearance of water in some of the undrained depressions give some indications of the amount of recharge, but the most significant indication is the great difference between the inflow into the three principal aquifers along the west line of the county and the outflow in these aquifers along the east, north, and south lines of the county. The water-table and piezometric-surface contour maps (figs. 14, 16, 17) show that the movement of the water in the three aquifers is toward the east. The Ogallala formation is essentially dry along the west line of the county but has an average thickness of saturation of about 25 feet along the east line and considerably greater thickness in the eastern part of the county along the north and south lines. The Dakota sandstone is essentially drained along the west line of the county except for a few miles on either side of U. S. Highway 160 but is largely saturated throughout its extent along the east line of the county. The Cheyenne sandstone member of the Purgatoire formation is drained along the west line of the county except for a few miles on either side of U. S. Highway 160 and for the northernmost 6 or 7 miles of the west line of the county, but it is completely saturated throughout its extent along the east line and along the eastern part of the north line of the county where the water leaves the county. Thus, it can be seen that most of the water leaving the county toward the east, northeast, and southeast is derived from recharge within the county.

DISCHARGE OF GROUND WATER

Ground water may be discharged from the zone of saturation either through evaporation and transpiration or as hydraulic discharge through seeps, springs, wells, or infiltration galleries. The principal types of ground-water discharge are discussed below.

Discharge by transpiration and evaporation.—Ground water may be taken into the roots of plants directly from the zone of saturation or from the capillary fringe, and be discharged from the plants by transpiration. The depth from which plants will lift ground water varies with the species of plants and the type of soil. The limit of lift by ordinary grasses and field crops is not more than a few feet; however, alfalfa and certain types of desert plants may send their roots to depths of several tens of feet to reach the water table.

Discharge of ground water by evaporation and transpiration in Baca County probably is restricted to areas of very shallow water such as the flood plains of the Cimarron River and some of the smaller stream valleys. Only a small acreage is sown to alfalfa in Baca County and the flood-plain areas of shallow water generally are covered with various types of grass whose roots extend to depths of only a few feet. The total loss of ground water by transpiration, therefore, probably is relatively small. Some ground water is lost by evaporation in Baca County, particularly along the channels of some of the streams where the water table is at or near the level of the stream channel.

The loss of water from the artesian aquifers by transpiration and evaporation probably is negligible. Throughout most of the county the aquifers are overlain by other formations and the processes of transpiration and evaporation have very little effect on the water in the aquifers.

Discharge from springs and seeps.—Considerable ground water is discharged from the ground-water reservoirs of Baca County by springs and seeps (pl. 9). The springs and seeps issue largely in the northwestern and southwestern parts of the county where the streams have cut steep-walled canyons through the three principal aquifers—the Ogallala formation, Dakota sandstone, and Cheyenne sandstone member of the Purgatoire formation. Other springs and seeps issue along some of the tributaries of the Cimarron River in the southeastern part of the county and along Bear Creek and some of its tributaries in the northern part of the county. The recovery of ground water from springs is discussed in a later section of this report (p. 49).

Discharge by wells.—Another method of discharge from the ground-water reservoirs of Baca County is the discharge from wells, either by pumping or by natural flow. Most of the wells in the county are domestic and stock wells that have yields ranging from less than a gallon a minute to only a few gallons a minute. Their yields generally are small because little water is available or because they have not been drilled and equipped to produce large quantities of water. The flowing artesian wells generally have larger yields because they may be allowed to flow at their full capacity. Their yields range from less than 1 gallon a minute to nearly 100 gpm. The irrigation and public-supply wells are drilled and equipped for large production and may discharge as much as 3,000 gpm by pumping.

Although most wells in the county are domestic and stock wells having small yields, the combined yield of all wells in the county is relatively large. The discharge from the flowing wells in the Walsh artesian area is considerable and increases as new wells are drilled. The discharge from large-diameter public-supply and irrigation wells has increased considerably since the investigation was begun and probably will continue to increase. The recovery of ground water from wells is discussed in a later section of this report (p. 52).

Discharge by subsurface outflow.—As discussed previously, considerable ground water moves out of the county by subsurface outflow to the east. The water-table and piezometric-surface contour maps (figs. 14, 16, 17) show that the water in the three principal aquifers moves generally eastward and leaves the county primarily across the east line of the county but also in part across the north and south lines of the county.

MOVEMENT OF WATER BETWEEN AQUIFERS

There is continuous recharge to or discharge from the various aquifers in Baca County that does not represent net addition to or depletion of the total ground-water supply of the county. This is the continuous movement of ground water from one aquifer into another. It may consist of movement from a confined aquifer to an unconfined aquifer, from an unconfined aquifer to a confined aquifer, from one confined aquifer to another, or from one unconfined aquifer to another. In Baca County the movement is largely to and from the three principal aquifers--the Cheyenne sandstone member, which is largely a confined aquifer in Baca County; the Dakota sandstone, the lower part of which is confined in most places and the upper part of which may be either confined or unconfined; and the Ogallala formation, which is unconfined throughout most of the county.

The movement of ground water from one aquifer to another is governed largely by the difference in pressure head of the water in the aquifers. The movement probably is considerable in areas where two aquifers are in direct contact, such as in the eastern part of Baca County where the Ogallala formation lies directly upon the eastward-dipping Dakota sandstone (pl. 2) and the head in the Ogallala is appreciably higher than that in the Dakota. Movement from one aquifer to another in places where they are separated by a confining layer of low permeability probably is much slower, but nevertheless the ground water does move through the confining layer if there is sufficient difference in pressure head of the water in the two aquifers. In parts of Baca County there is as much as 100 feet of difference in pressure head between the Dakota and Cheyenne. The piezometric-surface contours in figure 17 show that water in the Cheyenne moves generally eastward to the limits of the aquifer and through confining layers into other aquifers. The movement does not appear to be impeded greatly by the pinching out of the Cheyenne sandstone member between the overlying Kiowa shale member and the underlying red beds, although these rocks have relatively low permeabilities.

RECOVERY OF GROUND WATER

SPRINGS

There are many small springs and seeps in the more heavily dissected areas of Baca County, particularly in the canyon areas in the northwestern and southwestern parts of the county. The springs supply small quantities of water used chiefly for livestock but also for domestic purposes. At a few places water from springs is used to irrigate small garden plots.

Most of the springs issue from the Dakota sandstone (fig. 19), but some issue from the Cheyenne sandstone member of the Purgatoire formation and others from the Ogallala formation. The springs in this area are gravity springs; that is, the water does not issue under artesian pressure but discharges by gravity along outcrops of the aquifers. The water of a gravity spring percolates from permeable material or flows from large openings in a rock formation, under the action of gravity, as a surface stream flows down its channel (Meinzer, 1923b, p. 51). The types of gravity springs in Baca County are (1) depression springs, where water flows to the surface because the land surface coincides with or intersects the water table, and (2) contact

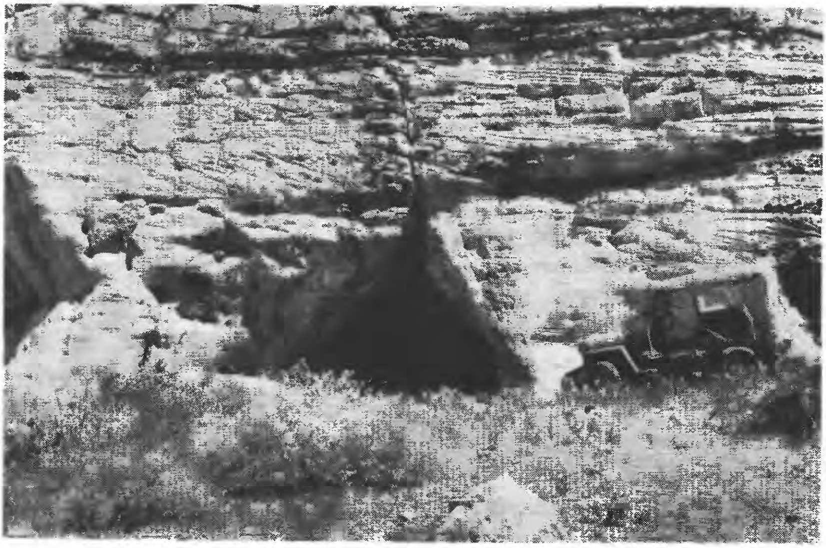

Figure 19. —Small springs issuing from cavern in the lower massive sandstone of the Dakota sandstone.

springs, whose waters issue from permeable material overlying material of relatively low permeability which retards or prevents further downward percolation of the ground water thus forming a perched water table (fig. 20). Depression springs issue mainly from the Ogallala formation along the Cimarron River and some of its tributaries in the southeastern part of the county and from the Dakota sandstone along Bear Creek and some of its tributaries in the northeastern part of the county. Contact springs issue from several formations in the northwestern and southwestern parts of the county. Water from the Cheyenne sandstone member issues at the contact of the Cheyenne and the underlying Morrison formation, principally in the southwestern part of the county.

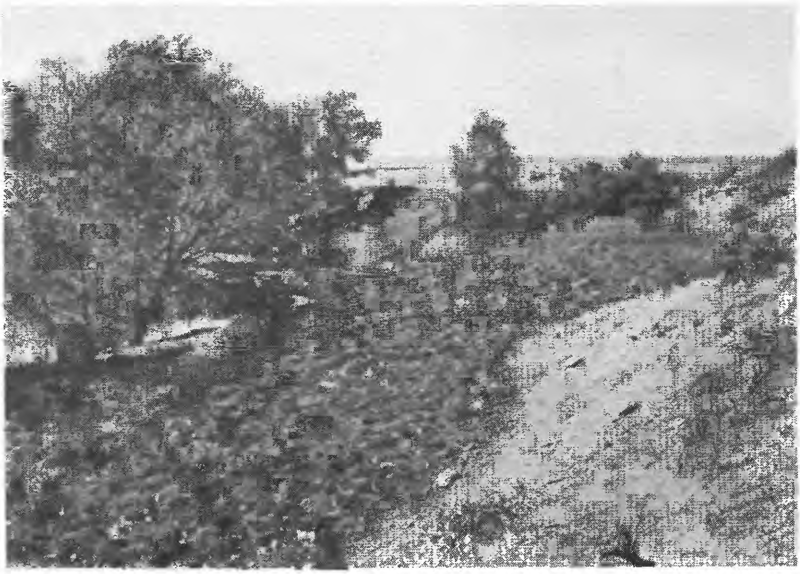

Figure 20.—Large seepage area (dark area) on the banks of Two Butte Creek. Water issues from basal gravel of the Meade(?) formation, near the contact of the Meade(?) and the relatively impermeable Graneros shale.

The Dakota sandstone is the principal source of spring water in Baca County. Water from the Dakota generally issues at the contact of the Dakota and Purgatoire formations (fig. 19) but may issue at the contact of the upper massive sandstone of the Dakota and the underlying sandy shale and shaly sandstone. Water from the Ogallala formation generally issues at the contact of the Ogallala with underlying formations of low permeability, but it may issue also at the contacts of beds of great difference in permeability within the formation. Most of the contact springs issuing from the Ogallala formation are in the northwestern part of the county where the formation is underlain by beds of relatively low permeability—particularly the Graneros shale and Greenhorn limestone. In the southwestern and northeastern parts of the county the Ogallala is underlain by the Dakota sandstone which is moderately permeable. Few or no springs issue at the contact of the Ogallala and Dakota formations. Instead, the water moves downward from the Ogallala into the Dakota and later issues as springs from the Dakota farther downdip.

Most springs in the county have small yields—generally less than 1 gpm—but a few are of moderate size and may discharge as much as 50 gpm. Most of the springs have not been developed and the water is dissipated by transpiration, evaporation, and infiltration. A few springs have been improved so that the water is utilized more fully.

PRINCIPLES OF RECOVERY FROM WELLS

Water is discharged from a well by means of a pump or some other lifting device or by natural artesian flow. When water is standing in a well, there is equilibrium between the head of the water inside the well and the head of the water outside the well. The head of the water inside a well may be reduced in two ways: (1) by lowering the water level by means of a pump or other lifting device and (2) by reducing the head at the mouth of a well that discharges by artesian pressure. Whenever water is removed from a well there is a resulting drawdown or lowering of the water level, or, in a flowing artesian well, an equivalent reduction in artesian head.

When water is discharged from a well the water table (or piezometric surface) is lowered in an area around the well to form a depression resembling an inverted cone, which is known as the "cone of depression", and the vertical distance that the water level is lowered is the "drawdown". The drawdown in a well increases as the rate of pumping increases.

The "capacity" or "sustained yield" of a well is the rate at which it will yield water after the water stored in the well has been removed; it depends upon the quantity of water available, the thickness and permeability of the water-bearing bed, and the construction and condition of the well. The capacity of a well generally is expressed in gallons a minute. The known or tested capacity of a strong well generally is less than its total capacity, but some weak wells are pumped at their total capacity.

The "specific capacity" of a well is the rate of its yield per unit of drawdown and is determined by dividing the tested capacity in gallons a minute by the drawdown in feet. For example, if a well yields 100 gpm with a drawdown of 10 feet, it has a specific capacity of 10. If a flowing well has a shut-in pressure head of 15 feet above the land surface and discharges 10 gpm through its discharge pipe which is 5 feet above land surface, the drawdown is 10 feet and the well has a specific capacity of 1.

When water is withdrawn from a well the water level, or pressure head, drops rapidly at first and then more slowly until it finally becomes nearly stationary. Conversely, when withdrawal of water from the well ceases the water level rises rapidly at first and then more slowly until it eventually resumes its original position or approximately its original position. When water discharges from a flowing artesian well the pressure head declines from the shut-in level to the level of the point of discharge (provided that the flow is not sufficiently large or the pipes sufficiently small to create back pressure) and the difference between these levels, the drawdown, remains constant. After the valve is opened the flow declines rapidly at first and then more slowly until the discharge becomes essentially constant. When the valve is closed the pressure head rises rapidly at first and then more slowly until the approximate original shut-in pressure is reached.

DUG WELLS

Dug wells are excavated with hand tools or power machinery and generally range from 2 to 6 feet in diameter. During the early period of settlement of Baca County, drilling machinery was scarce and most of the wells were dug—some to considerable depths. In recent years, however, most wells in this area have been drilled and only a few dug wells remain—mostly in areas of very shallow water. Inasmuch as dug wells generally cannot be deepened more than a few feet below the water table, many of them fail during extended droughts. In addition, dug wells cannot be sealed as easily as other types of wells and generally are more susceptible to surface contamination.

DRILLED WELLS

Most of the domestic, stock, irrigation, and public-supply wells in the county are drilled wells that have been excavated by means of percussion (cable-tool) or rotary drills. Most of the drilled wells in the county were constructed by means of portable cable-tool drilling rigs and only a small number of the wells by means of portable hydraulic-rotary drilling rigs. The drilled wells generally are cased with wrought-iron or galvanized-iron casing ranging from 4 to 8 inches in diameter in most domestic and stock wells to 24 inches in some large-capacity irrigation wells.

Drilled wells in consolidated deposits.—Many drilled wells in Baca County obtain water from consolidated rocks such as the Dakota sandstone or the Cheyenne sandstone member of the Purgatoire formation (figs. 16, 17.) Some uncased wells in these rocks have remained open for many years. Others, however, have caved and it has been common practice in recent years to case almost all wells, whether they are in consolidated or in unconsolidated deposits. The principal exceptions to this practice are the wells drilled into the Cheyenne sandstone member. Wells drilled to this member, particularly in the Walsh artesian area, generally are cased to some point within the Kiowa shale member where the casing is seated and a smaller hole is then drilled into the underlying Cheyenne. The section of the well in the Cheyenne is uncased and the casing in the upper part of the hole prevents leakage of the artesian water into the shallower aquifers. A few of these wells have been cased only through the unconsolidated surficial material, and artesian water from the Cheyenne leaks continuously into the Dakota sandstone.

Drilled wells in unconsolidated deposits.—Many drilled wells in the eastern part of the county obtain water from unconsolidated deposits of the Ogallala formation (fig. 14) and a few obtain water from unconsolidated alluvium along the major streams. Drilled wells that obtain all their water supply from these deposits are cased the full length of the hole to prevent caving. The casing generally is perforated opposite the aquifer but in some of the older wells the casing is not perforated and water must enter the well through the open end of the casing. The size of the perforations is an important factor in the construction of a well in unconsolidated deposits, particularly a large-capacity well such as may be used for irrigation or public supply, and the capacity or even the life of the well may be determined by it. If the perforations are too large, the fine material may filter through too rapidly and fill the well; if the perforations are too small, they may become clogged so that water will not enter the well freely.

Wells in unconsolidated sediments may be equipped with well screens or strainers. It is common practice to select, in respect to the texture and degree of assortment, a slot size that will pass the finer grained 30 to 60 percent of the water-bearing material. Retention of the coarser particles around the screen forms a natural gravel packing that greatly increases the effective diameter of the well, and hence increases its capacity.

Gravel-walled wells generally are effective for obtaining large supplies of water from relatively fine grained unconsolidated deposits, and they are used widely for irrigation and public supply. In constructing a well of this type, a hole 24 to 60 inches in diameter is first drilled and then is cased temporarily with iron or steel pipe. A well screen or perforated casing of smaller diameter than the hole is then lowered into place and centered in the larger pipe opposite the water-bearing beds. Unperforated casing extends from the screen to the surface. The annular space between the inner and outer casings is then filled with sorted gravel, preferably of a grain size just a little larger than the openings in the screen or perforated casing, and also slightly larger than the grains of the water-bearing material. In most wells of this type a medium- or coarse-grained gravel is used, but in very fine-grained deposits a fine-grained gravel or coarse-grained sand may be used. The outer casing is then withdrawn part way to uncover the screen and allow the gravel packing to come in contact with the water-bearing material. Some of the more recent wells in Colorado have been drilled with reverse-rotary drilling machines, making it possible to insert the perforated casing and fill the annular space with gravel without first inserting the blank casing.

In deciding whether to use gravel-wall construction it is important to know the character of the water-bearing material. If the material is a coarse gravel, as it is in parts of Baca County, it generally is unnecessary to use gravel packing. Many wells in eastern Colorado have been gravel packed with material that is less permeable than the water-bearing material. The large irrigation wells developed recently in the Walsh artesian area are largely in consolidated materials and are not gravel packed.

Drawdown can be kept at a minimum by drilling the well through all the most productive water-bearing materials, by using proper screen or perforated casing, and by developing the well completely so that water will flow freely into the well. Increasing the depth of a well will have a greater effect on reducing the drawdown than will increasing the diameter, provided that additional water-bearing materials are encountered.

METHODS OF LIFT

Most wells in Baca County are used for domestic and stock supplies; those so used generally are equipped with lift or force pumps. The cylinders or working-barrels in lift pumps and force pumps are similar and are placed below the water level in the well. A lift pump generally discharges water only at the pump head, whereas a force pump can force water above the pump head—generally to an elevated tank. Most of the pumps are operated by windmills, but a few are operated by hand. Most of the flowing wells are not equipped with pumps.

The discharge pipe in domestic and stock wells may be either clamped between two wooden blocks or steel bars that rest on the top of the casing or be held in place by a steel plate that rests on the casing and that has a center hole large enough to accomodate the pipe but small enough to prevent passage of the coupling. The flowing wells generally discharge over the top of the casing or are equipped with valves and reducers and discharge through 2- or 3-inch pipes. The large-diameter irrigation wells are equipped with deep-well turbine pumps consisting of a series of connected turbines, called bowls or stages, that are placed below the water level in the well and are connected by a vertical shaft to a pulley at the top. The turbine pumps may be belt-driven or may have gear heads that are directly connected to the source of power.

UTILIZATION OF WATER

Specific data on 424 wells and 10 springs in Baca County were obtained during this investigation (table 9). Of these, about 270 were used for domestic and stock supplies, 14 for irrigation supplies, 5 for industrial supplies, and 8 for public supplies. The remainder were either unused or their use was in doubt. Almost all the unused wells formerly had been either domestic or stock wells, or both. The inventory included most of the irrigation, industrial, and public-supply wells but included only some of the domestic and stock wells and only a few of the springs.

DOMESTIC AND STOCK SUPPLIES

Domestic wells supply water in homes for cooking, drinking, and washing, and in schools other than those supplied by municipal wells. Stock wells supply water for livestock—principally cattle, sheep, and poultry. Most of the domestic and stock wells are small-diameter drilled wells equipped with lift or force pumps operated by windmills or by hand. Water used for domestic and stock supplies in the county generally is moderately hard but is satisfactory. Some of the water contains sufficient fluoride to cause permanent mottling of the teeth when drunk regularly by children during the period of formation of the permanent teeth. (See section on Quality of water.)

PUBLIC SUPPLIES

The cities of Springfield, Walsh, Pritchett, and Campo have municipal water supplies, all derived from wells. These supplies are described briefly in the following paragraphs.

Springfield.—Springfield (population 2,026) is supplied by five wells, of which three (nos. 149-151) are owned by the city and two (nos. 153, 154) are owned by E. G. Huested. The wells are drilled into the lower part of the Dakota sandstone to depths ranging from 100 to 120 feet. The static water levels range from 20 to 54 feet below the land surface in the winter and from more than 20 to 74 feet in the summer when withdrawals of water are greatest. The wells are equipped with 4- to 6-inch turbine pumps powered by natural-gas or gasoline engines and discharge 100 to 200 gpm each. The drawdowns range from 26 to 27 feet. Water from the wells is pumped directly into the 4-, 6-, and 8-inch mains, the excess water going into two elevated storage tanks having a combined capacity of 150,000 gallons. No data on the consumption of water in Springfield are available but it is reported that the supply generally is not adequate during the summer. Two attempts to obtain additional water from the Cheyenne sandstone member of the Purgatoire formation have been unsuccessful but it is believed that additional test drilling through the Cheyenne probably would find enough supplemental water to ease the shortage during the summer and reduce the heavy draft on that in the Dakota sandstone. Water from well 151 was analyzed as a part of this investigation. The water is hard and has 1.5 parts per million (ppm) of fluoride, the maximum concentration permitted under standards of the U. S. Public Health Service; however, it is suitable for most domestic uses. (See analysis 151, table 6.)

Walsh.—Walsh (population 898) is supplied by a single drilled well (no. 134) which is 270 feet deep and obtains water from the Cheyenne sandstone member of the Purgatoire formation. The well has a static water level 90 feet below the land surface and is equipped with a 6-inch turbine pump powered by a natural-gas engine. Data on the discharge and drawdown were not available. The water is pumped directly into the mains, the excess going to an elevated steel tank at the well site. The water is moderately hard and contains 1.4 ppm of fluoride, which is sufficient to be beneficial to the teeth but not enough to cause objectionable mottling of tooth enamel. (See analysis 134, table 6.)

Pritchett.—Pritchett (population 282) is supplied by two wells (nos. 239, 240) which obtain water from the Dakota sandstone. The town was supplied for years by well 240, which is 268 feet deep and has a static water level of 146 feet. The well is cased with 10- and 8-inch iron casing and is equipped with a 4-inch turbine pump powered by a 10-horsepower electric motor. The bowls are set at 262 feet and are reported to pump air when discharging at the rate of 70 gpm, indicating a drawdown of 116 feet.

Well 239 was added to the system in 1948 because of repeated shortages of water during summers. Although this helped to some extent, the supply still is not adequate. The supply probably could be made adequate by obtaining supplemental water from the underlying Cheyenne sandstone member of the Purgatoire formation. Well 239 is 300 feet deep and has a static water level of 150 feet. It is cased with 10-inch iron casing and is equipped with a turbine pump powered by an electric motor. The discharge is reported to be 38 gpm, but the drawdown is not known.

Water from the two wells is pumped directly into the mains, the excess going into an elevated steel storage tank at the site of well 240. A sample of the water from well 240 was collected for analysis. The water is hard and contains 1.6 ppm of fluoride, which is above the Public Health Service's limit but is sufficient to cause only very slight mottling of the teeth of some children. The water contains an excess of iron (1.27 ppm), which causes a slightly bad taste and noticeable staining of kitchen and bathroom fixtures. (See analysis 240, table 6.)

Campo.—Campo (population 265) was constructing a new municipal water supply at the time of the field work of this investigation and it has since been put into operation. The town is supplied by one well (390) which obtains water from both the Dakota and the Cheyenne, although most of the water is derived from the Cheyenne. The well is cased with 6-inch iron casing. No data are available concerning the pump, power, discharge, or drawdown. The water is pumped directly into the mains, the excess going into an elevated steel storage tank. No data are available as to the quality of the water from the city well but a sample of water was collected from the nearby railroad well (391) which yields from the same water-bearing formations. The water from well 391 is moderately hard, contains 1.2 ppm of fluoride, and is satisfactory for most domestic uses. (See analysis 391, table 6.)

INDUSTRIAL SUPPLIES

The only industrial-supply wells in Baca County are those used by the Atchison, Topeka and Santa Fe Railway Co. to supply water for its steam locomotives. The company maintains large supply wells at Walsh, Pritchett, Campo, and Harbord switch north of Pritchett (wells 133, 241, 391, and 100). The wells range in diameter from 10 to 14 inches and in depth from 250 to 432 feet. Two wells (133 and 241) are equipped with cylinder pumps and two with turbine pumps—all powered by Diesel engines. The discharges range from 75 to 100 gpm and the drawdowns from 12 to 58 feet (no record of the drawdown in well 133 was available). Well 133 obtains all its water from the Cheyenne sandstone member of the Purgatoire, wells 100 and 391 from both the Cheyenne and Dakota, and well 241 from both the Dakota and the Ogallala.

IRRIGATION SUPPLIES

Prior to the time of this investigation there was only a small amount of irrigation with water from wells in Baca County, mostly with water from flowing wells in the Walsh artesian area. Most of the flowing wells in the artesian area have been used to irrigate small plots—generally gardens, small orchards, and perhaps some feed crops. Although the irrigation was not extensive, it was a vital factor in helping many farm families through the 10-year drought of the 1930's.

For many years there has been an interest in developing large-scale irrigation in and around the artesian area, but most early attempts were unsuccessful. Well 60 was reported to yield about 750 gpm with a pumping lift (static water level plus drawdown) of a little more than 80 feet, but it was no longer in use at the time this investigation was begun. Well 70 was reported to have had a moderately large discharge when pumped with a large pump, but it was reported to have stopped the flow of several nearby flowing artesian wells while pumping, and it has since been abandoned.

Credit for discovering the capacity of the Cheyenne sandstone member of the Purgatoire formation to yield large quantities of water to properly constructed wells belongs to R. R. Rutherford of Vilas, prominent Baca County rancher and farmer. Mr. Rutherford drilled and tested many wells tapping the Cheyenne sandstone member at various places on his extensive holdings. In 1947, a short time before this investigation was begun, he completed a 20-inch diameter well in the SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 29, T. 29 S., R. 44 W., along Horse Creek between Vilas and Two Buttes. The well was drilled to a depth of 208 feet and was bottomed in the Cheyenne sandstone member. It was equipped with a turbine pump having 10 3/4-inch discharge pipe and 14-inch bowls and was powered with a 138-horsepower Diesel engine. The well was reported to yield nearly 3,000 gpm with a drawdown of about 70 feet. Mr. Rutherford later abandoned this well and drilled a new well (83) about 100 feet west of the old well. Well 83 is 24 inches in diameter and is equipped with a 16-inch turbine pump powered by the same Diesel engine. It is reported to yield between 3,000 and 4,000 gpm and probably has the largest yield of any irrigation well in Colorado that derives water from consolidated sediments. The water can be pumped into a large earth reservoir for later use or through 1,500 feet of 12-inch steel pipe and then distributed through a sprinkler system of 6-inch pipe. The well was used to irrigate about 640 acres in 1950.

Irrigation has developed rapidly in and near the Walsh artesian area since the field work in Baca County was completed. Although an inventory of the new wells has not been made, it was reported that there were six irrigation wells in the area at the end of 1950. A new well was drilled by Mr. Hall in sec. 23, T. 29 S., R. 45 W., and is reported to yield several hundred gallons per minute. Mr. Rutherford has completed a 24-inch well in sec. 21 about a mile downstream from well 83. It is about 200 feet deep and is equipped with the 14-inch turbine pump taken from his first well and is powered by a Diesel engine. The well is reported to yield about 2,200 gpm. O. P. Scobey drilled a well farther downstream in sec. 27. It is 228 feet deep and is reported to yield about 800 gpm. James Thompson is reported to have three wells in secs. 9, 10, and 16, T. 29 S., R. 43 W. One is reported to yield about 1,100 gpm, another about 700 gpm, and the third (in the NW$\frac{1}{4}$ sec. 10) was abandoned after being test-pumped at the rate of 300 gpm. These three wells flowed when not being pumped.

Most of the new irrigation wells in the Walsh area are constructed in a similar manner. The wells are neither screened nor gravel packed. The hole is left open opposite the principal aquifer (Cheyenne) and blank casing is seated in the overlying shale (Kiowa). Some of the wells are cased only through the surficial material down to the Dakota sandstone. Inasmuch as the pressure head of the water in the Cheyenne exceeds the pressure head of the water in the Dakota throughout the Walsh artesian area, such construction results in nearly continuous discharge of water from the Cheyenne into the Dakota, which represents a drain—so far serving no useful purpose—on an aquifer having a very important but limited water supply. Irrigation wells constructed so far within the area of artesian flow are not equipped to prevent the natural flow between periods of pumping. As much of the flow is not put to beneficial use between irrigation seasons, it is a substantial waste of artesian water.

POSSIBILITIES OF ADDITIONAL DEVELOPMENT OF LARGE SUPPLIES OF WATER FROM WELLS

General features.—The feasibility of additional development of large supplies of water from wells for irrigation, public-supply, or industrial use is dependent upon the long-term yield of the ground-water reservoirs, the cost of drilling and pumping, the types of soil, the quality of water, the crops raised, the market and price conditions, and other factors.

The ability of a ground-water reservoir to yield water over a long period of years is limited, as is that of a surface reservoir. If water is withdrawn from a ground-water reservoir by pumping and by other means (natural flow, seeps, springs, evaporation, and transpiration) faster than water enters it, the water levels in wells will decline and the supply ultimately will be depleted. The amount of water that can be withdrawn annually over a long period of years without depletion of the ground-water reservoir is dependent upon the capacity of the underground reservoir and upon the amount of water that is added annually to the reservoir by recharge.

One important factor to consider is the effect on yield of an aquifer whose annual replenishment is small but in which a large quantity of water is stored and is available to wells. The annual replenishment may be inadequate to support a substantial continued development for irrigation or other large-scale uses. In such a case, it may be decided by competent authority to permit a large-scale development for a limited period of years—a period long enough, for example, to permit full amortization of investments in wells and related equipment and to realize a profit that will contribute materially to the public welfare—and then to restrict ground-water development to a rate that can be maintained indefinitely.

The cost of drilling and pumping is determined in part by the depth to the aquifer and the depth to water level. In areas where the water table or piezometric surface is relatively deep, the wells must be deep and the pumping lift is great. The cost of a well is also determined in part by the permeability and thickness of the water-bearing materials. Wells may penetrate relatively fine grained materials that cause the yield of the well to be relatively small. Gravel packing may increase the yield of some of these wells, but it also adds to the cost. The character of the soil and the contour of the land surface also are important factors in the use of ground water for irrigation. The soil may be very sandy, causing excessive loss of water in ditches or requiring the use of sprinkler systems. The land may be poorly drained or it may not have the proper slope, requiring large expenditures for leveling.

Ogallala formation.—The distribution of the Ogallala formation is shown in plate 1 and its thickness and character and the position of the water table within the formation are shown in part in plate 2. The general shape and slope of the water table in the Ogallala are shown in figure 14. The contours showing the depth to water in the eastern part of the county are shown in plate 1. With these data, together with the well logs, it is possible to determine the most feasible areas for development of large-capacity wells in the Ogallala formation. The feasibility is governed largely by (1) the character of the water-bearing materials, (2) the thickness of the saturated materials (vertical distance between the water table and the bedrock underlying the Ogallala), and (3) the depth to the water level below the land surface.

The materials in the Ogallala formation range from dense limestone and clay to highly permeable sand and gravel. Where the materials below the water table are highly permeable, they will yield water freely; where the materials are dense and relatively impermeable, they will yield little or no water to wells. The materials making up the Ogallala formation are shown in the diagrammatic cross sections (pl. 2) in generalized form. They are shown accurately only at the sites of the test holes drilled as a part of this investigation and have been interpolated between test holes. Inasmuch as the materials in the Ogallala change considerably within short distances, the reader should bear in mind that it is necessary to drill one or more test holes before choosing a site for an irrigation well or other well of large capacity. In general, the Ogallala contains a greater percentage of gravel in areas where it is thickest.

Large-capacity wells can be developed in the Ogallala formation only where there is an adequate thickness of saturated materials. If the saturated materials are moderately permeable sand and gravel, only 30 to 50 feet of materials may be required to yield a large quantity of water to a properly constructed well; if they are poorly sorted sand, silt, and clay, several hundred feet may be required to yield a large quantity of water to a well. As shown by plate 2, the Ogallala is largely drained in most of the western part of the county and the thickness of saturated materials is negligible. In the eastern part of the county the saturated thickness generally is much greater and is about 175 feet in the vicinity of test hole 17.

The depth to water level is a third controlling factor in the feasibility of developing large-capacity wells in the Ogallala formation. The greater the depth to water the greater will be the pumping lift and the greater will be the cost of pumping the water. The depth to water level beyond which pumping from wells for irrigation is too costly is difficult to determine and is variable. The limit may be influenced by type of crop, quality of the soil, price of crops, climate, cost of fuel, and drawdown in the well. Many wells having a depth to water in excess of 100 feet are now in operation in the High Plains of Colorado and Kansas and a few have been operated successfully in areas where the depth to water is between 150 and 200 feet. Many of these, however, are in the Hugoton gas field of southwestern Kansas where there is an abundant supply of cheap fuel. Even using cheap fuel it is doubtful that they could be operated successfully during periods of low crop prices.

The depth to water level beyond which pumping from wells for public or industrial supply is too costly is not as limited as for irrigation supply. It is doubtful if the depth to water in the Ogallala formation in any part of the county is beyond the economic limit of pumping lift for public and industrial supplies.

In view of the discussion above it appears that there are three areas in Baca County where large-capacity wells could be developed in the Ogallala formation. The first is a small area in the vicinity of test holes 17 and 18 in the southeastern part of the county (pl. 2) where the depth to water is less than 100 feet and the thickness of saturated materials ranges from about 100 to about 175 feet. Test drilling indicated a considerable thickness of highly permeable gravel capable of yielding moderately large quantities of water to wells. The area is moderately rough and sandy, which would make the use of sprinkler systems necessary in most of the area if the water is to be used for irrigation.

The second area is along the Cimarron River valley where the depth to water is less than 50 feet and where both the alluvium and the Ogallala formation could be tapped by a single well. Large-capacity wells probably would be difficult to obtain in the vicinity of the outcrop of Triassic rocks in the valley (pl. 1) because there is little or no Ogallala beneath the alluvium. Here, again, the land is moderately rough in places and sprinkler systems would be needed with most irrigation installations.

The third area is in the northeastern part of the county in the vicinity of test hole 1 (pl. 2) where the thickness of saturated materials is about 100 feet and the depth to water is about 150 to 160 feet. A short distance north, in Prowers County, the depth to water is less than 100 feet. Test hole 1 penetrated a considerable thickness of sand and gravel. The topography and soil in this area appear to be excellent for the development of irrigation.

In addition to the three principal areas named above, there are other areas where the prospects are less promising but that are worthy of being tested. In those areas where the thickness of saturated materials is between 50 and 100 feet, as indicated by plate 2, test drilling might reveal sufficient highly permeable gravel to yield moderate to large quantities of water to properly constructed wells. It should be emphasized again that no large-capacity well should be drilled without preliminary test drilling to ascertain the thickness and character of the water-bearing materials in order to determine the feasibility of drilling a large-capacity well and, if so, the proper well site.

There appears to be very little danger of overdevelopment of the water supply of the Ogallala formation, except locally. The soil, topography, and character and thickness of the water-bearing materials will not permit extensive development of large-capacity wells. The water in the small favorable areas is supplied by recharge from much larger areas in which large-capacity wells cannot be developed.

Purgatoire formation.—Throughout much of the central High Plains, the Cheyenne sandstone member of the Purgatoire formation yields only small quantities of water to wells. The new irrigation wells in Baca County are the first large-capacity wells to be developed in the Cheyenne sandstone member in this region. Although there have not been many attempts to develop large wells in the Cheyenne, the discharges and drawdowns of the many domestic and stock wells in the Cheyenne in this region indicate that the sandstone generally is not capable of yielding large quantities of water to wells and that the large discharges of the new wells in the Walsh artesian area are the exceptions rather than the rule. Development of large-capacity wells in the Cheyenne probably will be greatly limited by the difficulty of locating proper well sites in this comparatively low-capacity aquifer.

The feasibility of developing large supplies of water from the Cheyenne sandstone member of the Purgatoire formation is controlled largely by (1) the thickness of the aquifer, (2) the permeability of the aquifer, (3) the depth to the aquifer, and (4) the pressure head of the water in the aquifer. The Cheyenne is of moderately uniform thickness throughout most of the county, but it becomes very thin and pinches out in the southeastern part of the county. The sandstone thickens toward the northeast and appears to reach its maximum thickness in the central and northeastern parts of the county. The increased thickness may account in part for the relatively high productivity of the aquifer in the Walsh artesian area but it is not the only cause. The sandstone is more than 130 feet thick in the vicinity of Springfield, but two attempts to develop a large well in that vicinity have been unsuccessful.

The permeability of the aquifer probably is the principal factor controlling the development of large wells in the Cheyenne sandstone member. The Cheyenne, unlike the Ogallala, has a moderately uniform texture throughout the area. The grain size of the sand generally is very fine to medium, although the lower part may contain a few pebbles. The degree of cementation appears to be the principal factor affecting permeability of the sandstone. Where the sandstone is tight and well cemented, the permeability is relatively low; where the sandstone is loose and poorly cemented, the permeability is relatively high. The degree of cementation and hence the permeability differ considerably from place to place, and large-capacity wells have been developed short distances from unsuccessful wells.

One means by which the areas of greatest average permeability of the Cheyenne can be delineated is by use of the map of the piezometric surface of water in the Cheyenne (fig. 17). A decrease in the slope of the piezometric surface can be caused by an increase in permeability of the aquifer, an increase in thickness of the aquifer, or both. Inasmuch as the thickness of the Cheyenne changes very gradually in Baca County, the abrupt flattening (decrease in slope) of the piezometric surface of water in the Cheyenne in the areas north of Walsh and north of Campo probably is caused mainly by an increase in permeability of the Cheyenne.

The depth to the aquifer and the pressure head of water in the aquifer are controlling factors in the development of large-capacity wells in the Cheyenne sandstone member. In and near the areas of outcrop of the Purgatoire formation the Cheyenne is largely drained and will yield little or no water to wells. In other areas, particularly in the western half of the county, the depth to the Cheyenne may be as much as 300 or 400 feet and the pressure head of the water may be sufficient to raise the water only a short distance above the top of the aquifer. In these areas the depth of wells to the Cheyenne would be great and the pumping lift would be excessive for irrigation use under present conditions. Toward the east the Cheyenne is reached at somewhat shallower depths and the pressure head is sufficient to raise the water near to or above the land surface. The water levels in this area are within the economic limit of pumping lift for most uses.

Because of the factors discussed above, there apparently are two areas in Baca County that are favorable for the future development of large-capacity wells in the Cheyenne sandstone member of the Purgatoire. One is the area of decreased slope of the piezometric surface north of Walsh (the area between the 3,900- and 4,000-foot contours in fig. 17) and the other is north of Campo (between the 4,100- and 4,200-foot contours in fig. 17). In the area north of Walsh the Cheyenne is relatively thick and the water levels generally are at or near the land surface. In the area north of Campo the Cheyenne is thinner and the depth to water level generally is between 200 and 300 feet, which would make the pumping lift too great for irrigation supplies under present conditions.

The favorable designation of these areas is based on the relative permeability inferred from the slope of the piezometric surface. Inasmuch as the permeability of the Cheyenne changes greatly from place to place, many unsuccessful wells will be drilled within the areas listed above. It is likely that successful large-capacity wells will be drilled outside these two areas, but they appear to be the most favorable areas for prospecting.

Large-capacity wells in the Cheyenne sandstone member should be developed slowly and cautiously, with due consideration for proper well spacing. The recharge to the Cheyenne is derived mostly from precipitation and from influent stream loss in the areas of outcrop in the western part of the county. The rate at which water can be pumped from the aquifer, therefore, is determined almost entirely by the transmissibility of the aquifer (the rate at which water moves through the aquifer). The amount of water that moves through the aquifer is, as indicated by table 5, not sufficient to supply a large number of wells having high yields. The average storage coefficient of the Cheyenne where confined is only a small fraction of the average specific yield of many unconfined aquifers that yield large quantities of water to wells. The water from a confined aquifer is derived by compression of the aquifer and expansion of the water upon release of pressure, whereas the water from an unconfined aquifer is derived by unwatering the saturated materials. The water levels in wells penetrating the Cheyenne will decline rapidly with heavy pumping until they are below the top of the aquifer, after which the aquifer will no longer be confined and the water will be derived by unwatering the saturated materials. The cone of depression caused by heavy pumping in a confined aquifer quickly extends over a large area because, unlike the cone of depression in an unconfined aquifer, it is not developed by unwatering sediments adjacent to the well. Heavy pumping in and near the Walsh artesian area will cause declines in pressure head and discharge of the nearby flowing wells during the periods of pumping. If the aquifer is pumped heavily and continuously, the pressure heads of the flowing wells will decline permanently. As the piezometric surface is lowered, the flowing wells having the lowest pressure heads will cease flowing and the area of artesian flow (pl. 1) will gradually decrease. Large pumping wells that have already been developed in this area are reported to cause decrease or cessation of the output of the flowing wells within a radius of several miles of them during periods of pumping. It is not known whether the pumping has yet caused any permanent declines of pressure head.

Alluvium.—The flood plains of some of the major stream valleys, principally the Cimarron Valley, are underlain by moderate thicknesses of alluvium. Where these materials are coarse grained and are saturated, moderate quantities of water could be obtained by means of properly constructed wells. The water table in these areas would be shallow and the pumping lift would be small. Systematic test drilling along lines across the valleys, rather than parallel to the valleys, would be needed in order to select the most favorable sites (fig. 54 and p. 138). In the Cimarron River valley it would be advisable to tap both the alluvium and the underlying Ogallala formation except in the area adjacent to the outcrops of Triassic deposits (pl. 1). Along other streams the alluvium may be dry or may be very thin. Where the thickness of saturated materials is small, larger quantities of water may be obtained from properly constructed infiltration galleries or from a battery of wells connected to a single pump. These systems permit the development of larger supplies of water with smaller drawdown—a necessary factor in places where the thickness of saturated materials is small (p. 136 and fig. 53).

QUALITY OF WATER

The chemical character of ground waters in Baca County is indicated by the analyses of water from 60 representative wells and springs given in table 6. Figure 21 shows graphically the chemical character of typical ground waters from the principal aquifers in the county. The samples were analyzed in the laboratory of the Quality of Water Branch of the U. S. Geological Survey at Salt Lake City, Utah. The analyses show only the dissolved mineral content of the waters and do not show their sanitary condition. General statements on the quality of ground waters in this area are given below, and the quality of waters in the

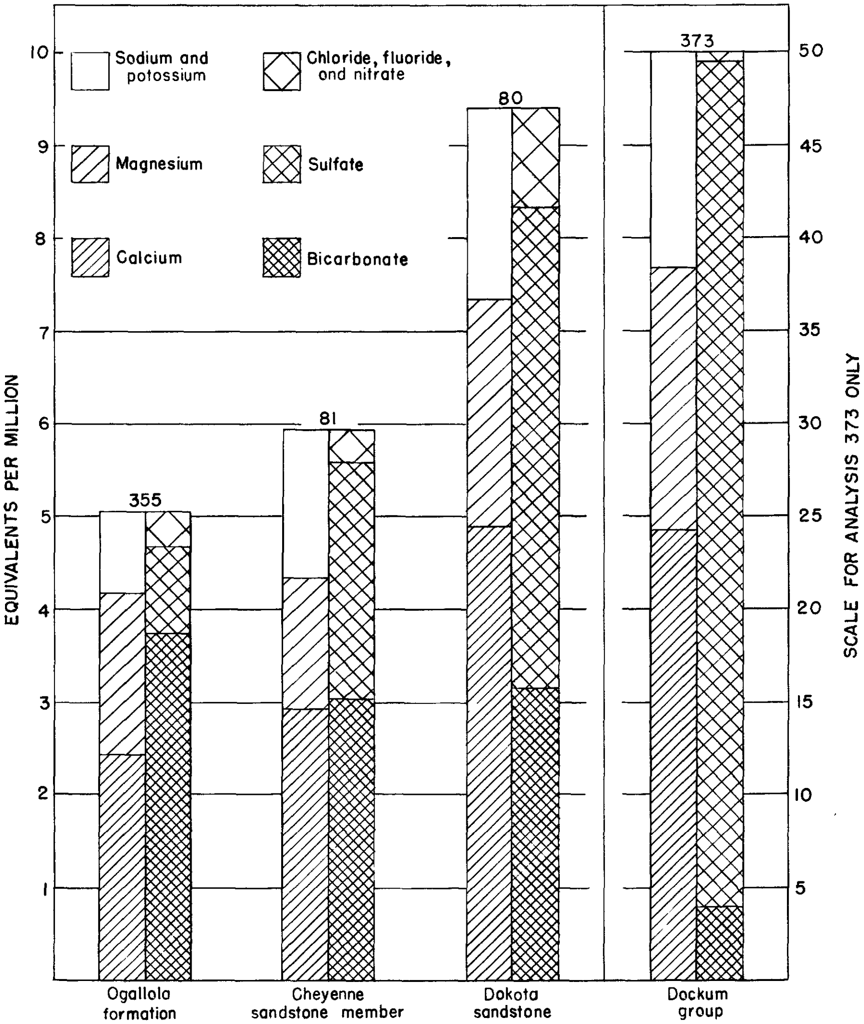

Figure 21. —Analyses of ground waters from Baca County, Colo.

Table 6.—*Analyses of water from typical*

No. on pl. 1	Location	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Specific conductance (K x 10[6] at 25°C)	Boron (B)	Silica (SiO_2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	T. 28 S., R. 41 W.							
1	SW¼SW¼ sec. 8........	181.7	Dakota ss.	8-25-48	60	451	....	13
	T. 28 S., R. 42 W.							
4	NW¼NW¼ sec. 4.......	137.3	Ogallala fm.	8-25-48	63	475	....	19
	T. 28 S., R. 43 W.							
8	SE¼SW¼ sec. 9........	172.5	.......do.......	8-25-48	60	492	....	18
10	Se¼SW¼ sec. 34......	425	Cheyenne ss. mem.	8-25-48	61	794	....	13
	T. 28 S., R. 44 W.							
17	SE¼SE¼ sec. 26.......	196.6	Dakota ss.	8-24-48	62	608	....	9
	T. 28 S., R. 45 W.							
18	NE¼NE¼ sec. 1.......	199.3	.......do.......	8-24-48	57	852	....	14
	T. 28 S., R. 46 W.							
23	SW¼NE¼ sec. 1.......	83.6	Entrada ss.	8-30-48	59	836	0.02	15
	T. 28 S., R. 47 W.							
27	SE¼NE¼ sec. 17........	264.4	Cheyenne ss. mem.	8-23-48	59	643	....	3.8
	T. 28 S., R. 49 W.							
36	NW¼SE¼ sec. 25......	42	Lincoln ls. mem.	8-23-48	60	2,440	....	31
	T. 28 S., R. 50 W.							
40	SE¼NW¼ sec. 17......	(b)	Dakota ss.	8-23-48	68	148	....	46
	T. 29 S., R. 42 W.							
48	SW¼NW¼sec. 11......	26	.......do.......	8-30-48	60	1,000	.02	29
	T. 29 S., R. 43 W.							
63	SW¼SW¼ sec. 22.....		Cheyenne ss. mem.	7-16-48	60	943	.04	14
	T. 29 S., R. 44 W.							
80	NE¼NW¼ sec. 5.......	200	Dakota ss.	8-30-48	60	859	.02	16
81	NE¼SW¼ sec. 27......	190	Cheyenne ss. mem.	8-24-48	58	553	....	17
	T. 29 S., R. 45 W.							
87	SW¼SW¼ sec. 15.....	100+	Cheyenne ss. mem. (?)	8-24-48	60	597	....	17
	T. 29 S., R. 46 W.							
92	NW¼NW¼ sec. 5......	112.3	Dakota ss.	8-23-48	61	402	....	20
	T. 29 S., R. 47 W.							
97	SE¼NE¼ sec. 31.......	180.5	.......do.......	8-23-48	59	5,640	....	4.9
	T. 29 S., R. 49 W.							
104	SE¼NE¼ sec. 12.......	219	.......do.......	8-23-48	61	1,930	....	5.5
	T. 30 S., R. 41 W.							
111	NW¼NW¼ sec. 7......	78.2	.......do.......	8-25-48	58	531	....	23
115	SW¼SW¼ sec. 33......	36.3	.......do.......	8-27-48	59	1,850	....	28
	T. 30 S., R. 42 W.							
117	NW¼SW¼ sec. 4.......	141	Dakota ss. (?)	8-30-48	59	801	.02	10
	T. 30 S., R. 43 W.							
134	SW¼SE¼ sec. 32	270	Cheyenne ss. mem.	7-16-48	63	453	.06	15

wells and springs in Baca County, Colo.

