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GEOLOGY AND GROUND WATER RESOURCES OF CIMARRON COUNTY, OKLAHOMA

by

STUART L. SCHOFF

Geologist of the United States Geological Survey

with a Section on

MESOZOIC STRATIGRAPHY

by

J. WILLIS STOVALL

Professor of Geology, University of Oklahoma

Prepared in cooperation between the Oklahoma Geological Survey and the Geological Survey, United States Department of the Interior

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CIMARRON VALLEY AS SEEN FROM THE NORTHEAST END OF BLACK MESA, LOOKING EAST.

OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA

GEOLOGY AND GROUND WATER RESOURCES OF CIMARRON COUNTY, OKLAHOMA

By

STUART L. SCHOFF

ABSTRACT

Cimarron County is at the west end of the long, narrow strip known as the Oklahoma Panhandle and is the westernmost county in the State. Boise City, the county seat, is about 300 miles northwest of Oklahoma City and 115 miles northwest of Amarillo, Texas. The county is 54 miles long from east to west, about 34.5 miles wide, and covers about 1,850 square miles.

Cimarron County is part of the southern High Plains. About 65 percent of the surface is a plain 100 feet or more above the major streams, and the rest is valleys. The plain slopes imperceptibly east-southeast at a rate of about 18 feet to the mile, from about 4,800 feet above sea level near the west boundary to about 3,700 feet at the east boundary.

Most of the plain appears very flat, but actually is gently undulating. In many places are shallow, roughly circular depressions a few feet to several miles in diameter; in other parts of the county, sand dunes break the monotony of the plain, making a hilly topography. A large part of the county is undrained. The rain that falls on most of the upland either runs off into the temporary lakes and ponds or evaporates or sinks into the ground. Only about a third of the area is drained by the Cimarron and North Canadian (Beaver) Rivers. The Cimarron takes an eastward course across the northern part of the county to a point within about 12 miles of the east boundary, where it turns north into Colorado. It carries a little water along parts of its course in winter and also through part of the summer if precipitation is high. The North Canadian River, which is locally called the Beaver River, crosses the southern part of the county and enters Texas about 6 miles west of the east county line. It is generally dry except during floods.

The rocks exposed in Cimarron County range in age from Triassic to Quaternary. They are of sedimentary origin with the exception of a basalt flow in the extreme northwest corner.

The Mesozoic rocks crop out at the surface in about 16 percent of the area, being well exposed at many places along Cimarron River. They include: Dockum group (Triassic), mostly variegated clays, marl, and sandstone; Exeter sandstone (Jurassic); Morrison formation (Jurassic), variegated clay, sandstone, and

limestone; Purgatoire formation (Lower Cretaceous), composed of the massive Cheyenne sandstone at the base, overlain by the Kiowa shale; Dakota sandstone (Upper Cretaceous), composed of two massive sandstones and an intervening shale; and beds, mostly shales, belonging to the Colorado group (Upper Cretaceous), and correlated with the Graneros and Greenhorn formations. The Dockum, Exeter sandstone, Cheyenne sandstone, and Dakota sandstone are locally important water-bearing formations, the Dakota probably being of greatest importance.

More than half the surface of the county is underlain directly by the "Ogallala" formation of Pliocene, and possibly Pleistocene age. This unit contains considerable thicknesses of sand and gravels that are partially saturated with water, and constitutes the principal water-bearing formation, and one of great importance to the region. The quality of the water in the "Ogallala" is good, and, although somewhat hard, is satisfactory for domestic, industrial, and irrigation uses. In common with water from the "Ogallala" in other parts of the High Plains, analyses of samples from this formation in Cimarron County show a content of fluoride much higher than normal, ranging from 1 to 4 parts per million.

Structure of the Mesozoic strata is related in general to that of the Great Plains, and more particularly to the Sierra Grande-Las Animas arch of adjacent parts of New Mexico and Colorado. Regional dip is eastward from this arch to a syncline trending from the southwest corner of T. 4 N., R. 1 E.C.M., northeast to T. 6 N., R. 5 E.C.M. Southeast and east of this syncline, the strata appear to rise again. Owing to the broad structural features, Triassic and Jurassic rocks are exposed on the flanks of the syncline, in the extreme northwest part of the county, and in an area north of Boise City. In the area northwest of the syncline, the regional dip has been modified by a system of long, parallel, anticlinal and synclinal folds, which plunge southeast, and whose axes are parallel to the regional dip. No closures of great magnitude appear to exist in the part of the county where Mesozoic rocks are exposed. Structure of the rocks south and southeast of the syncline is concealed by the cover of "Ogallala" formation, which was not affected by the folding that deformed the older rocks.

Few minerals of economic importance occur in the county. Thin beds of impure lignite are mined locally by ranchers for fuel, because of the scarcity of wood. Exploratory drilling for oil and gas began in 1917, but went unrewarded until May, 1943, when The Pure Oil Company completed a gas well in sec. 16, T. 5 N., R. 8 E.C.M.

Owing to variations in conditions over the county, a classification into 5 major and 16 minor local ground-water areas has been made, reflecting depths to water, character and capacity of the water-bearing formations, surface topography, and soil. This classification indicates the areas most favorable for additional irrigation development.

The annual replenishment of water in the underground reservoir in the Ogallala formation depends primarily on precipitation in the form of rain and snow that falls on the outcrop in Cimarron County and adjacent parts of the High Plains of Kansas, Texas, New Mexico, and Colorado. The water probably enters the ground through areas of sandy soils and sand dunes, through channels of intermittent streams, and through the bottoms of temporary lakes. A significant part of the flood waters which come down the North Canadian River from outside areas probably reaches the ground water reservoir through the intermittent part of the channel. There may be some recharge from the Dakota sandstone where it thins and pinches out beneath the Ogallala.

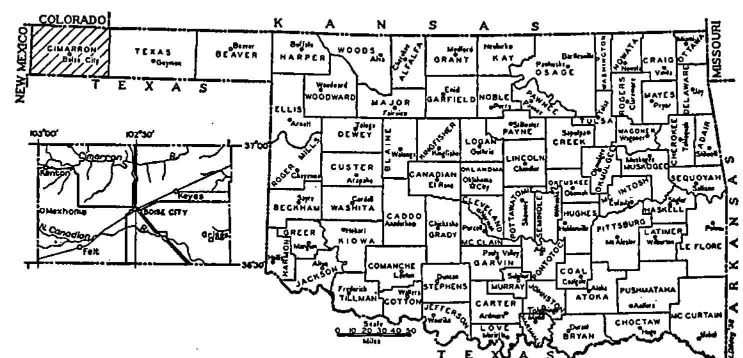


Fig. 1. Index Maps showing Location of Cimarron County, Oklahoma, and Principal Features in the County.

INTRODUCTION

Purpose and scope of this investigation. This is the second report in a series dealing with the geology and ground-water resources of the Oklahoma Panhandle, and presents the results of an investigation in Cimarron County. The first of these reports dealt with Texas County and was published by the Oklahoma Geological Survey as Bulletin 59. A third report, to deal with Beaver County, is in preparation.

The investigation of the rock formations exposed along the Cimarron River in the northwestern part of the county had its inception in 1931 when a road crew grading U. S. highway 64 turned up fossil bones about 100 yards east of South Carrizo Creek. In 1932 these were called to the attention of J. Willis Stovall, Professor of Paleontology of the University of Oklahoma, who found them to be the remains of dinosaurs. A quarry opened at this location under his supervision yielded thousands of bones, and other quarries in the northwestern part of the county also proved successful. The bones represented animals that lived during the Jurassic period, but they were found in rocks previously mapped as the Purgatoire formation, of Cretaceous age. It was evident, therefore, that the geologic maps and descriptions of the county needed extensive revision, and in the summers of 1936 and 1937, under the sponsorship of the Oklahoma Geological Survey, Stovall made a detailed geological study of the rock formations exposed along the Cimarron River and its tributaries in Cimarron County.

The ground-water investigation in Cimarron County was inspired by the drought of 1930-40. As one dry year followed another, partial or complete crop failures became the rule in the Oklahoma Panhandle and adjacent areas. Farm incomes declined sharply, some residents moved away, and wind erosion seriously damaged lands where no protective cover was afforded either by growing crops or by natural vegetation. Irrigation by pumping water from wells, either as a regular practice or as an occasional subsistence measure to carry the farmers over dry years, promised at least a partial solution to the drought problem.

The Tertiary sands and gravels that underlie the Southern

High Plains in parts of Texas, New Mexico, and Kansas contain large supplies of water and in several localities irrigation from wells has been practiced successfully. In climate, topography, and soil, the Oklahoma Panhandle is similar to these localities, and its need for a dependable water supply for growing crops is fully as great.

Ground water has already proved to be a natural resource of major importance to the Oklahoma Panhandle. The abundant supply of good water for domestic and stock use that can be obtained from wells drilled almost anywhere in the area has made possible its settlement and continued occupancy. The supplies of surface water, on the other hand, are both small and unreliable in most parts of the area because the precipitation is relatively low and is likely to be flashy, so that most of the time the streams are dry or carry very little water. In places, the meadows along the main streams have been successfully irrigated, and locally the surface run-off is caught in stock ponds made by constructing earthen dams in the smaller drainage courses, but the quantity of water obtained in this way is only a fraction of that taken from wells. At present, nearly all town, industrial, and farm supplies of water are obtained through wells.

In the early days of settlement, wells were drilled at wide intervals on the uplands and were equipped with windmills for pumping water for stock. Travelers knew these wells by name, and many homesteaders hauled water from them until they could afford to drill wells of their own. Now nearly every farm has a windmill well. Up to the present time, the drain on the underground reservoir has been small in proportion to its capacity, and depletion at the present rate of withdrawal is unlikely, but the possible effect of many irrigation wells is obviously of vital interest to both the present users of ground water and the potential irrigators. Accordingly, the chief purpose of the ground-water investigation has been to determine the availability of water from wells for irrigation, and to obtain a record of the normal fluctuations of the water table for comparison with the fluctuations that will occur if large-scale pumping is begun.

The ground-water investigation was conducted through cooperation between the Oklahoma Geological Survey and the Geological Survey of the United States Department of the Interior. It was made under the general direction of O. E. Meinzer, Geologist in Charge of the Division of Ground Water of the Federal Geological Survey, and Robert H. Dott, Director of the Oklahoma Geological Survey. W. N. White, Senior Engineer in the Federal Geological Survey, who is in charge of ground-water investigations in Texas, supervised the field work.

Location of the area. Cimarron County is the westernmost county in Oklahoma, at the western end of the area known as the Panhandle. (figure 1) It is about 300 miles northwest of Oklahoma City and 115 miles northwest of Amarillo, Texas, is 54 miles long from east to west, about 34.5 miles wide, and covers about 1,850 square miles. It extends from Lat. 36° 30′ N. to Lat. 37° 00′ N., and from a mile or two west of Long. 102° 00′ W. to Long. 103° 00′ W. It is bounded on the north by Colorado and the extreme western end of Kansas; on the east by Texas County, Oklahoma; on the south by the state of Texas; and on the west by New Mexico.

The land survey of the entire Oklahoma Panhandle is referred to parallel 36°-30′, as the base line, and meridian 103°, which is known as the Cimarron Meridian. A recent correction in the location of parallel 36°-30′, gave to Oklahoma a narrow strip of land south of the old base line. Cimarron County includes Tps. 1-6 N., inclusive, the narrow strip in T. 1 S., and Rs. 1-9 E.C.M., inclusive.

The Atchison, Topeka, and Santa Fe Railway operates two branch lines in Cimarron County. One crosses the county from north to south, and connects La Junta, Colorado, with Amarillo, Texas, passing through Boise City. The other extends from the northeast to Boise City, and connects with Dodge City, Kansas. This branch formerly extended southwest to Farley, New Mexico, but during the fall of 1942 was dismantled and abandoned, the steel being turned over to the Federal government in the scrap metal drive.

The Beaver, Meade, and Englewood Railroad (Missouri-Kansas-Texas) enters the county from the east, has about 13 miles of track within the county, and connects the Santa Fe Railroad at Keyes with the Missouri-Kansas-Texas at Forgan, in Beaver County. It provides an east-west freight service extending nearly the full length of the Oklahoma Panhandle.

Roads on section lines give access to almost all parts of the uplands of Cimarron County, but the roads crossing or leading into or along the principal valleys are fewer and generally are winding. Besides county roads, two Federal highways and two State highways cross the county (fig. 1 and Plate I). U. S. Highway 64 crosses from east to west, passing through Boise City and Kenton. It is a bituminous-surfaced road east of Boise City. U. S. Highway 287 enters the county from the south, extends northwestward to Boise City, and thence northward into Colorado. It is a bituminous-surfaced road north of Boise City. State Highway 3 is a link in the Oklahoma City-Denver highway, and in Cimarron County coincides with the eastern part of U. S. Highway 64 and the northern part of U. S. Highway 287. State Highway 78 extends southward from Boise City to the Texas State line, where it connects with the road to Dalhart, Texas.

Previous investigations. The fundamental facts regarding the occurrence of ground water in the Southern High Plains, of which Cimarron County is a part, and its source, availability, and limitations on its use, were set forth by W. D. Johnson[1] about 1900. Gould's[2] report on the geology and water resources of Oklahoma, published in 1905, included the Panhandle under the heading "High Plains", but the name Cimarron County does not appear in it because at that time the entire Panhandle was called Beaver County. This report includes records of 10 wells in the Panhandle, among them a well belonging to John Skelley, of Mineral, in the present Cimarron County.

Under provisions of House Bill 42[3], approved February 20, 1911, the Third Oklahoma Legislature appropriated $45,000 to be

1. Johnson, W. D., "The High Plains and Their Utilization": *U. S. Geol. Survey, 21st Ann. Rept.*, Pt. IV, pp. 631-669, 1901.
2. Gould, C. N., "Geology and Water Resources of Oklahoma": *U. S. Geol. Survey Water Supply Paper* 148, p. 88, 1905.
3. *Session Laws of Oklahoma*, Chap. 22, p. 42, 1911.

spent under the direction of the State Board of Agriculture in drilling test wells for artesian water on state school lands in the Oklahoma Panhandle. Locations were specified for 9 wells, 2 of them in Beaver County, four in Texas County, and three in Cimarron County.

The Cimarron County locations were:

Sec. 16, T. 1 N., R. 9 E.C.M.
Sec. 16, T. 3 N., R. 1 E.C.M.
Sec. 16, T. 3 N., R. 5 E.C.M.

Not more than $5,000 was to be spent at one location, and drilling was to begin not later than June 1, 1911.

Copies of the contracts that may have been let under the terms of this act are no longer available. All matters pertaining to irrigation were transferred by the Legislature of 1915 from the Board of Agriculture to the State Engineer, and the early records are lost. The minutes of the State Board of Agriculture, however, show that in 1912 the Board entered into a contract with J. G. Hammill and J. H. Chafe for drilling wells and making tests for artesian water as provided in the act, and later in the same year consented to the assignment of this contract to T. M. Latham. The Fourth Legislature in 1913 passed an Act entitled "An Act Repealing Sections 1, 2, 3, 4, and 5 of Chapter 22 of the Session Laws of 1911," thereby repealing the appropriation for the test-drilling. The minutes of the Board of Agriculture show, further, that T. M. Latham entered a claim for the drilling of well 6, on Section 16, T. 3 N., R. 5 E.C.M., near Boise City, to the depth of 20 feet and 8 inches at $5.25 per foot, for a total of $108.06. The board disapproved this claim because the act appropriating the money had been repealed.[4]

The above-mentioned test well, for which T. M. Latham entered a claim, appears to have been in the NE¼ NE¼ sec. 16, T. 3 N., R. 5 E.C.M., near the northwest corner of Boise City. A map of Cimarron County that was prepared by the Oklahoma Geological Survey in 1921 shows a "state well" in this location.

4. Scott, Joe C., President, State Board of Agriculture: Letter dated Feb. 2, 1942.

It does not show similar "state wells" at the other two Cimarron County locations specified in the act.

Other official records of this test-drilling are lacking, but an old well log in the files of the Oklahoma Corporation Commission records the strata that were penetrated in a well drilled in 1911 to a depth of 1,053 feet in sec. 34, T. 5 N., R. 17 E.C.M., near Hooker. According to local people, among them a well-driller, this well was put down "by the government." The log is published in the ground-water report on Texas County.[5] Another "government" well 800 feet in depth was reported in sec. 16, T. 5 N., R. 10 E.C.M., near the former Carthage post office, and is listed in the Texas County report as No. 505. Both these locations are in the list of proposed test sites specified in the appropriation of 1911.

In 1917, the geology of Cimarron County was described briefly in Oklahoma Geological Survey Bulletin 19[6], the second part of which dealt with the oil and gas possibilities of the state by counties. A more elaborate discussion of the geology of the county, based on field work in the summers of 1919 and 1921, was prepared by Rothrock[7] and was published by the Oklahoma Geological Survey in 1925. Rothrock's report was briefly criticised by DeFord[8] two years later.

Oklahoma Geological Survey Bulletin 19 was soon out of print, and a new report of the same type was published by the Survey as its Bulletin 40, first issued as separate chapters and later as 3 bound volumes. Six[9] prepared a chapter dealing with the three Panhandle counties, which was longer and more detailed than the discussion of Cimarron County in Bulletin 19, but was necessarily shorter than the county report by Rothrock. It was essen-

5. Schoff, S. L., "Geology and Ground Water Resources of Texas County, Oklahoma": *Okla. Geol. Survey Bull.* 59, p. 180, 1939.
6. Shannon, C. W., *et al*, "Petroleum and Natural Gas in Oklahoma: A Discussion of the Oil and Gas Fields and Undeveloped Areas of the State, by Counties": *Okla. Geol. Survey Bull.* 19, Pt. II, pp. 105-107, 1917.
7. Rothrock, E. P., "Geology of Cimarron County, Oklahoma": *Okla. Geol. Survey Bull.* 34, 1925.
8. DeFord, R. K., "Areal Geology of Cimarron County, Oklahoma": *Bull. Amer. Assoc. Petro. Geol.*, Vol. 11, pp. 753-755, 1927.
9. Six, R. L., "Oil and Gas in Oklahoma: Beaver, Texas, and Cimarron Counties": *Okla. Geol. Survey Bull.* 40, Vol. 2, pp. 479-491, 1930. Also published as 40-WW.

tially a condensation of the bulletins[10] that had been published separately for each county, supplemented by a limited amount of field work and new information with special bearing on oil and gas.

A survey of the chemical character of the ground water in Cimarron County in relation to agriculture was made by Houghton[11] and published by the Panhandle Experiment Station in 1932. In 1935 Theis, Burleigh, and Waite[12] released a mimeographed report summarizing the results of a 2-year reconnaissance study of the ground-water resources of the entire Southern High Plains. In June of the following year, W. N. White, of the Geological Survey, United States Department of the Interior, Robert H. Dott, Director, Oklahoma Geological Survey, and W. C. Burnham, Chief Engineer, Oklahoma Conservation Commission, made a brief ground-water reconnaissance of the Oklahoma Panhandle. The results of this investigation were summarized, with recommendations for further work, by White.[13]

In 1936, also, the State Mineral Survey[14] collected information on farm and ranch wells in part of the county in connection with a general investigation of mineral deposits, such as sand, gravel, and caliche. The well information obtained in this way included the depth of each well, the static water level, the estimated yield, and the performance during drought, as reported to the observers by the owners or tenants. These data have been tabulated by the Oklahoma Geological Survey, and typewritten manuscript reports may be examined at the Survey office in Norman. In contrast with the present ground-water study, the investigation by the State Mineral Survey did not include measurements in the wells, nor were well logs, drill cuttings, or water samples taken.

10. *Okla. Geol. Survey Bulletins* 34, 37, and 38, on Cimarron, Texas, and Beaver Counties.
11. Houghton, H. W., "Water Supply of Cimarron County, Oklahoma": *Panhandle Agri. Exper. Sta., The Panhandle Bulletin*, No. 38, 1932.
12. Theis, C. V., Burleigh, H. P., and Waite, H. A., "Ground Water in the Southern High Plains": *U. S. Geol. Survey Memorandum for the Press*, Oct., 1935.
13. White, W. N., "Ground Water in the Oklahoma Panhandle (Cimarron, Texas, and Beaver Counties)": *U. S. Geol. Survey Mimeograph Memorandum.* Copies on file at the offices of the Geological Survey, U. S. Dept. of the Interior, Washington, D. C.; and the Oklahoma Geological Survey, Norman.
14. Works Progress Administration Project 65-65-538, sponsored and directed by the Oklahoma Geological Survey, 1936-1937.

Stovall[15] published an abstract outlining the stratigraphy of the Cimarron Canyon area in the northwestern part of Cimarron County in 1937, and after completing the field mapping in that area he prepared a fuller statement of his findings.[16] The preliminary results of the ground-water investigation in the county were released in 1939 in the form of a mimeographed memorandum for the press[17], and a brief review of the ground-water resources of the entire Oklahoma Panhandle was published by Schoff[18] in 1940. Chapters reporting fluctuations of ground-water levels in observation wells in Cimarron County have been reported in the annual summaries of water levels and artesian pressures in the United States beginning with the volume for 1938.[19]

Methods of this Investigation. Mapping of the area of outcrop of Mesozoic rocks in the valleys of Cimarron River and its tributaries, in the northwest part of the county, was executed by Stovall, with a plane table, telescopic alidade, and stadia rod, supplemented with a Brunton compass and hand level. During the two seasons' field work, he was assisted by Byron Bolar and Don Savage.

Plane table control permitted accurate mapping of formation contacts. Elevations, based on United States Coast and Geodetic Survey bench marks, and referred to the base of the Dakota sandstone, supplied data for the preparation of a reconnaissance structure map which is of sufficient accuracy to portray the general structural features of the area.

Field work for the ground water investigation was begun about the middle of July, 1938, and carried on, with a few interruptions, until the middle of November. It was continued, again

15. Stovall, J. W., "Advance Notes on the Geology of the Cimarron Valley of Northwestern Oklahoma": *Okla. Acad. Science Proc.*, Vol. 17, pp. 78-79, 1937.
16. Stovall, J. W., "The Morrison of Oklahoma and its Dinosaurs": *Jour. Geol.*, Vol. 46, pp. 583-600, 1938.
"Geology of the Cimarron Valley of Cimarron County, Oklahoma": Thesis presented to the faculty of the University of Chicago in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 1938.
17. "Ground Water in Cimarron County, Oklahoma": *U. S. Dept. of Interior, Geol. Survey, Memorandum for the Press*, May 29, 1939. Copies on file in the offices of the Geological Survey, Washington, and the offices of the Oklahoma Geological Survey, Norman.
18. Schoff, S. L., "Ground Water in the Oklahoma Panhandle": *Econ. Geol.*, Vol. 35, pp. 534-545, 1940.
19. "Water Levels and Artesian Pressure in Observation Wells in the United States": *U. S. Geol. Survey, Water Supply Papers* 845, 886, 909, and 939 (1938-1941, incl.)

with interruptions, from mid-April to early July 1939. Additional information has been collected subsequently in connection with trips to the county to make the periodic water-level measurements in the observation wells.

Measurements with a steel tape were made in more than 400 farm and ranch wells in Cimarron County to determine their depth and the depth to the static water level, and reported depths and water levels were obtained for several other wells. Statements on the nature and thickness of the water-bearing materials penetrated by the wells, the general character of the water, and the uses to which it is put, were obtained from land owners, tenants, and well-drillers. Measurements were made of the yield of several of the springs issuing from the Dakota sandstone, and five test holes were dug to determine the depth to water below the channel of the North Canadian River. Samples of water from 42 wells and 7 springs were collected, and most of these were analyzed in the Water Resources Laboratory of the Geological Survey, United States Department of the Interior, in Washington. Surface exposures of the rock formations were examined in the field as a guide to the interpretation of well logs and to the hydrologic properties of the formations. Water-bearing sands from the channel of the North Canadian River and from wells drilled recently, and rocks in natural or artificial exposures were sampled for laboratory study. Part of these samples were studied in the hydrologic laboratory of the Geological Survey in Washington, and part were studied in the laboratory of the Oklahoma Geological Survey in Norman.

Altitudes of the measuring points at the wells on the uplands were obtained partly by leveling with a plane-table and alidade, and partly by short altimeter traverses. In the determination of altitudes by altimeter, one instrument stationed at a bench mark was read at 5-minute intervals and the second, or traveling, instrument was read at corresponding times. This procedure is thought to have eliminated much of the error that ordinarily is caused by barometric fluctuations due to weather conditions. Bench marks set by the United States Coast and Geodetic Survey furnished the principal control for the leveling, and all bench

marks recovered during this work are shown on the map (Pl. I).[20] Other points whose altitudes are known with a fair degree of accuracy were used as bench marks in areas remote from the Coast and Geodetic Survey's level lines.

Acknowledgments. The writers are indebted to the residents of Cimarron County, many of whom gave access to their lands or permitted measurements to be made in their wells, and furnished helpful information. Special thanks are given to William E. Baker, County Agricultural Agent, R. J. French, the H. H. Willson family, Mr. and Mrs. Rex Powelson, Si Strong, and R. C. Tate, all of Cimarron County; and the late Arthur Wedel, Bryon Bolar, and D. E. Savage, for their cooperation with Stovall in the stratigraphic work.

A. C. Brown, Lee Wright, E. B. Witten, Harrison Browder, and Glenn Mobray, all of whom have drilled water wells in the county, gave information on individual wells and on general subsurface conditions affecting water wells. The Santa Fe Railway, through its office in Amarillo, Texas, furnished records of its test wells at Keyes, Boise City, and Felt. The Cimarron Utilities Company furnished information on its wells at Boise City and Felt.

D. L. Powers, of Boise City, Oklahoma, assisted with the plane-table and altimeter work in determining well elevations, and made part of the periodic water-level measurements in the observation wells. F. A. Devin furnished many of the altitudes of road intersections determined by him in plane-table mapping for The Pure Oil Company. The Gulf Research and Development Company, through its office in Tulsa, Oklahoma, assisted in the study of the subsurface conditions in eastern Cimarron County by allowing Schoff to examine the shot-hole logs obtained by one of its seismograph parties. The writers are especially indebted to the Oklahoma Geological Survey, and especially to Director Robert H. Dott, for assistance in handling details of the field work and the preparation of this report, and for advice on the geological problems.

20. For descriptions of all bench marks set by the Coast and Geodetic Survey in Cimarron County, see *Oklahoma Geological Survey Bulletin* 61.

GEOGRAPHY

Topography and Drainage. Cimarron County is part of the High Plains section of the Great Plains Physiographic province[21]. It includes the highest point in Oklahoma, a place on Black Mesa near the New Mexico State line that is nearly 5,000 feet above sea level. The mesa, however, is above the general level of the rest of the county.

Part of Cimarron County is drained by the Cimarron and North Canadian Rivers, but large areas are essentially undrained except to the extent that surface water drains into local depressions. These undrained areas are the upland plains, and constitute about 65 percent of the area of the county. They are 100 feet or more above the major streams. From a topographic map (fig. 2) prepared by Schoff from the available surface altitudes, it appears that the upland plains slope east-southeastward at rates ranging from 17.5 to 28 feet per mile. Near Mexhoma, 1 mile east of the New Mexico State line, the altitude is 4,823 feet above sea level; at Boise City it is 4,165 feet; and on U. S. Highway 64 at the east line of the county it is 3,691 feet. The average slope between Mexhoma and the east line of the county is about 21 feet per mile. A complete list of Coast and Geodetic Survey bench marks in Cimarron County, with locations and elevations, is given in Oklahoma Geological Survey Bulletin 61. Bench marks that were recovered during this investigation are shown on Plate I.

Locally, the upland plain is very flat, but in most places it is gently undulating. In many parts of the county, also, the plain is dotted by shallow, roughly circular depressions ranging from a few feet to several miles across, in which water may stand for a time after heavy rains. One of the largest of these depressions lies southwest of Keyes and is occupied at times by Willowbar Lake. This is reported to have been dry about 1936, but in June 1937 an exceptionally heavy rain fell on the area draining into it. A large run-off resulted, and filled the lake to a reported depth of 10 or 15 feet. Small boats were brought to the lake and fish were planted in it, but by early 1940 the water was nearly all gone. The heavy rainfall of 1941 put little water in the lake, and at the

21. Fenneman, N. M., "Physical Divisions of the United States" (Map): *U. S. Geol. Survey*, 1930.

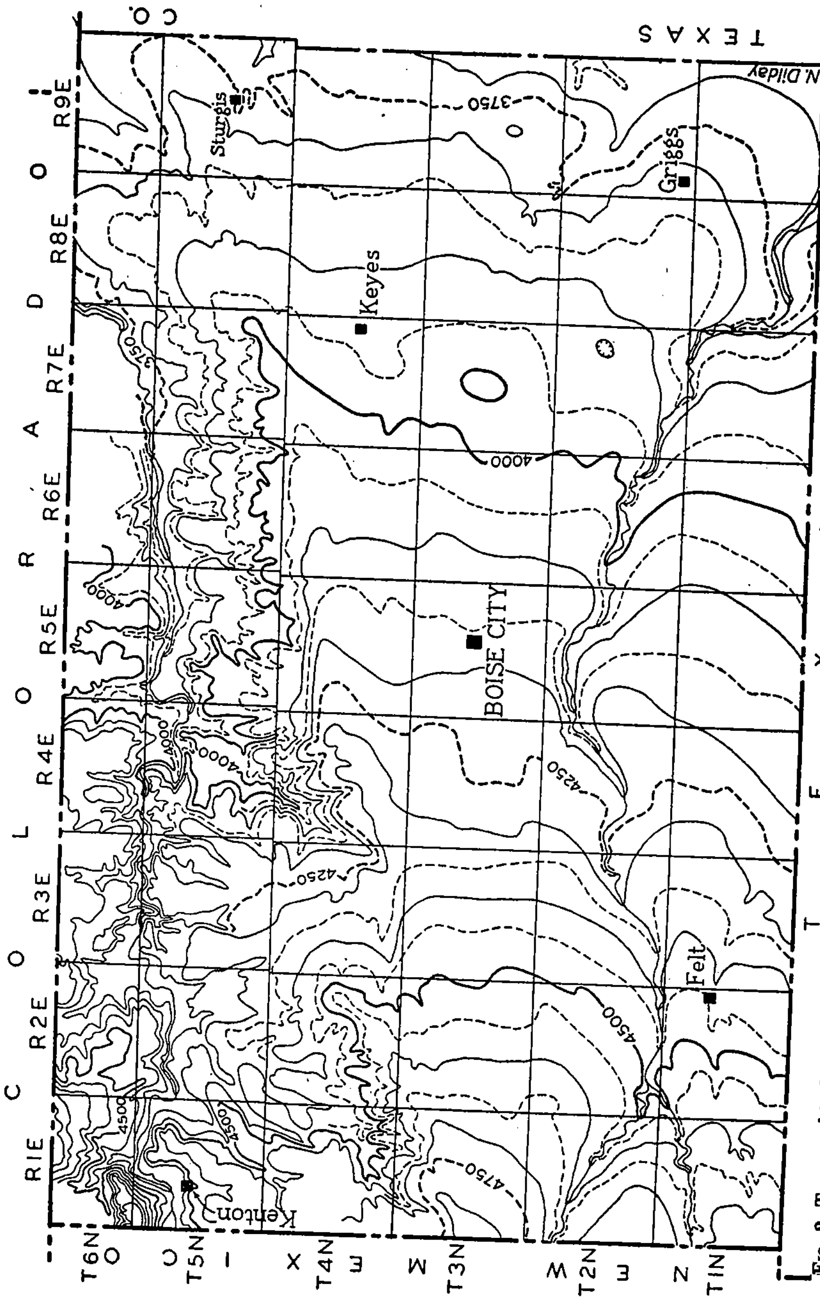


FIG. 2 Topographic Map of Cimarron County, based on bench marks of the U. S. Coast and Geodetic Survey, plane-table and altimeter altitudes, and surveys for the proposed Kenton Dam. Scale, 1:500,000. Contour interval, 50 feet.

end of the year it was dry. Another large depression occupies the northeastern quarter of T. 2 N., R. 7 E., just west of Sampsel Corner.

Some of the depressions have been called "buffalo wallows" and have been attributed to the action of the wind in removing dust loosened by buffalo that were searching for water at dry water holes, but it is more likely that they are due to subsidence following the compaction of unconsolidated sediments or the removal of soluble rocks beneath the surface. Such subsidence still seems to be in progress. Mr. and Mrs. E. J. Behrendt reported that in October 1935 strange rumblings resembling distant thunder were heard at their place in the NW¼ sec. 9, T. 3 N., R. 7 E., which is partly in a small depression. By November, 33 cracks about 4 feet in width at the surface had appeared. These cracks bounded roughly circular areas with diameters of about 40 feet (fig. 3). Behrendt examined one of them and found in it about 8 feet of soil, underlain successively by 10 feet of caliche and 4 feet of yellow sand. The writers believe that the effects observed by the Behrendts represent one of the many small, widely spaced steps in the development of the depression on their place. The origin of the depressions on the High Plains has been reviewed in a report on Texas County[22], and a special case of sink-hole development involving faults and an artesian basin in Kansas has been described by Frye and Schoff.[23]

Sand dunes mask the flatness of the upland plain, notably on the south side of the North Canadian River east of Felt; on the north side of the river in a belt extending northwestward from near Mexhoma into the western part of T. 4 N., R. 4 E. (Pl. I); on the north side of the river near Conrad station and in T. 1 N., R. 8 E.; and along the Kansas State line north of Sturgis station. Some of the dunes are 40 feet in height and they make a moderately hilly topography. (Pl. III).

The Cimarron River enters Cimarron County near the northwestern corner, flows eastward for more than 40 miles, and turns northward to enter Colorado about 12 miles west of the north-

22. Schoff, S. L., *op. cit.*, pp. 22-23.
23. Frye, J. C., and Schoff, S. L., "Deep-Seated Solution in the Meade Basin and Vicinity, Kansas and Oklahoma": *Amer. Geophys. Union, Trans.* (in press).

eastern corner of the county. Along the western part of its course in Oklahoma, the river is nearly perennial, but east of the highway bridge (middle of Range 5) it generally is dry through much of the year. The headwaters of the Cimarron drain a large area in northeastern New Mexico, whence flood waters frequently descend into Oklahoma.

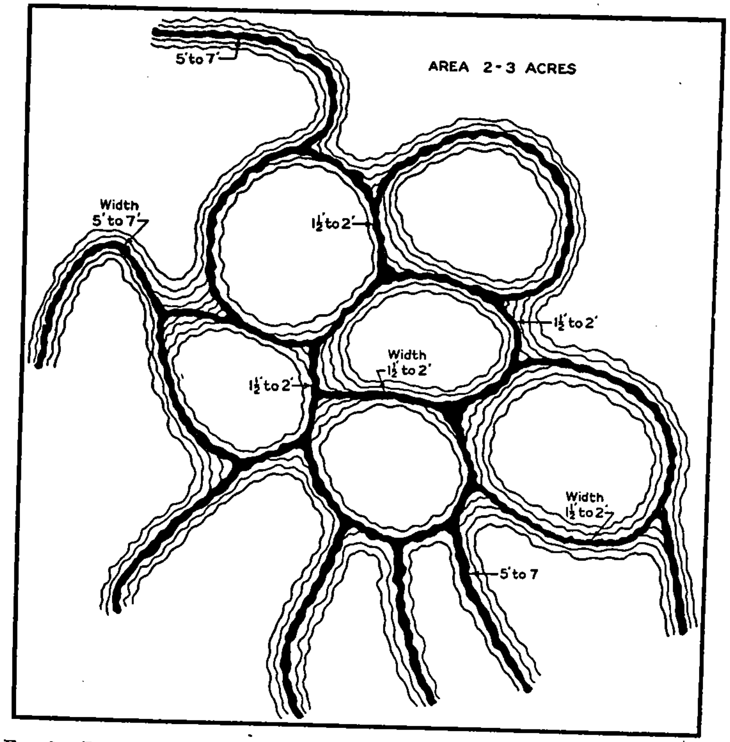


Fig. 3. Pattern of cracks developed in recent sink hole activity, based on sketch by land owner.

From the New Mexico State line to T. 5 N., R. 5 E., the Cimarron has carved a canyon that ranges from less than 0.5 mile to about 2 miles in width. The upper part of the valley wall generally is a cliff formed by the Dakota sandstone. Below this is a moderate slope, another sandstone cliff and a long gentle slope that merges into the flood plain. Many side canyons, among them Cold Springs Arroyo, Ute Canyon, and Gallienas, North

Carrizo, South Carrizo, and Tesesquite Creeks, open into the Cimarron. It is near the mouths of these tributaries that the cliffs recede farthest from the river.

The cliff-forming sandstones are missing along most of the Cimarron Valley east of the bridge on U. S. Highway 287, and the cross-profile of the valley is a broad, open "V". The tributaries have excavated short, rather shallow, wide valleys in the bluff of the main valley. All of them are dry except immediately after rains.

The maximum width of the flood plain along the Cimarron River is only about 1 mile, but the area that has been more or less dissected by the Cimarron and its tributaries has maximum width of about 19 miles, not counting the part that extends into Colorado.

The North Canadian River rises in northeastern New Mexico about 45 miles west of the Oklahoma State line. In Cimarron County the upper 7 or 8 miles, above the mouth of Cieneguilla Creek, is known by the name Currumpa Creek. A mile or two along the middle of this stretch is perennial. The portion below Cieneguilla Creek is known locally as Beaver River, and is generally dry except during floods. The only perennial flow along this part of the river that was observed by the writer is a stretch of 1 mile or less across sec. 21, T. 2 N., R. 6 E.

Although the "Currumpa" and Cieneguilla Valleys are 3 or 4 miles in width, the main portion of the North Canadian, or "Beaver", Valley is generally narrow, and the average width of the three valleys is only about 1.5 miles. At U. S. Highway 287 southeast of Boise City, near Conrad station, the width of the North Canadian Valley is only about 1.1 miles, the flood plain is 0.2 mile in width, and the cross-profile is a moderately broad "V". At places both upstream and downstream from U. S. highway 287, however, caliche cliffs on one side or the other give the valley a more rugged appearance (see Pls. XIII and XVI). Cliffs of Dakota sandstone line the channel near Harmer siding and along much of the "Currumpa" portion and along Cieneguilla Creek.

Except for Cieneguilla Creek, only short, unnamed ravines and gullies enter the North Canadian River in Cimarron County;

but North Fork, Tepee, and Goff Creeks, which join it to the east in Texas County, head in the eastern part of Cimarron County. Their headwaters have partly dissected the upland plain north and east of Griggs; north of Midwell school; and near Sturgis. All the tributaries of the North Canadian River in Cimarron County are dry except during floods.

Climate. Cimarron County has a semi-arid climate.[24] The average annual mean temperature, as recorded by U. S. Weather Bureau observers, is 53.9° F. and 54.8° F. at Boise City and Kenton, respectively.[25] In summer the days are usually hot, but the nights are cool because of the relatively high altitude. July and August are the warmest months, and January and December the coldest. The highest and the lowest recorded temperatures and the months in which they occurred are the same for both Weather Bureau stations: 108° F. in July and —20° F. in January (Table I). The average length of the growing season, as determined by the latest killing frost in the spring and the first killing frost in the fall, is about 180 days (Table II).