Iron (Fe) (10)	Calcium (Ca) (11)	Magnesium (Mg) (12)	Sodium and potassium (13)	Bicarbonate (HCO_3) (14)	Sulfate (SO_4) (15)	Chloride (Cl) (16)	Nitrate (NO_3) (17)	Fluoride (F) (18)	Dissolved solids (19)	Hardness (calculated as $CaCO_3$) Total (20)	Hardness (calculated as $CaCO_3$) Noncarbonate (21)
....	50	15	26	164	87	9	6.2	....	287	186	52
....	51	16	33	176	97	10	7.9	....	321	193	49
....	52	14	37	170	102	10	8.9	....	326	187	48
....	73	33	60	248	216	14	.0	....	531	318	114
....	57	24	22	201	104	11	.3	....	326	240	76
....	108	31	40	157	314	19	.9	....	604	397	268
5.08	98	30	45	192	275	14	.2	0.6	572	368	210
....	34	23	74	208	131	23	1.1	....	392	180	9
....	344	121	101	242	1,080	98	142	....	2,040	1,360	1,160
....	18	2.6	8.5	44	21	7	6.3	.4	132	56	20
.71	148	32	39	312	95	120	75	.6	692	501	246
.03	86	40	69	249	286	16	2.6	.8	637	379	175
.89	98	30	47	194	247	25	19	1.1	579	368	209
....	59	17	37	186	122	7	6.7	.9	358	217	64
....	56	20	43	212	114	14	3	....	371	222	48
....	44	12	26	174	56	7	6.6	....	257	160	17
....	452	356	607	156	3,550	32	42	2.8	5,120	2,590	2,460
136[c]	206	127	124	236	1,040	21	1.2	.0	1,640	1,040	842
....	50	21	37	204	95	11	6.7	2.0	346	212	44
....	126	90	132	254	342	245	77	....	1,170	684	476
2.86	58	45	51	240	210	15	.0	1.7	509	330	133
.03	44	20	25	216	55	5	1.9	1.4	274	192	15

Table 6.—*Analyses of water from typical wells*

No. on pl. 1	Location	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Specific conductance (K x 10^6 at 25°C)	Boron (B)	Silica (SiO_2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	T. 30 S., R. 44 W.							
137	NE¼SE¼ sec. 6	98.9	Dakota ss.	8-24-48	58	491	....	21
	T. 30 S., R. 46 W.							
151	NE¼SE¼ sec. 6	128	......do......	7-15-48	58	705	0.04	16
	T. 30 S., R. 49 W.							
164	SW¼SW¼ sec. 6	274	......do......	8-23-48	60	880	....	9.2
	T. 33 S., R. 50 W.							
177	SW¼SW¼ sec. 28	200	Cheyenne ss. mem.	8-31-48	58	831	.02	11
	T. 31 S., R. 42 W.							
198	NE¼SW¼ sec. 15	39.2	Ogallala fm.	8-27-48	59	696	....	....
	T. 31 S., R. 45 W.							
223	SE¼NW¼ sec. 1	103	......do......	8-30-48	62	738	.02	.17
	T. 31 S., R. 47 W.							
232	NW¼NW¼ sec. 1	83	......do......	8-19-48	59	297	....	....
237	NW¼NW¼ sec. 33	170.0	Dakota ss.	8-20-48	59	342	....	....
	T. 31 S., R. 48 W.							
240	NW¼SE¼ sec. 6	268	......do......	7-15-48	61	467	.06	1.27
	T. 32 S., R. 41 W.							
260	SE¼SW¼ sec. 7	86.0	Ogallala fm.	8-27-48	60	628	....	....
	T. 32 S., R. 42 W.							
266	NW¼NW¼ sec. 5	100	Dakota ss. (?)	8-30-48	61	753	.02	2.07
	T. 32 S., R. 44 W.							
280	SE¼SE¼ sec. 14	106.5	Ogallala fm.	8-25-48	60	570	....	....
	T. 32 S., R. 45 W.							
284	SW¼NW¼ sec. 13	110	......do......	8-25-48	60	430	....	....
	T. 32 S., R. 46 W.							
293	NE¼SW¼ sec. 22	161.8	......do......	8-20-48	65	391	....	....
	T. 32 S., R. 47 W.							
297	SE¼SE¼ sec. 27	408	Cheyenne ss. mem.	8-20-48	60	638	....	63
	T. 32 S., R. 48 W.							
303	SW¼SW¼ sec. 34	366	......do......	8-20-48	61	422	....	....
	T. 33 S., R. 49 W.							
305	SE¼SW¼ sec. 3	318	Dakota ss.	8-23-48	60	476	....	....
	T. 33 S., R. 41 W.							
317	NE¼NE¼ sec. 30	194.5	Dockum group (?)	8-26-48	61	624	....	....
	T. 32 S., R. 42 W.							
320	SE¼SE¼ sec. 19	177.8	Ogallala fm.	8-26-48	63	457	....	....
	T. 33 S., R. 43 W.							
322	NE¼NE¼ sec. 3	160	......do......	8-27-48	62	406	....	....
	T. 33 S., R. 44 W.							
327	NW¼SW¼ sec. 3	128.7	......do......	8-25-48	60	419	....	....

and springs in Baca County, Colo.—Continued

Iron (Fe) (10)	Calcium (Ca) (11)	Magnesium (Mg) (12)	Sodium and potassium (13)	Bicarbonate (HCO_3) (14)	Sulfate (SO_4) (15)	Chloride (Cl) (16)	Nitrate (NO_3) (17)	Fluoride (F) (18)	Dissolved solids (19)	Hardness (calculated as $CaCO_3$) Total (20)	Hardness (calculated as $CaCO_3$) Noncarbonate (21)
......	51	15	53	162	147	7	10	....	384	188	56
0.04	80	25	41	188	208	9.2	5.1	1.5	478	302	148
......	100	46	27	144	308	28	23	....	612	438	320
3.25	60	41	64	194	265	12	1.5	1.7	552	318	159
74	29	36	24	193	143	38	27	....	466	304	146
65	38	27	23	158	177	33	15	1.7	458	318	188
48	8.1	6.0	20	156	23	5	9.6	....	196	154	26
47	10	14	11	189	27	4	.0	....	206	158	4
43	20	29	12	199	72	6.8	.0	1.6	282	190	26
36	38	45	41	239	92	28	15	....	413	246	50
59	42	32	29	200	118	42	49	1.7	471	320	156
38	31	38	36	242	80	14	5.8	....	362	222	24
44	23	16	35	226	41	6	4.2	....	280	204	20
53	16	2	30	192	16	5	22	....	237	198	40
87	10	24	16	374	1.2	1	.5	....	324	258	0
48	20	13	27	216	32	10	6.5	....	263	202	25
54	20	21	18	288	6.2	12	.2	1.0	274	216	0
26	24	84	24	279	86	8	21	....	410	164	0
29	29	24	37	227	40	8	5.0	....	284	192	6
33	26	15	35	208	33	8	7.3	....	260	190	19
41	23	12	47	198	35	14	6.3	....	276	197	35

Table 6.—*Analyses of water from typical wells*

No. on pl. 1	Location	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	Specific conductance (K x 10^6 at 25°C)	Boron (B)	Silica (SiO_2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	T. 33 S., R. 46 W.							
335	NW¼SW¼ sec. 20....	305.5	Cheyenne ss. mem.	8-20-48	68	368	....	....
	T. 33 S., R. 48 W.							
350	NW¼NE¼ sec. 25....	365.4	Dakota ss. (?)	7-16-48	....	747	.04	2.55
	T. 33 S., R. 49 W.							
355	NE¼NE¼ sec. 29.....	272	Ogallala fm.	8-19-48	62	462	....	....
	T. 33 S., R. 50 W.							
360	NW¼SW¼ sec. 10....	61.9	Dakota ss.	8-19-48	58	524	....	....
	T. 33 S., R. 42 W.							
373	NW¼NE¼ sec. 22.....	4,967	Dockum group	9-1-48	60	3,490	.02	.25
	T. 34 S., R. 45 W.							
383	NE¼NE¼ sec. 7.......	229.5	Ogallala fm.(?)	8-25-48	63	396	....	....
387	SE¼SE¼ sec. 25	295	Dockum group(?)	8-26-48	61	475	....	....
	T. 34 S., R. 46 W.							
391	SE¼NE¼ sec. 10......	432	Cheyenne ss. mem.	7-16-48	65	409	.06	.03
	T. 34 S., R. 47 W.							
395	SW¼NW¼ sec. 2......	420	Cheyenne ss. mem.	8-20-48	63	417	....	....
	T. 34 S., R. 48 W.							
402	SW¼SE¼ sec. 18.....	133.8	Dakota ss. (?)	8-19-48	62	467	....	....
	T. 34 S., R. 50 W.							
413	NW¼SE¼ sec. 8......	79.5	Dockum group	9-1-48	59	1,290	.02	1.06
416	NW¼SW¼ sec. 32...	27	Alluvium	8-19-48	68	882	....	....
	T. 35 S., R. 41 W.							
417	SE¼SE¼ sec. 16......	183.7	Ogallala fm.	8-26-48	65	765	....	....
	T. 35 S., R. 43 W.							
420	NW¼NE¼ sec. 1......	22.0	.......do......	8-27-48	61	694	....	....
	T. 35 S., R. 44 W.							
422	SW¼SW¼ sec. 2	92.2	.......do......	8-26-48	64	559	....	....
	T. 35 S., R. 47 W.							
431	SE¼NW¼ sec. 5......	(b)	Dakota ss.	8-20-48	68	313	....	....
	T. 35 S., R. 50 W.							
434	NW¼NW¼ sec. 12...	53.5	Dockum group	8-19-48	61	812	....	....

[a]A part per million is equivalent to 1 pound of substance per million pounds of water or 8.33 pounds per million gallons of water.

and springs in Baca County, Colo.—Continued

Iron (Fe) (10)	Calcium (Ca) (11)	Magnesium (Mg) (12)	Sodium and potassium (13)	Bicarbonate (HCO_3) (14)	Sulfate (SO_4) (15)	Chloride (Cl) (16)	Nitrate (NO_3) (17)	Fluoride (F) (18)	Dissolved solids (19)	Hardness (calculated as $CaCO_3$) Total (20)	Noncarbonate (21)
39	18	15	10	182	43	6	1.5	....	222	172	22
105	29	22	38	468	28	7.5	5.6	.4	466	381	0
49	21	20	26	228	45	8	8.5	....	290	209	22
64	20	19	20	238	62	14	4.2	....	320	242	46
486	174	264	29	242	2,190	12	4.6	1.2	3,280	1,930	1,730
41	18	16	23	186	42	8	5.2	....	245	176	24
37	21	37	33	228	44	10	15	....	309	179	0
46	19	13	25	206	33	7	6.7	1.2	252	193	24
50	19	12	26	206	34	11	11	....	264	203	24
67	15	11	24	216	50	12	8.5	....	294	228	52
105	79	71	23	394	334	40	14	1.0	861	587	264
89	40	48	24	240	229	38	2.8	....	589	386	190
70	35	56	31	406	84	11	5.3	....	492	318	0
59	33	57	36	326	70	19	43	1.6	479	282	16
58	28	17	31	233	50	22	27	....	348	260	68
51	6.3	1.2	20	124	30	5	20	....	195	153	52
71	48	45	19	328	161	18	9.8	1.0	534	374	106

[b]Spring.
[c]Includes iron in suspended materials.

principal water-bearing formations of the county is discussed on pages 80 to 81 and in the section on Geologic formations and their water-bearing properties.

The dissolved mineral constituents are reported in parts per million. A part per million is a unit weight of a constituent in a million unit weights of water. Equivalents per million are not given in this report though the expression of analyses in equivalents per million is sometimes preferred. An equivalent per million is a unit chemical combining weight of a constituent in a million unit weights of water and is calculated by dividing the concentration in parts per million by the chemical combining weights of the constituent. For convenience in making this conversion the reciprocals of chemical combining weights of the most commonly reported constituents are given in the following list.

Constituent	Factor	Constituent	Factor
Iron (Fe^{++})................	0.0358	Carbonate (CO_3^{--})........	0.0333
Iron (Fe^{+++})..............	.0537	Bicarbonate (HCO_3^-)....	.0164
Calcium (Ca^{++})..........	.0822	Sulfate (SO_4^{--})............	.0208
Magnesium (Mg^{++})......	.0822	Chloride (Cl^-)............	.0282
Sodium (Na^+).............	.0435	Fluoride (F^-)	.0526
Potassium (K^+)..........	.0256	Nitrate (NO^-)..............	.0161

Results given in parts per million can be converted to grains per United States gallon by dividing by 17.12. A calculated quantity of sodium and potassium is given in some analyses and is the quantity of sodium needed in addition to the calcium and magnesium to balance the acid radicals.

The total hardness, as calcium carbonate ($CaCo_3$), is calculated from the equivalents of calcium and magnesium. The hardness caused by calcium and magnesium (and other ions if significant) equivalent to the carbonate and bicarbonate is called carbonate hardness. The hardness in excess of this quantity is called noncarbonate hardness. Carbonate hardness is not listed in Table 6, as it can be found by substracting noncarbonate hardness from total hardness.

CHEMICAL CONSTITUENTS IN RELATION TO USE OF WATER

The following discussion of the chemical constituents of ground water has been adapted in part from publications of the U. S. Geological Survey.

Dissolved solids.—The residue left after a natural water has evaporated consists of rock materials, with which may be included some organic material and some water of crystallization. Waters containing less than 500 ppm of dissolved solids generally are satisfactory for domestic use, except for the difficulties resulting from their hardness and, in some areas, excessive corrosiveness. Waters having more than 1,000 ppm generally are not satisfactory, for they are likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable in some other respects.

The dissolved solids contained in samples of water collected in Baca County ranged from 132 to 5,120 ppm and averaged 574 ppm. More than half the samples contained 200 to 300 ppm and 43 samples contained less than 500 ppm and, therefore, are suitable for most uses (table 7).

Table 7.—*Dissolved solids in samples of water*

Dissolved solids (ppm)	Number of samples				
	Ogallala	Dakota	Cheyenne	Other[1]	Total
101–200	1	2	0	0	3
201–300	7	6	4	1	18
301–400	4	4	4	1	13
401–500	5	3	0	1	9
501–600	0	2	2	3	7
601–700	0	3	1	0	4
701–800	0	0	0	0	0
801–900	0	0	0	1	1
901–1,000	0	0	0	0	0
More than 1,000	0	3	0	2	5
Total	17	23	11	9	60

[1]Includes sample from one well producing from both the Cheyenne and the Dakota.

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

In addition to the total hardness, the table of analyses shows the carbonate and noncarbonate hardness. Carbonate hardness is that caused by calcium and magnesium bicarbonate and is almost completely removed by boiling. In some reports this type of hardness is called temporary hardness. Noncarbonate hardness usually is caused by sulfate or chloride of calcium and magnesium; it cannot be removed by boiling and has been called permanent hardness. With reference to use with soap there is no difference between the carbonate and noncarbonate hardness. In general, the noncarbonate hardness forms harder scale in steam boilers.

Water having a hardness of less than about 50 ppm generally is rated as soft, and its treatment for the removal of hardness generally is not necessary. Hardness between 50 and 150 ppm does not seriously interfere with the use of water for most purposes, but it does increase the consumption of soap, and its removal by a softening process is profitable for laundries and for some other industries. Hardness of more than 150 ppm can be noticed by anyone, and if the hardness is more than about 200 ppm it is common practice in some areas to soften water for household use or to install cisterns to collect soft rainwater.

Water samples collected in Baca County ranged in hardness from 56 to 2, 590 ppm. None of the samples of water were soft, although one sample had a hardness (spring no. 40, hardness 56 ppm) only slightly higher than the upper limit for soft water. More than half the samples had a hardness between 150 and 300 ppm and 52 of the 60 samples had a hardness of less than 500 ppm (table 8).

Table 8.—*Total hardness of samples of water*

Dissolved solids (ppm)	Number of samples				
	Ogallala	Dakota	Cheyenne	Other[1]	Total
Less than 50	0	0	0	0	0
51–150	0	1	0	0	1
151–300	14	11	8	3	36
301–500	3	7	3	3	16
501–700	0	2	0	1	3
More than 700	0	2	0	2	4
Total	17	23	11	9	60

[1]Includes sample from one well yielding from both the Cheyenne and the Dakota.

Iron.—Next to hardness, iron is the constituent of natural waters that in general receives the most attention. The quantity of iron in ground waters may differ greatly from place to place, even though the waters are derived from the same formation. If a water contains much more than 0. 1 ppm, the excess may precipitate as a reddish sediment. Iron, which may be present in sufficient quantity to give a disagreeable taste to water and to stain cooking utensils, may be removed from most waters by simple aeration and filtration, but a few waters require the addition of lime or some other treatment.

The amount of iron was determined in only 17 of the 60 samples collected in Baca County. Only 4 of the 17 samples contained less than 0.1 ppm of iron; 10 contained 0.1 to 5.0 ppm.

Fluoride.—Although determinable quantities of fluoride are not so common as fairly large quantities of other constituents of natural waters, it is desirable to know the amount of fluoride present in waters that are likely to be used by children. Fluoride in water has been shown to be associated with the dental defect known as mottled enamel, which may appear on the teeth of children who drink water containing fluoride during the period of formation of the permanent teeth. This condition becomes more noticeable as the quantity of fluoride in water increases above 1.5 ppm. Recent reports indicate that the incidence of tooth decay is decreased or prevented by quantities of fluoride that are not sufficient to cause permanent disfigurement from mottled enamel.

The concentration of fluoride was determined in 23 of the 60 samples of water collected in Baca County. The amount of fluoride ranged from 0.0 to 2.8 ppm and averaged 1.2 ppm. Eight of the 23 samples contained more than 1.5 ppm. The fluoride content generally is highest in waters from the Dakota sandstone.

Nitrate.—The concentration of nitrate in waters used for drinking has caused increased attention since the recent discovery that nitrate-rich water may cause cyanosis of infants ("blue babies") when the water is used in the preparation of babies' formulas. Some nitrates can be dissolved from nitrate-bearing formations, but it is believed that large concentrations of nitrate generally are derived from surficial sources. Nitrates are very soluble and may readily be dissolved from soils having high concentrations of nitrate (in some cases from fertilizer) or from nitrogenous materials in privies, cesspools, and barnyards; hence, high concentrations of nitrate may indicate that the water contains harmful bacteria also. Large amounts of nitrate are more commonly found in waters from dug wells and springs, which generally are more poorly sealed from surface contamination, than from the deeper drilled wells.

Ninety parts per million of nitrate (as NO_3) in water is considered by some authorities as dangerous to infants, whereas a concentration of 45 parts is considered dangerous by others (Comly, 1945). Of the 60 samples of water collected, 4 contained more than 45 ppm of nitrate and only 1 contained more than 90 parts.

Water for irrigation.—The suitability of water for irrigation is commonly believed to depend mainly on the quantity of soluble salts and the proportion of sodium. The concentration of chloride in some waters may be large enough to affect their use for irrigation and in some waters other constituents, such as boron, may be present in sufficient quantity to be harmful to plants. The concentration of dissolved constituents may be expressed as equivalents per million of anions or cations, as parts per million of dissolved solids, or as electrical conductivity. Electrical conductivity is the measure of the ability of the inorganic salts in solution to conduct an electric current, and it is related to the concentration of dissolved solids. Conductivity is listed in column 7 of table 6 and for moderately mineralized water is about equal to the total equivalents per million of anions or cations multiplied by 100, or to the dissolved solids in parts per million divided by 0.7 (Wilcox, 1948, p. 4, 5). The percent of sodium is obtained by dividing the equivalents per million of sodium by the equivalents per million of the total cations (usually calcium, magnesium, sodium, and potassium) and multiplying by 100.

The specific conductance of 28 samples of water from the Ogallala and Cheyenne was plotted against the percent of sodium on a diagram prepared by Wilcox (fig. 22). The lower margin is a scale of conductivity ranging from 0 to 4,000 and the left margin is a scale of the percent of sodium. The upper limit of any class of water, other than "unsuitable," is defined by the percentage of sodium in the water, and as the concentration increases, the sodium limit for any class becomes lower. The plotted points for the analyses of all waters from the Ogallala and Cheyenne in Baca County fall almost entirely within the class of "excellent to good" and only four are in the class of "good to permissible." As with all other systems for classification of water for irrigation, that of Wilcox (1948a) is largely empirical and assumes average conditions of soil, crops, drainage, permeability, and climate.

The amount of boron was determined in four of the samples collected from wells in the Ogallala and Cheyenne. The concentrations ranged from 0.02 to 0.06 ppm and are well within the limit of suitability for irrigation. The concentration of chloride in the 28 samples from the two aquifers was very low; it ranged from 1 to 38 ppm and averaged 13—entirely satisfactory for irrigation use.

SANITARY CONSIDERATIONS

The analyses of water given in table 6 show only the amounts of dissolved mineral matter in the water and do not indicate the sanitary quality of the water. The water in a well may contain

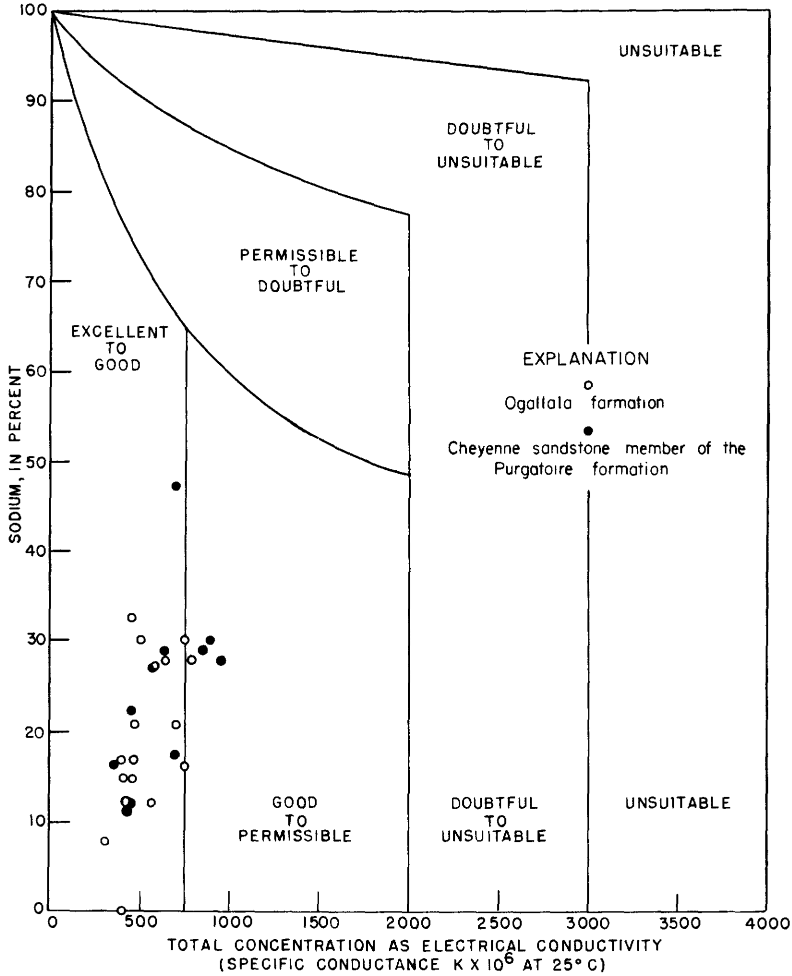

Figure 22. —Classification of waters from Baca County for irrigation use (after Wilcox).

mineral matter that imparts an objectionable taste or odor and yet be free from harmful bacteria and entirely safe for drinking. On the other hand, the water in a well may be clear and pleasant to the taste and yet contain harmful bacteria.

Most of the people of Baca County depend upon water supplied from wells and every precaution should be taken to protect this water supply from pollution. A well should not be constructed where there are possible sources of pollution, such as barnyards, privies, and cesspools, and every well should be tightly sealed to a level below that of the water table. Dug wells are more likely to be contaminated from surface sources than are drilled wells, chiefly because dug wells generally are not effectively cased or sealed at the surface. Drilled wells generally are well protected by casing, but many are poorly sealed at the top. Springs generally are more likely to be contaminated than are wells and should be improved properly before being utilized for domestic use. Also, the water should be tested to make sure that it is not contaminated at the source in such a way that it cannot be made safe by any method of spring development.

QUALITY IN RELATION TO WATER-BEARING FORMATIONS

The quality of water typical of the principal water-bearing formations in Baca County is shown in figure 21 and is discussed below.

Purgatoire formation.—Eleven samples of water were collected from wells tapping the Cheyenne sandstone member of the Purgatoire formation. The hardness of water from the Cheyenne ranged from 172 to 379 ppm, and the concentration of dissolved solids ranged from 222 to 637 ppm. Of the 4 samples for which the fluoride content was determined, only 1 contained more than the upper limit (1.5 ppm) set by the U. S. Public Health Service for drinking water used on interstate carriers. The concentration of iron was determined for 4 of the samples from the Cheyenne, and 2 contained enough iron to stain household fixtures. The quality of the water in the Cheyenne is moderately uniform except for the amount of dissolved iron. The analysis of a typical sample of water from the Cheyenne is shown in figure 21.

Dakota sandstone.—Twenty-three samples of water were collected from wells tapping the Dakota sandstone in Baca County. Water from the Dakota generally contains too much iron for satisfactory domestic use and much of it contains enough fluoride to cause mottling of tooth enamel. The quality of the water in the Dakota differs more from place to place than the quality of water in the Ogallala and Cheyenne. The softest and hardest waters analyzed during this investigation were from the Dakota sandstone.

Ogallala formation.—Water from the Ogallala formation is of better average quality than water from the other principal aquifers. The dissolved solids (as determined by 17 analyses) ranged from 196 to 492 ppm, and the total hardness ranged from 154 to 318 parts. Although the concentration of iron was determined in only one sample of water from the Ogallala, the formation generally contains water having less iron than the water in the Dakota and Cheyenne (judged on the basis of presence or absence of iron stain in stock tanks and household fixtures). The amount of fluoride in two of the samples tested was above the Public Health Service's limit. The analysis of a typical sample of water from the Ogallala is shown in figure 21.

Other formations.—Not enough samples were collected from wells tapping the other aquifers in Baca County to permit drawing conclusions as to the range in quality of their waters. Analyses 317, 373, 387, 413, and 434 (table 6) are of water from the Dockum group. Analysis 36 is of water from the Lincoln limestone member of the Greenhorn limestone, analysis 416 is of water from the alluvium of the Cimarron River, and analysis 23 is of water from the Entrada sandstone. The analysis of water from well 373 is shown in figure 21 not because the water is typical of water from the Dockum group in Baca County but because it issues from a flowing well and is of considerable interest to local residents. The quality of the water appears to be similar to that of water from other flowing wells in the Cimarron River valley artesian area. It is a high-sulfate water that is unsuitable for most uses.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

PERMIAN SYSTEM

TALOGA FORMATION (OF CRAGIN)

Rocks of Permian age are believed to crop out in only one small area in Baca County—along Two Butte Creek near the Prowers County line (pl. 1), although they may crop out also along the Cimarron River (see section on Dockum group). The uppermost beds, which belong to the Taloga formation (of Cragin) (Cragin, 1897) consist largely of poorly exposed red beds. They are principally red to yellowish-brown or buff shale, siltstone, and sandy shale containing thin beds of hard sandstone. The beds of sandstone range in thickness from a few inches to about 2 feet and generally are fine grained, argillaceous, and micaceous. A few beds are calcareous and contain streaks of white calcium carbonate. The beds of sandstone are largely brick red but a few are mottled tan and white.

The Taloga formation (of Cragin) probably underlies all Baca County, as it has been encountered in oil tests in the western part of the county (Maher, 1948), and beds of equivalent age have been found in adjacent areas to the east and south (Norton, 1939) of Baca County. Beds of equivalent age are reported to be 204 feet thick along Two Butte Creek in southern Prowers County (Sanders, 1934), where both the overlying Entrada sandstone and the underlying Day Creek dolomite are exposed (fig. 23), but only the upper part of the Taloga crops out in Baca County. The formation thins northeastward toward the Syracuse anticline in Hamilton County, Kans., and southward toward Oklahoma.

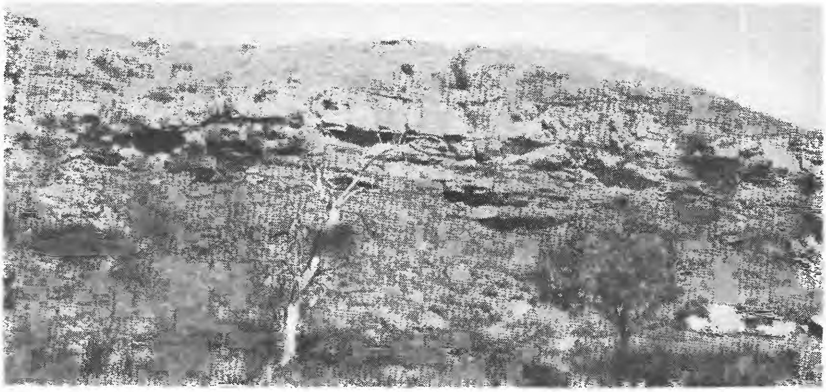

Figure 23. —Permian rocks in Two Butte Creek valley below dam in Prowers County. Massive bed is Day Creek dolomite.

No wells in Baca County obtain water from the Taloga formation (of Cragin) principally because throughout almost all the county it lies at relatively great depths and generally is overlain by more productive water-bearing formations. In parts of Oklahoma and Kansas where the formation is near the surface, it is a poor aquifer and yields only small quantities of water that in many places is too highly mineralized for most uses.

TRIASSIC SYSTEM

DOCKUM GROUP

In Baca County and in adjacent areas in Cimarron County, Okla., and Union County, N. Mex., there is a series of red beds and associated rocks that were first considered to be of Triassic age by Lee (1902). Darton (1928) later referred some of these beds to the Dockum but considered that the rest, together with Lee's Exeter formation, were a part of the Morrison formation. Parker (1933) later divided the rocks beneath the Exeter (Entrada) in Union County, N. Mex., into three units: Dockum group, Sloan Canyon formation, and Sheep Pen sandstone, named in ascending order, and considered that they were questionably Triassic in age. Stovall (Stovall and Savage, 1939; Schoff and Stovall, 1943) discovered Dockum fossils in beds of the Sloan Canyon formation, indicating that the Sloan Canyon and Sheep Pen formations should be included in the Dockum group. Throughout much of the southern High Plains the term Dockum group is used to designate all rocks of Triassic age and is so used in this report. In Baca County the Dockum group includes all rocks between Cragin's Permian Taloga formation and the Jurassic Entrada sandstone.

Character.--The lithology of the Dockum group differs greatly from one area of outcrop in Baca County to another. In the southwestern part of the county the beds are largely variegated shale, clay, and siltstone but include lesser amounts of sandstone, and conglomerate. The shale, clay, and siltstone generally are highly fractured and weather into small blocks and chips. The colors, which are distinctively vivid, are principally green and purple but also are red, brown, tan, and gray. The colors are discontinuous and change greatly in short distances, both vertically and horizontally. The green and gray are most pronounced along bedding and fracture planes. Some of the colors of the Dockum are similar to those of the Morrison formation in this area; a fact which has caused some confusion in differentiating the formations, but the colors of the Dockum can be distinguished easily by their greater brilliance. The sandstones of the Dockum group in the southwestern part of Baca County are typically white and cream to buff, fine grained, and thin bedded. Some are slightly calcareous and a few are quartzitic. Most of the beds of sandstone range in thickness from a few inches to a little more than 3 feet and in some places are highly ripple marked.

In the southeastern part of the county the beds in the Dockum group (pl. 1) are predominantly red and are considerably more sandy. The formation consists of alternating layers of brick-red clay and shale and light-gray, cream, buff, and red sandstone. The sandstones range from very fine grained to coarse grained but are predominantly fine grained. Most of them are well sorted and friable and are loosely cemented with calcium carbonate or limonite. One thin bed of very hard sandstone that crops out on the east side of Bogg Springs Draw (NW$\frac{1}{4}$ sec. 23, T. 34 S., R. 42 W.) is cemented with white chert and has a mottled appearance on weathered surfaces similar to that of some of the sandstones in the Morrison formation. The sandstones of the Dockum generally are less than 5 feet thick in Baca County but Stovall (Schoff and Stovall, 1943) observed much thicker beds along the Cimarron River northeast of Boise City in Cimarron County, Okla. The A. R. Jones No. 1 Boise Cattle Co. well in sec. 22, T. 34 S., R. 42 W., encountered mostly red beds and red sand above the Day Creek dolomite (log 132), but it is not certain how much of this section belongs to the Dockum group.

The Dockum group in the northwestern part of Baca County along Two Butte Creek (pl. 1) differs considerably from the

Dockum in other parts of the county. The beds are mostly dark-red to maroon siltstone and sandstone and gray limestone. The siltstone is hard and dense and is faintly maroon. The sandstone is maroon, very hard, and quartzitic. It ranges from fine to coarse grained but is largely fine and medium grained. It consists largely of grains of clear quartz but also contains white, amber, and orange-red grains of quartz. The cement is mostly silica, which renders the rock hard and dense (fig. 24). Many of

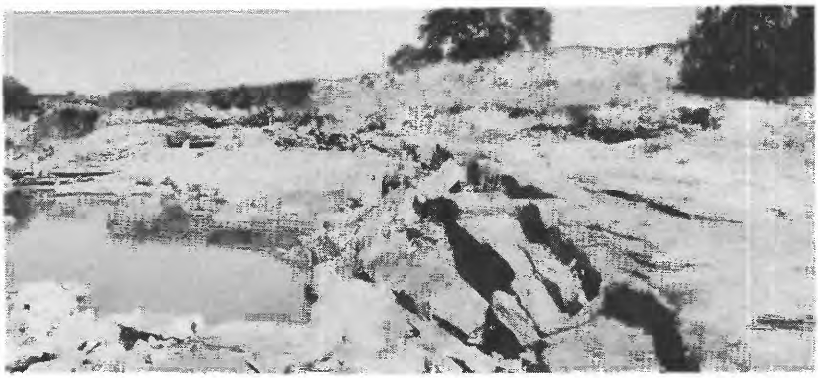

Figure 24.—Hard quartzitic sandstone of Dockum group along Two Butte Creek on Murray ranch in sec. 19, T. 29 S., R. 50 W.

the grains of quartz break when the rock is fractured. The beds of limestone are light gray to gray and dense to slightly crystalline, containing stringers and globules of amber crystalline calcite. One bed is gray, dense, compact, and crinkly. Oil tests drilled in areas adjacent to the outcrop of these beds encountered red shale and sandstone and only a small amount of limestone (Buehler, 1947), and the California Co. J. A. Spike no. 1. in sec. 13, T. 31 S., R. 48 W., encountered mostly red limy siltstone, sandstone, and shale containing a 10-foot bed of sandy dolomite at the base (log 105).

Distribution and thickness.—Rocks belonging to the Dockum group crop out in two areas in the valleys of Carrizo Creek and its tributaries in the southwestern part of the county, along the Cimarron River and a few of its tributaries in the southeastern part of the county, and in a small area along Two Butte Creek in the northwestern part of the county. (See pl. 1.) The Dockum group does not appear to extend northeastward as far as Two Buttes, and it is believed to pinch out eastward a short distance beyond

Point of Rocks in Morton County, Kans. The Dockum underlies large areas along the Cimarron River and its tributaries in Cimarron County, Okla. (Schoff and Stovall, 1943), and Union County, N. Mex. (Parker, 1933).

The thickness of the Dockum group in Baca County is not known. The base is not exposed in the county or in adjacent areas. The maximum thickness observed in Baca County is about 50 feet in the valley of Carrizo Creek near the Colorado-Oklahoma State line. Smaller thicknesses of the Dockum crop out along the Cimarron River and Two Butte Creek. Stovall (Schoff and Stovall, 1943, p. 47, 256) measured 67 feet of Dockum at Tate Butte in northwestern Cimarron County, Okla., and 111 feet along the Cimarron River northeast of Boise City in the same county. His estimate that the total thickness of the Dockum is about 550 feet compares closely with Sanders' estimate (1934, p. 866) of 575 feet. The Dockum probably is of about the same thickness in the western part of Baca County as it is in northwestern Cimarron County, Okla., but it thins toward the east. Buehler (1947) reported thicknesses of Triassic beds in three oil tests in northwestern Baca County (secs. 26, 27, 28, T. 29 S., R. 50 W.) ranging from 541 to 570 feet, but the California Co. J. A. Spike no. 1. (sec. 13, T. 31 S., R. 48 W.), near Pritchett, is reported to have penetrated only 320 feet (log 105). In the area of outcrop of the Dockum in southeastern Baca County the A. R. Jones Boise Cattle Co. no. 1 well is reported to have encountered the Permian Day Creek dolomite at a depth of about 340 feet (log 132), indicating that the thickness of the Dockum is considerably less than in the western part of the county.

Age and correlation.—The beds now referred to the Dockum group in this area were considered to be Triassic as early as 1902 by Lee (1902), but their age was not determined definitely until 1939 when Stovall and Savage (1939) discovered Triassic vertebrate fossils in these beds in Union County, N. Mex. Since that time, Triassic fossils have been collected from the Dockum in northwestern and north-central Cimarron County, Okla., by Stovall and by Edward Bloesch and in southwestern Baca County along Carrizo Creek by the writer.

There is some doubt concerning the age of the beds in southeastern and northeastern Baca County that are assigned to the Dockum group in this report. No fossils have been collected from either area; hence, correlations must be made on the basis of lithology. The beds that crop out along the Cimarron River in the southeastern part of the county differ greatly from those of the Dockum in the southwestern part of the county and in northwestern Cimarron County, Okla., but they resemble closely the deposits northeast of Boise City, Okla., from which fossils of Dockum age have been collected. Some geologists believe that the beds in southeastern Baca County are Permian, but the shallowest identifiable Permian formation in that area is the Day Creek dolomite, which was encountered in the A. R. Jones test (log 132) at a depth of 340 feet. Norton's report (1939) includes a cross section from Hamilton County, Kans., to Cimarron County, Okla., which indicated that the Permian deposits lying above the Day Creek dolomite are about 90 to 100 feet thick in southeastern Baca County. If his interpretations are correct, the upper 240 to 250 feet of material penetrated by the A. R. Jones test is Triassic. Owing to Norton's interpretation and to the similarity of these beds to the nearby beds of the Dockum northeast of Boise City, the beds in southeastern Baca County are here considered a part of the Dockum group.

The deposits that crop out along Two Butte Creek in northwestern Baca County bear very little resemblance to the Dockum in the southwestern and southeastern part of the county. They are composed mainly of red to maroon siltstone and quartzitic sandstone and hard gray limestone. The Triassic materials encountered in the three oil tests in T. 29 S., R. 50 W., however, were primarily red shale and sandstone (Buehler, 1947) and appear to be very similar to the Dockum group in southeastern Baca County. Buehler and other geologists have assigned these beds to the Triassic, and they are here included in the Dockum group. These beds probably are in part equivalent to the Lykins formation along the Front Range.

The Dockum in Baca County is similar to beds assigned to the Dockum group in other parts of the southern High Plains. Those cropping out in the southwestern part of the county have been traced into Cimarron County, Okla., and thence into northeastern New Mexico where Stovall found that they were equivalent to the Sloan Canyon formation of Parker. Stoval believes that the Dockum group northeast of Boise City is not equivalent to Parker's Sloan Canyon but may be equivalent to his Sheep Pen sandstone. If Stovall's interpretation is correct, the beds in southeastern Baca County that are assigned to the Dockum probably are also in part equivalent to Parker's Sheep Pen sandstone.

Water supply.—The materials in the Dockum group are largely fine grained and yield only small to negligible quantities of water to wells. In the southeastern part of the county, where the Dockum contains a greater percentage of sandstone, small supplies can be obtained for domestic and stock use. Where the Dockum is overlain by the Ogallala formation (pl. 2), water may enter the upper part of the Dockum by infiltration from above and the water is of moderately good quality (table 6). Water obtained from greater depths in aquifers overlain by relatively impermeable materials is replenished by lateral movement of water through the aquifers during which considerable mineral matter is dissolved, making the water unsuitable for most uses (analysis 373, table 6).

The beds of the Dockum in the southwestern part of the county are fine grained and yield only very small quantities of water to a few shallow wells. The water occurs principally in the thin beds of sandstone or along the joints and bedding planes of the finer grained materials. There is a possibility of obtaining small supplies of water from the Dockum at greater depths but the water probably would be of poor quality. It generally is difficult to find water in areas of outcrop of the Dockum in the southwestern part of the county (pl. 1). In prospecting for water in that area, tests should be made along the sides of small streams and draws where there generally is an accumulation of detrital material which may yield water more freely than the Dockum. The tests should not be made where the Dockum crops out in the banks and on the bottoms of the stream channels, but should be made only where unconsolidated silt, sand, and gravel are visible. In these places there is a possibility that the unconsolidated material may extend below the bed of the stream and may be saturated with water (fig. 52). If the tests of the shallow valley fill fail to encounter water or no suitable testing place can be found within a reasonable distance from where the water is needed, the beds of the Dockum group should then be tested. In general, it probably would be more economical to make several shallow tests at different places in the Dockum than to drill one deep test. Water in the Dockum in this area generally is very hard but is used for domestic and stock purposes.

The beds of the Dockum that crop in the northwestern part of the county are dense, compact rocks that would not yield water freely, although some water has been obtained from joints and openings along bedding planes in the beds of hard limestone. In prospecting for water in the area of outcrop of the Dockum in that part of the county (pl. 1), both the upper and the lower parts of the Dockum should be tested. If a well fails to encounter water in the upper beds, it should be drilled deeper in order to test the underlying beds of sandstone which have been encountered by oil tests in nearby areas. It is believed that one deep test would be more likely to encounter water than several shallow tests in the uppermost beds of the Dockum. Water in any part of the Dockum group in this area probably would be very hard and might be unsatisfactory for any but stock use.

JURASSIC SYSTEM

UPPER JURASSIC SERIES

ENTRADA SANDSTONE

The Entrada sandstone as used in this report refers to the massive sandstone beneath the Morrison formation and above the Permian and Triassic rocks. In the southwestern part of Baca County it is underlain nonconformably by the Dockum group of Triassic age. The beds were first described in that area by Lee (1902), who named them the Exeter sandstone, from exposures in the vicinity of Exeter (Exter) post office in Union County, N. Mex. Darton (1928) later included the Exeter, together with part of the Dockum, in the Jurassic Morrison formation, whereas De Ford (1927) considered the Exeter to be a separate formation and was the first to recognize it in Cimarron County, Okla. Stovall (Schoff and Stovall, 1943) used the term Exeter in his report on the Mesozoic stratigraphy of Cimarron County and recognized its correlation with the Entrada sandstone on the basis of the detailed cross sections prepared by Heaton (1939) showing the extension of the Entrada sandstone from the Front Range to the New Mexico-Oklahoma State line. Baker, Dane, and Reeside (1947) also recognized the extension of the Entrada into this area and the term is now approved for use in southeastern Colorado by the U. S. Geological Survey.

The sediments here mapped as the Entrada sandstone along Two Butte Creek in the north-central part of Baca County were first described by Gilbert (1896), who referred to them as unit 4 of the local section along Two Butte Creek. These beds, together with the underlying red beds, were shown as the Lykins formation on the geologic map of Colorado. In 1934, Sanders (1934) used the term Big sandstone for the beds in Gilbert's unit 4 and considered them of questionable Triassic age, in part on the basis of his belief that the Exeter (Entrada) is a lens in the Morrison formation. Parker (1934) and Stovall (Schoff and Stovall, 1943) have shown rather conclusively that the Exeter (Entrada) is not a lens in the Morrison; hence, the evidence strongly indicates that the beds described in Gilbert's unit 4 are Entrada. For a detailed discussion of this problem the reader is referred to papers by Sanders (1934), Parker (1933, 1934), and Stovall (Schoff and Stovall, 1943).

Character.—The Entrada sandstone in Baca County is very fine to medium grained, friable, and extensively crossbedded. It is predominantly white in the southwestern part of the county but is largely gray to buff along Two Butte Creek in the north-central part of the county. The formation consists almost entirely of quartz sand with a small amount of cement but contains a few thin layers of shaly material.

In the southwestern part of the county along Carrizo Creek near the Colorado-Oklahoma State line the lower part of the Entrada is buff to brown poorly bedded sandstone and the upper part is massive, white, friable crossbedded sandstone (fig. 25). In

Figure 25.—Outcrop of Entrada sandstone (Je), Morrison formation (Jm), Cheyenne sandstone member of the Purgatoire formation (Kc), Kiowa shale member of the Purgatoire formation (Kk), and Dakota sandstone (Kd). Butte is in secs. 12 and 13, T. 35 S., R. 50 W.

the northernmost area of outcrop along Carrizo Creek (pl. 1) the lower zone is absent and the formation is predominantly white. An unusual feature of the Entrada sandstone in the area along Carrizo Creek is its content of small specks and globules of copper-bearing minerals, principally chalcocite, malachite, and azurite. In Skull Canyon these minerals are concentrated along joints and have been mined commercially.

In the area of outcrop along Two Butte Creek (pl. 1) the Entrada is largely light gray to buff and brown and weathers to brown and reddish brown. In this area it consists principally of two massive ledges of friable fine- to medium-grained sandstone (fig. 26) separated by a soft earthy sandstone which forms a prominent reentrant on the cliff face. The lowest part consists of buff to red sandstone and red shale.

The Entrada weathers to smooth steep white cliffs in the southwestern part of the county and grades southwestward to the salmon-colored massive sandstone typical of the Entrada in the Colorado Plateaus. Here it weathers to smooth rounded cliffs having long rows of solution cavities.

Distribution and thickness.—The Entrada sandstone crops out as a prominent white ledge in two areas along Carrizo Creek and its

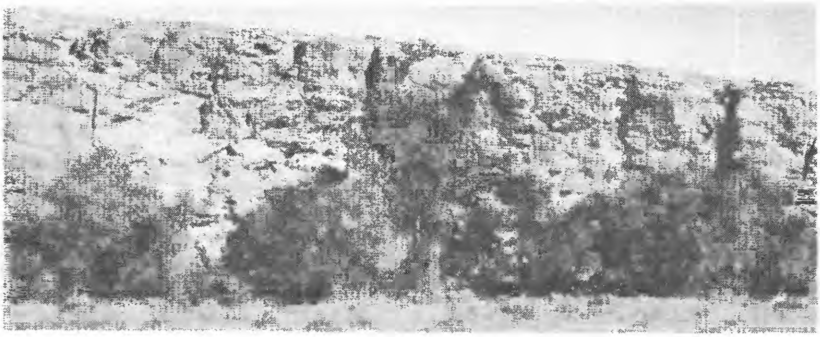

Figure 26. —Massive Entrada sandstone along Two Butte Creek below dam.

tributaries in the southwestern part of Baca County and as prominent buff to reddish-brown ledges along Two Butte Creek in the north-central part of the county (pl. 1). It is believed that it extends eastward about as far as Campo, but that it pinches out before reaching the areas of outcrop of older formations in the southeastern and northwestern parts of the county (pl. 2, fig. 27). The formation was not encountered in the California Co. J. A. Spike no. 1. a few miles southeast of Pritchett, and it is believed that the formation is not continuous across Baca County from the Two Butte Creek area to the Carrizo Creek area. The Entrada sandstone has been mapped (as the Exeter sandstone) by Stovall (Schoff and Stovall, 1943) and it extends westward along the Cimarron River into northeastern New Mexico. It has been shown, by means of cross sections (Heaton, 1939), to extend to areas of outcrop of the Entrada along the Front Range.

The thickness of the Entrada ranges from a feather edge to about 380 feet. It reaches its greatest thickness along Two Butte Creek in the north-central part of the county. In the southwestern part of the county it generally is 30 to 40 feet thick, although it pinches out locally between the Morrison and Dockum. Stovall reports a maximum thickness of 53 feet at Labrier Butte in northwestern Cimarron County and Parker reported a maximum thickness of 80 feet in Union County, N. Mex.

Age and correlation.—At its type locality in the area of the San Rafael Swell in eastern Utah the Entrada lies between the Curtis and Carmel formations. Fossils collected from the Curtis and Carmel in that area by Gilluly and Reeside (1928) were assigned

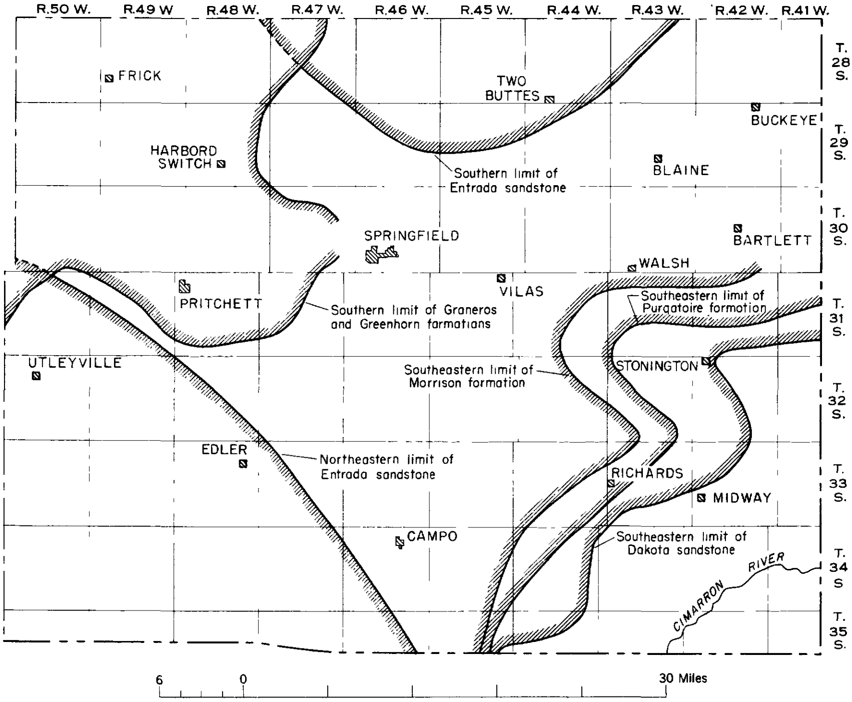

Figure 27. —The limits of several Mesozoic formations in Baca County.

to the Upper Jurassic; hence, the Entrada sandstone also is Upper Jurassic.

The Entrada of this area has been correlated with the Entrada of other parts of the southern Rocky Mountains by Heaton (1939), by Baker, Dane, and Reeside (1947), and by others. It is believed to be equivalent to a sandstone of the Sundance formation of Wyoming.

Water supply.—The Entrada sandstone is not an important aquifer in Baca County and at the time of this investigation it supplied water to only one domestic and stock well (no. 23). In the area of outcrop of the Entrada in the southwestern part of the county the formation has been cut by the canyons of Carrizo Creek and its tributaries and is largely drained of water. The formation probably would yield supplies of water adequate for domestic and

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stock use in the area north and east of Carrizo Canyon but in those areas water generally can be obtained more easily from the overlying Purgatoire and Dakota formations. The Dakota and Purgatoire probably are drained for a greater distance away from the canyon than is the Entrada; hence, it may be possible to obtain small supplies of water from the Entrada adjacent to the canyon where the Dakota and Purgatoire crop out and are largely drained.

In the north-central part of the county the water in the reservoir along Two Butte Creek is a source of direct recharge to the Entrada sandstone and small supplies of water probably can be obtained from the Entrada in areas adjacent to the reservoir. The formation transmits water very slowly, however, for little or no water escapes around the dam through the formation. The Entrada dips steeply away from its area of outcrop along Two Butte Creek and within a relatively short distance it lies at considerable depth and is overlain by more productive aquifers.

Water from well 23, which taps the Entrada sandstone, is hard and contains considerable iron but otherwise is suitable for most uses (analyses 23, table 6).

MORRISON FORMATION

The Morrison formation was named for exposures along the Front Range near Morrison, Colo. The name was extended into the Purgatoire and Cimarron River valley areas by Lee (1902), but was applied to beds now termed Morrison together with beds now called the Purgatoire formation. The term is now restricted in this area to the variegated shale, clay, marl, and sandstone lying below the Cheyenne sandstone member of the Purgatoire formation and above the Entrada sandstone. It is easily recognized in parts of Baca County by the predominantly maroon and green shaly slopes between the massive cliff-forming light-colored Entrada sandstone below and the Cheyenne sandstone member above (fig. 25).

Character.—The Morrison formation in Baca County is composed principally of marl, siltstone, clay, and shale containing sandstone, limestone, and conglomerate. The marl, siltstone, clay and shale are variegated; the principal colors are gray, red, green, and maroon. In much of the Carrizo Canyon area the lowest beds are predominantly red and the upper beds are largely gray, green, and maroon. The finer grained materials generally are structureless but some are shaly and others are highly jointed and weather into small irregular blocks. The softer materials generally form long slopes beneath the massive sandstone of the

Cheyenne and are largely covered with grass. Good exposures generally can be observed only in stream banks, in gullies, or along road cuts.

The sandstones of the Morrison formation in this area are distinctive. They generally are thin (less than 2 feet), hard, and lenticular and weather to buff, brown, and reddish brown. Most of the beds of sandstone are mottled on fresh fractures, the darker splotches of yellow or brown being caused by local concentrations of limonite. Some contain splotches of white chert or of white calcium carbonate. The sandstones are predominantly very fine grained to fine grained and are cemented by calcium carbonate, limonite, and silica. Some of the beds are cemented with crystalline calcite and cleave in a manner similar to calcite so that some of the grains break on fresh fractures. The beds of sandstone form low benches or terraces in the long slopes developed on the formation.

Stovall (Schoff and Stovall, 1943) and others have reported a thick white crossbedded sandstone in the Morrison in Oklahoma and in parts of northeastern New Mexico and southeastern Colorado. In Cimarron County, Okla., it is more than 100 feet thick and where it is overlain by the Cheyenne sandstone member of the Purgatoire it is difficult to determine the contact of the two formations. The sandstone does not appear to extend into Baca County except perhaps in Gallinas Canyon near the Colorado-Oklahoma State line where there is a massive white sandstone in the lower part of the exposed section of the Morrison. The sandstone is light gray to white, soft, friable, and in a few places, slightly calcareous. It is a uniformly fine grained sandstone consisting of subrounded to subangular quartz grains. It contains small white splotches that appear to consist largely of weathered chert or of kaolin. The bed pinches out within a short distance and can be observed only in the bank of Gallinas Creek.

The Morrison formation contains thin beds of limestone in the areas of outcrop in the southwestern part of the county, particularly in the canyons of Carrizo Creek and its tributaries. The section between the limestone and the overlying Purgatoire formation thins toward the east and the limestone pinches out somewhere west of Sand Canyon. The limestone generally is thin-bedded to platy, dense, compact, argillaceous, and gray to tan and light brown. A few thin beds are sandy and a few are crystalline. The limestone section is 5 to 10 feet thick and forms a prominent bench in the long Morrison slope in the Carrizo Canyon area.

The conglomerate in the Morrison generally consists of fine- to medium-grained sandstone containing pebbles of quartz, chert, or chalcedony. The pebbles of quartz and chalcedony generally are subangular to subrounded, whereas the chert generally is angular. Much of the chalcedony is agate and some is opaline.

The most distinctive beds in the Morrison formation are thin layers of red chert lying beneath the limestone of the Morrison at several places in the canyons of Carrizo Creek and its tributaries. A typical exposure may be observed on the south side of the road in Road Canyon in sec. 6, T. 35 S., R. 49 W. There a bed can be seen to consist of a mixture of amber quartz, red chert, and clear to amber crystalline calcite. On weathered surfaces the amber to red quartz and chert form irregular nodules separated by small grooves developed in the softer calcite. The nodules appear on weathered surfaces to be pebbles of a conglomerate, but they are interconnected and were formed in place. In Road Canyon the bed is speckled with many small brown pseudomorphs of limonite after pyrite.

The Morrison formation contains petrified wood in many places, particularly in the vicinity of Two Buttes where many petrified tree trunks have been collected.

Distribution and thickness.—The Morrison formation crops out in the deeper canyons in the southwestern part of the county, along Freezeout and Two Butte Creeks in the northwestern part of the county, and along Two Butte Creek in the north-central part of the county (pl. 1). Toward the southeast it pinches out between the Purgatoire formation and the underlying red beds, as shown in plate 2 and figure 27. The Morrison extends westward and southwestward into Las Animas County, Colo., Union County, N. Mex., and Cimarron County, Okla.

The thickness of the Morrison generally has been considered to range from about 125 to 225 feet, but Stovall (Schoff and Stovall, 1943) has shown that the entire thickness cannot be measured at any one place, owing to pre-Cretaceous warping and truncation of the Morrison. By correlating key beds of several measured sections he determined that the Morrison is 467 feet thick in the northwestern part of Cimarron County. The thickness of the Morrison at any one locality in southwestern Baca County is about 170 feet, but the total thickness probably is much greater. The platy limestone in the Morrison is an easily recognized unit and can be traced for several miles in the canyons of Carrizo Creek and its tributaries. The limestone lies 69 feet below the Cheyenne sandstone member of the Purgatoire formation in sec. 6, T. 35 S., R. 49 W., 51 feet below in sec. 4, T. 35 S., R. 49 W., and is absent in Gallinas and Sand Canyons to the east, indicating that the Morrison was also folded and truncated in this area before the Cheyenne was depostied. The interval between the limestone and the underlying Entrada sandstone also changes considerably from place to place, indicating an unconformity between the Morrison and Entrada and adding evidence that the so-called Exeter (Entrada) is not a lens in the Morrison. It was not possible to measure a complete section of the Morrison in Baca County, but the sum of the maximum interval between the limestone and the Cheyenne and the maximum interval between the limestone and the Entrada indicate a total thickness in excess of 325 feet.

Age and correlation.—The Morrison formation has yielded an abundance of fossil remains of dinosaurs in this area (Stovall, 1938; Schoff and Stovall, 1943) and in many other places in the Great Plains and Rocky Mountain regions. Although many fossils were collected from the formation, geologists and paleontologists were not in agreement as to its age. Some considered it Upper Jurassic, whereas others considered it Lower Cretaceous, owing in part to the presence of Comanche fossils in beds mistakenly identified as Morrison. The U. S. Geological Survey now classifies the Morrison as Upper Jurassic and it is so used in this report. The Morrison formation of this area is equivalent to the Morrison in other parts of the southern Great Plains and the Colorado Front Range.

The lower maroon section of the Morrison probably is equivalent to the Summerville formation of western Colorado. Gypsiferous beds in the Morrison along the Front Range are now believed to be equivalent to the Curtis formation of western Colorado. Gypsum has been observed in the Morrison as far east as Chacuaco Canyon in eastern Las Animas County but none was found in Baca County and none was reported by Stovall in Cimarron County, Okla. For a detailed discussion of the age and correlation of the Morrison formation the reader is referred to Baker, Dane, and Reeside (1936).

Water supply.—The Morrison formation yields no water to wells in Baca County and cannot be considered a potential aquifer owing to its fine texture and relatively low permeability. The beds of sandstone that could store water are thin and lenticular and generally are dry. In areas of outcrop of the Morrison it generally is difficult to obtain enough water for domestic and stock use. In prospecting for water in the areas of outcrop (pl. 1), wells should first be drilled through the valley fill along small streams or draws. If there is no valley fill or if the valley fill contains no water, wells should then be drilled through the Morrison and through the underlying Entrada sandstone. If the Entrada is dry it would be better to test the Entrada at another site rather than to drill a deep well into the underlying Dockum group. In areas where the Morrison crops out but where the underlying Entrada does not, such as in Pat, Gallinas, and Sand

Canyons, wells drilled into the underlying Entrada sandstone probably would yield sufficient water for domestic and stock use.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

PURGATOIRE FORMATION

The Purgatoire formation in this area includes those beds lying above the Jurassic Morrison formation and below the Dakota sandstone. For many years the term Dakota sandstone was used to designate all beds now included in the Purgatoire and Dakota formations. The term is still used in the same meaning by local residents who refer to the basal sandstone of the Purgatoire as the lower Dakota and the Dakota sandstone as the upper Dakota. Lee (Darton, 1905a) presented a paper at the annual meeting of the Geological Society of America in 1902 in which he reported the collection of fossils of Early Cretaceous (Comanche) age in northeastern New Mexico near the New Mexico-Oklahoma State line. In 1905, Stanton and Lee (Stanton, 1905) discovered a marine Comanche fauna in Purgatoire Canyon in shales between the upper and lower sandstones which were then regarded as Dakota. During the same year, Darton (1905a) also collected Comanche fossils from the same beds in the valley of Two Butte Creek about 5 miles downstream from Two Buttes (Fig. 28). In

Figure 28. —Dakota sandstone overlying the Kiowa shale member of the Purgatoire formation. Thick-bedded sandstone above dashed line is Dakota; thin-bedded sandstone and dark shale below white line is Kiowa shale member of the Purgatoire formation. Outcrop is along Two Butte Creek in Prowers County about 5 miles below the dam near the point where N. H. Darton collected Comanche fossils from the old Dakota formation in 1905.

1912, Stose (1912) assigned the name Purgatoire formation to the fossil-bearing shale and the underlying sandstone for typical exposures in Purgatoire Canyon in the Mesa de Maya quadrangle in eastern Las Animas County, Colo. The same beds were earlier called the Kiowa shale and Cheyenne sandstone by Cragin (1889, 1894) for exposures in Kiowa County, Kans., but the cover of younger rocks between the areas of outcrop in Kansas and Colorado prevented correlation between the areas and the three names became firmly established in geologic literature. Stovall (1938) was the first to combine the names and to classify the Cheyenne sandstone and Kiowa shale as members of the Purgatoire formation. Recent test drilling by the Ground Water Branch of the U. S. Geological Survey in cooperation with the State Geological Survey of Kansas and the Colorado Water Conservation Board has made it possible to trace these beds from the type locality of the Cheyenne and Kiowa formations in Kiowa County, Kans., to the type locality of the Purgatoire in Las Animas County, Colo. (Latta, 1941, 1944, 1948; McLaughlin, 1942, 1943, 1946; Waite, 1942). In this report the three names are retained and the Cheyenne and Kiowa are considered members of the Purgatoire formation.

The Purgatoire formation is equivalent to the Purgatoire in other parts of southeastern Colorado, northwestern Oklahoma, and northeastern New Mexico and to the Lytle and Glencairn members of the Purgatoire formation of the Colorado Front Range. It is equivalent also to the Cheyenne and Kiowa formations throughout central and western Kansas.

CHEYENNE SANDSTONE MEMBER

Character.—The Cheyenne sandstone is the lower member in the Purgatoire formation and in this area it overlies the Morrison formation and underlies the Kiowa shale member of the Purgatoire.

The Cheyenne is a fine- to coarse-grained friable sandstone. It generally is white to light gray on fresh fracture and weathers to cream, buff, and light tan. It is predominantly uniform grained, poorly cemented, and friable, but it generally contains lenses of conglomerate in the lower part, locally is tightly cemented, and in places contains fragments of petrified wood. The member is made up largely of grains of clear quartz but the larger fragments in the lenses of conglomerate consist of several varieties of quartz and chalcedony as well as quartzite, schist, and other materials. The larger fragments range in size from a fraction of an inch to 4 inches, but Stovall (Schoff and Stovall, 1943) has reported fragments as large as 6 inches in Cimarron County, Okla.

The Cheyenne sandstone member forms prominent cliffs, particularly in the canyons of Carrizo Creek and its tributaries in the southwestern part of the county (fig. 25). It resembles to some extent the massive sandstones of the Dakota, although it generally is lighter colored, less well cemented, more friable, and coarser grained. It can be distinguished easily by its lighter color, by the coarse pebbles, and by its stratigraphic position above the variegated shale of the Morrison and below the black shale of the Kiowa shale member.

Distribution and thickness.—The Cheyenne sandstone member crops out in most of the larger canyons in the southwestern part of the county and in a few of the canyons in the northwestern part of the county (pl. 1). It underlies a large part of the county but pinches out beneath the Kiowa shale member toward the southeast (pl. 2, fig. 27). Near the Kansas-Colorado State line it pinches out between the Kiowa shale member and the underlying red beds (pl. 2), whereas in northwestern Oklahoma it pinches out between the Kiowa shale member and the Morrison formation (Schoff and Stovall, 1943, p. 76).

The thickness of the Cheyenne sandstone member differs greatly from place to place but in general increases toward the northeast. In the southwestern part of the county it has an average thickness of about 50 feet and in the northeastern part of the county it has an average thickness of about 100 feet. The maximum thickness reported in this region is 134 feet at Springfield in central Baca County.

Water supply.—The Cheyenne sandstone member is one of the three principal aquifers in Baca County. It yields adequate quantities of water for domestic and stock use throughout a large part of the county and yields moderate to large quantities of water for municipal, industrial, and irrigation use in areas where its thickness and permeability are relatively great. Where the sandstone is moderately well cemented and poorly sorted, it will yield only small quantities of water; where it is poorly cemented and uniform-grained it may yield more than 1,000 gpm to a properly constructed well. Well 83 near Two Buttes yields more than 3,000 gpm from the Cheyenne. The sandstone is largely drained in some of the canyon areas in the northwestern and southwestern parts of the county where the streams have cut into the underlying Morrison formation, but it generally is saturated with water in other areas.

In the areas of outcrop of the Cheyenne the sandstone generally is dry except for the lowest part, from which small amounts of water discharge through springs at the contact of the Cheyenne and the underlying Morrison formation. Wells drilled into the

Cheyenne in and near its areas of outcrop (pl. 1) generally are unsuccessful. If the Morrison formation is not completely exposed and the underlying Entrada sandstone does not crop out in the vicinity, it would be advisable to deepen a well into the Entrada in search for water rather than to drill several shallower wells into the Cheyenne. In areas where the Kiowa shale member crops out but where the Cheyenne member does not (such as along the tributaries of Hackberry Creek in T. 28 S., R. 50 W.), wells drilled through the shale and into the underlying Cheyenne sandstone member generally yield sufficient water for domestic and stock use. The possibilities of obtaining large supplies of water from wells in the Cheyenne sandstone member are discussed on pages 63 to 66.

Water from the Cheyenne generally is moderately hard but is suitable for most uses. For a detailed description of the quality of the water from the Cheyenne the reader is referred to page 80 and table 6.

KIOWA SHALE MEMBER

Character.—The Kiowa shale is the upper member of the Purgatoire formation. It is overlain by the Dakota sandstone and generally overlies the Cheyenne sandstone member although it overlies the Morrison formation in parts of Cimarron County, Okla., and the red beds in southeastern Baca County (pl. 2) and parts of southwestern Kansas. The Kiowa is a dark-gray to black shale containing sandy shale and thin beds of sandstone near the top (fig. 28). The lower part generally is clayey, platy to blocky, and slightly calcareous in southwestern Baca County but is considerably more sandy and is only faintly calcareous in the northwestern part of the county. Eastward the lower part becomes more thinly laminated and more calcareous. The upper part of the Kiowa in southwestern Baca County consists of sandy shale containing thin beds of hard sandstone. The sandstones generally are very fine to fine grained, are well cemented, and are cream to buff. They weather to brown and contain streaks of vivid red, purple, and dark brown along bedding planes and joints. In the northwestern part of the county the upper part of the Kiowa contains more beds of sandstone. The sandstones generally are moderately hard, buff to rusty brown, earthy, and very fine grained. The sand grains are angular and are cemented with limonite. One prominent sandstone is about 8 feet thick and weathers to large rusty-brown rectangular blocks having characteristic pitted surfaces.

In the headwaters of Pat Canyon a short distance above the headquarters of the Welch ranch, the Kiowa consists of dense, hard blocky siliceous shale containing scattered flakes of mica.

The shale is overlain by quartzite of the Dakota and probably was altered at the same time the overlying sandstone was changed to quartzite.

Distribution and thickness.—The Kiowa shale member crops out in narrow, irregular areas in the major valleys and canyons in the southwestern and northwesternparts of the county (pl. 1), where it forms a conspicuous grassy slope between the steep cliffs of the Cheyenne and the Dakota (fig. 25). It underlies a large part of Baca County and pinches out southeastward between the overlying Dakota sandstone and the underlying redbeds (pl. 1, fig. 27).

The thickness of the Kiowa shale member averages about 45 feet in the southwestern part of the county but increases toward the north and east. The member is more than 50 feet thick in the northwestern part of the county and about 65 feet thick at Pritchett and Campo, and it reaches a maximum thickness of about 90 feet at a few places in the northeastern part of the county in the Walsh artesian area.

Water supply.—The Kiowa shale member of the Purgatoire yields no water to wells in Baca County, but it is an extensive confining layer over the Cheyenne sandstone member. The confined water in the underlying Cheyenne is under sufficient artesian pressure to reduce materially the pumping lift in a large part of the county and to flow at the surface in the Walsh artesian area. The Kiowa shale member retards the downward movement of water and reduces greatly the recharge to the underlying Cheyenne sandstone member.

In the areas of outcrop of the Kiowa shale member it generally is difficult to obtain water from wells, particularly where the underlying aquifers also are exposed and are largely drained. In the canyons in T. 28 S., R. 50 W., in the northwestern part of the county, the Kiowa shale member crops out (pl. 1), but the underlying Cheyenne sandstone member generally is covered and will yield sufficient water for domestic and stock use. Some wells in this area have been drilled to depths of 40 or 50 feet and abandoned as dry holes, whereas others have been drilled slightly deeper and have obtained adequate supplies of water from the underlying Cheyenne sandstone member. Tests in these areas should not be abandoned until the variegated shale of the underlying Morrison formation is encountered. In the southwestern part of the county, wells drilled in the areas of outcrop of the Kiowa should test the underlying sandstones of the Cheyenne and Entrada unless they crop out nearby.

DAKOTA SANDSTONE

The Dakota sandstone consists of a series of sandstones and sandy shales overlying the Purgatoire formation and underlying the Graneros shale. In the southeastern part of the county beyond the limits of the Purgatoire it overlies red beds, (probably of Triassic age), and where the Graneros shale has been removed by erosion the Dakota is overlain by the Tertiary Ogallala formation. The term Dakota sandstone formerly included beds now assigned to the Purgatoire and is still used in that manner by most laymen in the area.

Character.—The Dakota sandstone differs greatly in lithology from one part of Baca County to another (figs. 29-33). In the

Figure 29.—Channel sandstone and underlying sandy shale in Dakota sandstone in road cut along U. S. Highway 287 just north of Springfield

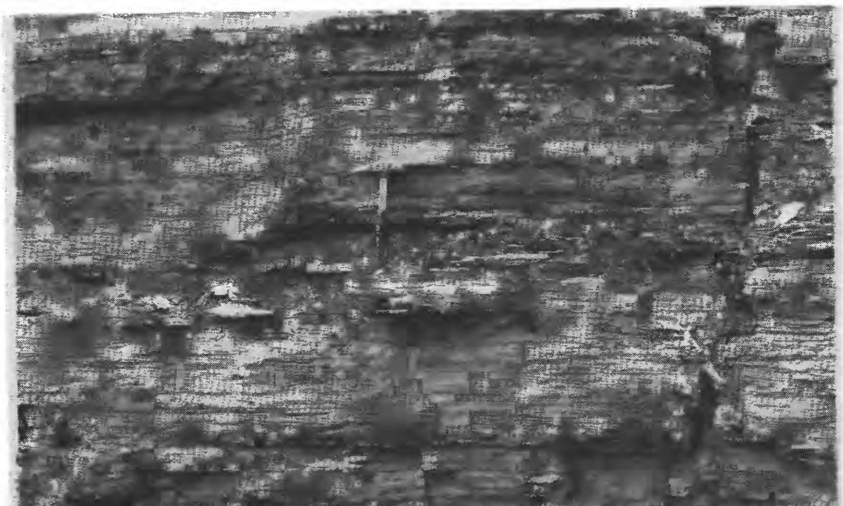

Figure 30.—Thin-bedded sandstone and sandy shale in the middle part of the Dakota sandstone in Soldier Canyon on the Ming Ranch west of Pritchett.

Figure 31.—Two massive sandstones and intervening beds of sandy shale in the Dakota sandstone in Soldier Canyon above the Ming ranchhouse.

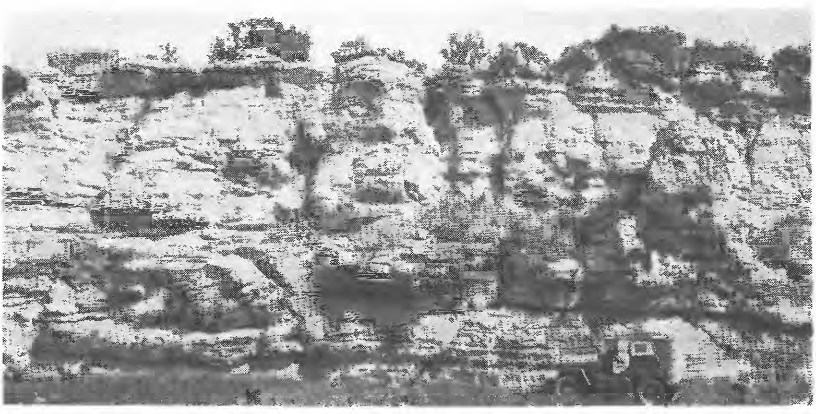

Figure 32.—Massive basal sandstone of the Dakota in small canyon above the Kirkpatrick ranchhouse. Thin-bedded sandstones at the base of the cliff are a part of the Kiowa shale member of the Purgatoire formation.

southwestern part it consists of a basal sandstone, a middle sandy shale, and an upper sandstone. The upper and lower sandstones form massive ledges and are about 50 feet thick, although Stovall (Schoff and Stovall, 1943, p. 86) reported that the lower sandstones reaches a maximum thickness of 115 feet in Cimarron County. The middle sandy shale forms a slope between the massive ledges and also is about 50 feet thick.

In the northwestern part of Baca County there are at least three massive beds of sandstone, each underlain by platy sandstone, sandy shale, and clay shale (figs. 31, 32, 33). The upper sandstone is about 45 feet thick and is capped by beds of hard dark-brown to black ironstone. It is underlain by 35 feet of thin-bedded to platy sandstone and sandy shale. The second massive sandstone is 20 feet thick and is underlain by 35 feet of platy sandstone, sandy shale, and clay shale. The lowest massive sandstone is about 10 feet thick and is underlain by 15 to 25 feet of platy sandstone, sandy shale, and clay shale.

In the eastern part of the county the upper part of the Dakota has been removed by erosion and the lower part does not crop out; hence, the lithologic character of the formation is not well known. In general, however, the formation becomes more shaly toward the east, the sandstones becomes thinner and less resistant to erosion, and the beds of sandy shale contain the highly cross-bedded lenticular channel sandstones (fig. 29) that are characteristic of the Dakota in western and central Kansas.

Most of the sandstones of the Dakota are cross bedded and are uniformly fine grained but they may range from silty to coarse grained and locally are conglomeratic. They generally consist of angular to well-rounded grains of clear quartz cemented with limonite but locally may be cemented with calcite, hematite, or silica. The sandstones are largely buff to tan although locally they may be light gray, white, yellow, or light red. On weathered surfaces the sandstones are case hardened and are stained various shades of brown.

The sandstones weather to form steep ledges and cliffs (fig. 32), some of which are more than 50 feet high. The sandstones forming the cliffs appear to be massive and to have little or no bedding, but the bedding planes are easily recognized on the more gently sloping weathered surfaces. In the western part of the county the sandstones locally weather to barrel-shaped columns, particularly the lowest sandstone in the southwestern part of the county and the uppermost sandstone in the northwestern part of the county. In the western part of the county the sandstones are fairly continuous. The basal sandstone that caps many of the ridges and buttes in the canyon areas of southwestern Baca County can be traced for many miles,and the upper sandstone in

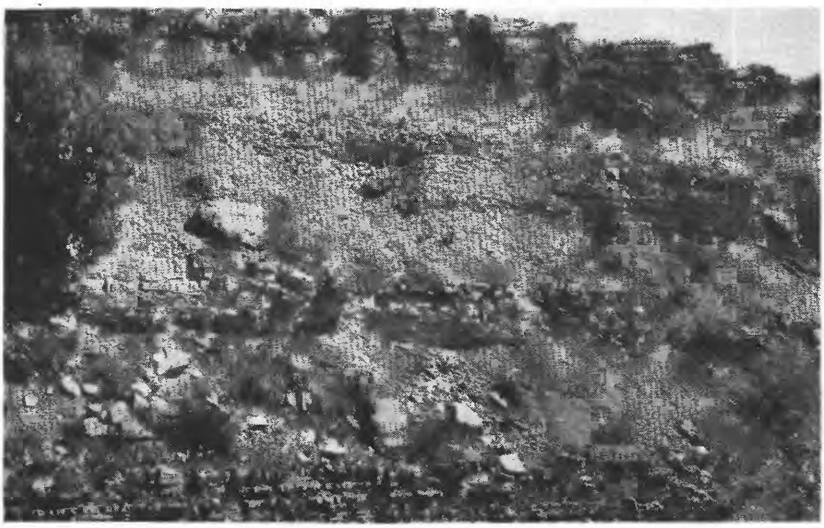

Figure 33. —Alternating thin-bedded sandstone and sandy shale in the Dakota sandstone in Cat Canyon.

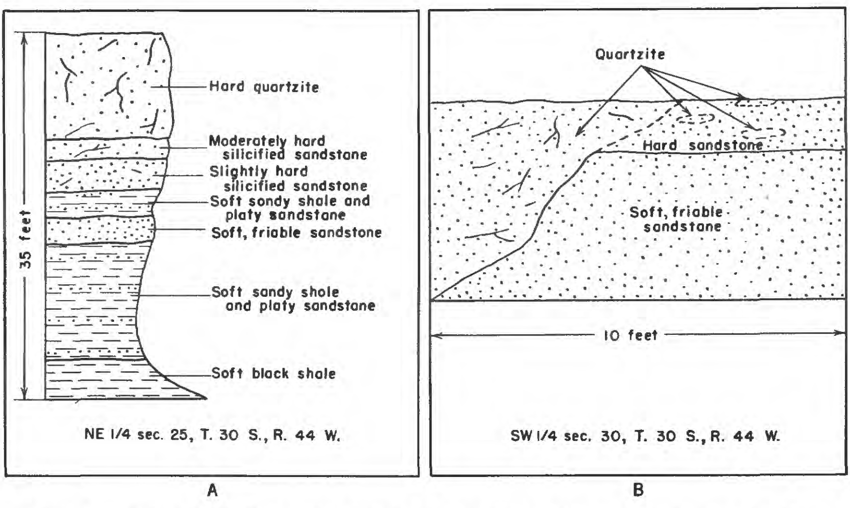

Figure 34. —Vertical and horizontal gradations of quartzite into sandstone in the Dakota Sandstone.

the northwestern part of the county can be recognized over a wide area. The sandstones that crop out in the eastern part of the county are more lenticular and extend only relatively short distances (fig. 35). Some ledges of sandstone along Bear Creek and its tributaries may grade into sandy shale within 100 to 1,000 feet. The highly cross bedded channel sandstones of the eastern area also pinch out in very short distances. A typical channel sandstone is exposed in a road cut on U. S. Highways 160 and 287 along Cat Creek at the south edge of Springfield (fig. 29).

The sandstones of the Dakota generally are loosely cemented with limonite and are therefore moderately porous and friable. Locally they are more highly cemented and therefore have little or no porosity and are very hard. A conspicuous feature of the Dakota sandstone is the occurrence of hard dark-brown to nearly black layers of ironstone which form prominent ledges and cap many buttes and mesas in the county. They may occur at almost any horizon in the Dakota but are most commonly near the top. A bed of ironstone caps the uppermost sandstone in the northwestern part of the area, and drillers report a hard brown "cap rock" at the top of the formation at many places in the western part of the county. The ironstone generally is tightly cemented with limonite and, in places, with hematite. The sand is so firmly cemented that as many as 90 out of 100 of the grains may be broken on fresh fracture.

Sedimentary quartzite is another conspicuous feature of the Dakota. The beds of quartzite form massive ledges and, though they generally are of only local extent, crop out at many places throughout the area of outcrop of the Dakota sandstone (pl. 1). Quartzite may be found at almost any horizon within the Dakota in Baca County and siliceous shale has been observed in the underlying Kiowa shale member of the Purgatoire on the Welch ranch. Swineford (1947) has studied quartzites from both the Dakota and the Kiowa throughout central and western Kansas and reports that the quartzite is not restricted to any one horizon of the Dakota in Kansas.

The quartzite of the Dakota in Baca County is predominantly very fine to fine grained and is of uniform texture. Some of it, however, is medium and coarse grained. It generally is tightly cemented and has little or no porosity, but in a few places it contains many pore spaces. The degree of cementation varies to the extent that from less than 50 to more than 90 percent of the quartz grains a broken on fresh fracture. The grains generally are widely spaced and in some samples practically no grains touch each other. Some specimens contain so much cement and so few sand grains that on fresh fracture the quartzite in appearance resembles tapioca pudding.

The quartzite of the Dakota generally grades into soft, friable sandstone within very short distances, both vertically and laterally. Figure 34 illustrates these gradations at two localities along Bear Creek northwest of Walsh. Section *A* illustrates the abrupt vertical gradation; the bed of hard quartzite grades into a hard sandstone within a few inches. This is turn grades abruptly into a much softer sandstone. These beds are underlain by typical soft sandstones and shales of the Dakota. Section *B* shows the abrupt lateral change from quartzite to soft, friable sandstone. The change generally occurs within a distance of 6 inches to 1 foot but in places the zone of gradation may extend for 5 or 6 feet. In the more extensive zones of gradation there are thin tabular lenses of quartzite.

The color of the quartzite generally is brown, gray, and pinkish purple. The brown quartzite grades into the typical buff and brown sandstone, the gray quartzite grades into white sandstone, and the pinkish purple grades into purple. The quartzite of the Dakota crops out in many small areas throughout the county, but the most accessible exposures are along Bear Creek in the NE$\frac{1}{4}$ sec. 25 and SW$\frac{1}{4}$ sec. 30, T. 30 S., R. 44 W., at Black Butte in secs. 2 and 3, T. 30 S., R. 44 W., and on a tributary of Ute Creek in the NW$\frac{1}{4}$ sec. 7, T. 35 S., R. 45 W.

The shales of the Dakota in Baca County commonly are gray to black but in places are variegated. They are predominantly fine sandy shales and are thin bedded (fig. 29). Locally, however, they contain no sand and may be clayey and blocky. They generally are interbedded with platy to thin-bedded sandstones that are dominantly buff and brown to gray. The sections of shale and thin platy sandstone make up a large part of the formation, particularly in the eastern part of the county, but are easily eroded and may form steep talus-covered slopes between the massive ledges of sandstone or very gentle soil-covered slopes in areas where no massive sandstones crop out. The sand in the sandy shale and the thin-bedded sandstones is generally very fine grained but may be fine grained and commonly is silty. The sandy shale is poorly bedded and weathers to rough, irregular chips. The thin-bedded sandstone generally is lenticular and weathers to dark-brown irregularly rectangular blocks. The platy sandstone is more evenly bedded and weathers to thin rectangular slabs.

The clay shale generally is gray to nearly black and may be platy to blocky. In a few places along Bear Creek near Walsh, however, it is poorly bedded, is tan to brown, is impregnated with thin veinlets of calcite, and contains marine fossils. The clay shales constitute a greater proportion of the Dakota toward the east. In central Kansas the Dakota is predominantly clay and clay shale.

The sections of shale and platy sandstone differ greatly in lithology from place to place. They contain highly crossbedded lenticular sandstone in the eastern part of the county and locally may grade into massive sandstone within a few feet. Figure 35 illustrates the abrupt gradation of sandy shale into massive sandstone along Bear Creek northwest of Vilas.

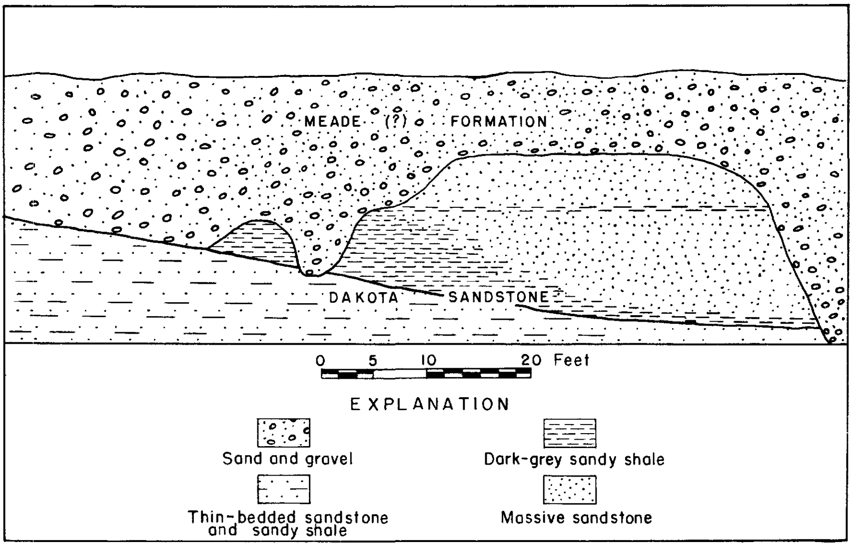

Figure 35. —Lateral gradation of sandy shale of the Dakota into massive sandstone (NW¼ sec. 34, T. 30 S., R. 45 W.)

Distribution and thickness.—The Dakota sandstone crops out in large areas along Two Butte Creek and its tributaries in the northwestern part of the county and along Carrizo, Gallinas, and Ute Creeks and their tributaries in the southwestern part. It crops out in relatively narrow bands along Bear Creek and its tributaries and Sand Arroyo in the eastern part of the county (pl. 1). The Dakota underlies a large part of Baca County and pinches out in the southeastern part between the Ogallala formation and the red beds (pl. 2, fig. 27).

The thickness of the Dakota sandstone in Baca County is difficult to determine by means of surface measurements. In a large part of the county the upper part of the Dakota and the overlying bedrock formations have been removed by erosion and the original thickness of the Dakota cannot be measured. In the northwestern part of the county where the overlying Graneros shale has not been removed, the outcrops of the top and the base of the Dakota generally are at least a mile apart and the intervening areas are largely covered. The most complete sections of the Dakota measured by the writer are in northwestern Baca County. In Soldier Canyon, sec. 21, T. 30 S., R. 50 W., where

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neither the base nor the top of the formation could be seen, the measured thickness was 135 feet. In sec. 18, T. 30 S., R. 50 W., in Freezeout Canyon the section of Dakota is 142 feet thick from the top of the Kiowa shale member of the Purgatoire formation to the hard layer of ironstone overlying the upper sandstone. It is believed that the ironstone is near the top of the Dakota but the thickness of the interval from the ironstone to the base of the Graneros shale is not known. Wells drilled in the northwestern part of the county where the Dakota is fully developed have encountered as much as 150 feet (log 105) and as little as 81 feet (log 104) of Dakota, indicating considerable differences in thickness from place to place. In the eastern part of the county where the upper part of the Dakota has been removed by erosion, most wells drilled to underlying formations have penetrated 75 to 125 feet of the Dakota (pl. 2). Stovall (Schoff and Stovall, 1943, p. 85) measured 185 feet of the Dakota in Cimarron County, Okla., and Plummer and Romary (1942, p. 330-331) report a maximum thickness of more than 200 feet in central Kansas.

Age and correlation.—Although the Dakota sandstone has long been considered a part of the Upper Cretaceous series; recent studies by Cobban and Reeside (1951) and by Katich (1951) indicate that the boundary between the Lower and Upper Cretaceous is above the Dakota sandstone in western Colorado. A fossil that was taken by the writer from the Dakota sandstone in northeastern Baca County has been identified by J. B. Reeside, Jr. as *Trigona emory* : Conrad, a species that is believed to be of Early Cretaceous age. Inasmuch as the Thatcher limestone member of the Graneros shale contains fossils of Late Cretaceous age, it appears that the boundary between the Lower and Upper Cretaceous series may be in the Graneros formation near the contact of the Dakota.

The Dakota sandstone is equivalent to the Dakota of adjacent areas in Colorado, New Mexico, Oklahoma, and Kansas, but its relation to beds assigned to the Dakota in the Julesburg Basin and other areas to the north is not known.

Water supply.—The Dakota sandstone is one of the three principal aquifers in Baca County. Although it does not yield large quantities of water to wells, it supplies small to moderate quantities of water to more wells and springs in the county than does any other aquifer. The Dakota is a dependable source of water throughout most of its extent in Baca County, but it is largely drained in the canyon areas where streams have cut into the underlying formations. The Dakota supplies water to many springs in the canyons of Carrizo Creek and its tributaries and to a few springs in the northwestern part of the county.

In the areas of outcrop of the Dakota sandstone in southwestern Baca County (pl. 1) water is difficult to obtain, particularly in the highly dissected areas adjacent to the deeper canyons. The amount of water in the Dakota increases away from the canyons toward the northeast and within a few miles from any canyon the formation generally is largely saturated and will yield adequate water to wells for domestic and stock use. In prospecting for water in the area of outcrop of the Dakota in southwestern Baca County it would be advisable to drill at some point located as far as possible from the deeper canyons. As one approaches the contact of the Dakota and Ogallala formations (pl. 1) from the southwest, the possibilities of obtaining water from the Dakota increase. If the canyons do not cut through the Dakota, water may be obtained from the lower sandstone; if the canyons cut into the underlying formations it may be necessary to drill to the underlying Cheyenne or Entrada in order to obtain an adequate supply.

It generally is easier to obtain water in the areas of outcrop of the Dakota in northwestern Baca County than in southwestern Baca County. The northwestern area is less dissected by canyons and the Dakota is not drained of water to the extent that it is in the southwestern area. In the northwestern area the beds dip eastward from the Las Animas arch and on the east side of the larger canyons they generally are saturated with water to a greater extent than are the more nearly horizontal beds of the southwestern area. The effect of the slope (dip) of beds upon the accumulation of water is illustrated in figure 36.

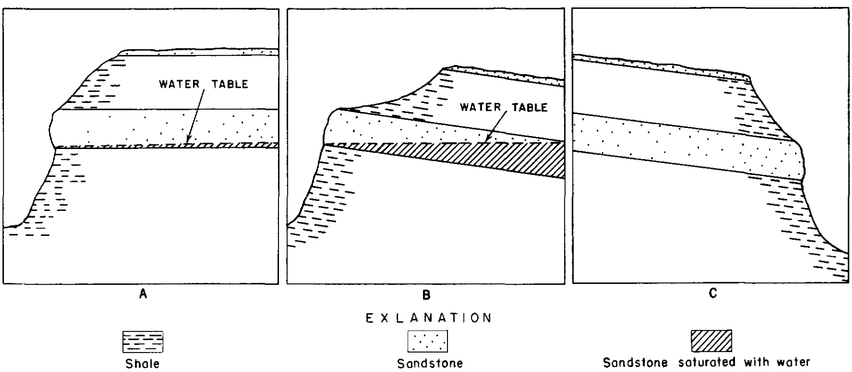

Figure 36.—Effect of structure on the occurrence of ground water in the Dakota sandstone. (Shaded part is saturated with water.) *A*, Flat-lying bed of sandstone from which water is largely drained; *B*, bed of sandstone that slopes away from the canyon and is only partly drained; *C*, bed of sandstone that slopes toward the canyon and is entirely drained.

In the narrow areas of outcrop of the Dakota along Bear Creek and its tributaries and the lower reaches of Two Butte Creek and Sand Arroyo, water is easily obtainable from the Dakota. Only the upper part of the formation crops out and is drained in these areas, whereas the lower part is saturated with water. If the Dakota does not yield enough water for the use to which it is to be put or if it contains too much iron, larger quantities of more suitable water generally can be obtained from the Cheyenne sandstone member below. The top of the Cheyenne generally lies 45 to 90 feet below the base of the Dakota. Where the quantity or quality of the water in the Dakota is unsatisfactory, it generally would be more economical to deepen the well to the Cheyenne than to drill another well into the Dakota.

In addition to supplying water to wells in its areas of outcrop, the Dakota sandstone supplies water to many wells in areas underlain by younger formations. The Dakota is saturated in a large part of its extent beneath areas of outcrop of the Ogallala formation and of dune sand. Where the overlying Ogallala formation is largely drained and will yield little or no water to wells, the underlying Dakota generally is saturated and will yield sufficient water for domestic and stock use. In the areas of outcrop of the Graneros, Greenhorn, Carlile, Niobrara, and Ogallala formations from the vicinity of Pritchett northward to the county line (pl. 1) the Dakota generally is the shallowest dependable source of water, although in some places it lies at a considerable depth.

The quantity of water available from wells in the Dakota sandstone generally is small although it is sufficient for most domestic and stock uses. Where the formation is well developed and is largely saturated, properly constructed wells that penetrate the entire formation may yield as much as 200 gpm, but most of them could be expected to yield only 50 to 100 gpm.

The depth of wells obtaining water from the Dakota differs greatly from place to place within the county. Wells in the areas of outcrop of the Dakota are less than 150 feet deep and may be as little as 50 feet deep. Where the Dakota is covered by a thick mantle of younger deposits the wells may be more than 350 feet deep. Wells in the north-central part of T. 28 S., R. 49 W., must penetrate the Graneros, Greenhorn, Carlile, and, in places, the Niobrara and Ogallala formations before reaching the Dakota sandstone. The thickness of materials between the base of the Niobrara formation and the top of the Dakota sandstone in this area is about 270 feet.

The depth to water in wells tapping the Dakota differs from place to place, depending upon the depth to the formation and on the pressure head of water in it. Where the Dakota is overlain by the Graneros shale (fig. 27) the water in the Dakota is under artesian pressure and will rise above the point at which it is encountered. Where the Dakota crops out or is overlain by permeable material, such as the Ogallala formation, water in the uppermost saturated sandstone may not be under artesian pressure. In these areas, however, the beds of sandy shale and platy sandstone generally are sufficiently impermeable to serve as a confining layer over the underlying sandstones, in which water generally is under sufficient artesian pressure to rise in wells.

The quality of water in the Dakota sandstone is discussed on page 80.

UPPER CRETACEOUS SERIES

GRANEROS SHALE

The Graneros shale includes the beds between the Dakota sandstone below and the Lincoln limestone member of the Greenhorn limestone above. It is not equivalent to the Graneros as originally defined by Gilbert (1896b, p. 564), inasmuch as he included in its upper part beds that are herein assigned to the Lincoln limestone and Hartland shale members of the Greenhorn limestone.

Character.—The Graneros shale consists primarily of dark-gray to black fissile noncalcareous shale (fig. 37). It contains many

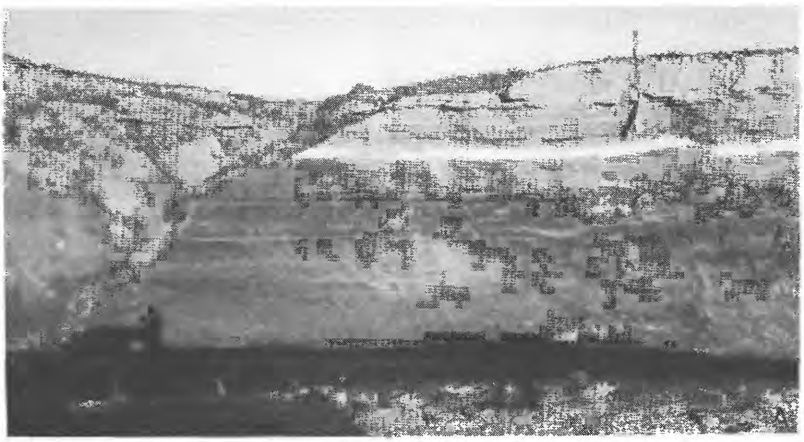

Figure 37.—Black fissile shale in the upper part of the Graneros shale in NE sec. 36, T. 28 S., R. 49 W. White band is 12-inch bed of bentonite lying 4.2 feet below the base of the Greenhorn limestone.

thin beds of bentonite throughout and contains a resistant limestone which lies about 23 feet above the top of the Dakota sandstone.

The shale of the Graneros is almost entirely dark gray to black, noncalcareous, and fissile, but it contains a few very thin layers of rusty-brown structureless sandy clay. The fissile shale contains many small crystals of gypsum at several horizons and in places weathers to light-brown slopes. The shale is not resistant to erosion and may be covered by soil and debris except locally in streambanks beneath ledges of the Lincoln limestone member or of the limestone in the Graneros.

The layers of bentonite generally are less than an inch thick and are distributed throughout the formation. The most prominent bed of bentonite is 10 to 12 inches thick and lies 4.1 to 4.3 feet below the basal limestone of the Lincoln limestone member of the Greenhorn limestone. The thicker beds of bentonite are light gray to cream in the middle and yellowish brown on the upper and lower surfaces. They are structureless and break with a conchoidal fracture. They are easily eroded and can be seen only on fresh exposures such as road cuts or streambanks.

The limestone unit in the Graneros is about 5 feet thick and consists of dark-gray to black dense compact argillaceous limestone. The top is thin bedded to platy and weathers to sharp angular rusty-brown chips. The platy beds are underlain by thicker beds which weather into large blocks on moderately fresh exposures but which eventually deteriorate into small rusty-brown chips. The thick beds are underlain by alternating thin platy earthy to crystalline limestone and sandy shale. This unit contains a 2-inch layer of bentonite (fig. 38). The limestone unit of the Graneros forms a low, persistent bench throughout the northwestern part of the county and facilitated the geologic mapping because it generally is the only recognizable unit of the Graneros in the long grassy slopes between the escarpments of the overlying Greenhorn limestone and the underlying Dakota sandstone. The limestone is sparingly fossiliferous but contains impressions of large cephalapods in a few places.

Distribution and thickness.—The Graneros shale crops out in relatively narrow bands along the east flank of the Las Animas arch, in the valley of Two Butte Creek, and in the valley of Bear Creek, all in the northwestern part of the county (pl. 1). It underlies younger formations in the northwestern fifth of the county and pinches out eastward and southward between the Dakota and Ogallala formations (pl. 2, fig. 27).

The Graneros is of uniform thickness throughout its small areal extent in the northwestern part in the county. The measured thickness along Two Butte Creek is 86 feet. The Graneros

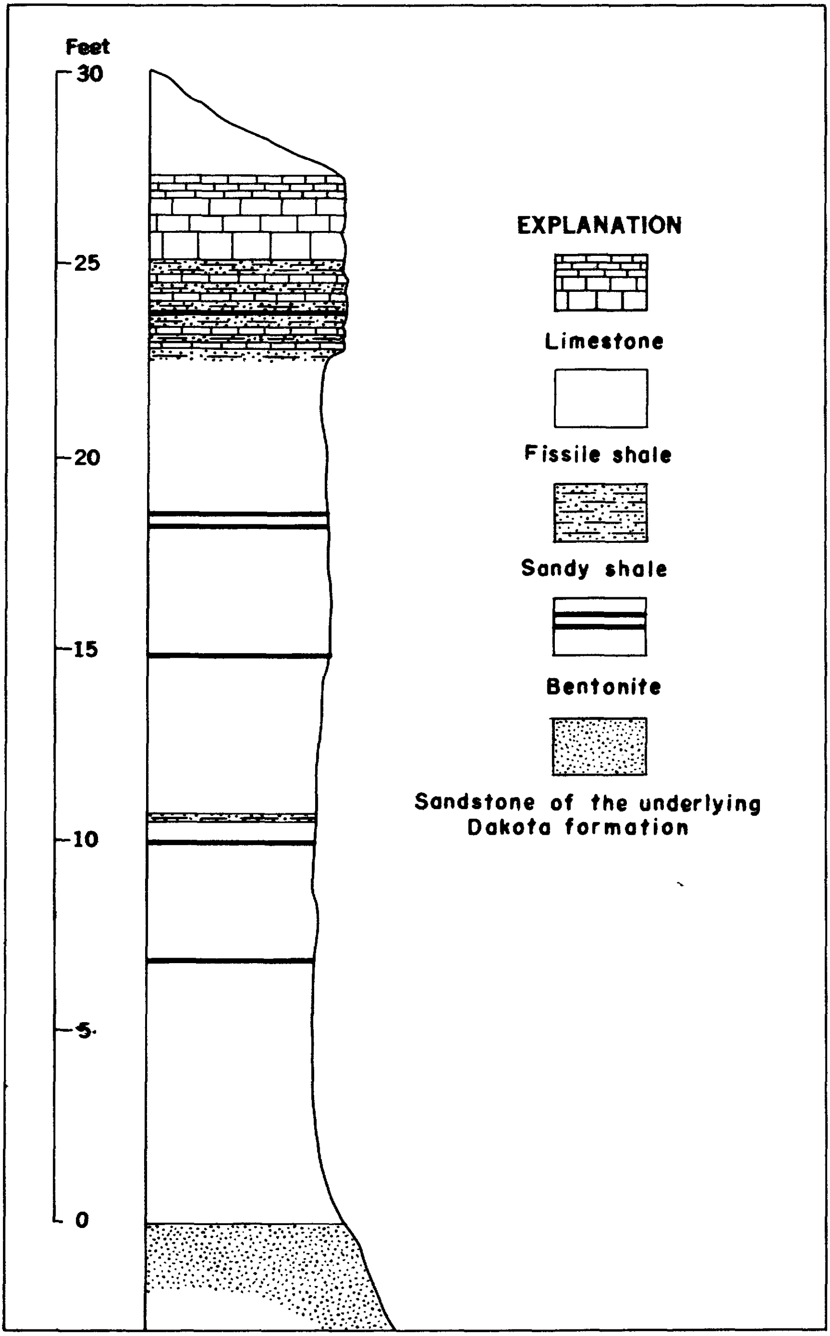

Figure 38. —Stratigraphic section of the lower part of the Graneros shale (SE¼ sec. 33, T. 27 S., R. 47 W., Prowers County).

thickens westward and thins eastward. It is 61 feet thick in Hamilton County, Kans., and 105 feet thick in the Model anticline in Las Animas County, Colo. (Bass, 1926, 1947).

Age and correlation.—The Graneros shale is largely of Late Cretaceous age but the lower part may be of Early Cretaceous age. It is equivalent to the Graneros of adjacent areas of Kansas, Oklahoma, and southeastern Colorado but is equivalent to only the lower part of the Graneros at the type locality in Pueblo County, Colo. The limestone unit is equivalent to the Thatcher limestone member in the Model anticline in Las Animas County (Bass, 1947), where it lies 34 to 41 feet above the Dakota sandstone. Similar thin limestones that weather to rusty-brown chips have been observed in the lower part of the Graneros as far west as the type locality in Pueblo County (Gilbert, 1896b) and as far east as Hamilton County, Kans. (Bass, 1926, p. 72).

Water supply.—The Graneros shale is relatively impermeable and yields no water to wells in Baca County. It overlies the Dakota sandstone and retards or prevents infiltration of water into the Dakota in a large part of northwestern Baca County. It serves as a confining layer over the Dakota in the northwestern part of the county; hence, water in the Dakota in that area generally is under artesian pressure and will rise in wells above the point at which it is encountered.

Water generally is easily obtainable from wells in the areas of outcrop of the Graneros shale (pl. 1). All or part of the underlying Dakota generally is saturated and will yield adequate quantities of water for domestic and stock use. If larger quantities of water are desired the well can be deepened into the Cheyenne sandstone member, which in the northwestern area is about 50 feet below the base of the Dakota. Wells drilled to the Dakota sandstone in the areas of outcrop of the Graneros will reach the top of the Dakota at a depth less than 85 feet, the bottom of the Dakota at a depth less than 235 feet, and the top of the Cheyenne at a depth less than 285 feet. Those wells drilled in the areas of outcrop of the Graneros near its contact with the Dakota probably will not encounter water in the upper sandstones of the Dakota but generally will encounter sufficient water in the lowest sandstone. Wells near the contact of the Dakota and Graneros formations will encounter the base of the Dakota near 150 feet and the top of the Cheyenne near 200 feet.

GREENHORN LIMESTONE

The Greenhorn limestone in this area includes all beds between the Graneros and the Carlile shales. It consists of three members which are, from the base upward, the Lincoln limestone, the Hartland shale, and the Bridge Creek limestone.

Character.—The Lincoln limestone member consists mainly of limy shale with thin platy limestone at the top and bottom. The shale is dark-gray to black and generally is fissile. It contains a few very thin layers of tan to rusty-brown bentonite. The upper limestone generally consists of one or two thin beds of dense platy limestone which weathers to small chips and has little resistance to erosion. The lower limestone is distinctively thin bedded to platy, hard, and crystalline, and it emits a strong petroliferous odor when broken. It is highly fossiliferous and contains many casts and molds of *Inoceramus prefagilis.* The beds of limestone are light tan but weather into small brown chips. The limestones are very resistant to erosion and form prominent benches throughout their areas of outcrop (figs. 39, 40, 41). The Lincoln limestone member is about 25 feet thick in Baca County (fig. 42). It thickens eastward 35 feet in Hamilton County, Kans., and thins westward to 19 feet in the Model anticline in Las Animas County, Colo. (Bass, 1926, 1947).

The Hartland shale member is poorly exposed in Baca County and a complete section could not be observed at any one place.

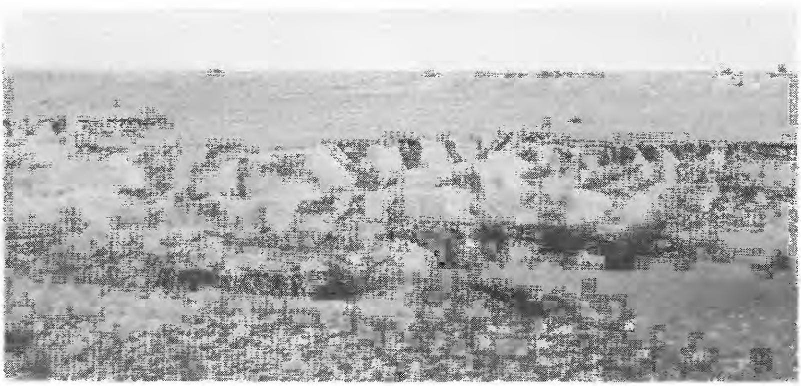

Figure 39.—Badlands developed in the Graneros shale along Freezeout Creek, Murray ranch; escarpment in the distance is formed by the Lincoln limestone member of the Greenhorn limestone.