TABLE I.

AVERAGE MONTHLY AND ANNUAL MEAN TEMPERATURE, AND HIGHEST AND LOWEST RECORDED TEMPERATURE, IN DEGREES FAHRENHEIT, AT BOISE CITY AND KENTON.

Month	Boise City (34-yr. record)	Kenton (41-yr. record)
Jan.	32.9	34.8
Feb.	36.0	37.3
Mar.	42.7	44.8
Apr.	51.8	53.3
May	61.3	62.1
June	72.1	71.6
July	76.8	76.3
Aug.	74.6	75.2
Sept.	66.7	67.9
Oct.	54.2	55.9
Nov.	42.1	44.1
Dec.	32.4	34.7
Annual	53.9	54.8

Highest recorded temperature (both stations): 108° F., (July).
Lowest recorded temperature (both stations): —20° F. (January).

24. Thornthwaite, C. W., "Atlas of Climatic Types in the United States, 1900-1939": *U. S. Dept. Agri., Misc. Pub.* 421, Pl. 3, 1941.

25. Except as noted, climatic data are either quoted or summarized from *U. S. Weather Bureau*, "Climatic Summary of the United States, Section 42, Western Oklahoma, 1930"; and "Climatological Data, Oklahoma Section, Annual and Monthly, 1931-1941."

TABLE II.

FROST DATA (GROWING SEASON) AT BOISE CITY AND KENTON.

	Average date of last killing frost in spring [1]	Average date of first killing frost in autumn [1]	Average length of growing season (days) [1]	Latest date of killing frost in in spring [2]	Earliest date of killing frost in autumn [2]
Boise City	April 22	Oct. 19	180	May 15	Oct. 5
Kenton	April 23	Oct. 19	179	May 22	Sept. 27

[1] Weather Bureau average based on figures from beginning of record through 1930.
[2] Through 1940.

Records of the precipitation have been kept by Weather Bureau observers at Kenton since 1900, at Hurley (5 miles north of Boise City) from 1908 through 1920, and at Boise City from 1921 to the present. The record for Hurley is considered unreliable and has been expunged.[26] The annual precipitation during the period of record has ranged from 9.21 inches to 35.56 inches at Kenton, and from 8.62 to 35.98 inches at Boise City. The highest annual precipitation has been about four times the lowest at both Boise City and Kenton. Winter temperatures are low enough so that part of the precipitation comes as snow. The annual amount of snow, as averaged by the Weather Bureau through 1930, was about 20 inches at Kenton and about 30 inches in the vicinity of Boise City. In addition to variations in precipitation from year to year, large differences between adjacent stations may appear for the same year (Tables III and IV).

The normal annual precipitation, as published by the Weather Bureau, is 16.05 inches for Boise City, and 18.03 inches for Kenton, but these figures do not appear to be fully satisfactory. If the precipitation year by year is compared with these standards, it is found that the precipitation at Boise City was above normal in 12 years out of 21, or nearly two years out of three, whereas the precipitation at Kenton was above normal only in 14 years out of 41, or about one year in three. The cumulative departure curves for the two stations diverge widely (fig. 4), because the station having the higher normal actually received less precipitation over the period of record than the station with the lower normal.

26. Wahlgren, H. F., Meteorologist, Oklahoma City, Letter 4/1/42.

TABLE III.

MONTHLY AND ANNUAL PRECIPITATION, IN INCHES, AT BOISE CITY, OKLAHOMA, 1921-1941.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Departure from average [3]
1921	1.83	1.00	1.60	1.27	4.13	4.57	4.24	1.48	0.37	1.12	T	0.20	21.81	+6.33
1922	0.24	1.40	1.42	3.84	2.45	2.84	4.82	0.82	2.52	0.41	1.03	0.21	22.00	+6.52
1923	T	1.02	0.84	1.45	4.86	6.02	5.83	2.81	3.00	6.21	1.11	1.20	34.35	+18.87
1924	0.10	0.33	1.44	0.81	2.44	0.68	5.32	2.05	0.86	2.35	T	1.33	17.71	+2.23
1925	0.70	0.63	0.22	1.28	2.06	0.95	4.08	2.30	5.47	0.68	0.65	0.10	19.12	+3.64
1926	0.15	0.34	2.38	1.81	3.00	3.39	1.14	1.49	2.82	0.41	0.03	0.68	17.64	+2.16
1927	T	0.15	0.30	1.40	0.00	4.13	5.77	6.33	1.30	0.28	0.00	0.03	19.69	+4.21
1928	0.00	0.44	1.10	1.35	7.72	4.63	1.63	1.24	0.50	3.85	3.39	1.00	26.85	+11.37
1929	T	0.45	0.97	0.31	1.68	0.59	2.13	2.85	1.18	0.36	1.55	0.20	12.27	—3.21
1930	0.20	T	0.65	0.88	1.39	0.84	3.03	1.35	1.56	9.77	1.22	0.20	21.09	+5.81
1931	0.00	0.50	1.32	1.95	1.71	1.53	2.49	1.75	0.91	0.65	0.40	1.43	14.64	—0.84
1932	1.00	0.35	1.10	1.60	0.31	3.68	0.40[1]	1.13	1.22	0.56	0.31	0.61	12.27[1]	—3.21
1933	T	0.15	0.97	0.53	2.17	0.93	1.82	6.79	0.51	0.47	0.88	0.35	15.57	+0.09
1934	T	1.51	0.45	0.23	0.99	1.66	0.90	1.31	1.23	0.04	0.30	T	8.62	—6.86
1935	0.53	T	0.30	T	2.17	1.25	0.77	0.52	1.91	1.07	0.95	0.15	9.62	—5.86
1936	0.55	T	T	0.15	2.84	0.48	1.72	0.67	2.27	0.52	T	0.35	9.55	—5.93
1937	0.07	0.28	0.96	0.26	2.44	4.30	0.83	0.35	0.64	0.63	0.24	0.82	11.82	—3.66
1938	0.03	0.77	0.53	1.04	1.66	4.77	3.48	0.30	2.48	2.42	0.25	0.77	18.50	+3.02
1939	1.70	0.80	1.81	1.91	2.67	1.25	1.53	0.49	0.51	T	0.06	1.30	14.03	—1.45
1940	0.52	0.46	1.01	1.90	3.39	1.10	0.55	2.15	1.30	0.53	2.92	0.40	16.23	+0.75
1941	0.32	0.53	1.47	3.18	8.61	6.16	3.79	3.21	4.61	3.77	0.12	0.21	35.98	+20.50
Average [2]	0.32	0.41	0.92	1.02	2.28	2.30	1.98	1.91	1.61	1.39	0.82	0.52	15.48	

Average annual snowfall through 1930: 30.3 inches.
[1] Interpolated, or partly interpolated.
[2] Average as computed for the period Sept. 1925 through 1940 by H. F. Wahlgren.
[3] Computed from average for period Sept. 1925 through 1940.
T—Trace

TABLE IV.

MONTHLY AND ANNUAL PRECIPITATION, IN INCHES, AT KENTON, OKLAHOMA, 1900-1941.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Departure from average [2]
1900	......	......	......	......	......	......	......	......	......	......	T	0.20	......	......
1901	0.40	0.30	0.45	1.76	3.03	1.02	0.49	3.42	1.72	0.61	0.50	0.10	13.80	—0.47
1902	0.30	0.40	1.20	0.50	4.88	1.12	1.61	1.03	0.14	2.00	0.29	0.50	13.97	—0.30
1903	0.15	3.40	0.10	0.85	0.73	3.06	1.10	0.85	0.04	0.82	0.10	0.10	11.30	—2.97
1904	0.20	T	0.26	0.58	0.99	1.14	2.95	0.83	5.22	0.40	0.10	0.75	13.42	—0.85
1905	0.60	0.35	1.56	5.93	3.38	3.29	2.14	2.62	2.48	0.25	1.70	T	24.30	+10.03
1906	0.40	0.24	0.31	2.43	1.44	4.39	3.37	1.16	3.32	1.11	0.74	0.82	19.73	+5.46
1907	0.27	T	T	2.94	3.97	1.27	2.43	2.29	0.66	0.50	0.75	0.60	15.68	+1.41
1908	T	1.36	T	1.35	0.38	T	2.11	3.96	0.15	2.63	0.60	0.05	12.59	—1.68
1909	0.10	T	2.39	0.75	4.48	3.11	2.44	2.09	1.26	1.05	1.52	0.60	19.79	+5.52
1910	0.10	0.40	0.02	0.69	1.50	0.68	3.63	3.16	0.11	0.03	0.19	T	10.51	—3.76
1911	T	1.31	0.01	0.21	3.95	0.14	2.42	1.08	0.61	2.03	0.10	1.36	13.22	—1.05
1912	T	1.82	0.20	1.10	1.77	3.60	1.05	5.30	1.87	0.23	0.13	0.05	17.12	+2.85
1913	0.50	1.17	0.45	1.85	0.66	1.71	2.34	1.53	1.49	0.70	1.82	4.20	18.42	+4.15
1914	0.17	0.10	0.68	6.61	6.05	2.00	3.97	0.68	0.39	1.82	0.00	0.48	22.95	+8.68
1915	0.48	1.51	0.77	4.76	6.47	4.96	2.63	2.45	1.59	0.36	0.03	0.24	26.25	+11.98
1916	0.90	T	0.29	1.57	0.38	1.33	0.49	4.37	0.21	1.27	0.29	0.89	11.99	—2.28
1917	1.05	0.92	0.75	1.94	2.26	0.57	1.58	4.75	3.39	0.65	1.29	0.06	19.21	+4.94
1918	0.90	0.88	3.57	1.95	2.21	2.70	1.99	1.28	3.50	2.87	0.62	2.30	24.77	+10.50
1919	0.11	1.69	3.98	6.10	2.00	1.34	5.19	3.55	4.76	2.42	1.17	0.33	32.64	+18.37
1920	0.35	0.45	0.24	1.01	3.02	2.35	1.36	4.40	1.73	1.92	0.18	0.44	17.45	+3.18
1921	1.63	0.72	0.59	0.75	2.50	4.75	5.46	1.75	1.01	0.69	0.01	0.29	20.15	+5.88
1922	0.06	1.12	0.51	2.26	1.44	1.52	3.29	1.08	1.01	0.01	0.68	0.07	13.05	—1.22
1923	T	0.85	0.57	0.60	3.76	4.38	1.61	2.90	2.43	6.13	0.67	1.38	25.28	+11.01
1924	0.15	1.18	1.62	0.74	1.47	0.29	0.35	1.94	0.71	0.41	T	0.86	9.72	—4.55
1925	0.37	0.52	0.02	0.68	1.54	0.87	8.06	2.63	4.99	0.80	0.41	0.47	21.36	+7.09
1926	0.37	0.07	2.52	3.07	2.10	2.81	2.76	0.40	0.99	0.20	0.09	0.52	15.90	+1.63
1927	0.12	0.06	0.29	0.59	T	2.66	4.37	6.47	2.28	0.41	0.12	0.20	17.57	+3.30
1928	T	0.65	1.10	0.82	6.01	3.09	2.87	3.12	0.49	4.57	1.72	0.66	25.10	+10.83
1929	0.16	0.44	1.09	0.06	2.38	0.77	3.16	3.02	1.61	0.35	1.66	0.23	14.84	+0.57
1930	0.37	0.06	0.80	0.79	1.07	1.73	3.83	1.31	0.67	5.19	1.41	0.31	17.54	+3.27

TABLE IV.

MONTHLY AND ANNUAL PRECIPITATION. IN INCHES AT KENTON, OKLAHOMA, 1900-1941. (Cont.)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Departure from average [2]
1931	0.00	0.66	1.02	1.26	2.47	0.23	0.31	2.35	2.41	0.84	0.39	0.30	12.24	—2.03
1932	0.66	0.25	1.18	1.58	0.25	6.03	0.37	3.75	1.45	0.52	0.10	0.60	16.74	+2.47
1933	T	0.16	0.54	0.73	2.01	1.43	0.96	2.45	0.40	0.94	0.49	0.31	10.42	—3.85
1934	T	1.11	0.36	0.33	0.50	1.47	2.55	1.84	1.59	0.63	0.44	0.04	10.86	—3.41
1935	0.90	0.05	0.51	0.02	2.75	0.55	0.16	1.02	1.89	0.42	0.75	0.19	9.21	—5.06
1936	0.22	0.01	0.04	0.07	2.77	0.95	1.93	1.19	2.02	0.25	T	0.14	9.59	—4.68
1937	0.08	0.27	0.60	0.39	1.39	3.12	0.66	1.43	2.13	0.59	0.27	0.46	11.39	—2.88
1938	0.02	0.44	1.03	1.05	3.18	1.67	2.24	0.49	3.94	1.81	0.12	0.41	16.40	+2.13
1939	1.71	0.87	0.47	1.00	2.40	0.26	2.57	2.47	1.07	0.03	0.83	1.14	14.82	+0.55
1940	0.42	0.49	0.47	1.05	2.02	0.29	1.17	1.35	1.26	0.54	2.49	0.34	11.89	—2.38
1941	0.57	0.16	1.67	3.07	8.20	4.03	4.28	0.73	9.81	3.91	0.02	0.11	36.56	+22.29
Normal [1]	0.34	0.37	0.71	0.85	2.09	1.87	1.99	2.18	1.82	1.13	0.55	0.37	14.27	

Average annual snowfall (through 1930): 20.4 inches.

[1] Average as computed for the period Sept. 1925 through 1940 by H. F. Wahlgren.

[2] Computed from the average for the period September 1925 through 1940.

T—Trace

This situation was called to the attention of Harry F. Wahlgren, Meteorologist in the Weather Bureau, Oklahoma City, and he made a special study of the record of the precipitation for the two stations. He pointed out that the record for Boise City from September, 1925 through 1940 is reliable, and that the averages for Boise City (15.48 inches) and Kenton (14.27 inches) for this period should be satisfactory "normals."[27] Departures calculated from these averages indicate that precipitation at Boise City was above normal in 13 years out of 21, and at Kenton was above normal in 24 years out of 41. Thus the precipitation has been above normal in about 60 per cent of the years of record. The cumulative departures from these averages, calculated from January 1926, are very similar (fig. 4).

The average relative humidity in Cimarron County is probably about 60 percent. In the Oklahoma Panhandle, records of relative humidity are available only for Goodwell, in Texas County, and these show that during the 7-year period 1925-1931 the daily maximum relative humidity averaged 85.56 percent, and the daily minimum relative humidity averaged 36.84 percent; that the average daily mean relative humidity ranged from 57.76 percent in April to 64.87 percent in November; and that the average annual mean relative humidity was 61.16 percent.[28] Humidity conditions in Cimarron County doubtless are similar to those at Goodwell.

Measurements of the amount of water evaporated from a sunken tank 6 feet in diameter, in which the water level was maintained level with the land surface or lower, showed that evaporation at Goodwell ranged from 61.8 to 70.8 inches per year during the period 1925-1931, and averaged 65.91 inches. During the same period, the total annual precipitation at Goodwell ranged from 15.93 to 24.30 inches, and averaged 18.13 inches. Thus, the average annual evaporation from a free water surface is about 3.6 times the average annual precipitation. These figures indicate that water is evaporated rapidly from the soil. They also suggest the quantities of water that may be evaporated from open storage tanks, reservoirs, and irrigation ditches.

27. *Idem.*

28. Finnell, H. H., "Agricultural Significance of Climatic Features at Goodwell, Oklahoma": *The Panhandle Bulletin, No. 40, Panhandle Agri. Exp. Sta.*, pp. 37-38, 1932.

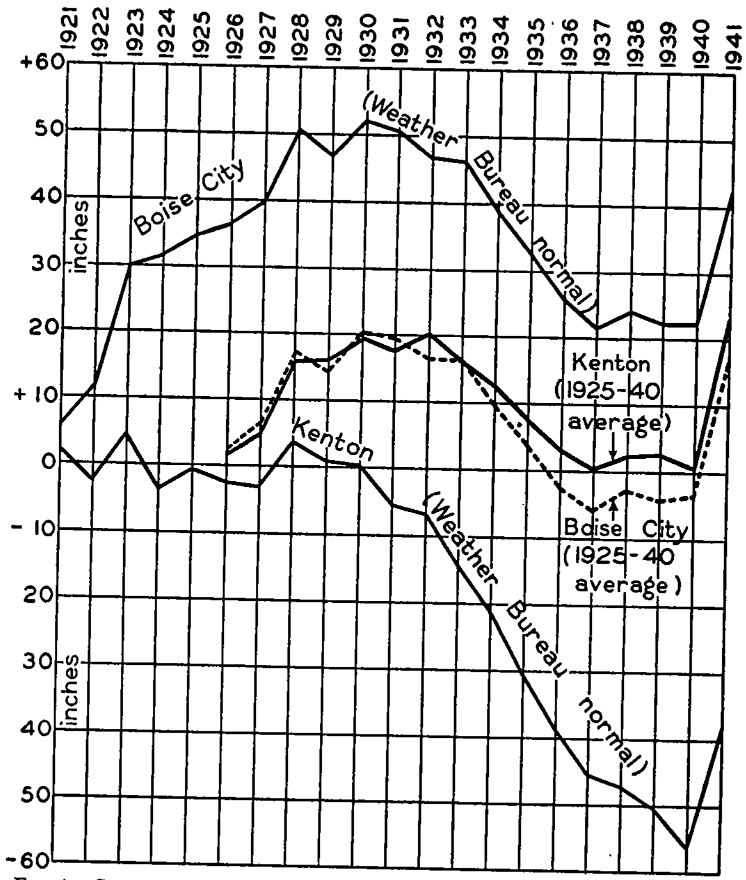


FIG. 4. Cumulative departure from published Weather Bureau normal annual precipitation at Boise City and Kenton, and cumulative departure from the average annual precipitation for the period September 1925 through 1940 at each station.

The prevailing winds in Cimarron County are from the south and southwest. At Boise City, which is on the upland plain, the prevailing wind is from the southwest every month of the year, but at Kenton, which is in the Cimarron Valley, it is from the north in February, March, and December, and from the south in the other months.

As recorded by the Panhandle Experiment Station at Goodwell, in Texas County, wind velocities at crop level—2.5 feet above the land surface—averaged 7.9 miles per hour in the period 1925-1931. The daily wind velocity averaged by months ranged from 6.3 miles per hour for August to 9.7 miles per hour for March. The average velocity at a height of 20 feet above the surface was estimated as 11.8 miles per hour.[29] Similar wind velocities doubtless prevail in Cimarron County.

ECONOMIC DEVELOPMENT

Farming and ranching are the principal industries in Cimarron County. Cattle-raising came first in the economic development of the county, and still accounts for more than half the acreage in use. The ranches use large areas in the broken lands along the Cimarron Valley and in the sand dunes of the western and southern parts of the county for grazing.

Later in the development of the county, the better parts of the uplands were divided into farms, and wheat became a leading commercial crop. The grain sorghums, among them standard and dwarf red maize, golden and white maize, several types of kafir corn, hegari, and cane, are extensively raised. Broom corn, sudan grass, and alfalfa are also grown. The alfalfa is grown chiefly on the lowlands along the Cimarron River, where it can be irrigated with flood water from the river or with water pumped from wells. A brief summary of the agricultural possibilities and development in Cimarron County, based on data furnished by County Agricultural Agent W. E. Baker, was published by Rothrock.[30]

TABLE V.

CROP DISTRIBUTION IN CIMARRON COUNTY IN 1936 [a]

	Percent
Small grains	9.6
Hay	.1
Row crops	31.8
Idle	9.5
Fallow	48.9
All other	.1
Total	100.0

[a] Land use survey, 1936. Information supplied by H. C. Hyer, formerly County Agricultural Agent for Texas County, Okla.

29. *Idem*, p. 25.
30. Rothrock, *op. cit.*, pp. 90-92.

PLATE III. Blow-out in sand dunes otherwise anchored by vegetation. Southeast of Mexhoma post office, sec. 3, T. 2 N., R. 1 E.

The original homesteads in Cimarron County, as elsewhere, were a quarter section, or 160 acres, in size, but since settlement of the area the average size of farms has increased greatly. Some farmers lease land in addition to what they own, and it is not uncommon for one man to control more than 1,000 acres of land. About 400 square miles of State School land is located in the northwestern part of the county, and most of it is leased to ranchers.

Population. In 1940 the population of Cimarron County was 3,654.[31] This represented a decline of 1,754 since 1930. Boise City, the county seat and largest town (fig. 1), had a population of 1,144 in 1940, and Keyes, which is about 20 miles to the northeast, had 227. Felt, in the southwestern part of the county, and Kenton in the northwestern part, are settlements whose population was not reported separately in the 1940 census.

Mexhoma and Wheeless in the western part of the county, Regnier in the northwest, and Griggs in the southeast, are rural post offices. Conrad, Castaneda, Ludlam, McCullough, and Sturgis are sidings on the Santa Fe Railroad, and Burton and Hopkins, are sidings on the Beaver, Meade, and Engelwood (Missouri-Kansas-Texas) Railroad. Nieto and Harmer were sidings on the now abandoned (December, 1942) Boise City-Farley branch of the Santa Fe Railroad.

Delfin, Garlington, Marella, Midwell, O'Shusky, and Garrett are abandoned towns and rural post offices, the names of which are still used for rural schools or churches in the same vicinity. Some of the schools were not in use at the time of the field investigation because the school districts had been consolidated with others. Wilkins, Mineral, Hurley, Sampsel, Willowbar, Benola, and Minnetonka are abandoned townsites or rural post offices. The approximate locations of all but the last two are indicated on Plate I, for example "Sampsel Corner." Some of the names listed above are in use for political townships in the county.

31. 16th Census of the United States: Population—Oklahoma.

GENERAL GEOLOGY

STRATIGRAPHIC SUMMARY

Mesozoic and Cenozoic rocks, ranging in age from Upper Triassic to Recent, are exposed in Cimarron County. Mesozoic rocks are exposed in an area of 375 square miles in the valleys of Cimarron River and its tributaries, in the northwestern part of the county, and in small outcrops along North Canadian River (Currumpa Creek) and its principal tributary, Cieneguilla (Seneca) Creek. They include, in ascending order, the Dockum Group (Triassic), Exeter sandstone (Jurassic), Morrison formation (Jurassic), Purgatoire formation (Lower Cretaceous), and Dakota sandstone and the Graneros-Greenhorn formation (Upper Cretaceous).

The Mesozoic rocks are overlain, unconformably, by the "Ogallala" formation of Pliocene and Pleistocene (?) age, and by Recent terrace deposits and alluvium. Most of the ground water supplies of the region are obtained from the "Ogallala" formation, although the Dakota sandstone and the Cheyenne sandstone member of the Purgatoire formation supply water through springs and some wells in the outcrop areas, and probably contribute water to some wells on the upland.

STRUCTURAL SUMMARY

The bed-rock structure of Cimarron County is related in general to that of the Great Plains, and more particularly to the Sierra Grande-Las Animas Arch of northeastern New Mexico and southeastern Colorado. This and other structural features of eastern Colorado and adjacent areas is shown in figure 5. The structure of the Central Great Plains, northward from the north lines of Oklahoma and New Mexico, is shown by Darton[32] by structure contours drawn on top the Dakota sandstone.

Schoff's remarks relative to the regional structure of Texas County[33] probably are applicable to Cimarron County as well. He states:

32. Darton, N. H., "The Structure of Parts of the Central Great Plains": *U. S. Geol. Survey Bull.* 691, Pl. I, 1919.
33. Schoff, S. L., "Geology and Ground Water Resources of Texas County, Oklahoma": *Okla. Geol. Survey Bull.* 59, p. 42, 1939.

> Texas County is in the western Oklahoma-Dodge City basin.[34] Meager subsurface evidence on key beds in the Pennsylvanian and Permian rocks indicates a gentle east dip, as shown by Six[35] for the Panhandle counties, by Green[36] for western Oklahoma, and by Dott[37] for the "Lansing Lime" of petroleum geologists, in Hamilton, and Finney and Seward Counties, Kansas. Mull[38] reports that formations below the Blaine, at least, dip eastward in Texas County from sec. 21, T. 6 N., R. 14 E., to sec. 23, T. 6 N., R. 16 E., at a rate of 18 feet per mile. This general east dip is also indicated by surface exposures of Lower Cretaceous sandstones and the underlying red beds at the Red Point locality in central Texas County, which are about 850 feet lower than exposures of corresponding rocks 50 miles to the northwest in Cimarron County.

A small-scale contour map, by Francis N. Bosco, based on the top of the Dakota sandstone, published in the April 16, 1942, issue of *The Oil and Gas Journal,* shows the principal structural features of eastern Colorado and adjacent areas, consisting of the front ranges of the Rocky Mountains, the Denver basin, and the Sierra Grande-Las Animas arch (fig. 5). This latter feature is located a short distance west of Cimarron County, Oklahoma, and the structure of Cimarron County is related to it.

Reconnaissance structure mapping on the base of the Dakota sandstone, with a plane table and alidade by Stovall in 1936-1937, in the area of Cretaceous outcrops in northwestern Cimarron County, indicates a continuation of the general southeast dip of the flank of the Sierra Grande-Las Animas arch, almost to the margin of the Cretaceous and lower Mesozoic outcrops.

The regional dip is interrupted by a syncline trending from the southwest corner of T. 4 N., R. 1 E., northeast to T. 6 N., R. 5 E. Southeast and east of this syncline, the strata appear to rise again. Field data are insufficient to determine the significance of this reversal of dip, owing to the Mesozoic rocks being concealed by the "Ogallala" formation, and no drill records are

34. See *The Oil Weekly,* May 14, 1934, and February 11, 1935, map supplements.
35. Six, R. L., "Oil and Gas in Oklahoma; Beaver, Texas, and Cimarron Counties": *Okla. Geol. Survey Bull.* 40, Vol. 2, pp. 479-491, 1930. Also published as 40-WW.
36. Greene, Frank C., unpublished manuscript cross section.
37. Dott, R. H., "Kansas' Future Crude Oil Reserve Status": *The Oil Weekly,* Feb. 11, 1935.
38. Mull, J. O., personal communication to State Geologist R. H. Dott.

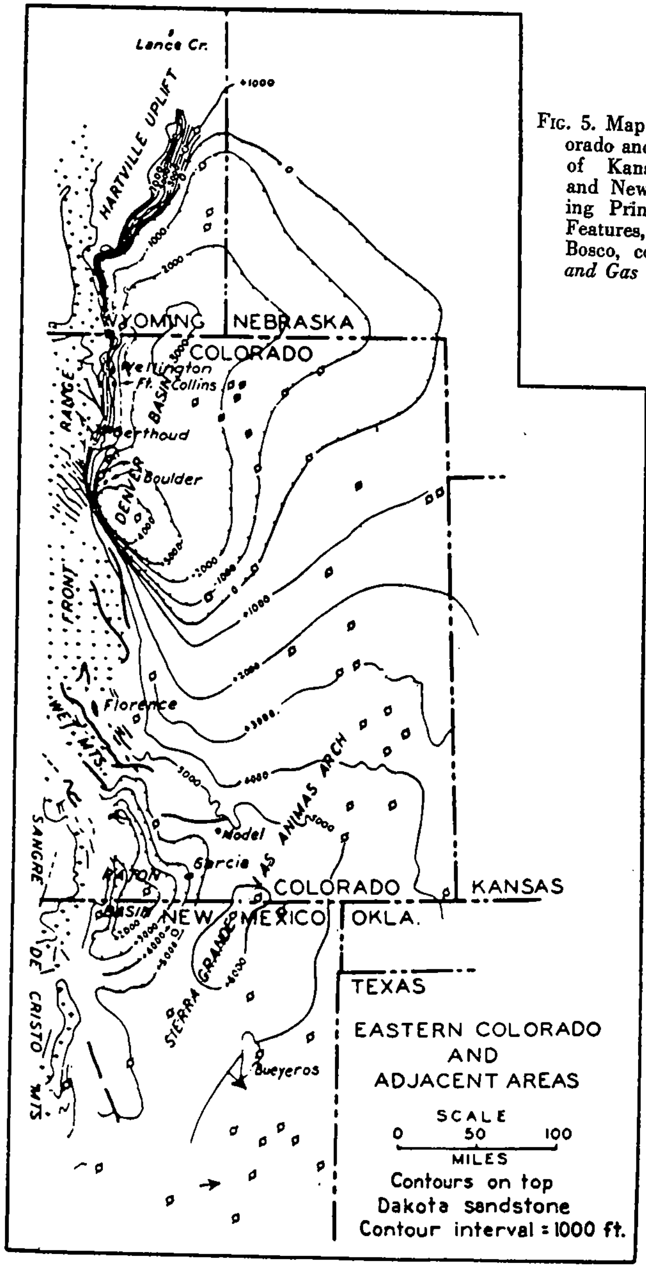


FIG. 5. Map of Eastern Colorado and Adjacent Parts of Kansas, Oklahoma, and New Mexico, Showing Principal Structural Features, by Francis N. Bosco, courtesy *The Oil and Gas Journal.*

available to the writers to indicate the structural position of the Dakota sandstone beyond the outcrop area.

In the area northwest of the syncline described above, the regional dip is modified by a system of long anticlinal, and intervening synclinal noses, whose axes trend parallel to the general dip. Structural data over these folds indicate arching of considerable magnitude, transverse to the axes, but no definite evidence was obtained to indicate areas of closure, and it may be stated with reasonable certainty that no closures of great magnitude exist in this part of the county.

These anticlinal and synclinal noses are shown by structure contours, and axial lines, on fig. 6. The most pronounced anticlinal axis trends southeast from the northwest corner of T. 6 N., R. 2 E., to east-central T. 5 N., R. 2 E. Two anticlines of considerable prominence lie in the west and east parts of T. 6 N., R. 3 E., and another trends diagonally southeast across T. 6 N., R. 4 E.

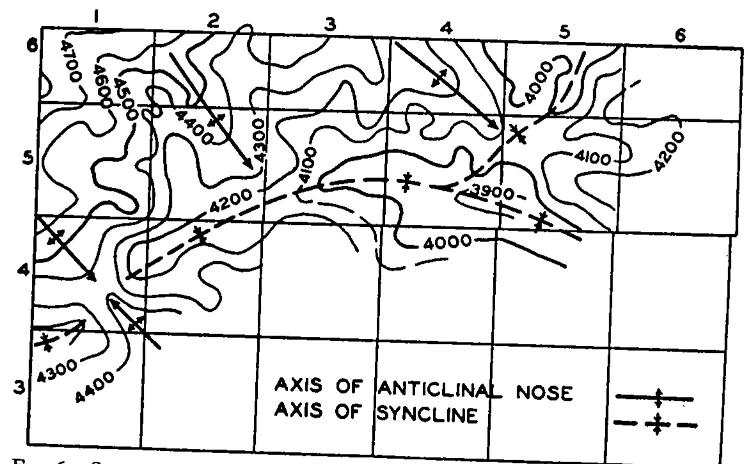


FIG. 6. Structure Contour Map of Northwestern Cimarron County, Contoured on the Base of the Dakota Sandstone. Results of Detail-Reconnaissance with Plane Table and Alidade by J. W. Stovall. Contour Interval, 100 feet.

Another anticlinal nose trends diagonally across T. 4 N., R. 1 E., and near the center of the township, forms a conspicuous saddle at the intersection with the large syncline described above.

The most significant feature of this axis is the magnitude of the structural uplift in the southeastern part of the township, which has brought Kiowa shale to the surface in a limited area in the valley of South Carrizo Creek and its tributaries. The Kiowa is here exposed in a roughly star-shaped inlier, and is completely surrounded by the younger Dakota sandstone.

ECONOMIC GEOLOGY

Aside from soil and ground water, Cimarron County has few important mineral resources. Beds of very poor grade lignite, from 0.5 to 1.5 feet thick, are found in the Dakota sandstone in the region just south of Cimarron River, particularly in secs. 19 and 20, T. 4 N., R. 1 E., and sec. 5, T. 3 N., R. 1 E. Rothrock[39] reports that the lignite in the NW¼ sec. 5, T. 3 N., R. 1 E., had been mined by stripping, and that two tunnels were opened in the thin beds of lignite in secs. 19 and 20, T. 4 N., R. 1 E., but were not worked. This coal has a very low fuel value, but at the present time is used locally by two or three ranchers because wood is very scarce. The town of Mineral, now marked by one or two abandoned buildings and several old foundations, was established when coal was first discovered, and many people believed that the area would become one of importance in the production of coal.

Overlying the lignite is from 2 to 3 feet of clay that may have some possibility as a refractory material. This clay is of considerable lateral extent indicating fairly large quantity, but is covered by a rather thick overburden. No laboratory tests have been made of this material; so its commercial possibility is unknown.

Some varieties of caliche are satisfactory for road building, and crushed caliche has been widely used in surfacing county roads. It is also suitable for construction of bituminous-surfaced highways. Tests by the Industrial Research Laboratory of the Oklahoma Geological Survey have shown that some kinds of caliche from Texas County made a good grade of rock wool.[40]

39. Rothrock, E. P., "Geology of Cimarron County, Oklahoma": *Okla. Geol. Survey Bull.* 34, pp. 86-88, 1925.
40. Wood, F. C., "Rock Wool Possibilities in Oklahoma": *Okla. Geol. Survey Bull.* 60, pp. 20, 52-53, 1939.

As the caliche in Cimarron County is similar to that in Texas County, some of it, also, may be suitable for the manufacture of rock wool.

Sand for use in concrete can be obtained from the channels and flood plains of the larger streams, and from the "Ogallala" formation. Gravel may be obtained from the same sources, but is less abundant. Pebbles consist mainly of quartzite, granite, and other crystalline rock, and range in size from that of a pea to cobbles 8 or 10 inches in largest dimension. Concrete aggregate could be prepared by crushing the basalt from Black Mesa, and quartzitic sandstone from the Morrison and Dakota formations.

In places the Dakota and Cheyenne sandstones are well indurated and can be broken into blocks suitable for building, and many of the houses, fences, and other ranch structures in the Cimarron Valley have been constructed of them. The lava on Black Mesa is said by Rothrock[41] to be satisfactory for building stone and for concrete aggregate, but it is of very limited areal extent, is difficult to work into suitable shape, and is relatively inaccessible.

A thin-bedded, fine-grained sandstone member of the Morrison formation, referred to locally as "striped rock", occurs at numerous places, particularly on the Willson and Strong ranches, sec. 8, T. 6 N., R. 2 E., and SE¼ sec. 29, and NE¼ sec. 32, T. 5 N., R. 5 E., respectively. This stone carves easily, and has sufficient toughness and hardness to be cut and used for building trim, and to be worked into various kinds of art objects. Material from sec. 29, T. 5 N., R. 5 E., was used for trim in the Boise City high school, and local individuals carve it into ash trays, book ends, and the like.

Rothrock[42] reports that pellets and stringers of black copper sulfide associated with a green sandstone near Black Mesa inspired much prospecting for copper in that vicinity. The green color, however, is due to chloritic minerals that do not contain copper, and analyses of samples from the prospect pits have not shown copper in commercially workable amounts.

41. Rothrock, E. P., *op. cit.*, p. 89.
42. Rothrock, E. P., *op. cit.*, pp. 88-89.

TABLE VI.

Test Wells Drilled for Oil and Gas in Cimarron County
(Principally from logs in files of Oklahoma Corporation Commission)

Name of farm	Company	Location	Sec.	T.	R.	Date of Completion	Total depth
Cox No. 1	Gulf Oil Corporation	SE	35	2	8	1-31-42	6,168
Israel No. 1	Gladys Belle Oil Company	NE	25	3	7	11-5-27	4,392
State Land	Segregated Oil Company	NE	22	4	1	1918	2,030
State School Land	W. R. and W. E. Ramsey	SE	34	4	1	4-13-28	4,306
State School Land No. 48	Sinclair Oil and Gas Co.	NE	22	5	2	3-8-28	4,872
State School Land No. A2	W. R. and W. E. Ramsey	SW	21	5	5	4-30-28	4,360
State School Land No. 11A	Magnolia Petroleum Co.	NE	22	5	5	7-29-29	4,356
	Empire Gas and Fuel Co.	NW	22	5	5	1917	1,583
State School Land No. 1	W. R. and W. E. Ramsey	NE	27	5	5	3-4-28	4,681
State School Land No. 33	Magnolia Petroleum Co.	NE	27	5	5	10-17-30	4,758
State School Land No. 1	Barnsdall Oil Company	SE	35	5	5	6-15-38	5,503
State No. 1—C	W. R. and W. E. Ramsey	SE	4	5	6	10-14-27	4,200
Cox No. 1 (gas well)	Pure Oil Company	SW	16	5	8	May 1943	6,277
	J. R. Phillips	NE	24	6	2	1-29-27	4,370

Oil and gas. Beginning in 1917, 14 test wells have been drilled for oil and gas in Cimarron County (Table VI), but only within recent months has commercial production been found. *The Daily Oklahoman,* under date of May 12, 1943, reports that the Pure Oil Company ". . . has opened a new gas field and has added Cimarron County to the list of oil and gas productive areas in the state . . ." with its No. 1 Cox, located in SW¼SE¼SW¼ sec. 16, T. 5 N., R. 8 E. According to the same report, the well was drilled to granite at about 6,277 feet, and casing was subsequently perforated at 4,670 to 4,755 feet, producing a flow of gas estimated at 19,000,000 cu. ft. per day, with 850 pounds pressure.

About half the previous drilling was concentrated in the vicinity of Castenada station, T. 5 N., R. 5 E., north of Boise City. Four of these tests were drilled between the years 1926 and 1930, the first having had a show of oil at 4,095 to 4,125 feet.[43] The fifth was drilled in 1938, to a depth of 5,503 feet.

During the period 1938 to 1941, several major oil companies did considerable geological and geophysical exploratory work in the county, including core-drilling to Mesozoic formations on the upland flat. At least two large blocks of leases were taken, and an unsuccessful test well was drilled to a total depth of 6,165 feet, in sec. 35, T. 2 N., R. 8 E. The Pure Oil Company gas well is in the other block of leases, located principally in T. 5 N., Rs. 7 and 8 E.

Information on the subsurface stratigraphy of the area, of interest in connection with oil and gas possibilities, is obtained from the log of the Gulf Oil Corporation's deep well in sec. 35, T. 2 N., R. 8 E. Samples of drill cuttings were furnished to the Oklahoma Geological Survey, and examined by Ted Voiles, under the supervision of R. W. Harris, Professor of Geology, University of Oklahoma. Charles Ryniker, geologist of the Gulf Oil Corporation, Tulsa, kindly furnished information for correlating the important markers, and this assistance is gratefully acknowledged. A summary of formations encountered is given in Table VII.

43. Well logs from files of the Oklahoma State Corporation Commission, Oklahoma City.

TABLE VII.

FORMATIONS ENCOUNTERED IN GULF OIL CORPORATION, No. 1 Cox, SE¼ SEC. 35, T. 2 N., R. 8 E.[a]

Surface elevation of well 3,854 feet. See well 204, under Well Logs for details.

	Thickness (feet)	Depth (Feet) From	To
Tertiary and Quaternary			
"Ogallala" formation			
Sand, caliche cement	411	0	411
Triassic and/or Permian			
Shale, reddish, sandy	168	411	579
Permian			
Red beds, with gypsum and sand	2,637(?)	579	3,216(?)
DAY CREEK dolomite at 579′			
BLAINE gypsum at 910′			
STONE CORRAL dolomite at 1,700′			
COTTONWOOD limestone at 2,984′			
NEVA limestone at 3,066′			
FORAKER zone at 3,120′			
Pennsylvanian			
(Permian-Pennsylvanian contact indefinite. May be at approximately 3,216 feet.)			
Virgil series			
Wabaunsee group (?)			
Dolomitic limestone, cherty and sandy near base	217(?)	3,216(?)	3,433
Shawnee group			
Limestone, TOPEKA	427	3,433	3,860
Unconformity			
Des Moines series			
(Rocks of Missouri series and Marmaton group of Des Moines series are missing; Pennsylvanian rocks below this point are classified as "Cherokee". In wells in southwestern Kansas there is definite evidence that the Morrow series is represented, and Morrow beds probably are present in this test.)			
Cherokee formation			
Limestone; shale breaks	650	3,860	4,510
Shale, dark; some sandstone	573	4,510	5,083
Mississippian	742	5,083	5,825
Ordovician			
Viola limestone	90	5,825	5,915
Simpson group	80	5,915	5,995
Arbuckle (Cotter) dolomite	173	5,995	6,168

[a] Determinations by Charles Ryniker, geologist, Gulf Oil Corporation, Tulsa.

STRATIGRAPHY OF THE CIMARRON VALLEY (MESOZOIC ROCKS)

By J. W. STOVALL

TRIASSIC SYSTEM

UPPER TRIASSIC SERIES

DOCKUM GROUP

Throughout the Southern Great Plains area in Oklahoma, Texas, and New Mexico, all rocks of Triassic age are classified as belonging to the Dockum[44] group. Thus the Dockum embraces all strata from the top of the Permian to the base of the Exeter sandstone (Jurassic). In parts of Texas and in New Mexico, the Dockum Group has been divided about as follows:

TABLE VIII.
SUBDIVISIONS OF DOCKUM GROUP [45]

Eastern New Mexico	Texas Panhandle			
	Southern		Central	Northern
Darton	Adams	Hoots	Drake	Gould
Chinle shales	Chinle shales	Upper red clay	Sandy clay, some sandstone	(Thin or absent)
"Santa Rosa" sandstone	"Santa Rosa" sandstone	Basal red clay and sandstone	Sandstone and conglomerate, some clay	Trujillo sandstone and shale
(Generally absent)	Basal shales	Generally absent	Sandy clay	Tecovas basal shale

In the Cimarron valley, northeastern Union County, New Mexico, there are many square miles of outcrops of rocks, mostly red beds, that have been considered Triassic since 1902[46], and part of which were referred to the Dockum by Darton, in 1928.[47] Darton excluded from the Dockum some varicolored calcareous shales and interbedded gray marls, overlain by sandstone, and referred

44. Cummins, W. F., "The Permian of Texas and its Overlying Beds": *Texas Geol. Survey* 1st *Ann. Rept.*, p. 189, 1890.
45. Sellards, E. H., Adkins, W. S. and Plummer, F. B., "Geology of Texas, *Vol. I, Stratigraphy*": Univ. of Texas Bull. 3232, p. 243, 1932.
46. Lee, W. T., "The Morrison Shales of Southern Colorado and Northern New Mexico": *Jour. Geol.*, Vol. 10, pp. 36-58, 1902.
47. Darton, N. H., "'Red Beds' and Associated Formations in New Mexico": *U. S. Geol. Survey Bull.* 794, p. 306, 1928.

these strata, together with the overlying Exeter sandstone of Lee[48], to the Morrison formation (Jurassic). Discovery in 1939 of Dockum fossils in the varicolored shales and marls[49] indicates that Darton was in error in including these beds in the Morrison, and suggests further the validity of Lee's Exeter sandstone as an independent formation.

In 1933, Parker[50] described several clastic plugs and dikes, and included notes on the geology of the associated beds cropping out in an area 10 to 15 miles west of the New Mexico-Oklahoma state line, 500 to 1,000 feet down stream from the slab crossing over Sloan Canyon Creek. (W½ sec. 7, T. 31 N., R. 36 E.) He divided the pre-Exeter rocks into three units, named from the base upward, Dockum group, Sloan Canyon, and Sheep Pen formations, and followed Darton by excluding these latter from the Dockum, but rejected Darton's assignment of them to the Morrison. He classified the "Dockum group", Sloan Canyon and Sheep Pen formations as questionably Triassic. The three units are shown in the following table:

TABLE IX.

PARKER'S CLASSIFICATION OF TRIASSIC STRATA IN NORTHEASTERN NEW MEXICO

Stratigraphic unit		Character	Thickness (ft.)
Triassic (?) System	Sheep Pen sandstone	Tan to buff sandstone, thin bedded to massive.	68
	Sloan Canyon formation	Varicolored, argillaceous, and calcareous shales with thin layers of hard, gray marl and a bed of red sandstone near the base.	125-150
	Dockum group	Maroon to purple conglomerates, sandstones and shales with interbedded layers of white sandstone in the lower portion of the exposures.	400+

48. *Idem.*, pp. 45-46.
49. Stovall, J W., and Savage, D. E., "Phytosaur in Union County, New Mexico": *Jour. Geol.*, Vol. 47, pp. 759-766, 1939.
50. Parker, Ben H., "Clastic Plugs and Dikes of the Cimarron Valley, New Mexico": *Jour. Geol.*, Vol. 41, pp. 38-51, 1933. See also: *Kansas Geol. Soc. Guidebook*, 4th *Ann. Field Conf.*, 1930.

The strata which Parker named Sloan Canyon and Sheep Pen Canyon formations, should be included in the Dockum, for the discovery of Dockum fossils in the Sloan Canyon beds indicates their affinity with the Dockum of other parts of the Great Plains, and such classification is used in this report. The underlying red shale formation remains unnamed.

The upper contact of the Triassic in the Cimarron Valley shows marked angularity with the overlying Exeter sandstone, indicating pre-Exeter warping of considerable magnitude at least locally. The area described by Parker is located in a pre-Exeter syncline, and the Sheep Pen formation is truncated by the Exeter sandstone to the east of Parker's locality, and despite a reversal of dip further east, the Sheep Pen formation probably is not present in Oklahoma.

The oldest rocks exposed in Cimarron County, consisting of a series of shale, clay, marl, sandstone and conglomerate, lying unconformably beneath the Exeter sandstone (Jurassic), are assigned, at least in part, to the Sloan Canyon formation. This may be the only representative of the Dockum group and of the Triassic system in Cimarron County. The base is not exposed, and the total thickness is uncertain, but is estimated to be about 550 feet.

History of Usage. Lee[51] suggested that the upper part of the "Red Beds" along Cimarron River in Union County, New Mexico, might be Triassic in age, but concluded that the Red Beds did not extend into Oklahoma. Gould[52] mapped the Dockum beds of the Kenton area, with the Comanche series but showed 100 feet of "Red Beds" in a columnar section and included similar beds, exposed north and northeast of Boise City, with the Permian, as "Red beds of uncertain relationship." Rothrock[53] was the first to do detailed geologic work in the county and suggested that three small areas in Tps. 5 and 6 N., R. 6 E. are probably Triassic in age but failed to recognize the Triassic in the

51. Lee, W. T., *op. cit.*
52. Gould, C. N., "Geology and Water Resources of Oklahoma": *U. S. Geol. Survey Water Supply Paper* 148, Pl. I and p. 82, 1905.
53. Rothrock, E. P., "Geology of Cimarron County, Oklahoma": *Okla. Geol. Survey Bull.* 34, pp. 26-27, 31, 1925.

northwest corner of the county, and described Dockum beds in what he presented as a typical section of the Morrison. DeFord[54] was the first to suggest that the variegated "shales" beneath the Exeter in the western part of the area are Triassic in age. Stovall[55] pointed out in 1937 that the areas described by Rothrock as probably Triassic, are Dockum, on the basis of lithology and stratigraphic position. Subsequently (1941) the discovery of phytosaurs and the amphibian *Buettneria* in these beds confirmed this conclusion.

Distribution. The present investigation has shown that the Dockum is more widely distributed in Cimarron County than was supposed by previous writers. There are two principal areas of exposures in the county, one in the extreme northwest, and the other north and northeast of Boise City.

The best exposures lie north of Black Mesa in an area of about 8 square miles along Cooper's Draw and North Carrizo Creek, where Dockum rocks form the valley floor except where covered by Recent alluvium. The Dockum extends north and west from this region into Colorado and New Mexico.

On the south side of Black Mesa rocks of this age occupy an elongated triangle of slightly more than one square mile. Exposures may be seen for one half mile south of the bridge over Carrizozo Creek on Highway 64 on the Oklahoma-New Mexico state line. They extend northward from the bridge just mentioned, to the foot of Black Mesa, gradually widening out until they attain a maximum width of one mile.

In the larger area north and northeast of Boise City the Dockum covers about 27 square miles along Cimarron River, but is less well exposed than in the western end of the area because of lower relief. The red soil that colors the gently-sloping lower part of the valley bluffs indicates the presence of the Dockum underneath, and its probable extension beneath the alluvium in the central part of the valley.

54. DeFord, R. K., "Areal Geology of Cimarron County, Oklahoma": *Bull. Amer. Assoc. Petro. Geol.*, Vol. 11, pp. 753-755, 1927.
55. Stovall, J. W., "Advance Notes on the Geology of the Cimarron Valley of Northwestern Oklahoma": *Okla. Acad. Sci. Proc.*, Vol. 17, 1937.

Excellent exposures are found in Trujillo Canyon, (secs. 18 and 19, T. 5 N., R. 6 E.), and in House Creek (secs. 9 and 16, T. 5 N., R. 6 E.). Good exposures with considerable areal extent but limited vertical section are found on the north side of Cimarron River along Nevit Springs Draw (sec. 33, T. 6 N., R. 6 E.) and in Schnaufer Canyon (secs. 25 and 36, T. 6 N., R. 5 E.). Another good exposure is revealed in the railroad cut about 1.5 miles south of Cimarron River (sec. 16, T. 5 N., R. 5 E.).

Thickness. The maximum exposed thickness of the Dockum in Cimarron County is 67 feet at Labrier (Tate) Butte on the north side of Black Mesa. Because the base of the Dockum is not exposed in the county, the total thickness is uncertain. Deep wells in the area have doubtless passed through the Triassic, and Sanders[56] assigns a thickness of 575 feet to the Triassic of the region, apparently upon the evidence of the log of a well in the northwestern part of the county. This is a greater thickness than in the Two Buttes area where it is said by the same writer to be 240 feet thick, and on the Canadian River in the Texas Panhandle where it is reported by Gould[57] to range from 150 to 300 feet in thickness. Parker[58] has assigned a total thickness of 610+ feet for the Triassic in the Sloan Canyon area of New Mexico, and whereas the Sheep Pen sandstone probably is not present in Oklahoma, the Dockum would be represented by Parker's "Dockum" (400+ feet) and Sloan Canyon (125 to 150 feet), or a total thickness of at least 550 feet of strata.

Character. The Dockum group of Cimarron County is composed of highly variegated shale, clay, conglomerate, sandstone, and marl. The colors are commonly brilliant, particularly on wet surfaces, and range from purplish red, brick red, brown, buff and gray, to cream. The purple, red and brown colors tend to give way, vertically and horizontally, to greenish-gray, particularly along joints and bedding planes. In places beds two or three feet

56. Sanders, C. W., "Geology of Two Buttes Dome in Southeastern Colorado": *Bull. Amer. Assoc. Petro. Geol.*, Vol. 18, pp. 860-870, 1934.
57. Gould, C. N., *op. cit.*
58. Parker, Ben. H., "Clastic Plugs and Dikes of the Cimarron Valley, New Mexico": *Jour. Geol.* Vol. 41, pp. 38-51, 1933.

in thickness grade laterally from red or purple to green or gray within a distance of thirty feet, more or less. The distribution of gray and green along fracture planes suggests that the red and purple colors have been changed by leaching processes subsequent to deposition.

Toward the eastern end of the Dockum exposures on the south bank of North Carrizo Creek near Labrier (Tate) Butte, the lowest bed is a pink marl, 3.5 feet thick, that weathers into small cubical blocks, averaging less than one half inch in diameter. The next 10 feet consist of purple-stained, grayish marl and sandstone and a bed of jointed, greenish to purple marl. The succeeding 18 feet consist of a uniform, brick red, gray-streaked marl. The remainder of the beds alternate between shale, clay, and marl, ranging in color from gray, brown, green, buff, brown, to purple. The topmost 1.5 feet are bluish gray sandstone, but in the road cut at the north end of Labrier Butte the uppermost beds are thin alternating sandstone and shale, brown and purple or green in color. At this locality the green and gray mottling is a very conspicuous feature. (Pl. IV)

Beds similar to those near Labrier (Tate) Butte are exposed on the south side of Black Mesa, near the Oklahoma-New Mexico state line and in a location a few rods down-stream from the slab crossing over Sloan Canyon on Highway 64, 11 miles west of Kenton, Oklahoma.

In the region north and northeast of Boise City, Oklahoma, the dominant color of the Dockum is brick red although here, too, the range of color is wide. In contrast with the Dockum of the western area, sandstones dominate these exposures. The sandstone is commonly thin bedded, fine-grained and almost fissile, for on exposed surfaces the rock tends to peel off in thin layers from one to three millimeters in thickness. Some of the sandstone is cream colored and locally is almost white.

An exposure in the east bank of Trujillo Creek, a short distance south of the stone crossing on the road to the Burnett Ranch (T. 5 N., R. 6 E.), shows excellent examples of lenticularity in continental deposits—local cross-bedding in sandstone, conglomerate and clay, occuring in small lenses ranging up to 1.5 feet in thickness and 75 feet in length. The reddish conglomerate contains many concretionary, vertical masses from one half inch to two inches in diameter and a foot or more in length that apparently represent root fillings. On the slope above the creek bank there are wide terraces separated by ledges one foot or less in height and about 100 feet east of the creek bank the Dockum is overlain by the Exeter sandstone, which is visible only in a few places, being generally covered by wind-blown sand or alluvium.

In the bed of House Creek (T. 5 N., R. 6 E.) a flinty marl is exposed, and at the Burnett windmill (well 521 of this report) it covers an area of several hundred square feet. Toward the sides of the valley, variegated sandstone and shale form talus slopes above the harder marl. From this location eastward to the limit of Dockum exposures, brick-red shale and sandstone are exposed on both north and south sides of Cimarron River. On the north side of the river the most conspicuous exposures are found in Schnaufer Canyon and Nevit Springs Draw opposite the Burnett ranch. Red sandstone alternates with gray sandstone and brick red clay and forms low ledges on the gentle slopes of the valleys.

Correlation. The beds identified as Dockum in Cimarron County, Oklahoma, are similar to the rocks assigned to the Dockum group in widely scattered areas in the high plains of West Texas and New Mexico. These beds were traced from the Oklahoma outcrops, westward into northeastern New Mexico, and tied into beds that have been referred to the Triassic by Lee[59], Stanton[60] and others, and classified as Sloan Canyon formation, by Parker.[61]

In the Kenton area, extreme northwestern Cimarron County, the exposed Dockum strata are characterized by variegated beds of clay, marl, and sandstone, and closely resemble those called Sloan Canyon by Parker, as exposed in his type locality. Their similar lithology and demonstrated continuity leaves little question as to correlation between the two areas.

59. Lee, W. T., *op. cit.*
60. Stanton, T. W., "The Morrison Formation and its Relations with the Comanche Series and the Dakota Formation": *Jour. Geol.*, Vol. 13, pp. 657-669, 1905.
61. Parker, Ben H., *op. cit.*

The dominance of sandstone over clay and marl, and the more dominant red color in the exposures north and northeast of Boise City, suggest that perhaps some other portion of the Dockum section than Sloan Canyon is here represented. The differences suggest three possibilities: the dominant sandstone may indicate a correlation with the Sheep Pen sandstone; the deep red color may indicate a correlation with the pre-Sloan Canyon part of the Dockum (Parker's "Dockum"); or, the differences may be explained by lateral variations, or facies change, in equivalent beds of continental origin. The writer inclines toward the third alternative.

There can be little doubt that all these strata are equivalent to parts of the typical Dockum, as known in other areas of the southern High Plains, and the Sloan Canyon and Sheep Pen formations certainly belong to the Dockum group. Stovall and Savage[62] discovered the phytosaur *Machaeroprosopus* and the pelecypod *Unio* probably *dockumensis,* both of which are typical Dockum fossils, in the Sloan Canyon formation, a short distance east of the type locality in New Mexico.

The area northeast of Boise City also has yielded fossil evidence. In 1941, Dr. Ed Bloesch collected a few fragmentary bones from an outcrop on the east bank of Trujillo Creek, about 100 yards south of the stone crossing on the road to the Burnett ranch. Among the collection the writer identified the articular of the right jaw of a phytosaur, and a portion of the interclavicle of the amphibian *Buettneria,* both definitely Dockum in age.

The evidence seems conclusive that the strata at the base of the section exposed in Cimarron County are of Triassic age, and are properly referred to the Dockum group.

Detailed sections. Detailed sections of the Dockum group may be found in Appendix A. They include numbers 19, 21, 22, 25-30, incl., 32 and 33.

62. Stovall, J. W., and Savage, D. E., *op. cit.*

JURASSIC SYSTEM

EXETER SANDSTONE

The term Exeter sandstone is applied in Cimarron County to the massive, white and buff, cross-bedded sandstone that lies, unconformably, on rocks of the Dockum group and is overlain, disconformably, by the Morrison formation. It occupies the same stratigraphic position as the Exeter at the type locality a few miles to the west in New Mexico, but differs somewhat in thickness and color.

First reference. Lee, W. T., 1902.

Nomenclator. Lee, W. T., 1902.

Type locality. Lee[63] did not specify a type section but stated that the Exeter occurs in the vicinity of the *Exeter* (Exter) post office, New Mexico, which he spelled incorrectly. Some writers[64] have attempted to establish the spelling of the formation so that it would conform with the spelling of the old "Exter" post office, but Lee's spelling has become so firmly entrenched in geologic literature that the use of "Exter" serves chiefly to cause confusion. The spelling "Exeter" is approved by the U. S. Geological Survey[65] and will be used in this paper. Exter post office no longer exists. The location, name, and ownership of the store that served as post office have been changed several times. It is now known as Johnson's store, and is located near Valley school, Union County, New Mexico.

A photograph[66] in the paper in which Lee described the Exeter, shows Ship Rock butte (Mountain) in the left hand side. He, therefore, possibly referred to exposures at that location. Ship Rock butte is 15 miles west of Kenton, Oklahoma, on U. S. Highway 64, and is an easily accessible landmark in the Cimarron

63. Lee, W. T., *op. cit.*, p. 45.
64. Stanton, T. W., "The Morrison Formation and its Relation with the Comanche Series and the Dakota Formation": *Jour. Geol.* Vol. 13, p. 665, 1905.
Garrett, Dan L., "Stratigraphy and Structure of Northeastern New Mexico": *Bull. Amer. Assoc. Petro. Geol.*, Vol. 4, p. 75, 1920.
DeFord, R. K., "Areal Geology of Cimarron County, Oklahoma": *Bull. Amer. Assoc. Petro. Geol.*, Vol. 11, Pt. 2 p. 754, 1927.
65. Wilmarth, M. G., "Lexicon of Geologic Names of the United States": *U. S. Geol. Survey Bull.* 896, p. 712, 1938.
66. Lee, W T., *op. cit.*, fig. 4, p. 42.

Valley. The Exeter here consists of about 75 feet of massive, pink to white sandstone, and overlies the red clay and shale of the Dockum. Because a few feet of the upper part of the formation may have been removed by erosion at Ship Rock butte, and because Lee's type locality cannot be identified positively, the writer is here designating the type section of the Exeter sandstone as the almost vertical cliffs south of U. S. Highway 64, in sec. 32, T. 32 N., R. 35 E., Union County, New Mexico. At this locality the Exeter has a thickness of 80 feet, is typical of the formation as it is exposed in Ship Rock butte and elsewhere in the vicinity, and is sharply separated from overlying and underlying beds.

Original description.

". . . It is a firm, hard, and rather coarse but evenly laminated sandstone, pink to white in color. The lower strata are pink, while those above grow progressively lighter colored. It has the appearance of being composed of the coarse material from the eroded Red Beds, and may be a basal sandstone formed by the encroaching waters from the east or south, which cut away the Red Beds. The sandstone has a maximum thickness of 75 feet, and extends from a point several miles west of Exeter, where it thins out, eastward to the New Mexico line where it drops beneath the Canyon bottom."[67]

History of usage. Lee[68] reported that the Exeter extends eastward from the type locality to the New Mexico-Oklahoma state line, where "it dips beneath the canyon bottom." Rothrock[69], who was first to prepare a detailed map of Cimarron County referred the beds, now recognized as Exeter in the Black Mesa area, to the Morrison and Purgatoire. In his measured section on p. 33, of the bulletin cited, the upper 2 units, consisting of massive, white sandstone at the top, that he calls Purgatoire, overlying a fine-grained, white sandstone, weathering buff, that he classifies as Morrison, have been identified by the writer as Exeter. Rothrock assigns a total thickness of 12 feet to these 2 units; the writer measured 53 feet in the same locality.

67. Lee, W. T., *op. cit.*
68. Lee, W. T., *op. cit.*
69. Rothrock, E. P., "Geology of Cimarron County, Oklahoma": *Okla. Geol. Survey Bull.* 34, p. 33, 1925.

So far as the writer knows, DeFord[70] was the first to recognize the Exeter in Oklahoma, and to mention it by name in a published article. Although the brevity of his notes did not permit a detailed description, he mentioned exposures of the formation in Tps. 5 and 6 N., R. 1 E., and referred to it as a "massive sandstone." In 1937 Stovall[71] briefly described the Exeter in Cimarron County, gave a measured section, showed its stratigraphic position, and its areal distribution. In 1938 Stovall[72] published a brief decription and small scale map of the area.

Distribution. The Exeter sandstone generally has a narrow exposure in Cimarron County, Oklahoma, because it is a cliff-making formation, but locally, as in the vicinity of Tate Butte, it forms flat benches. The best exposures are along North and West Carrizo Creeks, just north of Black Mesa, and along Carrizozo Creek where U. S. Highway 64 enters New Mexico. It also makes a white band at the foot of Black Mesa near the state line, and at the base of many of the buttes and escarpments in the valleys north and west of Kenton. Like the Dockum, it dips eastward and disappears under cover near the middle of T. 6 N., R. 1 E., and, owing to reversal of dip (see structure), reappears at the surface near the middle of T. 5 N., R. 5 E., and loops headward for a maximum distance of 5 miles along the tributaries of the Cimarron River, in T. 6 N., R. 5 E., and Tps. 5 and 6 N., R. 6 E. Its easternmost exposure is about 1 mile west of the east line of T. 5 N., R. 6 E. It is thinner in these eastern exposures, is generally covered, and, therefore, less well exposed. (Pl. V).

Thickness. In his original description Lee[73] assigned a thickness of 75 feet to the Exeter sandstone, and stated that it thins to the eastward. Stanton[74] and Parker[75] reported a maximum

70. DeFord, *op. cit.*, p. 753.
71. Stovall, J. W., "Geology of the Cimarron Valley of Cimarron County, Oklahoma": Thesis presented to the faculty of the University of Chicago in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 1938.
72. Stovall, J. W., "The Morrison of Oklahoma and its Dinosaurs": *Jour. Geol.*, Vol. 46, fig. 1, pp. 585 and 587, 1938.
73. Lee, W. T., *op. cit.*, p. 45.
74. Stanton, T. W., *op. cit.*, p. 665.
75. Parker, Ben H., "Clastic Plugs and Dikes of the Cimarron Valley Area of Union County, New Mexico": *Jour. Geol.*, Vol. 41, p. 40, 1933.

thickness of 80 feet for it in northeastern Union County, New Mexico. In a paper on the Morrison of Cimarron County, Stovall[76] inadvertently gave the thickness of the Exeter as 18 feet, which is its thickness in the incomplete section exposed on the east side of Carrizozo Creek on the New Mexico-Oklahoma state line, at the bridge for U. S. Highway 64; whereas the maximum thickness observed by him in Cimarron County is 53 feet, at Labrier (Tate) Butte. The formation thins eastward, either from pre-Morrison erosion or lack of deposition. In most exposures north and northeast of Boise City the Exeter is less than five feet in thickness, and is locally absent because of post-Mesozoic erosion.

Character. From a distance, the Exeter appears to be a uniform, massive sandstone, but closer examination shows two distinctly different phases, or members. At the type locality in New Mexico the lower member is pink and the upper is white, whereas in the northwestern part of Cimarron County, the lower part is dominantly brown, and the upper part is somewhat whiter than it is at the type locality.

At Labrier (Tate) Butte, the best exposure in the county, the lower member is a massive, irregularly-bedded, brown sandstone, 15 feet thick. (Pl. IV). It is uniform in character, having only two or three zones a few inches thick in which there is some concentration of argillaceous material that permits more rapid weathering than occurs in the remainder of the beds. The overlying white member of the Exeter is removed at the south end of Labrier Butte, exposing the upper surface of the brown member. Several vertical northwest-southeast joints are visible on this surface and some of them are indicated by narrow ridges 1 to 1.5 feet high, resembling sandstone dikes, that probably are made up of vein-filling material more completely cemented than the sandstone. This bed differs from the corresponding bed of pink sandstone in the type area not only by its brown color but by its considerably reduced thickness. The presence of rounded pebbles, small lenses of clay, and the regularity of the cross-bedding, suggest that this member is of subaqueous origin.

76. Stovall, J. W., *op. cit.*, p. 586.

The upper member is a white, friable, relatively coarse, cross-bedded sandstone, 38 feet thick at Labrier Butte. The cross-beds are extreme, with long, sweeping overlaps that, in general, are inclined sharply to the north. It contains a few flecks of darker material and the sand grains are well etched and fairly well rounded. The etched grains, and the type of cross-bedding suggest to the writer eolian deposits of a dune character. The upper surface of the Exeter is not irregular, as might be expected in sand dunes, but this may be explained as due to planation and reworking of material in the upper part of the formation, prior to Morrison deposition.

In the region north of Boise City only the upper white member of the Exeter is present. There it is sugary in texture, is very friable, and forms ledges a foot or slightly more, in height.

Stratigraphic Relations. The Exeter formation is underlain unconformably by the Dockum, and is overlain disconformably by the Morrison. The contact between the Exeter and the Morrison is a sharp line and apparently represents a complete change in conditions of deposition.

Correlations. Lee[77] was uncertain as to the correlation of the Exeter with other formations in the Texas-New Mexico-Colorado area. Following Hill's reasoning that the red beds of the Canadian River area in the Texas Panhandle were of Permian age[78] —a conclusion that has proved incorrect—Lee suggested: "It is possible, then, that the Red Beds of the Canadian and perhaps the Exeter sandstone of the Rio Cimarron may be of Triassic age." In the same paper he also suggested the possibility that the Exeter might be equivalent to the Trinity, of Lower Cretaceous age.

Darton[79] thought the Exeter might be equivalent to a bed in the middle of the Morrison formation of southwestern Union County, and eastern San Miguel County, New Mexico. Duce[80]

77. Lee, W. T., *op. cit.*, p. 56.
78. Hill, R. T., "Physical Geography of the Texas Region": *U. S. Geol. Survey Topographic Folio* 3, p. 2, 1900.
79. Darton, N. H., "'Red Beds' and Associated Formations in New Mexico": *U. S. Geol. Survey Bull.* 794, p. 306, 1928.
80. Duce, J. T., "Geology of Parts of Las Animas, Otero, and Bent Counties, Colorado": *Colo. Geol. Survey Bull.* 27, Pt. 3, p. 83, 1924.

stated that "This sandstone (Exeter) is probably the equivalent of the Dockum of North Texas as described by Drake," but apparently was not aware that Triassic fossils reported by Stanton[81] had come from the Dockum rather than the Exeter. Duce, also, was of the opinion that the Exeter is a lentil between the Morrison and the Lykins, and Sanders[82] believed it to be a lentil in the lower part of the Morrison.

The most recent, and the most tenable suggestions on the age of the Exeter, based on regional studies, are by Heaton.[83] This paper presents a series of stratigraphic sections covering exposures of Triassic and Jurassic rocks along the eastern flank of the Rocky Mountains in New Mexico and Colorado, and in the region comprising northern Utah, and adjoining parts of Wyoming and Idaho. One line of sections extends eastward from Badito, Colorado to the New Mexico-Oklahoma state line, and includes exposures in the Cimarron valley. Sections in the eastern area were contributed by Ben H. Parker.

As shown in a correlation chart, only Upper Jurassic is present along the Colorado Front Range, in southeastern Colorado, north and northeast New Mexico. In the entire region covered by the sections, the Upper Jurassic generally is divided into three parts, variously named, but in the Colorado Front Range, southeastern Colorado and northeastern New Mexico, called in ascending order: Entrada sandstone, Todilto formation (gypsums and limestone, considered by some writers a member of the Morrison formation), and the Morrison formation.

The Todilto appears to be absent in the area closest to Cimarron County, Oklahoma, and Heaton suggests that the Exeter sandstone of the Cimarron valley is equivalent to the Entrada sandstone, and therefore is of Upper Jurassic age. Heaton correlates the Entrada with the Sundance sandstone (lower part of the Sundance formation) of Wyoming.

81. Stanton, T. W., *op. cit.*, p. 663.
82. Sanders, C. W., "Geology of Two Buttes Dome in Southeastern Colorado": *Bull. Amer. Assoc. Petro. Geol.*, Vol. 18, p. 866, 1934.
83. Heaton, Ross L., "Contribution to Jurassic Stratigraphy of Rocky Mountain Region": *Bull. Amer. Assoc. Petro. Geol.*, Vol. 23, pp. 1165-1166, 1939.

Measured Sections. Detailed sections of the Exeter sandstone may be found in Appendix A. They include numbers 19, 21, 22, 25, and 30.

MORRISON FOMATION

The name Morrison, as used in this report, is applied to the alternating succession of variegated sandstones, limestones, dolomites, shales, clays, and conglomerates that lie immediately above the cross-bedded, white Exeter sandstone, and below the cross-bedded, white to cream or buff Cheyenne sandstone member of the Purgatoire formation. Where exposed, the Morrison is easily recognized, but generally is covered by talus and valley-fill.

First reference. Cross, Whitman, 1894.

Nomenclator. Eldridge, G. H., 1896. "The formation was named by Eldridge in U. S. Geol. Survey Monograph 27, within the area of which is its type locality; but Pikes Peak Folio (No. 7) by Whitman Cross, in which the formation was also described *by name,* was published in 1894, before publication of the Monograph."[84]

Type locality. Near the town of Morrison, Colorado, fifteen miles southwest of Denver.

Original description.

"The marls are green, drab or gray, and carry in the lower two-thirds numerous lenticular bodies of limestone of a characterteristic drab color and a texture compact and even throughout. A small but persistent band of sandstone and limestone in thin alternating layers occurs about 20 feet above the base; in some places the arenaceous elements largely predominate, and at Mount Vernon, 3 miles north of Morrison, and in the vicinity of Van Bibber Creek, there are at about this horizon from 10 to 15 feet of dull-gray or yellowish sandstone carrying small pebbles of flint of various colors. The clays of the lower two-thirds of the Jura are remarkable for their reptilian remains, and from the predominating form have been designated Atlantosaurus clays.

"The upper third of the Jura is generally a succession of sandstones and marls, of which the former predominate; locally, however, either may prevail to almost the entire exclu-

84. Wilmarth, *op. cit.*, p. 1423.

sion of the other. The most important sandstone occurs just above the Atlantosaurus clays, is very persistent, and from contained saurian remains has been called the Saurian sandstone. It varies in thickness between 5 and 35 feet, and in its distance below the Dakota, from 10 to 135 feet, although more generally from 50 to 80 feet.''[85]

History of usage. Eldridge named the Morrison in 1896, having abandoned the term Gunnison for beds of similar age named by him in 1894 from exposures in the Crested Butte, Colorado, area. Both before and since Eldridge named the formation, it has been variously called: "Atlantosaurus Beds", "Jurassic Beds", "Dakota Beds", "Variegated Beds", "Buelah Shales", "Como Beds", "La Plata Sandstone", and the "McElmo Formation."[86] In some places, however, the above terms have been applied to units including more or less than the present accepted use of the term. Gould[87] included the Morrison in the Dakota, and Lee[88] included the Cheyenne sandstone and the Kiowa shale with the Morrison, whereas Rothrock[89] included in the Purgatoire, the beds on North Carrizo Creek and at Labrier (Tate) Butte that are defined as Morrison in this paper.

The age of the formation has long been debated by many geologists, some considering it to be upper Jurassic and others considering it lower Cretaceous. The latter view was greatly influenced by Lee's discovery of Kiowa fossils in rocks that he took to be Morrison at the old Garrett post office (sec. 25, T. 6 N., R. 4 E.). The U. S. Geological Survey long classified the Morrison as Lower Cretaceous, but lately has reclassified it and assigned it to the upper Jurassic and it is so considered in this paper. An excellent digest of the usage of the term may be found in the paper by Baker, Dane, and Reeside, cited above.

Distribution. The Morrison is the most widespread formation in the canyons of Cimarron County, covering an area of

85. Emmons, S. W., Cross, Whitman, and Eldrige, G. H., "Geology of the Denver Basin in Colorado": *U. S. Geol. Survey Monograph* 27, p. 61, 1896.
86. Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., "Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado": *U. S. Geol. Survey Prof. Paper* 183, pp. 9, 33-44, 1936.
87. Gould, C. N., "Geology and Water Resources of Oklahoma": *U. S. Geol. Survey Water Supply Paper* 148, pp. 78-79, 1905.
88. Lee, W. T., *op. cit.*, pp. 36-58.
89. Rothrock, E. P., *op. cit.*, pp. 49-57.

from 100 to 105 square miles. Its distribution is exceeded only by the Dakota, which formation has its greatest areal extent on the uplands.

The Morrison formation occurs in three disconnected areas. The largest exposure is in the northwestern part of the county, where it occupies the valley floors and extends from the New Mexico-Oklahoma state line and beyond, eastward to the eastern side of the Gallienas Valley, and from 2 miles north of the Colorado-Oklahoma state line, southward to the headwaters of Tesequite Creek. In this region it not only forms the valley floors but is exposed well up the walls of the canyons. A second area of exposure is a small, elongate inlier along Cimarron River, lying largely in sec. 2, T. 5 N., R. 3 E. The other exposure is the second largest and lies north of Boise City, where it occupies the greatly widened valley of Cimarron River and its tributaries for a distance of 10.5 miles east and west and 11.3 miles north and south.

Thickness. The Morrison formation has a maximum thickness of 467 feet in Cimarron County, which is thicker than was supposed by previous writers and most previous workers, and is greater than has been reported for the *true* Morrison in northeastern New Mexico and southeastern Colorado. Rothrock[90] mistook the Triassic for Morrison, hence the thickness of 55 feet given in his section in sec. 28, T. 6 N., R. 1 E. (Labrier Butte) is not applicable. DeFord[91] was first to recognize the true Morrison in this area, but did not report its thickness.

Lee[92] reported 206 feet of Morrison near Long Canyon on the Cimarron River, in Union County, New Mexico, and 300 feet in the Canadian River Canyon south of Springer, New Mexico; but he included in these measurements, respectively, 77 and 73 feet of the Purgatoire formation, so that the *true* Morrison at those locations is 129 feet thick in the former, and 227 feet thick in the latter section.

90. *Idem.*
91. DeFord, R. K., "Areal Geology of Cimarron County, Oklahoma": *Bull. Amer. Assoc. Petro. Geol.*, Vol. 11, pp. 753-755, 1925.
92. Lee, W. T., *op. cit.*

Stanton[93] reported about 200 feet of Morrison in a section on the Purgatoire River, about 15 miles southwest of Higbee, Colorado, but was of the opinion that another 125 feet of underlying gypsiferous shales should be included with it; thus making a total of 325 feet for the Morrison in that area. This is the greatest thickness previously assigned to the Morrison formation, as described in this paper, in the Oklahoma-northeastern New Mexico-southeastern Colorado region.

A complete section of the Morrison cannot be measured in any one locality in Cimarron County, and a northeast-southwest flexure resulting from pre-Cretaceous warping, whose axis lies just east of Black Mesa, must be taken into account in calculating the complete thickness. Pre-Cheyenne truncation of upper Morrison beds west of the flexure, gives a much reduced Exeter-Cheyenne interval in the Labrier Butte section. Farther east, beyond the influence of the flexure, where strata are essentially parallel, the Exeter and lower Morrison have dipped under Cimarron River, and only the upper Morrison beds are exposed. (See fig. 7).

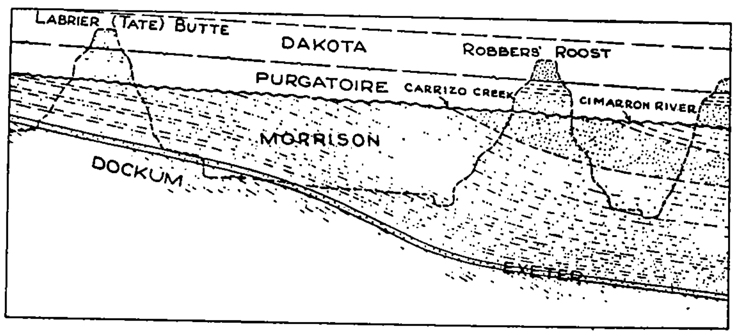


FIG. 7. Profile from Labrier (Tate) Butte, Southeastward Through Robbers' Roost to the South Side Cimarron River, Sec. 2, T. 5 N., R. 1 E., Showing Relationship of the Morrison and Underlying Formations. Owing to a Flexure between Labrier Butte and Robbers' Roost, and Truncation Prior to Purgatoire Time, the upper and middle parts of the Morrison are missing at Labrier Butte; the upper part at Robbers' Roost; but the youngest Morrison is present in sec. 2. From Guidebook of Oklahoma City Geological Society field trip, May 1941.

93. Stanton, T. W., "The Morrison Formation and its Relations with the Comanche Series and the Dakota Formation": *Jour. Geol.*, Vol. 13, pp. 657-669, 1905.

To compute a total thickness of the Morrison, it was necessary to depend on correlations, and measurements in three different locations, and the section was divided as follows: 158 feet of lower beds at Tate Butte; 219 feet of middle beds at Robbers' Roost; and 90 feet of upper beds in an exposure on the south side of Cimarron River, about 1.5 miles southeast of Robbers' Roost; making a total of 467 feet.