Figure 40. —Thin-bedded resistant limestone at the base of the Greenhorn limestone, underlain by soft Graneros shale. Outcrop is along Two Butte Creek below O'Neil ranchhouse.

It consists almost entirely of light-gray chalky shale. Locally it contains one or more thin beds of dense chalky limestone and a few very thin layers of bentonite. The member is about 30 feet thick in northwestern Baca County. It thins eastward to 23 feet in Hamilton County, Kans., and is 29 feet thick in the Model anticline (Bass, 1926, 1947).

Figure 41. —High bluffs formed by basal limestone beds in Lincoln limestone member of the Greenhorn limestone. Slopes in foreground are underlain by the Graneros shale. Outcrop along Freezeout Creek on Murray ranch.

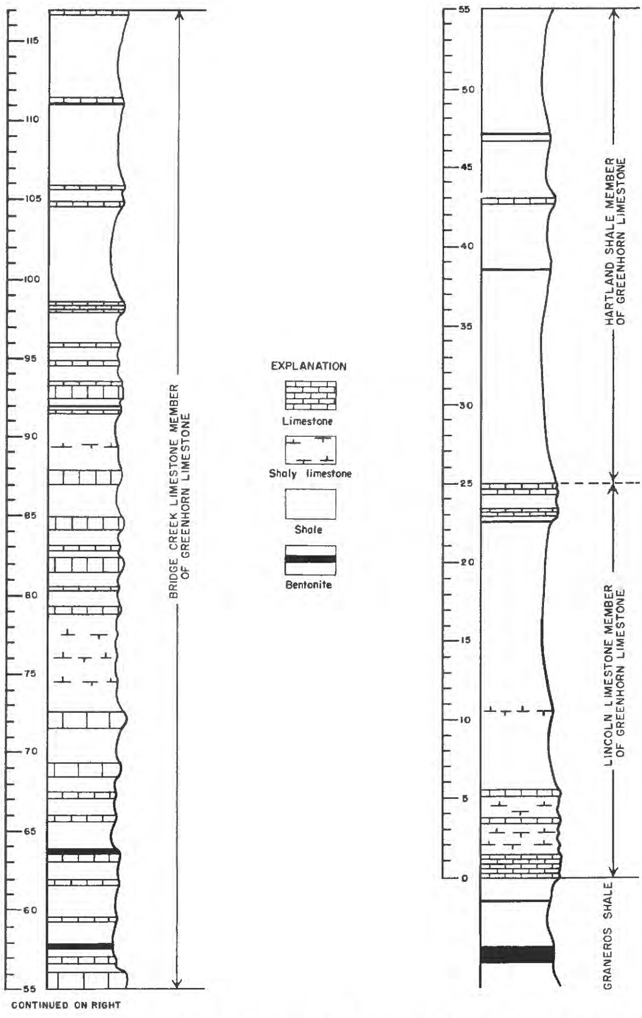

Figure 42.—Stratigraphic section of the Greenhorn limestone. The Lincoln limestone member was measured in the NE¼ sec. 36, T. 28 S., R. 49 W., and SW¼sec. 28, T. 28 S., R. 48 W.; the Hartland shale member was measured in the NE¼sec. 7, T. 30 S., R. 47 W., and NW¼sec. 14, T. 28 S., R. 48 W.; the Bridge Creek limestone member was measured in the NW¼sec. 14, T. 28 S., R. 48 W.

The Bridge Creek limestone member contains alternating beds of chalky limestone and limy shale (figs. 42, 43) with a few thin layers of bentonite. The beds of limestone are 3 to 12 inches thick and are separated by 6 inches to 6 feet of shale. The limestones are dense, are gray to cream, and weather to chalky white. Many of the beds in the upper part contain abundant remains of *Inoceramus labiatus*. The beds of limestone are more resistant to erosion than the intervening shales; consequently, they form small benches on weathered slopes. Aerial photographs of

Figure 43. —Thin-bedded limestones of Bridge Creek limestone member of the Greenhorn limestone in sec. 6, T. 30 S., R. 49 W.

Figure 44. —White limestone of the Fort Hays limestone member of the Niobrara formation in the foreground and on the skyline in the left distance. The flat-topped ridge in the middle and right background is capped by resistant limestone that is the equivalent of the Codell sandstone member of the Carlile shale in Kansas. Grassy slopes of the valley are underlain by the Blue Hill shale member of the Carlile. Outcrops are near Deora.

some areas of outcrop of the Bridge Creek limestone member resemble contour maps; the white lines representing the outcrops of the beds of limestone resemble contours along a hillside.

The most distinctive bed in the Bridge Creek limestone member is the basal limestone, which is light gray to gray, hard, and dense. It appears massive in fresh cuts, but weathers to sharp vertical chips or slices 1 or 2 inches thick and 3 to 5 inches in diameter. The bed is separated by 6 inches of shale from an overlying very hard dense to finely crystalline limestone that weathers into semirounded boulders. That limestone is overlain by a 6-inch bed of shale and a 4-inch bed of bentonite. The basal limestone forms the first prominent bench above the basal limestone of the Lincoln limestone member.

The uppermost bed of the Bridge Creek limestone member is a buff chalky limestone having thin rusty bands near the middle and containing remains of *Inoceramus labiatus*. It is believed that this bed is the equivalent of the "fence-post limestone" which marks the top of the Greenhorn throughout northwestern Kansas. It is 8 to 10 inches thick in Kansas and serves as a key bed in mapping structure in that area. The bed is only 3 inches thick in Baca County and is not as resistant to erosion.

The Bridge Creek limestone member is 62 feet thick along Two Butte Creek in Baca County. It thickens eastward to 74 feet in Hamilton County, Kans., and thins westward to 35 feet in the Model anticline (Bass, 1926, 1947).

Distribution and thickness.—The Greenhorn limestone crops out primarily along Plum and Two Butte Creeks and their tributaries in the northwestern part of Baca County (pl. 1). It underlies the Ogallala formation in an area lying mostly north and west of Pritchett (fig. 27). The Greenhorn underlies a large area in southeastern Colorado and western Kansas.

The thickness of the Greenhorn limestone in Baca County is about 115 feet. It is moderately uniform but increases eastward to 132 feet in Hamilton County, Kans., and thins westward to 83 feet in the Model anticline (Bass, 1926, 1947). The Greenhorn appears to thicken at the expense of the Graneros shale, inasmuch as the combined thickness of the Greenhorn and Graneros is quite uniform throughout the area. The combined thickness is 188 feet in the Model anticline, 203 feet in Baca County, and 193 feet in Hamilton County, Kans.—a range of only 15 feet in more than 125 miles. The thickness of the Greenhorn and Graneros formations and of the three members of the Greenhorn is shown in figure 45.

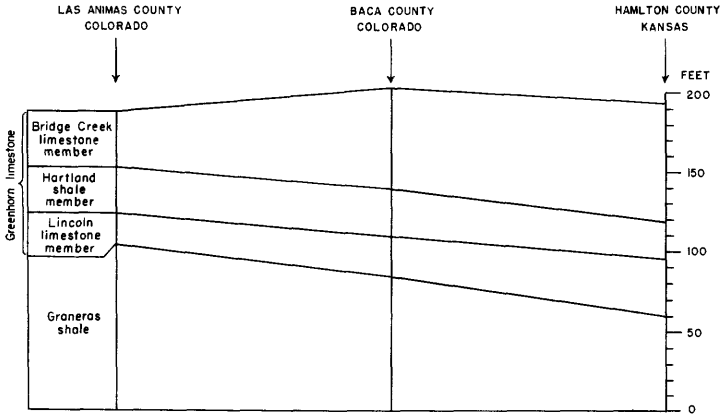

Figure 45.—Range in thickness of the Greenhorn and Graneros formations between Las Animas County, Colo., and Hamilton County, Kans.

Age and correlation.—The Greenhorn limestone is of Upper Cretaceous age and is equivalent to the Greenhorn of western Kansas and southeastern Colorado. The Bridge Creek limestone member is equivalent to the Pfeifer shale and Jetmore chalk members of northwestern Kansas, and is equivalent to the entire section of the Greenhorn limestone as defined by Gilbert (1896b) at the type locality in Pueblo County, Colo. Gilbert's Graneros shale included beds that are now defined as the Lincoln limestone and Hartland shale members throughout western Kansas and southeastern Colorado.

Water supply.—The Greenhorn limestone yields small quantities of very hard water to a few shallow dug wells in the northwestern part of the county. Well 36 yields a small quantity of hard water from fractures and openings along bedding planes in the basal limestone of the Lincoln limestone member (analysis 36 in table 6). Small quantities of water probably could be obtained at many places from limestones within the Greenhorn in its areas of outcrop, but the quantity generally is not adequate for domestic and stock use and the quality is not suitable for most uses. Owing to the low productivity of the limestones, it generally is necessary to construct a large-diameter well having large capacity to store water between periods of pumping. These wells are the first to fail during periods of drought.

In the areas of outcrop of the Greenhorn (pl. 1) it generally is advisable to drill a well to the underlying Dakota sandstone to obtain a dependable supply of water. The maximum depth to the top of the Dakota sandstone in the areas of outcrop of the Greenhorn is about 200 feet (at the contact of the Greenhorn and Carlile formations), and the minimum depth is 86 feet (at the contact of the Greenhorn and Graneros formations. If the quality or quantity of the water in the Dakota sandstone is not satisfactory for its intended use, additional supplies can be obtained from the Cheyenne sandstone member which lies about 50 feet below the base of the Dakota.

CARLILE SHALE

Character.—The Carlile shale overlies the Greenhorn limestone and underlies the Fort Hays limestone member of the Niobrara formation. The lower unit, the Fairport chalky shale member, consists of alternating beds of chalky limestone and tan platy to fissile chalky shale. The shale is lighter colored and more chalky than the shale in the upper part of the Greenhorn but the contact between the Carlile and the Greenhorn can be determined with certainty only by means of the contained fossils.

The middle unit of the Carlile shale, the Blue Hill shale member, constitutes more than half the formation and consists of dark-gray to black fissile clay shale having a few thin layers of brown platy shale. The shale becomes lighter colored upward and contains silt and a little sand near the top. About 15 to 20 feet below the top of the shale unit is a zone of large gray to light-brown septarian concretions. They range in diameter from a few inches to several feet and contain veins of massive amber calcite and highly crystallized yellowish-amber calcite.

The uppermost unit of the Carlile shale, the Codell sandstone member, consists of 2½ to 3 feet of light-tan to rusty-brown hard finely crystalline limestone containing a few sand grains. The limestone is highly fossiliferous and emits a strong petroliferous odor when freshly fractured. It is similar to the limestone of the Lincoln limestone member of the Greenhorn limestone in that both emit a petroliferous odor on fresh fractures, have a similar color, and have a similar texture. The upper limestone of the Carlile, however, is not as thin-bedded as that of the Lincoln limestone member of the Greenhorn limestone, but it weathers into small slabs that can easily be confused with weathered slabs of the Lincoln limestone. The upper limestone of the Carlile is very resistant to erosion and forms the capping ledge of several high bluffs in the vicinity of Deora in T. 28 S., R. 49 W. (fig. 44). It weathers into large rectangular blocks which, in turn, split parallel to the bedding planes into small irregular slabs.

Distribution and thickness.—The Carlile shale underlies an area of a few square miles in the vicinity of Deora and Frick and a very small area along Two Butte Creek in sec. 14, T. 28 S., R. 48 W., where there are a few beds of limestone and shale between the top of the Greenhorn limestone and the Ogallala formation (pl. 1).

The Carlile is only about 85 feet thick in Baca County but thickens eastward and westward. It is 160 feet thick in the Model anticline, 250 feet in Hamilton County, Kans., and about 300 feet in Ellis County, Kans. (Bass, 1926, 1947).

Age and correlation.—The Carlile shale in Baca County is Upper Cretaceous and is equivalent to the Carlile shale of southeastern Colorado and western Kansas. The capping limestone contains a characteristic fauna and is equivalent to the Codell sandstone member of western Kansas and to a part of the Frontier formation of Wyoming. The limestone grades eastward into sandstone but can be traced westward to the foothills of the Front Range in Las Animas, Huerfano, and Pueblo Counties, Colo. The underlying dark shale is equivalent to the Blue Hill shale member of central and western Kansas and can be traced westward to the Front Range. The zone of septarian concretions has been observed in this unit throughout southeastern Colorado and western Kansas and in Nebraska. The lower division, of limestone and shale, has been called the Fairport chalky shale member throughout central and western Kansas.

Water supply.—The Carlile shale does not yield water to wells in Baca County but supplies water to a few small springs. Very small supplies might be obtained from fractures in the lowest limestone beds, but these generally would be unsatisfactory. The shallowest dependable source of water in the area of outcrop of Carlile shale (pl. 1) is the Dakota sandstone, which lies at considerable depth. The depth to the top of the Dakota sandstone in the area of outcrop of the Carlile ranges from about 200 feet at the contact of the Carlile and Greenhorn formations to about 285 feet at the contact of the Carlile and Niobrara formations. If the Dakota sandstone will not yield as much water as is needed, additional supplies can be obtained from the Cheyenne sandstone member of the Purgatoire formation. The top of the Cheyenne is about 200 feet below the top of the Dakota in this area and, hence, is 400 to 485 feet below the land surface.

NIOBRARA FORMATION

General features.—The Niobrara formation is represented in this area by the basal Fort Hays limestone member, which crops out in a very small area in the vicinity of Deora (pl. 1). It consists of beds of chalky limestone 4 to 12 inches thick separated by thin beds of chalky shale. It weathers into rectangular blocks which, in turn, break into numerous small white chips that cover the surface (fig. 44). The full thickness of the member is not present in Baca County, and the maximum thickness cropping out in the county is estimated to be about 20 feet. The limestone is equivalent to the Fort Hays limestone member of the Niobrara formation in western Kansas and eastern Colorado and to the lower part of of the Timpas limestone in areas to the west.

Water supply.—The Niobrara formation yields no water to wells in Baca County. Elsewhere it is a poor aquifer and yields only small quantities to a few shallow dug wells. The shallowest dependable source of water in the areas of outcrop of the Niobrara in Baca County (pl. 1) is the Dakota sandstone. The top of the Dakota in this area lies at depths ranging from about 285 to more than 300 feet, and the Cheyenne sandstone member of the Purgatoire lies at depths ranging from about 485 to more than 500 feet.

TERTIARY SYSTEM

MIOCENE (?) SERIES

INTRUSIVE ROCKS

Igneous rocks have been intruded into the older sedimentary rocks in southernmost Prowers County to form a laccolithic mass known as Two Buttes. Many dikes and a few sills that were associated with the intrusion crop out adjacent to Two Buttes in both Prowers and Baca Counties. These intrusive rocks can be observed in Baca County along Two Butte Creek in the vicinity of Two Butte Reservoir in T. 28 S., Rs. 45 and 46 W. The dikes are nearly vertical and transect both the Taloga formation of Cragin and the Entrada sandstone and are truncated by the Ogallala formation. A few of the dikes are more resistant to erosion than the sedimentary rocks into which they are intruded and locally form small linear ridges standing 10 or 15 feet above the local land surface (figs. 46, 47). Other dikes are less resistant than the adjacent sedimentary rocks; hence, their outcrops are marked by shallow linear trenches. Gilbert (1896b) observed approximately 50 dikes associated with the Two Buttes intrusion but only a few of them are in Baca County. He reported that most of the dikes trend at right angles to the border of the laccolith and that if projected they would pass near the center of the main intrusion. A few of the dikes, however, are parallel to the border of the laccolith. The igneous rocks composing the dikes range from acidic to basic but are largely intermediate.

The sills are less abundant than the dikes in this area. A few thin layers of porphyry have been observed in the red beds along Two Butte Creek below the reservoir.

One other intrusive mass, which appears to be a small plug but may be a dike, crops out in sec. 6, T. 28 S., R. 47 W., along

Figure 46.—Igneous rocks in Baca County. Small dike in the foreground is along Two Butte Creek below dam; Two Buttes, in the distance, consist of Permian red beds capped by the Entrada sandstone; the low dark mound to the right of Two Buttes is the main mass of the Two Buttes intrusive.

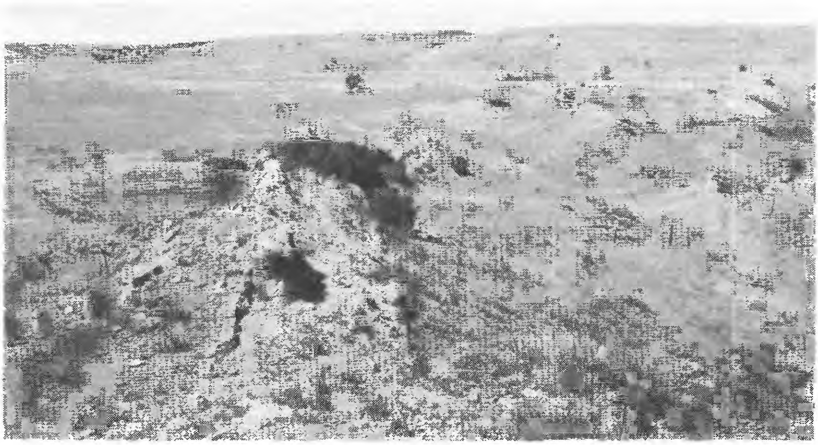

Figure 47. —Long, narrow dike transecting Permian red beds along Two Butte Creek below dam.

Two Butte Creek about 11 miles west of Two Buttes (pl. 1). The material resembles the dikes around Two Buttes and may be associated with that intrusion. It is intruded into the Lincoln limestone member of the Greenhorn limestone and has uplifted the beds, locally exposing the underlying Graneros shale. The beds of shale and limestone have been altered by contact metamorphism for a distance of several feet from the intrusive.

The age of the intrusive rocks is not known. The youngest sedimentary formation transected by the igneous rocks in Baca County is the Lincoln limestone member of the Greenhorn limestone. The igneous rocks are overlain in some places by the Ogallala formation, which contains large fragments of igneous material apparently derived from erosion of the older intrusive rocks (fig. 48). The time of the intrusion, therefore, was after the deposition of the Lincoln limestone member and before the completion of deposition of the Ogallala formation. Inasmuch as most of the intrusive activity in this region began in Tertiary time, the intrusion of the laccolith and associated dikes and sills at Two Buttes probably began in Tertiary time. Inasmuch as the Ogallala formation in this area contains large blocks of material derived from the intrusive rocks, it would appear that most of the rocks were intruded in pre-Ogallala time—perhaps during the Miocene epoch. In a few places near the buttes, however, the algal limestone that marks the top of the Ogallala dips steeply away from the main intrusive, indicating additional uplift of the rocks in post-Ogallala time. There is no evidence of intrusive activity during the time of this uplift.

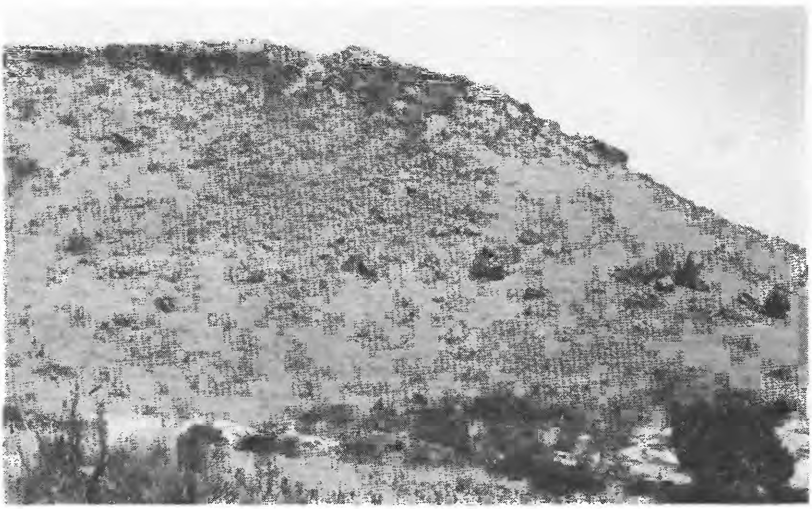

Figure 48.—Massive ledge of caliche containing fragments derived from the intrusive at Two Buttes and from adjacent bedrock formations. Largest fragments are small boulders. Outcrop along small tributary of Two Butte Creek just north of Baca-Prowers County line.

The intrusive rocks are relatively impermeable and yield no water to wells in Baca County.

PLIOCENE SERIES

OGALLALA FORMATION

The Ogallala formation, as that term is used in this report, consists of those sediments lying above the Paleozoic and Mesozoic bedrock formations and beneath the younger basalt, dune sand, and other deposits. For convenience in mapping, the Ogallala formation as shown in plates 1 and 2 includes local deposits classified as the Meade(?) formation and terrace deposits.

Character.—The Ogallala formation is poorly exposed in Baca County, owing to its content of soft, poorly resistant beds and to the extensive cover of soil and dune sand. The character of the Ogallala can be determined only from small outcrops along some of the major streams and from the cuttings from wells and test holes. The formation consists largely of silt, clay, sand, gravel, and caliche and lesser amounts of hard sandy algal limestone. In general, sand and gravel is most abundant in the lower part of the formation and silt, clay, and caliche are most abundant in the upper part. The formation generally is capped by the algal limestone (fig. 49).

Figure 49.—Hard thin rounded slabs of algal limestone at the top of the Ogallala formation at the east line of sec. 2, T. 32 S., R. 48 W.

Most of the sand and gravel is poorly sorted and may range in grain size from very fine sand to coarse gravel. The material may become well sorted within a short distance vertically or laterally and may be interbedded with thin layers of silt and clay. The coarsest and best-sorted sand and gravel was encountered in the lower part of the formation in those areas where the Ogallala is thickest, such as at test holes 1, 17, 18, and 144 (pl. 2). The sand in the Ogallala consists predominantly of grains of quartz, whereas the gravel consists mostly of fragments of reworked sandstone and, to a lesser extent, of grains of quartz. The fragments of sandstone generally are white to tan and brown and are largely fine grained. They resemble closely the Dakota sandstone and probably were derived largely from that formation, although they may have been derived in part from sandstones in other Mesozoic formations. Locally, in the southeastern part of the county, the gravel consists in part of fragments of red sandstone which probably were derived from beds of the Dockum group.

The beds of sand and gravel in the Ogallala locally are cemented with calcium carbonate to form mortar beds. The mortar beds are only a few feet thick and may grade into unconsolidated sand and gravel within a short distance. They are light gray to nearly white and are friable. A few are tightly cemented and hard and weather to form large blocks. The mortar beds in most places consist of coarse sand and gravel composed of grains of quartz and feldspar, but they may consist in part of large cobbles and boulders derived from sandstones of the Dakota and other Mesozoic formations.

The silt in the Ogallala is largely tan to light brown but may be various shades of pink and red. It generally is admixed with very fine to fine sand and with clay. The silt is found principally in the upper part of the formation but may occur in almost any zone within the formation. In many places beds of sandy silt contain stringers and nodules of caliche, which may be hard and stand out in relief on weathered surfaces or may be soft and chalky. In a few places the hard nodules weather out and form gravelly rubble at the base of the outcrop and on weathered slopes.

The clay in the Ogallala may be different shades of brown, green, and gray. Most beds contain silt and a little sand but a few beds are nearly pure clay having a blocky fracture. The clay is largely in the upper part of the formation but may occur in any part. The clay in the upper part of the formation generally contains sand or silt, whereas the clay in the lower part most commonly is relatively pure and generally is interbedded with layers of sand and gravel. Nodules and stringers of caliche may be found in the clay as they are in sandy silt, but they are not as abundant.

One of the most widespread and most frequently observed constituents of the Ogallala is caliche. It generally is sufficiently hard to resist erosion and to form small steep ledges along the sides of the many small valleys that transect the area of outcrop of the formation. Caliche is an admixture of sand and calcium carbonate. It may be predominantly sand with calcium carbonate cement or predominantly calcium carbonate with scattered grains of sand. The sand generally is very fine to fine but may be coarse. It consists almost entirely of grains of quartz but may also contain grains of magnetite and other minerals. The caliche generally is different shades of gray and tan or even pink. In some places it case-hardens and is resistant to erosion but in most places it is soft and can be broken easily with a hammer or even cut with a shovel. Caliche most commonly occurs in the upper part of the Ogallala formation but has been observed in almost all parts of the formation. In the NW$\frac{1}{4}$ sec. 7, T. 34 S., R. 41 W., for example, five beds of caliche were observed in a 40-foot section of the upper part of the Ogallala. The beds of caliche ranged from 1 to 4 feet thick and the intervals between the beds ranged from 3 to 10 feet. Locally the caliche may contain a little fine gravel and in a few places it contains large boulders. Along Two Butte Creek on the southeast flank of the Two Buttes dome, the Ogallala consists of about 10 feet of caliche containing large rounded and angular blocks of igneous and sedimentary rocks derived locally from the intrusive rocks and from the older sedimentary rocks (fig. 48). Along Dry Creek in the NE$\frac{1}{4}$ sec. 36, T. 30 S., R. 44 W., there is an 8-foot bed of caliche containing angular blocks of the Dakota sandstone as large as 1 foot in diameter. The caliche is capped by a 5-inch bed of algal limestone which marks the top of the Ogallala formation.

The uppermost bed of caliche in the Ogallala formation is the thickest and most persistent in Baca County. It generally is at least 5 feet thick and locally may be 20 to 25 feet thick. The bed is capped by a 2- to 6-inch layer of algal limestone and is quarried extensively in the eastern part of the county for use as road metal.

The hardest and most persistent bed in the Ogallala is the capping limestone. It is 2 to 6 inches thick and marks the top of the formation. The limestone is hard and dense and contains scattered grains of quartz ranging in size from very fine sand to fine gravel. In some places the sand consists in part of magnetite. The limestone generally is compact but may contain a few small fractures and pores. It generally is so hard that many of the grains of quartz break when the limestone is fractured. The color may be uniformly cream to light tan but in most places the rock is banded. The bands are various shades of brown, tan, and pink and may be straight or curved. Locally the limestone displays the typical algal structure so common throughout the central High Plains. The uniform and banded limestone weathers into rectangular slabs, whereas the algal limestone has irregular vertical joints and weathers into rounded biscuitlike cobbles having an irregular surface and displaying the typical tan and pink concentric bands characteristic of algal structure (fig. 49). The capping limestone in many parts of the county forms a prominent low bench which can be traced for a considerable distance in the field and is conspicuous on aerial photographs.

The Ogallala formation locally contains thin layers of chert, chalcedony, and opal. These have been observed beneath the basalt on the northeast side of Carrizo Mesa and in the east half of sec. 10, T. 33 S., R. 50 W.

Distribution and thickness.—The Ogallala is the most widely distributed formation in Baca County (pls. 1, 2). It underlies all the upland areas in the county and in adjacent parts of the central High Plains. The only parts of Baca County not underlain by the Ogallala are the canyon areas in the northwestern and southwestern parts of the county and small areas along some of the major stream valleys in the eastern part of the county.

The thickness of the Ogallala ranges from a feather edge to about 260 feet (pl. 2). It is thickest in the northeastern and southeastern parts of the county and is thinnest over the bedrock ridge extending east-west across the northern part of the county and on Two Buttes dome. The lower part of the formation was deposited in the low areas farthest from the ridge and dome and younger deposits of the formation progressively overlapped the ridge and dome. At some places along Bear Creek and its tributaries the capping limestone lies on the Dakota sandstone, and on the Two Buttes dome it lies on Permian rocks. The Ogallala thickens eastward and is several hundred feet thick in parts of southwestern Kansas.

Age and correlation.—The Ogallala formation, as used in this report, includes those beds extending from the capping limestone to the underlying Mesozoic bedrock formations. Although the Ogallala formation at the type locality near Ogallala, Nebr., is of middle Pliocene age, the term "Ogallala group" has been used in Nebraska to include beds of lower, middle, and upper Pliocene age. The Ogallala formation has been used for many years in Kansas to describe beds of middle Pliocene age but the State Geological Survey of Kansas has now adopted a usage similar to that of Nebraska (Moore and others, 1951, p. 18). The Ogallala formation in Baca County is largely of middle Pliocene age, although some of the basal beds may be older. The formation can be traced into the Oklahoma panhandle where thousands of middle Pliocene horse teeth have been collected.

The Ogallala formation is equivalent to part of the Ogallala of the central and southern High Plains in western Nebraska, southeastern Wyoming, western Kansas, and the Oklahoma and Texas panhandles. The beds of the Ogallala of Baca County appear to be equivalent to the Kimball and Ash Hollow members of the Ogallala of Kansas and Nebraska usage.

Water supply.—The Ogallala formation is one of the three principal aquifers in Baca County. It yields small to moderate quantities of water to domestic and stock wells throughout a large part of the southern half of the county and in the northeastern corner of the county (fig. 14). At the time of this investigation no large-capacity wells had been developed in the formation in Baca County but, as indicated on pages 61 to 63, the formation is capable of yielding large quantities of water to properly constructed wells in several areas in the eastern part of the county, particularly in the vicinities of test holes 1, 2, 17, and 18.

As indicated by plate 2, a large part of the Ogallala is unsaturated in Baca County, although more than half the formation is saturated with water in a few areas. Plate 2 is not a true picture of the occurrence of water in the Ogallala formation because the vertical scale of the illustration is so small that only the thicker sections of saturated material can be shown. In many areas where no water table is shown in plate 2 there is a few feet of saturated material at the base of the formation which generally will yield adequate supplies of water for domestic and stock use. Figure 14 is a more accurate picture of the area of occurrence of water in the Ogallala because all wells listed in table 9 that obtain water from the Ogallala are shown. Within the areas of distribution of these wells it generally is possible to obtain water from wells in the Ogallala, although it may be necessary to drill to the underlying formations in some places where the thickness of saturated materials is too slight, where the saturated materials are too fine grained to yield water freely, where the formation locally is completely dry, or where larger supplies are required. Supplies larger than those required for domestic and stock use generally can be obtained from the Ogallala only in the areas of considerable saturated thickness as shown on plate 2.

Supplies of water can be obtained in most of the areas of outcrop of the Ogallala formation (pl. 1), although it may be necessary to drill to considerable depth at some places. As stated above, water generally can be obtained from the Ogallala formation within the areas of distribution of wells as shown in figure 14. Wells in these areas may obtain water at relatively shallow depths in some parts of southeastern Baca County but in other parts the water table is deep, particularly in the south—central part. Where the Ogallala is dry, it is necessary to drill to underlying aquifers to obtain a supply of water. The depth to the underlying aquifers cannot be determined from the geologic map, owing to the great difference in thickness of the Ogallala in various parts of the county. The depths can best be estimated by the use of the diagrammatic cross section shown on plate 2.

EXTRUSIVE ROCKS

Several remnants of basaltic lava flows crop out in the southwestern part of the county. The largest of these, that of Carrizo Mesa (fig. 50), is in T. 33 S., R. 50 W., and underlies an area of about 3 square miles; five smaller remnants in T. 35 S., R. 49 W., have a combined area of less than 1 square mile.

The thickness of the basalt ranges from a few tens of feet in the smaller remnants to more than 100 feet at Carrizo Mesa. A well on Carrizo Mesa penetrated 110 feet of basalt.

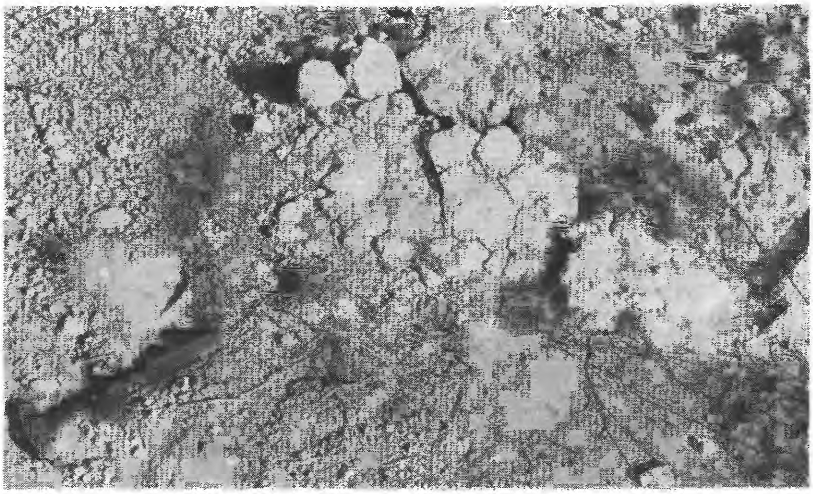

Figure 50.—Carrizo Mesa. Hard ledge at top is basalt. Upper two-thirds of grassy slope is underlain by the Ogallala formation, and the lower third is underlain by the Dakota sandstone.

The age of the lava flows probably is upper Pliocene or Pleistocene. The flow on Carrizo Mesa and other similar flows in northwestern Oklahoma, northeastern New Mexico, and southeastern Colorado overlie the middle Pliocene Ogallala formation and, hence, their age is post middle Pliocene. Along the edges of the smaller flows in T. 35 S., R. 49 W., are deposits forming the high terrace of the Cimarron River. It was not possible to determine whether these deposits extend beneath the lava, indicating late Pleistocene or Recent age for the flows, or whether the terrace deposits were laid down over and against pre-existing flows. Scattered cobbles on top of the flows indicate that the terrace deposits were laid down after the lava congealed and was eroded and that the time of the flow dates between middle Pliocene and late Pleistocene.

The extrusive rocks, although moderately permeable, lie above the water table and yield no water to wells in Baca County. On Carrizo Mesa (pl. 1) water has been obtained by drilling to the underlying Dakota sandstone at a depth of 150 to 200 feet. On the other remnants of lava flows it probably would be necessary to drill to the Cheyenne sandstone member or Entrada sandstone to obtain water as the Dakota and possibly the Cheyenne are largely drained of water.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

MEADE(?) FORMATION

Thin deposits of silt, sand, and gravel overlie the Ogallala formation at scattered points in the northern part of the county and are believed to be equivalent to the lower Pleistocene Meade formation of southwestern Kansas. Although no fossils have been collected from these beds in Baca County, their tentative correlation with the Meade formation is based on (1) their position above the algal limestone, the top of the Ogallala formation, and (2) the presence in them, at a place only a few hundred yards east of the Baca-Stanton County line, of an ash bed that is believed to be the Pearlette ash bed of the Meade formation.

The silt and sand of the Meade(?) formation in Baca County are poorly sorted and contain many nodules and stringers of caliche. The color is largely various shades of red and brown. The mixture of silt and sand is characteristic of the upper part of the Meade formation of Kansas and probably is equivalent to the Sappa member of the Meade formation of Kansas usage. The member resembles parts of the Ogallala formation, although it generally contains much less caliche.

The sand and gravel in Baca County is at the base of the Meade(?) formation and can be observed at a few places along Bear Creek and its tributaries in the northeastern part of the county where it is channeled into the underlying Ogallala formation. The sand and gravel is poorly to moderately well sorted and is locally cemented with calcium carbonate to form mortar beds. The sand and gravel consists largely of fragments derived from igneous rocks and does not contain an abundance of sandstone pebbles so common in the sand and gravel of the Ogallala formation in this area. In some places, however, the Meade(?) contains fragments of locally derived material such as blocks of limestone from the Greenhorn limestone (fig. 51) and fragments of sandstone from the Dakota or other Mesozoic formations.

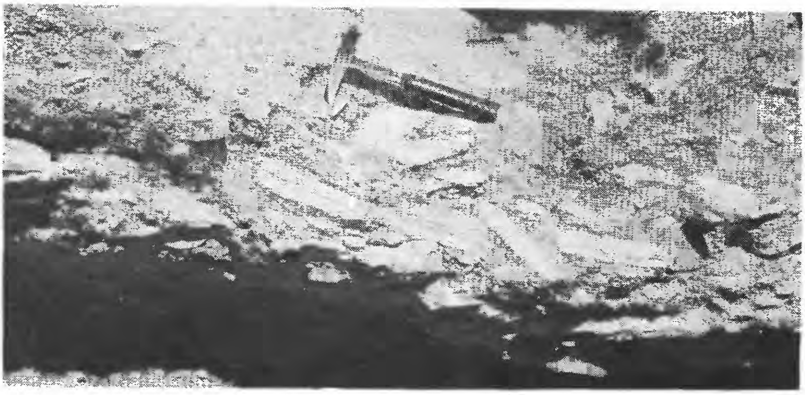

Figure 51.—Mortar beds of the Meade(?) formation containing large rectangular slabs of Greenhorn limestone. Outcrop along small draw in SW NW sec. 33, T. 28 S., R. 48 W.

The thickness of the Meade(?) formation in the county is not known because it generally is poorly exposed. The greatest thickness observed in the county was about 40 feet and it is believed that the total thickness probably does not exceed 50 feet at any place in the county.

The Meade(?) lies above the water table in most places and is not known to yield water to wells in Baca County. In some places along Bear Creek and its tributaries a part of the formation is saturated and probably would yield water to wells. Owing to the similarity of the Meade(?) to the Ogallala the two formations were mapped as one unit (the Ogallala formation) and are considered one aquifer.

TERRACE DEPOSITS

Remnants of deposits of terrace gravel laid down by the Cimarron River may be observed at scattered localities in the southern part of the county. The gravel is very coarse and contains fragments as large as 2 feet in diameter. The dominant material was derived from intrusive igneous rocks and consists principally of quartz and feldspar. Large cobbles of porous basalt are common in these deposits both in Baca County and in southwestern Kansas and serve to distinguish the terrace gravel from the gravel in the Ogallala and Meade formations.

The top of the terrace deposits is less than 50 feet below the upland surface, which in many parts of southernmost Baca County is developed on the algal limestone of the Ogallala formation. The deposits are best exposed along a road near the center of sec. 5, T. 34 S., R. 49 W., at a point 12 to 14 miles north of the present channel of the Cimarron River. Eastward the deposits are nearer the present channel of the Cimarron River. They are within 3 miles of the river at the Kansas-Colorado State line and are within 2 or 3 miles of the river throughout much of southwestern Kansas. The deposits are poorly preserved and in many places form a thin veneer over older rocks. Their thickness and distribution in the county were not determined in detail.

The terrace deposits of the Cimarron River in Baca County are equivalent to the highest terrace observed along the Cimarron River in southwestern Kansas. According to Hibbard (Frye and Hibbard, 1941, p. 420), fossils collected from these deposits in southwestern Kansas are of latest Pleistocene age.

The terrace deposits lie above the water table in Baca County and yield no water to wells.

RECENT SERIES

ALLUVIUM

Character.—Deposits of sand, gravel, silt, and clay underlie the flood plains of the major stream valleys. The material may be fairly well sorted in the larger valleys such as those of the Cimarron River and Carrizo Creek but generally is poorly sorted along the small streams, where a large amount of the material is derived from local sources by slope wash. The alluvium in the larger valleys that drain large areas and in the smaller valleys that drain areas underlain by coarse-grained sediments, such as parts of the Ogallala formation, generally consists largely of coarse-grained materials. The alluvium in the smaller valleys that drain areas underlain by fine-grained sediments, such as the Graneros and Carlile shales, generally consists of fine-grained materials. No test holes were drilled into alluvium during this investigation; hence, no detailed data as to its lithology were obtained.

Distribution and thickness.—Alluvium underlies most of the larger valleys in Baca County but its distribution could be mapped accurately only along the Cimarron River (pl. 1). The alluvium along other streams is not shown on the geologic map. The larger streams have well-developed flood plains which are underlain by alluvium throughout the valleys. The smaller streams have no well-developed flood plains and the alluvium generally is thin and discontinuous.

No data are available on the thickness of alluvium in Baca County but it should be of approximately the same thickness as the alluvium in valleys of similar size in southwestern Kansas where some data are available. A test hole in the flood plain of the Cimarron River in southern Grant County, Kans. (McLaughlin, 1946, p. 134), penetrated 70 feet of alluvium. Inasmuch as the single test hole probably did not penetrate the thickest section of alluvium, it is reasonable to assume that the maximum thickness of alluvium in the Cimarron Valley in Baca County is at least 50 and perhaps as much as 75 feet. The thickness of alluvium in some of the other valleys having fairly well developed flood plains, such as Carrizo, Two Butte, and Bear Creek valleys, probably averages 10 to 20 feet and probably does not exceed 30 feet. The thickness in the smaller valleys probably does not exceed 20 feet.

Age.—The alluvium in the valleys of Baca County is younger than the terrace deposits, which were laid down at higher levels. Inasmuch as the highest terrace deposits of the Cimarron River contain fossils of late Pleistocene age, the age of the alluvium probably is Recent.

Water supply.—The availability of ground water in alluvium is dependent to a large extent on the size of the valley it occupies. In the larger valleys the alluvium is thicker, coarser, and better sorted and will yield adequate quantities of water for domestic and stock use. The alluvium of the Cimarron Valley would yield sufficient water for irrigation in many places and, where the alluvium is underlain by the Ogallala formation, moderate to large supplies of water can be obtained from wells tapping both the alluvium and the underlying Ogallala.

Small to moderate quantities of water can be obtained from the alluvium of the moderate-sized valleys having well-developed flood plains, such as the valleys of Two Butte, Carrizo, and Bear Creeks. Domestic and stock supplies of water can be obtained from shallow wells in most places on the flood plains of these valleys and, with proper test drilling, small irrigation supplies can be obtained in a few places from wells, sumps, or infiltration galleries. The alluvium in parts of these valleys, particularly along Carrizo Creek, has been deeply channeled and the water table lowered to the extent that the alluvium is largely drained. In these areas it generally is not possible to develop supplies of water larger than those required for domestic and stock use (fig. 52).

Supplies of water adequate for domestic and stock use can be obtained at shallow depths at some places from the alluvium along the smaller valleys. In those areas underlain by relatively impermeable rocks such as the Graneros, Greenhorn, Carlile, and Niobrara formations, it would be advisable to test for shallow water along the small draws and stream valleys before attempting to drill to the deeper aquifers. Adequate water supply in the

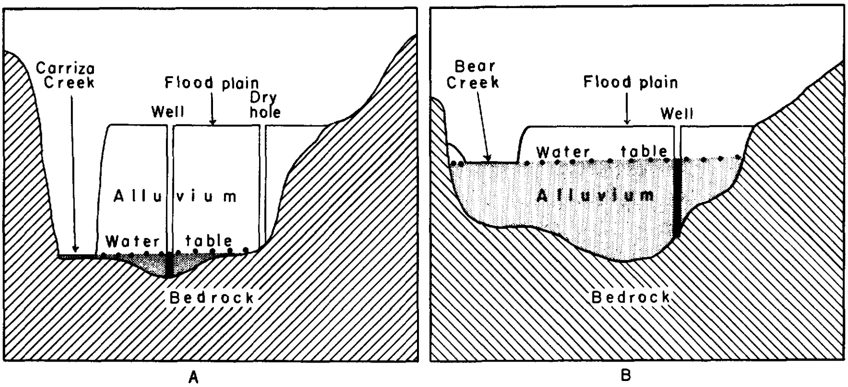

Figure 52. — *A*, Idealized cross section of Carrizo Creek valley showing how the deeply cut channel of Carrizo Creek has drained most of the ground water from the alluvium; *B*, Idealized cross section of Bear Creek valley showing how the shallow channel of Bear Creek has drained only a part of the ground water from the alluvium.

alluvium along the small valleys is dependent to a large extent on the geologic setting. Figure 53, for example, illustrates four geologic settings in which the alluvium of stream valleys in Baca County may contain water and two in which the alluvium may be dry. In *A* the alluvium overlies the relatively impermeable Graneros shale and water cannot move downward, and a perched water table exists; hence, well *a* obtains water from the alluvium. Where the alluvium overlies a permeable bedrock formation, as shown in *B* and *C*, the alluvium may be either dry or saturated. In *B* the Dakota sandstone is largely drained and only the lower part is saturated. Water entering the alluvium moves downward through the permeable sandstone to the water table. Well *b* is a dry hole but would produce water if deepened into the saturated part of the Dakota. The Dakota sandstone in *C* is more completely saturated and the water table slopes toward the valley from both sides. The water, therefore, moves from the Dakota into the alluvium and well *c* obtains water from saturated alluvium. The well would produce more water if drilled to the base of the Dakota sandstone. Where alluvium overlies a surficial deposit such as the Ogallala formation it may be either saturated or dry, as shown by *D*, *E*, and *F* in figure 53. In *D* the Ogallala is largely drained but the formation contains beds of relatively impermeable silt or clay beneath the alluvium which prevent or retard the downward movement of water and form a perched or local water table. Well *d* obtains water from saturated alluvium overlying the silt and clay. As the quantity of water in alluvium is rather limited, additional water could be obtained by drilling to the base of the Ogallala formation. Well *e* was dry because the alluvium

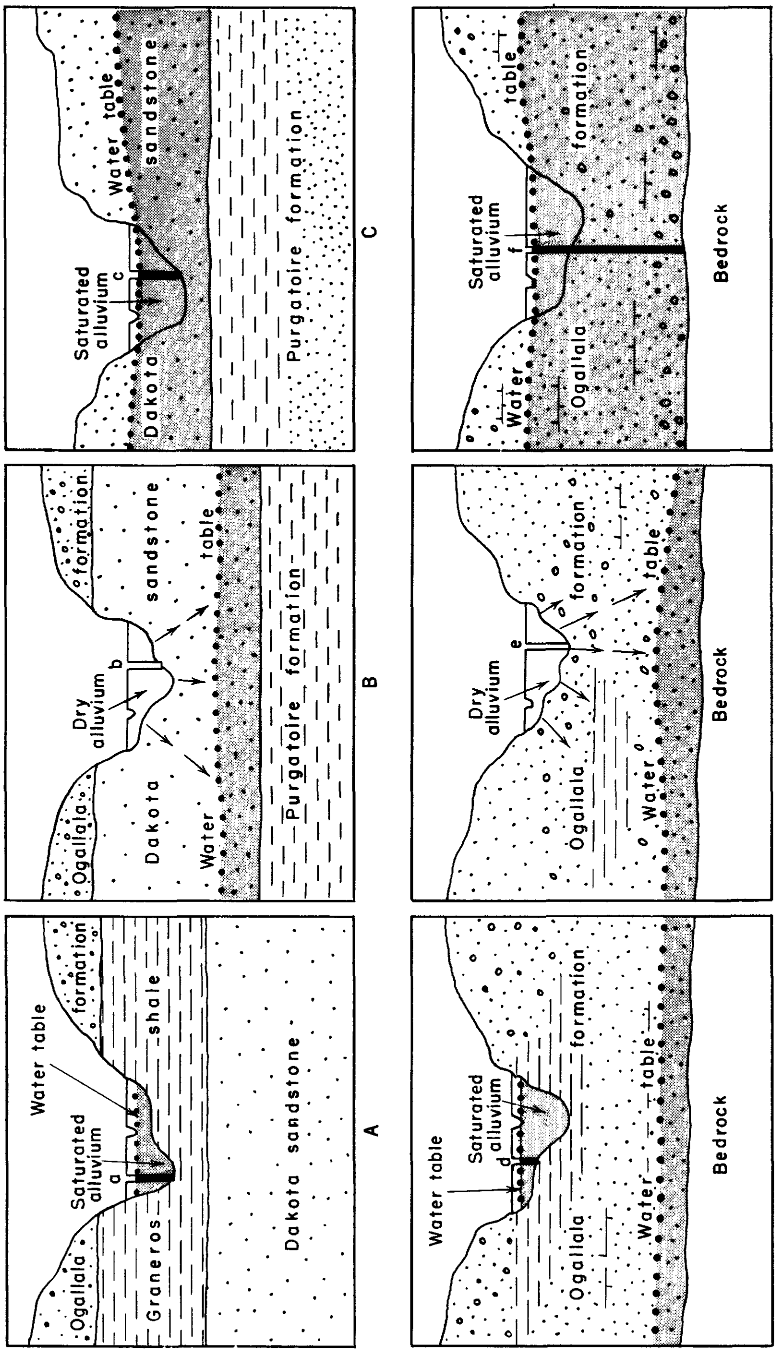

Figure 53.—Occurrences of ground water in the alluvium of small stream valleys.

overlies permeable materials in the Ogallala formation (fig. 53*E*); no perched water exists, as the water moves downward from the alluvium to the water table in the lower part of the Ogallala. In *F* the Ogallala is largely saturated as it is in the vicinity of the Cimarron River valley and the water table slopes toward the valley from both sides. Well *f* obtains a supply of water from both the alluvium and the Ogallala formation. Properly constructed wells in parts of the Cimarron River valley would obtain enough water from both formations for irrigation.

Care should be taken in prospecting for water in stream valleys, particularly if moderate to large quantities of water are being sought in the larger valleys. It is advisable to drill several test holes in order to locate the thickest and most permeable water-bearing materials before drilling an expensive large-diameter well. Unfortunately, many unsuccessful large-diameter wells have been drilled without previous test drilling or the test drilling was poorly planned. Beneath the flood plains of the larger valleys there generally is a buried channel that marks the position of the thickest and most permeable water-bearing materials. The buried channels necessarily lie beneath the flood plain and between the valley walls and generally have a much straighter course than the present meandering streams. The position of the buried channel is in no way related to the position of the present channel and its width and extent can be determined most easily by test drilling or, in some cases, by geophysical surveys. In many valleys the only places where large-capacity wells can be developed are along the buried channels where the saturated materials are thickest and most permeable. In these valleys, therefore, careful prospecting must be done in order to locate the buried channel at minimum cost.

Figure 54 shows schematically the correct and incorrect methods of test drilling. Illustration *A* in the figure is a plan of a stream valley showing the flood plain, the bedrock walls of the valley, the buried channel, the present channel, and two lines of test holes (*A-A'* and *B-B'*)—one parallel to the trend of the valley and one across the valley. The cross sections along the two lines are shown in *B* and *C*. Line *A-A'* was drilled parallel to the valley trend (up- and downstream) and, although 14 holes were drilled, the buried channel was not located. The alluvium became thicker in test holes 13 and 14 and if 4 additional test holes had been drilled at the same spacing the buried channel would have been encountered in the 18th test hole. If the buried channel is narrow, as it is in some valleys, and if the holes are not uniformly spaced, the channel might be missed even by many more test holes.

Lines of test holes should be drilled across the flood plain of a valley in order to locate the buried channel with a minimum of test drilling. Line *B-B'* was drilled across the flood plain at

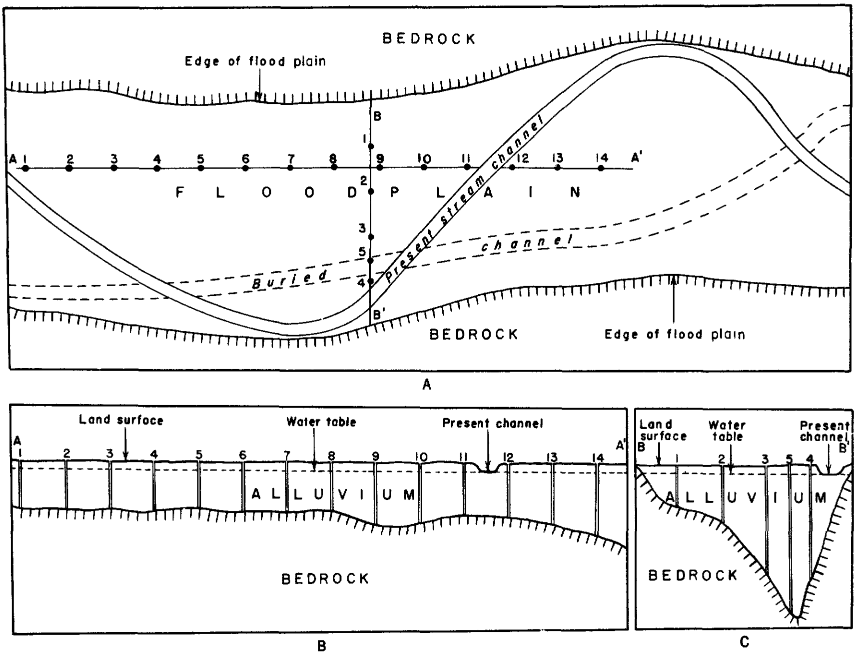

Figure 54. —Method of locating a buried channel in a stream valley by test drilling.

right angles to the trend of the valley. The spacing between the test holes and between the end holes (1 and 4) and the edges of the flood plain was uniform. The number and the spacing of test holes will depend upon the size of the valley. Four holes were drilled along line *B-B'* and the data plotted on a cross section such as the one shown in figure 54. The thickest water-bearing materials were encountered in test holes 3 and 4, so a fifth test hole (no. 5) was drilled between test holes 3 and 4 and located nearly the deepest part of the buried channel. The channel could be outlined more accurately, if necessary, by drilling additional closely spaced tests between test holes 3 and 5 and between 5 and 4.