The highest Morrison beds of the Labrier Butte section dip sharply to the southeast, and may be identified in the bank of North Carrizo Creek, adjacent to Robbers' Roost; the upper part of the Morrison in the Robbers' Roost section consists of a massive sandstone, which is overlain with angular unconformity, by the Cheyenne sandstone; the base of this massive sandstone may be seen in the river bluffs 1.5 miles southeast of Robbers' Roost, where it is essentially parallel with the base of the Cheyenne sandstone, and where its entire thickness, together with that of the overlying shale, can be measured.

The correctness of the foregoing interpretation and correlations was confirmed in the field by the late Arthur Wedel and Robert H. Dott.

Only 25 feet of the upper part of the Morrison are exposed in the small inlier in sec. 2, T. 5 N., R. 3 E. Measurements in the railroad cut, and in a hill located 50 yards to the east, in secs. 9 and 16, T. 5 N., R. 5 E., north of Boise City, show a thickness of 31 feet above the top of the Exeter sandstone. (Table XII.) This section is incomplete, for it does not reach the base of the Purgatoire. This is an area of anomalous dips, and the total thickness of the Morrison is difficult to determine. It is estimated at 75 feet.

Character. Before discussing the character of the Morrison in Cimarron County, as observed during the writer's studies, it should be stated that Rothrock[94] mistakenly assigned to the Morrison, beds that are now known to be Triassic; hence his descriptions apply to the Dockum and not to the Morrison.

94. Rothrock, E. P., *op. cit.*

In general, the Morrison formation is composed of variegated shale, clay, marl, sandstone, conglomerate, considerable limestone, some dolomite, and quartzite. Pl. VI. Its lateral and vertical variability are no less pronounced in this region than elsewhere. Traceable beds are few and rather limited, and limestones appear to show greater continuity and wider local distribution than any of the other beds. This may be due in part to the difficulty of distinguishing one bed from another, particularly among the sandstones, in isolated outcrops. The dominant color is greenish-gray, although brown, red, purple, yellow, turquoise-green, and white are common.

Sandstones that range in texture from very fine silt-like material to coarse conglomerate beds are important in the Morrison. Some of the beds of fine sand grade laterally into brown banded siltstones that are, where indurated, called "striped rock". A microscopic examination of this material reveals that it is composed almost wholly of exceedingly fine-grained particles of quartz. It carves easily, and is worked into ash trays and desk ornaments by local people. In many places the coarse-grained beds occur as ledges. They are commonly buff in color, but may be yellow or brown, and are generally flecked with brown or white. In many localities the sandstone has been altered, perhaps by hydrochemical processes, into quartzite of such density that it was used by Indians in making arrow and spear points.

A conspicuous portion of the Morrison in this area is composed of shale, marl, and clay containing more or less sand, and in some places considerable amounts of calcium carbonate. The more clay-like portions have been described as "joint-clays" owing to their tendency to quarry out in blocky masses. In color, they are dominantly gray, but commonly are purple, red, green, or mottled.

The best exposures of the Morrison, and the most complete sections, are two of those that were studied to determine the thickness of the formation; namely, Labrier (Tate) Butte and Robbers' Roost. The lower part of the formation is exposed only in the extreme east and west ends of the area of Mesozoic outcrops, north of Boise City, and in the vicinity of Kenton. The best exposures, and the best area for studying this part of the formation are in the two tiers of sections north and west of Kenton (north and south of Black Mesa), and in a few square miles east, west, and south of Kenton. The exposures in Labrier Butte are typical, and the Labrier Butte section is given as representative of the lower Morrison. (Pl. VII).

TABLE X.

SECTION OF THE MORRISON FORMATION AT LABRIER (TATE) BUTTE, NE¼ SEC. 29, T. 6 N., R. 1 E.

	Feet
Cretaceous system	
Purgatoire formation	
Cheyenne sandstone member	
Jurassic system	
Morrison formation	
7. Shale, emerald green	1.0
6. Shale, green; and sandstone, buff to brown; in alternating beds. Considerable talus cover	53.0
5. Limestone, with shale partings of about equal thickness. Limestone is dove-colored, contains many lenses of chert; layers about 8 inches thick. Surface of limestone layers irregular. Limestone at top of unit grades upward into sandstone	40.0
4. Sandstone, white, massive	34.0
3. Sandstone and shale. Sandstone is thin-bedded, but becomes more massive 100 yards south, where thick sandstone ledge is in evidence	21.0
2. Dolomite, dove to pink, contains many small dolomite rhombs, varies in thickness from 8 to 20 inches. Average	1.0
1. Sandstone, buff, thin-bedded. Has numerous easily-eroded bands	8.0
Total thickness of Morrison	158.0
Exeter sandstone	

As already stated, it was not found possible to trace individual beds or units any great distances, and few of the units could be identified in separate exposures. The one notable exception is the emerald-green shale which occurs at the top of the Labrier Butte section (unit 7). Shale of similar lithology and color was found beneath the Cheyenne sandstone along Highway 64, on 101 Pass, NE¼ sec. 15, T. 5 N., R. 1 E., 2 miles east of Kenton; and just above water level in North Carrizo Creek, at Robbers' Roost, and is correlated with this unit, with considerable assurance.

It seems probable that the dinosaur quarry located in the NE¼ sec. 5, T. 5 N., R. 1 E., on the south flank of Black Mesa, and perhaps some others, occur in beds equivalent to unit 5 of the

Labrier Butte section. This correlation implies that the limestones in Labrier Butte grade into marl or clay in the intervening 2 miles—a possibility that is entirely tenable, considering the variable character of the Morrison.

The lower part of the Morrison in the Wolf Mountain area, north of Boise City, where the underlying Exeter sandstone is again exposed, differs somewhat in lithologic character from the Labrier Butte section, and there may be some doubt of its being the same part of the formation, although it is considered to be approximately equivalent.

The section of the Morrison at Robbers' Roost comprises a series of rocks higher in the formation than those at Labrier Butte. The dip at Labrier Butte is 4 degrees to the southeast, but this angle of dip increases to 7 degrees before Robbers' Roost is reached. At the creek level at Robbers' Roost is an emerald-green shale that is correlated with a similar bed at the top of the Morrison in Labrier Butte, and just beneath the Cheyenne sandstone at 101 Pass (sec. 15, T. 5 N., R. 1 E.). This correlation gives a tie between the Labrier Butte and Robbers' Roost sections. The Robbers' Roost exposures are the best available for study of the middle portion of the Morrison of the area, and are shown in the following section:

TABLE XI

Section of the Morrison Formation at Robbers' Roost, sec. 34, T. 6 N., R. 1 E.

	Feet
Cretaceous system	
Purgatoire formation	
Cheyenne sandstone member	
Jurassic system	
Morrison formation	
Sandstone, white, cross-bedded	114.6
Sandstone, buff, brown-flecked, conglomeratic	15.2
Shale, red	6.5
Sandstone, brown, fissile, ledge-forming	4.0
Shale, red; grades into green shale toward top	5.0
Sandstone, brown; forms ledge	1.5
Shale, purplish red	2.0
Sandstone, buff, flecked with brown, thin layers	3.0
Shale, red to gray	3.7
Sandstone, brown	1.5
Shale, purplish	2.5
Sandstone, brown	4.5
Shale, purple	2.0
Sandstone, brown	2.7
Sandstone, white, flecked with brown; shows a decided inclination toward cross-bedding	6.0

Plate IV. Upper Part of Dockum Beds, Showing Contact with Overlying Exeter Sandstone, in South Bank of North Carrizo Creek, at Foot of Labrier (Tate) Butte, NE¼ sec. 29, T. 6 N., R. 1 E. Dockum is Composed of Variegated Clays and Even-Bedded Siltstone. Lower, Brown Phase of Exeter Sandstone Caps the Bluff.

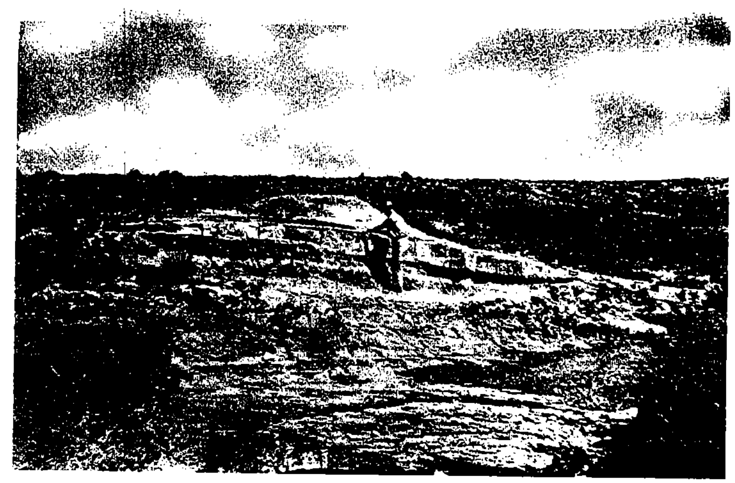
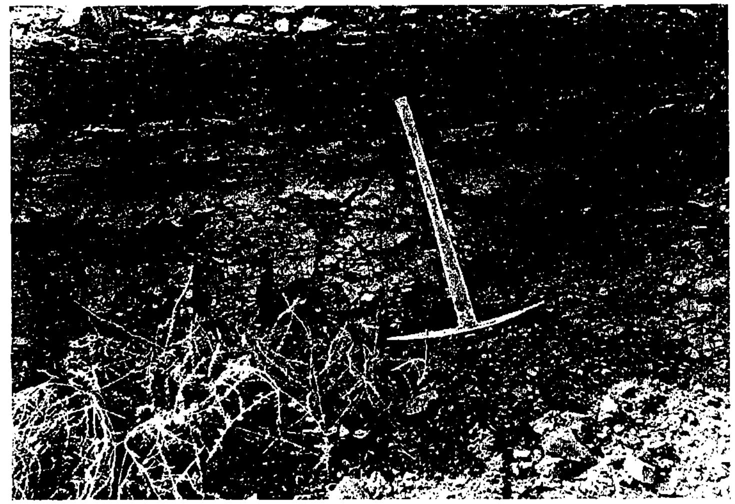


Plate V. Exeter sandstone on Dripping Springs Creek, sec. 26, T. 5 N., R. 5 E. The Exeter here is about 1.5 feet thick, and this exposure shows a good contact with the underlying Dockum beds.

A



B

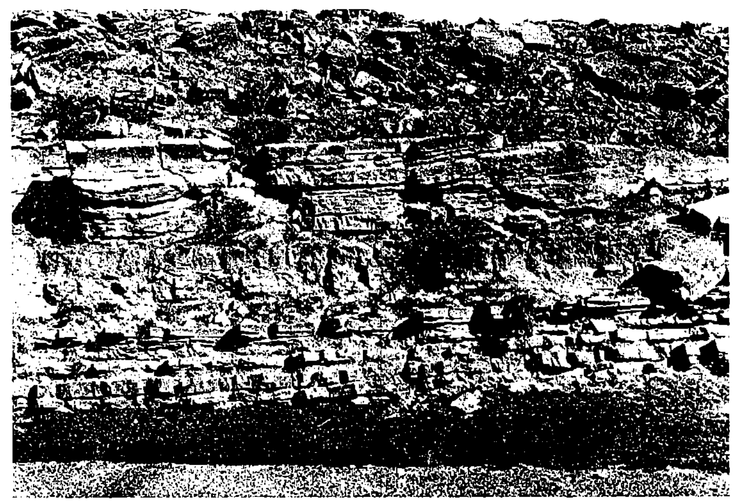


PLATE VI. A. Massive shale and thin-bedded sandstone of the Morrison Formation, east side of Cimarron River, north of Kenton, sec. 4, T. 5 N., R. 1 E. Small thrust fault is seen at right.
B. Thin beds of dove-gray limestone of the Morrison Formation, overlain by somewhat more massive sandstone. Near Robbers' Roost, in bank of North Carrizo Creek. Sec. 34, T. 6 N., R. 1 E.

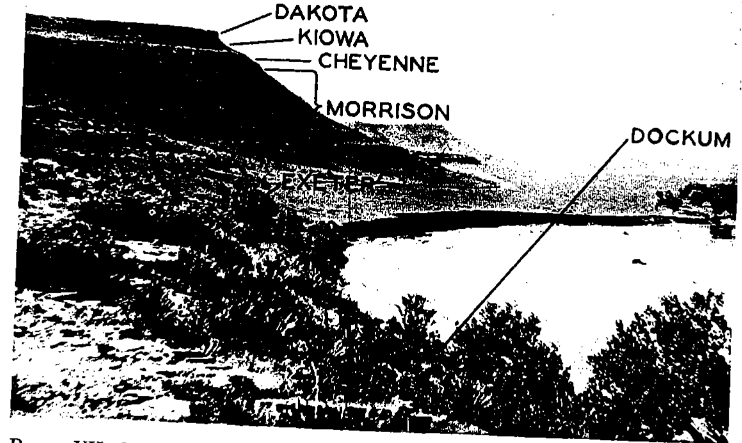


PLATE VII. Southeast end of Labrier (Tate) Butte, showing Mesozoic Formations from Exeter Sandstone to Dakota Sandstone, inclusive. The upper, white member of the Exeter Sandstone is seen in the left foreground. The lower member and the Dockum beds are exposed in the bank of North Carrizo Creek to the right. (See Pl. IV). Only the lower part of the Morrison is present here, owing to pre-Cretaceous uplift and planation.

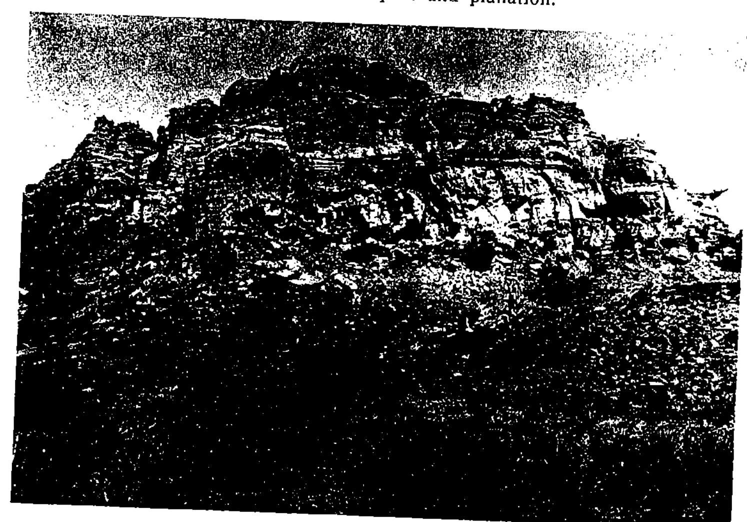


PLATE VIII. Cheyenne sandstone, showing irregular-bedding, and light color, jointing, and unequal weathering into rather fantastic forms. The man at the right is standing on a green shale which, in this locality, is the upper member of the Morrison formation. Sec. 22, T. 5 N., R. 1 E., along road to John Regnier ranch.

PLATE XI. The "Three Sisters", erosion remnants of the Dakota sandstone, showing typical cross-bedding. 100 yards south of Highway 64, in sec. 18, T. 5 N., R. 2 E.

Shale, purple	1.7
Sandstone, white, cross-bedded	6.0
Sandstone, white, brown flecked, cross-bedded	4.0
Sandstone, white, brown flecked; shows ledges	4.6
Sandstone, white, brown flecked	0.6
Sandstone, very platy, gray, lenticular	0.2
Sandstone, white, brown flecked, dense	0.4
Sandstone, white, with brown flecks	0.3
Sandstone, white, fine-grained, dense	0.5
Sandstone, ash colored, very platy, fine-grained, recess-forming, friable	0.5
Sandstone, buff, dense, ledge-forming	1.1
Shale, greenish	1.0
Shale, purple; on exposure slakes into paper-thin particles	1.0
Sandstone, white	1.8
Shale, gray	0.1
Sandstone, white, very fine-grained, containing calcium carbonate; stained with brown along the fractures and outer surface; flecked with brown throughout the entire mass; very tough and ledge-forming	1.8
Shale, greenish-gray	1.5
Sandstone, purple, very friable, platy	2.5
Dolomite, buff colored, arenaceous	0.5
Sandstone, buff, friable	0.1
Dolomite, buff, "bird's eye"	0.2
Shale, white, limey, containing calcite partings 1/8 inch thick	0.2
Dolomite, buff	0.2
Shale, varying between gray, lavender, and pink, calcareous; contains quarter-inch calcite partings	0.4
Dolomite, cream colored	0.9
Talus covered slope	2.1
Sandstone, buff, with parallel, closely spaced fractures	0.5
Sandstone, buff, thin, platy	0.2
Sandstone, light to dark brown, with white stain along bedding planes; fractures into blocks from one-half to 14 inches in width and of unknown length; blocks from the same stratum which have been entirely exposed by erosion were five to six feet long, suggesting fence posts	0.3
Sandstone, buff, platy	0.3
Dolomite, cream, dense	0.2
Dolomite, sandy, friable	0.3
Shale, gray	0.4
Limestone, dove colored	0.9
Shale, gray	0.3
Limestone, dove colored; has a slaty character in its lower two inches	1.3
Limestone, mottled	0.3
Shale, gray	0.1
Limestone, dove to buff, mottled, "bird's eye"	0.3
Shale, greenish	0.1
Dolomite, buff	0.3
Shale, brown	0.3
Limestone, dove colored, slightly banded	0.4
Shale, slate-gray	0.5
Limestone, dove-gray	0.5
Shale, light brown to buff	0.4
Dolomite, light-dove layer, weathers readily into small blocks which show rounded corners	1.0
Shale, green; slakes into more or less rectangular pieces	1.5
Bed of North Carrizo	
Total thickness	219.3

The top member of the Morrison at Robbers' Roost is a bed of white, cross-bedded sandstone, 114 feet thick, which lies immediately beneath the base of the Cheyenne sandstone, with marked angular unconformity. This relation may be seen best in the west-facing escarpment 0.5 mile northwest of the foundation of the old building that is known as "Robbers' Roost." One and a half miles southeast of Robbers' Roost, in the bluffs south of Cimarron River, this same white sandstone of the Morrison is overlain by a unit of shale, alternating with vari-colored sandstones, 90 feet thick. The exposures are too poor for detailed study. This shale constitutes the highest unit of the Morrison formation in the area, and is overlain, without angularity of dip, by conglomeratic sandstone of the basal Cheyenne.

The thick sandstone of the upper Morrison does not appear east of Gallienas Creek. It may be represented in the lower sandstone of the bluffs on the west side of Gallienas valley; but, if so, it is indistinguishable from the overlying Cheyenne, and it is the opinion of the writer that this sandstone is wholly Cheyenne.

The eastward disappearance of the upper Morrison sandstone cannot be explained on the basis of any definite field observations. It may be due to pinching-out, in common with the characteristic lenticularity of many units of the formation. It seems more probable, however, that its eastward disappearance results from the same cause as its westward disappearance—pre-Cheyenne truncations, resulting from post-Jurassic uplift. The fact that only some 75 feet of Morrison—probably lower Morrison—is preserved in the vicinity of Wolf Mountain, north of Boise City, supports this hypothesis. From this reasoning it would follow that the massive sandstone and overlying shale was preserved in a pre-Cheyene syncline whose axis lies between North Carrizo and Gallienas Creeks.

The following section, measured along the railroad, and in a hill located 50 yards to the east, in secs. 9 and 16, T. 5 N., R. 5 E., north of Boise City, shows the character of the lower part of the Morrison formation in that area:

TABLE XII

SECTION ALONG RAILROAD, AND IN SMALL HILL, SECS. 9 AND 16, T. 5 N., R. 5 E.

	Feet
Top of Hill	
Jurassic system	
Morrison formation	
Limestone cap of hill	3.0
Covered to top of hill	14.0
Sandstone, gray, platy	0.1
Shale, gray-purple	0.3
Sandstone, gray, fine-grained, blocky	0.3
Clay, purple-gray	0.3
Marl, gray, fine-grained	0.2
Clay, purple	0.5
Marl, gray to purple	0.3
Shale, maroon and gray	1.7
Marl, gray	0.3
Clay, purple to gray	0.3
Marl, purple to gray	0.2
Clay, gray and purple	0.3
Marl, light gray	0.3
Clay, purple to gray	0.8
Marl, pinkish	0.4
Clay, purple to gray	1.2
Marly nodules, gray and purple	0.3
Clay, purple, some gray	3.2
Clay, purple, with gray zones, platy	0.8
Clay, purple, with 2-inch nodular zone at top	2.0
Sandstone, purple, thin-bedded; forms ledge	0.9
Sandstone, purple and gray, thin-bedded, alternating with clay	3.5
Clay, purple and gray	1.5
Sandstone, purple and gray, even-bedded, in beds 1-inch or less	1.2
Clay, purple and gray, in alternating thin beds	7.5
Sandstone, purple, calcareous, in thin, regular beds, with partings of purple clay. Some mottling on clay	2.8
Total thickness of Morrison in section	48.2
Exeter sandstone	
Sandstone, white, massive, hard.	

Although the succeeding 27± feet of the Morrison was not measured in this area, several exposures studied indicate that it is composed dominantly of shale, interbedded with numerous thin beds of limestone.

Stratigraphic Relations. The Morrison formation overlies the Exeter sandstone (Jurassic) disconformably and underlies the Cheyenne sandstone member of the Purgatoire formation (lower Cretaceous) unconformably in Cimarron County. Here and westward, in Union County, New Mexico, the contact between the Exeter and the overlying Morrison is very sharp, and represents an apparent planation of the Exeter. Processes of sedimentation changed quickly from dune to fluviatile conditions, and a certain amount of time was necessary for the Exeter dunes to be smoothed off. Furthermore, the absence here of considerable thicknesses of Jurassic sediments that are present between the Morrison and Triassic in other parts of this general region may be accounted for by the removal of those sediments by erosion prior to the deposition of the Morrison.

The Morrison-Cheyenne sequence represents a complete change from continental to marine conditions. During post-Morrison- pre-Cheyenne time, folding occurred that produced uplifts in both the western and eastern parts of the area under consideration, and the subsequent removal by erosion of 304 feet of Morrison sediments at Tate Butte and some 390 feet in the area north of Boise City. Following truncation of beds involved in this folding, the Purgatoire formation was laid down, with marked unconformity.

Between Labrier Butte and Gallienas valley, the Cheyenne sandstone—lower member of the Purgatoire—successively overlies lower Morrison shales, a thick, massive sandstone of the upper Morrison, and a shale unit 90 feet higher. Continuing eastward, the Purgatoire is in the contact with older parts of the Morrison, until, in the area north of Boise City, only about 75 feet of the latter formation is present.

In some places, notably in the eastern area of Morrison exposures, the Cheyenne apparently was not deposited, and the Kiowa shale rests on the Morrison. This situation suggests relatively higher pre-Purgatoire topography in that vicinity, which locally prevented deposition of the Cheyenne.

Throughout most of the area, the Morrison is overlain by Purgatoire rocks, but in the eastern exposures, the Purgatoire and higher Cretaceous formations have been removed, and the Morrison is overlain by Tertiary and Recent sediments.

Paleontology. The Morrison is characterized by an abundance of dinosaur remains, more than 75 species having been described from the formation. Other reptiles, primitive mammals, fish, invertebrates, and plants have been found in considerable numbers. In the Oklahoma area, among the vertebrates, dinosaurs, crocodiles, turtles, and fish, but no mammals, have been found. Invertebrates, particularly ostracods and small gastropods, have been found. The ostracods appear in considerable numbers although the writer has made only a small collection. The late Dr. Arthur Wedel collected many ostracods in this area; and, in collaboration with Mrs. Betty Kellett Nadeau, was preparing a paper on them at the time of his death. Mrs. Nadeau is completing the paper. She says concerning them:

> "Dr. Wedel collected many thousands of ostracods from the Morrison formation of New Mexico, Oklahoma, and Colorado. Many are beautifully preserved. We found that this fauna consisted of about sixty species of about twenty-five genera, many of the genera and most of the species being new. About half of the ostracod species are found in Oklahoma, where, in certain strata, they occur in great abundance. As in the Pennsylvanian, many of the species occur everywhere in the Morrison and seem to be of little stratigraphic value, while other species, particularly the genus *Metacypris*, appear to be quite significant."[95]

A small collection of invertebrates was made by the writer three-fourths of a mile west of the Si Strong ranch headquarters and in the railroad cut north of Boise City (sec. 28, T. 5 N., R. 5 E.). The forms collected at the latter location were identified by Professor R. W. Harris, of the University of Oklahoma. No attempt is made to describe the new species because of the forthcoming paper by Mrs. Nadeau. The list follows:

TABLE XIII.

INVERTEBRATES AND PLANTS FROM THE MORRISON FORMATION, SEC. 28, T. 5 N., R. 5 E., CIMARRON COUNTY, OKLAHOMA

Chara
- *Chara verticillata*
- *Aclistochara cf lata*

Ostracoda
- *Paracypris simplus*.
- *Paracypris acuminatus*
- *Paracypris* n. sp.
- *Metacypris minnekahtensis*
- *Metacypris pahasapensis*
- *Metacypris* n. sp.
- *Cypridea* n. sp.
- *Bairdiocypris morrisonensis*
- *Bairdiocypris* n. sp.

95. Nadeau, Betty Kellett, personal letter dated April 19, 1942.

Gastropoda
Planorbis veternus
Valvata ? jurassica
Pelecypoda
Vetulonaia whitei

The molluska collected by Dr. Wedel from the Morrison are being studied by Professor R. E. Peck of the Department of Geology and Geography at the University of Missouri. His findings will be published in the near future.

The Morrison plants of the Oklahoma area, in addition to the Chara, consist of small unidentifiable fragments of roots, stems, and a few small leaves.

As elsewhere, the dinosaurs of the Morrison of Cimarron County, Oklahoma, are the most conspicuous fossils of that formation. They were discovered by Pard Collins and Truman Tucker, of Kenton, Oklahoma, in 1931, and reported by the writer in 1938.[96] Since then eight other dinosaur locations have been discovered in the county; and, with federal and state aid, excavation was continuous from 1932 until March 1942. About 6,000 bones have been excavated and prepared. They are now in storage or on exhibition at the University of Oklahoma, Norman. Four genera, *Ceratosaurus* ? Marsh, *Brontosaurus excelsus* Marsh, *Camptosaurus* ? Marsh, and *Stegosaurus* Marsh, were tentatively identified from the first quarry and the report published in 1938.[97] This quarry also yielded two new genera of dinosaurs. One is a small sauropod. The other is a carnivore, almost equalling in size *Tyrannosaurus rex* Osborn, from the Cretaceous of Montana; and because of its great size and because it is the largest carnivore known from the Morrison, this form has been named *Saurophagus maximus*. Detailed descriptions of these two, previously undescribed, forms are in process of preparation.

The later quarrying operations yielded many bones of *Antrodemus* Leidy, *Atlantosaurus* Marsh, *Diplodocus* Marsh, and small unidentified carnivorous dinosaurs. Quarry number 8 yielded small carnivore teeth, two excellent crocodile skulls, probably of

96. Stovall, J. W., "The Morrison of Oklahoma and its Dinosaurs": *Jour. Geol.*, Vol. 46, pp. 596-600, 1938.
97. *Idem.*

the genus *Goniopholis* Owen, many crocodile bones, six chelonians, and many small fish vertebrae, details of which are to be published at a later date.

Correlation. Regional correlations of the Morrison are unnecessary in this paper. That problem has been discussed fully by Baker, Dane, and Reeside,[98] and by others. Rocks assigned to the Morrison in Cimarron County are similar to the continental Morrison at the type locality and other occurrences along the Rocky Mountain front, southeastern Colorado, northeastern New Mexico, and elsewhere. According to Shimer[99] the lower part of the Morrison is the time equivalent of the marine Stump sandstone of Idaho and the marine Malone formation of south Texas. Shimer also correlates the Morrison of the Colorado area with the Unkpapa sandstone and the Morrison formation of the Black Hills area.

Detailed sections. Detailed sections of the Morrison formation may be found in Appendix A of this report. They include numbers 17-23, incl., 30, and 31.

CRETACEOUS SYSTEM

Rock of both Lower and Upper Cretaceous age, equivalent to parts of the Comanche and Gulf series, are exposed in Cimarron County. They are classified as Purgatoire, Dakota, and Graneros-Greenhorn formations. The Cretaceous rocks overlie the Morrison formation (Jurassic), and are in turn overlain by Tertiary and Recent beds.

Lower Cretaceous Series

PURGATOIRE FORMATION

The Purgatoire formation includes lower Cretaceous strata, between the Morrison formation (Jurassic), and the Dakota sand-

98. Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., "Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado": *U. S. Geol. Survey Prof. Paper* 183, pp. 10-31, 1936.
99. Shimer, Hervey W., "Correlation Chart of Geologic Formations of North America": *Bull. Geol. Soc. Amer.*, Vol. 45, Pl. 121, 1934.

stone (upper Cretaceous), and consists of two members: a lower sandstone called Cheyenne; and an upper shale, called Kiowa.

First reference. Stanton, T. W., 1905.

Nomenclator. Stose, G. W., 1912.

Type locality. Purgatoire Canyon, in the Mesa de Maya quadrangle (eastern Las Animas County), Colorado.

Original description. Stose's original description reads, in part:

> ". . . In 1905 Stanton[100] and Lee discovered a marine Comanche fauna in the shales between the two sandstone beds previously called Dakota in the canyons of Purgatoire, Cimarron, and Canadian Rivers southeast of the Apishapa quadrangle, and similar Comanche strata were found by Stanton and the present writer between the Morrison and the upper portion of what had been regarded as the Dakota sandstone in the Apishapa area. Upon this discovery rests the separation of the Purgatoire from the Dakota. The formation takes its name from Purgatoire Canyon, in the Mesa de Maya quadrangle.
>
> "The upper third of the formation is composed largely of shale and minor thin, platy sandstone beds, but the lower two-thirds is almost wholly sandstone. . ."[101]

History of usage. As indicated in the quotation above, the rocks now classified as Purgatoire had formerly been assigned to the Dakota, and the lower member (Cheyenne sandstone of the present report) was called "lower Dakota." Stanton and Lee discovered Comanche fossils in the shale between the "upper" and "lower Dakota", and Stanton concluded:

". . . there is no doubt that the horizon is the equivalent of some part of the Washita group, and should be directly correlated with the Kiowa shales of southern Kansas. It must certainly be removed from the Dakota. The underlying sandstone . . . probably goes with the shales in the Comanche series. . ."[102]

100. Stanton, T. W., "The Morrison Formation and its Relations with the Comanche Series and the Dakota Formation": *Jour. Geol.*, Vol. 13, pp. 657-669, 1905.
101. Stose, G. W., *U. S. Geol. Survey Geol. Atlas, Apishapa (Colorado) Folio,* (No. 186), 1912.
102. Stanton, T. W., *op. cit.*, p. 662.

In 1902, Lee[103] erroneously included in the Morrison, beds exposed in the Oklahoma-New Mexico area, that are now recognized as Purgatoire; and Gould[104] included the Purgatoire in the "Dakota group."

In the course of the investigation on which the 1905 paper was based, Stanton and Lee recognized the true relations of the strata now termed Purgatoire, in the valley of Cimarron River, near the old Garrett post office, (sec. 25, T. 6 N., R. 4 E.)[105]

The application of the term Purgatoire to rocks in Cimarron County was first made by Rothrock,[106] but as already shown, he incorrectly included the Morrison beds in this grouping.

DeFord[107] pointed out that the dark shale and white sandstone of the Purgatoire of the Cimarron County section, respectively correspond to the Kiowa shale and Cheyenne sandstone, of Kansas.

In southern Kansas are two formations that together occupy essentially the same stratigraphic position as the Purgatoire formation. These are the Cheyenne sandstone, below, named from Cheyenne Rock, Belvidere, Kiowa County; and the Kiowa shale, above, named from Kiowa County, Kansas.

Stovall[108] was the first to use Purgatoire, Cheyenne, and Kiowa in the same classification, and considered the Cheyenne and Kiowa as members of the Purgatoire formation, in Cimarron County, Oklahoma. Following his usage, the matter was presented to the U. S. Geological Survey Committee on Geologic Names, in connection with the publication of Oklahoma Geological Survey Bulletin 59, "Geology and Ground Water Resources of Texas County, Oklahoma", by Stuart L. Schoff, 1939.

103. Lee, W. T., "The Morrison Shales of Southern Colorado and Northern New Mexico": *Jour. Geol.*, Vol. 10, pp. 36-58, 1902.
104. Gould, C. N., "Geology and Water Resources of Oklahoma": *U. S. Geol. Survey Water Supply Paper* 148, p. 82, 1905.
105. Stanton, T. W., *op. cit.*, p. 664, 1905.
106. Rothrock, E. P., "Geology of Cimarron County, Oklahoma": *Okla. Geol. Survey Bull.* 34, 1925.
107. DeFord, R. K., "Areal Geology of Cimarron County, Oklahoma": *Bull Amer. Assoc. Petro. Geol.*, Vol. 11, pp. 753-755, 1925.
108. Stovall, J. W., *op. cit.*, p. 587.

In a letter to Robert H. Dott, Schoff stated: "The Committee pointed out that 'Purgatoire' has been recognized as a formation for Colorado and Cimarron County, Oklahoma, and perhaps some other places, but has not been extended to Kansas; and that the Kiowa and Cheyenne are *formation* names in Kansas, and have not been extended to Cimarron County, Oklahoma. In view of the forthcoming Cimarron County report (the present publication), the Committee agreed to extend the Kiowa and Cheyenne into Cimarron County, Oklahoma, as members of the Purgatoire formation—but not into Colorado or into New Mexico. . ."[109]

Distribution. The Purgatoire formation is almost continuously exposed from beyond the New Mexico-Oklahoma state line, eastward to the east part of Tps. 5 and 6 N., R. 5 E. Its outcrop forms a narrow, irregular band, in the bluffs flanking the valley of Cimarron River, and in the valleys of most of its tributaries, at the inner margin of the outcrop of the Dakota sandstone. In most places, the Purgatoire occupies the lower and middle portions of escarpments that are capped by the Dakota.

Thickness and character. The Purgatoire ranges from about 40 feet to 119 feet in thickness.

Cheyenne sandstone member.[110] The Cheyenne sandstone member of the Purgatoire formation overlies the Morrison, unconformably. The Cheyenne is characterized by its white color, and is easily recognized in the lower bluffs of the Cimarron Valley in this area. Its appearance throughout the area is much the same, but differs locally in details of color, thickness, amount and distribution of conglomerates, and in character of bedding. It is locally absent, but where present ranges in thickness to a maximum of 70 feet, with an average of about 35 feet.

Cragin's original description of the Cheyenne at its type locality, except for the brilliant colors and somewhat greater thickness, is generally applicable to the Cimarron County section: "Obliquely laminated, mostly incoherent (rarely hard) sandstone, 20 to 40 feet thick, often gray but in large part gorgeously decorated with crimson, purple, scarlet, orange, yellow, brown, and other colors."

109. Letter dated Washington, D. C., Jan. 1, 1939.
110. Cragin, F. W., "Geological Notes on the Region South of the Great Bend of the Arkansas (Kansas)": *Washburn Coll. Labr. Nat. History Bull.* 2, pp. 33-37, 1889.

The Cheyenne sandstone in Cimarron County is buff to white, coarse-grained, cross-bedded to irregularly bedded, massive-appearing, and generally poorly cemented. It is inclined to weather into fantastic shapes, a feature that it shares with the Dakota. Pl. VIII. The Cheyenne lacks the "foreset" type of cross-bedding common in the Dakota, and in general, is much lighter in color and not so inclined to case-hardening as is the Dakota.

The conglomeratic phases of the Cheyenne sandstone are more common and extensive than has been thought by most writers, though conglomerates probably are not present throughout the area. Rothrock's description of lenses ". . . not more than 5 or 6 feet thick nor 10 to 30 feet long . . ."[111] is misleading, for the writer observed beds of conglomerate in several localities that could be traced laterally for distances of 100 to 700 yards. Generally the conglomerate occurs in a definite zone at or near the base.

In sec. 29, T. 6 N., R. 3 E., there is a 66-foot butte with vertical wall that is composed of buff, friable, irregularly-bedded sandstone and conglomeratic lenses. Material in these lenses ranges in size from very fine sand to 6-inch cobbles. The cobbles are well worn and apparently have been polished by wind blast. The pebbles and cobbles are composed of flint, milky quartz, rose quartz, very fine, black, and green schists, brown quartzite, petrified wood, and limestone; the latter probably from the Morrison. The schists are more abundant in the cobbles than any other rock type. This development of conglomeratic lenses is not characteristic of the Cheyenne in the area as a whole. In this exposure of the Cheyenne there are many fine lines of granular white secondary deposits of calcite. There are also many narrow bands of bright red stain, measuring from a fraction of an inch to 4 inches in width. Numerous vertical joints trending northwest, cut the butte from top to bottom, but no displacement along the joints was observed.

111. Rothrock, E. P., *op. cit.*, p. 42.

South of the Highway 64 bridge at the Oklahoma-New Mexico state line, the conglomerate is exposed for a distance of more than half a mile, and probably continues under a cover of talus from the rocks above. A conglomerate exposed half a mile to the east on the opposite side of the same hill is probably the same bed. Other good exposures of conglomerate are found at Labrier (Tate) Butte (sec. 28, T. 6 N., R. 1 E.), 101 Hill (sec. 18, T. 5 N., R. 2 E.), and on the Kohler ranch north of Boise City. At Tate Butte 1 foot of buff, friable sandstone separates the Morrison from a 9-foot bed of Cheyenne conglomerate. At 101 Hill the conglomerate may be traced laterally for several hundred yards. The conglomerate exposed on the Kohler farm is similar to other exposures already mentioned.

The Cheyenne sandstone contains abundant remnants of petrified logs, including many almost complete tree boles that measure 1 to 2.5 feet in diameter and from 10 to 85 feet in length. The fossil trees are mostly coniferous, with several species represented. They are most abundant near the base, but are present throughout the sandstone. No leaves were discovered in the sandstone member, but fossil wood is present at many localities.

The distribution of the conglomeratic facies, the presence of marine fossils in the probable Cheyenne at Red Point, Texas County, Oklahoma, and elsewhere, suggest deposition under marine conditions for part of the Cheyenne sandstone, and the absence of positive evidence of the work of streams and the wind implies a possible marine origin for the entire member.

In some places, notably northeast of Boise City, the Cheyenne is absent, being overlapped by the Kiowa shale which rests on the Morrison formation. The irregular surface of the Cheyenne and the variable thickness of the overlying Kiowa shale member suggest a slight unconformity at the top of the Cheyenne member.

Kiowa shale member.[112] The upper member of the Purgatoire formation consists of dark gray to black shale weathering buff. In some areas of Cimarron County it is mostly clay shale, particularly in the lower portions, but almost everywhere grades upward into sandy shale, and in the upper part contains platy sandstone, the individual beds of which range from a fraction of an inch to 6 inches in thickness.

112. Cragin, F. W., "Description of Invertebrate Fossils from the Comanche Series in Texas, Kansas, and Indian Territory": *Colo. Coll. Studies, Ann. Publ.* 5, pp. 49-68, 1894.

The shale is locally calcareous, and fossiliferous, and in places, as in the southwest part of T. 5 N., R. 5 E., it contains thin beds of dense, gray limestone, up to 6 inches thick. The fossil zone, which generally occurs in the upper part, locally contains an abundance of *Gryphea* and other Washita forms. (Pl. IXB)

There are several localities where the fossiliferous zone of the Kiowa is well exposed, and where fossils may be studied or collected. Fossils occur on the upper, gentle slopes of Wolf Mountain, in sec. 27, T. 5 N., R. 5 E., east of U. S. Highway 287. Another fossil locality that is readily reached is in the cut of U. S. Highway 64, at 101 Hill, sec. 18, T. 5 N., R. 2 E. On the Kohler ranch, near old Garrett post office, north of Cimarron River in sec. 25, T. 6 N., R. 4 E. is the locality where Lee collected the fossils which he attributed to the Morrison.[113]

The upper sandstone phase is irregularly bedded, generally brown in color on weathered surfaces, but is cream to yellow and buff on fresh surfaces. (Pl. IXA). In nearly all exposures, it is marked with vermillion, purple, and dark-brown splotches on bedding planes and in fractures. The sandstones are generally hard and brittle, but are friable in some places. The uppermost portion of the Kiowa shows slight, local channeling, into which the irregular basal beds of the overlying Dakota sandstone have been deposited. Such a relationship is well shown at the head of Bingaman Canyon in sec. 33, T. 6 N., R. 2 E.

The Kiowa shale crops out in a relatively narrow, irregular band, at the inner margin of the Dakota sandstone, in the valleys of Cimarron River and its tributaries. In the deeper portions of the canyons it forms talus slopes a few rods wide between the Cheyenne and Dakota sandstones. In some areas, notably in T. 5 N., Rs. 3 and 4 E., such a talus slope spreads gently toward

113. Lee, W. T., *op. cit.*

the stream valleys and is over a mile wide in several places. The Kiowa shale occurs in the upper gentle slopes of all the buttes that are still capped with Dakota. One such occurrence is at Wolf Mountain in sec. 27, T. 5 N., R. 5 E., where the Cheyenne sandstone is absent, and the Kiowa rests on beds of the Morrison formation.

The maximum measured thickness of the Kiowa is 49 feet in sec. 27, T. 6 N., R. 1 E. Here the lower 42 feet is shale, and the upper 7 feet is platy sandstone. Elsewhere the shale thins to 12 feet and the sandstone division is from 2 to 12 feet thick. However, the log of well number 376 of this report, located at the Donley ranch headquarters, sec. 8, T. 4 N., R. 4 E., shows 63 feet of dark colored shale which is interpreted as being Kiowa. In test wells of the Santa Fe Railway at Felt, Oklahoma, near the southern boundary of the county (sec. 12, T. 1 N., R. 2 E.), 20 to 59 feet of Kiowa were encountered, but as each well stopped in the Kiowa, its true thickness could not be determined. Known thickness of the Kiowa, including subsurface measurements, ranges from 15 to 63 feet in Cimarron County. At least part of this variation appears to be due to an irregular surface on the underlying Cheyenne sandstone.

The Kiowa shale is marine in origin, probably representing off-shore deposition of a retreating sea.

Stratigraphic relations. The Purgatoire is underlain unconformably, and locally with considerable angularity, by the Morrison formation (Jurassic). In SW¼ sec. 2, T. 5 N., R. 1 E., the Cheyenne is in contact with the uppermost Morrison beds of the region, thought to be 467 feet above the base, whereas in the Labrier (Tate) Butte section (sec. 29, T. 6 N., R. 1 E.), 3.5 miles northwest, it rests on beds that are only 158 feet above the base of the Morrison, and in the area north of Boise City, the Morrison is estimated as 75 feet thick, and the Cheyenne sandstone is generally absent. The discordance in dip may be seen plainly in the escarpments east of Black Mesa, north of Kenton. This relationship indicates uplift and truncation, prior to deposition of the Purgatoire.

Evidence of a slight unconformity between the Cheyenne and Kiowa members has already been cited.

The Purgatoire is overlain by the Dakota sandstone. Slight local channeling in the Kiowa shale member indicates a disconformity between the Purgatoire and Dakota. The sandstones in the upper Kiowa may be mistaken for lower Dakota sandstone, but the Kiowa sandstones are distinctive in character, and in the head of Bingaman canyon (sec. 33, T. 6 N., R. 2 E.) channels in the Kiowa sandstones are filled with unquestionable Dakota material. This disconformity is of local, rather than regional prominence, despite the fact that paleontologic evidence places a series boundary here.

Correlations. The correlation of the Purgatoire of Cimarron County with the Purgatoire of the type locality in southeastern Colorado, is established beyond little question. Furthermore, correlation of the Cheyenne sandstone and Kiowa shale members of the Purgatoire in Cimarron County with the Cheyenne sandstone and Kiowa shale formations of Kiowa County, Kansas, is generally accepted.

Although containing much petrified wood, leaves from the Cheyenne sandstone have not been identified, nor has it yielded invertebrate fossils, in Cimarron County. However, blocks of sandstone near Red Point, Texas County, that are probably remnants of a former Cheyenne outcrop, contain numerous casts of fossils of undoubted Washita age.[114]

Fossils in the Kiowa were recognized as of Washita (upper Comanche) age by Stanton in 1905. After collecting from the area near the old Garrett post office, he stated: "The Comanche horizon has yielded a varied fauna which is clearly the same as the Washita fauna that has long been known at Mesa Tucumcari, New Mexico, in northern Texas, and in the Kiowa shales of southern Kansas."[115]

114. Bullard, Fred M., "Lower Cretaceous of Western Oklahoma": *Okla. Geol. Survey Bull.* 47, pp. 90-92, 1928.
Schoff, S. L., "Geology and Ground Water Resources of Texas County, Oklahoma": *Okla. Geol. Survey Bull.* 59, pp. 54-57, 1939.
115. Stanton, T. W., *op. cit.*, p. 664.

Bullard summarized the information on the correlation of the Kiowa shale member:

> "This fauna (Oklahoma Panhandle) differs however from that of the Kiowa shale (Kansas) in one important respect. The Kiowa shale (Kansas) is correlated with the Kiamichi formation of southern Oklahoma and northern Texas, but the Purgatoire shale (Kiowa, Oklahoma Panhandle) carries in addition to the Kiamichi fauna species which are characteristic of the overlying formation, the Duck Creek. The characteristic Duck Creek species listed above are: *Pachydiscus brazoensis* (Shumard), *Hamites fremonti* Marcou, and *Inoceramus comancheanus* Cragin. It appears, therefore, that the Purgatoire (Kiowa, Oklahoma Panhandle) represents the Kiowa shale of Kansas and in the Texas section is represented by the Kiamichi clay and at least the basal portion of the Duck Creek."

Stanton published the first list of fossils from the Kiowa shale of Cimarron County. The fossils were collected from several places, but principally from "East of Garrett P. O." This place is about 2 miles north of the present Garrett School, and is situated on the north side of Cimarron River about 4 miles west of U. S. Highway 287, in sec. 25, T. 6 N., R. 4 E. Although collections of fossils have been obtained from the Kiowa shale in this area since Stanton published his list, neither Rothrock,[116] Bullard,[117] nor the present writer has discovered any additional species. Stanton's list follows:

Gryphaea corrugata
Ostrea subovata
Ostrea quadriplicata
Plicatula incongrua
Inoceramus comancheanus
Gervilliopsis invaginata
Trigonia emoryi
Protocardia multilineata
Pholadomya sancti-sabae
Anchura kiowana
Turritella seriatim-granulata
Hamites fremonti
Pachydiscus brazoensis

The fossiliferous Mentor beds, described and named by Cragin[118] from exposures in Salina and McPherson Counties, central Kansas, contain an upper Comanche fauna similar to that of the Kiowa shale of southern Kansas. The exact stratigraphic relations

116. Rothrock, E. P., *op. cit.*
117. Bullard, F. M., *op. cit.*
118. Cragin, F. W., "The Mentor Beds, a Central Kansas Terrane of the Comanche Series": *Amer. Geol.*, Vol. 16, pp. 162-165, 1895.

are not definitely established, but the Mentor beds are generally thought to be equivalent to part or all of the Kiowa.

At the base of the Kiowa shale in the type area is an oyster bed to which Cragin[119] gave the name "Champion shell bed," and which has been successively excluded from and included with the Kiowa by various writers. In the lower part of the Kiowa in Cimarron County is a zone of rather well compacted *Gryphaea* that may correspond to the Champion bed.

Detailed Sections. Detailed sections of the Cheyenne and Kiowa members of the Purgatoire may be found in Appendix A. Those of the Cheyenne include numbers 17-20, incl., 23, 30, and 31; of the Kiowa, numbers 1, 17-19, incl., 23, 24, 30, and 31.

Upper Cretaceous Series

DAKOTA SANDSTONE

The term Dakota is applied in Cimarron County to those sediments, principally sandstone, lying above the Kiowa shale member of the Purgatoire formation, and below the Graneros shale; or where the Graneros has been removed by erosion, below Tertiary and Quaternary rocks. The Dakota thus is the lowest formation of the Upper Cretaceous series; and the base of the Dakota is the contact, in this area, of the Upper and Lower Cretaceous series.

The Dakota is conspicuous, and easily recognized in the bluffs along the valley of Cimarron River and its main tributaries, in the northwestern part of Cimarron County, being the upper of two massive sandstone beds that are very prominent features of the landscape. The Cheyenne sandstone member of the Purgatoire formation is the lower, and is separated by 12 to 50 feet of Kiowa shale from the Dakota, which generally caps the bluffs, and is the rimrock of this picturesque canyon area. The Dakota also is exposed in the southwestern part of the county, along North Canadian River (Currumpa Creek) and its main tributary, Cieneguilla (Seneca) Creek.

119. Cragin, F. W., "A Study of the Belvidere Beds": *Amer. Geol.*, Vol. 16, pp. 358-371, 1895.

The Dakota is widely distributed in the Great Plains and in the foothills of the Rockies. It has been the subject of much study and many excellent geological reports during the past 80 years, despite which it still presents many local and regional problems. There is no unanimity of opinion as to its exact age or proper rank.

Throughout the vast region of Dakota outcrops, the Dakota sandstone is an integral part of a sequence of strata that are essentially similar to the Purgatoire-Dakota sequence of Cimarron County, and include beds of both late Lower Cretaceous and early Upper Cretaceous age. As a consequence, some geologists have included all these strata in the "Dakota", and have variously referred to the unit as "series", "group", "stage", and "formation"; whereas others have restricted the term to beds of Upper Cretaceous age; and still others have gone so far as to exclude Upper Cretaceous rocks, holding that the Dakota of the type locality is wholly Lower Cretaceous.

The problem of classifying the Cretaceous rocks of Cimarron County is ideally simple. The Purgatoire formation has definite upper and lower boundaries, and the upper member, the Kiowa shale, contains an abundant fauna of definite Washita (upper Comanche) age. Both lithologically and paleontologically, the Dakota in this area is a distinct, and easily-recognized stratigraphic unit, with well-marked upper and lower contacts, and is obviously entitled to formation rank.

It is recognized that the problems of stratigraphy, classification, terminology, and correlation of the Dakota in various parts of the Great Plains and the Rocky Mountain front, bear on possible future usage in Cimarron County. Except that some previous writers have included the overlying Graneros-Greenhorn, the term Dakota has been used in this area in its present sense for many years, and it is deemed expedient to continue to restrict the designation Dakota to the sandstone and shale at the base of the Gulf series, in this area.

First reference. Meek, F. B., and Hayden, F. V., 1862 (Designated "Formation No. 1" in 1857)[120]

Nomenclators. Meek and Hayden.

Type Locality. Bluffs of the Missouri River southwest of Dakota City, Dakota County, Nebraska.

Original description.

"Yellowish, reddish and occasionally white sandstone, with at places, alternations of various colored clays and beds and seams of impure lignite. Also silicified wood, and great numbers of leaves of the higher types of dicotyledonous trees; with casts of *Pharella? Dakotensis, Axinaea Siouxensis,* and *Cyprina arenarea.*"[121]

History of Usage. The restriction of the term Dakota to its present use, as applied to rocks in the southeastern Colorado-northeastern New Mexico-Oklahoma panhandle region, has been summarized in the foregoing discussion of the Purgatoire formation. Tester[122] carefully reviewed all the published literature dealing with the Dakota of the central Great Plains, beginning with the Journals of Lewis and Clark, 1804-1806, and presents a detailed re-study of the exposures of the type area. He concludes that the visible Cretaceous strata beneath the Graneros, in that area, should be grouped in the Dakota "stage".

Both Gould and Stanton recorded Dakota sandstone in what is now Cimarron County, in 1905. Gould included as Dakota, all strata between the red beds (now considered Dockum) and beds of Tertiary age, in a graphic section of Black Mesa, but he also mentioned, under a discussion headed "Comanche series (Lower Cretaceous)" that " . . . in the extreme northwestern part of Beaver (now Cimarron) County a series of clays containing typical Cretaceous fossils, *Gryphaea, Exogyra, Ammonites,* etc.,

120. Meek, F. B., and Hayden, F. V., "Descriptions of New Species and Genera of Fossils, Collected by Dr. F. V. Hayden in Nebraska Territory": *Acad. Nat. Sci. of Philadelphia Proc. for* 1857, pp. 117-148, 1857.
121. Meek, F. B., and Hayden, F. V., "Descriptions of New Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary Fossils, Collected in Nebraska Territory, with Some Remarks on the Rocks from Which They Were Obtained": *Nat. Sci. Acad. Philadelphia Proc. for* 1861, Vol. 13, p. 419, bound 1862.
122. Tester, A. C., "The Dakota Stage of the Type Locality": *Iowa Geol. Survey,* Vol. 35, Ann. Report, 1929, pp. 195-332, 1931.

are found lying conformably below the Dakota sandstone".[123] In a generalized section of the area near old Garrett post office (sec. 25, T. 6 N., R. 4 E.), Stanton specifically placed the Dakota sandstone above "dark shales . . . . . with Comanche fauna".[124]

The next, and most comprehensive study of the area was made by Rothrock, who was of the opinion that the ". . . . . term Dakota should be restricted to the sandstone beds above the shale carrying the Comanche fauna". (Kiowa).[125] He so mapped it, but erroneously included the Graneros-Greenhorn in the Dakota. DeFord[126] pointed out this, and other errors, in Rothrock's report and suggested a restudy of the area. Six[127] placed the Dakota above the Morrison. Other writers have assigned the beds above the Purgatoire formation and beneath the Tertiary in Union County, New Mexico, to the Dakota. Notable among these are Darton[128] and Parker.[129] In 1937 the writer[130] described the Dakota as a formation overlying the Kiowa shale and underlying Graneros (Colorado) and Tertiary rocks, a practice followed in this paper.

Distribution. The Dakota is the most widespread Mesozoic formation in Cimarron County. It is exposed around the older formations and extends from beyond the New Mexico and Colorado state lines, eastward for a distance of 27 miles and southward for a distance of about 19 miles. The southern limits of the largest area of outcrop are marked by the contact with the Tertiary.

123. Gould, C. N., "Geology and Water Resources of Oklahoma": *U. S. Geol. Survery Water Supply Paper* 148, p. 78, 1905.
124. Stanton, T. W., "The Morrison Formations and its Relations with the Comanche Series and the Dakota Formation": *Jour. Geol.*, Vol. 13, p. 664, 1905.
125. Rothrock, E. P., "Geology of Cimarron County, Oklahoma": *Okla. Geol. Survey Bull.* 34, p. 49, 1925.
126. DeFord, R. K., "Areal Geology of Cimarron County, Oklahoma": *Bull. Amer. Assoc. Petro. Geol.*, Vol. 11, pp. 753-755, 1927.
127. Six, R. L., "Oil and Gas in Oklahoma: Beaver, Texas, and Cimarron Counties": *Okla. Geol. Survey Bull.* 40, Vol. II, pp. 479-490, 1930. Also published as *Bull.* 40-WW.
128. Darton, N. H., "'Red Beds' and Associated Formations in New Mexico": *U. S. Geol. Survey Bull.* 794, p. 306, 1928.
129. Parker, Ben H., "Clastic Plugs and Dikes of the Cimarron Valley, New Mexico": *Jour. Geol.*, Vol. 41, p. 40, 1933. See also: *Kansas Geol. Soc. Guidebook*, 4th *Ann. Field Conf.*, 1930.
130. Stovall, J. W., "The Morrison of Oklahoma and its Dinosaurs": *Jour. Geol.*, Vol. 46, pp. 586-588, 1938.

There are four small exposures in the southwestern part of the county. The largest two of these extend along the North Canadian River (Currumpa Creek) from sec. 15, T. 2 N., R. 1 E., to sec. 31, T. 2 N., R. 2 E., and along Cieneguilla Creek from secs. 1 to 8, T. 1 N., R. 1 E. (Pl. X). A small exposure occurs on the North Canadian River, in secs. 13 and 24, T. 2 N., R. 3 E., and in sec. 19, T. 2 N., R. 4 E., east and west of the A. T. & S. F. railroad bridge. The fourth and smallest exposure is on Dove's Ranch, near the south line of the county in sec. 32, T. 1 N., R. 3 E.

Thickness. The Dakota underlies the surface of much of the area of Mesozoic exposures in Cimarron County, and owing to removal of the upper part of the Dakota in most of the area, complete thickness of the formation cannot be measured at any one outcrop.

The maximum complete thickness of the formation determined by the writer in Cimarron County is 185 feet in T. 4 N., R. 1 E. The traverse along which the measurement was made begins near the John Regnier ranch headquarters in the W½ sec. 9, where the base of the Dakota is well exposed, and from there up Tesesquite Creek, across secs. 8, 17, and 20, to the SW¼ sec. 21, where the top of the Dakota may be seen in some outliers capped by Graneros-Greenhorn.

Other writers have reported from 115 to 315 feet of Dakota in this area, but these measurements failed to include all the Dakota, or included formations other than Dakota. Stanton[131] observed a few square miles in the neighborhood of the Strong ranch (T. 5 N., R. 4 E.) and reported a thickness of 150 feet of Dakota, which seems excessive for that locality. Gould[132] reported 315 feet for the Dakota in Black Mesa, but included all Jurassic and Lower Cretaceous formations in his measurements and here the upper Dakota is missing. Rothrock[133] reported a maximum thickness of 115 feet of Dakota, measured in the bluffs in sec. 4 and 9, T. 5 N., R. 4 E. This measurement represents

131. Stanton, T. W., *op. cit.*
132. Gould, C. N., *op. cit.*
133. Rothrock, E. P., *op. cit.*

the maximum thickness of the lower, massive Dakota sandstone in that locality, but here again, the upper beds are missing.

Character. The Dakota is composed of three lithologic phases, a lower sandstone, middle shale, and upper sandstone, which are distinct enough to class as members. Owing to the limited areal distribution of the middle and upper parts in Cimarron County, formal member names are not deemed necessary or advisable in this report. The lower part is dominantly buff, crossbedded sandstone, that crops out in massive, wall-like ledges that cap most of the bluffs of the canyons of Cimarron River and its tributaries. Locally it is only 15 feet thick, due, in part at least, to erosion, and the maximum thickness, as stated above, is 115 feet. (Pl. X).

The middle and upper parts have been removed from most of the area, and are exposed only in T. 4 N., R. 1 E., but are probably present, though covered, in the northwest part of T. 4 N., R. 2 E., the southeast part of T. 5 N., R. 2 E., and the west-central part of T. 5 N., R. 3 E., in the area northwest of the outcrops of the Graneros-Greenhorn formation. The middle part is dominantly gray shale, with a thickness of 47 feet; and the upper part consists of 53 feet of sandstone that closely resembles the lower member.

The lower sandstone is normally buff in color, but may range from white, through cream, buff, red, or gray, to black. It is dominantly fine-grained, locally conglomeratic, contains some argillaceous material, and is conspicuously cross-bedded. All its characters vary from one locality to another.

Cross bedding is the most conspicuous feature of the sandstones of the Dakota, in Cimarron County. Part of the cross bedding is irregular, and part is of the foreset type. The foreset beds are not deltaic, as neither topset nor bottomset beds are present, but rather, they are in groups of inclined beds separated by horizontal layers less than 0.1 foot thick. The beds in each group are inclined at angles of 15 to 25 degrees, in a generally southerly direction, and the separating horizontal layers are from 0.2 to 1.5 feet apart, the average distance being 0.5 to 0.7 foot. This type

of bedding is common throughout the lower sandstone of the Dakota in Cimarron County, and is well shown along U. S. Highway 64, a few miles east of Kenton.

Similar bedding is common in Dakota outcrops in Kansas, Nebraska, Iowa, and Colorado. Many investigators have interpreted these cross beds as channel filling, and Tester[134] believes that the thin, horizontal strata separating the groups of inclined beds represent truncation planes in a deltaic deposit. The writer cannot subscribe to such an interpretation, but believes the nature of the cross bedding more closely resembles the sub-aqueous dunes described by Evans.[135]

Massive beds are not common in the lower Dakota sandstone, and such as are present do not exceed 3 to 4 feet in thickness, and are restricted to the lower part. In some bluffs, recently exposed to weathering, notably on Currumpa Creek, bedding planes may be inconspicuous, giving the sandstone an appearance of great massiveness. (Pl. X B). In a few such outcrops, definite bedding may be found at the same horizon in nearby parts of the exposure where weathering has progressed farther.

In general, bedding consists of layers ranging from thin laminae to 0.5 foot thick. An excellent exposure in the railroad cut in sec. 9, T. 4 N., R. 5 E. shows the lower Dakota with an unusual, even-bedded character, but exemplifies the normal thinness of the bedding. Individual layers generally are less than 0.1 foot thick, and few of them exceed 0.2 foot.

The sandstone is dominantly composed of fine quartz grains, which are subangular to well rounded. Many of the grains show secondary enlargement due to deposition of silica, producing minute crystal faces, and euhedral quartz crystals. A few grains of apatite and rutile inclusions are found in the grains of sand. Size analyses made in the laboratory of the Oklahoma Geological Survey show 61 to 68 percent of grains between ⅛ and ¼ millimeter. For most samples, less than 1 percent exceeds 1 millimeter. The sand

134. Tester, A. C., *op. cit.*
135. Evans, O. F., "The Ball and Low of the Eastern Shore of Lake Michigan": *Jour. Geol.*, Vol. 48, p. 497, 1940.

is well sorted, only about 6 grain sizes being represented in an average sample.

Other local variations in the lithology of the lower Dakota are high iron content, and quarzitic character. Local cementation of individual layers by iron oxide is a rather common feature, but in Black Mountain, (not to be confused with Black Mesa), sec. 24, T. 6 N., R. 2 E., on the Willson ranch, the iron content of the sandstone is so great that from a short distance the Dakota resembles lava. The sandstone is thoroughly cemented with iron oxide to an unknown depth, but the black phase is limited laterally to less than half a mile.

About 1 mile southeast of Black Mountain, in sec. 30, T. 6 N., R. 3 E., a small isolated butte is capped by red, quartzitic sandstone. Here as elsewhere, the quartzitic character is most pronounced in strata near the top of the lower sandstone of the Dakota. A similar quartzitic phase may be seen on the Strong Ranch, sec. 18, T. 5 N., R. 5 E., where the rock is pink in color, and there are other exposures in the area in which the lower Dakota is pink or red, and quartzitic. Considerable argillaceous material, and a few beds of shale are present locally in this sandstone.

A bed of conglomeratic sandstone, 3.7 feet thick, is present 1 foot below the top of the lower Dakota sandstone as exposed in the railroad cut in sec. 33, T. 5 N., R. 5 E. The sandstone is red to brown, and contains pebbles up to 1 inch in diameter composed predominantly of quartzite.

The conspicuous physiographic expression of the lower Dakota as the cap rock of the canyon walls and buttes has already been described. Equally striking are the fantastic columns, generally capped by a hard, somewhat ferruginous layer of sandstone that has been carved by the combined action of wind and rain. Some of these features are landmarks, and have received names that are well known throughout the region. At Old Maid Gap, on U. S. Highway 64, sec. 16, T. 5 N., R. 2 E., a rough image of a human head has been named the "Old Maid" because of its resemblance to a rather sharp-featured, female person. South of U. S. Highway 64 in sec. 18, T. 5 N., R. 2 E., are three columns

called "Three Sisters." (Pl. XI). These particular features have been carved from the lower member of the Dakota, but similar ones are common in the upper member, as well.

The middle part of the Dakota consists mostly of shale which is 47 feet thick in the only place where satisfactory measurement could be made. This part of the Dakota is exposed in T. 4 N., R. 1 E., near the headwaters of Tesesquite and South Carrizo Creeks, and is probably present in the area extending about 12 miles to the northeast. At, or shortly above the base is a bed of lignite from 0.5 to 1.5 feet thick, and in a few places of sufficient purity to serve as a poor grade of fuel. Several pits or mines have been driven horizontally into this "coal", the largest of the drifts being located in secs. 19 and 20, T. 4 N., R. 1 E. A pit on the Will Baker homestead, sec. 33, T. 4 N., R. 1 E., exposes the lignite which is here about 1.0 foot thick, and contains a large amount of shale, and thin sand lenses. A better grade of lignite, 1.5 feet thick, is mined by C. A. Kirtley along South Carrizo Creek in sec. 5, T. 3 N., R. 1 E., and sec. 32, T. 4 N., R. 1 E., and used as fuel.

Above the lignite is 27 feet of gray, sandy shale, with several beds of bentonite, 0.5 to 0.8 foot thick. The overlying 19 feet of buff shale contains, near the bottom, a bed of fine-grained, dark brown sandstone, averaging 0.1 foot thick, that is cemented with iron oxide on the upper surface and along joint planes, producing rectangular blocks or pans that are used locally for ash trays.

Interbedded with the upper portion of this middle Dakota shale are several irregular, lenticular layers of brown, ferruginous sandstone that contain spherical concretions of iron-cemented sands that average 0.1 foot in diameter, but range up to 0.3 foot. They are cemented together in masses or are attached to the upper surfaces of thin beds of sandstone. Owing to the iron cement, these concretions are resistant to weathering, and form pebbles on the upland slopes.

Above the middle shale is 53 feet of buff, cross-bedded, conglomeratic sandstone that closely resembles the lower sandstone of the Dakota, and may be mistaken for it. Most of the remarks about the lower sandstone member apply equally to the upper.

It is exposed only in the central part of T. 4 N., R. 1 E., but is present in the 12 miles to the eastward below and north of the outcrops of the Graneros-Greenhorn formation.

Considerable discussion has appeared in the literature in attempts to account for the origin of the Dakota sandstone, and many theories have been presented. Twenhofel and Tester[136] have contended that the Dakota of Kansas and Nebraska represents the deposits of streams, probably under deltaic conditions, and that the sandstones are largely channel fillings. The most recent suggestion is by Plummer and Romary[137], who studied the Dakota formation in north-central Kansas, by test-pitting and sampling, primarily to determine the occurrence and ceramic properties of clay deposits. They found the Dakota to be largely clay, with lenticular sandstones, and concluded that the material is of non-marine origin, deposited on flats not far above sea level.

Evidence from exposures in the Cimarron valley of Oklahoma and adjacent New Mexico—principally the types of cross-bedding, the high degree of sorting of the sand grains, the presence of gravels and of marine fossils—leads the writer to suggest that the sandstone of the Dakota of this area, at least, was deposited in flat-bottomed, protected arms of the sea.

The close resemblance of the cross-bedding in the Dakota of Cimarron County, to subaqueous deposits being laid down at the present time in Lake Michigan and inland lakes of Michigan, suggests a similar origin. Evans[138] has observed and described the formation of subaqueous "dunes", by a process similar to the formation of subaerial dunes. The sand is swept forward by currents, to form the counter-part of a subaerial dune except that the stoss side is almost horizontal, and the lee side is steep, corresponding to the angle of repose of sand under water. The protected condition prevents destruction of the sets of beds before another set is laid down. There is thus produced a series of cross-beds of uni-

136. Tester, A. C., *op. cit.*
Twenhofel, W. H., "The Geology and Invertebrate Paleontology of the Comanchean and 'Dakota' Formations of Kansas": *State Geol. Survey of Kans. Bull.* 9, p. 40, 1924.
137. Plummer, Norman, and Romary, J. F., "Stratigraphy of the Pre-Greenhorn Cretaceous Beds of Kansas": in *State Geol. Survey of Kans. Bull.* 41, pp. 313-348, 1942.
138. Evans, O. F., *op. cit.*

form dip and varying thickness, but without topset and bottomset beds. Evans visited Cimarron County in company with the writer, and commented on the similarity of structure.

It has been suggested, largely on the evidence of fossil plants, that the Dakota is of fresh-water origin. The presence of so many well-preserved leaves of land plants, especially trees, in the formation, neither confirms nor denies its fresh water origin, the only requisite for their preservation being that the leaves came to rest quickly in quiet water.

A high degree of sorting, and conglomerate, may occur in fresh-water lake deposits, as well as in marine; but the great areal extent of the Dakota and its correlatives suggest an epicontinental sea as a more likely alternative environment. The presence of marine fossils supports such a conclusion.

Fossils. Well-preserved imprints of fossil angiosperm leaves are common in lower member of the Dakota sandstone, and have been collected from several places, notably near the east end of Black Mesa, sec. 33, T. 6 N., R. 1 E.; west of the old townsite of Mineral, sec. 14, T. 4 N., R. 1 E.; 2 miles southwest of the old Brown Ranch, sec. 2, T. 3 N., R. 1 E.; and in sec. 24, T. 6 N., R. 2 E. Petrified logs had not been previously reported from the Dakota, but two were found by the writer in secs. 9, T. 5 N., R. 4 E., and 33, T. 6 N., R. 4 E.

Noe[139] figures and describes 6 identified species of plant leaves, 3 unidentified plant stems, and 1 unidentified seed impression, from the lower Dakota of this area. Of the lot, only one is monocotyledonous.

NOE'S LIST OF FIGURED SPECIES[140]

- Angiosperms
  - Monocotyledons
    - Alismophyllum victor-masoni
  - Dicotyledons
    - Salix flexuosa,
    - Quercus groenlandica,
    - Platanus guillelmae,
    - Sterculia snowii,
    - Sterculia mucronata,
    - Unidentified Branches
    - Unidentified Seeds

139. Noe, A. C., see Rothrock, E. P., *op. cit.*, pp. 93-107, 1925.
140. *Idem.*, p. 94.

A sandstone member in sec. 26, T. 4 N., R. 1 E. contains many casts of invertebrates and the middle shale member contains both casts and some poorly preserved tests. At the only location (secs. 4 and 9, T. 4 N., R. 5 E.) where identifiable specimens were found, 9 species were collected. No new species were discovered and only 2 forms—*Arcopagella mactroides* and *Corbula* (species unidentified) are new to the Dakota. The following table shows species of marine invertebrates collected from the Dakota in Kansas, Nebraska, Iowa, and Oklahoma.

DAKOTA FAUNA

	"Dakota" of Authors Kan.	Neb.	Ia.	Dakota of this Report Okla.
Arcopagella? macrodonta	X	X	X	
Arcopagella mactroides				X
Barbatia parallela		X	X	
Cardium? kansasense		X	X	
Crassatellina oblonga		X	X	
Corbicula? nucalis		X	X	
Corbicula? subtrigonalis		X	X	
Corbula (unidt. species)				X
Cyrena dakotensis	X			X
Leptosolen conradi		X	X	X
Mactra siouxensis	X			X
Margarita mudgeana	X			X
Margaritina nebrascensis	X	X	X	
Mesalia? kansasensis		X	X	
Ostrea (unidt. species)		X	X	X
Pharella? dakotensis	X	X	X	
Protocardia salinaensis		X	X	
Tellina subscitula		X	X	X
Trigonarca salinaensis		X	X	
Trigonarca siouxensis	X			
Yoldia microdonta		X	X	X

Number of genera: 18
Number of species: 21

Several fragmentary fish remains have been collected from the lower sandstone member of the Dakota 1 mile south of Kenton, Oklahoma.. They are about 7 inches in length but have not been identified as yet beyond the fact that they are Teleosts. The specimens were almost all badly damaged by local boys who collected them.

Stratigraphic relations. The Dakota is disconformable above the Kiowa shale member of the Purgatoire, and probably conformable beneath the Graneros shale and younger rocks in the Cimarron County area. There is, everywhere, an abrupt break between the Kiowa shale and Dakota sandstone although the upper few feet of the Kiowa is thin-bedded sandstone. The upper surface of the Kiowa is irregular and commonly channeled to depths of 10 to 25 feet. These channels may be seen in the upper end of Bingaman Canyon (sec. 33, T. 6 N., R. 2 E.) and in canyons to the west, on the north side of Cimarron River. The irregular surface and channeling clearly points to a pre-Dakota erosion interval.

Outcrops of uppermost Dakota and lowermost Graneros beds are limited to a few square miles in this area, and the exact Dakota-Graneros contact is not exposed, but can be determined within 5 or 10 feet. It is, therefore, impossible to determine whether the Dakota is unconformable beneath the Graneros, as it is reported to be in other areas. The Graneros-Greenhorn formation has been removed from most of the area and in general the Dakota is unconformably overlain by rocks of Tertiary (probably Middle Pliocene), Quaternary, and Recent age. The upper surface of the Dakota was channeled in pre-Tertiary time. Examples may be seen in the railroad cut north of Boise City in sec. 4, T. 4 N., R. 5 E. These channels are now filled with Tertiary sediments consisting of alternating beds of sand, clay and caliche.

Correlation. It is now generally agreed that the Dakota in Cimarron County is of Upper Cretaceous age, occupies a position at the base of the Upper Cretaceous series, rests on rocks of the unquestioned Lower Cretaceous (Washita) age, and underlies rocks that are correlated with the Graneros formation.

Regardless of the merits and outcome of the controversy over the classification and age of the "Dakota" (in its broadest sense) in Kansas, Nebraska, and Iowa, the Dakota of Cimarron County is equivalent at least to the upper portion of that sequence—to beds variously called Solomon sandstone, Cockrum sandstone, and by other local names.

The Dakota of Cimarron County occupies the same position in the section as the Woodbine sandstone of Texas, and is equivalent to that formation.

Measured Sections. For detailed sections of the Dakota, see measured sections numbered 1, 13, 16-19, 23, 24, 30 and 31, in Appendix A.

Colorado Group

Graneros-Greenhorn Beds. In Cimarron County the youngest Cretaceous rocks, lying above the Dakota sandstone and below the Tertiary-Quaternary overlap, are regarded as equivalent to the Graneros shale and the Greenhorn limestone formations of the Colorado group. As now defined by the U. S. Geological Survey (Wilmarth)[141], the Colorado Group includes the Benton and Niobrara groups of older usage. The Graneros shale is regarded as lower Benton, and therefore is the basal formation of the Colorado group. The Greenhorn limestone lies above the Graneros, and is middle Benton.

The Graneros and Greenhorn beds are difficult to separate in Cimarron County, and use of the broader term Colorado group may be more convenient in this area.

First reference. Gilbert, G. K., 1896. Referred to both Graneros and Greenhorn.

Nomenclator. Gilbert, 1896. Named both Graneros and Greenhorn.

Type localities. Graneros Creek, Walsenburg quadrangle, southwestern Pueblo County, Colorado. Name suggested by R. C. Hills for excellent development along Graneros Creek.

141. Wilmarth, M. Grace, "Lexicon of Geologic Names of the United States": *U. S. Geol. Survey Bull.* 896, Pt. 1, p. 492, 1938.

Town of Greenhorn and Greenhorn Creek, southwestern Pueblo County, Colorado.

Original descriptions. For the Graneros shale:

"It is characteristically a laminated, argillaceous, or clayey shale with very little admixture of limy or sandy material. Where the shale has not been acted upon by the weather it shows little tendency to split, and its lamination appears chiefly as a delicate marking on the surface. Brief exposures to the weather causes it to divide into thin flakes (laminae), and prolonged weathering reduces it to clay. The middle third of the formation is dark gray, and thin bands of it are nearly black, as though highly bituminous. The upper and lower parts are medium gray. At various horizons, especially in the lower part, are thin beds of white, structureless clay, resembling in appearance the fire clays which underlie coal seams, but a test shows that they have not the refractory property of fire clays. At various levels and localities are rows of calcareous concretions, and one of these rows, from 20 to 30 feet above the base of the formation, changes in certain districts into a layer of dark-gray limestone, with a maximum thickness of about a foot, which acquires by weathering a surface of bright orange. There are also, especially in the eastern part of the district, a few thin calcareous layers containing many fossil shells of small oysters. Twenty or thirty feet below the top of the formation is a rather persistent sandy limestone, only 1 to 3 inches thick, and this also contains fossils."[142]

For the Greenhorn formation:

"It contains strata of limestone, from 3 to 12 inches thick, separated by somewhat thicker shale beds. * * The limestone is pale bluish-gray, fine grained and compact. Where exposed to the weather most of the beds are divided by vertical approximately parallel seams into plates from one-fourth of an inch to 1 or 2 inches in thickness. Of the thicker beds there is only one near the bottom of the series, which does not exhibit this vertical structure. The shales have a light-gray color, are laminated, and contain more lime than do those of the formations above and below. Among them are a few bands of white clay, like that mentioned as occuring in the Graneros shale."[143]

History of Usage. Early writers on Cimarron County, including Rothrock,[144] grouped the youngest Cretaceous rocks with the Dakota, and DeFord[145] was first to point out the presence of "Ben-

142. Gilbert, G. K., "The Underground Water of the Arkansas Valley in Eastern Colorado": *U. S. Geol. Survey* 17th *Ann. Rept.*, Pt. 2, p. 564, 1896.
143. *Idem.*, p. 564.
144. Rothrock, E. P., *op. cit.*
145. DeFord, R. K., *op. cit.*

ton shales and limestones", and was followed by Six.[146] In 1938, the writer measured 135 feet of Colorado strata, and erroneously assigned the whole thickness to the Graneros formation.[147] In 1941, Anthony Folger, of the Gulf Oil Corporation, Wichita, Kansas, while on a field conference sponsored by the Oklahoma City Geological Society in the area, suggested the possibility that a portion of the section is Greenhorn. Specifically, he suggested that the rocks exposed along Cottonwood Creek in the NE¼ SW¼ sec. 2, T. 4 N., R. 2 E., closely resemble the Lincoln limestone member of that formation. A restudy of the problem has convinced the writer of the validity of Folger's suggestion that part of the Colorado group in Cimarron County is of Greenhorn age.

Distribution. The Graneros-Greenhorn occupies an area about 13 miles east and west and about 5 miles north and south on the south side of the Cimarron River valley. Exposures extend from sec. 28, T. 4 N., R. 1 E., northeast to sec. 20, T. 5 N., R. 3 E. Some of the exposures in T. 4 N., R. 1 E. occur as outliers in mounds a few yards to three-fourths of a mile in extent.