DUNE SAND

A large part of the surface of the southern half of Baca County is underlain by dune sand of Recent age. The dune sand overlies principally the Ogallala formation but in parts of southeastern Baca County it overlies alluvium and terrace deposits. The sand is very fine to coarse grained and generally contains a small amount of clay. The material is poorly sorted and loose to friable and in some places is moderately well indurated because of a larger proportion of clay. The sand grains are principally subangular to subrounded fragments of quartz.

The distribution of dune sand could not be shown on plate 2 because of the small vertical scale. The distribution as shown on plate 1, was taken from detailed soil maps prepared by the Soil Conservation Service. The correlations between soils and dune sand were made by B. H. Williams, Senior Soil Correlator, Bureau of Plant Industry, Soils, and Agricultural Engineering of the U. S. Department of Agriculture. In a personal communication dated November 27, 1951, Mr. Williams states as follows:

--the only true dune-sand areas are the Tivoli soils---. This soil has developed, insofar as there is soil development, in loose eolian sands probably six to many feet thick.

The Springer soils---have developed almost if not entirely in sands. These would be the old dune areas that have lost considerable of their original height and sharp outline through erosion of the ridges and filling in of the troughs between the ridges. Some silt and clay has been incorporated in the sands in the process of reworking and some clay formed in the subsoil due to weathering.

The subsoils of the Springer soils are a sandy loam to sandy clay loam in texture but grade into loose sands or loamy sands at a depth of 4 or 5 feet in all places I have examined them in their substrata in other areas. The substrata sands are quite fresh and do not seem to be greatly different from the sands of adjoining or nearby young dunes.

It is my opinion that the Dalhart soils---are in part from old dune deposits and part from locally wind reworked sands over Tertiary sandstones or old Pleistocene deposits. In much of their distribution they occur in association with Springer soils but are more likely to occupy areas where eolian sands are thinnest and the underlying bedrock, consolidated or unconsolidated, is seldom more than 4 or 5 feet below the surface.

Since *some* Dalhart soils have relatively strong developed sandy clay loam to clay loam subsoils and much accumulated lime in their lower subsoils, I would surmise---*those areas* of the Dalhart soils to be developed from very old dune deposits that were subsequently eroded down to near the pre-dune land surface.

The topography of the dune-sand areas is dependent upon the stage of erosion of the sand dunes. In some areas, particularly on the south side of the Cimarron River, there is a typical dune-sand topography wherein the sand dunes generally are grass-covered moderately steep irregular hills between which are small valleys or undrained basins. In other areas the dune-sand topography comprises broad, subdued swells and swales. The soils in these areas are heavier and are cultivated extensively.

The thickness of the dune sand in Baca County is not known but it may be as much as 50 feet thick south of the Cimarron River where the dunes are well developed. In areas where the dunes have reached the old-age stage of erosion the dune sand may be only a few feet thick.

The dune sand in Baca County lies above the water table and, therefore, yields no water to wells; however, it forms ideal catchment areas for rainfall and, hence, facilitates the recharge of underlying formations.

RECORDS OF WELLS AND SPRINGS

Information pertaining to wells and springs in Baca County is tabulated on the following pages (table 9). The numbers in the first column correspond to well numbers on the map (pl. 1) and in the table of analyses (table 6). The numbers in the first column that are in parentheses indicate wells and springs from which samples of water were taken for analysis (table 6).

Table 9.—*Records of wells and*

Well number: Number in parenthesis indicates that analysis of water is given in Table 6.
Type of supply: DD, dug and drilled well; Dr, drilled well; Du, dug well; Sp, spring.
Depth: Reported depths below land surface are given in feet; measured depths are given in feet and tenths below measuring points.
Type of casing: C, concrete; GI, galvanized iron; I, iron; N, none; R, rock.
Method of lift: C, horizontal centrifugal; Cy, cylinder; F, natural flow; N, none; T, turbine.

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	T. 28 S., R. 41 W.							
(1)	SW¼ SW¼ sec. 8	J. P. Pearson	Dr	181.7	6	GI	Sandstone	Dakota ss.
2	NW¼ NW¼ sec. 33	Albert Peachy	Dr	98.0	5½		Sand	Ogallala fm.
	T. 28 S., R. 42 W.							
3	SW¼ SE¼ sec. 2	J. J. Asher	Dr	173.6	6	GI	Sandstone	Dakota
(4)	NW¼ NW¼ sec. 4	Frank Holmes	Dr	137.3	6	GI	Sand	Ogallala fm.
5	NW¼ SW¼ sec. 6	John Hardin	Dr	162.7	6	GI	do	do
6	NW¼ SW¼ sec. 20	F. L. Wells	Dr	144.7	6	GI	Sandstone	Dakota ss.
7	SW¼ NW¼ sec. 26	Ray Burns	Dr	197.9	6	GI	do	do
	T. 28 S., R. 43 W.							
(8)	SE¼ SW¼ sec. 9	M. R. Gorley	Dr	172.5	6	GI	Sand	Ogallala
9	SE¼ NE¼ sec. 32	J. P. Sullivan	Dr	144.8	6	GI	do	do
(10)	SE¼ SW¼ sec. 34	Amos Bland	Dr	425	....	......	Sandstone	Cheyenne ss.
11	SW¼ SE¼ sec. 34	do	Dr	100.0	6	GI	Sand	Ogallala fm.
12	SW¼ NW¼ sec. 35	M. R. Gorley	Dr	......	6	I	Sandstone	Cheyenne ss. mem.
	T. 28 S., R. 44 W.							
13	NW¼ SW¼ sec. 3	B. G. and Doris M. Jarns.	Dr	162.5	6	GI	Sand	Ogallala fm.
14	SW¼ SE¼ sec. 12	J. W. Baughman Farms Co.	Dr	226.5	6	GI	do	do
15	NW¼ NW¼ sec. 19	E. S. Benson	Dr	198.7	5	I	Sandstone	Dakota ss.
16	NE¼ NE¼ sec. 21	Bordners brothers	Dr	182.7	6	GI	do	do
(17)	SE¼ SE¼ sec. 26	D. K. Staples	Dr	196.6	6	GI	do	do
	T. 28 S., R. 45 W.							
(18)	NE¼ NE¼ sec. 1	A. Peterson	Dr	199.3	6	GI	do	do
19	SE¼ NW¼ sec. 3	Two Buttes Water Association.	Dr	243.5	6	GI	do	do

springs in Baca County, Colo.

Type of power; B, butane engine; D, Diesel engine; E, electric motor; G, gasoline engine; H, hand-operated; NG, natural-gas engine; T, tractor; W, windmill.
Use of water: D, domestic; I, irrigation; In, industrial; N, not being used; O, observation; P, public water supply; S, stock.
Measured depths to water level are given in feet, tenths, and hundredths; reported depths to wa-water level are given in feet.

Method of lift	Use of water	Measuring point: Description	Measuring point: Distance above or below (-) land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Cy,G, W	D,S	Top of 3-inch pipe, north side.	1.3	3,684.7	178.62	8-2-47	
N	N	Top of casing southwest side.	-1.0	3,681.0	93.93	8-1-39	Abandoned, formerly a domestic and stock well.
Cy, W	D,S	Top of clamp, east side.	.2	3,740.4	149.07	8-2-47	
Cy, W	D,S	Top of tin cover,... west side.	1.1	3,795.4	132.64	8-2-47	
Cy, W	D,S	Top of clamp,...... northwest side.	.4	3,865.1	158.80	8-3-47	
Cy, W	D,S	Bottom of clamp.... south side.	.4	3,842.9	106.22	8-3-47	
Cy, W	D,S	Top of wooden support, west side.	.9	3,757.1	194.97	8-2-47	
Cy, W	D,S	Bottom of clamp.... north side.	.1	3,951.8	166.98	8-3-47	
Cy	N	Top of clamp........ north side.	0	3,952.9	126.80	8-3-47	Abandoned, formerly a domestic and stock well. Measured flow, 2.
F	D,S	Top of discharge.... pipe.	....	3,906.8	....	....	
Cy,H	D,S	Top of casing,....... south side.	.1	3,899.8	80.53	7-30-47	
F	S	....	....	3,867.9	....	....	Measured flow, 1¼
Cy	N	Bottom of pipe....... joint, west side.	0	4,080.3	140.19	8-3-47	Abandoned, formerly a domestic and stock well.
Cy	N	Top of clamp,...... west side.	0	4,032.2	192.77	8-3-47	Do.
Cy, W	S	Top of casing,...... west side.	.9	4,144.9	165.09	8-4-47	
Cy, W	D,S	Top of clamp,....... east side.	.9	4,082.9	168.03	8-3-47	Water rose above aquifer.
Cy, W	D,S	Top of pipe clamp, north side.	.8	4,028.4	141.84	8-3-47	
Cy, W, G	D,S	Bottom of clamp.... east side.	.8	4,169.0	190.92	8-4-47	
N	N	Top of casing,...... west side.	0	4,223.8	163.46	8-4-47	Abandoned, formerly a domestic and stock well.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (feet)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
20	NE¼NE¼sec. 16	C. Churchill.....	Dr	371	6	I	Sandstone	Cheyenne ss. mem.
21	SE¼SE¼sec. 32	C. R. Owsley...	Dr	70.5	6	GI	do	Dakota....... ss.
22	NE¼ NE¼ sec. 35	Mr. Truman.....	Dr	199.5	6	GI	do	do
	T. 28 S., R. 46 W.							
(23)	SW¼ NE¼ sec. 1	R. C. Best.......	Dr	83.6	6	GI	do	Entrada....... ss.
24	NE¼ SE¼ sec. 13	T. E. Kitzmiller	Dr	176.5	6	GI	Sandstone	Dakota........
25	SW¼ SE¼ sec. 16	do	Dr	141.6	6	GI	do	do
26	SW¼ SE¼sec. 34	Glen Murphy.....	Dr	90.5	....	......	do	do
	T. 28 S., R. 47 W.							
(27)	SE¼ NE¼sec. 17	N. E. Arbuthnot	Dr	264.4	6	I	do	Cheyenne.... ss. mem.
28	NW¼ SW¼ sec. 24	J. R. Jones.......	Dr	140.5	5	I	do	Dakota....... ss.
29	SE¼ SE¼ sec. 32	D. R. Thompson	Dr	133.5	6	......	do	do
30	SW¼SW¼ sec. 35	Floyd Chenoweth	Dr	123.5	6	GI	do	do
	T. 28 S., R. 48 W.							
31	NW¼ SW¼ sec. 4	L. Taylor.........	Dr	25.8	6	GI	Sand and gravel.	Alluvium.....
32	NE¼ SW¼ sec. 11	J. T. McEndree	Du	27.9	....	......	do	do
	T. 28 S., R. 49 W.							
33	SW¼ NW¼sec. 8	A. S. Curry......	Dr	239.3	6	GI	Sandstone	Dakota....... ss.
34	NW¼ SW¼sec. 12	Bert Chitwood...	Du	25	36	N	Sand and gravel.	Alluvium.....
35	SE¼ SW¼ sec. 19	A. T. & S. F....... Railway Co.	Dr	276	6	I	Sandstone	Dakota........ ss.
(36)	NW¼ SE¼ sec. 25	J. T. McEndree	Dr	42	5	I	Limestone	Lincoln....... ls. mem.
37	SW¼ NW¼ sec. 30	Mr. Lancaster....	Dr	161	5	I	Sandstone	Dakota........ ss.
38	NE¼ NW¼sec. 34	J. T. McEndree	Dr	132.4	6	I	do	do
	T. 28 S., R. 50 W.							
39	NE¼ NW¼ sec. 11	Leslie Van Camp	Dr	83.6	6	I	do	do
(40)	SW¼ NE¼sec. 17	E. B.............. Baumgardner.	Sp	......	....	......	do	do
41	NE¼SW¼sec. 25	Ted Barker.......	Dr	86.3	6	GI	do	do

in Baca County, Colo.—Continued

Method of lift	Use of water	Measuring point: Description	Measuring point: Distance above or below (-) land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Cy, W	D, S	Top of pipe clamp, south side.	2.3	4,241.6	225.23	8-4-47	First water at 217 feet. Second water encountered at 325 feet and rose about 100 feet.
N	N	Top of pipe, south side.	.9	4,157.4	56.38	8-4-47	Abandoned, formerly a domestic and stock well.
Cy, G	S	Top of tin cover, east side.	.4	4,162.5	177.46	8-4-47	
Cy, W	D, S	Top of hole in clamp, east side.	1.0	....	57.86	8-4-47	Low yield.
Cy, G	D, S	Top of pipe clamp, north side.	-2.7	4,294.3	167.18	8-4-47	
Cy	N	Top of pipe clamp, northeast side.	.3	4,363.7	140.58	8-17-47	Unused domestic and stock well.
Cy, W	S	Top of pipe clamp, northwest side.	.3	....	82.34	8-4-47	
Cy, W	D, S	Top of casing, east side.	.4	4,528.7	168.70	8-17-47	
Cy	N	Top of pipe clamp, west side.	1.6	4,447.3	124.03	8-17-47	Abandoned, formerly a domestic and stock well.
Cy, W	N	Base of pipe clamp, north side.	0	4,498.8	110.84	8-11-47	Do.
Cy, W	D, S	Top of pipe clamp, southwest side.	.6	4,465.9	112.73	9-1-47	
Cy, W	S	Top of casing, west side.	.9	....	19.26	8-26-47	
N	N	Top of pipe clamp, north side.	.3	....	18.99	8-26-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Top of pipe clamp, south side.	1.2	4,632.4	234.69	8-27-47	High iron content.
Cy, W	D, S	Top of barrel, west side.	3.8	....	16.12	8-26-47	
Cy, W	S	Land surface	0	4,741.7	210.5	2-13-48	Log 58.
Cy, W	D, S	do	0	....	30	....	
Cy, W	D, S	do	....	....	120	....	Water rose above aquifer.
Cy, W	S	Top of casing, south side.	.4	4,648.1	116.40	8-26-47	High iron content.
Cy, G	S	Top of iron cover, northwest side.	2.9	....	68.56	8-27-47	
F	D, S	....	....	....	....	....	Two or three openings. Estimated yield, 1.
N	N	Top of 2-inch tee, south side	4.1	4,644.1	84.44	8-27-47	Abandoned, formerly a domestic and stock well. High iron content.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
42	NE¼ SW¼ sec. 30	Ingle Cattle Co..	Dr	46.5	5	I	Sand and gravel.	Alluvium...
43	NE¼ SW¼ sec. 32	do	Dr	133.7	6	GI	Sandstone	Cheyenne... ss. mem.
	T. 29 S., R. 41 W.							
44	SW¼ SE¼ sec. 8	O. H. Vail.......	Dr	106.7	6	GI	do	Dakota....... ss.
45	SE¼ NE¼ sec. 19	J. F. Whisenant	Dr	108.7	6	GI	do	do
	T. 29 S., R. 42 W.							
46	SW¼ NW¼ sec. 7	G. W. Ryan......	Dr	131.0	....	....	do	do
47	SE¼ NE¼ sec. 10	Harold Walker...	Dr	26.1	5	GI	do	do
(48)	SW¼ NW¼ sec. 11	do	Dr	26	5	GI	do	do
49	SE¼ NE¼ sec. 16	L. M. Brown.....	Dr	346	5	I	do	Cheyenne... ss. mem.
50	SW¼ NW¼ sec. 17	do	Dr	375	6	I	do	do
51	SW¼ SW¼ sec. 18	do	Dr	294.4	6	I	do	do
52	SW¼ NW¼ sec. 26	A. J. Collingwood.	Dr	103.0	6	GI	do	Dakota....... ss.
53	NW¼ NW¼ sec. 32	L. M. Brown.....	Dr	....	6	I	do	do
54	SW¼ SW¼ sec. 35	Colby brothers...	Dr	265	....	....	do	Cheyenne... ss. mem.
	T. 29 S., R. 43 W.							
55	NE¼ NE¼ sec. 1	R. B. Holt........	Dr	....	6	I	do	do
56	NW¼ SE¼ sec. 16	James Thompson	Dr	400	6	I	do	do
57	SW¼ SE¼ sec. 16	do	Dr	400	6	I	do	do
58	do	do	Dr	400	6	I	do	do
59	SE¼ SE¼ sec. 16	do	Dr	435	4	I	do	do
60	NW¼ NE¼ sec. 17	L. W. Bailey.....	Dr	......	12	I	do	do
61	NW¼ SE¼ sec. 19	Felix Mondell....	Dr	374.6	6	I	do	do
62	NW¼ SW¼ sec. 22	James Thompson	Dr	....	....	....	do	do
(63)	SW¼ SW¼ sec. 22	do	Dr	....	6	I	do	do
64	SW¼ SE¼ sec. 22	R. R. Rutherford	Dr	....	5	I	do	do
65	NW¼ NW¼ sec. 23	James Thompson	Dr	550	6	I	do	do

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level below measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute drawdown in feet) (17)
Cy, W	S	Top of casing, east side.	1.8	....	23.70	9-4-47	
Cy, W	S	Bottom of 2-inch pipe joint, west side.	2.5	....	104.22	9-4-47	
N	N	Top of casing, south side.	0	3,677.3	83.96	8-2-47	Abandoned, formerly a domestic and stock well.
N	N	Top of casing, east side.	.2	3,675.9	103.15	8-2-47	Abandoned, formerly a stock well.
Cy, W	D, S	Bottom of clamp, east side.	.4	3,855.4	93.29	8-3-47	
Cy, W	N	Top of casing, southeast side.	0	3,702.2	18.93	6-1-47	Unused domestic and stock well.
Cy, W	S	Top of casing, south side.	.8	....	21.92	6-1-47	
Cy, G	S	Top of pipe clamp, south side.	.9	3,783.3	66.80	7-30-47	Encountered Cheyenne at 248 feet.
Cy, W	N	Top of casing, north side.	.1	3,822.8	83.79	7-28-47	Unused stock well.
N	N	Top of casing, east side.	.7	3,844.9	11.46	7-29-47	To be used as a stock well.
Cy, H, G	D, S	Top of casing, north side.	0	3,758.4	57.63	7-28-47	
N	N	Top of casing, east side.	.5	3,813.4	21.33	7-29-47	Do.
Cy, W	D, S	Bottom of pump outlet, west side.	2.6	3,720.2	14.85	7-25-47	
F	N, O	Top of casing, northeast side.	.5	3,848.0	.13	7-29-47	Flows intermittently. Abandoned, formerly a domestic and stock well.
F	S	Top of 3-inch elbow	.5	3,926.6	....	5-27-49	Pressure head, 15.46 feet above measuring point. Measured flow, 59.9
F	N	....	....	....	....	7-30-47	Abandoned, formerly an irrigation well. Meas- flow, ½
F	N	....	....	....	....	....	Abandoned, formerly an irrigation well.
F	D, S	Top of 4-inch casing.	3.9	3,919.1	....	5-22-47	Pressure head, 16.92 feet above measuring point. Measured flow, 37.3.
T, G	N	Top of flange inside discharge.	1.0	3,953.7	11.48	7-31-47	Unused irrigation well. Reported yield, 750; reported drawdown 70.
Cy, W	S	Top of pipe clamp south side	.6	3,957.7	16.51	7-31-47	
F	N	....	....	....	....	....	Abandoned, formerly an irrigation well.
F	D, S, I	....	....	3,893.1	....	7-30-47	Measured flow, 3.9.
F	S	....	....	....	....	....	Measured flow, 13.
Cy, H	N	Top of casing, east side.	0	3,895.7	18.07	7-29-47	Abandoned, formerly a domestic and stock well.

Tabl .—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
66	SW¼ SW¼ sec. 25	Mrs. Grover Mondell.	Dr	400	....	......	Sandstone	Cheyenne ss. mem.
67	NE¼ NE¼ sec. 26	J. W. Baughman Farms Co.	Dr	491.5	6½	I	do	do
68	NW¼ NW¼ sec. 26	Dr. J. C. Whitmer.	Dr	....	....	....	do	do
69	SW¼ SW¼ sec. 26	Marvin Merrill	Dr	500	10	I	do	do
70	NW¼ NE¼ sec. 27	R. R. Rutherford.	Dr	471	12	I	do	do
71	NW¼ NW¼ sec. 27	James Crill	Dr	283	5	I	do	do
72	SW¼ NW¼ sec. 28	Felix Mondell	Dr	400	5	I	do	do
73	NW¼ SE¼ sec. 28	do	Dr	226	4½	I	do	do
74	SW¼ SE¼ sec. 31	H. McMurtry	Dr	306	5	I	do	do
75	NW¼ NW¼ sec. 34	Osa Packard	Dr	350	4½	I	do	do
76	NW¼ SW¼ sec. 34	R. B. Holt	Dr	370	....	......	do	do
77	SW¼ SW¼ sec. 35	M. E. Smith	Dr	370	....	......	do	do
78	SE¼ NE¼ sec. 36	Wilbur Tolbert	Dr	416	4	I	do	do
	T. 29 S., R. 44 W.							
79	NE¼ NE¼ sec. 5	R. Haddock	Dr	148.6	6	GI	do	Dakota ss.
(80)	NE¼ NW¼ sec. 5	W. H. Myers	Dr	200	6	......	do	do
(81)	NE¼ SW¼ sec. 27	O. P. Scobee	Dr	190	5½	I	do	Cheyenne ss. mem.
82	NE¼ SE¼ sec. 28	Warner Mathes	Dr	200	6	I	do	do
83	SW¼ NE¼ sec. 29	R. R. Rutherford	Dr	208	20	I	do	do
84	SE¼ SE¼ sec. 31	Arthur Walton	Dr	195.1	6	I	Sand	Ogallala fm.
85	NE¼ NE¼ sec. 35	Herman Oakes	Dr	250	5	I	Sandstone	Cheyenne ss. mem.
	T. 29 S., R. 45 W.							
86	NE¼ NW¼ sec. 12	J. W. Baughman Farms Co.	Dr	155.7	6	GI	do	Dakota ss.

in Baca County, Colo. — Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level below measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute drawdown in feet) (17)
F	N	....	....	....	....	....	Abandoned, formerly a domestic and stock well. Reported flow, 5.
F	S	Top of casing........	6.1	3,876.8	....	7-18-47	Well did not flow until recently.
F	N	....	....	....	....	....	Abandoned, formerly a domestic and stock well. Very small flow.
F	S	....	....	....	....	....	Water in Dakota between 40 and 100 feet. Reported original flow, 300.
F	N	....	....	....	....	....	Abandoned, formerly an irrigation well. Reported yield after several hours of pumping, 400.
F	D,S	....	....	....	....	....	Estimated flow, 4.
F	S	Land surface..........	....	3,906.5	....	....	Measured flow, 2.
F	D,S	do	....	....	....	....	First water at 85 feet. Measured flow, 28.
Cy,W	D,S	Top of casing........	.3	3,946.3	8.70	11-21-49	
F	D,S, I	do	.2	3,833.5	....	9-8-47	Pressure head, 66.43 feet above measuring point. Measured flow, 33.5.
F	N	Land surface..........	....	....	....	....	Abandoned, formerly a domestic and stock well. Very small flow, Cheyenne at 200 feet.
F	N	do	....	3,794.7	....	....	Abandoned, formerly a domestic and stock well. Measured flow, 1.
F	N	do	....	....	....	....	Abandoned, formerly a domestic and stock well. Measured flow, 12.
Cy,W	N	Bottom of pipe....... clamp, west side.	.3	4,093.2	130.37	8-3-47	Abandoned, formerly a domestic and stock well.
Cy,W	D,S	Land surface..........	....	....	175	....	
F	D,S I	do	....	3,969.2	....	....	Reported pressure head, 1.5 feet above land surface; reported flow 20.
C,G	D,S I	Top of 5-gallon can, east side.	.2	3,947.3	1.44	7-27-47	Reported flow, when drilled, 4.
T,D	I	Base of pump........	....	....	26	....	Yield, 3,000; drawdown, 71.
N	N	Top of casing,....... east side.	0	4,084.1	190.77	8-6-47	Abandoned, formerly a domestic and stock well. Estimated flow, 40.
F	D,S, I	Land surface..........	....	....	....	....	Estimated flow, 40.
Cy,H	N	Bottom of pump base, northeast side.	.5	4,131.5	142.48	8-4-47	Abandoned, formerly a domestic and stock well.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(87)	SW¼ SW¼ sec. 15	R. R. Rutherford	Dr	100+	5	I	Sandstone	Cheyenne ss. mem. (?).
88	SW¼ SW¼ sec. 18	J. N. Stalnaker	Dr	188.6	6	GI	do	Dakota....... ss.
89	SW¼ SW¼ sec. 22	R. R. Rutherford	Dr	350	24	N	do	Cheyenne.... ss. mem.
90	do	do	Dr	1,400	8½	I	do	Dakota....... ss.
91	SW¼ SW¼ sec. 35	W. R. Crawford	Dr	181.8	6	GI	Sand......	Ogallala..... fm.
	T. 29 S., R. 46 W.							
(92)	NW¼ NW¼ sec. 5	Ada Williams....	Dr	112.3	5	I	Sandstone	Dakota....... ss.
93	SE¼ NE¼ sec. 18	Louisa Morris....	Dr	78.4	6	GI	do	do
94	SW¼ SW¼ sec. 27	School district...	Dr	81	6	GI	do	do
	T. 29 S., R. 47 W.							
95	NW¼ NW¼ sec. 19	A. W. Cook.....	Dr	234	6	GI	do	do
96	SW¼ SW¼ sec. 24	M. J. Kauffman	Dr	80.9	6	GI	do	do
(97)	SE¼ NE¼ sec. 31	Clarence Harden	Dr	180.5	6	I	do	do
	T. 29 S., R. 48 W.							
98	NW¼ NW¼ sec. 3	J. T. McEndree..	Dr	280	....	......	do	do
99	NW¼ SW¼ sec. 19	M. R. Namber...	Dr	266.5	6	......	do	do
100	NW¼ NW¼ sec. 28	A. T. & S. F.... Railway Co.	Dr	401	14, 10	I	do	Dakota ss.... Cheyenne ss. mem.
101	SE¼ NE¼ sec. 34	W. H. Bamber....	Dr	140.2	6	GI	do	Dakota ss.
	T. 29 S., R. 49 W.							
102	SE¼ SW¼ sec. 6	S. Holloway and C. Colwick.	Dr	149.0	6	I	do	do
103	SE¼ NE¼ sec. 9	Ervin Chenoweth	Du	40	....	R	Sand and gravel.	Alluvium
(104)	SE¼ NE¼ sec. 12	Floyd Chenoweth	Dr	219	6	I	Sandstone	Dakota....... ss.
105	SE¼ SE¼ sec. 28	J. L. Whitaker...	Dr	189.0	6	I	do	do
	T. 29 S., R. 50 W.							
106	NW¼ NE¼ sec. 3	Foster.............. Kirkpatrick.	Dr	41	5	I	do	do
107	SE¼ NE¼ sec. 18	I. V. Record.....	Du	15	36	R	do	do

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level below measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute drawdown in feet) (17)
Cy, W	S	Top of steel plate, east side.	0.9	4,172.0	47.84	8-11-47	Unable to measure total depth.
Cy, W	S	Top of wooden...... cover, west side.	.3	4,257.0	62.60	8-11-47	
N	N	Land surface.........	0	4,135.1	31.62	8-11-47	
N	N	Top of casing,...... west side.	2.3	4,137.0	19.47	8-11-47	
Cy, W	D, S	Top of wooden supports, south side.	.5	4,163.3	158.56	8-7-47	
Cy, W	D, S	Top of casing,...... north side.	3.7	4,389.3	100.27	8-4-47	
N	N, O	Top of casing,...... east side.	-.3	4,350.7	45.22	8-4-47	Abandoned, formerly a domestic and stock well.
Cy, W, H	D	Top of casing,...... south side.	.5	4,338.5	55.96	8-11-47	School well.
Cy, W	S	Top of casing,...... east side.	.5	4,527.8	130	....	
Cy	N	Top of clamp,...... north side.	.7	4,451.4	72.38	8-17-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Top of wooden....... clamp, northwest side.	.5	4,553.6	102.06	8-14-47	
Cy, G	N	Top of hole in pipe clamp, north side.	.1	4,675.0	184.30	8-12-47	Unused stock well.
Cy, W	N	Top of 6-inch hole in concrete base, northwest side.	.4	4,754.0	130.96	8-11-47	Do.
T, D	In	Land surface.........	0	4,676.9	135	....	Encountered Cheyenne at 347 feet. Reported yield, 75; drawdown, 58. Log 78.
N	N	Top of casing,...... east side.	0	4,578.0	89.67	8-12-47	Abandoned, formerly a domestic and stock well.
Cy, W, G	S	Top of pipe clamp, east side.	2.6	4,710.0	135	....	Yields carbon dioxide.
Cy, W	D, S	Top of wooden...... platform, east. side.	.8	....	36.56	8-26-47	
Cy, W	S	Top of casing,...... northeast side.	1.9	4,668.0	151.27	8-27-47	High iron content
Cy	N	Top of casing,...... south side.	.2	....	186.93	8-26-47	Abandoned, formerly a stock well.
Cy, W	S	Top of hole in....... pipe clamp, east side.	2.1	....	19.91	8-18-47	
N	N	Top of stone wall, north corner.	2.0	....	7.8	9-4-47	Abandoned, formerly a domestic well.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
108	SE¼ SW¼ sec. 24	J. C. Murray.....	Dr	40.7	4½	I	Sandstone	Dakota....... ss.
109	SW¼ SE¼ sec. 31	Ingle Cattle Co.	Dr	92	5	I	Limestone	Dockum...... group (?)
110	SE¼ SE¼ sec. 33	School district...	Dr	34.4	6	GI	Sandstone	Dakota....... ss.
	T. 30 S., R. 41 W.							
(111)	NW¼ NW¼ sec. 7	Earl Mathews.....	Dr	78.2	6	GI	do	do
112	NW¼ NE¼ sec. 9	C. M. Harrison..	Dr	164.0	6	......	do	do
113	SW¼ NW¼ sec. 19	E. White..........	Dr	99.7	6	GI	do	do
114	SW¼ SW¼ sec. 32	George Bohl......	Dr	45.7	6	I	do	do
(115)	SW¼ SW¼ sec. 33	Oral Hedrick.....	Dr	36.3	6	GI	do	do
	T. 30 S., R. 42 W.							
116	SE¼ NW¼ sec. 4	Felix Mondell....	Dr	300	4	I	do	Cheyenne.... ss. mem.
(117)	NW¼ SW¼ sec. 4	do	Dr	141	6	I	do	Dakota....... ss. (?)
118	NW¼ NE¼ sec. 8	do	Dr	....	5	I	do	Cheyenne.... ss. mem.
119	NW¼ SW¼ sec. 18	do	Dr	500	8	I	do	do
120	NW¼ NW¼ sec. 27	H. O. West.......	Dr	99.4	6	GI	do	Dakota....... ss.
121	SW¼ NW¼ sec. 32	C. W. Radford..	Dr	113.7	6	GI	do	do
122	SE¼ SW¼ sec. 35	W. A............. Greathouse.	......	82.2	....	......	do	do
	T. 30 S., R. 43 W.							
123	NE¼ NE¼ sec. 4	Johnson brothers.	Dr	400	....	......	do	Cheyenne.... ss. mem.
124	SW¼ NE¼ sec. 6	H. McMurtry.....	Dr	165	6	I	do	do
125	SW¼ SW¼ sec. 8	Wesley Piper......	Dr	70.6	6	GI	do	Dakota....... ss.
126	NE¼ NE¼ sec. 9	Guy S. Speakman	Dr	400	4½	I	do	Cheyenne.... ss. mem.
127	SE¼ NE¼ sec. 12	Wilbur Tolbert...	Dr	345	4	I	do	do
128	NW¼ SE¼ sec. 12	do	Dr	400	6	I	do	do
129	do	do	Dr	345	12	I	do	do

in Baca County, Colo.—Continued

Method of lift	Use of water	Measuring point			Depth to water level below measuring point (feet)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
		Description	Distance above or below (-) land surface (feet)	Height above mean sea level (feet)			
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
N	N	Top of casing, north side.	0	...	28.99	9-4-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Land surface	0	...	84	...	
Cy, H	D	Top of casing, south side.	.6	4,954	22.25	8-18-47	School well.
Cy, W	D, S	Top of clamp, north side.	.6	3,699.1	56.77	8-2-47	
Cy, W	N	do	2	3,679.0	143.19	8-29-39	Abandoned, formerly a domestic well.
N	N	Top of casing, west side.	.7	3,716.5	70.75	8-2-47	Abandoned, formerly a domestic and stock well.
Cy, W	D	Top of iron hub, north side.	1.5	3,679.1	28.01	7-9-47	
Cy, W	D	Top of casing, south side.	1.0	3,669.2	29.47	7-7-47	
F	D, S, I	...	...	...	...	...	Reported flow, 200.
F	D, S, I	Top of tee	0	3,718.1	...	8-29-47	Pressure head, 30.78 feet above measuring point. Measured flow, 63.
F	S	...	...	3,767.6	...	...	Estimated flow, 1.
N	N	Top of casing, east side.	3.3	3,855.7	27.25	7-7-47	Abandoned, formerly a domestic and stock well.
N	N	Top of casing, south side.	0	3,786.7	71.26	8-2-47	Do.
Cy, W	D, S	Top of tin cover, east side.	.1	3,842.4	91.55	7-16-47	
Cy, W	D, S	Top of wooden pipe clamp, north side.	1.2	3,762.4	31.28	7-10-47	
F	D, S	...	...	...	...	...	Measured flow, 1.
F	S	Top of casing, southwest side.	.8	3,922.1	...	8-27-47	Pressure head, 12.62 feet above measuring point. Measured flow, 22.
Cy, W	D, S	Top of tin cover, northeast side.	.2	3,951.2	53.71	7-27-47	
F	D, S	...	...	3,905.3	...	...	Measured flow, 1. First water encountered at 80 feet.
F	D, S	...	...	...	...	...	Measured flow, 15.
F	D, I	...	...	...	...	...	Estimated flow, 1. The use of this well is largely replaced by adjacent well.
F	D, S, I	Top of casing, north side.	0	3,802.9	...	9-6-47	Pressure head, 23.10 feet above measuring point. Measured flow, 42. First water at 33 feet.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
130	SW¼ NE¼ sec. 21	Herbert Holt......	Dr	475	6	I	Sandstone	Cheyenne... ss. mem.
131	NE¼ NE¼ sec. 26	R. B. Holt........	Dr	126.7	....	......	do	Dakota...... ss.
132	NW¼ NW¼ sec. 30	L. W. Hebberd..	Dr	113	4	I	do	do
133	NW¼ SE¼ sec. 32	A. T. & S. F.... Railway Co.	Dr	266	14	I	do	Cheyenne... ss. mem.
(134)	SW¼ SE¼ sec. 32	City of Walsh....	Dr	270	....	......	do	do
135	NE¼ SE¼ sec. 35	A. F. Loelsh......	Dr	169.3	6	I	do	Cheyenne ss. mem. (?).
	T. 30 S., R. 44 W.							
136	SW¼ SW¼ sec. 8	R. E. Alfrey......	Dr	400	4	I	do	Cheyenne... ss. mem.
(137)	NE¼ SE¼ sec. 21	Ben Hermes.......	Dr	98.9	6	GI	do	Dakota ss.
138	SW¼ SW¼ sec. 35	J. C. Trean......	Dr	120.2	6	GI	do	do
	T. 30 S., R. 45 W.							
139	SW¼ SE¼ sec. 14	B. V. Hanna......	Dr	115	6	GI	do	do
140	SE¼ SE¼ sec. 17	R. V. Thompson	Dr	177.2	6	GI	do	do
141	SE¼ SE¼ sec. 30	Horace Ward.....	Dr	189.5	6	GI	do	Cheyenne... ss. mem.
142	SE¼ NW¼ sec. 32	Deat Rutherford..	Dr	129.6	6	GI	do	Dakota....... ss.
143	SW¼ SW¼ sec. 34	C. J. Alfrey......	Dr	136.7	6	GI	Sandstone and sand	Dakota and Ogallala fm.
	T. 30 S., R. 46 W.							
144	SW¼ SW¼ sec. 5	R. K. Knight.....	Dr	128.5	6	GI	Sandstone	Dakota.......
145	SW¼ SW¼ sec. 12	J. W. Baughman Farms Co.	Dr	192.6	6	GI	do	do
146	SW¼ NW¼ sec. 17	Maude A. Rarex	Du	14.7	120	R	Sand and.. gravel.	Alluvium....
147	NE¼ SE¼ sec. 25	Horace Ward......	Dr	185.6	6	GI	Sandstone	Cheyenne.... ss. mem.
148	SW¼ SW¼ sec. 29	A. T. & S. F....... Railway Co.	Dr	80	6	I	do	Dakota....... ss.
149	NE¼ SE¼ sec. 30	City of............. Springfield.	Dr	130	10	I	do	do
150	do	do	Dr	111	10	I	do	do
(151)	do	do	Dr	128	10	I	do	do
152	SW¼ SE¼ sec. 30	A. T. & S. F...... Railway Co.	Dr	75	6	I	do	do
153	NW¼ NW¼ sec. 32	E. G. Huested...	Dr	110	....	......	do	do
154	do	do	Dr	110	....	......	do	do
	T. 30 S., R. 47 W.							
155	SW¼ NE¼ sec. 3	Harvey............. McGuinness.	Dr	123.4	5	I	do	do

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level below measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute; drawdown in feet) (17)
F	S	Land surface........	0	3,878.3	....	....	Estimated flow, 20.
Cy, W	S	Top of pipe clamp, south side.	.3	3,875.6	53.02	7-26-47	
Cy, W	D, S	Bottom of pipe....... clamp, south side.	.8	3,935.5	31.63	7-27-47	
Cy, D	In	Land surface........	....	3,962.4	93	....	Reported yield, 80.
T, B	P	....	....	....	90	....	
Cy, W	D, S	Top of pipe clamp, southeast side.	.7	3,860.2	85.43	7-16-47	
Cy, W	D, S	Top of pipe clamp, northwest side.	.8	4,087.7	96.06	8-6-47	
Cy, W, G	D, S	Top of pipe clamp, southwest side.	.3	4,052.5	80.47	8-6-47	
Cy, W	S	Top of clamp,....... west side.	1.0	4,008.0	79.85	8-6-47	
Cy	N	Top of steel pipe,... north side.	.4	4,161.1	107.22	8-6-47	Abandoned, formerly a domestic and stock well.
Cy, G	D, S	Top of pipe clamp, south side.	.3	4,222.0	172.38	8-7-47	
Cy, W, G	D, S	Top of casing,....... south side.	.4	4,230.7	80.30	8-6-47	
Cy, W	S	Top of pipe clamp, north side.	.3	4,209.2	114.69	8-6-47	
Cy, W	S	Base of steel pipe... clamp, west side.	1.3	4,189.7	88.52	6-3-47	
Cy, W	N, O	Base of steel pipe.... clamp, south side.	.5	....	93.43	3-24-47	Abandoned, formerly a domestic and stock well.
N	N	Top of iron cover,.. west side.	-.4	4,293.0	166.58	8-7-47	Do.
Cy, W C, G	S, I, O	Bottom of pump...... base, south side.	1.2	....	10.91	3-24-47	
N	N	Top of casing,....... west side.	1.6	4,237.4	61.89	8-6-47	To be used as stock well.
Cy, Wg	S	Land surface.........	0	4,349.5	28	....	Reported yield, 30; drawdown, 8.
T, NG	P	do	0	....	53	....	Reported yield, 120; drawdown, 61.
T, NG	P	do	0	....	53	....	Reported yield, 100; drawdown, 46.
T, NG	P	do	0	....	53	....	Reported yield, 126; drawdown, 61.
Cy, W, G	D	do	0	....	31	....	Reported yield, 25; drawdown, 10.
T, G	P	do	0	....	20	....	Reported yield, 100; drawdown, 75.
T, G	P	do	0	....	20	....	Reported yield, 200; drawdown, 76.
Cy, W	S	Top of casing........ north side.	2.2	4,475.9	64.37	8-14-47	

Table 9.—*Records of wells and springs*

No. pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
156	SE¼ SE¼ sec. 24	A. Patterson......	Dr	105.5	....	....	Sandstone	Dakota....... ss.
157	NW¼NW¼ sec. 29	J. E. Deniston...	Dr	69.4	6	GI	Sand.......	Ogallala..... fm. (?).
	T. 30 S., R. 48 W.							
158	SW¼ SW¼ sec. 7	J. M. Latta...... Estate.	Dr	175	10	I	Sandstone	Dakota....... ss.
159	SE¼ NE¼ sec. 12	J. W. Winfield	Dr	145.7	4½	I	do	Cheyenne ss. mem. (?).
160	SW¼ NW¼ sec. 16	Henry Jesser......	Dr	196	5	....	do	Dakota ss....
161	NE¼ sec. 23	Tilden............ Scarborough.	Dr	125	5	GI	do	do
162	SE¼ NE¼ sec. 27	J. E. Scannell...	Dr	257	6	I	do	do
163	SE¼ SE¼ sec. 31	Grace Pierpont..	Dr	102	6	GI	Sand.......	Ogallala fm.
	T. 30 S., R. 49 W.							
(164)	SW¼ SW¼ sec. 6	J. L. Whitaker..	Dr	274	6	I	Sandstone	Dakota ss....
165	SE¼ SE¼ sec. 15	W. G. Carson... Estate.	Dr	211.5	6	GI	do	do
166	NW¼NE¼ sec. 19	Mr. Talley.......	Dr	271	5	I	do	do
167	NE¼ NE¼ sec. 25	W. H. Deeds....	Dr	18.9	....	....	Sand and gravel.	Alluvium....
168	SE¼ NW¼ sec. 27	Guy Deeds........	Dr	82	5	I	do	Ogallala fm.
169	SE¼ NE¼ sec. 28	J. W. Lynch.....	Dr	209.5	6	GI	Sandstone	Dakota....... ss.
170	SW¼ SE¼ sec. 35	George B. Reed	Dr	230	5	GI	do	do
171	NW¼ NW¼ sec. 36	Howard Deeds...	Dr	100	5	I	Sand.......	Ogallala fm.
	T. 30 S., R. 50 W.							
172	NW¼NE¼ sec. 6	C. N. Ingle.....	Du	13	36	R	Sandstone	Alluvium....
173	SE¼ sec. 12	W. A. Ratliff...	Dr	256	6	GI	do	Dakota ss....
174	SE¼NW¼ sec. 18	G. R. Goodwin	Sp	....	....	....	do	do
175	do	do	Dr	26.8	6	GI	Sand and gravel.	Alluvium.....
176	NE¼ NW¼ sec. 21	A. C. Ming.....	Dr	100	6	I	Sandstone	Cheyenne.... ss. mem.
(177)	SW¼ SW¼ sec. 28	do	Dr	200	....	....	do	do
178	NW¼ SW¼ sec. 31	do	Dr	100	5	I	do	Dakota ss.....
179	NW¼ NE¼ sec. 33	do	Sp	....	....	....	do	do
180	SE¼ NE¼ sec. 33	R. B. Holt.......	Dr	85.3	6	GI	do	do
	T. 31 S., R. 41 W.							
181	SW¼NW¼ sec. 6	Lowell Bohl......	Dr	62.1	6	GI	do	do
182	SE¼SE¼ sec. 6	Ivan Knokel.....	Dr	50.4	....	....	do	do

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level below measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute; drawdown in feet) (17)
Cy	N	Top of pipe clamp, northwest side.	0	....	74.36	9-2-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Top of casing, west side.	.3	4,538.8	34.72	8-15-47	
Cy, W	N	Top of ½ -inch hole in bushing, southeast side.	2.3	4,678.9	61.46	8-15-47	Unused stock well.
Cy, G	D, S	Top of pipe clamp, west side.	1.0	4,517.7	57.43	9-2-47	
Cy, W	D, S	Land surface..........	0	4,686.6	50	....	Data from W. P. A. log.
....	D, S	do	0	....	50	....	Do.
Cy, W	N	Top of casing, west side.	0	....	135.13	8-15-47	Abandoned, formerly a domestic and stock well.
Cy, W	N	do	.6	....	98.00	8-14-47	Unused domestic and stock well.
Cy, W	D, S	Land surface..........	0	4,944.6	260	....	
Cy, W	N	Top of casing, ... north side.	.8	4,826.6	170.99	8-14-47	Abandoned, formerly a domestic and stock well.
Cy, W	N	Land surface..........	0	4,889.5	240	....	Unused stock well. Yields carbon dioxide under a pressure of 16 pounds per square inch.
Cy, W	N	Top of metal ring, .. south side.	0	....	15.09	8-11-47	Unused domestic and stock well.
Cy, W	S	Land surface..........	0	....	65	....	
Cy, W	S	Bottom of pipe....... clamp, west side.	.6	4,854.2	154.12	9-4-47	
Cy, W	D, S	Land surface..........	0	....	90	....	Data from W. P. A. log.
Cy, W	S	do	0	....	85	....	
N	N	Top of casing, ... southeast corner.	.9	....	11.15	9-4-47	Abandoned, formerly a domestic and stock well.
....	....	Land surface..........	0	....	221	....	Data from W. P. A. log.
F	S	....	....	....	....	....	Four openings. Estimated flow, 2.
Cy, W	S	Top of casing, ... north side.	3.4	....	22.80	8-26-47	
Cy, W	N	Land surface..........	0	....	40	....	Unused domestic and stock well.
Cy, W	D, S	do	0	4,976.1	50	....	
Cy, W	S	do	0	....	19	....	
F	S	....	....	....	....	....	Estimated flow, 1.
Cy, W	S	Top of pipe clamp, northeast side.	.8	....	50.94	8-26-47	
Cy, W	D, S	Top of casing, ... north side.	.5	....	33.24	7-9-47	
Cy, G	D, S	Top of concrete..... foundation, south side.	.9	....	48.20	7-9-47	

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
183	NE¼ SE¼ sec. 7	Fred Bryan........	Dr	49.3	6	I	Sandstone	Dakota....... ss.
184	SE¼ SE¼ sec. 9	George W. Mills and sons.	Dr	58.4	6	GI	do	do
185	SW¼ NE¼ sec. 16	do	Dr	67.5	6	GI	do	do
186	NW¼ SE¼ sec. 17	do	Dr	52.3	6	GI	do	do
187	SW¼ NW¼ sec. 18	Roy Bryan.........	Dr	500+	....	......	do	Dakota ss..... and Dockum group (?)
188	SE¼ SE¼ sec. 21	Carl Hedrick......	Dr	69.2	6	GI	do	Dakota....... ss.
189	SW¼ SW¼ sec. 28	Will Collins.......	DD	44.8	6	GI	Sand.......	Ogallala...... fm.
190	NE¼ NW¼ sec. 29	Limon Calahan...	Dr	44.4	6	GI	do	Ogallala...... fm. (?)
191	NW¼ SW¼ sec. 32	Orlen Harvey.....	Dr	54.5	6	N	do	Ogallala fm.
	T. 31 S., R. 42 W							
192	SW¼ NW¼ sec. 7	John Mobley......	Dr	89.9	6	GI	Sandstone	Dakota........ ss.
193	NE¼ NE¼ sec. 8	J. L. Nicholson..	Dr	74.2	6	GI	do	do
194	NW¼ SW¼ sec. 10	H. Harlow.........	Dr	68.1	....	......	do	do
195	SW¼ SW¼ sec. 11	W. L. Semmens	Dr	59.8	....	......	do	do
196	SE¼ SW¼ sec. 12	Vigil Bryan........	Dr	79.5	5½	I	do	do
197	SW¼ SE¼ sec. 13	E. Bryan...........	Dr	300+	....	......	do	Cheyenne .. ss. mem. (?)
(198)	NE¼ SW¼ sec. 15	L. Gibson..........	Dr	39.2	6	GI	Sand.......	Ogallala..... fm.
199	SE¼ SW¼ sec. 17	L. L. Munnsey....	Dr	83.5	6	GI	Sandstone	Dakota........ ss.
200	SE¼ SE¼ sec. 24	Bernard McGowan	Dr	51.3	6	GI	Sand	Ogallala...... fm. (?)
201	SW¼ SW¼ sec. 25	Ross Ellis..........	Dr	77.3	6	GI	Sand and. gravel.	Ogallala...... fm.
202	NW¼ NE¼ sec. 26	R. B. Holt.........	Dr	39.1	6	GI	do	do
203	NE¼ NE¼ sec. 29	Lewis Robbins	Dr	105.1	6	GI	Sandstone	Dakota........ ss. (?)
204	SE¼ SE¼ sec. 29	E. W. Moore.....	Dr	129.0	....	......	do	Dakota........ ss.
205	SE¼ NE¼ sec. 33	Earl Hartley	Dr	77.5	6	GI	Sand.......	Ogallala...... fm.
206	SE¼ SW¼ sec. 36	Everett Switzer....	Dr	67.9	6	GI	do	do
	T. 31 S., R. 43 W.							
207	SW¼ NW¼ sec. 2	Minnie Boll.......	Dr	87.0	6	GI	Sandstone	Dakota........ ss.
208	NW¼ NW¼ sec. 3	Walsh cemetery..	Dr	157.4	4½	I	do	Cheyenne ss. mem. (?)
209	SE¼ NE ¼ sec. 9	John Schweitzer...	Dr	97.2	6	GI	do	Dakota........ ss.