Thickness. The Colorado group represented in Cimarron County is about 135 feet thick. In the type area the Graneros-Greenhorn beds are 250 feet thick, 200 to 210 feet being assigned to the Graneros and 25 to 40 feet to the Greenhorn. The Greenhorn is generally thicker than the Graneros in Kansas, and in the Oklahoma area, thicknesses of about 65 feet and 70 feet have been tentatively assigned to the Graneros and Greenhorn respectively.

Character. Rocks belonging to the Colorado group consist of alternating beds of white to chocolate-brown shale, marl, limestone, sandstone, and bentonite. The most accessible, and also one of the most typical sections is along Cottonwood Creek, in secs. 2, T. 4 N., R. 2 E., and 34, T. 5 N., R. 2 E., just west of U. S. highway . A generalized section is as follows:

[146] Six, R. L., *op. cit.*
[147] Stovall, J. W., *op. cit.*

A

B

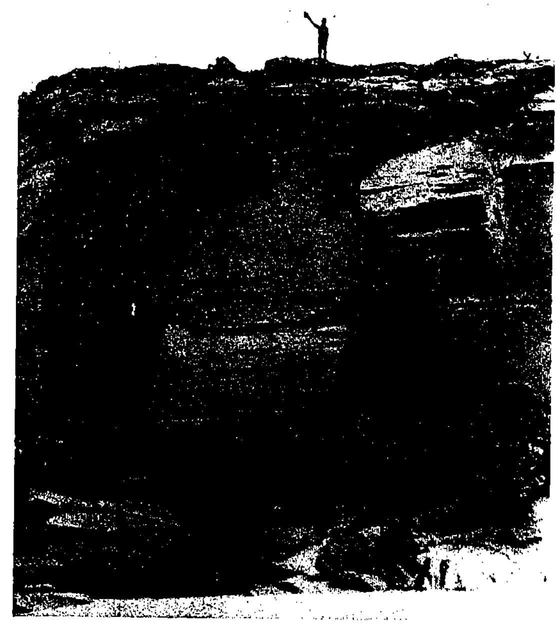


PLATE X. A. Lower sandstone member of the Dakota sandstone, capping bluff along Tesesquite Creek, near John Regnier Ranch House, sec. 9, T. 4 N., R. 1 E.
B. Dakota sandstone cliff, south side Cieneguilla (Seneca) Creek, sec. 10 T. 1 N., R. 1 E. Bedding appears inconspicuous, but in more weathered parts of the outcrop, the normal bedding and cross-bedding may be seen.

A

B

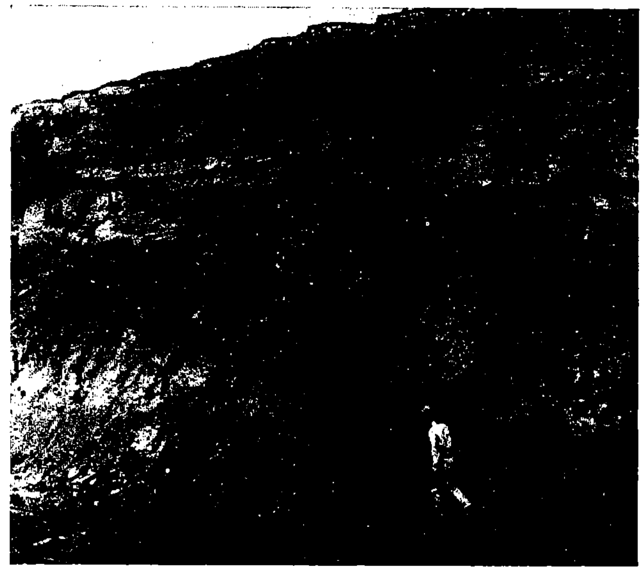


Plate IX. A. Thin-bedded sandstone in the upper part of the Kiowa shale. The lower, clay-shale part of the Kiowa is seen in the lower left corner; the calcareous zone with *Gryphaeas* is about 25 feet lower, in same locality. Sec. 18, T. 5 N., R. 2 E., at road cut along Highway 64, at 101 Hill.

B. Contact of Kiowa shale and overlying Dakota sandstone, in Santa Fe Railroad cut, near U. S. Highway 287, SW¼ sec. 34, T. 5 N., R. 5 E., north of Boise City. The upper sandstone of the Kiowa is absent, and the Kiowa is fossiliferous.

Section of Rocks of Colorado Group Along Cottonwood Creek,

Secs. 2, 10, and 11, T. 4 N., R. 2 E., and 34 and 35, T. 5 N., R. 2 E.

	Thickness (feet)
Top of hill	
Greenhorn formation	
19. Alternating thin beds of gray, crystalline limestone and buff shale, easily weathered and poorly exposed. Limestone at top of section is finely and evenly laminated, apparently unfossiliferous	21.3
18. Covered interval between base of steep slope of hill and nearest exposure in creek bank to southeast	22.5
17. Shale, weathers buff, contains small aggregates of selenite, sticky when wet. Exposed at intervals in creek bank	20.2
Beds 14-16 probably equivalent to Lincoln limestone member:	
16. Limestone, dark gray, finely crystalline, platy, with veinlets of calcite and partings of shale; very fossiliferous, containing *Gryphaea* and *Inoceramus* cf. *labiatus*	0.9
15. Shale, gray, thinly and evenly bedded, with irregular layers of limestone less than 1 inch thick	0.6
14. Limestone, light brown, platy, fossiliferous, contains fragments of carbonized wood	0.7
Total thickness Greenhorn formation	66.2
Graneros formation	
13. Bentonite, lower 0.1 to 0.2 foot white, upper part dark gray, stained brown along bedding planes. (Folger and others have suggested that this bed is the top of the Graneros).	0.6
12. Limestone, dark gray, weathers buff; fucoidal, appears sandy; in beds ¼ to 1 inch thick	1.8
11. Shale, carbonaceous, thinly but regularly bedded, fissile, with thin nodular layers of limestone	3.0
10. Covered	5.0
9. Shale, weathers buff	3.0
8. Covered along ¼ mile or more of creek	30.0
7. Shale, weathers buff, thin-bedded, fissile	3.6
6. Limestone, impure, weathers buff	0.9
5. Shale, gray, thin-bedded, fissile, contains several layers of clay-iron concretions, and in upper part, several sandy or limy layers	6.6
4. Limestone, gray, weathers buff, platy, fossiliferous; with iron-stained concretionary masses in upper part; 3 layers 1 to 3 inches thick stained dark brown to black by iron	3.6
3. Limestone, platy, like bed above, but containing 1 layer of buff limestone 2 inches thick that is dark brown when fresh, and mottled with light colored, rounded bodies arranged parallel to bedding. Apparently unfossiliferous. Includes a layer of gray shale 2 inches thick, 0.5 foot below top	2.2
2. Limestone, dark to light gray, appears sandy, nearly fissile	1.1
1. Covered, along creek, estimated at	5.0
Total thickness Graneros formation	66.4
Total thickness Colorado group	132.6
Top of Dakota sandstone	

In T. 4 N., R. 1 E., are several isolated hills, composed of shale, and rising 5 to 30 feet above the top of the Dakota sandstone. The shale is buff to gray in color, weathers rapidly, generally is grass-covered, and doubtless is the Graneros. Covering some of the flatter slopes produced by erosion of the underlying Dakota sandstone in the vicinity of the hills, there is a "shingle" of thin, angular, dark-brown, iron-cemented fragments that are a residue of a sandstone occurring at or near the base of the Graneros formation.

In the flanks of the largest of these hills (NW¼ sec. 22), the shale contains a 2 to 3 inch layer of ocherous sandstone, containing many hollow, inverted, rectangular "trays", similar to those described from the upper part of the Dakota sandstone. Cementation has taken place on the upper surface of the sandstone, and along vertical cracks in the sandstone, producing a case-hardening affect that, on weathering and loosening of the blocks, has produced the natural "ash trays."

This same hill is capped by a bed of gray to brown, crystalline limestone about 5 inches thick, that may represent the base of the Greenhorn. However, such a correlation does not allow for a thickness of the Graneros comparable to that seen in the Cottonwood Creek section, and this limestone more probably corresponds to one of the limestone beds in the lower part of the Graneros.

The best exposed section of rocks of the Colorado group in this area is on the Wright ranch, in secs. 17 and 20, T. 4 N., R. 2 E. The generalized section is as follows:

Section of Rocks of Colorado Group on Wright Ranch
Secs. 17 and 20, T. 4 N., R. 2 E.

	Thickness (feet)
Top of section	
Greenhorn formation	
6. Limestone, bluish-white, fine-grained, no fossils noted; beds are thin, most of them fissile; rock weathers readily, and fragments are abundant in washes on upper slopes of the rounded hills	62.0
Greenhorn (?) or Graneros (?) formation	
5. Limestone, buff to yellow, locally marly, contains a considerable number of *Inoceramus labiatus*	22.0
4. Limestone, dark brown, fossiliferous	0.5
Graneros formation	
3. Shale, buff to cream, weathers readily	17.0
2. Shale, chocolate-brown; and buff limestone	12.0
1. Sandstone, buff to brown, contains several layers of gray, non-fossiliferous shale	20.0
Total thickness Colorado group	133.5

The Graneros and Greenhorn formations cannot be satisfactorily distinguished in this section, although it seems probable that the Lincoln limestone member of the Greenhorn, as identified in the Cottonwood Creek section, is represented in bed 5.

Stratigraphic relations. The writer has not seen the Dakota-Graneros contact in this area, because in all the sections studied, this contact is covered by soil and talus, hence its nature could not be observed. The upper contact of the Colorado group is one of erosional unconformity beneath the Tertiary rocks of the "Ogallala" formation.

Fossils. Invertebrate fossils of the rocks of the Colorado group in this area are poorly preserved, but great numbers of *Inoceramus labiatus* Schlotheim are present in the yellowish limestone 65 to 70 feet below the top of the section on the Wright ranch. *Ostrea congesta* Conrad, and *Gryphaea* ? sp., are present at several localities and at different stratigraphic positions. The buff limestone capping the outliers in T. 4 N., R. 1 E. contain a few sharks teeth of an undetermined genus. The late Arthur Wedel called the writer's attention to some fossil bone fragments about the middle of the stratigraphic section in sec. 16, T. 4 N., R. 2 E. The bones were broken and badly scattered over the surface, hence the exact position from which they came could not be ascertained. Two of the largest pieces were identified as the humerus of a plesiosaur.

Correlation. The rocks belonging to the Colorado group of Oklahoma, on the basis of stratigraphic position, general lithologic character, and the abundance of *Inoceramus labiatus* in certain beds, are considered to be of Graneros-Greenhorn age. The presence and position of the bed of bentonite, and the character of the immediately overlying limestone in the Cottonwood Creek section, led Folger[148] to suggest that the Graneros-Greenhorn contact should be placed between them, and that the limestone probably represents the Lincoln limestone (lowest) member of the Greenhorn, as developed in Kansas. Accepting this correlation, the Cottonwood Creek section, at least, is equally divided, as to thick-

148. Folger, Anthony, oral communication on Oklahoma City Geological Society Field Conference in Cimarron County, May, 1941.

ness, between the Graneros and Greenhorn formations. Subdivision and detailed correlation of some of the other sections is not so clear.

Detailed Sections. Detailed sections of the Colorado group may be found in Appendix A. They include numbers 13 and 15.

TERTIARY AND QUATERNARY SYSTEMS

PLIOCENE AND PLEISTOCENE UNDIFFERENTIATED "OGALLALA" FORMATION

BY STUART L. SCHOFF

For many years the deposits of silt, sand, and gravel that overlie the Paleozoic and Mesozoic bed rocks and underlie loess, alluvium, and dune sand in the southern High Plains, including the Panhandle of Oklahoma and adjacent parts of Texas, Colorado, New Mexico, and Kansas, have been classed as one formation designated as "Late Tertiary"[149], Ogallala[150], or by other names.

Recently it has been shown that part of the rocks classified as the Ogallala formation, of Pliocene age, in southern Kansas contain vertebrate fossils of younger age and should be referred to the Pleistocene. This evidence, and the classifications that have been proposed, are discussed under *Age and Correlation and Nomenclature.*

In this report the Pleistocene sediments that may occur in Cimarron County are grouped with the Ogallala formation because they cannot be readily distinguished from the Ogallala on the basis of lithologic character in the absence of reliable fossils. For convenience, the Pliocene and Pleistocene are called "Ogallala" but the limitations and inaccuracies inherent in this use of the name should not be overlooked. This usage has a practical advantage because the water-bearing part of these rocks probably belongs to the Ogallala formation, of Pliocene age.

149. Rothrock, E. P., *op. cit.*, pp. 57-70, 1925.
Gould, C. N., and Lonsdale, J. T., "Geology of Texas County, Oklahoma": *Okla. Geol. Survey Bull.* 37, pp. 26-33, 1926.
Gould, C. N., and Lonsdale, J. T., "Geology of Beaver County, Oklahoma": *Okla. Geol. Survey Bull.* 38, pp. 23-33, 1926.

150. Schoff, S. L., "Geology and Ground Water Resources of Texas County, Oklahoma," *Okla. Geol. Survey Bull.* 59, pp. 57-77, 1939.
See also Geologic Maps of New Mexico, (1928), Colorado, (1935), Kansas, (1937), and Texas, (1937).

Distribution. The "Ogallala" formation is the principal formation underlying the surface of the upland plains in Cimarron County, being covered only locally by dune sand, by alluvium in some of the valleys, and perhaps in places by thin Pleistocene loess. Such loess has been recognized widely on the Southern High Plains, and in recent reports on southwestern Kansas has been mapped separately.[151] The "Ogallala" extends down the spurs in the eastern part of the Cimarron Valley to, or nearly to, the flood plain level. It is the only formation, other than dune sand and alluvium, exposed along the North Canadian Valley between the mouth of Cieneguilla Creek and the Texas line in T. 1 N., R. 8 E.

Thickness. The thickness of the "Ogallala" ranges from a few feet to 300 feet or more. In the Santa Fe railroad cut 6.5 miles north of Boise City (SE¼ sec. 9, T. 4 N., R. 5 E.), only 3 to 10 feet of caliche and 1 to 4 feet of sand and soil lie between the top of the Dakota and the land surface, which at this place is almost at the original level of the High Plains. Likewise, in the road cut on the south side of the North Canadian River near Harmer Station (NE¼ sec. 24, T. 2 N., R. 3 E.), the Dakota is less than 10 feet below the surface.

The "Ogallala" seems to be thin in parts of T. 3 N., Rs. 7 and 8 E., T. 4 N., R. 9 E., and parts of adjacent townships, and probably was deposited over a "red-bed" ridge of the pre-"Ogallala" topography. It is reported that "red beds" were encountered at a depth of about 75 feet in several water wells in and near the NW¼ sec. 17, T. 3 N., R. 7 E. The Gladys Belle Oil Company test well (log 318), in sec. 25 of this township, encountered a 4-foot layer of gypsum at a depth of 90 feet, with "red rock" below it. This evidence is abundantly supported by seismograph shot-holes, logs of which show the thickness of the "Ogallala" to be less than 100 feet in a rather large area (fig. 8).

151. Latta, Bruce F., "Geology and Ground-Water Resources of Stanton County, Kansas": *State Geol. Survey of Kans. Bull.* 37, Pl. 1, 1941.
McLaughlin, T. G., "Geology and Ground-Water Resources of Morton County, Kansas": *State Geol. Survey of Kans. Bull.* 40, Pl. 1, 1942.

The records of wells 280, 281, and 284 indicate that the "Ogallala" near Boise City may be 200 to 250 feet in thickness. It is not certain, however, that all of the 50 to 100 feet of sand, sandstone and clay immediately above the "red beds" in these wells is "Ogallala." As described by the drillers, these strata seem to belong to the "Ogallala", but part of them possibly are of Cretaceous age.

Similarly, in the logs of wells 11, 15, 17-19, 20, and 31, near Felt, the Dakota sandstone, if present, cannot be identified with certainty. In this vicinity it appears that the "Ogallala" is not less than 115 feet in thickness, and may exceed 200 feet.

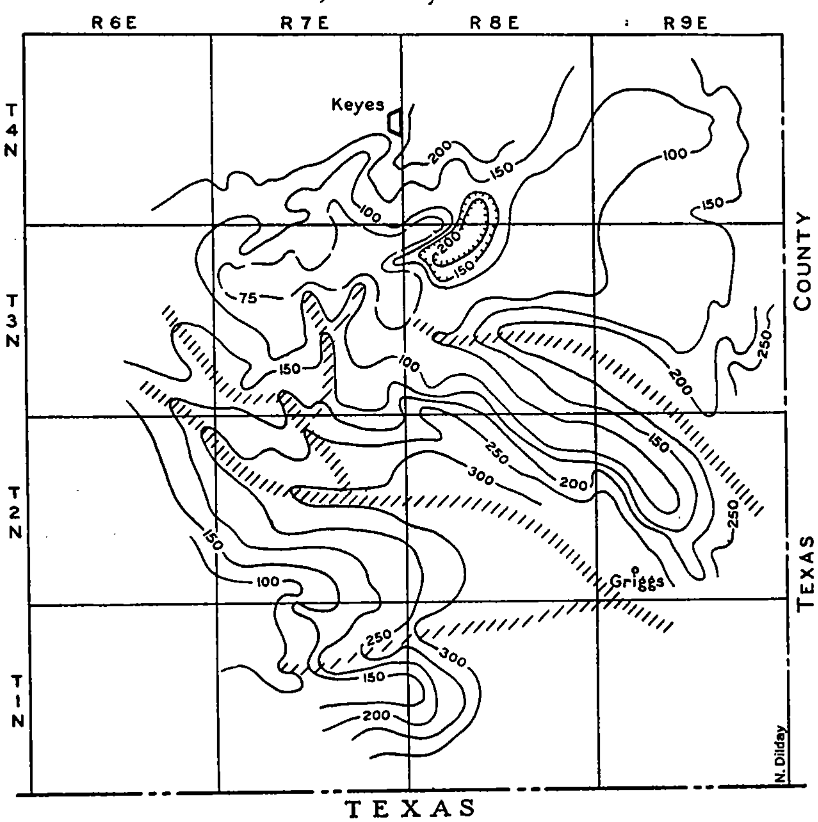


FIG. 8. Map showing thickness, in feet, of Tertiary and Quaternary formations in eastern Cimarron County and hypothetical pre-Tertiary drainage.

The Santa Fe railroad well at Kerrick, Texas, (log T-1), about half a mile south of the Oklahoma State line, penetrated 330 feet of sand, gravel, and clay above the "red beds." Coarse sand and gravel are reported between depths of 280 and 310 feet, and as such materials generally are not found in the Mesozoic formations, it is likely that all of the 330 feet is "Ogallala". The formation probably is correspondingly thick in southern Cimarron County east of Beaver School, except for an area in the central part of T. 1 N., R. 7 E., where the basement red beds seem to be relatively near the surface (fig. 8).

In the logs of wells 405-409, and 433, near Keyes, no strata that can be identified definitely as Cretaceous are reported above the "red beds", which occur at depths ranging from 169 to more than 207 feet. In this vicinity, therefore, the thickness of the "Ogallala" probably is about 200 feet. It seems to increase to 250 or 300 feet in the area north of Keyes. Well logs are not available for this area, but the wells obtain ample supplies of water similar in chemical character to water from the "Ogallala" elsewhere in the Oklahoma Panhandle, at depths between 200 and 275 feet. Similar conditions prevail near Sturgis, and southwest of Midwell School. Between Griggs post office and Plainview School the water table is about 300 feet below the surface, and the thickness of the "Ogallala", therefore, probably exceeds 300 feet.

Character. Despite its extensive outcrop, the "Ogallala" formation is poorly exposed in Cimarron County. In general, only the caliche and the limestone cap rock are exposed, and these by no means continuously. Rothrock[152] described the formation as "a heterogeneous mixture of clays, sands, and gravels, the last two being cemented in many cases by a lime cement", and stated further that "the great bulk of the formation is composed of sand . . . . almost uniformly brown in color." Much of the sand is fine-grained, and not very well sorted.

One of the best exposures in the county is a cut bank about 35 feet high on the north side of a tributary of the Cimarron

152. Rothrock, E. P., "Geology of Cimarron County, Oklahoma": *Okla. Geol. Survey Bull.* 34, pp. 58, 62, 1925.

River in sec. 30, T. 6 N., R. 8 E. About 75 percent of it is sand, ranging from fine to gravelly; about 20 percent is conglomerate, some of it very coarse (Pl. XII); and about 5 percent is sand, silt and clay. Uneven contacts at 14 and 25 feet above the base of the exposure may be local, intraformational unconformities, although it is also possible that the upper one marks the top of the true Ogallala at this place. Immediately over it is 7 feet of coarse gravel that may correspond with the basal gravel of the Meade formation as the latter is developed in Meade County, Kansas[153]. It is obvious, however, that fossil evidence is needed to prove this point. Rothrock[154] measured an exposure in this same section that contained at the base 2 beds of clay totaling 7 feet in thickness, but the present writer found only 2.6 feet of sandy silt or clay in two lenticular beds that pinch out in a horizontal distance of 100 to 150 feet. It is probable that somewhat different exposures were measured by Rothrock and the writer, and that the clay beds reported by Rothrock pinch out between them. If so, the difference between the two measured sections is further evidence of the lateral gradation described by many writers as typical of the Ogallala. Its topographic position suggests that the exposure described above is in the middle part of the "Ogallala" of Cimarron County.

As indicated by exposures along the North Canadian River and Coldwater Creek, the upper part of the formation is very calcareous. Rothrock[155] measured a 26.5-foot exposure in the valley of Coldwater Creek (sec. 17, T. 1 N., R. 3 E.) that must be in the upper part of the formation because the valley itself is not very deeply entrenched below the upland level. He described 65 percent of it as limestone (impermeable) and 35 percent as sand (permeable).

Rothrock[156] also measured a 48-foot section along the North Canadian River in sec. 10, T. 2 N., R. 5 E., describing 70 percent

153. Frye, J. C., and Hibbard, C. W., "Pliocene and Pleistocene Stratigraphy and Paleontology of the Meade Basin, Southwestern Kansas": *State Geol. Survey of Kans. Bull.* 38, pp. 400-411, 1941.
154. Rothrock, E. P., *op. cit.*, pp. 58, 66.
155. Rothrock, E. P., *op. cit.*, p. 64.
156. Rothrock, E. P., *op cit.*, p. 64.

of the material as limestone and shale (impermeable), and 30 percent as sand and conglomerate (permeable). The present writer measured a section at about the same place, (Pl. XIII), and found that the highest well-exposed bed in the cliff is about 30 feet below the upland level. The cliff is about 48 feet high, and 76 percent of the material in it is clay, silt, mixtures of clay with sand and gravel, and caliche; and 24 percent is more or less permeable sand and gravel. Only a few hundred feet distant to the west-northwest, the proportions in a 45-foot section are: permeable sand and gravel, 60 percent; impermeable clay, sandy clay, clayey sand, caliche and limestone, 40 percent.

Between sec. 10, T. 2 N., R. 5 E., and Conrad Station, the writer measured nine sections in the cliffs along the North Canadian, including the two sections mentioned in the preceding paragraph. The thickness of the rocks exposed in these sections ranges from 11 to 75 feet. In one of them, all of the material is impermeable caliche or limestone; but in another, 83 percent is more or less permeable sand and gravel. In several of the better exposures the permeable materials make up 60 percent and impermeable materials 40 percent, and this 60-40 ratio probably is fairly representative of the exposed materials. The exposed materials, however, may not represent accurately the formation as a whole, for the following reasons: (1) exposures occur where materials are resistant enough to make cliffs. Such materials are the better cemented, and therefore less permeable parts of the formation. Hence a large proportion of permeable materials may occur where the valley bluffs are smooth, rounded, grass-covered slopes without projecting ledges. (2) The material in the cliffs is probably less permeable than the corresponding material under cover nearby. Case-hardening of sands in natural exposures is indicated by the comparison of the section in the Santa Fe Railway cut on the north side of the North Canadian River near Conrad station with the natural exposure in the cliff on the east side of the river only a few hundred feet away. Most of the materials in the cliff are well enough cemented with calcium carbonate to be classed as mortar bed, grading up into hard limestone, but the lower part of the materials in the artificial cut can be described as fine, loose, calcareous sands, with scattered calcareous nodules and irregular cemented patches.

In the upper, calcareous part of the formation, soft loose sand generally grades upward into hard limestone (Pl. XIV). The following outline suggests the vertical relationships of the main types of calcareous materials, although in any given exposure one or more of these types may be omitted, and others may be repeated. Furthermore, lateral gradations from one type to another are common, and make completely accurate descriptions of exposures very complicated. The descriptions of several exposures are given in paragraphs following the outline, and will indicate the diversity in the calcareous materials and their mutual relations.

A. At the bottom, soft, unconsolidated sand, silt or sandy clay, with scattered soft, white, calcareous nodules or pipes. The calcareous portions are very sandy or silty and appear to have resulted from the calcification of material similar to, if not identical with, the material surrounding them. The volume of calcareous material increases upward.

B. Soft, earthy or chalky material, locally with scattered bodies of loose sand or silt unaffected by cementation; easily cut with a shovel; disintegrates to powder or sand when struck with a hammer.

C. Scattered hard calcareous nodules in a moderately hard calcareous matrix, which, however, can be cut with a shovel.

D. Calcareous sandstone-arenaceous limestone, consisting of a calcium carbonate matrix in which are embedded abundant grains and granules of sand and, locally, pebbles an inch or more across; generally light-gray or dirty white in color, but in places faintly pinkish; massive; bedding very obscure; weathers unevenly, with many irregular, rounded projections and knobs. This is the mortar bed of Hay[157] and others.

E. Hard nodules and irregular masses in a somewhat softer matrix, generally rather sandy, the whole cut by many irregular

157. Hay, Robert, "Water Resources of a Portion of the High Plains": *U. S. Geol. Survey*, 16th *Ann. Report*, p. 81, 1896.

joints and cracks so that it breaks down readily to form a caliche gravel or rubble (Pl. XV).

F. Limestone, hard, arenaceous, gray, or grayish-brown, broken by curving joints and irregular "bedding" planes into rounded, biscuit-like masses; locally contains irregular wavy red or pink bands, and nodules with concentric red markings suggestive of algal origin. The base generally is extremely irregular because of gradational relationships with underlying caliche of types D or E. (Pl. XVI). In an exposure in the SE¼ sec. 10, T. 2 N., R. 5 E., the whole bed is irregular, the top of it bending sharply down into joints or cracks, producing sub-spherical forms several feet in diameter (Pl. XVII). This condition suggests that (a) the limestone was originally deposited over an uneven, jointed or cracked surface; or (b), the limestone is the result of downward concentration of soil-lime carried by rainwater, is only a thoroughly indurated phase of the caliche, is irregular because the top of the caliche was irregular, and is related either to the present land surface or to an older topographic surface. If (b) is correct, the red bands and nodules with concentric red markings can hardly be of algal origin. Where exposed, the limestone makes a prominent ledge along the valleys just below the upland level. It corresponds with the cap rock as that term is used in the High Plains in Texas, with the capping limestone of southwestern Kansas as used by Smith[158], and may be more or less equivalent to the algal limestone of Elias[159].

Except for the slightly calcified zone A, at the bottom, and perhaps the hard limestone (F) at the top, these calcareous materials can be classed as caliche. They correspond with the plateau-blanket caliche of Price's classification[160]. By local people and drillers they often are called "gyp", but are not true gypsum.

The lower 33 feet of an exposure on the east side of the road near the W¼ cor. sec. 6, T. 1 N., R. 8 E. is material correspond-

158. Smith, H. T. U., "Geologic Studies in Southwestern Kansas": *State Geol. Survey of Kans. Bull.* 34, p. 44, 1940.
159. Elias, M. K., "The Geology of Wallace County, Kansas": *State Geol. Survey of Kans. Bull.* 18, pp. 136-141, 1931.
160. Price, W. A., "Origin of Caliche": *Bull. Geol. Soc. America*, Vol. 51, p. 1939 (abst.), 1940.

ing to A in the above outline, with about 4 feet of somewhat more calcified material like B near the middle, and several hard, thin layers of limestone in the upper part. Above this is a rubble-covered slope capped by 1.5 to 2 feet of mortar bed (D) and 0.5 to 1 foot of hard limestone (F).

In an exposure on the west side of the road in the SE¼ sec. 26, T. 1 N., R. 8 E., type A is overlain by a covered interval followed by type C. Above a second covered interval, 5.5 feet of mortar bed (D) crops out, capped by 1.5 feet of hard limestone. The mortar bed in this exposure includes several irregular pipes that are somewhat harder than the surrounding material.

Mortar beds (D) exposed on the north side of a bend in Cold Springs Arroyo about 1.25 miles southwest of the OTO ranch (SE¼ sec. 29, T. 4 N., R. 3 E.) are slightly pinkish and contain pebbles and cobbles of quartzite, sandstone, and scoria up to 4 inches in diameter. The rock is rather soft, and breaks readily, but makes a ledge 3 or 4 feet high. Above it is about 25 feet of assorted whitish beds including several layers of thin, platy, irregular limestone.

Caliche overlies the Dakota sandstone unconformably in the Santa Fe railroad cut 6.5 miles north of Boise City (SE¼ sec. 9, T. 4 N., R. 5 E.), and ranges from 3 or 4 feet in thickness to about 10 feet. Where it is thickest, it is overlain by only 0.7 foot of dark gray silty soil, but in other parts of the cut, it is separated from the soil by 2 to 4 feet of reddish sand with abundant calcareous nodules. Several varieties of caliche are represented. Directly over the Dakota is 1.5 to 2 feet of gravel cemented with calcium carbonate, containing many sandstone pebbles that probably came from the Dakota or other Mesozoic sandstones. Most of the pebbles do not exceed 6 inches across, but an egg-shaped piece of friable, medium-grained, reddish sandstone about 4 feet long is exposed at one point. About three-fourths of the material in the cut is chalky but rather firm caliche (type C), in places grading into harder, nodular caliche (E). Locally, as has been reported by Smith[158], the hard, dense limestone with wavy markings (type F) is exposed at the top of the cut.

A 16-foot exposure on the east side of a meander loop near the middle of sec. 1, T. 5 N., R. 7 E. consists principally of pinkish mortar beds. The lower part is loose, porous sand with many vertical, tubular openings (root tubes?) and only a few calcareous nodules and pipes. This material grades upward into more calcareous sands that are exposed in smooth vertical faces. The top is irregular mortar bed. Faintly suggested horizontal beds or zones in part of the exposure may be related to the original stratification and permeability of the sands. Water descending through the sands may have been checked on reaching less permeable layers, and forced to spread laterally, depositing calcium carbonate as a cement in the more permeable zone. The depth of penetration of the water might also have been governed, in part, by the intensity of rains and the volume of water descending through the sand. In this way calcification at several different levels can be explained. The root tubes extending to different depths would also allow the water to penetrate to different levels, and on being filled with calcareous material the tubes themselves would become pipes. The land surface at the top of the cliff is sparingly covered with fine gravel that would favor downward percolation of rain water, rather than immediate run-off, but the calcification of the materials in the exposure may have antedated the development of the present surface.

Large "boulders" or "concretions" are found in the caliche in places (Pl. XVIII). In a 30-foot cliff on the east side of the North Fork of Beaver Creek, in the SE¼NW¼ sec. 31, T. 3 N., R. 9 E., such "concretions" reach 1 foot in diameter and are embedded in fine, reddish sand. They are disposed in all positions, something like boulders in an alluvial fan, but mechanical deposition from a stream is not necessarily implied, as they may have developed in place by deposition of calcium carbonate around a nucleus. One of the smaller concretions in this exposure was found to have a structureless central core surrounded in the outer 0.25 to 0.5 inch by concentric bands. The concretions overlie material of type B, in which considerable loose, fine-grained, reddish sand is more or less enclosed in chalky caliche. The limestone (F) exposed at the top of the cliff is hard, dense, arenaceous, contains much pink coloring, and ranges from 1 to 2 feet in thickness. Its upper and lower surfaces are warped and uneven.

In an exposure on the east side of a draw in the SW¼ SE¼ sec. 1, T. 2 N., R. 8 E., rounded, calcareous, concretionary "cobbles" and "boulders", some more than a foot in diameter, are embedded in a matrix of soft caliche (type B), and are grouped together like bunches of overgrown grapes. Slabs of limestone tilted on edge are associated with them, and suggest that the whole is the deposit of swift-flowing currents, and has been cemented by calcium carbonate, perhaps from ground water long after the original deposit was made. The deposition of crusts of calcium carbonate over them would round off the sharper corners of cobbles and boulders and give them a concretionary appearance. Caliche of types C and E also occurs in the cliff, which is about 15 feet high and is capped by 0.5 foot of gray to white limestone (F). Limestone is also exposed on the west side of the same draw a few hundred feet upstream (near N¼ cor. sec. 12), where it overlies 2 feet of chalky caliche (type B).

A concretion or cobble zone was also noted just below the capping limestone in a natural exposure about a hundred feet east of the southeastern end of the first Santa Fe Railway cut on the north side of the North Canadian River near Conrad station (SE¼ sec. 23, T. 2 N., R. 6 E.; see Pl. XVIII).

Concretions in the capping limestone on the southwest side of the same railroad cut average about 1 inch in diameter and have a core of hard, dense, gray or grayish-brown limestone surrounded by alternating fine pink, red, and white wavy bands. The bands are suggestive of algal origin and in general are confined to the outer 20 percent regardless of the size of the concretionary nodule. In other words, the larger the concretion, the larger the structureless limestone core. This fact suggests that algae grew around pebbles of different sizes, but if so the original outline of the pebbles has been obscured by the algal growth, which is as dense and hard as the core. Several samples of hard capping limestone from this railroad cut were sent to M. K. Elias, of the Nebraska Geological Survey, who has studied the Tertiary deposits of the

High Plains, and the plant remains in them, in both Nebraska and Kansas. He replied:

> The rock corresponds rather well to the samples previously described and identified by me as the algal (*Chlorellopsis*) limestone at the top of the Ogallala in Kansas and Colorado.
>
> Your observation that the rock is made of pebbles, angular fragments and sand grains, which are encrusted by banded calcium carbonate is indeed correct . . . In your samples under my examination the angular fragments represent the banded limestone of essentially the same nature, (except darker in color) as the encrustation around them, which thus appears to be the second generation of the same finely-banded dense limestone. The mechanical breaking into angular fragments of the first generation of the banded limestone suggests sub-aerial or wave-action erosion, but not soil-lime accumulation. The second generation of the same banded nature could be a soil-lime accumulation, but its similarity to the first generation limestone and its density seem to indicate rather the same origin as that of the first generation limestone. The pale-brown and pinkish to brownish-red bands in the first and second generation dense limestone . . . apparently developed entirely in the uppermost Ogallala layer, the cap rock of the Ogallala throughout the High Plains.
>
> The encrusting finely-banded structure and its modification into cauliflower-like outgrowth is typical of the fossil *Stromatolithi* Pia, where belong *Cryptozoan*, *Collenia* and other artificial genera, which represent the various types of precipitation of calcium carbonate by the algae alone or, more likely, by a combined action of algae and inorganic precipitation. The remains of the algae themselves can be only rarely observed in these calcareous structures. Sand grains, pebbles and other impurities are often incorporated in them.[161]

Many nodules in type E caliche on the east side of the North Canadian in a 10-foot cliff in the N½ sec. 10, T. 2 N., R. 5 E., contain a nucleus of ferruginous sandstone similar to ferruginous parts of the Dakota and Cheyenne sandstones.

In general, a hard limestone (F) is the highest bed exposed along the valleys and may be considered to be near the top of the formation, but it is not necessarily the uppermost bed. Several hand-level measurements along the North Canadian River valley in the central part of the county indicate that it may be

161. Elias, M. K., letter dated February 27, 1942.

as much as 30 feet below the level of the upland plains. The nature of the material in this 30-foot zone, and its age, remain an unsolved problem because of inadequate exposures.

Likewise, the relation of the hard limestone along the valleys to similar hard, algal-like limestones and caliche that crop out here and there in road ditches and excavations on the upland plains is uncertain. On the basis of topographic position it would seem that the limestone ledges along the valleys must be lower in the section and therefore somewhat older. On the other hand, if the hard limestone is a concentration of soil-lime carried downward by rainwaters and was formed at a uniform depth beneath the present land surface, the caliche deposits may rise somewhat under cover on either side of the main streams and be equivalent to, if not continuous with, the limestone and caliche of the upland plains.

An excavation for a small cellar about 2 miles southwest of Sandy View School exposes caliche to within 1.3 feet of the surface. This location (NE¼ sec. 18, T. 3 N., R. 4 E.) is on the High Plains between the valleys of the Cimarron and North Canadian Rivers, and several miles distant from either. The excavation is about 5 feet deep, and the lower part exposes 2.7 feet of caliche, mostly rather soft and corresponding to types B and C but including a zone of hard nodules near the middle. In part of the west wall of the pit, the nodules extend down to the floor, and some are 4 to 6 inches across. In places this zone is capped by a thin, hard, irregular limestone (F?). At one point the upper part contains a circular calcareous band about 9 inches in diameter enclosing a body of calcareous soil 4 inches in diameter. The caliche is overlain by 0.8 foot of loose soil containing soft calcareous streaks and "nodules", followed by 1.2 feet of fine, brown, silty sand. Boundaries between these zones are fairly well marked but are uneven in detail. At the west end of the pit an earthy pipe of the middle zone extends downward through the caliche zone.

Hard limestone crops out in the ditch beside the road near the SE cor. sec. 33, T. 4 N., R. 9 E.; and in T. 3 N., R. 9 E. near the NW cor. sec. 10 and along the north line of secs. 27 and 28. Caliche gravel or rubble along roads and in fields in many

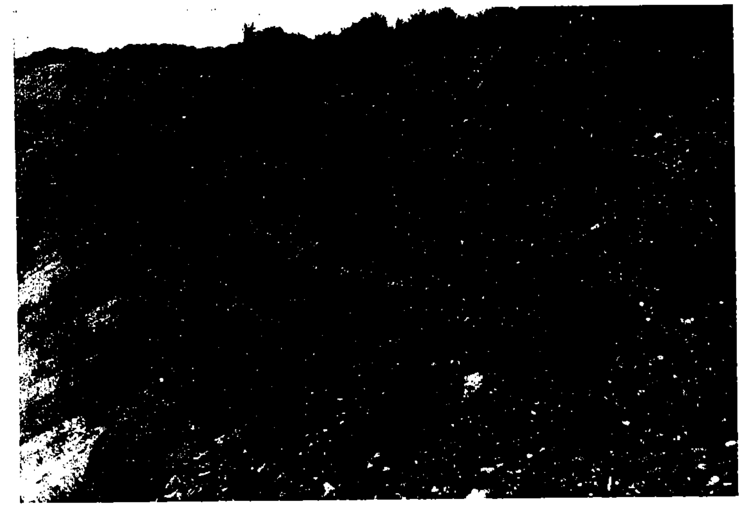


PLATE XII. Coarse gravel overlying layers of sand. Tertiary and Quaternary, undifferentiated—"Ogallala" formation. NW¼ sec. 30, T. 6 N., R. 8 E.

PLATE XIII. Lower third of 37-foot cliff of undifferentiated Tertiary and Quaternary rocks ("Ogallala" formation) is chocolate brown, sandy clay; upper part is sand and "caliche" with hard limestone layer at top. SE¼ sec. 10, T. 2 N., R. 5 E.

PLATE XIV. Soft caliche grades upward into a hard, irregular limestone layer; overlain by 4 feet of silty soil. East side Santa Fe Railroad cut near Conrad Station, SE¼ sec. 23, T. 2 N., R. 6 E.

PLATE XV. Nodular, much-jointed caliche with thin layers of dense limestone at top. East side North Canadian River, NE¼ sec. 22, T. 2 N., R. 6 E.

PLATE XVI. Hard, dense limestone with many joints and cracks overlying irregularly nodular, moderately hard caliche. West side North Canadian River, sec. 10, T. 2 N., R. 5 E.

PLATE XVII. Hard limestone at top of cliff in Plate XIII is rounded on exposed upper surface.

PLATE XVIII. "Concretionary" zone in caliche, just below the hard capping limestone. NW¼ SE¼ sec. 23, T. 2 N., R. 6 E.

PLATE XIX. A dense, hard layer of limestone resembling the "algal" limestone near the top of the "Ogallala" formation of some areas, crops out just above the North Canadian River channel at Conrad Station.

parts of the county indicates that fairly hard caliche occurs only a few feet, or in some cases, a few inches, below the upland surface, and that it is very widespread if not continuous.

Hard limestone, however, is not confined to the top of the formation. At Conrad station (SW¼ sec. 24 and NW¼ sec. 25, T. 2 N., R. 6 E.), hard, gray, and grayish brown, arenaceous limestone with algal-like nodules crops out as a ledge about 5 feet above the bed of the North Canadian River. (Pl. XIX). It is underlain by softer materials corresponding to C and E in the above classification, and is overlain by 3 or 4 feet of material corresponding to B. About 0.5 mile upstream the only observed hard limestone layer is 61 feet above the bed of the river, but in the N½ sec. 10, T. 2 N., R. 5 E., such a layer crops out about 10 feet above the bed, and on the east side of the river. Immediately east of the Boise City dump ground, in the SE¼ sec. 3, T. 2 N., R. 5 E., three hard limestone layers crop out at 22, 39, and 52 feet above the bed of the river. The lower two make prominent ledges but the upper one is poorly exposed.

Stratigraphic relations. The "Ogallala" overlies rocks of Mesozoic age unconformably. Minor details of the unconformity are revealed in the Santa Fe railroad cut 6.5 miles north of Boise City, where the Dakota-"Ogallala" contact can be seen to rise and fall 3 or 4 feet in a horizontal distance of only a few hundred feet.

The larger irregularities on the surface of unconformity are inferred from outcrops and from well records. If all of the materials recorded above the first "red beds" in the deepest of the Cimarron Utilities Company wells at Boise City (log 280) is "Ogallala," the pre-"Ogallala" surface is about 250 feet lower at Boise City than in the railroad cut mentioned above. Even if all of the sand in this log is interpreted as Dakota sandstone, the old surface is 150 feet lower than in the railroad cut.

The Dakota is exposed along Cieneguilla Creek (T. 1 N., R. 1 E.) and on the south side of the North Canadian River near old Harmer Siding (NE¼ sec. 24, T. 2 N., R. 3 E.), but none crops out between these two localities. The Harmer outcrop, therefore, is either a local structural uplift that brings the Dakota to the surface, or it is an isolated hill—an outlier—of Dakota on the pre-"Ogallala" surface. The writer favors the latter explanation. The implied topographic relief on the old surface may be about 75 feet.

A buried "red-bed" ridge in parts of T. 3 N., Rs. 7 and 8 E. and adjacent townships, already mentioned in the section on *Thickness,* is illustrated by Fig. 8, in which the thickness of the "Ogallala" is represented. As the present land surface is nearly flat, the "Ogallala" should be thickest in the valleys of the pre-"Ogallala" topography, and the difference between the greatest and least thickness should be about equal to the relief on the surface of the unconformity. In the area of the thickness map, this relief is 225 feet or more.

The "Ogallala" underlies unconformably the alluvium along most of the North Canadian Valley and the eastern part of the Cimarron Valley, and in the valleys of their major tributaries. It also underlies the dune sand unconformably.

Age. The "Ogallala" of Cimarron County appears to include beds of both Pliocene and Pleistocene age, but the evidence is scanty. Stovall[162] obtained small collections of vertebrate remains from the formation near Nigger Springs, below the lava that caps Black Mesa; along U. S. highway 64 east of Cottonwood Creek; and near the edge of the upland south of Strong's ranch. Most of this material is so poorly preserved that the species cannot be identified, except for a horse tooth from Nigger Springs that proved to be *Pliohippus interpolatus* (Cope), of middle Pliocene age. Assignment of the major part of the "Ogallala" of Cimarron County to middle Pliocene age is at least in keeping with the fact that the beds appear to continue eastward into similar deposits in Texas County, Oklahoma, from the upper part of which Stovall[163] collected many bones and teeth of middle Pliocene age. It also agrees with the age of the deposits at the type locality of the Ogallala, which Hesse[164] concluded are confined to middle Pliocene age.

162. Stovall, J. W., Oral communications, 1941, and 1942.
163. Schoff, S. L., *op. cit.*, p. 62.
164. Hesse, C. J., "A Vertebrate Fauna from the Type Locality of the Ogallala Formation": *Kans. Univ. Bull.*, Vol. 22, No. 5, pp. 79-118, 1935.

The only fossils that have been found in the upper part of the "Ogallala" formation of Cimarron County are a few fragmentary camel bones discovered by County Agricultural Agent W. E. Baker. These bones had been but slightly altered, and it is therefore probable that they were deposited in Pleistocene time rather than Pliocene. More positive evidence was uncovered in Dallam County, Texas, about 18 miles southwest of Boise City. This locality is 2 or 3 miles south of the State line and is on the High Plains, which are an extension of and continuous with the High Plains in Cimarron County. Most of a skeleton of *Elephas columbi,* with the bones well articulated, was uncovered immediately below the soil, which had been blown away after ploughing. This discovery was reported by Baker to Stovall, who examined the remains and found that they were embedded in a dark colored sandy silt that might have been deposited in the bottom of an ancient lake. The remains of a camel were found at the same locality, and nearby the remains of *Megalonyx jeffersonii,* a ground sloth, were uncovered by the wind. These remains are of Pleistocene age, and clearly indicate that the upper part of the "Ogallala" of this part of the High Plains includes beds of Pleistocene age.

Correlation and nomenclature. Darton[165] first mentioned the Ogallala formation by name in 1898. He referred to the type locality only in general terms, but Hay[166], in describing the same deposits two years before, had mentioned exposures of "Tertiary grit along the North Platte northwest of Ogallala, Nebraska." In 1920 Darton[167] mentioned "the type locality near Ogallala station in western Nebraska," and this is generally accepted as the type locality. Hay's description of the strata exposed there has been summarized and discussed by Elias[168], and the vertebrate fauna has been described by Hesse[169].

165. Darton, N. H., "Preliminary Report on the Geology and Water Resources of Nebraska West of the 103rd Meridian": *U. S. Geol. Survey* 19th *Ann. Rept.* (for 1897-98), Pt. 4, 1899.
166. Hay, Robert, "Water Resources of a Portion of the Great Plains": *U. S. Geol. Survey,* 16th *Ann. Rept.* (for 1894-95), Pt. 2, p. 580, 1896.
167. Darton, N. H., *U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin, (Kansas) Folio* (No. 212), p. 6, 1920.
168. Elias, M. K., "The Geology of Wallace County, Kansas": *State Geol. Survey of Kansas Bull.* 18, pp. 133-134, 1931.
169. Hesse, C. J., *op. cit.*

The Ogallala was also described by Darton for other parts of the High Plains outside of Nebraska, and the name has been applied by other geologists to deposits of similar character and stratigraphic position from southern South Dakota to northwestern Texas and eastern New Mexico. The Ogallala was defined as a formation and usually has been treated as such, but Lugn[170] has elevated the Ogallala of Nebraska to the rank of group with four formations ranging from early to very late Pliocene in age. These formations have not been recognized in other states. The Committee on a Provincial North American Tertiary Time Scale, of the Vertebrate Section of the Paleontological Society[171] also considers the Ogallala to be a group, and recognizes three of the four formations of Lugn. Hesse's study of the vertebrate remains from the Ogallala at the type locality led him to the conclusion that all of the rocks exposed there belong to Lugn's Ash Hollow formation of middle Pliocene age. As the meager fossil evidence for the Tertiary-Quaternary sequence of Cimarron County suggests middle Pliocene age, the assignment of at least part of these rocks to the Ogallala, and correlation with the Ash Hollow, seem proper.

The reclassification of the old "Ogallala" of the Southern High Plains was begun by Smith[172] in a report on southwestern Kansas that was published in 1940. At the time Smith's paper was being prepared, detailed work by Hibbard[173] and Frye[174] was in progress in Meade County, Kansas, where the Pliocene and Pleistocene formations have been distinguished with the most success. This work

170. Lugn, A. L., "Classification of the Tertiary System of Nebraska": *Bull. Geol. Soc. America*, Vol. 50, pp. 1245-1276, 1939.
171. Wood, H. E., *et al*, "Nomenclature and Correlation of the North American Continental Tertiary": *Bull. Geol. Soc. America*, Vol. 52, pp. 1-48, 1941.
172. Smith, H. T. U., "Geologic Studies in Southwestern Kansas": *State Geol. Survey of Kans. Bull.* 34, pp. 37-39, 41, 74-75, 95-97, 100, 107-111, 114, 1940.
173. Hibbard, C. W., "Paleoecology and Correlation of the Rexroad Fauna from the Upper Pliocene of Southwestern Kansas, as indicated by the Mammals": *Univ. of Kans. Sci. Bull.*, Vol. 27, Pt. 1, No. 6, 1941.
Hibbard, C. W., "Mammals of the Rexroad Fauna from the Upper Pliocene of Southwestern Kansas": *Kans. Acad. Sci. Trans.*, Vol. 44, pp. 265 ff., 1941.
174. Frye, J. C., and Hibbard, C. W., "Pliocene and Pleistocene Stratigraphy and Paleontology of the Meade Basin, Southwestern Kansas": *State Geol. Survey of Kans. Bull.* 38, 1941.

showed the need for extending and modifying somewhat the classification proposed by Smith, as follows:

Quaternary system
  Kingsdown formation
  Disconformity
  Meade formation
    "Odee beds" (Odee formation of Smith)
  Disconformity
Tertiary system
  Pliocene (Upper and Middle)
    Ogallala formation
      Rexroad member
      Local disconformity
      Lower member
    Nonconformity
  Pliocene (Lower) and Miocene
    Laverne formation

The extent to which these other formations have been included in the "Ogallala" as mapped in Cimarron County is not known. The Laverne formation of lower Pliocene age, is characterized by massive, porous chalk beds that have not been observed in Cimarron County; and the writer, therefore, believes that this formation is not represented. The Odee formation of Smith also has fairly distinctive lithologic characteristics that to date have not been observed in Cimarron County; and this unit, therefore, may be absent or indistinguishable. The Rexroad is thought by Smith[175] and by Frye and Hibbard[176] to have been deposited in a local basin. Although deposits of equivalent age occur outside of the basin, they are not continuous with the Rexroad of the type locality and are not genetically related to it. Thus it is unlikely that any of the "Ogallala" of Cimarron County could properly be referred to the Rexroad member of the Ogallala as it is known in Meade County, Kansas. The Meade formation is enough like the Ogallala to make identifications based only on lithology rather uncertain and liable to large errors, especially where rock exposures are widely scattered and are distant from the type localities.

In conclusion, it appears reasonably certain that the "Ogallala" of Cimarron County includes deposits of Ogallala age, and that the Pleistocene formations also are present. Until much more field work has been done, especially in collecting and studying verte-

175. Smith, H. T. U., *op. cit.*, p. 98.
176. Frye, J. C., and Hibbard, C. W., *op. cit.*, p. 407.

brate remains from these rocks, it will be impossible to distinguish the Pleistocene from the Pliocene, or to determine what subdivisions of these major units should be recognized and mapped.

Detailed Sections. Detailed sections of the "Ogallala" formation may be found in Appendix A. They include numbers 2-12, incl., 14, and 34.

Pliocene (?) Series

BASALT

Distribution and thickness. The only igneous rock exposed in this area is a lava flow that caps Black Mesa in the extreme northwest corner of the county. The flow consists of basalt and is approximately ½ mile wide and 3 miles long, and extends into Cimarron County from New Mexico in an east-northeast direction from the NW corner sec. 6, T. 6 N., R. 1 E. Black Mesa is a finger of Mesa de Maya which has its center in Las Animas County, Colorado. Rothrock[177] was of the opinion that the lava capping Mesa de Maya was extruded at Piney Mountain, Colorado, 7 miles north-northwest of the place where it enters Oklahoma.

177. Rothrock, E. P., *op. cit.*, p. 73.

The lava extends westward and northwestward into New Mexico and Colorado. Several small buttes located 6 miles northeast of Black Mesa, in Baca County, Colorado, are capped by similar lava that probably represents remnants of the same flow, indicating that the original flow was much more extensive than the present Black Mesa and Mesa de Maya. The lava probably followed the ancestral Cimarron Valley.

The lava thickens from about 50 feet at the east end of Black Mesa to about 85 feet at the New Mexico line, but cannot be measured exactly because the base of the lava is covered by coarse debris.

Character. The volcanic rock of Cimarron Connty is a dense, olivine basalt with ophitic texture. It is black, greenish gray, and brown in color. Rothrock[178] says, concerning its composition:

178. *Idem.*, p. 71.

"It is composed of about 45 percent labradorite, 45 percent augite, 7 percent magnetite and 1 percent olivine, a large part of which has been altered to idingsite."

The lower part of it is finely crystalline, but toward the top it is markedly vesicular, and many of the vesicles are filled with calcite. The upper part of the flow is fine-grained and in places contains considerable amounts of glass. There is a tendency for the rock to break with conchoidal fracture and in a few places crude columnar jointing is evident.

Age of the lava. In the area with which this report is concerned the lava overlies 110 feet of sand and gravel from which Stovall collected many fragments of mammal bones and one identifiable tooth of *Pliohippus interpolatus,* a horse of Middle Pliocene age. The only sediments on top of the lava are a few scattered chert and quartzite pebbles. Except for smaller average size, these pebbles are similar to many on the upland plain south of the Cimarron River Valley. They probably were deposited over the lava at the time when adjacent drainage stood at a higher level. The presence of *Elephas imperator* in the floor of the Cimarron River Valley, and *Equus complicatus* and *Camelops* (early Pleistocene age) in the Indian shelter caves underlying the debris of an Indian culture, indicates that the carving of the valley, at least to the level of the shelter caves, took place between Middle Pliocene and early Pleistocene times. In any event the major streams have cut through the lava and about 700 feet of underlying Tertiary and Mesozoic sediments. (See fig. 9). The evidence seems to indicate a post Middle Pliocene and pre-early Pleistocene age for the flow.

This conclusion agrees with that of Johnson[179], who says concerning the beginning of active erosion of the High Plains:

The destruction of the old surface, of which the High Plains are a belt of great fragmentary survivals merely, began, then, with the opening of the Pleistocene.

179. Johnson, W. D., "The High Plains and Their Utilization": *U. S. Geol. Survey 21st Ann. Rept.*, Pt. 4, p. 631, 1901.

QUATERNARY SYSTEM

BY J. W. STOVALL AND S. L. SCHOFF

Pleistocene and Recent

In addition to the possible Pleistocene deposits that have been grouped with the "Ogallala" and are discussed elsewhere in this report, the Pleistocene and Recent sediments of Cimarron County include deposits in caves, stream deposits, and dune sand. The

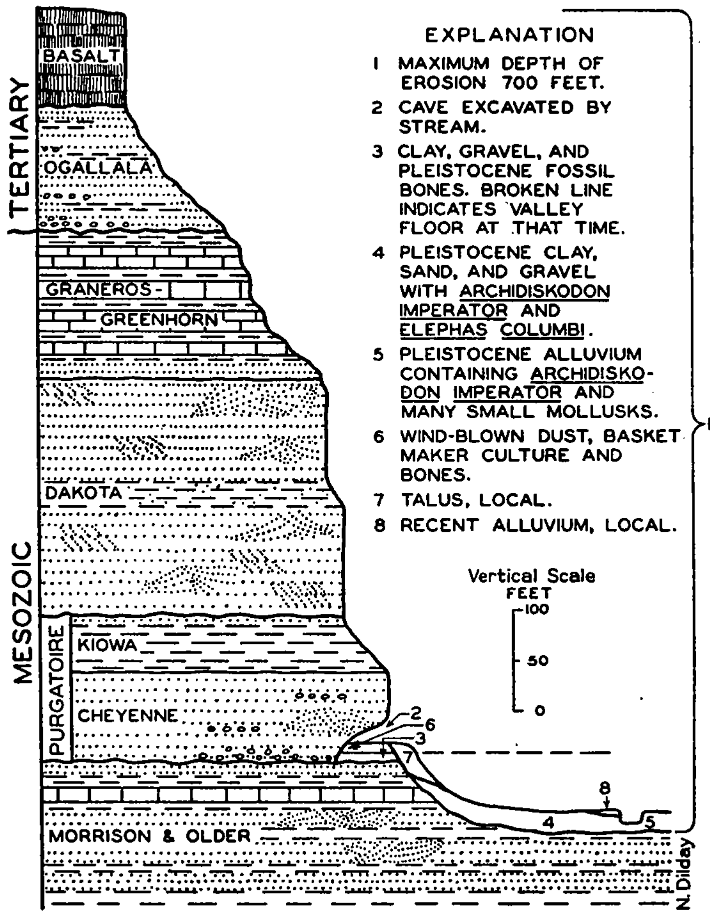


Fig. 9. Sketch to indicate the amount of erosion in the Cimarron valley subsequent to the Pliocene (?) lava flow, showing the relative position of the Mesozoic, Tertiary, and Quaternary deposits, including deposits in caves and stream deposits.

cave deposits are small and are distinctly separated from other types of deposits. The wind-blown sand, also, is sharply separated from underlying materials; but the Pleistocene and the Recent deposits of the valley bottoms are so similar that they cannot be separated readily.

DEPOSITS IN CAVES

Distribution. Several natural recesses in the sandstone bluffs along the canyon walls of the tributaries to the Cimarron River in the northwestern part of Cimarron County contain deposits that appear to have been laid down by the nearby streams when their channels were at the level of the caves. The streams made the recesses by cutting laterally at the base of the cliffs along their valleys, a suggestion that is heightened by irregular re-entrants in the caves. The streams then deposited muds and sands in them. The bed-rock bottoms of most of the caves lie well below the surface of the piles of talus that have accumulated at their entrances.

Most of the caves are in the Cheyenne sandstone (fig. 9), and they are called "shelter caves" because many of the larger ones have been occupied by man. The largest cave, in sec. 11, T. 5 N., R. 1 E., is approximately 45 feet in length, 75 feet in width, and from 10 to 35 feet in height. The smallest cave that has been occupied is approximately 4 feet by 10 feet by 6 feet.

Thickness and character. The lower part of the deposits in the caves consists of interbedded layers of buff clay and sand. In some of the caves these beds contain fragmentary horse, camel, and elephant bones. The stratification of the beds and the broken condition of the bones indicate that the sediments and the bones were deposited by the streams that carved the caves. These materials are generally overlain by wind-blown dust mixed with the skeletons of the inhabitants of the caves, their artifacts, and the sand carried in by them for the purpose of burying their dead.

The maximum thickness of the deposits in the largest cave was estimated by R. C. Tate[180], of Kenton, as about 30 feet. The lower 16 feet is the deposit of the stream, and the upper 14 feet

180. Tate, R. C., Personal Communication.

has accumulated since the beginning of human occupancy. In other caves, the thickness of the Recent deposit ranges from 2 to 16 feet.

Fossils and age. Fossil remains in the stream-laid portion of the cave deposits consist of fragmentary bones, all more or less permineralized. Many of them are not identifiable, but among them are identifiable fragments of *Equus complicatus,* and *Camelops,* and a fragment of the pelvis of an elephant. These are of early Pleistocene age; and, therefore, indicate that the water-laid cave deposits are not older than early Pleistocene.

The upper part of the cave deposits, which contains the evidence of human occupancy, is of Recent age. The caves may have been abandoned by their last occupants within the last 500 years, and wind-blown dust is still accumulating in them.

BASKETMAKER CULTURE IN THE OKLAHOMA PANHANDLE

BY FORREST E. CLEMENTS

The existence of a prehistoric culture in Oklahoma resembling Basketmaker II was first reported by Mr. William Baker of Boise City, Oklahoma. Mr. Baker is a well known amateur archaeologist, and about 1927 he discovered evidence of ancient habitation in a number of natural caves or rock shelters in the northwestern part of Cimarron County. This part of the Oklahoma Panhandle lies along the upper Cimarron River and is dissected into numerous canyons and mesas. The canyons are cut down through the Dakota and Cheyenne sandstones, and it is in these formations that the caves are found. A large number exist but only five have been extensively explored for evidence of occupancy by the Basketmakers. The largest of these is about 45 feet deep, 35 feet wide at the entrance and 22 feet from floor to roof. They are rock shelters rather than true caves but were well adapted to the uses of prehistoric man.

Mr. Baker reported his discovery to Dr. Leslie Spier of the University of Oklahoma and Dr. Spier planned to conduct excavations the following summer, but was forced to abandon these plans, and the cave deposits remained undisturbed until 1929 when a field party from the Colorado Museum of Natural History under the direction of Dr. E. B. Renaud partially excavated three of the

sites[181]. In 1930 Mr. J. B. Thoburn of the Oklahoma State Historical Society resumed archaeological work in the largest of the three caves which had been partially excavated by Renaud. Thoburn also explored a number of the other canyons and discovered two additional caves with small archaelogical deposits[182]. There still remained an extensive deposit in the largest cave although it had been much disturbed. In 1932 a party of picnickers discovered the dessicated body of a child in the debris covering the cave floor and a fanfare of publicity resulted from the finding of this "mummy." Many curiosity seekers visited the site and most of what was left of the deposit was carelessly ransacked by relic hunters. Finally, in 1933, a field party from the University of Oklahoma completely removed the now sadly churned deposit but did find one small area where the original stratification was intact.

Except for the evidences of the Folsom culture, also found in the Panhandle, these Basketmaker sites of Cimarron County are the oldest known remains of prehistoric man in Oklahoma. They present the usual early Basketmaker traits, and their chief interest lies in their proof that this ancient southwestern culture had spread as far east as the Oklahoma Panhandle. This culture probably flourished around 1500 years ago in its center of development in Arizona, southern Utah, and western New Mexico; and so far as is known, these remains represent the easternmost diffusion of the culture and are thus quite marginal to the Basketmaker area.

The Basketmaker people of Oklahoma had no domestic animals, for even the almost universally present dog bones are lacking in these sites. They were without pottery and did not possess the bow and arrow. They did, however, practice a rudimentary

181. Renaud, E. B., "Archaeological Research in Northeastern New Mexico and Western Oklahoma": *El Palacio,* Vol. XXVII, Nos. 23-24, 1929. Santa Fe.
Renaud, E. B., "Prehistorio Cultures of the Cimarron Valley, Northeastern New Mexico and Western Oklahoma": *Colo. Sci. Soc. Proc.,* Vol. 12, No. 5, pp. 113-150, 1930. Denver.
Renaud, E. B., "Prehistoric Relics: Cimarron Valley of Oklahoma": *Science News Letter,* Vol. 17, No. 473, p. 281, Science Service, May 3, 1930, Washington.

182. Thoburn, J. B., "The Prehistoric Cultures of Oklahoma": *Chronicles of Oklahoma,* Vol. 7, No. 3, pp. 211-241, 1929.
Thoburn, J. B., "The Prehistoric Cultures of Oklahoma", in Moorehead, W. K., "Archaeology of the Arkansas River Valley": *Yale Univ. Press,* New Haven, pp. 53-82, 1931.

horticulture and grew a primitive type of maize and perhaps squash. Their stone implements were flaked by percussion and consisted of knives and hide scrapers. Stone metates were used to grind maize and other seeds; but these with their attendant manos, a few ornaments, and dart shaft abraders were the only implements made of ground stone. Bone awls and beads of various sizes were used and a number of implements were made of wood. Except for some problematical objects which may have been ornamental in character, the wooden implements consisted of fire drills, dart shafts, atlatls, and curved throwing sticks for small game. They made a great variety of cordage ranging from threads up to cords ¼ inch in diameter. Thousands of these fragments were found and most of them have at least one knot, the square knot being typical. The predominant feature of this culture is, of course, its development of basketry. Most of this is twined but coiled specimens do occur. Woven sandals of the square-toed type having up to six different layers in the soles, were abundant. Bags made of small animal skins were found, together with many fragments of fur cords, probably the remains of rabbit skin blankets.

The classical Basketmaker II culture of Arizona dates from 300-500 A. D. Inasmuch as the Oklahoma occurrence is extremely marginal to the center of the Basketmaker area, it is likely that the occupation of the Panhandle caves was later than 500 A. D., and may not be more than 1,200 or 1,000 years old. On the other hand, the Oklahoma sites may represent an early diffusion of the primitive Basketmaker Culture which later became more elaborate in northern Arizona.*

STREAM DEPOSITS

The stream deposits of Cimarron County include the terrace gravels that represent the alluvial fill of the valley at a previous, higher level, the sediments that underlie the flood plains, or bottom lands, and the materials in the channels themselves. In many places these deposits are still being laid down.

Distribution. The stream deposits occur along all of the streams in Cimarron County. The terrace gravels are in small

* This section on Basketmaker culture was prepared by Forest E. Clements, formerly Professor of Anthropology, University of Oklahoma.

isolated patches on high-level flat benches that are the remnants of an ancient valley floor, and they are scattered here and there along the main streams, chiefly the Cimarron River. The materials underlying the stream valleys are more extensive, extending from valley wall to valley wall. The materials in the channels are in a state of interrupted transit, soon to be moved downstream by a flood to a new resting place and to be replaced by similar materials from upstream. Such deposits are present in the channels of North Canadian and Cimarron Rivers, and their larger tributaries, but are lacking in the well-sodded bottoms of some of the smaller headwater tributaries where channels have not been cut.

The valleys of North Canadian River and its principal tributaries—Cieneguilla, Beaver, and Goff Creeks—in Cimarron County are so narrow that the bottom lands and the stream deposits underlying them are no more than narrow, irregular strips.

Cimarron River has a much wider strip of valley fill than the North Canadian, except near the middle of Range 3 E., where it flows through a steep, narrow canyon cut over 100 feet into Mesozoic rocks. Here the stream deposits are almost entirely confined to the sediments in the stream channel.

The valleys of the tributaries of the Cimarron River contain stream deposits that resemble those along the master stream except that the width of the deposit generally is less. North Carrizo Creek, however, has a broad flood plain in the area north of Black Mesa; and Gallienas Creek has broad flat bottomlands.

Thickness. Stream deposits in Cimarron County range up to 40 feet thick, or more, in the deepest portion of the valleys. The North Canadian River Valley, downstream from the mouth of Cieneguilla Creek, has been excavated largely in the "Ogallala" formation; and the stream deposits, therefore, overlie the "Ogallala". As the "Ogallala" contains similar materials, they could not be readily distinguished. Water wells measured in this valley range from 7 to 157 feet in depth, but the deeper wells doubtless go through the Recent and Pleistocene deposits to obtain water in the "Ogallala". Hence a reliable figure for the thickness of the valley-fill along the North Canadian is not available.

Along the Cimarron River valley and the valleys of its principal tributaries, the stream deposits overlie Mesozoic and Tertiary formations, and should be distinguished readily from them in drilling; but few well logs are available. The driller of the Alliance Insurance Company irrigation well, in sec. 4, T. 5 N., R. 7 E., reported sandstone at a depth of 40 feet. This doubtless was the bed rock and the materials above it can all be assigned to the valley-fill. At Watson's Crossing and at Kenton, the bridge builders reported the depth to bedrock as 25 or 30 feet. A well in sec. 12, T. 5 N., R. 4 E., (No. 500) on the flood plain north of the Cimarron, about half a mile northwest of the Strong ranch, apparently stopped in the valley-fill at a depth of 26 feet. Other wells measured in the Cimarron River Valley range from 10 to 102 feet in depth, but the deeper ones probably tap water in the Mesozoic rocks. Of 21 wells measured in the valley of the Cimarron, only 4 are more than 40 feet deep; and these may be the only ones that penetrated below the valley fill. Of 13 wells measured in the valleys of tributaries of the Cimarron, only 2 are more than 25 feet deep. Channels of the tributaries range from 2 to 15 feet in depth, as a rule do not reach bed rock, and, therefore, merely suggest thicknesses in excess of 15 feet. Thus, the evidence seems to indicate a maximum thickness of 40 or 50 feet for the stream deposits along the Cimarron and lesser thicknesses along its tributaries.

Character. The channel of the North Canadian River is floored with sand, in which small pebbles are sparingly mixed. Mechanical analyses of samples taken at depths ranging from 1.5 to 8 feet in the river channel showed that the channel deposits are composed chiefly of well sorted, medium-grained sand, but that the coarseness of the sand and the degree of sorting are far from uniform. A sample from a depth of about 15 feet proved to be a poorly sorted fine gravel, in which the largest fraction represented less than 30 percent of the whole (fig. 12, histograms 23-27).

The materials underlying the valley bottom along the North Canadian also consist chiefly of sand. About 39 percent of a sample from the river bank about 4.5 feet above the channel of the North Canadian proved to be fine sand; and 56 percent of

a sample from the bank of the North Fork of Beaver Creek was medium sand (fig. 12, histograms 28 and 30). A sample from a cut bank of another fork of the North Fork was rather poorly sorted. The largest fraction was fine sand and represented only 32 percent of the whole, and about 2 percent was fine gravel. This sample may represent a local terrace deposit (histogram 29, fig. 12). A sample from another branch of the North Fork of Beaver Creek was rather poorly sorted. The largest fraction was only 32 percent fine sand. About 2 percent was fine gravel. This sample came from a cut bank within 10 feet above the channel bottom, and above the level of the lowest "flood plain". It may represent the terrace deposit of the stream at a former stage.

The sands in the channel of Cimarron River are similar to those in the channel of the North Canadian but contain abundant cobbles and boulders. The materials exposed in the cut banks are clay, silt, sand, pebbles, cobbles, and boulders. In general, the gravels are poorly sorted and contain pebbles and cobbles from each of the formations crossed by the stream. Locally, the gravel lenses have been cemented to form conglomerate. The terrace deposits are similar in character but appear to be less well sorted, perhaps because of higher and more erratic stream velocities at the time of their deposition. In places the terrace deposits are continuous with the stream deposits on the bottom lands, and cannot be distinguished from them.

The valleys of the tributaries contain stream deposits that resemble those along the Cimarron, but increase in coarseness toward the headwaters. North Carrizo Creek, in the northwestern part of the county, flows across outcrops of the Dockum, Morrison, and Purgatoire formations, and because of the clay and shale in these rocks, it carries much more fine-grained material than the other tributaries of the Cimarron. North of Black Mesa, its flood plain deposits consist chiefly of silt and fine sand, but locally, as at Tate Butte, its deposits contain lenses of conglomerate in which quartzite and basalt are common. These lenses are in both the cut banks and the terrace deposits that stand well above the banks of the stream.

After Tesesquite Creek had carved its canyon to about its present depth, it deposited from 20 to 30 feet of sediments, the upper 1 to 3 feet of which formed a good, rich, dark-colored soil. In historical times this creek had no channel, but flowed over a well-sodded valley bottom. In 1914 and 1924 excessive floods cut the present channel, which is from 4 to 15 feet deep, and exposed the older stream deposits. These consist of poorly sorted lenticular masses of clay, silt, sand, and gravel, and are red, brown, gray, green, and buff in color. In general, the gravel becomes coarser upstream, and in places it is in thick beds. It includes pebbles and cobbles of basalt similar to the basalt on Black Mesa and in northeastern New Mexico. The pebbles and cobbles must have been derived secondarily from deposits of older streams of the area which flowed at higher levels than the present streams. Tesesquite Creek does not have access directly to the lava.

Cold Springs Arroyo and South Carrizo Creek have had a history similar to that of Tesesquite Creek, and the stream deposits exposed in these valleys are much like those in Tesesquite Valley. Along Cold Springs Arroyo, the deposits contain much reworked Dakota sandstone, silt, and pebbles from the Tertiary rocks.

Gallienas Creek Valley probably contains more alluvium of Recent age than other valleys in the area. In Colorado this stream crosses areas of sandy soils, active dune sand, and the easily eroded Dakota sandstone, and much of the material picked up from these sources is deposited in Cimarron County where its gradient is relatively low. Gallienas Creek is the only creek in northwestern Cimarron County that is depositing sediments along much of its course. The valley fill consists chiefly of fairly well sorted, fine-grained sand and silt, with considerable gravel. The gravel contains pebbles of quartzite from the Morrison formation and the Dakota sandstone, and pebbles of the harder but non-quartzitic phases of the Dakota. These gravels occur as lenses both in the cut-banks of the stream and in terrace deposits at higher levels. In places the deposits of Gallienas Creek include red clay derived from the shaly parts of the Morrison formation.

The tributaries of the Cimarron River east of U. S. Highway 287, and the stream deposits in them, are enough alike so that they can be considered together. The cut-banks contain valley fill to a depth of 12 or 15 feet. It consists of lenticular masses of clay, silt, sand, and a little gravel. The gravel contains pebbles derived from the "Ogallala" formation and cobbles of basalt, the latter weathered to a dark reddish brown. The stream deposits are dark brown, buff, gray, and green in color, and in general are similar to the deposits of the other tributaries of the Cimarron River. Locally they contain an abundance of small mollusks.

Stratigraphic relations. The valley-fill overlies, unconformably, all formations from the Dockum, of Triassic age, to the "Ogallala", of Tertiary age. It overlies the older rocks in the western part of the county where the valleys are deeper, and overlies the "Ogallala" in the eastern part. Locally it is overlain by dune sand.

Fossils. The fossils from the valley fill and terrace deposits of Cimarron County include bones and teeth of elephants of Pleistocene age. They were found at several widely separated localities along the Cimarron River and its tributaries and along the North Canadian River, as follows:

Fossil Elephants Discovered in Cimarron County, Oklahoma

1. *Elephas columbi*—teeth and fragments of leg bones. Found on a tributary of North Carrizo Creek, in the NW¼ sec. 18, T. 6 N., R. 1 E., on the Tucker farm. The sediments had been somewhat reworked, suggesting that the fossils had been moved since first deposited.

2. *Elephas columbi*—upper molar. Found in bed of North Carrizo Creek, east of Black Mesa, in sec. 34, T. 6 N., R. 1 E. Washed into creek from cut bank near Robbers' Roost.

3. *Archidiskodon (Elephas) imperator*—excellent mandible with teeth, portion of skull with one almost perfect tusk. Found in cut bank of the Cimarron River, near the boundary of sec. 4, T. 5 N., R. 1 E. Here the cut bank grades upward into higher sediments without appreciable break.

4. *Archidiskodon imperator*—almost perfect mandible, tusks, and a portion of the pelvis. Associated with great quantities of small fresh-water mollusks. Found in recently enlarged channel of Tesesquite Creek, sec. 27, T. 5 N., R. 1 E. Sediments were reddish clay, sand, and some gravel. Other sediments were well stratified but lenticular. A soil profile of about 1 foot capped the sediments.

5. *Elephas sp.*—femur, in good condition. Found several feet above the bed of a small tributary to South Carrizo Creek in sec. 33, T. 5 N., R. 2 E., in reddish clay, sand, and gravel.

6. *Elephas columbi*—considerable portion, too badly preserved to warrant excavation. Found in barrow pit on the south side of Highway 64, 300 yards west of the bridge over South Carrizo Creek in sec. 15, T. 5 N., R. 2 E. The bones were about 15 feet above the bed of the creek, in the first terrace, in buff to reddish clay.

7. *Elephas columbi*—upper molar. Found in bed of Cimarron River, north of Si Strong's ranch house, sec. 7, T. 5 N., R. 5 E. The cut bank is here about 15 feet high and composed of sand, clay, and gravel. A tooth, tentatively identified by Stovall as belonging to *Equus niobrarensis,* was collected from the plain near the ranch house.

8. *Elephas columbi*—upper molar, in good condition. Found near bed of the Cimarron River, 2.5 miles down stream from the Strong ranch, and had apparently been washed into the Cimarron from a small tributary. Sec. 5, T. 5 N., R. 5 E.

9. *Elephas columbi*—lower molar, in good condition. Found in bed of North Canadian River, sec. 18, T. 2 N., R. 6 E. Derived from cut bank, nearby, from deposits underlying the bottomlands.

Age. The alluvium occupying the stream channels and a few feet of some of the river banks are obviously very young, and Recent in origin. It is not so easy, however, to determine the age of the greater portion of the valley-fill which was itself deposited by the same streams but in much earlier times. It is even more difficult to distinguish phases of the Pleistocene in this area although there is evidence to indicate both an early and middle or

late Pleistocene time for the deposition of the sediments under consideration. Evidences indicating Pleistocene age of the valley-fill, especially along the Cimarron River and its tributaries in the northwestern part of the county, are: The great amount of erosion that has taken place since the eruption of the lavas capping Black Mesa (fig. 9); the presence of basaltic cobbles in the valley-fill along the streams on the south side of the Cimarron River; the fact that, in some places, the materials in the cut banks are continuous with the terraces that stand well above flood level; the excavation of recesses of considerable size in the walls of the canyons during an earlier phase of the streams; the distribution of the remains of fossil elephants in cut banks and terraces alike; the presence of *Camelops* and *Equus complicatus* in the shelter caves; and the thick soil profile developed in the valley-fill. In view of these facts it is concluded that the caves were developed in early Pleistocene time; that the terrace deposits, also, may be, in part, early Pleistocene, and that the greater portion of the valley-fill along the Cimarron and its tributaries in this area is Pleistocene in age. These conclusions are, of course, not applicable to the materials in the stream beds, nor to several places where the streams are known to have deposited a thin veneer of alluvium on their flood plains.

DUNE SAND

Dune sand occurs in many places in Cimarron County, the main areas being as follows: (a) south of the North Canadian River and east of Felt; (b) on the divide between Cieneguilla Creek and the North Canadian River (Currumpa Creek); (c) north of the North Canadian in an irregular strip extending from sec. 32, T. 3 N., R. 1 E. (Pl. III) eastward and northeastward to sec. 17, T. 4 N., R. 4 E., being best developed in T. 3 N., R. 3 E.; (d) north of the North Canadian, as patches, in T. 2 N., Rs. 6-7 E., and T. 1 N., R. 8 E.; (e) along the Colorado State line in T. 6 N., R. 4 E.; and (f) east of the Cimarron River in T. 6 N., Rs. 8-9 E. Small strips, patches, and isolated hills of sand also occur in places on the bluffs and flood plains of the North Canadian and Cimarron Rivers. The largest of these is a strip about 0.5 mile wide along the north side of the Cimarron between sec. 36, T. 6 N., R. 6 E. and the Colorado State line.