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level below measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute; draw-down in feet) (17)
Cy, W	D, S	Top of wooden support, north side.	1.8	3,711.5	24.92	7-9-47	
Cy, W	D	Top of concrete foundation, north side.	.8	3,669.5	56.58	7-7-47	
Cy, W	N	Top of wooden pipe clamp, south side.	3.3	....	52.15	7-7-47	Abandoned, formerly a domestic and stock well.
Cy, W	N	Top of wooden pipe clamp, west side.	.3	....	50.70	7-9-47	Abandoned, formerly a stock well.
Cy, W	N	Top of wooden pipe clamp, north side.	.1	....	39.13	7-9-47	Unused domestic and stock well.
Cy, W	S	Top of wooden pipe clamp, east side.	.5	3,675.4	54.46	7-7-47	
Cy, W	D, S	Top of steel cap, ... east side.	.1	....	33.82	7-7-47	
Cy, W	D, S	Top of concrete foundation, south side.	.5	3,686.4	34.78	7-9-47	
N	N	Land surface..........	0	3,701.9	45.00	7-7-47	
Cy, W	D, S	Top of casing, ... east side.	.8	3,838.0	69.56	7-16-47	
Cy, W	N	Top of tin cover, ... east side	.5	....	40.99	7-11-47	Abandoned, formerly a domestic and stock well.
Cy, W	N	Top of board cover, .. west side.	2.0	3,807.8	36.07	7-10-47	Do.
Cy, W	D, S	Top of wooden clamp, south side.	.5	....	46.64	7-10-47	
N	N	Top of casing, ... east side.	3.6	3,746.0	54.47	7-9-47	Unused stock well.
Cy, W	N	Top of concrete...... foundation, west side.	.3	....	30.43	7-9-47	Abandoned, formerly a domestic and stock well.
Cy, W	D, S	Top of casing, ... north side.	.2	....	37.96	7-10-47	
Cy, W	D, S	Top of pipe clamp, northeast side.	1.6	3,819.5	74.64	7-11-47	Do.
N	N	Top of 2-inch pipe, south side.	6.7	3,718.6	27.95	7-10-47	Do.
Cy, W	I	Top of pipe clamp, south side.	.4	....	32.10	7-10-47	Abandoned, formerly a domestic and stock well.
N	N	Top of casing, ... north side.	1.7	....	20.28	7-10-47	Do.
Cy, W	D, S	Bottom of pipe....... clamp, south side.	.3	....	79.09	7-11-47	
N	N	Top of 2-inch pipe, south side.	1.4	3,806.9	91.63	7-19-47	Do.
Cy, W	D, S	Top of pipe clamp, east side.	.1	....	60.46	7-10-47	
Cy, W	D, S	Top of pipe clamp, north side.	1.2	3,720.3	38.77	7-10-47	
Cy, W	D, S	Top of pipe clamp, southwest side.	.4	3,889.5	49.27	7-16-47	
Cy, W	I	Top of 4-way connection, south side.	2.4	3,922.5	78.16	7-16-47	
Cy, W	D, S	Top of casing, ... east side.	.1	....	87.33	7-16-47	

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (feet)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
210	NE¼ NE¼ sec. 15	C. E. Hartley...	Dr	64.4	6	GI	Sandstone	Dakota ss.
211	SW¼ SW¼ sec. 15	P. Welchka......	Dr	82.9	6	I	do	do
212	NE¼ SE¼ sec. 17	R. B. Holt.......	Dr	81.8	6	GI	do	do
213	NE¼ SE¼ sec. 21	L. R. Schreper..	Dr	120.1	6	GI	do	do
214	NE¼ NE¼ sec. 23	Mrs. O.F. Ross..	Dr	93.7	6	GI	do	do
215	SE¼ SW¼ sec. 26	Lea and LaVeta Ross.	Dr	94.0	6	GI	do	do
216	SE¼ SE¼ sec. 29	Edmund Bishop..	Dr	146.3	6	I	do	do
217	SE¼ SE¼ sec. 36	W.H. Bair........	Dr	129.9	6	GI	do	do
	T. 31 S., R. 44 W.							
218	NE¼ NW¼ sec. 5	R. R. Rutherford.	Dr	200	8	C	do	Dakota ss. (?).
219	SW¼ SW¼ sec. 22	L. M. Eaton.....	Dr	96.4	6	I	Sand......	Ogallala fm. (?).
220	NE¼ SW¼ sec. 23	William Thompson.	Dr	96.3	6	GI	do	Ogallala fm.
221	NW¼ SW¼ sec. 36	C. F. Clayton..	Dr	64.3	6	GI	Sandstone	Dakota ss. (?).
	T. 31 S., R. 45 W.							
222	NE¼ NW¼ sec. 1	A.T. & S.F. Railway Co.	Dr	161	6	I	do	Dakota ss.
(223)	NE¼ SW¼ sec. 1	Homer Havens...	Dr	103	6	......	Sand......	Ogallala fm.
224	NE¼ NE¼ sec. 2	Mr. Hurst.........	Dr	120	6	GI	do	do
225	SW¼ SW¼ sec. 8	J. M. Royster...	Dr	198	6	GI	Sandstone	Cheyenne ss. mem.
226	SE¼ SE¼ sec. 13	E. E. Wilson and S.E. Gordon.	Dr	67.4	6	GI	Sand......	Ogallala fm.
227	SE¼ SE¼ sec. 18	W. A. Lanterman.	Dr	143.1	6	I	Sandstone	Dakota ss.
228	SE¼ SE¼ sec. 26	U.S. Government	Dr	45	6	I	Sand......	Ogallala fm.
	T. 31 S., R. 46 W.							
229	SW¼ NW¼ sec. 18	J. N. Jett........	Dr	62.4	6	GI	Sand......	Ogallala fm. (?).
230	NW¼ NW¼ sec. 28	Ethyl Taylor.....	Dr	162.7	6	GI	Sandstone	Dakota ss.
231	SE¼ SW¼ sec. 34	U.S. Government	Dr	157	4½	I	do	do
	T. 31 S., R. 47 W							
(232)	NW¼ NW¼ sec. 1	W. H. Means...	Dr	83	6	I	Sand and gravel.	Ogallala fm.
233	do	do	Dr	77	6	I	do	do
234	NE¼ NW¼ sec. 2	do	Dr	....	6	GI	do	do
235	NW¼ NE¼ sec. 17	U.S. Government	Dr	79.5	6	GI	Sand......	do

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level below measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute; drawdown in feet) (17)
Cy, W	D, S	Top of casing, north side.	0.8	3,863.3	37.66	7-16-47	
Cy, W	D, S	Top of concrete foundation, north side.	1.0	....	53.34	7-16-47	
Cy, W	D, S	Top of tin cover, south side.	.7	3,906.5	61.26	7-21-47	
Cy, W	D, S	Top of pipe connection, east side.	1.3	....	100.98	7-21-47	
Cy, W	D, S	Top of pipe clamp, northeast side.	.4	....	67.62	7-19-47	
Cy, W	S	Top of pipe clamp, south side.	.7	3,882.0	72.67	7-21-47	
Cy, W	D, S	Top of casing, south side.	2.9	3,941.3	110.21	7-21-47	
Cy	N	Top of pipe clamp, south side.	.4	3,833.8	75.91	7-19-47	Abandoned, formerly a stock well.
N	N	Top of concrete casing, north side	.6	4,090.5	56.24	8-6-47	Abandoned, formerly a domestic and stock well.
Cy, W	D, S	Top of steel cover, south side.	1.6	4,072.1	75.36	8-12-47	
Cy, W		Top of clamp, south side.	1.1	4,045.9	64.53	8-12-47	
Cy, W	D, S	Top of clamp, north side.	.9	4,035.3	40.95	8-12-47	
Cy, H	S	Land surface	0	4,158.9	85	....	Reported yield, 10; drawdown, 55.
Cy, E	D	Land surface	0	....	87	....	
....	....	do	0	....	100	....	Data from W.P.A. log.
....	....	do	0	....	153	....	Do.
N	N	Top of casing, west side.	0	4,165.2	64.75	8-12-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Top of pipe clamp, south side.	.7	4,288.2	124.53	8-12-47	
Cy, W	S	Land surface	0	....	31	....	
Cy, W	S	Bottom of pipe connection, north side.	1.0	4,446.7	37.13	8-16-47	
Cy	N, O	Top of casing, east side.	1.0	4,440.9	135.11	3-21-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Land surface	0	4,385.9	97	....	
Cy, W	S	do	0	4,475.5	65	....	
Cy, W	D, S	do	0	....	60	....	
N	N	Top of casing, north side.	.6	....	55.40	9-2-47	Do.
Cy, H	N	do	.1	....	73.16	8-16-47	Do.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
236	SE¼ SW¼ sec. 25	U. S. Government	Dr	50.3	6	GI	Sand......	Ogallala..... fm.
(237)	NW¼ NW¼ sec. 33	Liberty school....	Dr	170.0	6	GI	Sandstone	Dakota....... ss.
	T. 31 S., R. 48 W.							
238	NE¼ NW¼ sec. 6	Mr. Terrell.......	Dr	248	5	I	do	do
239	SE¼ SW¼ sec. 6	City of Pritchett..	Dr	300	10	I	do	do
(240)	NW¼ SE¼ sec. 6	do	Dr	268	10, 8	I	do	do
241	SW¼ SE¼ sec. 6	A. T. & S. F...... Railway Co.	Dr	250	10	I	do	do
242	NW¼ SW¼ sec. 16	U. S. Government	Dr	200	6	GI	do	do
243	SE¼ SE¼ sec. 16	do	Dr	113.9	6	GI	Sand......	Ogallala..... fm.
244	NE¼ SE¼ sec. 17	E. B. Eskew......	Dr	190	6	GI	Sandstone	Dakota ss.
245	NW¼ NW¼ sec. 33	F. S. Pearce.....	Dr	246	5	GI	do	do
246	SE¼ SW¼ sec. 35	U. S.............. Government.	Dr	343	5½	I	do	Cheyenne ss. mem. (?).
247	NE¼ NW¼ sec. 36	Santa Fe State... Bank.	Dr	117.2	6	GI	Sand and gravel.	Ogallala..... fm.
	T. 31 S., R. 49 W.							
248	SW¼ SE¼ sec. 7	U. S. Government	Dr	73	5½	I	Sand......	do
249	SE¼ NE¼ sec. 10	....	Dr	187.0	6	GI	Sandstone	Dakota....... ss.
250	NE¼ NW¼ sec. 11	J. D. Grage......	Dr	206.7	5	I	do	do
251	NE¼ NE¼ sec. 20	W. H. Plagge...	Dr	141.2	4½	I	Sand and.. gravel.	Ogallala..... fm.
252	NE¼ NW¼ sec. 23	Mr. Emrick......	Dr	98.4	6	GI	do	do
253	NW¼ SE¼ sec. 26	Mr. Brinkley.....	Dr	286	5	I	Sandstone	Dakota....... ss.
254	NW¼ NE¼ sec. 35	Grace Pierpont..	Dr	231.7	4	I	do	do
	T. 31 S., R. 50 W.							
255	SW¼ SE¼ sec. 1	W. G. Carson...	Dr	98.1	6	GI	Sand and gravel.	Ogallala..... fm.
256	SE¼ NE¼ sec. 6	U. S. Government	Dr	164	6	I	Sandstone	Dakota ss.
257	SW¼ SE¼ sec. 14	do	Dr	128.3	6	GI	do	do
258	NE¼ NE¼ sec. 20	do	Dr	178	6	GI	do	do
259	SE¼ NE¼ sec. 28	U. S. Government	Dr	238	5½	I	do	do
	T. 32 S., R. 41 W.							
(260)	SE¼ SW¼ sec. 7	C. A. Newman..	Dr	86.0	6	GI	Sand and.. gravel.	Ogallala..... fm.
261	SW¼ NW¼ sec. 9	Raymond Cross..	Dr	104.8	6	N	do	do
262	NE¼ NW¼ sec. 30	Arch Frink.......	Dr	77.3	6	GI	do	do
263	NW¼ SW¼ sec. 33	Ratliff Estate.....	Dr	84.8	5	GI	do	do

in Baca County, Colo.—Continued

Method of lift	Use of water	Measuring point: Description	Measuring point: Distance above or below (-) land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Cy, W	S	Top of pipe clamp, east side.	0.4	4,480.3	39.78	8-16-47	
Cy, W, H	D	Top of casing, south side.	.4	....	124.54	8-16-47	School well.
Cy, W	D, S	Land surface	0	4,811.6	147	....	Water in Ogallala cased off.
T, E	P	do	0	....	150	....	Used by pipeline company for washing casing.
T, E	P	do	0	4,827.3	146	....	
Cy, D	In	do	0	4,817.6	137	....	Reported yield, 80; drawdown, 53.
Cy, W	S	do	0	....	198	....	
Cy	N	Top of pipe, west side.	2.4	4,702.6	109.01	8-16-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Land surface	0	....	60	....	
Cy, W	D, S	do	....	....	146	....	Data from W. P. A. log.
Cy, W	S	do	0	4,708.5	173	....	
N	N	Top of casing, south side.	.3	4,636.3	84.53	8-16-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Land surface	0	....	43	....	
N	N	Top of casing, east side.	.7	4,878.4	160.49	1-10-50	Do.
Cy, W	N, O	Top of casing, southeast side.	.5	4,879.8	180.22	3-24-47	Do.
Cy, W	N	Top of pipe clamp, south side.	1.0	4,911.4	88.17	8-20-47	Unused domestic and stock well.
Cy, W	N	Top of galvanized-iron cover over casing, west side.	.4	4,848.9	86.97	8-14-47	Unused stock well.
Cy, W	S	Land surface	0	....	205	....	Water rose 60 feet above aquifer.
N	N	Top of casing, south side.	1.0	....	214.07	8-15-47	Abandoned, formerly a domestic and stock well.
N	N	Top of casing, southeast side.	.2	5,044.1	80.54	8-14-47	Abandoned, formerly a stock well.
Cy, W	S	Land surface	0	5,178.2	104	....	
Cy, W	S	Top of wooden pipe clamp, west side.	.3	5,051.3	63.87	8-20-47	
N	N	Top of casing, west side.	1.1	....	139.64	8-13-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Land surface	0	5,123.2	176	....	
Cy, W	D, S	Top of casing west side.	.4	3,718.2	72.98	7-19-47	
N	N	Land surface	0	3,681.0	60.61	7-19-47	
Cy, W	D, S	Top of pipe clamp, north side.	.6	3,698.6	66.82	7-22-47	
Cy, W	D, S	Top of pipe clamp, south side.	0.3	3,676.2	76.84	7-23-47	

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	T. 32 S., R. 42 W.							
264	SW¼ NW¼ sec. 2	Lewis Robbins...	Dr	71.7	6	GI	Sand and.. gravel.	Ogallala.... fm.
265	SW¼ SE¼ sec. 4	Trahern........... brothers.	Dr	129.3	6	GI	Sandstone	Ogallala fm. and Dockum group.
(266)	NW¼ NW¼ sec. 5	John Mease.......	Dr	100	6	....	do	Dakota...... ss. (?).
267	NE¼ NE¼ sec. 15	C. A. Newman	Dr	116.5	6	GI	Sand.......	Ogallala.... fm.
268	NW¼ NE¼ sec. 17	R. B. Holt.......	Dr	111.9	6	GI	do	Ogallala.... fm. (?).
269	NE¼ SE¼ sec. 18	Lee Twyford.....	Dr	129.5	6	GI	do	Ogallala.... fm.
270	SW¼ SW¼ sec. 19	LeRoy Haney....	Dr	135.0	6	GI	do	do
271	SW¼ SE¼ sec. 21	Arthur Davis......	Dr	114.9	6	GI	Sandstone	Dakota...... ss.
272	SE¼ NE¼ sec. 27	C. A. Newman..	Dr	152.3	6	GI	Sand.......	Ogallala.... fm.
	T. 32 S., R. 43 W.							
273	NW¼ NW¼ sec. 3	R. B. Holt and... J. K. McKinnis	Dr	113.3	6	GI	Sandstone	Dakota...... ss.
274	SE¼ SE¼ sec. 12	O. L. Trahern...	Dr	139.2	6	GI	do	do
275	SW¼ SE¼ sec. 15	W. O. Kerr......	Dr	172.1	6	GI	Gravel.....	Ogallala.... fm.
276	NE¼ NE¼ sec. 20	H. F. Koelsh....	Dr	170.9	6	GI	Sandstone	Dakota...... ss.
277	NE¼ SE¼ sec. 23	Osa Moore........	Dr	163.5	6	GI	Sand.......	Ogallala.... fm. (?).
278	SE¼ SW¼ sec. 35	R. B. Holt.......	Dr	184.0	6	GI	Sand and.. gravel	Ogallala.... fm.
	T. 32 S., R. 44 W.							
279	NW¼ SW¼ sec. 9	Earl Brown........	Dr	64.5	6	GI	do	do
(280)	SE¼ SE¼ sec. 14	M. A. Lippoldt..	Dr	106.5	6	GI	do	do
281	NW¼ NE¼ sec. 28	R. B. Holt.......	Dr	134.2	6	GI	do	do
	T. 32 S., R. 45 W.							
282	SE¼ NW¼ sec. 6	S. E. Gordon....	Dr	46.5	6	GI	do	do
283	SW¼ sec. 6	George Watkins..	Dr	132	6	GI	Sandstone	Dakota......
(284)	SW¼ NW¼ sec. 13	S. B. McGill.....	Dr	110	5	....	Sand and.. gravel	Ogallala.... fm.
285	SE¼ NE¼ sec. 14	Millie McGowan	Dr	121.6	6	GI	do	do
286	SW¼ SW¼ sec. 21	G.F. Williams..	Dr	117.8	6	GI	do	do
287	SE¼ SE¼ sec. 24	U.S. Government	Dr	84.8	6	GI	do	do

in Baca County, Colo.—Continued

Method of lift	Use of water	Measuring point: Description	Measuring point: Distance above or below (-) land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Cy, W	D, S	Top of pipe clamp, north side.	0.7	3,755.1	61.19	7-10-47	
Cy, W	D, S	Top of pipe clamp, west side.	.8	3,788.6	82.80	7-19-47	
Cy, W	D, S	Land surface..........	0	....	90	....	
Cy, W	S	Top of wooden support, south side.	.3	3,788.1	102.07	7-19-47	
N	N	Top of casing, ... east side.	.4	3,815.3	108.54	7-19-47	Abandoned, formerly a domestic and stock well.
Cy, W	N	Top of 6-inch hole.. in concrete southeast side.	.4	3,808.1	100.50	6-2-47	Do.
Cy, W	N	Top of pipe clamp,.. north side.	1.3	3,841.1	125.79	7-22-47	Do.
N	N	Top of casing, ... east side.	-.6	3,802.1	99.19	7-22-47	Do.
Cy, W	S	Top of pipe clamp, east side.	.7	3,763.4	94.83	7-15-47	
Cy, W	S	Top of pipe clamp, south side.	.9	3,892.8	81.57	7-21-47	
Cy, W	N	Bottom of pipe clamp, northeast side.	.7	3,840.3	118.31	7-19-47	Do.
Cy, G	D, S	Top of tin cover, ... south side.	.2	3,897.6	143.50	7-22-47	
N	N, O	Top of casing, ... north side.	.5	3,927.8	86.99	7-22-47	Do.
Cy, W	N	Top of tubing, ... north side.	.2	....	144.18	7-22-47	Do.
Cy, G	D, S	Top of pipe clamp, east side.	.6	3,897.6	162.38	8-5-47	
Cy, W	D, S	Top of pipe clamp, south side.	5.5	4,088.0	49.43	8-12-47	
Cy, W	D, S	Top of pipe clamp,.. northeast side.	1.2	4,033.0	89.90	8-12-47	
Cy, W	D, S	Top of iron ring, southeast side.	.6	4,086.9	72.24	9-1-47	
Cy, W	N	Top of casing, ... north side.	1.5	4,263.9	29.11	8-13-47	Do.
....	....	Land surface..........	0	....	72	....	Data from W. P. A. log.
Cy, W	D, S	do	0	....	80	....	
Cy, W	D, S	Top of tin cover, ... south side.	.7	4,213.0	113.22	8-13-47	
Cy	N	Top of pipe clamp,.. northwest side.	.6	4,280.6	109.56	9-1-47	Abandoned, formerly a domestic and stock well.
N	N	Top of casing, ... north side.	0	4,143.4	75.10	8-12-47	Do.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of sup-ply	Depth of well (feet)	Diam-eter of well (in.)	Type of cas-ing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	T. 32 S., R. 46 W.							
288	SE¼ sec. 3	H. D. Smith.....	Dr	77	6	GI	Sand and gravel.	Ogallala.... fm.
289	SE¼ SE¼ sec. 4	A. E. Johnson....	Dr	167.3	6	GI	Sandstone	Dakota...... ss.
290	NE¼ SW¼ sec. 5	U. S. Government	Dr	151	6	I	do	do
291	SW¼ SW¼ sec. 7	do	Dr	153.7	5	I	do	do
292	SE¼ SW¼ sec. 15	A. T. & S. F...... Railway Co.	Dr	187	6	I	Sand and gravel.	Ogallala.... fm.
(293)	NE¼ SW¼ sec. 22	Floyd Lashley....	Dr	161.8	6	GI	do	do
294	SE¼ SE¼ sec. 31	Ray Bryan........	Dr	400	6	I	Sandstone	Cheyenne.. ss. mem.
	T. 32 S., R. 47 W.							
295	NE¼ SE¼ sec. 8	Charles O........ Jackson.	Dr	166.0	6	GI	do	Dakota...... ss.
296	SE¼ SE¼ sec. 25	Harring and...... Stinson.	Dr	350	4½	I	do	Cheyenne.. ss. mem.
(297)	SE¼ SE¼ sec. 27	U. S............... Government.	Dr	408	5	I	do	do
	T. 32 S., R. 48 W							
298	SW¼ NW¼ sec. 7	Owner not known	Dr	391	4½	I	do	do
299	NW¼ SW¼ sec. 8	S. D. Huff.......	Dr	247.0	6	GI	do	Dakota...... ss.
300	SE¼ SE¼ sec. 11	R. C. Current...	Dr	230.5	4	I	do	do
301	Center SE¼ sec. 23	U. S. Government	Dr	331	5½	I	do	do
302	SW¼ SW¼ sec. 31	Owner not known	Dr	715	....	I	do	Dockum..... group or Morrison fm.
(303)	SW¼ SW¼ sec. 34	Mr. Hileman.....	Dr	366	4	....	do	Cheyenne... ss. mem.
304	SE¼ NE¼ sec. 35	C. L. Bosley	Dr	400	5	I	do	do
	T. 32 S., R. 49 W.							
(305)	SE¼ SW¼ sec. 3	J. K. Hill........	Dr	318	5	I	do	Dakota...... ss.
306	SW¼ NW¼ sec. 7	Owner not known	Dr	391	4	I	do	Cheyenne ss. mem. (?).
307	NE¼ NW¼ sec. 8	U. S............... Government.	Dr	261.4	5	I	do	Dakota...... ss.
308	SW¼ SW¼ sec. 33	Paul Roehr........	Dr	240.6	5	I	do	do
309	NW¼ NE¼ sec. 34	Charles H. Smith	Dr	300	6	I	do	do
	T. 32 S., R. 50 W.							
310	SE¼ NE¼ sec. 4	U. S............... Government.	Dr	178.0	5	I	Sand and gravel.	Ogallala..... fm.
311	NE¼ NE¼ sec. 13	Dick Kerr	Dr	253	5	I	do	do

in Baca County, Colo.—Continued

Method of lift	Use of water	Measuring point: Description	Measuring point: Distance above or below (-) land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
....	....	Land surface.........	0	....	57	....	Data from W.P.A. log.
Cy, W	S	Top of steel cover, south side.	.9	4,370.8	98.53	8-13-47	
Cy, W	S	Land surface.........	0	4,399.5	111	....	
Cy, W	S	Top of pipe clamp, north side.	.6	4,439.1	136.38	8-16-47	
Cy, W	In	Land surface.........	0	4,387.1	150	....	
Cy, W	D, S	Top of casing, ... east side.	.4	4,375.8	148.17	9-1-47	
Cy, W	D, S	Land surface.........	0	4,452.7	300	....	
Cy, W	D, S	Top of wagon wheel east side.	.6	....	155.68	8-16-47	
....	....	....	....	....	190	....	Do.
Cy, W	S	Top of casing, ... east side.	1.5	4,529.7	306.23	8-18-47	
....	....	....	....	....	351	....	
N	N, O	Top of casing, ... southeast side.	.3	4,798.8	194.65	6-3-47	Abandoned, formerly, a domestic and stock well.
Cy, W	D, S	Top of second iron ring from bottom, north side.	1.8	4,713.7	223.74	8-16-47	
Cy, W	S	Land surface.........	0	4,651.2	261	....	
....	....	....	....	....	615	....	Yields carbon dioxide. Data from W.P.A. log.
Cy, W	D, S, I	do	0	4,693.6	240	....	
Cy, W, G	D, S	Hole in casing, ... west side.	.1	4,643.1	251.59	8-19-47	
Cy, W	D, S	Top of casing, ... south side.	2.0	4,923.9	298.26	8-16-47	Well pumping at time of measurement.
....	....	....	....	....	351	....	Data from W.P.A. log.
Cy	N	Top of casing, ... east side.	1.8	4,952.8	222.86	8-15-47	Abandoned, formerly a domestic and stock well.
Cy, W	N	Top of pipe clamp, east side.	1.9	4,904.9	212.99	8-19-47	Unused stock well.
Cy, W	D, S	Land surface............	0	....	280	....	
Cy, W	N	Top of galvanized-iron cover, north side.	.5	5,103.4	128.63	8-13-47	Do.
Cy, G	D, S	Top of hole in pipe..... clamp, east side.	.9	5,016.3	236.36	8-19-47	

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
312	NE¼ NW¼ sec. 21	Henry McGuinney	Dr	241	4, 3½	I	Sandstone	Dakota ss...
313	SW¼ NW¼ sec. 24	W. A. Campbell	Dr	300.6	6	GI	do	Cheyenne ss mem. (?)
314	SE¼ NE¼ sec. 28	R. C. Eikleberry	Dr	334.2	6	GI	do	Cheyenne... ss. mem.
315	NE¼ SE¼ sec. 30	U. S............... Government.	Dr	263.6	5	I	do	Dakota...... ss.
	T. 33 S., R. 41 W.							
316	NW¼ SW¼ sec. 16	Harley Cogburn	Dr	175.0	6	GI	do	Dockum..... group.
(317)	NE¼ NE¼ sec. 30	R. T. Russell...	Dr	194.5	6	GI	do	do
	T. 33 S., R. 42 W.							
318	SE¼ SE¼ sec. 7	W. A. Wilson....	Dr	151.2	6	GI	Sand and gravel.	Ogallala.... fm.
319	NE¼ NE¼ sec. 11	Frank Bauman....	Dr	162.4	4	I	do	do
(320)	SE¼ SE¼ sec. 19	E. B. Bruce......	Dr	177.8	4	GI	Gravel....	do
321	SE¼ NE¼ sec. 22	C. B. Cogburn...	Dr	149.9	6	GI	Sand and gravel.	do
	T. 33 S., R. 43 W.							
(322)	NE¼ NE¼ sec. 3	W. O. Harris.....	Dr	160	6	......	do	do
323	NW¼ SE¼ sec. 6	M. Wally..........	Dr	163.0	6	GI	do	do
324	NW¼ SW¼ sec. 14	Roy E. Ackley...	Dr	179.6	....	....	do	do
325	NW¼ NW¼ sec. 33	R. B. Holt.......	Dr	198	....	......	do	do
326	SE¼ NE¼ sec. 34	V. A. Brown.....	Dr	199.8	6	GI	do	do
	T. 33 S., R. 44 W.							
(327)	NW¼ SW¼ sec. 3	Darrell Utt........	Dr	128.7	5½	GI	do	do
328	SW¼ SW¼ sec. 23	U. S............... Government.	Dr	324.5	6	GI	Sandstone	Cheyenne.. ss. mem.
329	SE¼ SE¼ sec. 32	A. I. Hess	Dr	252.5	6	GI	do	Dakota....... ss. (?).
	T. 33 S., R. 45 W.							
330	SE¼ SE¼ sec. 4	W. F. Ownbey...	Dr	136.9	6	GI	do	Dakota...... ss.
331	NE¼ SE¼ sec. 13	J. A. and M. W... Davis.	Dr	186.5	6	GI	do	do
332	SE¼ SW¼ sec. 21	O. V. Ray.......	Dr	259.6	3½	I	do	Cheyenne... ss. mem.
333	SW¼ NW¼ sec. 24	Len Weld.........	Dr	110	5¾	GI	Sand and gravel.	Ogallala.... fm.
	T. 33 S., R. 46 W.							
334	NE¼ SE¼ sec. 2	E. G. Huested...	Dr	218.4	6	GI	Sandstone	Dakota...... ss.

in Baca County, Colo.—Continued

Method of lift	Use of water	Measuring point: Description	Measuring point: Distance above or below (-) land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
....	....	....	....	....	225	....	Data from W. P. A. log.
Cy, W	N	Bottom of iron support, west side.	0.4	5,010.5	152.90	8-24-47	Abandoned, formerly a domestic and stock well.
Cy, W	D, S	Top of hole in pipe clamp, north side.	.2	5,095.1	138.73	8-24-47	
Cy, W	S	Top of casing, ... west side.	.6	5,186.0	252.32	8-24-47	
Cy, W	D, S	Top of pipe clamp, south side.	.5	3,688.7	106.16	7-23-47	First water at 145 feet; second water at 175 feet.
Cy, W	S	Top of pipe clamp, west side.	2.0	3,723.5	149.83	7-23-47	
N	N	Top of 2-inch pipe, north side.	1.2	....	138.92	8-5-47	Abandoned, formerly a domestic and stock well.
Cy, W	D, S	Top of casing, ... north side.	.5	3,761.9	118.40	8-5-47	
Cy, W	D, S	Top of pipe clamp, north side.	1.3	3,847.2	154.31	8-4-47	
Cy, W	D, S	Top of pipe clamp, west side.	1.4	3,786.3	137.10	8-5-47	
Cy, W	D, S	Land surface........	0	....	130	....	
Cy, W	D, S	Top of pipe clamp, west side.	.3	3,985.3	144.26	8-12-47	
Cy, W	D, S	Top of pipe connection, north side.	.3	3,913.9	172.15	8-5-47	
N	N	Top of 2-inch pipe, north side.	5	3,941.2	166.37	7-25-47	Do.
Cy, W	D, S	Top of pipe clamp, north side.	1.2	3,915.4	196.41	8-5-47	
Cy, W	D, S	Top of tin cover, .. east side.	.5	4,075.3	124.22	8-12-47	
Cy	N	Top of pipe clamp, south side.	.8	4,058.4	200.39	8-13-47	Do.
Cy, W	D, S	Top of pipe clamp, east side.	0	4,094.2	201.27	8-14-47	
Cy, W	D, S	Top of pipe clamp, southeast side.	.4	4,246.6	127.33	8-13-47	
Cy	N, O	Top of 2½-inch pipe, southeast side.	3.8	4,154.5	83.76	6-3-47	Do.
Cy	N	Top of casing, ... north side.	.9	4,267.1	119.54	8-13-47	Do.
....	....	Land surface........	0	....	86	....	Data from W. P. A. log.
Cy, W	N	Top of wooden pipe clamp, south side	.7	4,349.7	186.10	8-13-47	Abandoned, formerly a domestic and stock well.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (feet)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(335)	NW¼ SW¼ sec. 20	Frank McGurk....	Dr	305.5	6	I	Sandstone	Cheyenne.... ss. mem.
336	NW¼ NW¼ sec. 26	J. N. Jett.........	Dr	270.3	6	GI	Sand.......	Ogallala ..... fm. (?).
337	SE¼ SW¼ sec. 27	U.S. Government	Dr	300	6	I	Sand and. gravel.	Ogallala..... fm.
338	SW¼ SW¼ sec. 28	do	Dr	291	5½	I	Sandstone	Dakota ss....
	T. 33 S., R. 47 W.							
339	SW¼ SE¼ sec. 8	Fred Bosley.......	Dr	165	4½	I	Sand and gravel.	Ogallala..... fm.
340	SE¼ SW¼ sec. 15	U.S. Government	Dr	270	5½	I	do	do
341	SE¼ SE¼ sec. 21	Ruby Southworth	Dr	324.4	....	......	Sandstone	Dakota....... ss.
342	NE¼ NW¼ sec. 27	Elmer Terry......	Dr	299	5½	I	Sand and gravel.	Ogallala..... fm.
343	NE¼ NW¼ sec. 33	U.S. Government	Dr	332	5½	I	do	do
	T. 33 S., R. 48 W							
344	NE¼ SW¼ sec. 4	Roy Finley........	Dr	404	7	I	Sand,..... gravel, and sandstone.	Ogallala fm. and Dakota sandstone.
345	NW¼ SW¼ sec. 4	A. C. Fourtner..	Dr	414 .	4½	I	Sandstone	Cheyenne.... ss. mem.
346	NW¼ NW¼ sec. 5	U.S. Government	Dr	381.6	....	......	do	do
347	SE¼ SW¼ sec. 18	W. D. Higgs......	Dr	392.4	5	I	do	do
348	NE¼ NW¼ sec. 22	U.S. Government	Dr	343.4	4½	I	do	Dakota....... ss.
349	NE¼ SE¼ sec. 23	Mrs. Coulter.....	Dr	387	4½	I	do	Cheyenne.... ss. mem.
(350)	NW¼ NE¼ sec. 25	U.S. Government	Dr	365.4	5½	I	do	Dakota....... ss. (?).
351	Center SE¼ sec. 32	do	Dr	335	5½	I	do	Cheyenne ss. mem. (?).
	T. 33 S., R. 49 W							
352	NW¼ SE¼ sec. 7	Hannah Baker.....	Dr	227.8	4	I	do	Dakota....... ss.
353	SE¼ NE¼ sec. 10	Richard Birt.......	Dr	206.2	6	I	do	do
354	SE¼ NE¼ sec. 19	S. B. Peters......	Dr	270	5½	I	do	do
(355)	NE¼ NE¼ sec. 29	R. E. Ormiston.	Dr	272	5	I	Sand and gravel.	Ogallala..... fm.
356	SE¼ SW¼ sec. 33	U.S. Government	Dr	281	....	......	Sandstone	Dakota....... ss. (?).
	T. 33 S., R. 50 W.							
357	NE¼ SW¼ sec. 6	John MacArthur..	Dr	88.4	....	......	do	Dakota....... ss.
358	NE¼ NE¼ sec. 8	do	Sp	......	....	......	do	do
359	SE¼ SW¼ sec. 9	T. P. Hughes.....	Sp	......	....	......	do	do

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level below measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute; drawdown in feet) (17)
Cy, W, G	D, S	Top of casing, west side.	1.6	4,435.9	274.76	8-18-47	
Cy, W	S	Top of pipe clamp, northwest side.	.5	4,339.1	251.00	8-13-47	
Cy, W	S	Land surface	0	....	250	....	
Cy, W	S	do	0	4,402.1	251	....	
Cy, W	D, S	do	0	....	135	....	
Cy, W	S	do	0	4,530.6	240	....	
Cy	N	Top of pipe clamp, north side.	-.2	4,538.5	276.77	8-18-47	Abandoned, formerly a domestic and stock well.
....	....	Land surface	0	....	283	....	Data from W.P. A. log.
Cy, W	S	do	0	4,539.7	302	....	
Cy, W	S	do	0	4,728.4	325	....	Encountered Dakota at 357 feet.
....	....	....	....	....	296	....	Data from W.P.A. log.
Cy, W	S	Top of pipe clamp, east side.	.7	....	245.62	8-19-47	
Cy, W	D, S	Top of pipe clamp, northeast side.	.4	....	242	8-19-47	
Cy, W	S	Top of iron plate, east side.	.2	....	336.24	8-19-47	
....	....	Land surface	0	....	287	....	Do.
Cy, W	S	do	.6	....	324	....	
Cy, W	S	do	0	....	304	....	
Cy, W	N	Top of hole in pipe clamp, east side.	.2	4,922.8	203.37	8-19-47	Abandoned, formerly a domestic and stock well.
Cy, G	D, S	Top of casing, east side.	.4	4,831.0	200.94	8-19-47	
....	....	Land surface	0	....	225	....	Data from W.P.A. log.
Cy, W	D, S	do	0	4,905.6	254	....	
Cy	N	Top of 2-inch tee, east side.	4.4	4,869.6	275.45	8-19-47	Abandoned, formerly, a domestic and stock well.
Cy, W	S	Bottom of tee, south side.	2.2	....	55.87	8-24-47	
F	S	....	....	....	....	....	Waters 30 to 40 head of cattle.
F	S	....	....	....	....	....	Carrizo Springs, two openings. Estimated flow, 20.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(360)	NW¼ SW¼ sec. 10	U. S. Government	Dr	61.9	4	I	Sandstone	Dakota ss.
361	NW¼ NW¼ sec. 11	do	Dr	210.1	6	GI	do	Cheyenne ss. mem.
362	SW¼ SW¼ sec. 11	Robert Dodge	Dr	228	5	I	do	Cheyenne ss. mem. (?).
363	NE¼ NW¼ sec. 16	T. P. Hughes	Sp	......	....	......	do	Dakota ss.
364	SW¼ SE¼ sec. 20	do	Dr	139.7	6	GI	do	Cheyenne ss. mem.
365	NE¼ NW¼ sec. 26	U. S. Government	Dr	84.6	6	I	do	Cheyenne ss. mem. (?).
	T. 34 S., R. 41 W.							
366	NE¼ NW¼ sec. 7	Willard Mayberry	Dr	107.0	5	I	Sand and gravel.	Ogallala fm.
367	SE¼ NW¼ sec. 32	Clara Speaker	Dr	48	6	GI	do	do
368	SW¼ SE¼ sec. 34	Mr. Hamilton	Dr	65	6	GI	do	do
	T. 34 S., R. 42 W.							
369	NE¼ SE¼ sec. 5	C. I. Wray	Dr	103.3	6	GI	do	do
370	SW¼ SE¼ sec. 10	C. L. Griffith, Sr.	Dr	17.6	6	GI	do	do
371	SE¼ NE¼ sec. 16	do	Dr	65.5	6	GI	do	do
372	NW¼ NW¼ sec. 18	B. D. Cossman	Dr	80.5	6	GI	Sand and gravel.	Ogallala fm.
(373)	NW¼ NE¼ sec. 22	R. B. Holt	Dr	4,967	....	I	Sandstone	Dockum group. (?).
374	NW¼ SW¼ sec. 22	do	Dr	......	6	I	do	do
375	NE¼ NE¼ sec. 29	A. B. Nelson	DD	14.1	6	GI	Sand	Ogallala fm.
376	SW¼ SW¼ sec. 29	R. B. Holt	Dr	12.4	6	GI	do	do
	T. 34 S., R. 43 W.							
377	NE¼ NE¼ sec. 21	E. J. Coulter	Dr	105.5	5	I	Sand and gravel.	do
378	SW¼ SW¼ sec. 32	M. C. Brisendine	Dr	91.4	6	GI	do	do
379	SE¼ NE¼ sec. 34	S. E. West	Dr	68.5	6	GI	do	do
	T. 34 S., R. 44 W.							
380	NW¼ SW¼ sec. 1	U. S. Government	Dr	216.4	3	I	Sand	Ogallala fm. (?).
381	SW¼ SW¼ sec. 23	do	Dr	123.5	6	GI	Sand and gravel.	Ogallala fm. (?).
382	NE¼ SE¼ sec. 29	G. F. Williams	Dr	96.5	6	GI	do	do

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level above measuring point (feet) (15)	Date of measure-ment (16)	Remarks (Yield given in gallons a minute; draw-down in feet) (17)
Cy,H	N	Top of casing, west side.	0.5	....	43.40	8-20-47	Abandoned, formerly a domestic and stock well.
Cy,W	S	Top of casing, east side.	.4	....	196.55	8-19-47	
Cy,W	S	Land surface	0	....	176	....	
F	S	....	....	....	....	....	Carrizo Springs, two springs. Estimated flow, 20.
Cy,W	S	Top of wooden pipe clamp, southwest side.	.6	....	119.24	8-25-47	
Cy,W	S	Top of pipe clamp, west side.	.4	....	69.19	8-25-47	
Cy,W	D,S	Top of pipe clamp, east side.	3.1	3,633.9	68.59	8-5-47	
Cy,W	S	Top of galvanized-iron plate over casing, south side.	-.2	3,575.2	38.11	7-24-47	
Cy,W	N	Top of pipe clamp, east side.	.3	3,575.9	57.52	9-2-47	Do.
Cy,W	S	do	1.3	3,759.7	95.80	8-5-47	
Cy,W	S	Top of metal disc over casing, north side.	.3	....	10.48	7-25-47	
N	N	Top of casing, south side.	.4	3,690.9	62.90	7-25-47	Abandoned, formerly a stock well.
Cy	N	Top of pipe clamp, east side.	.7	3,769.9	73.31	8-5-47	Abandoned, formerly a domestic and stock well.
F	S	Land surface	0	3,618.0	....	....	Estimated flow, less than 1. Formerly an oil test.
F	S	do	0	....	....	....	Estimated flow, less than 1.
Cy,H	D,S	Top of casing, east side.	1.3	3,599.3	10.42	7-25-47	
Cy,W	S	Top of pipe clamp, north side.	2.7	3,622.4	5.62	7-25-47	
N	N	Top of casing, south side.	.3	3,842.4	93.03	8-14-47	Abandoned, formerly a domestic and stock well.
Cy,W	D,S	Bottom of iron pipe clamp, northwest side.	.5	3,842.8	73.82	8-15-47	
N	N	Top of casing, east side.	.4	3,757.5	52.98	7-25-47	Do.
N	N	Top of casing, south side.	.6	4,015.4	201.75	8-14-47	Do.
N	N	Top of 2-inch pipe, east side.	5.1	3,959.3	107.76	8-15-47	Do.
Cy	N	Top of 1½-inch pipe, east side.	4.9	3,981.6	88.49	8-15-47	Do.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	T. 34 S., R. 45 W.							
(383)	NE ¼ NE ¼ sec. 7	Owner not known	Dr	229.5	....	......	Sand.......	Ogallala... fm.
384	NW ¼ NW ¼ sec. 8	M. H. O'Maley..	Dr	249.7	5	GI	do	do
385	NE ¼ NW ¼ sec. 11	U. S. Government	Dr	217.2	6	GI	do	do
386	SE ¼ SE ¼ sec. 19	do	Dr	281.2	6	GI	Sandstone	Cheyenne.. ss. mem.
(387)	SE ¼ SE ¼ sec. 25	T. E. O'Maley..	Dr	295	....	......	do	Dockum.... group(?)
388	NW ¼ NW ¼ sec. 26	J. P. Harper.....	Dr	140	6	GI	Sand.......	Ogallala... fm.
389	SE ¼ SE ¼ sec. 32	U. S. Government	Dr	184	5 ½	I	Sand and.. gravel.	do
	T. 34 S., R. 46 W.							
390	NE ¼ NE ¼ sec. 10	P.D. Miller......	Dr	424	6	I	Sandstone	Dakota..... ss.
(391)	SE ¼ NE ¼ sec. 10	A. T. & S.F...... Railway Co.	Dr	432	14, 10	I	do	Cheyenne ss. mem.
392	NE ¼ SE ¼ sec. 19	J. Deweese.......	Dr	197.5	5	GI	Sand and.. gravel.	Ogallala... fm.
393	NE ¼ NE ¼ sec. 34	U. S. Government	Dr	217.3	....	......	Sandstone	Dakota..... ss.
	T. 34 S., R. 47 W.		Dr					
394	SE ¼ SE ¼ sec. 1	C. J. and A....... Wolff.	Dr	297.4	6	GI	do	do
(395)	SW ¼ NW ¼ sec. 2	U. S. Government	Dr	420	6	I	do	Cheyenne ss. mem.
396	SW ¼ NW ¼ sec. 19	Lloyd Brown......	Dr	228.3	6	I	do	do
397	SE ¼ NE ¼ sec. 21	U. S. Government	Dr	320.0	5	I	do	do
	T. 34 S., R. 48 W.							
398	SW ¼ NW ¼ sec. 6	E. L. Collins....	Dr	125	6	I	Sand and gravel.	Ogallala... fm.
399	SW ¼ NW ¼ sec. 8	U. S. Government	Dr	122	6	I	do	do
400	NE ¼ NE ¼ sec. 12	do	Dr	302.8	3	I	Sandstone	Cheyenne.. ss. mem.
401	SW ¼ SE ¼ sec. 15.	Edward Wait.....	Dr	232.7	6	I	do	do
(402)	SW ¼ SE ¼ sec. 18	Ted Schuler......	Dr	133.8	5 ½	I	do	Dakota..... ss. (?).
403	SW ¼ sec. 20	W. L. Brown.....	Dr	50	6	....	do	Dakota ..ss.
404	SE ¼ SE ¼ sec. 26	U. S. Government	Dr	87.5	....	......	do	do
405	NE ¼ SW ¼ sec. 33	E. E. Wilson.....	Sp	......	....	......	Sand and sand- stone.	Alluvium... and Da- kota ss.
406	SW ¼ NW ¼ sec. 34	do	Sp	....	....	......	Sandstone	Dakota..... ss.

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level above measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute; drawdown in feet) (17)
Cy, W	D, S	Land surface........	0	....	240	....	
Cy	N	Top of casing, ... west side.	.7	4,274.0	239.61	8-14-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Top of pipe clamp, east side.	1.2	4,204.1	148.28	8-14-47	
Cy, W	S	Bottom of iron ring, east side.	.9	4,268.1	237.01	8-15-47	
Cy, W	D, S	Land surface........	0	....	220	....	
Cy, W	D, S	Top of pipe clamp, north side.	1.1	4,107.1	137.20	8-15-47	
Cy, W	S	Land surface........	0	4,148.2	154	....	
Cy, W	N	do	0	....	280	....	To be used as municipal supply for the town of Campo.
T	In	do	0	4,338.0	253	....	Reported yield, 100; drawdown, 12.
Cy, W, G	D, S	Bottom of pipe .... clamp, east side.	.1	4,313.6	149.36	10-20-47	
Cy, W	S	Bottom of 2-inch.... tee, east side.	1.2	4,280.8	203.37	10-20-47	
Cy	N	Top of pipe clamp, west side.	.5	....	293.16	8-18-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Land surface........	0	....	350	....	
Cy, W	D, S	Top of pipe clamp, north side.	.4	....	168.16	8-23-47	
Cy, W	S	Top of casing, ... north side.	0	....	295.92	8-22-47	
....	....	Land surface........	0	....	65	....	Data from W. P. A. log.
N	N	Top of casing, ... south side.	.8	4,587.5	87.26	9-27-49	Abandoned.
Cy, W	N	Top of 2-inch pipe connection, west side.	1.7	....	242.67	8-19-47	Abandoned, formerly a domestic and stock well.
Cy, W	D, S	Top of iron plate, ... northwest side.	1.0	....	193.37	8-23-47	
Cy	D, I	Top of iron rim, ... north side.	.4	4,525.1	105.33	8-23-47	Mill to be installed.
....	....	Land surface........	0	....	30	....	Data from W. P. A. log.
Cy, W	S	Top of pipe clamp, northwest side.	.8	....	67.63	8-12-47	
F	S	....	....	....	....	....	Spring known as J. J.'s tubs. Six or seven openings. Estimated flow, 6.
F	S	....	....	....	....	....	Capansky Springs. Estimated flow, 1.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of sup-ply	Depth of well (feet)	Diam-eter of well (in.)	Type of cas-ing	Principal water-bearing bed: Character of material	Principal water-bearing bed: Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	T. 34 S., R. 49 W.							
407	NE¼ SW¼ sec. 8	Dick Welch.......	Dr	216	8	I	Sandstone	Cheyenne.... ss. mem.
408	SE¼ SE¼ sec. 14	Roy Welch........	Dr	176.5	5½	I	do	Dakota ss.(?).
409	NW¼ SE¼ sec. 16	do	Sp	......	....	......	do	Dakota ss....
410	SW¼ SW¼ sec. 25	Ted Schuler.......	Dr	180	5¼	I	do	Dakota ss. or Cheyenne ss. mem.
411	NW¼ NW¼ sec. 26	do	Dr	29.9	5	I	Sand and.. gravel.	Alluvium(?)
	T. 34 S., R. 50 W.							
412	NE¼ NE¼ sec. 2	U.S. Government	Dr	43	36	R	do	Alluvium....
(413)	NW¼ SE¼ sec. 8	Fred Mizer.........	Dr	79.5	6	I	Sandstone	Dockum...... group.
414	SE¼ NW¼ sec. 13	Harley Sheldon...	Sp	......	....	......	do	Cheyenne.... ss. mem.
415	NW¼ SW¼ sec. 22	Cora Dunlap......	Dr	29.9	....	......	do	Dockum..... group.
(416)	NW¼ SW¼ sec. 32	Singer brothers...	Du	27	72	I	Sand and.. gravel.	Alluvium....
	T. 35 S., R. 41 W.							
(417)	NE¼ SE¼ sec. 16	R. B. Holt........	Dr	183.7	6	I	do	Ogallala..... fm.
418	SW¼ SW¼ sec. 18	D. W. Richards..	Dr	160	....	......	do	do
	T. 35 S., R. 42 W.							
419	SW¼ SE¼ sec. 9	Bowers Holt.......	Dr	149.9	6	GI	do	do
	T. 35 S., R. 43 W.							
(420)	NW¼ NE¼ sec. 1	R. B. Holt........	Dr	22.0	6	GI	do	do
421	SW¼ SW¼ sec. 17	S. S. Browning...	Dr	60.9	6	GI	do	do
	T. 35 S., R. 44 W.							
(422)	SW¼ SW¼ sec. 2	U.S. Government	Dr	92.2	6	GI	do	do
423	SW¼ SE¼ sec. 6	do	Dr	87.5	6	GI	do	do
	T. 35 S., R. 45 W.							
424	NW¼ SE¼ sec. 7	G. S. Shaw.......	Dr	230.7	6	GI	Sandstone	Cheyenne... ss. mem.
425	SW¼ NW¼ sec. 10	Ralph Harper.....	Dr	175.0	....	......	do	Dakota....... ss. (?).
	T. 35 S., R. 46 W.							
426	SW¼ SE¼ sec. 1	U.S. Government	Dr	115.6	5	GI	do	Dakota....... ss.

in Baca County, Colo.—Continued

Method of lift	Use of water	Measuring point: Description	Measuring point: Distance above or below (-) land surface (feet)	Measuring point: Height above mean sea level (feet)	Depth to water level above measuring point (feet)	Date of measurement	Remarks (Yield given in gallons a minute; drawdown in feet)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Cy, G	S	Land surface..........	0	....	205	....	
Cy, W	S	Top of casing, east... side.	1.2	....	146.07	8-23-47	
F	D	....	....	....	....	....	Estimated flow, ½.
Cy, W	S	Land surface..........	0	....	151	....	
Cy, W	S	Top of casing, ... west side.	.4	....	14.36	8-23-47	
Cy, W	S	Top of cement cover, east side.	1.0	....	23.44	8-25-47	
Cy, W	D	Top of concrete foundation, southeast side.	.6	....	54.15	8-25-47	
F	D, S	....	....	....	....	....	Estimated flow, 1½.
Cy, W	S	Top of casing, east.. side.	2.3	....	28.06	8-25-47	
Cy, W	D, S	Land surface..........	0	....	20	....	
Cy, W	S	Top of wooden pipe clamp, south side.	.4	3,671.1	150.75	8-24-47	
Cy, W	N	Top of 2-inch tee,... west side.	6.9	3,696.6	150	....	Abandoned, formerly a domestic and stock well.
Cy, W	D	Top of casing, ... south side.	.3	3,737.9	142.10	9-2-47	Well pumping at time of measurement.
Cy, W	S	Top of casing, ... west side.	2.3	3,674.1	14.82	7-25-47	
Cy, W	D, S	Top of pipe clamp,.. southwest side.	.4	3,805.6	52.90	8-15-47	
Cy, W	S	Bottom of pipe........ clamp, north side.	.2	3,913.5	85.73	8-15-47	
N	N	Top of casing, ... east side.	0	3,972.2	83.11	8-15-47	Abandoned, formerly a domestic and stock well.
N	N, O	Top of casing, ... east side.	.1	4,098.3	168.61	3-24-47	Do.
Cy, W	N	Top of pipe clamp, west side.	1.5	4,104.5	167.39	8-15-47	Do.
N	N	Top of hole in concrete, west side.	.3	4,138.2	91.96	8-15-47	Do.

Table 9.—*Records of wells and springs*

No. on pl. 1	Location	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (in.)	Type of casing	Principal water-bearing bed	
							Character of material	Geologic source
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
427	SE¼ SE¼ sec. 6	U. S. Government.	Dr	222.6	5	I	Sandstone.	Cheyenne ss. mem. (?).
428	NE¼ SW¼ sec. 11	do	Dr	53.1	5	I	do	Dakota ss.
	T. 35 S., R. 47 W.							
429	NE¼ NE¼ sec. 3	Roy F. Wait	Dr	208.5	4	GI	do	Cheyenne ss. mem.
430	SE¼ NW¼ sec. 5	W. N. Perkins	Dr	191	6	GI	do	do
(431)	do	do	Sp	......	....	......	do	Dakota ss.
432	NE¼ SE¼ sec. 9	Henry Hatchett	Dr	163	5	I	do	Cheyenne ss. mem.
	T. 35 S., R. 50 W.							
433	SE¼ SE¼ sec. 3	Singer brothers	Dr	102.8	....	......	Sand and sandstone.	Alluvium and Dockum group.
(434)	NW¼ NW¼ sec. 12	Eric Capansky	Dr	53.5	....	......	Sandstone	Dockum group.

in Baca County, Colo.—Continued

Method of lift (10)	Use of water (11)	Measuring point: Description (12)	Measuring point: Distance above or below (-) land surface (feet) (13)	Measuring point: Height above mean sea level (feet) (14)	Depth to water level above measuring point (feet) (15)	Date of measurement (16)	Remarks (Yield given in gallons a minute; drawdown in feet) (17)
Cy, W	S	Top of pipe clamp, south side.	.7	....	203.44	8-20-47	Abandoned, formerly a domestic and stock well.
Cy, W	S	Top of casing, ... east side.	.4	....	42.43	8-20-47	
Cy, W	D, S	Top of pipe clamp, northwest side.	.8	....	157.18	8-22-47	
N	N	Top of casing, ... west side.	.4	....	33.68	8-22-47	Mill not yet installed; to be a domestic and stock well.
F	D	....	....	....	....	....	Spring maintains level in trough, but never spills over.
N	N	Top of casing, ... north side.	.8	....	124.25	8-22-47	Mill not yet installed, to be a domestic and stock well.
Cy	N	Top of pipe clamp, .. northwest side.	1.0	....	62.65	8-23-47	Abandoned, formerly a domestic and stock well.
Cy, W	I	Top of pipe clamp, .. southeast side.	.7	....	46.51	8-23-47	Irrigates small garden.

MEASURED SECTIONS

The stratigraphic sections listed on the following pages were measured by the writer in Baca County. Additional sections are shown in figures 38 and 42. Many other sections were measured in Baca County and adjacent areas but owing to the poor exposures they are not sufficiently complete to warrant description in this report.

Section including Entrada sandstone in east bank of Carrizo Creek in SE¼SW¼ sec. 10, T. 34 S., R. 50 W.

	Thickness (feet)
Morrison formation	
10. Limestone, dense, gray. Weathers to small irregular plates	2.5
9. Interval covered. Probably underlain by soft varicolored siltstone	46.0
Entrada sandstone	
8. Sandstone, medium-grained, friable, poorly bedded and jointed, white, weathering to light-tan. Upper part becomes thinner bedded, darker colored, and finer grained. Forms sheer cliff	36.9
Dockum group	
7. Siltstone, slightly calcareous, blocky, light-tan to green	1.5
6. Limestone, silty, compact, hard, light gray-green. Platy and thinly banded in upper part. Brown stains along joint planes	1.0
5. Siltstone, fine sandy, platy, light-green	.1
4. Sandstone, fine-grained, silty, moderately hard, light gray-green. Weathers to light tan	3.2
3. Siltstone, thin-bedded to blocky, green to purple. Contains a little very fine sand and clay. Upper part largely blocky and breaks with conchoidal fracture. Narrow streaks of green stain	6.7
2. Sandstone, quartzitic, hard, gray. Contains thin streaks of gray siltstone along fractures. Highly ripple marked. Weathers brown	.2
1. Siltstone, blocky, bright-green and purple. Contains a little very fine sand. Brown stains along some fracture and joint planes. Base not exposed	4.0

Section of Morrison formation in road cut in SW¼ sec. 4 and SE¼ sec. 5, T. 35 S., R. 49 W.

	Thickness (feet)
Purgatoire formation	
Cheyenne sandstone member	
17. Sandstone, fine-grained, white. Locally stained yellow, brown, and purple. Weathers to smooth rounded surfaces	11.6
Morrison formation	
16. Siltstone, sandy, blocky, green and purple	7.2
15. Siltstone, fine sandy, compact, blocky, slightly calcareous, light-gray to nearly white. Massive and poorly jointed in lower part; thinly bedded to platy in upper part	2.3
14. Sandstone, fine-grained, calcareous, compact, hard, reddish-brown to yellowish-brown. Weathers to irregular white- and brown-stained slabs	3.0
13. Siltstone, light-green	1.4
12. Sandstone, in part thinly bedded, very hard, gray mottled with limonite stains. Weathers to gray-brown	4.3
11. Siltstone, fine sandy, blocky, light-gray to green and purple. Contains small lenses of hard siltstone that weathers to rounded blocks	15.5
10. Siltstone, sandy, hard, light-tan to gray. Grades in places into earthy, hard, fine-grained sandstone. Contains a few thin concretions of dense tan limestone	1.0
9. Siltstone, fine sandy, calcareous, blocky, light-gray to green and purple	7.7
8. Sandstone, fine- to medium-grained, calcareous, very hard, mottled yellow-brown and gray. Weathers to gray-tan and light brown	3.4
7. Siltstone, green and purple, largely covered	4.8
6. Siltstone, compact, light greenish-gray. Contains a little fine sand. Breaks with conchoidal fracture. Weathers to thin plates	.7
5. Siltstone, soft, green and purple, largely covered	2.1
4. Limestone, sandy, pinkish-brown	1.4
3. Limestone, crystalline, thin-bedded, light- to pinkish-brown. Weathers to hard rusty-brown irregular platy slabs	2.1
2. Limestone, massive, slightly banded, tan to light-brown. Contains thin seams and splotches of crystalline calcite. Weathers to thin irregular plates	5.0
1. Limestone, dense, platy, greenish-gray	.6
Total of Morrison formation exposed	62.5

Section of Dakota sandstone in Soldier Canyon in NE¼SW¼ sec. 21, T. 30 S., R. 50 W.

	Thickness (feet)
Dakota sandstone:	
12. Interval covered. Rubble indicates interval is underlain by brown sandstone and ironstone	5.0
11. Sandstone, fine-grained, friable, massive, light-tan to yellowish-buff with brown streaks and splotches. Lower part faintly bedded with individual beds 0.5 to 2 feet thick. Upper part is massive and crossbedded	42.1
10. Interval covered. Small dug pits in this interval revealed thin-bedded fine-grained sandstone and sandy to silty clay	6.2
9. Sandstone, fine-grained, mottled buff and brown. Ripple marks at top	.7
8. Interval largely covered. Appears to be mostly gray to brown thin-bedded crinkly fine-grained sandstone and a little sandy shale	28.5
7. Sandstone, fine-grained, light-buff to dark rusty-brown. Faint to moderate crossbedding in upper part. Weathered surfaces in lower part stained dark reddish brown to black. Forms massive ledge along canyon wall	20.4
6. Shale, silty, thin-bedded to blocky, dark-gray with yellow-green stains along joint planes. Contains a few pockets of yellow-green very fine-grained sandstone	.8
5. Clay-shale, thin-bedded, dark-gray to black. Yellow-green stains along joint planes	1.5
4. Sandstone, fine-grained, thin-bedded, tan to brown, alternating with dark blue-gray sandy shale	18.0

	Thickness (feet)
Dakota sandstone—Continued	
3. Sandstone, fine-grained, light-tan to buff, with irregular dark-brown to black streaks and splotches. Appears massive on fresh surfaces but displays irregular bedding planes on eroded surfaces	1.7
2. Clay-shale, laminated, dark-gray. Partly sandy in lower part. Lower part weathers to black; upper part weathers to light gray	3.8
1. Clay-shale, in part sandy, blocky, light-gray in lower part to dark blue-gray in upper part. Weathers to irregular rounded blocks	6.4
Total of Dakota sandstone exposed	135.1

Section of Meade(?) and Ogallala formations in railroad cut in N½ sec. 24, T. 29 S., R. 49 W.

	Thickness (feet)
Meade(?) formation:	
5. Clay and silt, brown to gray-brown. Contains a few small pebbles in lower part	10
4. Sand and gravel; crossbedded, light-tan. Gravel consists in part of irregular fragments of Dakota sandstone and Greenhorn limestone. Becomes coarser toward base. Erosional unconformity at base	17-20
Ogallala formation:	
3. Clay, sand, and caliche grading downward into clay containing a few lenses of sand. Reddish to buff in upper part and brown in lower part	12-15
2. Sand, fine to coarse, dull-red. Contains a little silt and clay and a few clay lenses	8
1. Sand, fine to coarse, containing a little fine gravel	27

LOGS OF WELLS AND TEST HOLES

Listed on the following pages are the logs of 144 wells and test holes in Baca County, including 18 test holes drilled for the Colorado Water Conservation Board in cooperation with the Ground Water Branch of the U. S. Geological Survey, and two test holes drilled by the State Geological Survey of Kansas in cooperation with the Ground Water Branch of the U. S. Geological Survey as a part of a study of the geology and ground-water resources of Morton County, Kans. Most of the logs were supplied by well drillers, well owners, and oil companies. The source of some of the oil-company logs is not shown, as requested by those companies. The logs are numbered by townships and ranges as are the wells and springs. (See p. 5.) The numbers of the logs are the same as those shown on the diagrammatic cross sections (pl. 2).

Logs entitled "sample logs" are those for which the well cuttings were collected and studied by the writer. The "drillers' logs" are logs obtained from written records of drillers or other sources, whereas "reported logs" are those based on the memory of drillers or well owners.

Data from the logs were used in compiling the diagrammatic cross sections shown in plate 2. The materials composing the Ogallala formation are shown accurately in the cross sections only at those wells or test holes where sample logs were available. Between those points the materials shown in the cross sections were interpolated. The logs of most of the wells or test holes that penetrated bedrock formations were drillers' logs and, although a great many of them were of sufficient accuracy to permit the determination of the contacts between the various formations, they generally were too brief to show details of lithology. For this reason standard symbols have been used to designate the lithology of the various bedrock formations in the diagrammatic cross sections. For example, the Morrison formation, which largely is shale, is shown by dashed lines indicating that the formation is made up entirely of shale because not enough sample logs were available to indicate the position, distribution, or thickness of the various beds of sandstone, limestone, and conglomerate contained in the formation. The logs of most of the wells and test holes penetrating the Purgatoire formation were sufficiently accurate to permit delineation of the Cheyenne sandstone and Kiowa shale members. The thickness of these members as shown in the cross sections are believed to be approximately correct.

The logs shown in the diagrammatic cross section are not the only sources of data used in preparing the cross section. Logs of many wells and test holes in areas not crossed by the various sections were used. Where the sections lie between two or more wells, the data from the logs of these wells were interpolated to determine the approximate position of the various formations at the section. In other areas the available logs were so numerous that it was not feasible to show them on the cross section. In the northeastern part of the cross section, for example, the irregular contact between the Dakota and Ogallala formations was delineated accurately on the basis of information from more than 300 logs covering a relatively small area. Selected logs from this group of 300 logs are shown in the following pages.

Many additional data used in the preparation of the cross sections were obtained from various oil companies with the agreement that the data could be used by the writer in preparing this report and that the location of the wells or test holes and the sources of information would not be divulged.

1. *Sample log of test hole 1 at the NW cor. sec. 3, T. 28 S., R. 43 W.*

[Surface altitude, 3,936 feet]

	Thickness (feet)	*Depth (feet)*
Ogallala formation:		
Clay, calcareous, plastic, light-tan, containing very fine to medium sand	7	7
Clay, sandy, calcareous, plastic, brown, and fine to medium sand, containing coarse sand and fine to medium gravel	4	11

	Thickness (feet)	Depth (feet)
Ogallala formation—Continued		
Clay, sandy, calcareous, light-tan, and fine to coarse sand, containing fine to medium gravel	7	18
Clay, sandy, plastic, tan	4	22
Clay, sandy, tan, and white caliche, containing coarse sand and and fine to medium gravel	11	33
Silt and sand; very fine to fine; calcareous, light-brown; contains a little clay	6	39
Clay, fine to coarse sand, and fine to medium gravel; light-tan, contains light-cream caliche. Few thin beds of gravel in lower part	14	53
Gravel and sand; fine to coarse; poorly sorted	15	68
Clay, sandy, calcareous, plastic, light-tan	8	76
Clay, calcareous, plastic, and very fine to coarse sand, containing fine to medium gravel; light-tan	11	87
Sand, fine to very fine, calcareous, compact, containing silt; light-tan	4	91
Clay, sandy, calcareous, plastic, light-tan	7	98
Sand, very fine to coarse, in part calcareous, light-tan. Sand becomes coarser and contains fine gravel in lower part	23	121
Gravel and sand; fine to coarse; interbedded with layers of coarse gravel. Contains thin stringers of sandy clay at depths of 125, 150, 167, and 171 feet. Pebbles derived largely from igneous rocks but many are reworked fragments of Dakota sandstone	119	240
Gravel, coarse, well-sorted	15	255
Dakota sandstone:		
Sandstone, very fine to medium, hard, white, light-tan, and brown	5	260
Clay, plastic, tan, containing a little sandstone	5	265

2. *Sample log of test hole 2 at the NW cor. sec. 6, T. 28 S., R. 44 W.*

[Surface altitude, 4,168 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, sandy, in part calcareous, plastic, and fine to coarse sand	12	12
Caliche, sandy, and fine to coarse sand; light-tan to cream	14	26
Clay, sandy, calcareous, fine to coarse sand, and fine to medium gravel; well-cemented, tan	12	38
Gravel, fine to coarse, containing sand; brown. Stringer of clay at 39 feet	22	60
Clay, sandy, calcareous, plastic, containing a little sand and gravel; light-tan	14	74
Sand and gravel; fine to coarse; contains a little calcareous clay; tan	10	84
Caliche and clay; sandy, light-tan	6	90
Gravel and sand; fine to coarse; poorly sorted; contains a little sandy clay	4	94
Gravel, fine to coarse, and sandy caliche; interbedded	16	110
Sand, fine, to gravel, medium; contains calcareous cement and a little coarse gravel; light-brown	24	134
Sand, very fine to medium, caliche, and calcareous clay; contains fine gravel	26	160
Sandstone, fine-grained, white to tan, containing light-tan clay	10	170
Sandstone, fine- to medium-grained, brown, containing a little clay	10	180

3. *Sample log of test hole 3 at the NE cor. sec. 19, T. 29 S., R. 46 W.*

[Surface altitude, 4,379 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, sandy, plastic	2	2

	Thickness (feet)	Depth (feet)
Ogallala formation—Continued		
Caliche, clay, and fine to coarse sand, containing fine to medium gravel; tan	8	10
Gravel, fine to medium, and fine to coarse sand; in part cemented with lime	9	19
Clay, fine to coarse sand, and fine to medium gravel; contains caliche	22	41
Dakota sandstone:		
Shale, black, containing fine- to very fine-grained dark-gray and brown sandstone	3	44
Sandstone, fine- to very fine-grained, tan, brown, and rusty-brown	11	55
Sandstone, fine-grained, brown, and light-gray sandy plastic clay	3	58

4. *Sample log of test hole 4 at the SW cor. sec. 21, T. 29 S., R. 47 W.*

[Surface altitude, 4,527 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, calcareous, plastic, and fine to medium sand; light-brown	7	7
Clay, calcareous, plastic, light-tan, and very fine to coarse sand; contains gravel in lower part	11	18
Sand and gravel; fine to coarse; poorly sorted; light-tan; cemented with calcareous silt and clay	4	22
Sand and gravel; fine to coarse; cemented with calcium carbonate to form mortar beds	11	33
Gravel and sand; fine to coarse; interbedded with thin layers of light-tan plastic clay	8	41
Sand and gravel; fine to coarse; poorly sorted; contains a little calcareous silt and clay	29	70
Clay, plastic, and very fine to coarse sand; contains fine gravel and caliche; light-tan	12	82
Sand and gravel; fine to coarse; poorly sorted; contains a little calcareous clay; light-tan	4	86
Clay, sandy, calcareous, plastic, and fine to coarse sand; contains fine to medium gravel	7	93
Sand and gravel cemented with calcium carbonate to form mortar bed. Sample also contains gray to light-tan hard fine sandy to very fine sandy limestone	7	100
Dakota sandstone:		
Clay, slightly calcareous, soft, plastic, yellow-tan to tan and gray, containing white to light-tan and brown fine-grained sandstone	13	113
Sandstone, fine-grained, calcareous, very hard, white, light-tan, and brown	2	115
Shale, plastic, black, containing thin strips of very fine-grained sandstone and blue-gray limestone	25	140
Sandstone, very fine to medium-grained, gray and brown	3.5	143.5
Shale, blocky, blue-black	11.5	155
Shale, sandy, plastic, dark-gray	3	158
Shale, blue-black, and fine-grained gray sandstone	4.5	162.5
Sandstone, fine-grained, hard	2.5	165

5. *Sample log of test hole 5 at the SE cor. sec. 33, T. 30 S., R. 42 W.*

[Surface altitude, 3,766 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, fine sandy to plastic, calcareous, light-tan; contains medium to coarse sand in lower part	12	12

	Thickness (feet)	Depth (feet)
Dakota sandstone:		
Sandstone, fine- to very fine-grained, soft, varicolored; contains a little sandy clay	29	41
Sandstone, fine- to very fine-grained, hard, yellow to tan and brown	6	47
Sandstone, fine- to very fine-grained, hard to soft, containing soft clay; varicolored	13.5	60.5
Shale, in part fine sandy, liminated, dark-gray	19.5	80

6. *Sample log of test hole 6 at the NE cor. sec. 4, T. 31 S., R. 41 W.*

[Surface altitude, 3,668 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, sandy to silty, calcareous, plastic, dark-brown	14	14
Clay, caliche, and fine to coarse sand; light-tan	7	21
Dakota sandstone:		
Sandstone, fine-grained, friable, tan, rusty, and white, containing gray plastic clay	11	32
Shale, silty, laminated, gray	6	38
Sandstone, fine-grained, tan to rusty-brown	3	41
Sandstone, fine-grained, light-gray	3.5	44.5
Sandstone, very fine- to fine-grained, rusty-brown, interbedded with light-gray sandstone	13	57.5
Sandstone, very fine- to fine-grained, varicolored, interbedded with varicolored sandy shale	20.5	78
Sandstone, very fine- to fine-grained, light-gray to light-tan, containing thin stringers of clay	25	103
Sandstone, fine-grained, tan to dark-gray	13.5	116.5
Purgatoire formation(?):		
Kiowa shale member(?):		
Shale, soft, blue-black	3.5	120

7. *Sample log of test hole 7 at the SE cor. sec. 33, T. 31 S., R. 41 W.*

[Surface altitude, 3,657 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay and very fine to coarse sand; brown; contains caliche	9	9
Caliche, clay, and very fine to coarse sand; light-tan; contains fine gravel in lower part	32	41
Sand, very fine, to gravel, medium; cemented with calcium carbonate to form mortar beds. Thin bed of unconsolidated gravel at 58 feet	20	61
Clay, plastic, and very fine to fine sand; brown	14	75
Gravel, fine to coarse, containing a little sand. Gravel comprised largely of reworked fragments of sandstone and caliche	4	79
Clay, sandy, reddish-brown	6	85
Dockum group(?):		
Sandstone, fine-grained, friable, red, containing a little hard dark-brown sandstone	2	87
Sandstone, very fine-grained, red	3	90

8. *Sample log of test hole 8 at the SW cor. sec. 34, T. 31 S., R. 42 W.*

[Surface altitude, 3,773 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, sandy, and silty, dark-tan	3	3

	Thickness (feet)	Depth (feet)
Ogallala formation—Continued		
Clay, caliche, and fine to coarse sand; light-tan	14	17
Caliche, sandy, cream-tan	11	28
Gravel and sand; fine to coarse; light-brown	12	40
Caliche, sandy clay, and fine to coarse sand; light-tan	15	55
Sand, very fine to coarse, light-tan	3	58
Caliche, clay, and fine to coarse sand; light-tan	6	64
Sand and gravel; fine to coarse; in part cemented with calcium carbonate; poorly sorted	4	68
Caliche, sandy, in part hard and dense, white	3	71
Dockum group(?): Clay, silty, red, containing thin beds of very fine-grained white sandstone	9	80

9. *Sample log of test hole 9 at the SW cor. sec. 33, T. 31 S., R. 43 W.*

[Surface altitude, 3,928 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, calcareous, and fine to coarse sand; reddish-brown	8	8
Clay and very fine to medium sand; contains caliche	24	32
Clay, silty, blocky, and very fine sand; yellow-tan	6	38
Dakota sandstone:		
Clay, plastic, varicolored, and brown fine-grained sandstone	15	53
Sandstone, fine- to medium-grained, containing thin layers of clay; rusty-brown	2	55
Clay, silty to very fine sandy, varicolored	3	58
Sandstone, fine- to medium-grained, tan to red-brown, and gray to tan sandy clay	3	61
Shale, silty, hard, brittle, blue-gray	4	65
Sandstone, fine- to medium-grained, light-gray, containing thin beds of light-gray clay. Material becomes tan to brown in lower part	23	88
Sandstone, fine- to medium-grained, hard, interbedded with light-gray sandstone and sandy clay	5	93
Sandstone, very fine-grained, silty, containing a little clay; yellow-tan	2	95
Sandstone, very fine- to fine-grained, varicolored, containing thin strips of clay	19	114
Sandstone, very fine- to fine-grained, hard, tan and brown	8.5	122.5
Sandstone, fine- to medium-grained, calcareous, hard, tan	12.5	135
Sandstone, fine- to medium-grained, rusty-brown, containing thin strips of clay in lower part	36	171
Dockum group(?): Sandstone, fine- to medium-grained, containing siltstone and very fine-grained sandstone; red	4	175

10. *Sample log of test hole 10 at the SE cor. sec. 32, T. 32 S., R. 43 W.*

[Surface altitude, 3,940 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, calcareous, and fine to coarse sand; light-brown	4	4
Caliche and very fine to coarse sand; light-tan. Very hard in lower 4 feet	16	20
Sand, very fine to medium, in part consolidated, containing hard sandy caliche	12	32
Caliche and very fine to medium sand	3	35
Clay and very fine to medium sand; light-tan	10	45
Sand, fine to coarse, containing thin layers of lime-cemented sand and gravel	6	51

	Thickness (feet)	Depth (feet)
Ogallala formation—Continued		
Clay, sandy to silty with fine to medium sand; light-tan; contains fragments of caliche	22	73
Sand, very fine to coarse, containing clay; tan	5	78
Gravel, fine to coarse, containing fine to coarse sand. Thin layers of clay at about 85 feet	15	93
Sand, fine to coarse, containing thin layers of tan calcareous clay and beds of fine to medium gravel	25	118
Clay, sandy, plastic, light-tan, containing a little sand and gravel	14	132
Clay, sandy, calcareous, light-tan, containing thin beds of sand and gravel	18	150
Sand, very fine to medium, grayish-tan, containing silt	12	162
Clay, sandy, light-tan	13	175
Sand, very fine to fine, reddish-tan, containing silt and caliche. Contains a few pebbles of reworked Dakota sandstone	17	192
Dakota sandstone:		
Sandstone, fine- to very fine-grained, in part calcareous, yellowish-brown and reddish-brown	5	197
Sandstone, fine- to very fine-grained, varicolored	3	200

11. *Sample log of test hole 11 at the NW cor. sec. 8, T. 32 S., R. 48 W.*

[Surface altitude, 4,810 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, plastic, brown, containing fine to medium gravel and a few fragments of caliche	13	13
Caliche, white, containing fine to coarse sand. Sand is largely medium-grained	5	18
Caliche, hard, white to light-tan, containing fine sand	13	31
Caliche, white, containing fine sand to medium gravel. Thin beds of brownish-tan clay	8	39
Sand, fine to medium, dark-tan, containing a little silt	5	44
Caliche, containing fine sand to medium gravel; light-tan	8	52
Sand, fine, to gravel, fine; poorly sorted; light-tan	6	58
Sand, medium, to gravel, coarse; poorly aorted; light-tan; contains a little fine sand and caliche	2	60
Clay, plastic, containing silt and fine to coarse sand; reddish-brown	11	71
Sand, fine to medium, well-sorted, dark-tan	8.5	79.5
Sand, fine to medium, containing caliche and clay; yellowish-tan	11.5	91
Sand, fine to medium, well-sorted, containing coarse sand and fine gravel in lower part; light-brown	6	97
Sand, fine to medium, well-sorted, tan	9	106
Clay, plastic, containing fine to coarse sand and a little caliche	3	109
Sand, very fine to coarse, containing a little clay and caliche. Caliche increases downward	14	123
Sand, fine, to gravel, fine; poorly sorted; contains a little clay. Some medium gravel between 130 and 135 feet	24	147
Gravel, medium, to sand, coarse; poorly sorted; contains reworked fragments of sandstone	9	156
Sand, fine to coarse, cemented with calcium carbonate to form mortar bed	2	158
Sand, fine, to gravel, fine, poorly sorted; light-tan	2	160
Sand, fine, to gravel, fine, cemented with calcium carbonate to form mortar bed; whitish-tan. Fine sand increases in lower part	2.5	168.5
Sand, medium, to gravel, fine; poorly sorted; light-tan; contains fragments of reworked Dakota sandstone	5.5	174
Clay, plastic, tan to yellow-tan and rusty-tan, containing a little fine to medium sand	9	183
Clay, slightly calcareous, plastic, light-tan, containing very fine to coarse sand	2	185
Dakota sandstone: Sandstone, very fine-grained, compact, hard, varicolored	3	190

12. *Sample log of test hole 12 at the NE cor. sec. 4, T. 33 S., R. 41 W.*

[Surface altitude, 3,642 feet]

	Thickness (feet)	*Depth (feet)*
Ogallala formation:		
Clay, slightly calcareous, plastic, containing very fine to coarse sand; brown	5	5
Caliche, containing fine sand to medium gravel; light-tan	10	15
Sand, very fine to fine, calcareous, containing silt and a little medium to coarse sand; light-tan	3	18
Caliche, sandy, light-tan	5	23
Clay, sandy to gravelly, calcareous, cream-colored	8	31
Caliche, sandy, very hard, containing thin stringers of clay at 35 feet	21	52
Gravel, medium, to sand, fine, light-tan	3	55
Clay, sandy, in part calcareous, plastic, light-tan, containing thin stringers of hard caliche at about 68 feet	25	80
Caliche, fine to medium sandy, white, and yellowish-tan fine sand	4	84
Sand, fine, containing fragments of caliche, red quartz, and gypsum. Material derived largely from underlying red beds	10	94
Dockum group(?):		
Sandstone, fine-grained, white to brown and red	12	106
Sandstone, very fine-grained, and siltstone; brick-red	4	110

13. *Sample log of test hole 13 at the NW cor. sec. 5, T. 33 S., R. 42 W.*

[Surface altitude, 3,845 feet]

	Thickness (feet)	*Depth (feet)*
Ogallala formation:		
Clay, plastic, silty to very fine sandy; brown	5	5
Clay, very fine to medium sandy, calcareous, plastic, containing a little silt; tan	6	11
Caliche, sandy, hard, light-tan	22	33
Gravel, coarse, to sand, fine, light-tan	4	37
Caliche, sandy, hard, light-tan, containing clay in lower part	13	50
Sand, very fine to medium, compact, rusty-tan, containing thin stringers of caliche	10	60
Clay, very sandy, calcareous, plastic, light-tan	7	67
Gravel, medium, to sand, very fine; poorly sorted; contains thin stringers of blocky clay; dark-tan	4	71
Clay, calcareous, plastic, and very fine to medium sand; light-tan	9	80
Sand, fine to coarse, calcareous, dark-tan	2	82
Clay, very fine to medium sandy, plastic, light-tan	18	100
Clay, plastic to blocky, tan interbedded with very fine to coarse sand	10	110
Gravel, medium, to sand, fine; poorly sorted; light-brown	3	113
Clay, very fine to medium sandy, plastic, rusty-tan	3	116
Sand, very fine, to gravel, fine; tan; contains thin stringers of caliche	14	130
Gravel, medium, to sand, fine; poorly sorted; light-brown	3	133
Clay, very fine to medium sandy, calcareous, plastic, light-tan	9	142
Sand, very fine, to gravel, medium; tan	3	145
Clay, very fine to fine sandy, plastic to blocky, light-tan	5	150
Sand, very fine to coarse, poorly sorted	6	156
Sand, fine to medium, containing a little silt and clay	5	161
Clay, very fine to fine sandy, tan	9	170
Sand, very fine to coarse, soft, rusty-tan	22	192
Clay, very sandy, calcareous, plastic, tan to brown	9	201
Clay, sandy, calcareous, rusty-tan, interbedded with thin stringers of caliche	11	212
Sand, very fine to medium, clayey, rusty-tan, interbedded with thin stringers of caliche	17	229
Caliche, sandy, white to light-tan	2	231

	Thickness (feet)	Depth (feet)
Dakota sandstone:		
Sandstone, fine- to medium-grained, slightly calcareous, very hard, white to light-tan	5	236
Sandstone, fine- to medium-grained, slightly calcareous, light-tan to yellowish-tan, containing tan clay	5	241
Sandstone, very fine- to medium-grained, varicolored, interbedded with brown blocky silty clay	26	267
Sandstone, very fine- to fine-grained, in part faintly calcareous, compact to friable, varicolored, interbedded with brown sandy clay	5	272
Dockum group(?): Sandstone, fine- to medium-grained, hard, reddish-brown, grading downward into brick-red siltstone	3	275

14. *Sample log of test hole 14 in the NE¼NW¼ sec. 1, T. 33 S., R. 44 W.*

[Surface altitude, 4,002 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, sandy, plastic, brown, becoming highly calcareous in lower part	7	7
Sand, fine, to gravel, coarse; cemented with calcium carbonate to form mortar bed	6	13
Gravel, coarse, to sand, fine; poorly sorted; brown	3	16
Gravel, coarse, to sand, very fine; cemented with calcium carbonate to form mortar bed	8	24
Caliche, sandy, light-tan	3	27
Clay, sandy, calcareous, plastic, rusty-tan	3	30
Sand, very fine to medium, well-sorted, tan	2	32
Caliche, sandy, whitish-tan	4	36
Sand, fine to medium, rusty-brown, interbedded with tan sandy clay and brown blocky clay	20	56
Sand, fine, to gravel, coarse, containing thin stringers of sandy clay	5	61
Sand, very fine to coarse, poorly sorted, containing thin stringers of brown blocky clay	4	65
Sand, very fine to coarse, tan	8	73
Clay, sandy, plastic, interbedded with blocky clay and fine sand	6	79
Sand, very fine, to gravel, coarse; poorly sorted; tan	6	85
Caliche, sandy, dense, hard, gray	2	87
Sand, very fine to coarse, containing thin layers of calcareous clay in lower part; tan	8	95
Gravel, fine to medium, containing a little fine to coarse sand; light-tan	6	101
Gravel, fine to coarse, interbedded with fine to coarse sand and containing a few thin layers of calcareous sandy clay	9	110
Sand, fine to coarse, well-sorted, dark-tan	4	114
Clay, sandy, plastic, light-tan	3	117
Gravel and sand; fine to coarse; poorly sorted; light-tan	6	123
Sand, very fine to medium, well-sorted, tan; contains a little coarse sand	8	131
Sand, very fine, to gravel, fine; tan; contains thin layers of calcareous clay	10	141
Gravel, fine to medium, containing fine to coarse sand; rusty-tan	3	144
Clay, sandy, calcareous, light-tan	3	147
Dakota sandstone: Sandstone, fine-grained, varicolored	13	160

15. *Sample log of test hole 15 at the NE cor. sec. 4, T. 33 S., R. 47 W.*

[Surface altitude, 4,561 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay, very fine to medium sandy, in part calcareous, containing silt; brown	7	7

	Thickness (feet)	Depth (feet)
Ogallala formation—Continued		
Clay, very fine to medium sandy, calcareous, light-tan. Becomes increasingly calcareous downward	26	33
Clay, very fine to medium sandy, plastic	3	36
Clay, sandy, highly calcareous, plastic, containing a little coarse sand and gravel in lower part	8	44
Gravel, fine, to sand, medium. Cemented with calcium carbonate	11	55
Sand, very fine to medium, calcareous, containing a little coarse sand; tan	5	60
Clay, sandy, calcareous, light-tan	11	71
Sand, very fine to coarse, containing silt; light-tan	9	80
Clay, sandy, containing a little gravel and blocky clay; light-tan	35	115
Sand, coarse, and gravel, fine; contains a few thin layers of blocky clay. A little fine to medium sand in lower part	21	136
Clay, sandy, calcareous, plastic, light-tan	27	163
Caliche, fine sandy, light-pink to white	1	164
Dakota sandstone: Sandstone, fine-grained, friable, tan to white	11	175

16. *Sample log of test hole 16 at the SW cor. sec. 20, T. 33 S., R. 48 W.*

[Surface altitude, 4,748 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay and very fine to coarse sand; calcareous; dark-brown	8	8
Caliche, fine to coarse sandy, whitish-tan	26	34
Caliche, fine sandy to gravelly, light-tan	9	43
Caliche, containing fine to coarse sand; light-tan	11	54
Caliche, very fine to medium sandy, cream-colored	3	57
Clay, sandy, plastic, brown	17	74
Clay, sandy, plastic, in part calcareous, containing a few thin layers of blocky clay; brown	10	84
Clay, in part sandy and calcareous, containing a little gravel and sand; light-brown	2	86
Gravel, coarse, to sand, medium; dark-brown; contains fragments of reworked Dakota sandstone	11	97
Clay, sandy to silty, light-brown	6	103
Gravel, coarse, to sand, medium; dark-brown; contains many fragments of reworked Dakota sandstone	23.5	126.5
Clay, sandy, calcareous, plastic, light-tan	16.5	143
Gravel, coarse, to sand, medium, containing a little calcareous fine sandy clay; tan	6	149
Clay, sandy to silty, plastic, containing a little gravel and blocky clay	27	176
Clay, in part silty, calcareous, plastic, light-tan, becoming sandy in lower part	17	193
Clay, fine sandy, calcareous, tan, containing a few fragments of reworked Dakota sandstone	3	196
Clay, in part sandy, plastic, pink to tan	31	227
Dakota sandstone: Sandstone, fine-grained, hard, varicolored, containing a little tan plastic clay	3	230

17. *Sample log of test hole 17 at the SW cor. sec. 2, T. 35 S., R. 44 W.*

[Surface altitude, 3,900 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Sand and gravel; fine to coarse; silty; poorly sorted; in part calcareous; brown	7	7
Sand and gravel; fine to coarse; poorly sorted; cemented with calcium carbonate; light-tan	5	12

	Thickness (feet)	Depth (feet)
Ogallala formation—Continued		
Gravel, coarse, to sand, medium; poorly sorted. Several thin layers cemented with calcium carbonate. Much reworked Dakota sandstone	57.5	69.5
Clay, sandy to silty, calcareous, plastic, light-brown	10.5	80
Sand, fine to medium, well-sorted, light-tan. Little clay in upper part	10	90
Gravel and sand; fine to coarse; well-sorted; light-tan	5	95
Sand, fine, to gravel, fine; cemented with calcium carbonate to form mortar bed	5	100
Sand, very fine to fine, well-sorted, light-tan	15	115
Clay, sandy, in part calcareous, plastic, light yellow-tan	11	126
Clay, in part sandy, calcareous, plastic, light-tan	5	131
Sand, very fine to medium, well-sorted, containing thin stringers of sandy clay; light-tan	5	136
Clay, blocky, interbedded with calcareous sandy clay; rusty-tan	6	142
Sand, very fine to coarse, containing silt and clay; light-tan	26	168
Clay, sandy, plastic, interbedded with hard blocky clay; calcareous; grayish-tan	4	172
Sand, very fine to coarse, containing silt and clay; yellowish-tan	4	176
Gravel, medium, to sand, fine; poorly sorted; rusty-brown. Much reworked Dakota sandstone	3	179
Sand, very fine to coarse, rusty-brown, containing thin layers of blocky calcareous clay	5	184
Gravel, coarse, to sand, fine; brown. Fragments are predominantly reworked Dakota sandstone but also consist of quartz and reworked caliche	71	255
Dakota sandstone(?):		
Sandstone, very fine-grained, argillaceous, soft, light-gray to tan	3	258
Sandstone, very fine- to fine-grained, yellow to pink, and light-tan compact clay	16	274
Sandstone, very fine- to fine-grained, varicolored	4	278
Dockum group: Sandstone, very fine- to medium-grained, argillaceous, brick red	2	280

18. *Sample log of test hole 18 at the SW cor. sec. 6, T. 35 S., R. 44 W.*

[Surface altitude, 3,985 feet]

	Thicknses (feet)	Depth (feet)
Ogallala formation:		
Clay, sandy to gravelly, plastic, brown, containing nodules of caliche	7	7
Clay, sandy to silty, in part calcareous, plastic, dark-brown	7	14
Gravel, coarse, to sand, fine; poorly sorted; light-brown	12	26
Sand, very fine to fine, clayey, tan	4	30
Sand, very fine, to gravel, coarse; poorly sorted; contains thin layers of clay; light-brown	4	34
Sand, very fine to medium, well-sorted, containing thin stringers of caliche; tan	11	45
Sand, medium, to gravel, fine; contains very fine to fine sand. Thin layer of calcareous clay at about 56 feet	24	69
Clay, calcareous, blocky, interbedded with plastic calcareous sandy clay	5	74
Gravel, medium, to sand, fine; light-tan	12	86
Sand, very fine, to gravel, medium. Some layers cemented with calcium carbonate to form mortar beds	13	99
Sand, very fine to medium, well-sorted, tan	5	104
Clay, sandy, plastic, tan	3	107
Sand, very fine to coarse, containing thin layers of plastic sandy clay; light-tan	9	116
Sand, fine to coarse, light-brown. Many fragments of reworked Dakota sandstone	10	126

	Thickness (feet)	Depth (feet)
Ogallala formation—Continued		
Sand, fine, to gravel, coarse; contains a few stringers of caliche and sandy clay	11	137
Sand, fine, cemented with calcium carbonate. Contains a little calcareous sandy clay	2	139
Sand, medium, to gravel, fine; well-sorted; light-tan	2	141
Caliche, sandy to gravelly, containing a little blocky calcareous clay	2	143
Sand, fine, to gravel, coarse; poorly sorted. Some fragments of reworked Dakota sandstone	15	158
Sand, very fine to medium, clayey, interbedded with fine to coarse sand, fine gravel, and a little blocky clay	2	160
Clay, very fine sandy to silty, calcareous, plastic, rusty-tan	7	167
Sand, very fine to fine, well-sorted, containing thin layers of fine sandy clay; reddish-tan	5	172
Clay, sandy, in part calcareous, light-tan to reddish-tan	8	180
Gravel, medium, to sand, fine; poorly sorted. Largely material reworked from Dakota sandstone	5	185
Dakota sandstone(?):		
Sandstone, fine-grained, varicolored	1.5	186.5
Clay, sandy, calcareous, reddish-tan	4.5	191
Clay, fine sandy, calcareous, very soft, light-tan to reddish-tan	6	197
Clay, very fine sandy, soft, plastic, varicolored	2.5	199.5
Dockum group(?): Siltstone, very fine sandy, slightly calcareous, brick-red	0.5	200

19. *Driller's log of test hole in the SW¼NW¼SW¼ sec. 4, T. 28 S., R. 41 W.*

[Surface altitude, 3,539 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand, gravel, and clay	178	178
Dakota sandstone: Sandstone and shale	12	190

20. *Driller's log of well in the SE¼SW¼ sec. 4, T. 28 S., R. 41 W.*

[Drilled by L. W. Collins]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Soil and clay	8	8
Gravel and clay	25	33
Rock	2	35
Sand, fine, and clay	8	43
Cement rock (probably consolidated sand and gravel)	4	47
Gravel	9	56
Cement rock	5	61
Gravel	9	70
Cement rock	3	73
Sand, fine	16	89
Boulders and sand, coarse	3	92
Sand, coarse	10	102
Sand, coarse, containing boulders and clay	18	120
Gravel (water from 126 to 138 feet)	18	138

21. *Driller's log of well in the SW¼SW¼ sec. 5, T. 28 S., R. 41 W.*

[Drilled by L. W. Collins]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Soil and clay	10	10
Gyp	15	25

	Thickness (feet)	Depth (feet)
Dakota sandstone—Continued		
Joint clay, soft	5	218
Joint clay, hard	9	227
Shell rock	4	231
Sand rock (water between 240 and 265 feet)	41	272
Gravel	14	39
Clay, tough, yellow-brown	10	49
Sand, containing boulders	18	67
Joint clay	4	71
Clay, sandy	16	87
Joint clay	2	89
Sand and gravel	24	113
Cement rock	4	117
Clay, sandy	10	127
Joint clay, yellow	8	135
Dakota sandstone:		
Sandstone and clay	13	148
Shale, soft, black	18	166
Shale, hard, black	8	174
Shell rock and joint clay	4	178
Sand rock and clay, yellow	13	191
Shale, gray	5	196
Rock, sandy	2	198
Shale, sticky, black	2	200
Shale, sticky, gray	8	208
Shale rock	5	213

22. *Driller's log of test hole at the NE cor. sec. 6, T. 28 S., R. 41 W.*

[Surface altitude, 3,654 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and gravel	100	100
Dakota sandstone: Shale	50	150

23. *Driller's log of test hole at the NE cor. sec. 16, T. 28 S., R. 41 W.*

[Surface altitude, 3,669 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	60	60
Sand and gravel with clay strips	145	205
Dakota sandstone:		
Sandstone and shale	12	217
Sandstone, hard	2	219
Sandstone and shale	11	230

24. *Driller's log of test hole in the NW¼NW¼NW¼ sec. 17, T. 28 S., R. 41 W.*

[Surface altitude, 3,680 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and gravel	150	150
Dakota sandstone: Shale and sandstone	50	200

25. *Driller's log of test hole in the SW¼NW¼SW¼ sec. 17, T. 28 S., R. 41 W.*

[Surface altitude, 3,693 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand, gravel, and clay	138	138
Dakota sandstone: Shale and sandstone	32	170

26. *Driller's log of test hole at the NE cor. sec. 21, T. 28 S., R. 41 W.*

[Surface altitude, 3,671 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	35	35
Sand and gravel with clay strips	53	88
Clay	32	120
Sand, gravel, and clay	45	165
Dakota sandstone: Shale with sandstone strips	25	190

27. *Driller's log of test hole in the NE¼SE¼NE¼ sec. 28, T. 28 S., R. 41 W.*

[Surface altitude, 3,680 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay with few sand streaks	80	80
Sand and gravel	74	154
Dakota sandstone: Sandstone and shale	26	180

28. *Driller's log of test hole at the SE cor. sec. 28, T. 28 S., R. 41 W.*

[Surface altitude, 3,672 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay and sand	70	70
Sand and gravel with clay strips	60	130
Dakota sandstone: Shale and sandstone	30	160

29. *Driller's log of test hole at the SW cor. sec. 31, T. 28 S., R. 41 W.*

[Surface altitude, 3,710 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Sand	30	30
Sand and gravel	60	90
Dakota sandstone:		
Sandstone	10	100
Shale	20	120
Shale with few sand streaks	70	190

30. *Driller's log of test hole in the NE¼NW¼NE¼ sec. 32, T. 28 S., R. 41 W.*

[Surface altitude, 3,693 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and clay	132	132
Dakota sandstone: Sandstone	28	160

31. *Driller's log of test hole at the SW cor. sec. 32, T. 28 S., R. 41 W.*

[Surface altitude, 3,690 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Shale and sand	40	40
Sand and gravel with shale strips	50	90
Dakota sandstone: Shale with sandstone strips	40	130

32. *Driller's log of test hole at the NW cor. sec. 32, T. 28 S., R. 41 W.*

[Surface altitude, 3,695 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and clay	120	120
Dakota sandstone: Sandstone and shale	40	160

33. *Driller's log of test hole at the SW cor. sec. 33, T. 28 S., R. 41 W.*

[Surface altitude, 3,638 feet]

	Thicknese (feet)	Depth (feet)
Ogallala formation:		
Sand and gravel	50	50
Shale and sand	15	65
Dakota sandstone: Sandstone and shale	45	110

34. *Driller's log of test hole at the NW cor. sec. 1, T. 28 S., R. 42 W.*

[Surface altitude, 3,722 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand, gravel, and clay	160	160
Dakota sandstone: Shale with sandstone strips	30	190

35. *Driller's log of test hole at the SW cor. sec. 1, T. 28 S., R. 42 W.*

[Surface altitude, 3,736 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay, sand, and gravel	130	130
Dakota sandstone: Clay containing sandy strips	50	180

36. *Driller's log of test hole at the NE cor. sec. 3, T. 28 S., R. 42 W.*

[Surface altitude, 3,739 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	20	20
Sand, clay, and gravel	135	155
Dakota sandstone: Shale and sandstone	45	180

37. *Driller's log of test hole at the SE cor. sec. 3, T. 28 S., R. 42 W.*

[Surface altitude, 3,741 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	20	20
Sand and gravel	70	90
Clay and sand	40	130
Clay, sand, and gravel	20	150
Dakota sandstone: Shale containing sandstone strips	30	180

38. *Driller's log of test hole at the NE cor. sec. 12, T. 28 S., 42 W.*

[Surface altitude, 3,712 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and gravel	121	121

	Thickness (feet)	Depth (feet)
Dakota sandstone:		
Sandstone and shale	27	148
Sandstone, hard	2	150

39. *Driller's log of test hole at the NE cor. sec. 13, T. 28 S., 42 W.*

[Surface altitude, 3,712 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Shale	50	50
Sand and gravel with shale strips	70	120
Dakota sandstone: Shale and sandstone	30	150

40. *Driller's log of test hole in the NW¼NE¼NW¼ sec. 14, T. 28 S., R. 42 W.*

[Surface altitude, 3,759 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Shale	60	60
Sand and gravel	65	125
Dakota sandstone: Shale and sandstone	25	150

41. *Driller's log of test hole at the SW cor. sec. 14, T. 28 S., R. 42 W.*

[Surface altitude, 3,773 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Shale and sand strips	60	60
Sand and gravel	35	95
Dakota sandstone: Shale and sandstone	35	130

42. *Driller's log of test hole in the NE¼NW¼NE¼ sec. 16, T. 28 S., R. 42 W.*

[Surface altitude, 3,780 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand, gravel, and clay	75	75
Dakota sandstone:		
Sandstone and clay containing sandstone strips	25	100
Shale and sandstone	30	130

43. *Driller's log of test hole in the NW¼SW¼NW¼ sec. 16, T. 28 S., R. 42 W.*

[Surface altitude, 3,810 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay, sand, and gravel	83	83
Dakota sandstone: Sandstone containing a few strips of sand and shale	57	140

44. *Driller's log of test hole in the NE¼NE¼NE¼ sec. 20, T. 28 S., R. 42 W.*

[Surface altitude, 3,815 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand, gravel, and clay	75	75
Dakota sandstone: Sandstone and clay	55	130

45. *Driller's log of test hole at the SW cor. sec. 22, T. 28 S., R. 42 W.*

[Surface altitude, 3,788 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	40	40
Sand and gravel	38	78
Dakota sandstone: Shale and sandstone	52	130

46. *Driller's log of test hole at the SW cor. sec. 23, T. 28 S., R. 42 W.*

[Surface altitude, 3,757 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Sand	35	35
Sand and gravel	50	85
Dakota sandstone:		
Sandstone	23	108
Shale	22	130
Sandstone and shale breaks	60	190

47. *Driller's log of test hole in the NE¼SE¼NE¼ sec. 24, T. 28 S., R. 42 W.*

[Surface altitude, 3,718 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Shale	50	50
Sand and gravel with shale strips	65	115
Dakota sandstone: Shale, red, with sandstone strips and blue shale	35	150

48. *Driller's log of test hole at the NW cor. sec. 24, T. 28 S., R. 42 W.*

[Surface altitude, 3,740 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	60	60
Sand, gravel, and clay	45	105
Dakota sandstone: Sandstone and shale	25	130

49. *Driller's log of test hole in the NE¼SE¼NE¼ sec. 25, T. 28 S., R. 42 W.*

[Surface altitude, 3,728 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Shale	40	40
Sand and gravel	80	120
Dakota sandstone: Sandstone strips and shale	30	150

50. *Driller's log of test hole at the NE cor. sec. 26, T. 28 S., R. 42 W.*

[Surface altitude, 3,740 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and gravel	104	104
Dakota sandstone: Shale	36	140

51. *Driller's log of test hole at the SW cor. sec. 26, T. 28 S., R. 42 W.*

[Surface altitude, 3,760 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Sand	30	30
Sand and gravel	50	80
Dakota sandstone:		
Sandstone	28	108
Shale	12	120
Sandstone	40	160
Shale	20	180
Sandstone	10	190

52. *Driller's log of test hole at the SE cor. sec. 26, T. 28 S., R. 42 W.*

[Surface altitude, 3,729 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	20	20
Sand, gravel, and clay	70	90
Dakota sandstone: Shale and sandstone	40	130

53. *Driller's log of test hole at the NW cor. sec. 28, T. 28 S., R. 42 W.*

[Surface altitude, 3,815 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and clay	60	60
Dakota sandstone: Sandstone and shale	70	130

54. *Driller's log of test hole at the SW cor. sec. 28, T. 28 S., R. 42 W.*

[Surface altitude, 3,817 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	50	50
Sand and gravel	35	85
Dakota sandstone: Sandstone and shale	45	130

55. *Driller's log of test hole in the SE¼NE¼SE¼ sec. 32, T. 28 S., R. 42 W.*

[Surface altitude, 3,763 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and gravel	40	40
Dakota sandstone: Sandstone and shale	90	130

56. *Driller's log of test hole in the SW¼NW¼SW¼ sec, 36, T. 28 S., R. 42 W.*

[Surface altitude, 3,735 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	35	35
Sand, gravel, and clay	60	95
Dakota sandstone: Shale and sandstone	35	130

57. *Reported log of well in the SW¼SW¼ sec. 21, T. 28 S., R. 43 W.*

[Drilled in 1917. Record by W.P.A.]

	Thickness (feet)	Depth (feet)
Soil	10	10
Ogallala formation: Sand and gravel	134	144
Dakota sandstone: Sandstone	4	148

58. *Driller's log of well(35) of Atchison, Topeka and Santa Fe Railway Co. at Frick in the SE¼SW¼ sec. 19, T. 28 S., R. 49 W., drilled by J. F. Daur, 1937*

[Surface altitude, 4,742 feet]

	Thickness (feet)	Depth (feet)
Carlile shale:		
Soil and yellow clay	7	7
Clay, sandy	21	28
Limestone	1.5	29.5
Greenhorn limestone:		
Shale, yellow	5.5	35
Shale, black	10	45
Shale, black, lighter	10	55
Shale, black, softer	7	62
Shale, black, harder	8	70
Shale, black, softer	15	85
Shale, black, lighter	5	90
Shale, black, harder, darker	10	100
Shale, black, lighter	7	107
Shale, black	27	134
Rock, gray (basal Lincoln limestone member)	2	136
Graneros shale:		
Shale, black, softer	5	141
Shale, black	53	194
Shale, black, harder, lighter(Thatcher limestone member?)	2	196
Shale, black	24	220
Dakota sandstone:		
Sandstone (water)	22	242
Shale, sandy	18	260
Sandstone	10	270
Shale, gray	6	276

59. *Driller's log of well in the SW¼NW¼ sec. 17, T. 28 S., R. 50 W.*

[Drilled by L. C. Williamson]

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Alluvium: Clay, soft	26	28
Dakota and Purgatoire formations:		
Shale, black	79	107
Shale, gray	23	130
Purgatoire formation:		
Cheyenne sandstone member: Sandstone (water)	20	150

60. *Driller's log of test hole at the SW cor. sec. 5, T. 29 S., R. 41 W.*

[Surface altitude, 3,681 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	30	30
Clay, sand, and gravel	40	70
Dakota sandstone: Sandstone and shale	60	130

61. *Driller's log of test hole at the SW cor. sec. 6, T. 29 S., R. 41 W.*

[Surface altitude, 3,711 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay sand, and gravel	76	76
Dakota sandstone: Sandstone and shale	54	130

62. *Driller's log of test hole at the SW cor. sec. 7, T. 29 S., R. 41 W.*

[Surface altitude, 3,677 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand	10	10
Dakota sandstone: Sandstone and shale	100	110

63. *Driller's log of test hole in the SW¼NW¼SW¼ sec. 8, T. 29 S., R. 41 W.*

[Surface altitude, 3,682 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay and sand	50	50
Dakota sandstone: Shale and sandstone (hard layers of sandstone at 54 and 117 feet)	80	130

64. *Driller's log of test hole in the NE¼SE¼NE¼ sec. 9, T. 29 S., R. 41 W.*

[Surface altitude, 3,623 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay, sand, and boulders	40	40
Dakota sandstone:		
Shale and hard sandstone	70	110
Shale	20	130

65. *Driller's log of test hole at the NE cor. sec. 16, T. 29 S., R. 41 W.*

[Surface altitude, 3,644 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay and sand	50	50
Dakota sandstone: Shale and sandstone	80	130

66. *Driller's log of test hole at the NW cor. sec. 2, T. 29 S., R. 42 W.*

[Surface altitude, 3,760 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Sand	80	80
Sand and gravel	15	95
Dakota sandstone: Sandstone	15	110

67. *Driller's log of test hole in the NW¼NW¼NW¼ sec. 3, T. 29 S., R. 42 W.*

[Surface altitude, 3,778 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay, sand, and gravel	74	74
Dakota sandstone: Sandstone and shale	56	130

68. *Driller's log of test hole in the NW¼SW¼NW¼ sec. 11, T. 29 S., R. 42 W.*

[Surface altitude, 3,713 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay and sand	17	17
Dakota sandstone: Sandstone and shale	113	130

69. *Driller's log of test hole at the SE cor. sec. 11, T. 29 S., R. 42 W.*

[Surface altitude, 3,683 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand, gravel, and loose rock	20	20
Dakota sandstone: Sandstone and shale	110	130

70. *Reported log of well 71 in the NW¼NW¼ sec. 27, T. 29 S., R. 43 W.*

[Drilled by L. W. Collins]

	Thickness (feet)	Depth (feet)
Soil	4	4
Ogallala formation: Clay, light-yellow	76	80
Dakota sandstone:		
Sandstone	10	90
Shale, blue	70	160
Purgatoire formation:		
Kiowa shale member: Shale, black	70	230
Cheyenne sandstone member: Sandstone	53	283

71. *Reported log of well 72 in the SW¼NW¼ sec. 28, T. 29 S., R. 43 W.*

[Drilled by L. W. Collins, 1910. Surface altitude, 3,907 feet]

	Thickness (feet)	Depth (feet)
Topsoil	4	4
Ogallala formation: Clay, light-yellow	76	80
Dakota and Purgatoire formations:		
Joint clay	20	100
Sandstone	10	110
Joint clay	20	130
Sandstone (water)	20	150
Joint clay	10	160
Shale, blue to black	140	300
Purgatoire formation:		
Cheyenne sandstone member: Sandstone (artesian water)	110	410

72. *Reported log of well 73 in the NW¼SE¼ sec. 28, T. 29 S., R. 43 W.*

[Drilled by L. W. Collins, 1917]

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Ogallala formation: Clay, light-yellow	23	25
Dakota and Purgatoire formations:		
Sandstone (water)	35	60
Joint clay	10	70
Sandstone (water)	10	80
Shale, blue to black	120	200
Purgatoire formation:		
Cheyenne sandstone member: Sandstone (artesian water)	26	226

73. *Driller's log of well 74 in the SW¼SE¼ sec. 31, T. 29 S., R. 43 W.*

[Drilled by L. W. Collins, 1948. Surface altitude, 3,946 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Soil and clay	20	20
Gravel	17	37
Clay, yellow	22	59
Dakota sandstone:		
Sand rock, tight	2	61
Joint clay, sticky	5	66
Sand rock	32	98
Joint clay	8	106
Shale, gray, containing streaks of black shale	99	205
Purgatoire formation:		
Kiowa shale member: Shale, black	67	272
Cheyenne sandstone member: Sand rock, tight (water rose to 8.7 feet)	34	306

74. *Reported log of well 78 in the SE¼NE¼ sec. 36, T. 29 S., R. 43 W.*

[Drilled by L. W. Collins, 1918]

	Thickness (feet)	Depth (feet)
Topsoil	1	1
Dakota and Purgatoire formations:		
Sand rock and clay	29	30
Joint clay	50	80
Sandstone	5	85
Shale, blue to black	100	185
Purgatoire formation:		
Cheyenne sandstone member: Sandstone (artesian water)	215	400
Morrison formation(?): Red beds	16	416

75. *Reported log of well 81 in the NE¼SW¼ sec. 27, T. 29 S., R 44 W.*

[Drilled in 1934. Surface altitude, 3,969 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Topsoil and round rocks	14	14
Gravel	16	30

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	Thickness (feet)	Depth (feet)
Dakota and Purgatoire formations: Shale, blue	120	150
Purgatoire formation:		
Cheyenne sandstone member: Sandstone	40	190

76. *Reported log of well 85 in the NE¼NE¼ sec. 35, T. 29 S., R. 44 W.*

[Drilled by John Kilpatrick, 1935]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Topsoil and smooth cobble stones	16	16
Sand and gravel (water)	10	26
Dakota sandstone: Clay and layers of sand rock	82	108
Purgatoire formation:		
Kiowa shale member: Shale, blue	82	190
Cheyenne sandstone member:		
Sandstone (artesian water)	40	230
Clay, very yellow	20	250

77. *Reported log of well in center of sec. 9, T. 29 S., R. 48 W.*

[Drilled by T. A. Bamber, 1918]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Topsoil and subsoil	20	20
Sand and gravel	20	40
Dakota and Purgatoire formations:		
Sand rock	2	42
Joint clay	20	62
Sandstone	2	64
Shale, black	136	300
Purgatoire formation:		
Cheyenne sandstone member: Sandstone	33	333

78. *Driller's log of well (100) of Atchison, Topeka and Santa Fe Railway Co. at Harbord switch in the NW¼NW¼ sec. 28, T. 29 S., R. 48 W.*

[Drilled by J. F. Bauer, 1936. Surface altitude, 4,677 feet]

	Thickness (feet)	Depth (feet)
Soil	3	3
Ogallala formation: Clay and gyp	47	50
Greenhorn limestone:		
Hartland shale and Lincoln limestone members:		
Shale, black	42	92
Stone, gray	1	93
Graneros shale:		
Shale, black	57	150
Shale, black, softer	33	183
Dakota sandstone:		
Sandstone, gray	2	185
Shale, black, containing black sandstone and some pyrite	30	215
Sandstone, white	10	225
Shale, black, containing layers of black sandstone and a little pyrite	25	250
Sandstone, coarse, white (water)	6	256
Limestone, thin-bedded, pink	4	260
Limestone, white	7	267
Sandstone, gray	13	280
Sandstone, gray, softer	10	290
Sandstone, gray	8	298
Sandstone, hard, gray	2	300

	Thickness (feet)	Depth (feet)
Purgatoire formation:		
Kiowa shale member:		
Shale, soft, black	2	302
Sandstone, white, fine	4	306
Shale, black	1	307
Sandstone, gray	4	311
Sandstone, gray, and shale, black	7	318
Sandstone, hard, gray	1	319
Sandstone, fine, white	3	322
Sandstone, gray, harder	1	323
Sandstone, medium hard, white	7	330
Sandstone, white, and black shale	4	334
Sandstone, white, and blue shale	13	347
Cheyenne sandstone member(?):		
Sandstone, fine, white	27	374
Shale, black	1	375
Sandstone, hard, dark-gray	8	383
Sandstone, gray, softer	8	391
Sandstone, hard, dark-gray	6	397
Shale, dark-gray	4	401

79. *Driller's log of well 109 in the SW¼SE¼ sec. 31, T. 29 S., R. 50 W.*

[Drilled by L. C. Williamson, 1948]

	Thickness (feet)	Depth (feet)
Topsoil	4	4
Morrison formation:		
Rock, loose	4	8
Shale, red and green	48	56
Dockum group:		
Lime, hard	1	59
Rock and shale	25	84
Lime rock (water)	8	92

80. *Reported log of well 116 in the SE¼NW¼ sec. 4, T. 30 S., R. 42 W.*

[Drilled by L. W. Collins]

	Thickness (feet)	Depth (feet)
Dakota and Purgatoire formations:		
Topsoil	15	15
Clay, sandy	10	25
Soapstone	25	50
Shale, blue to black	210	260
Purgatoire formation:		
Cheyenne sandstone member: Sandstone (artesian water)	40	300

81. *Reported log of well 117 in the NW¼SW¼ sec. 4, T. 30 S., R. 42 W.*

[Drilled by L. W. Collins. Surface altitude, 3,718 feet]

	Thickness (feet)	Depth (feet)
Dakota sandstone:		
Clay, sandy	20	20
Sand and rock	10	30
Joint clay	10	40
Purgatoire formation:		
Kiowa shale member: Shale	70	110
Cheyenne sandstone member: Sandstone (artesian water)	31	141

82. *Driller's log of well of Atchison, Topeka and Santa Fe Railway Co. at Bartlett in the SW¼NW¼ sec. 15, T. 30 S., R. 42 W.*

[Drilled by L. C. Williamson, 1926]

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Ogallala formation:		
Clay, soft, yellow	1	3
Clay, hard, yellow	21	24
Clay, sandy, soft	4	28
Sand, soft	34	62
Sand and gravel; soft	6	68
Clay, yellow	2	70
Sand and gravel; soft	11	81
Clay, yellow	1	82
Sand and gravel	1	83
Clay, yellow, and gravel	13	96
Shale, black, and gravel	72	168
Sand and gravel; cemented	9	177
Dakota sandstone:		
Sand rock, white	11	188
Sand rock, red	2	190
Sand rock, white	2	192
Sand rock, yellow	1	193
Sand rock, white	2	195
Sand rock, red	5	200

83. *Reported log of well 127 in the NW¼SE¼ sec. 12, T. 30 S., R. 43 W.*

[Drilled by L. W. Collins, 1912]

	Thickness (feet)	Depth (feet)
Topsoil	5	5
Dakota and Purgatoire formations:		
Clay	20	25
Joint clay	35	60
Sandstone	10	70
Soapstone	10	80
Shale	120	200
Purgatoire formation:		
Cheyenne sandstone member: Sandstone (artesian water)	145	345

84. *Driller's log of well in the SW¼ sec. 32, T. 30 S., R. 43 W.*

[Drilled by Western Drilling Co., 1947]

	Thickness (feet)	Depth (feet)
Soil	2	2
Ogallala formation:		
Clay	3	5
Clay, chalky rock, and gyp	9	14
Gravel	13	27
Dakota sandstone:		
Clay and strips of rock	13	40
Clay, yellow	9	49
Clay and strips of hard rock	6	55
Clay, yellow	10	65
Sandstone	9	74
Clay	2	76
Sandstone	4	80
Purgatoire formation:		
Kiowa shale member:		
Shale, blue	80	160
Shale, blue, containing strips of sandstone and clay	18	178

	Thickness (feet)	Depth (feet)
Purgatoire formation—Continued		
Cheyenne sandstone member:		
Sandstone, fine	14	192
Clay, sandy, green	22	214
Clay, sandy, yellow	4	218
Sand, fine	10	228
Sand, fine, and clay; containing a little gravel	10	238
Sand, fine, and clay	28	266
Rock and clay	10	276
Morrison formation(?): Red beds	12	278

85. *Driller's log of well (133) of Atchison, Topeka and Santa Fe Railway Co. at Walsh in the NW¼SE¼ sec. 32, T. 30 S., R. 43 W.*

[Drilled by L. C. Williamson, 1926. Surfsce sltitude, 3,962 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Gyp and clay	2	2
Clay	15	17
Clay, containing a little sand	6	23
Sand, gravel, and some clay; soft	5	28
Dakota sandstone:		
Sand, clay, and rock	5	33
Clay, hard, yellow	7	40
Clay, hard, yellow tinted with red	2	42
Sand rock and red clay	5	47
Clay, yellow, and sand	2	49
Sand rock, yellow	16	65
Sand rock, containing some blue clay	5	70
Sand rock interbedded with blue clay	8	78
Sand rock, gray, and red clay	5	83
Sand rock, hard, pink	7	90
Sand rock, hard, gray	3	93
Sand rock, hard, pink	4	97
Sand rock, hard, interbedded with black shale	4	101
Purgatoire formation:		
Kiowa shale member:		
Shale, black	11	112
Shale, blue	38	150
Shale, black	15	165
Flint rock	1	166
Shale, black and sand rock	14.5	180.5
Cheyenne sandstone member:		
Sand rock (water)	81.5	262
Sand rock and some brown clay	4	266

86. *Sample log of test hole drilled for the town of Springfield, Colo., 10 feet west and 24 feet north of the SE corner of lot 6, block 21, Stewart-Thompson addition in west half of the SW¼ sec. 20, T. 30 S., R. 46 W.*

[Drilled by Juel Wster Well Co., 1948. Surface altitude, 4,668 feet [1]]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Sand, fine, to gravel, fine, containing silt and clay	10	10
Sand, medium, to gravel, medium, containing a little clay	8	18
Gravel, fine to coarse	10	28
Dakota sandstone:		
Shale, dark-gray, sandy, and sandstone, fine-grained, yellow to brown	11	39
Sandstone, fine-grained, varicolored, containing dark-gray sandy shale	10	49

	Thickness (feet)	*Depth (feet)*
Dakota sandstone—Continued		
Sandstone, fine to medium-grained, gray to yellow-brown, containing gray shale	21	70
Sandstone, fine-grained, and shale, sandy; dark-gray	41	111
Purgatoire formation:		
Kiowa shale member: Shale, calcareous, platy, dark-gray to black	62	173
Cheyenne sandstone member:		
Sandstone, fine- to coarse-grained, friable, white	31	204
Sandstone, fine- to medium-grained, white, containing a little clay	10	214
Sandstone, fine-grained, gray, containing a little medium-grained sand and cemented with silt and clay	31	245
Sandstone, fine- to medium-grained, containing small pebbles of quartz and chert and a little clay	11	256
Sandstone, fine- to medium-grained, friable, white	10	266
Sandstone, very fine- to fine-grained, and clay, gray. Clay becomes predominant downward	31	297
Sandstone, fine- to medium-grained, friable, white	10	307
Morrison formation:		
Siltstone, maroon and green, containing hard white fine-grained sandstone	31	338
Limestone, hard, compact, white	5	343
Siltstone, maroon and green, containing hard fine-grained sandstone	31	374
Silt and clay; maroon and green	41	415
Sandstone, fine-grained containing a little maroon and green silt	10	425
Silt and clay; maroon and green; containing thin beds of hard white fine-grained sandstone	50	475

[1]Samples generally were collected only at the completion of each length of drill stem, hence, the depths given in the log may be as much as 10 feet in error.

87. *Driller's log of well (148) of Atchison, Topeka and Santa Fe Railway Co. at Springfield in the SW¼SW¼ sec. 29, T. 30 S., R. 46 W.*

[Drilled by L. C. Williamson, 1926. Surface altitude, 4,350 feet]

	Thickness (feet)	*Depth (feet)*
Soil	2	2
Ogallala formation:		
Sand and clay; soft	11	13
Dakota sandstone:		
Clay, interbedded with sand rock	16	29
Clay, sticky, yellow	5	34
Shale and soapstone; light-blue	6	40
Shale, hard, and soapstone	5	45
Sand rock, soft, brown (water)	20	65
Sand rock, soft, gray (water)	11	76
Sand rock, soft, brown (water)	3	79
Sand rock, hard	1	80

88. *Driller's log of well (152) of Atchison, Topeka and Santa Fe Railway Co. at Springfield in the SW¼SE¼ sec. 30, T. 30 S., R. 46 W.*

[Drilled by L. C. Williamson, 1926]

	Thickness (feet)	*Depth (feet)*
Soil	2	2
Ogallala formation: Clay, yellow	8	10
Dakota sandstone:		
Sand rock, hard	26	36
Sand rock, soft, yellow	7	43
Sand rock, hard, yellow	7	50
Sand rock, brown	7	57
Sand rock, light-brown	13	70
Sand rock, brown	2.5	72.5
Shale, black	2.5	75

89. *Reported log of well 161 in the NE¼ sec. 23, T. 30 S., R. 48 W.*

[Drilled in 1913. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Ogallala formation: Soil and sand	14	14
Greenhorn and Graneros formations: Shale	106	120
Dakota sandstone: Sandstone (water raised to 50 feet)	5	125

90. *Driller's log of well in the SW¼SW¼ sec. 9, T. 30 S., R. 49 W.*

[Drilled by L. C. Williamson]

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Clay, soft	20	22
Greenhorn limestone:		
Shale, hard	25	47
Lime, hard	4	51
Graneros shale: Shale, black	84	135
Dakota sandstone: Sand rock	29	164

91. *Driller's log of well 166 in the NW¼NE¼ sec. 19, T. 30 S., R. 49 W.*

[Drilled by L. C. Williamson, 1945. Surface altitude, 4,890 feet]

	Thickness (feet)	Depth (feet)
Topsoil	3	3
Ogallala formation: Clay (small seep of water between 22 and 24 feet)	21	24
Greenhorn and Graneros formations: Shale, black	101	125
Dakota sandstone:		
Hard shell (probably ironstone at top of Dakota)	1	126
Sand rock	34	160
Sand rock, dark-brown	12	172
Clay, white	3	175
Shale, gray	37	212
Sand rock, gray	10	222
Shale, sandy	10	232
Shale, sticky	13	245
Shale, sandy (carbon dioxide gas)	5	250
Sand rock (water rose to 240 feet)	21	271

92. *Reported log of well 170 in the SW¼SE¼ sec. 35, T. 30 S., R. 49 W.*

[Drilled in 1916. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Ogallala formation: Topsoil and sand	153	153
Graneros shale: Shale, blue	75	228
Dakota sandstone: Sand and gravel (probably sandstone). (Water rose to 90 feet)	2	230

93. *Driller's log of well 178 in the NW¼SW¼ sec. 31, T. 30 S., R. 50 W.*

[Drilled by L. C. Williamson, 1947]

	Thickness (feet)	Depth (feet)
Topsoil	4	4
Dakota sandstone:		
Sand rock, hard (little water between 18 and 22 feet)	18	22
Shale, sandy	18	40
Sand rock (water)	35	75

	Thickness (feet)	Depth (feet)
Dakota sandstone—Continued		
Sand rock, soft (water)	10	85
Sand rock, hard	12	97
Shale, sandy	3	100

94. *Driller's log of test hole 1 on Orlen Harvey farm in the NW¼SW¼* sec. *32, T. 31 S., R. 41 W.*

[Drilled by Western Drilling Co., 1947]

	Thickness (feet)	Depth (feet)
Surface	3	3
Ogallala formation:		
Sand, fine	3	6
Clay, yellow	12	18
Sand, fine	18	25
Clay	19	44
Clay, sandy	10	54
Clay	4	58
Gravel	8	66
Clay, very sandy, and gyp	23	89
Gravel	3	92
Clay, containing layer of rock	3	95
Dockum group(?):		
Clay, red	3	98
Shale, weathered	12	110
Clay	5	115
Sandstone	22	137
Red beds	4	141

95. *Driller's log of test hole 2 on Orlen Harvey farm in the SW¼NW¼* sec. *32, T. 31 S., R. 41 W.*

[Drilled by Western Drilling Co., 1947]

	Thickness (feet)	Depth (feet)
Surface	3	3
Ogallala formation:		
Clay	12	15
Sand, fine	11	26
Clay, yellow	9	35
Clay, sandy, containing strips of limestone	9	44
Gravel	3	47
Clay, chalky	18	65
Dockum group(?):		
Clay, red, and rocks	20	85
Red beds	10	95

96. *Reported log of well at the SW* cor. sec. *12, T. 31 S., R. 44 W.*

[Drilled by C. F. Robins]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Topsoil and dirt	110	110
Sand	23	133
Dakota sandstone:		
Soapstone	14	147
Shale	103	250
Quartz	2	252
Sandstone (water rose to 100 feet)	21	273

97. *Driller's log of well (222) of Atchison, Topeka and Santa Fe Railway Co. at Vilas in the NE¼NW¼ sec. 1, T. 31 S., R. 45 W.*

[Drilled by L. C. Williamsoh, 1926. Surface altitude, 4,159 feet]

	Thickness (feet)	Depth (feet)
Soil	4	4
Ogallala formation:		
Gyp and clay	11	15
Clay, sandy	7	22
Gyp and clay	24	46
Clay, sandy	6	52
Clay, sticky, yellow	12	64
Clay, red	8	72
Clay, yellow	14	86
Dakota sandstone:		
Shale, light-blue	4	90
Shale, black	24	114
Shale, light-blue	27	141
Rock, gray	1	142
Rock, black	1	143
Rock, gray	9	152
Sand rock, soft, brown (water)	4	156
Sand rock, hard, gray (water)	5	161

98. *Reported log of well 225 in the SW¼SW¼ sec. 8, T. 31 S., R. 45 W.*

[Drilled in 1920. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Ogallala formation: Soil and dirt	20	20
Dakota and Purgatoire formations:		
Sand rock	55	75
Shale, blue	120	195
Purgatoire formation:		
Cheyenne sandstone member: Sand rock (water rose to 153 feet)	3	198

99. *Driller's log of well at the NE cor. SE¼NW¼ sec. 33, T. 31 S., R. 46 W.*

[Drilled by the Soil Conservation Service]

	Thickness (feet)	Depth (feet)
Topsoil	2.5	2.5
Ogallala formation:		
Gyp rock (probably caliche)	13.5	16
Sand rock	22	38
Sand	20	58
Dakota sandstone(?):		
Rock	8	66
Clay	14	80
Sand rock, yellow	24	104
Shale, black	27	131
Shale, gray	13	144
Sand rock, yellow (water)	21	165
Purgatoire formation:		
Kiowa shale member: Shale, black	115	280
Cheyenne sandstone member:		
Sand rock	10	290
Shale, black	3	293
Sand rock (water)	10	303

100. *Reported log of well in the NW¼NW¼ sec. 4, T. 31 S., R. 48 W.*

[Drilled by C. F. Robins, 1930]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Topsoil and dirt	40	40
Gravel, loose	20	60
Dirt	50	110
Limestone	1.5	111.5
Gravel	4	115.5
Graneros shale:		
Shale, gray	50	165.5
Shale, black	19.5	185
Dakota sandstone: Sandstone (water)	16	201

101. *Driller's log of well in the NE¼NW¼ sec. 6, T. 31 S., R. 48 W.*

[Drilled by L. C. Williamson, 1948]

	Thickness (feet)	Depth (feet)
Topsoil	3	3
Ogallala formation:		
Clay and gyp	5	8
Sand and gravel	119	127
Graneros shale: Shale, black	9	136

102. *Driller's log of well 238 in the NE¼NW¼ sec. 6, T. 31 S., R. 48 W.*

[Drilled by L. C. Williamson. Surface altitude, 4,812 feet]

	Thickness (feet)	Depth (feet)
Topsoil	3	3
Ogallala formation:		
Clay	17	20
Sand	72	92
Clay	13	105
Sand and gravel	10	115
Clay	15	130
Sand, cemented (little water)	7	137
Greenhorn and Graneros formations: Shale, black	99	236
Dakota sandstone: Sandstone (water rose to 147 feet)	12	248

103. *Driller's log of well 240 in the NW¼SE¼ sec. 6, T. 31 S., R. 48 W.*

[Drilled by Sammons brothers, 1930. Surface altitude, 4,827 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Surface soil	20	20
Sand and gravel (water at bottom)	136	156
Graneros shale:		
Joint clay, yellow	12	168
Shale, black	30	198
Slate rock, hard	2	200
Shale, black to dark-blue	20	220
Dakota sandstone:		
Sandstone and slate; interbedded	30	250
Sandstone (water)	17	267
Shale, hard, blue	1	268

104. *Driller's log of test hole at site of well (241) of Atchison, Topeka and Santa Fe Railway Co. at Pritchett in the SW¼SE¼SE¼ sec. 6, T. 31 S., R. 48 W.*

[Drilled by L. C. Williamson, 1926. Surface altitude, 4,818 feet]

	Thickness (feet)	Depth (feet)
Soil	2	2
Ogallala formation:		
Clay, yellow	13	15
Clay, soft, and sand	3	18
Sand, soft	14	32
Sand and gravel; hard	3	35
Sand and gravel; soft	5	40
Clay, soft, containing sand and gravel	5	45
Sand and clay	9	54
Sand, soft	10	64
Sand and gravel; hard	11	75
Sand and gravel; soft	5	80
Sand and gravel; hard	22	102
Clay	13	115
Sand, gravel, and clay, soft	5	120
Sand and clay; soft	3	123
Sand, clay, and gravel	6	129
Sand and gravel	7	136
Sand, gravel, and clay (water)	3	139
Sand, gravel, and rock	1	140
Graneros shale:		
Slate and gravel, very hard	4	144
Shale, sticky, black (water at 180 feet)	48	192
Dakota sandstone:		
Sand rock	3	195
Slate	5	200
Shale, black	15	215
Sand rock	20	235
Shale and slate	5	240
Sand rock, white (water)	10	250
Sand rock, gray	10	260
Slate and shale	13	273
Malpine granite (probably ironstone)	1	274
Purgatoire formation:		
Kiowa shale member:		
Slate and blue shale (water from 290 to 308 feet)	34	308
Slate and shale; hard	3	311
Soapstone, gray	27	338
Cheyenne sandstone member:		
Sand rock, gray	21	359
Shale, black	3	362
Sand rock, gray (water)	18	380
Sand rock and blue shale	14	394
Shale, black	23	417

105. *Incomplete driller's log of the California Co.'s J. A. Spike no. 1 at the center of the SW¼NE¼ sec. 13, T. 31 S., R. 48 W.*

[Drilled in 1947. Surface altitude, 4,668 feet]

	Thickness (feet)	Depth (feet)
Cellar (no samples, this section 0–16.6 ft because of well cellar)		16.6
Ogallala formation:		
Siltstone, shaly, light-brown, and sandstone, fine, calcareous	43.4	60
Sand, medium-grained, well rounded, poorly cemented	30	90
Sand, very coarse, well rounded	10	100
Conglomerate, coarse. Rounded to sub-angular pebbles as much as one-half inch in diameter	10	110
Clay, yellow to black	10	120

	Thickness (feet)	Depth (feet)
Graneros shale:		
Clay-shale, black	60	180
Clay-shale, black, and sandy shale, black; containing a little anhydrite	10	190
Shale, gray, and lime, dense to slightly friable, steel-gray to gray brown	10	200
Shale, laminated, hard, gray-black, containing streaks of dense brown lime	10	210
Dakota sandstone:		
Sandstone, fine, uniform grained, friable, light-gray, containing hard dense brown dolomite and gray shale	10	220
Sandstone, very fine, white, containing disseminated fragments of carbonaceous material	30	250
Sandstone, fine, and shale, dark-gray, laminated	30	280
Shale, silty, soft, gray	10	290
Clay-shale, soft, brown	20	310
Siltstone, hard, dark-gray, and sandstone, fine, gray	20	330
Sandstone, fine, hard to soft, gray, in part containing disseminated specks of carbonaceous material	30	360
Purgatoire formation:		
Kiowa shale member:		
Siltstone, calcareous, hard, dark-gray	10	370
Clay-shale, hard, dark-gray to black	30	400
Shale, slightly calcareous, slightly hard, dark-gray	10	410
Shale, silty, dark-gray	10	420
Cheyenne sandstone member:		
Sandstone, uniformly fine-grained, firmly cemented, light-gray	10	430
Sandstone, fine- to medium-grained, very friable, light-gray	10	440
Limestone, silty, dense, medium-gray	10	450
Sandstone, uniformly fine-grained, porous, very light-gray	20	470
Sandstone, uniformly fine-grained, friable	10	480
Dolomite, silty, hard, light-gray to cream, containing minute red specks	10	490
Morrison formation:		
Shale, soft, dark-red to purple and pale-green, containing hard light-gray to cream silty dolomite	10	500
Lime, dolomitic, light-cream and reddish, and shale, fine-sandy, light-green	20	520
Dolomite, very sandy, crystalline, white to cream, and fine dolomitic sandstone; containing particles of orange quartz	40	560
Sandstone, dolomitic, fine, hard, gray, containing red and orange chert	10	570
Sandstone, dolomitic, fine, light-gray to cream, containing a few grains of glauconite and coarse sub-angular quartz and a little pale-green fine sandy shale	10	580
Dolomite and lime, dolomitic; crystalline, light-cream	10	590
Limestone, dense, friable, light-cream	20	610
Dolomite, friable, pale-green, and shale, light-gray; containing light-brown friable lime	10	620
Shale, silty, pale-red	20	640
Siltstone, calcareous, pale-red, containing disseminated fragments of biotite and red chert	10	650
Sandstone, very fine, limy, friable, white, containing fragments of biotite and orange chert	10	660
Siltstone, calcareous, hard, red and orange, containing green and gray-green shale in lower part	20	680
Sandstone, fine-grained, loosely cemented, white to slightly red. Grains are round and uniformly frosted	10	690
Conglomerate, consisting of red limestone, soft white crystalline limestone, green and red shale, white and light-brown chert, clear medium quartz, and containing pyrite in lower part	20	710
Conglomerate, sandy, coarse, consisting mainly of coarse rounded quartz and pink feldspar	10	720

	Thickness (feet)	Depth (feet)
Dockum group:		
No sample	10	730
Shale, calcareous, silty, light- to medium-red	20	750
Siltstone, dolomitic, hard, white and red	10	760
Siltstone, calcareous, red	30	790
Shale, silty, dark-red	10	800
Siltstone, dolomitic, red, containing a little white crystalline gypsum	20	820
Siltstone, dolomitic, red	20	840
Siltstone, dolomitic, hard, red, containing white crystalline gypsum	30	870
Siltstone, dolomitic, red, containing layers of light-orange hard crystalline sandy dolomite	10	880
Sandstone, dolomitic, fine-grained, pale-orange	10	890
Siltstone, coarse, red	10	900
Sandstone, dolomitic, fine, flesh-colored	20	920
Sandstone, dolomitic, very fine, friable, red flesh-colored	30	950
Shale, gypsiferous, dark-red	10	960
Siltstone, slightly dolomitic, fine medium dark-red, containing a little crystalline gypsum	30	990
Shale, slightly dolomitic, silty, dark-red	20	1,010
Shale, silty, red, containing streaks of coarsely crystalline red and tan lime	10	1,020
Siltstone, dolomitic, friable to hard, red	10	1,030
Dolomite, very fine sandy, hard, pale-orange	10	1,040
Permian(?) "red beds" at		1,040

106. *Driller's log of well 246 in the SE¼SW¼ sec. 35, T. 31 S., R. 48 W.*

[Drilled by the Soil Conservation Service]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Gyp rock (probably caliche)	30	30
Sand and gravel	15	45
Sand rock	37	82
Clay	34	116
Sand and gravel	23	139
Clay and sand	48	187
Clay, yellow	9	196
Gravel	12	208
Dakota sandstone:		
Shale, black	19	227
Shale, gray	56	283
Shale, black	5	288
Shale, gray	38	326
Clay, blue	9	335
Sand rock	8	343

107. *Driller's log of a well in the SE¼SW¼ sec. 14, T. 31 S., R. 49 W.*

[Drilled by L. C. Williamson]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Sand and clay	30	30
Sand and gravel	90	120
Graneros shale: Shale, black	45	165
Dakota sandstone:		
Sandstone (water)	30	195
Lime	3	198

108. *Reported log of a well in the SE¼NE¼ sec. 15, T. 31 S., R. 49 W.*

[Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and clay	150	150
Graneros shale: Shale, blue	64	214
Dakota sandstone: Sandstone (water)	5.5	219.5

109. *Reported log of a well in the SW¼SW¼ sec. 21, T. 31 S., R. 49 W.*

[Drilled in 1926. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Soil, sandy	9	9
Limestone, flakey, and dirt	15	24
Sand	206	230
Dakota sandstone:		
Sand rock	10	240
Sand	50	290
Shale, red	13	303

110. *Reported log of a well in the NE¼NW¼ sec. 10, T. 31 S., R. 50 W.*

[Drilled in 1920. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Soil	3	3
Ogallala formation: Sand and gravel	61	64
Dakota sandstone:		
Sand rock and shale	50	114
Sandstone (water)	13	127

111. *Reported log of well 257 in the SW¼SE¼ sec. 14, T. 31 S., R. 50 W.*

[Data from W.P.A. Surface altitude, 5,051 feet]

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Ogallala formation:		
Clay	38	40
Shale, red	.5	40.5
Dakota sandstone: Sand rock, white	94.5	135

112. *Driller's log of well 258 in the NE¼NE¼ sec. 20, T. 31 S., R. 50 W.*

[Drilled by L. C. Williamson, 1945]

	Thickness (feet)	Depth (feet)
Topsoil	3	3
Ogallala formation:		
Clay, sandy	87	90
Clay (small seep of water at base)	30	120
Graneros shale: Shale, black	18	138
Dakota sandstone: Sand rock (water)	42	180

113. *Driller's log of well 259 at the NW cor. SE¼NE¼ sec. 28, T. 31 S., R. 50 W.*

[Drilled by the Soil Conservation Service. Surface altitude, 5,123 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand and clay	107	107
Dakota sandstone:		
Sand rock	23	130
Shale	27	157
Sand rock	8	165
Shale, gray	63	228
Sand rock	10	238

114. *Driller's log of test hole 1 on Raymond Cross farm in the W½ sec. 9, T. 32 S., R. 41 W.*

[Drilled by Western Drilling Co., 1947]

	Thickness (feet)	Depth (feet)
Soil	10	10
Ogallala formation:		
Gyp, sandy	5	15
Clay, sandy, interbedded with limestone	65	80
Limestone, interbedded with clay	30	110
Limestone, gravel, and strips of sandy clay	20	130
Gravel and strips of rocks	15	145
Dockum group(?):		
Rock	3	148
Red beds	12	160

115. *Driller's log of test hole 2 on Raymond Cross farm in the W½ sec. 9, T. 32 S., R. 41 W.*

[Drilled by Western Drilling Co., 1947]

	Thickness (feet)	Depth (feet)
Surface	10	10
Ogallala formation:		
Clay, tight	30	40
Clay, sandy, and lime	23	63
Lime	10	73
Lime, clay, and gravel	5	78
Gravel, containing strips of rock	8	86
Gravel, containing strips of clay	12	98
Clay	5	103
Rock and sandy clay; interbedded	7	110
Sand and strips of rock	11	121
Dockum group(?): Red beds	9	130

116. *Driller's log of test hole 3 on Raymond Cross farm in the W½ sec. 9, T. 32 S., R. 41 W.*

[Drilled by Western Drilling Co., 1947]

	Thickness (feet)	Depth (feet)
Surface	10	10
Ogallala formation:		
Clay, tight	5	15
Gyp	10	25
Clay	39	64
Clay and strips of limestone	9	73
Clay, sandy, and gravel	32	105
Gravel and strips of rock	3	108
Clay	8	116
Dockum group(?): Red beds	24	140

117. *Driller's log of test hole 4 on Raymond Cross farm in the W½ sec. 9, T. 32 S., R. 41 W.*

[Drilled by Western Drilling Co., 1947]

	Thickness (feet)	Depth (feet)
Surface	8	8
Ogallala formation:		
Clay	6	14
Gravel	9	23
Clay, sandy, and strips of sand	40	63
Limestone strips and sandy clay	7	70
Clay, sandy, and strips of sand	17	87
Clay, sandy, and mixed sand and rock	33	120
Gravel, fine	5	125
Dockum group(?):		
Sandstone	10	135
Red beds	5	140

118. *Driller's log of a well in the NW¼SW¼ sec. 28, T. 32 S., R. 41 W.*

[Drilled by Western Drilling Co., 1948]

	Thickness (feet)	Depth (feet)
Surface	8	8
Ogallala formation:		
Gyp, sandy	7	15
Limestone, soft	8	23
Clay and strips of limestone	17	40
Gravel, fine	4	44
Clay	3	47
Gravel, fine	6	53
Gravel, fine, containing strips of clay	7	60
Sand, cemented	7	67
Clay, tight	3	70
Gravel	7	77
Clay, very sandy	38	115
Dockum group(?): Red beds	7	122

119. *Driller's log of a well in the NE¼SE¼ sec. 6, T. 32 S., R. 42 W.*

[Drilled by John Kilpatrick, 1934. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Topsoil	4	4
Ogallala formation:		
Clay, yellow	10	14
Sand, fine	30	44
Clay, rocky	58	102
Dakota sandstone: Sand rock, brown (water)	18	120

120. *Reported log of well 283 in the SW¼ sec. 6, T. 32 S., R. 45 W.*

[Drilled by H. D. Smith, 1916. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Ogallala formation: Soil, clay, and sand	70	70
Dakota sandstone:		
Shale, black	32	102
Sand rock	24	126
Joint clay	3	129
Quick sand(?)	3	132

121. *Formation tops from driller's log of test hole in the SE cor. sec. 34, T. 32 S., R. 45 W.*

	Thickness (feet)	Depth (feet)
Ogallala formation	115	115
Dakota and Purgatoire formations	205	320
Top of Morrison formation		320

122. *Driller's log of well 290 at the NE cor. NE¼SW¼ sec. 5, T. 32 S., R. 46 W.*

[Drilled by the Soil Conservation Service. Surface altitude, 4,400 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay	110	110
Dakota formation:		
Shale, brown	14	124
Shale, black	10	134
Sand rock (water level, 111 feet)	17	151

123. *Driller's log of well (292) of Atchison, Topeka and Santa Fe Railway Co. at Bisonte in the SE¼SW¼ sec. 1*5*, T. 32 S., R. 46 W.*

[Drilled by Walter Briles, 1936. Surface altitude, 4,387 feet]

	Thickness (feet)	Depth (feet)
Soil	4	4
Ogallala formation:		
Gyp	21	25
Sand, soft	10	35
Sand and clay	15	50
Pack sand	20	70
Sand, yellow	24	94
Clay	6	100
Sand, fine, yellow	55	155
Clay, yellow	9	164
Sand, yellow (water)	9	173
Gravel, coarse (water)	10	183
Dakota sandstone(?): Shale	4	187

124. *Driller's log of well 301 at the center of the SW¼ sec. 23, T. 32 S., R. 48 W.*

[Drilled by the Soil Conservation Service. Surface altitude, 4,651 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Clay	109	109
Dakota sandstone:		
Sand rock	51	160
Shale, black	10	170
Shale, blue	4	174
Sand rock	84	258
Purgatoire formation:		
Kiowa shale member:		
Shale, black	18	276
Shale, gray	36	312
Shale, black	12	324
Cheyenne sandstone member: Sand rock	7	331

125. *Reported log of a well in the SE¼ sec. 30, T. 32 S., R. 49 W.*

[Drilled in 1921. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Ogallala formation: Topsoil and sand	180	180

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	Thickness (feet)	Depth (feet)
Dakota sandstone:		
Sand rock	10	190
Shale, sandy, crumbly, blue	37	227

126. *Reported log of a well in the NW¼SW¼ sec. 10, T. 32 S., R. 50 W.*

[Drilled in 1930. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Ogallala formation: Soil, sand, and gravel	170	170
Dakota sandstone: Sand rock	104	274

127. *Driller's log of well 311 at the NE cor. sec. 13, T. 32 S., R. 50 W.*

[Drilled by L. C. Williamson, 1947. Surface altitude, 5,016 feet]

	Thickness (feet)	Depth (feet)
Topsoil	3	3
Ogallala formation:		
Clay, sandy	47	50
Sand, fine	120	170
Sand and gravel (water level, 235 feet)	83	253

128. *Reported log of a well in the NW¼NE¼ sec. 30, T. 32 S., R. 50 W.*

[Drilled in 1918. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Topsoil and dirt	100	100
Sandstone, honeycombed	2	102
Gravel, flinty, black	98	200
Dakota sandstone(?):		
Sandstone, red (water at 210 feet)	10	210
Sand and soap stone	40	250

129. *Driller's log of well 351 at the center of the SE¼ sec. 32, T. 33 S., R. 48 W.*

[Drilled by the Soil Conservation Service]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Clay	20	20
Sand and gravel	78	98
Clay	64	162
Dakota sandstone:		
Sand rock	3	165
Sand and gravel (probably sandstone)	33	198
Clay, yellow	40	238
Purgatoire formation:		
Kiowa shale member:		
Shale, gray	21	259
Shale, black	25	284
Cheyenne sandstone member: Sand rock (water)	51	335

130. *Reported log of a well in the SW¼ sec. 3, T. 33 S., R. 50 W.*

[Drilled in 1919. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Topsoil	1	1

	Thickness (feet)	Depth (feet)
Ogallala formation: Gyp, white, with dirt, shale, and sand	39	40
Dakota sandstone: Sand rock, yellow	78	118

131. *Driller's log of well 362 in the SW¼SW¼ sec. 11, T. 33 S., R. 50 W.*

[Drilled by L. C. Williamson, 1948]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Sand and gravel	15	15
Clay, light	5	20
Sand, brown	15	35
Sand, brown and gray	67	102
Dakota sandstone:		
Shale, black	5	107
Slate, hard	1	108
Shale, black	3	111
Shale, brown	11	122
Shale, black	13	135
Shale, gray	42	177
Sand rock, brown	8	185
Sand rock, yellow	5	190
Shale, white	10	200
Sand rock, brown (water at 203 feet)	5	205
Sand rock, yellow	22.5	227.5

132. *Incomplete driller's log of A. R. Jones' Boise Cattle Co. no. 1 (well 373) in the NE¼NW¼NE¼ sec. 22, T. 34 S., R. 42 W.*

[Completed in May 1931. Surface altitude, 3,618 feet]

	Thickness (feet)	Depth (feet)
Dockum group and Taloga formation (of Cragin):		
Shale, red	22	22
Sand, red	8	30
Sand, gray	20	50
Sand, red	75	125
Sand, white (two bailers of water per hour)	10	135
Red bed	25	160
Sand, red (five bailers of water per hour)	20	180
Red bed	10	190
Sand, red (water flows at surface)	10	200
Sand, red	10	210
Red bed	20	230
Sand, red	10	240
Red bed	10	250
Gypsum	10	260
Red bed and gypsum shells	55	315
Red bed	25	340
Red bed (a dolomite believed to be the Day Creek dolomite was encountered at 340 feet[1])	105	445
Gravel	30	475
Sand, red	50	525
Red bed and gravel	65	590
Shale, sandy	55	645
Sand, red	30	675
Red bed	20	695
Gypsum (believed to be the top of the Blaine formation[1])	10	705
Total depth of well		4,967

[1] Personal communication from Harry W. Oborne who examined the well cuttings.

133. *Driller's log of test hole at the NE cor. sec. 21, T. 34 S., R. 43 W.*

[Surface altitude, 3,843 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation: Sand, gravel, and caliche	270	270
Dockum group: Red sand	130	400

134. *Driller's log of well (391) of Atchison, Topeka and Santa Fe Railway Co. at Campo in the SE¼NE¼ sec. 10, T. 34 S., R. 46 W.*

[Drilled by J. F. Bauer, 1936. Surface altitude, 4,338 feet]

	Thickness (feet)	Depth (feet)
Soil	2	2
Ogallala formation:		
Clay, sandy, yellow	6	8
Clay, yellow, and gyp	22	30
Sand, containing some gravel	22	52
Clay, sandy, yellow	12	64
Clay, sandy, yellow, and gyp	9	73
Clay, sandy	67	140
Sand and gravel	3	143
Clay, sandy	21	164
Gravel, coarse	1	165
Sand and gravel	8	173
Clay, sandy	11	184
Sand and gravel	9	193
Sand and gravel; cemented	7	200
Sand, fine (water)	9	209
Clay, brown	6	215
Sand and gravel	20	235
Dakota sandstone(?):		
Clay, sandy	12	247
Sand, white (water)	15	262
Sandstone, soft, gray	8	270
Joint clay	14	284
Sand, white (water)	7	291
Purgatoire formation:		
Kiowa shale member:		
Shale, black	28	319
Sand, white (water)	4	323
Joint clay, yellow	3	326
Shale, blue	4	330
Sand rock, soft	8	338
Joint clay and gray shale	17	355
Cheyenne sandstone member:		
Sandstone, soft (water)	45	400
Gravel, coarse	2	402
Sandstone, soft	12	414
Sandstone, hard	4	418
Sandstone, soft	4	422
Sandstone, hard	4	426
Morrison formation: Shale, gray, very hard	6	432

135. *Driller's log of well 395 at the SW cor. NW¼ sec. 2, T. 34 S., R. 47 W.*

[Drilled by the Soil Conservation Service]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Topsoil and gyp	40	40
Clay	35	75
Sand	55	130
Clay	28	158

	Thickness (feet)	Depth (feet)
Dakota sandstone(?):		
Sand	75	233
Clay, yellow	37	270
Shale	3	273
Clay	17	290
Purgatoire formation:		
Kiowa shale member: Shale, gray	58	348
Cheyenne sandstone member:		
Sand rock	32	380
Granite (probably hard sandstone)	1	381
Sand rock	39	420

136. *Reported log of a well in the NW¼SW¼ sec. 10, T. 34 S., R. 48 W.*

[Drilled in 1920. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Soil, sandy	1.5	1.5
Ogallala formation:		
Clay	20	21.5
Sand and gravel	39.5	61
Dakota sandstone(?):		
Clay, red	100	161
Fire clay	2	163
Clay, red	92	255
Sand rock (water)	10	265
Sandstone, yellow	10	275
Purgatoire formation(?):		
Kiowa shale member(?):		
Limestone, blue	15	290
Soapstone, black, and slate	37	327

137. *Driller's log of a well in the SW¼SE¼ sec. 18, T. 34 S., R. 48 W.*

[Drilled by L. C. Williamson, 1948]

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Ogallala formation:		
Clay, brown	13	15
Clay, yellow	35	50
Dakota sandstone:		
Sand rock, yellow (little water, 50 to 65 feet)	25	75
Shale, black	5	80
Sand rock, brown	4	84
Shale, black	16	100
Shale, sandy (little water)	10	110
Shale and rock (little water, 110 to 130 feet)	30	140
Sand rock, gray	6	146
Shale, black	5	151

138. *Driller's log of test hole in the NW¼SW¼SW¼ sec. 3, T. 35 S., R. 43 W.*

[Surface altitude, 3,753 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Surface	84	84
Sand	56	140
Dockum group: Test hole ended in red beds		140

139. *Incomplete driller's log of test hole at the SW cor. sec. 15, T. 35 S., R. 43 W.*

[Surface altitude, 3,710 feet]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Caliche and sand	10	10
Caliche, sand, and gravel	10	20
Caliche and sand	10	30
Sand, red	50	80
Sand and gravel	50	130
Dockum group: Sand and shale, red, below 130 feet		

140. *Reported log of well in the SW¼NE¼ sec. 6, T. 35 S., R. 50 W.*

[Drilled in 1931. Data from W.P.A.]

	Thickness (feet)	Depth (feet)
Topsoil	1	1
Dakota sandstone: Sandstone, yellow	40	41
Purgatoire formation:		
Kiowa shale member: Shale, blue	50	91
Cheyenne sandstone member: Sandstone, yellow	72	163
Morrison formation: Well ended in green shale		163

141. *Incomplete driller's log of well 1 of the Watkins Land Co. in the NW¼NW¼ sec. 11, T. 31 S., R. 43 W., Morton County, Kans.*

[Cited by Darton, 1920]

	Thickness (feet)	Depth (feet)
Soil	5	5
Ogallala formation:		
Clay, yellow	20	25
Clay, sandy	10	35
Gravel, water-bearing	20	55
Caliche	25	80
Dakota sandstone:		
Clay, yellow	15	95
Sand, water-bearing	5	100
Clay, yellow	10	110
Sand, water-bearing	6	116
Clay, yellow	19	135
Sand, blue, water-bearing	35	170
Purgatoire formation:		
Kiowa shale member: Shale, blue	80	250
Cheyenne sandstone member: Sand, white, water-bearing	125	375
Dockum group(?):		
Shale, red	5	380
Total depth of well		1,150

142. *Driller's log of test hole at the NW cor. sec. 24, T. 31 S., R. 43 W., Morton County, Kans.*

[Drilled by L. C. Williamson, 1948]

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Ogallala formation:		
Clay, sandy	26	28
Clay, sticky, yellow	27	55
Clay, sandy, soft	35	90

	Thickness (feet)	Depth (feet)
Dakota sandstone(?):		
Sand rock, soft (1 g.p.m. of water)	5	95
Clay, sticky	5	100
Shale, sticky, black	7	107
Shale, gray	78	185
Dockum group(?):		
Shale, red	40	225
Shale, brown	105	330
Shale, red	9	339

143. *Sample log of test hole at the SW cor. sec. 31, T. 33 S., R. 43 W., Morton County, Kans.*

[Drilled in 1940. Surface altitude, 3,687 feet. (Cited by McLaughlin, 1942)]

	Thickness (feet)	Depth (feet)
Loam, dark	1	1
Soil, silty	2	3
Ogallala formation:		
Silt, brown	5.5	8.5
Silt, light-brown and gray	4.5	13
Silt, gray to brown, and caliche	6	19
Sand, fine, light-brown	2	21
Silt, white, and caliche	4	25
Sand, fine, brown	7	32
Sand, fine to coarse, brown	5	37
Sand, fine, brown	6	43
Sand, light-gray to brown	2	45
Sand, fine, brown	2	47
Sand and fine gravel: brown	11	58
Sand, light-gray to light-brown	9	67
Sand, fine, brown	4	71
Silt, light-brown	6	77
Sand, fine, brown	4	81
Sand, light-brown	4	85
Limestone, light-gray, and sand	4	89
Silt, light-gray, and sand	11	100
Sand and coarse gravel; brown	5	105
Clay, brown	8.5	113.5
Sand and coarse gravel; brown	19.5	133
Sand, gravel, and clay	8	141
Limestone, pink, containing sand and caliche	3	144
Dockum group:		
Sandstone, maroon and gray, and white clay	5	149
Sandstone, buff and yellow, with red siltstone and gypsum	1	150
Sandstone, buff, yellow, and blue-green	1.5	151.5
Sandstone, fine-grained, maroon	2	153.5
Sandstone, buff	4.5	158
Sandstone, very fine-grained, light-gray and brown	2	160
Sandstone, very fine-grained, maroon	2	162
Sandstone, light-gray, and clay	3	165
Sandstone, very fine-grained, buff, and clay	3	168
Sandstone, buff and red	1	169
Sandstone, fine-grained, buff to yellow-brown	16	185
Sandstone, buff to red	5	190

144. *Sample log of test hole at SW cor. sec. 21, T. 35 S., R. 43 W., Morton County, Kans.*

[Drilled in 1940. Surface altitude, 3,673 feet. (Cited by McLaughlin, 1942)]

	Thickness (feet)	Depth (feet)
Soil, brown	4	4
Ogallala formation:		
Sand, fine to medium, brown	22	26

	Thickness (feet)	Depth (feet)
Ogallala formation—Continued		
Silt, caliche, and sand	9	35
Sand, fine, brown	10	45
Silt, light-gray to brown, and some sand	11	56
Sand, fine to medium	8	64
Sand and gravel; coarse	6	70
Silt, brown	12	82
Sand, fine, and clay	4	86
Sand, fine to coarse, brown	6	92
Silt and sand	3	95
Sand, medium and fine, tan	3	98
Silt and sand	1.5	99.5
Sand and gravel	6.5	106
Gravel, fine to coarse	4	110
Silt and some sand	6	116
Silt, sandy, and caliche	8	124
Silt, gray-green to brown, with caliche and sand	27	151
Sand, fine, brown	11	162
Silt, gray-green to brown	3	165
Sand, medium and fine, brown	25	190
Sand and gravel	27	217
Silt and gray caliche	3	220
Silt, brown	4	224
Gravel, fine to coarse	46	270
Gravel, fine to coarse, and silt	10	280
Sand, fine to coarse, red-brown	14	294
Dockum group:		
Siltstone, gray to red-brown	8.5	302.5
Siltstone, red-brown	1.5	304
Silt, gray-green	6	310
Silt, gray-green, and sandstone	10	320

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