The sand is mostly rather fine-grained and light brown in color. The thickness ranges from a thin film at the margins of the sand dune areas and between some of the sand hills, to about 40 feet. The maximum thickness is based on the assumption that the highest hills in the dune areas are entirely of sand, not hills or ridges of older rocks mantled with sand. Sand pits in a few of the larger dunes indicate that this assumption is justified.

The dune sands of the uplands overlie the "Ogallala" formation of Pliocene and perhaps Pleistocene age, and therefore are not older than Pleistocene. The dune sands on the valley bluffs overlie the "Ogallala" formation, and those on the flood plain overlie the valley-fill. Small, active dunes derived from the sands of the river channels or from the alluvium occur here and there, and are of Recent age. The dune sands, therefore, range in age from possibly Pleistocene to Recent.

Sand dunes similar to those of Cimarron County are widespread in southwestern Kansas. Smith[183] has described these dunes in considerable detail, and has outlined their development. The dunes in Cimarron County, Oklahoma, doubtless were developed in a similar manner.

183. Smith, H. T. U., "Geologic Studies in Southwestern Kansas": *State Geol. Survey of Kans. Bull.* 34, pp. 153-168, 1940.

THE WATER-BEARING PROPERTIES OF THE ROCK FORMATIONS

BY S. L. SCHOFF

The occurrence of ground water, and the possibility of recovering it through wells, are controlled by the texture, thickness and structure of the rock formations, and the chemical character of the water is controlled by the mineral composition of the rocks. The texture of a rock formation governs the ease with which water can enter the formation at the intake area and move through it to points of natural discharge or to wells. The structure of the rocks, together with the topography of the land, determines the size of the outcrop area. The relation of the water-bearing formations to the regional structure and to other formations determines whether the water will occur under artesian or water-table conditions. Because of structural conditions, a water-bearing formation that crops out at the surface at one place may be so deeply buried at another place that obtaining a ground-water supply from it in some localities may be impractical.

Some formations in Cimarron County seem everywhere to yield an abundant supply of good water, but others yield little or no water, or yield water of unsatisfactory chemical character. In the pages that follow, the water-bearing properties of the formations exposed in the county are discussed. The relative importance of the different formations as sources of ground water is indicated by the number of wells drawing water from them.

TRIASSIC SYSTEM

DOCKUM GROUP

The sections in the Dockum group measured by Stovall indicated that about half of the Dockum is shale or clay, a little more than a third is sandstone, and the rest is limestone. In general, shales and clays are rather impervious, but may yield small to moderate supplies of water from joints and cracks where such openings are numerous and interconnected. Sandstones are much better aquifers unless they are too tightly cemented, but most of those in the Dockum are thin. It would be necessary to drill through a considerable thickness of shale in order to penetrate enough sandstone layers to furnish a large supply of water. The limestones in the Dockum range from 1 foot to 18 feet thick, and some of them may yield water from joints and cracks, or from solution channels. Large supplies of water probably cannot be obtained from the Dockum.

Of the wells from which records were obtained, only 6 (1 percent) appear to tap water in the Dockum. Well 515 seems to penetrate only the Dockum, and, therefore, must draw water from it. This is a stock well, and the supply of water probably is adequate for stock use. The low productivity of the water-bearing material is indicated by the report that when a larger well about 75 feet away was pumped for drilling water for an oil-test well, the water in well 515 was drawn down below the cylinder[184].

Well 521 begins on an outcropping sandstone of the Dockum group, and as the well is only 25 feet deep and the water level in it is less than 10 feet below the surface, it may tap water either in the sandstone or in both the sandstone and underlying shale.

Wells 624 and 625 are on the outcrop of the Dockum, but whether they end in it or go into underlying Permian red beds is not known. For one thing, although Stovall's thickest section of Dockum totaled only 66 feet, it is not complete because the base is not exposed. The wells begin many feet below the base of the Exeter sandstone, which marks the top of the Dockum and which is exposed in a ridge to the east; and therefore they probably penetrate below the lowest beds in the measured sections.

Well 614 begins on the lower part of the Morrison formation and probably passes through the Exeter sandstone into the Dockum. Most of the water is reported by the owner to come from red shale at a depth of about 200 feet.

JURASSIC SYSTEM

EXETER SANDSTONE

The Exeter is a massive, fine- to medium-grained sandstone that ranges from 18 to 53 feet in thickness. Three samples, representing the outcrops of the Exeter at two widely separated localities, were tested in the laboratory. Coefficients of uniformity for these two differed widely—1.5 and 11; the coefficients of permeability were obtained from the consolidated samples, and were 5 and 20; the porosities were 22.6 and 35 percent; and the specific yields were 14.8 and 25 percent. (Table XVIII).

184. Witten, E. B., driller, Oral communication, Nov. 1938.

This sandstone where saturated should yield at least moderate supplies of water to wells penetrating it. The water should be under artesian pressure, because the Exeter dips in a general easterly direction from its outcrop near Kenton to the vicinity of the Cimarron River bridge on U. S. Highway 287 north of Boise City, and it is overlain by the less permeable Morrison formation. Water taken into the Exeter at the outcrop, either directly from rainfall or from the streams that cross it, may move eastward down the dip and be under artesian head because of confinement beneath the Morrison. That such is the case is indicated by wells 469 and 480, which are described below.

Of the wells for which records were obtained, only 3 (0.7 percent) seem to tap water in the Exeter. Well 469 begins on the outcrop of the Morrison formation, and as reported by the driller, A. C. Brown, it encountered some water in varicolored shale between depths of 46 and 96 feet and reached a coarse, white, water-bearing sandstone at 96 feet. The water rose in the well above the level at which it was struck, and might have flowed at the surface if the well had been cased. The sandstone probably is the Exeter.

Corroborating this conclusion is the report that a core hole (well 480) drilled about 1.75 miles to the southwest struck artesian water in the Exeter at a depth of about 150 feet, and that the water flowed at the surface until it found a way to escape into lower formations as the well was deepened[185]. Relative elevations are not available, but the core hole was begun at an elevation that probably is enough higher to account for most of the 50-foot difference in depth to the Exeter between the two locations. In the spring of 1941 this well was observed to have been cased. It was flowing a small stream of water that left a white deposit on evaporation.

185. Devin, F. A., Oral communication.

Well 522 begins on the outcrop of the "Ogallala" formation where it is thin, and the well probably enters the older rocks, which should be either the Exeter or the Dockum, or both. Well 523 also begins on the "Ogallala" where it is thin. The owner reported that the water was obtained in a yellowish-white sandstone like that exposed about 0.75 mile down the draw. The exposed sandstone is thought to be the Exeter, and is the one for which the permeability tested as 5. This low coefficient of permeability is verified by the fact that the draw-down in the well is about 7 feet for a discharge of only 1 or 2 gallons per minute.

MORRISON FORMATION

The Morrison formation, of upper Jurassic age, consists of variegated sands and shales and a few beds of limestone, and has a maximum thickness of about 465 feet. Sections measured by Stovall indicate that about 60 percent of the formation is sandstone, somewhat more than 25 percent is shale or clay, and the rest is limestone or dolomite. The sandstones, in part, are thin-bedded, cross-bedded, friable, and fine-grained; some are very quartzitic. Many of them range from a few inches to a few feet in thickness, but a white, crossbedded sandstone in the upper part is 114 feet thick. Some of these sandstones, if saturated, should yield water to wells. Obviously the quartzitic sandstones are only slightly permeable.

The shales may yield small quantities of water from joints and cracks but cannot be expected to furnish large supplies of water to wells. The limestones and dolomites range from an inch to 1½ feet in thickness. Because of their relative thinness, they are unimportant as sources of ground water.

Of the wells for which records were obtained, 18 (4 percent) appear to draw water chiefly from the Morrison formation. To these it may be fair to add the 29 wells (7 percent) that tap pre-Tertiary "red beds" in the area of the red-bed high in the east-central part of the county. The geological identity of these rocks has not been determined with certainty, but the chances are good that they are the Morrison.

Julius Kohler reported to the writer that well 617 taps the "third water" in a sandstone between depths of 63 and 81 feet.

This may be one of the sandstones in the Morrison. The static water level in the well is about 25 feet below the surface, or about 38 feet above the top of the sandstone, despite the fact that the upper water-bearing strata were cased out. Hence, the water in the sandstone is under artesian pressure.

Different water levels are indicated by wells 610 and 618 at the Bangerter ranch. Well 610 is on the slope north of and higher than the house, is 74 feet deep, and is unused. The water level in it has been measured repeatedly in connection with the observation-well program, and has ranged from about 28.5 to nearly 35 feet below the surface. Well 618, on the other hand, begins 15 or 20 feet lower on the slope, but the water level in it is about 56 feet below the surface. This well is about 90 feet deep, and it, therefore, penetrates deeper strata than well 610. The yield was reported to be only 4 gallons an hour, and Houghton[186] found the water from this well to be the most highly mineralized of the 65 Cimarron County waters analyzed by him. Further discussion of the quality of the water from the Morrison will be found in the section on *Chemical Character of the Water.*

Two windmill wells at the Strong ranch encountered water at comparable depths in the Morrison, but in different amounts. As reported by Mr. Strong, well 518 obtained water in sand between depths of 79 and 85 feet, yielded 14 gallons per minute when tested, and in ordinary use yields about 10 gallons a minute. Well 518-a, which is about 100 feet west of No. 518, encountered only a seep at 70 feet, and yields 7 gallons a minute. Both wells passed through alluvium, which is 15 or 20 feet thick, and reached the first water at 26 or 27 feet, about on a level with the nearby Cimarron River. It may be that water from the river seeps through the Morrison toward the wells and helps make possible the yields of 7 and 10 gallons a minute, which are high for windmill wells in any formation in Cimarron County. In this connection it is to be noted that the yield of well 517, which is also in the Morrison but distant from the river, was measured by the writer as 4 gallons per minute.

186. Houghton, H. W., "Water Survey of Cimarron County, Oklahoma": *Panhandle Agri. Exp. Sta. Bull.* 38, No. 25, p. 17, 1930.

Other wells that draw water chiefly from the Morrison formation are listed in the tables of well records. Well 469, described under the *Exeter Sandstone,* draws some water from the Morrison. A few other wells also draw some water from the Morrison but depend chiefly on higher or lower formations.

CRETACEOUS SYSTEM

PURGATOIRE FORMATION

Cheyenne sandstone member. The Cheyenne sandstone member of the Purgatoire formation consists of white to buff sandstone and fine conglomerate. It is porous and moderately permeable, and in places, at least, contains water under artesian pressure. In a 50-foot section Stovall measured 9 feet of conglomerate and 41 feet of sandstone. He reports the maximum measured thickness as 66 feet.

The coefficients of permeability of 3 outcrop samples from the road cut on the east side of 101 pass, about 2 miles east of Kenton, were determined in the hydrologic laboratory of the United States Geological Survey as 3, 50, and 55. The total thickness represented by these samples is about 41 feet, and the weighted average permeability, in which the thickness represented by each sample is considered, is 39. This is only a very moderate permeability, and it is low compared with the coefficients of 280 and 875 that were obtained for 2 samples representing the Cheyenne as penetrated by well 376. The weighted average permeability for the 2 well samples is 577, and probably is much higher than the permeability of the rock in place because of the inevitable loss of the finer grains in the drilling water, the destruction of any cement that may have held the grains together, and the complete rearrangement of the grains. On the other hand, the permeability of the outcrop samples may be lower than that of the sandstone under cover if some cementation, or "case-hardening", of the sandstone has taken place at and near the exposed surfaces. It should be noted, however, that the samples were taken from a road cut where they had been exposed for only a few years, and that cementation prior to the making of the road cut must have affected a zone extending 10 feet or more back from the outcrop if it reached them. Despite this contradictory evidence regarding the

permeability that should be assigned to the Cheyenne, it is clear that the Cheyenne is moderately permeable, should transmit water readily, and should yield it to wells rather freely.

Laboratory tests also were made of other hydrologic properties of the samples of the Cheyenne. (Table XVIII). The mechanical analysis (fig. 11) indicated that the sandstone is mostly fine-grained but locally is medium-grained, and that coefficients of uniformity range from 1.6 to 2.2. The porosities ranged from 19.1 to 37.8 percent, and specific yields ranged from 13.1 to 32.3 percent.

Of the wells for which records were obtained, 7 (about 1.6 percent) appear to draw water chiefly from the Cheyenne, and 3 others draw a part of their water from it. In addition, a few springs issue from it. The Kiowa shale member of the Purgatoire, overlying the Cheyenne, is an impervious confining layer, and the rocks dip gently eastward.

Two wells that flow at the surface, or formerly flowed, probably tap the Cheyenne. Well 364 was drilled in 1938 by A. C. Brown for the J. L. Donley ranch. It reached a depth of 205 feet, and the log shows that it penetrated two zones of sandstone, the first between depths of 80 and 161 feet and the second between depths of 194 and 205 feet. The upper sandstone probably is the Dakota, and the lower one, from which the artesian water comes, probably is the upper part of the Cheyenne. The driller reported that on completion of the well the yield was 10 gallons of water a minute. After a few weeks of unrestricted flow, however, the discharge was measured by the writer as 3.5 gallons a minute, and after several months the well stopped flowing. This failure may have been caused by the continuous withdrawal of water from the well, although the owner was of the opinion that the water was escaping into beds above the water-bearing zone.

Well 367, in the NE¼ sec. 23, T. 4 N., R. 3 E., is only a foot or two above the bed of Cold Springs Arroyo. This is an old well, and little information is available regarding it. It is said to be deep, and as it begins below the top of the Dakota sandstone it probably goes into the Cheyenne. By the fall of 1938 it had almost stopped flowing, and local rumor charged the decline to the flow from the newly drilled Donley well (No. 364), but later events showed that the stoppage was due to plugged casing. In the spring of 1939 the writer measured a flow of 4 gallons a minute from the well, and he was told that the well had been cleaned out during the preceding winter.

Artesian water that did not rise high enough to flow at the surface was found in well 376 on the south side of Cold Springs Arroyo about 0.25 mile south of the Donley ranch house. The log of this well shows two sandstone zones separated by 63 feet of gray shale and fine-grained, bluish-gray sandstone. As the well begins near exposures of Dakota sandstone, the sequence shown in this well clearly is Dakota underlain by the Kiowa shale and the Cheyenne sandstone.

Well 119 indicates that artesian water also may be obtained along the stretch of the North Canadian River that is known in Cimarron County by the name Currumpa Creek. This well is behind the barn at the Lorenzo Lujan ranch, about 2 miles east and 5.25 miles south of Mexhoma. No log is available, but the well begins near the top of the Dakota, and is said to have been drilled to a depth of 200 feet. As the Dakota in this vicinity seems to be thinner than it is in the Cimarron Valley, the well doubtless enters the Cheyenne sandstone. When measured in 1939, the depth of the well was only 83 feet, but the water still stood about 1 foot below the surface. This level was 11.5 feet above the water level in a nearby dug well (No. 120) that taps water in the alluvium.

On the other hand, well 122, at the Rufus Wright ranch, begins on a bench behind a low cliff of Kiowa shale on the south side of the North Canadian River (Currumpa Creek). The mouth of the well is 27 feet above the level of the stream, but the water level in the well, about an hour after pumping stopped, was 39 feet below the surface—that is, 12 feet below the channel. It may be that the water level had not fully recovered from the effects of pumping, but two measurements made 5 minutes apart showed no rise in the water level and indicate that further water-level recovery would proceed very slowly.

Other wells that tap water in the Cheyenne are Nos. 346, 351, 385, 491, 496, and 595. The water from the Cheyenne is similar in quality to that from the Dakota (for details, see section on *Chemical Character of the Water.*)

Kiowa shale member. The Kiowa member of the Purgatoire formation, overlying the Cheyenne sandstone, is predominantly a shale unit. As measured by Stovall, about 86 percent (42.5 feet) of a section in the Kiowa near Kenton is gray to black fossiliferous shale, and about 14 percent (the upper 7 feet) is platy sandstone. This section totals 49.5 feet and is the thickest that was measured, but the log of well 376 indicates that the Kiowa may be as much as 63 feet thick under cover. In some exposures the shale is considerably jointed, and if these joints continue under cover away from the outcrop they may permit the movement of more or less water through the shale. On the whole, however, the shale of the Kiowa is unsatisfactory as an aquifer, and only small supplies of water may be obtained from it at best. The sandstone in the upper part of the Kiowa member probably would yield some water to a well, especially from its many closely spaced-bedding planes, but the extent to which it does so is unknown. In wells it would not be distinguishable from the overlying Dakota sandstone.

No wells are known to draw water chiefly in the Kiowa member, but some of the wells that obtain water principally from underlying formations may also receive a small amount of water from it.

DAKOTA SANDSTONE

The Dakota consists chiefly of massive, cross-bedded, generally friable sandstone, but locally it includes rather thick lenses of shale. The maximum thickness is about 185 feet.

Laboratory tests of hydrologic properties were made for six samples of the Dakota (Table XVIII). The mechanical analyses (fig. 11, histograms 8-13) indicated that the Dakota ranges from fine- to medium-grained and is well sorted. Between 60 and 85 percent of the material in the samples fell in either the "fine" or the "medium" sizes. The coefficients of uniformity ranged from 1.3 to 1.9. Porosities ranged from 27.8 percent to 39.4 percent, and specific yields ranged from 19.3 to 35.9 percent.

The coefficients of permeability of 5 samples from an exposure of the Dakota on the south side of Cieneguilla Creek, 1.5 miles northeast of Delfin School, range from 30 to 255. If allowance is made for the thickness represented by each sample, the weighted average permeability for 55 feet of sandstone is about 110. Saturated sandstone from Flag Spring (No. 513) was found to have a coefficient of permeability of 50, and drill cuttings representing 22 feet of Dakota sandstone in well 376 proved to have a coefficient of permeability of 165. The mechanical analysis of the latter, however, showed much poorer sorting than the samples from the outcrop and suggests that the sample had been considerably contaminated with sand from another source, and therefore is hardly representative of the Dakota.

The high degree of sorting and the moderate permeability indicated by these laboratory tests suggest that the Dakota sandstone should be a fairly good aquifer. If the whole 175 feet of the Dakota were saturated, a well passing through it from top to bottom would obtain an abundant supply of water, but the small size of the springs issuing from it indicates that the Dakota is nearly dry in the outcrop area along the Cimarron River, and probably, also, in a wide band paralleling the outcrop. The Dakota can be fully saturated only at some distance back from the outcrop, under the upland flats.

The water in the Dakota may be under artesian pressure locally where the overlying beds are impervious shales in the Graneros formation or, possibly, silts or clays in the lower part of the "Ogallala". Where sands or gravels of the "Ogallala" rest directly on the Dakota, there is no confining bed and therefore no artesian pressure. In such situations, also, it may be difficult to determine whether a well has entered the Dakota.

Of the wells for which records were obtained, 45 (10 percent) appear to draw water chiefly from the Dakota. Most of them were sunk by drilling, but the one at the J. C. Lujan ranch house (No. 123) is a dug well about 48 inches in diameter. It begins on the outcrop of the formation.

It was found by test that the draw-down of well 359 is 3 feet at a pumping rate of 4 gallons a minute, but otherwise little information on the performance of wells tapping the Dakota is available. Many springs issue at the Dakota-Kiowa shale contact or at the top of shale lenses in the Dakota. They range from seeps discharging a few gallons of water a day to strong springs discharging 20 gallons a minute, or more. Such springs are responsible for the nearly perennial flow of some of the tributaries of the Cimarron River.

The water of the Dakota sandstone, as indicated by the analyses of water samples from several wells and springs in Cimarron County, is rather hard and is similar to the water from the Ogallala formation. (See section on *Chemical Character of Water*.)

COLORADO GROUP

Graneros and Greenhorn Beds. The Graneros and Greenhorn formations consist chiefly of fossiliferous limestone, shale, and sandstone, and have a maximum thickness of 135 feet. Nearly two-thirds of a generalized section prepared by Stovall is limestone, about one-fifth is shale, and the rest is sandstone. On the other hand, more than half of a section that was measured along Cottonwood Creek appears to be clay or shale.

No wells are known to obtain water from the Graneros. The sandstone is in the lower part of the formation and therefore can receive little or no water directly from rainfall except where the overlying shales and limestones have been removed by erosion. For this reason the Graneros in the outliers in T. 4 N., R. 1 E. probably is dry. Where the Graneros crops out in a moderately wide band between the Dakota and the Ogallala, in T. 4 N., R. 2 E., and T. 5 N., Rs. 2 and 3 E., some water that falls on the outcrop may move through the sandstone beds and perhaps through joints in the limestone to wells on the upland flats, but the quantity of water involved probably is small, and at best only supplements larger supplies of water in other formations.

TERTIARY AND QUATERNARY SYSTEMS

"OGALLALA" FORMATION

From the well records that were obtained, it is estimated that about 61 percent of the domestic, stock, railroad, and municipal wells in Cimarron County tap water in the sands and gravels of the "Ogallala" formation. The upland areas are almost entirely dependent on wells for water, nearly all of which is drawn from the "Ogallala." The exceptions are an upland area in T. 3 N., Rs. 7 and 8 E., T. 4 N., R. 9 E., and parts of adjacent townships, where the "Ogallala" is thin and the wells obtain only meager supplies of poor water from the underlying "red beds"; the upland south of the North Canadian River and west of Felt; the upland between Cieneguilla Creek and the North Canadian River; and the upland in the vicinity of Wheeless and Mexhoma, where part of the wells may tap water in the Dakota sandstone.

The existing wells are mostly of small diameter and produce from 1 to about 100 gallons of water a minute. The formation has not been thoroughly tested, however, and it is possible that larger yields could be obtained from properly constructed wells equipped with suitable pumps. Because the "Ogallala" is nearly unconsolidated, it is necessary to case almost every well from the surface to the bottom. Wells intended to yield large quantities of water should be equipped with screens to keep out loose sand.

The water from the "Ogallala" formation is generally of good quality, although rather hard. The details regarding the quality of the water are given in the section on *Chemical Character of the Water.*

The "Ogallala" formation of the Southern High Plains is a vast reservoir that is only partly full of water. The upper part is dry because there is not enough rain to fill it, and because, as Johnson[187] has pointed out, such streams as the North Canadian and Cimarron have cut deeply into the reservoir, and, being partly supplied from it, have drawn the water table down to low levels. The part of the reservoir below the water table is known as the zone of saturation because the spaces between the mineral frag-

187. Johnson, W. D., "The High Plains and Their Utilization": *U. S. Geol. Survey 21st Ann. Rept.*, Pt. IV, p. 644, 1901.

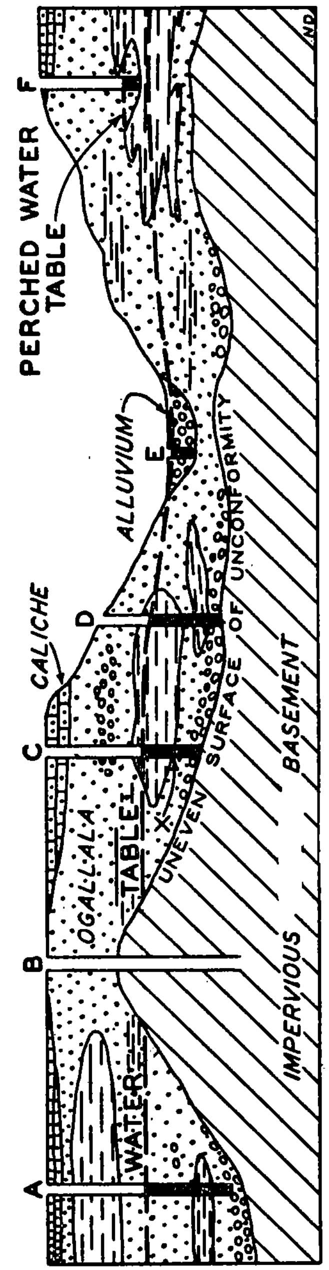


FIG. 10. Generalized cross-section to show the occurrence of water in the "Ogallala" formation. Where the Quaternary formations other than alluvium are saturated, similar conditions are found.

A. Well penetrates a considerable thickness of pervious, saturated sand and gravel, separated into two water-bearing zones by a lens of clay.

B. A hill on the uneven surface of the red bed basement rises above the water table, so that all of the "Ogallala" is dry. The well penetrates the red beds without obtaining water, or perhaps obtain a meager supply of mineralized water.

C. Well encounters a lens of impervious clay at the level of the water table. When pervious sands are entered at X, water fills the hole to the water-table level.

D. Well encounters two clay lenses, and the driller reports two water-bearing beds. Total thickness of saturated pervious materials is about the same as in well C.

E. Valley has been cut deeply into the "Ogallala", drawing the water table down, and the stream has a permanent flow because it is fed from the underground reservoir. The well begins in valley fill (alluvium) practically at the water table, and obtains a good supply of water at slight depth.

F. Well encounters a small supply of water in a perched reservoir.

ments are filled with water. The clays and silts in this zone are also saturated, but the spaces between the individual grains are so small that water moves through them only very slowly. Therefore the strongest wells are those penetrating saturated gravels and sands (fig. 10).

As a rule, no written record is kept of the kind of water-bearing material encountered in farm and ranch wells. Oral statements by owners and drillers, however, were obtained by the writer and by investigators of the State Mineral Survey[188] for about 350 wells that probably draw water from the Ogallala. These indicate that gravel is the water-bearing stratum in about 49 percent of the wells; sand in 19 percent; sand and gravel in 13 percent; sandstone in 11 percent; clay or shale in 3 percent; and limestone, conglomerate, flint rock, or mixtures of clay with sand and gravel in the remaining 5 percent.

The available logs of water wells and test holes drilled near Felt, Boise City, and Keyes, Oklahoma, and at Kerrick, Texas, furnish a record of the character and thickness of the strata in the zone of saturation, and indicate that sands are more important than gravels as aquifers. They also illustrate how the characteristic vertical and horizontal gradations from one kind of material to another in the "Ogallala" affect the relative proportions of permeable and impermeable materials in wells only a short distance apart. (Table XIV and fig. 10). On the average, 36 per cent of the materials in the zone of saturation in the "Ogallala" is sand, gravel, or sandstone, 38 percent is clay, shale, or other impermeable material, and 26 percent is mixed sand, gravel, and clay. The later mixture is relatively impermeable if it consists of clay mixed through the sand and gravel, but is partly permeable if it consists of thin layers of clay interbedded with thin layers of sand or gravel. The averages for the four localities indicate that the zone of saturation in the "Ogallala" contains more permeable material at Boise City, Oklahoma, and Kerrick, Texas, than at Felt and Keyes:

188. Works Progress Administration Project 65-65-538, sponsored and directed by the Oklahoma Geological Survey, 1936-1937.

TABLE XIV.

MATERIALS LOGGED BELOW THE WATER TABLE (OR BELOW DEPTHS AT WHICH FIRST WATER WAS RECORDED) IN THE "OGALLALA" FORMATION.

From well logs furnished by the A. T. & S. F. Railway Company and the Cimarron Utilities Company.

Location	No. of wells	Sand, gravel & sandstone		Clay, shale etc.		Mixed sand, gravel and clay		Total
		Feet	Pct.	Feet	Pct.	Feet	Pct.	Feet
Near Felt	8	137.5	23	271.5	46	184	31	595
Near Boise City	4	140	59	58	25	39	16	237
Near Keyes	6	102	36	94	33	88.5	31	284.5
At Kerrick, Tex.	1	43	65	23	35	......	....	66
Total, all wells	19	422.5	36	446.5	38	311.5	26	1,182.5

These wells were drilled several years before the investigation of the ground-water resources in the county was begun, and no samples of the water-bearing materials were available. Laboratory tests of the hydrologic properties were made for four samples taken from natural exposures and for 1 sample from a well. (Table XVIII). All of the samples that were tested were sand, and they ranged from fine- to coarse-grained. (fig. 12, histograms 31-37). The samples from outcrops were rather poorly sorted. The coefficients of uniformity ranged from 2.2 to 6.7, and the coefficients of permeability ranged from 14 to 3,050. The most permeable sample was sand bailed from a well of the Cimarron Utilities Company in Boise City (No. 278), and may not be representative of the materials in place because it had been disturbed by bailing and because the finer grains had been removed with the water pumped from the well. The porosity of this sample was 36.6 percent, and the specific yield was 33.1 percent.

The permeability of water-bearing sands may also be evaluated roughly by comparing the performance of different wells as indicated by their specific capacities. The specific capacity of a well is the number of gallons of water it will produce per minute for each foot of draw-down (gallons per minute divided by draw-down in feet). It depends on the permeability of the water-bearing sands and gravels and on the construction of the well. It should be higher for wells in gravel or clean, coarse sand than for wells in fine sand, and higher for properly constructed wells than for wells that are poorly constructed or in poor condition. Specific capacities of 4 wells in and near Cimarron County range from 3 to 12, and average 8, (Table XV), a low figure compared with specific capacities of several wells in Texas County. Estimates of the specific capacity of the first large irrigation well at the Experimental Farm at Goodwell range from 16 to 29 gallons per minute per foot of draw-down, and the specific capacity of one of the wells of the General Atlas Carbon Company, at Guymon, is about 63. The experiment farm well yields about 960 gallons a minute, and the Carbon Company well about 628.

TABLE XV.

Specific Capacities of 3 Wells in the "Ogallala" Formation in Cimarron County, Oklahoma, and One Well at Kerrick, Texas.

Well No.	Depth in Feet: To Bottom	Depth in Feet: To Water	Thickness of saturated sand and gravel (feet)	Gallons per minute	Draw-down (feet)	Specific Capacity
284	265	147	21	65	8	8
406	199	133	36	90	10	9
Kerrick	334	264	43	63	21	3
280	382	147	63	111	9.2	12

BASALT FLOW

There are no wells on top of Black Mesa, and therefore no wells in Cimarron County are drawing water from the basalt. Part of the rock is very dense, and its porosity and permeability are both very low. The openings in the vesicular part give the rock a high porosity, and may or may not favor the passage of water through the rock, depending on whether they are continuous. If the rock is jointed under cover, the joints may permit more or less rain water to percolate downward into underlying formations (Pl. XX).

QUATERNARY SYSTEM

Pleistocene and Recent

STREAM DEPOSITS

The sands and gravels of the alluvium, where they are clean and are saturated with water, are excellent aquifers, but the silts and clays, like those in other formations, will yield little water. Because the sands and gravels were deposited in channels that are

now buried, test drilling is necessary to find them and should precede the drilling of wells intended to furnish large supplies of water.

Laboratory tests were made of saturated sands taken from 5 hand-auger and shovel holes in the North Canadian River channel between Felt and Conrad station, and of 3 samples from cut banks along the North Canadian and its tributaries. The sieve analyses show that these materials consist chiefly of fine- to medium-grained sand, but differ considerably in the degree to which they are sorted. In 7 of the samples, the largest fractions ranged from 28 to 71 percent by weight. Another sample, from Conrad station, was a poorly sorted fine gravel. In it the largest fraction was about 27 percent (fine gravel) and the next largest was about 25 percent (coarse sand). The coefficients of uniformity ranged from 2 to 6, and the coefficients of permeability ranged from 12 to 760. The porosities of 5 of the samples ranged from 38 to 63 percent, and the specific yields ranged from 29.9 to 59.2 percent (Table XVIII).

The water from the alluvium is of good quality, on the whole, but differs more from place to place than the waters from the "Ogallala" and Dakota because of mixing with underground seepage from the different older formations (see *Chemical Character of the Water*).

Of the wells for which records were obtained, 50 (12 percent) tap water in the alluvium. Most of them are from 4 to 6 inches in diameter and were put down by drilling, but several are large wells dug by hand. Water from the alluvium is used principally for domestic and stock purposes, and to some extent for irrigation.

DUNE SAND

The dune sands are above the water table, even where the dunes are on flood plains, and therefore no wells tap water in them. Occasionally, after heavy or protracted rains, there may be a thin, perched zone of saturation in the basal part of the dunes because the downward movement of water absorbed by the sands is retarded by less pervious materials below, but the water in this zone would be too limited and too temporary to justify development by wells.

Laboratory tests were made of about 25 samples of dune sand. The mechanical analyses showed that the material consists chiefly of medium-grained sand, although in some samples fine sand predominated. Coefficients of uniformity ranged from 1.6 to 4.8, and coefficients of permeability ranged from 2 to 605. The porosity and specific yield of one sample were 42.1 percent and 33.1 percent, respectively (Table XVIII).

The principal hydrologic importance of the dune sands is the fact that, because of their porosity and good permeability, they take in rain water that ultimately may reach the water table. This subject is discussed further in the section on *Recharge.*

LABORATORY TESTS

The quantity of water that a water-bearing material will yield, and the rate of yield, depend principally on the hydrologic properties of the material. These properties differ greatly even where differences in the texture of the material appear to be negligible, hence ordinary geologic descriptions are inadequate for hydrologic purposes, and laboratory or field determinations of the hydrologic properties are essential.

The hydrologic properties of greatest significance are permeability and specific yield. Mechanical analyses and determinations of porosity and moisture equivalent are indirect means of determining these two essential hydrologic properties.

Many samples, some from natural rock exposures and others from wells, were collected in Cimarron County. Part of them were tested in the hydrologic laboratory of the Geological Survey, United States Department of the Interior, in Washington, D. C., by V. C. Fishel; and part were tested in the laboratory of the Oklahoma Geological Survey, in Norman, by Schoff and others working under his direction.

Mechanical analyses. A mechanical analysis consists of sorting the mineral grains in a sample by sizes, and expressing the weight of the material in each size as a percentage of the weight of the entire sample. Sand and gravel are sorted by passing the material through a set of screens. Fine-grained materials, such

as silt and clay, may be analysed by one of several methods based on the rates of settling of different sized mineral grains in water, but as such materials generally are not water-bearing they were not tested in this investigation.

The mechanical analyses of the sands and related materials were made according to standard methods employing screens that separated the sand grains according to the following approximate sizes:[189]

Descriptive name	Approximate size in mm.
Fine gravel	4 to 2
Very coarse sand	2 to 1
Coarse sand	1 to 0.5
Medium sand	0.5 to 0.25
Fine sand	0.25 to 0.125
Very fine sand	0.125 to 0.062
Silt and clay	less than 0.062

In the work that was done in the laboratory of the Oklahoma Geological Survey, it was found desirable to include a short period of handshaking in the procedure because the available shaking device produced a motion that was chiefly rotatory, without the jarring action of the Rotap machine. Therefore the uniform practice of shaking by machine for 10 minutes and by hand for 2 minutes was adopted. Weights were determined on an analytical balance, recorded to 0.01 gram, and in this paper are reported to 0.1 gram. Percentages were calculated to 0.01 percent and are reported to 0.1 percent.

Some preliminary treatment of the sample prior to sieving was generally necessary. Fragments of vegetable matter had been included accidentally in the outcrop samples, and were removed by washing in water. The sample and the water were shaken or stirred, set aside long enough to allow the mineral grains to settle, and then the vegetable matter was poured off with the water. Some of the mineral grains in the silt and clay sizes doubtless were lost by this procedure, but as the samples consisted chiefly of sand and the settling time was ample to allow for settling of particles of silt size, the losses are negligible.

189. Adopted from Wentworth, C. K., "Methods of Mechanical Analysis of Sediments": *Univ. of Iowa Studies,* new series 117, Vol. II, No. 11, p. 24, 1926.

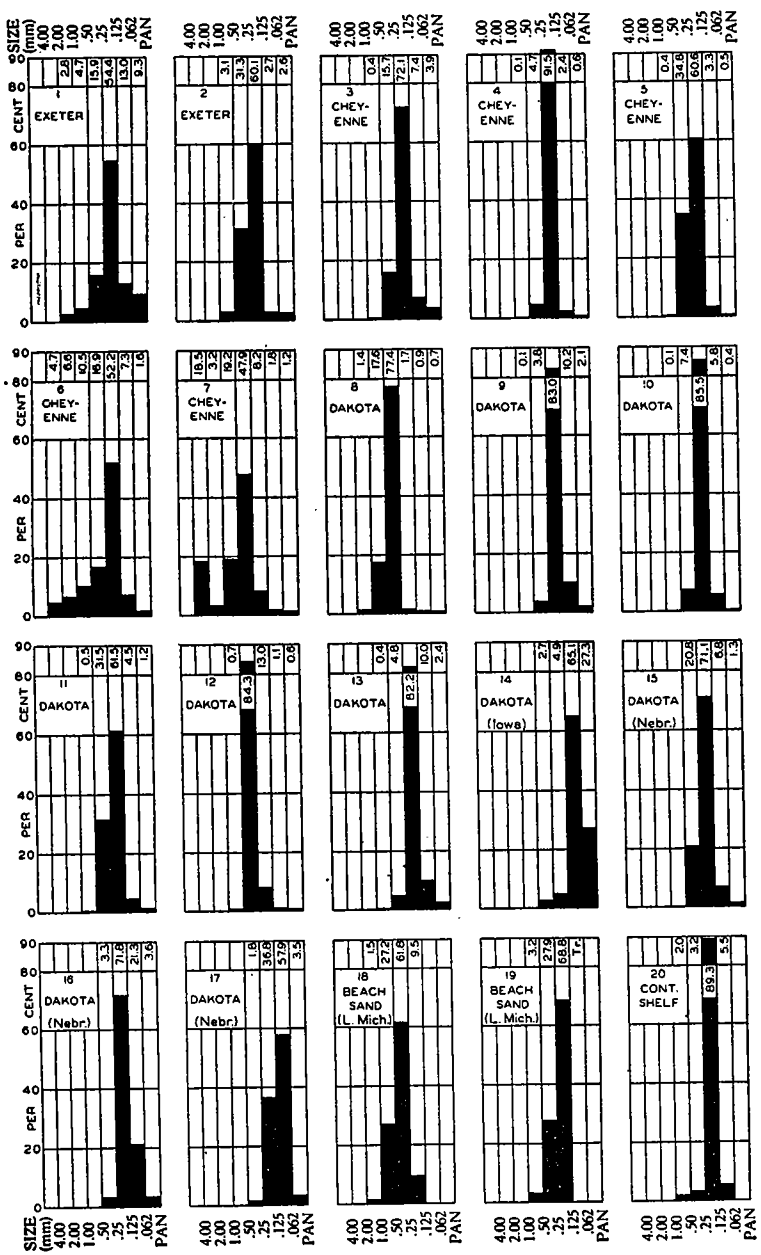


FIG. 11. Histograms showing results of Mechanical Analysis of materials from the Exeter, Cheyenne, and Dakota sandstones, from Cimarron County, Oklahoma, Iowa, and Nebraska; of Beach sand from Lake Michigan; and from the Continental shelf.

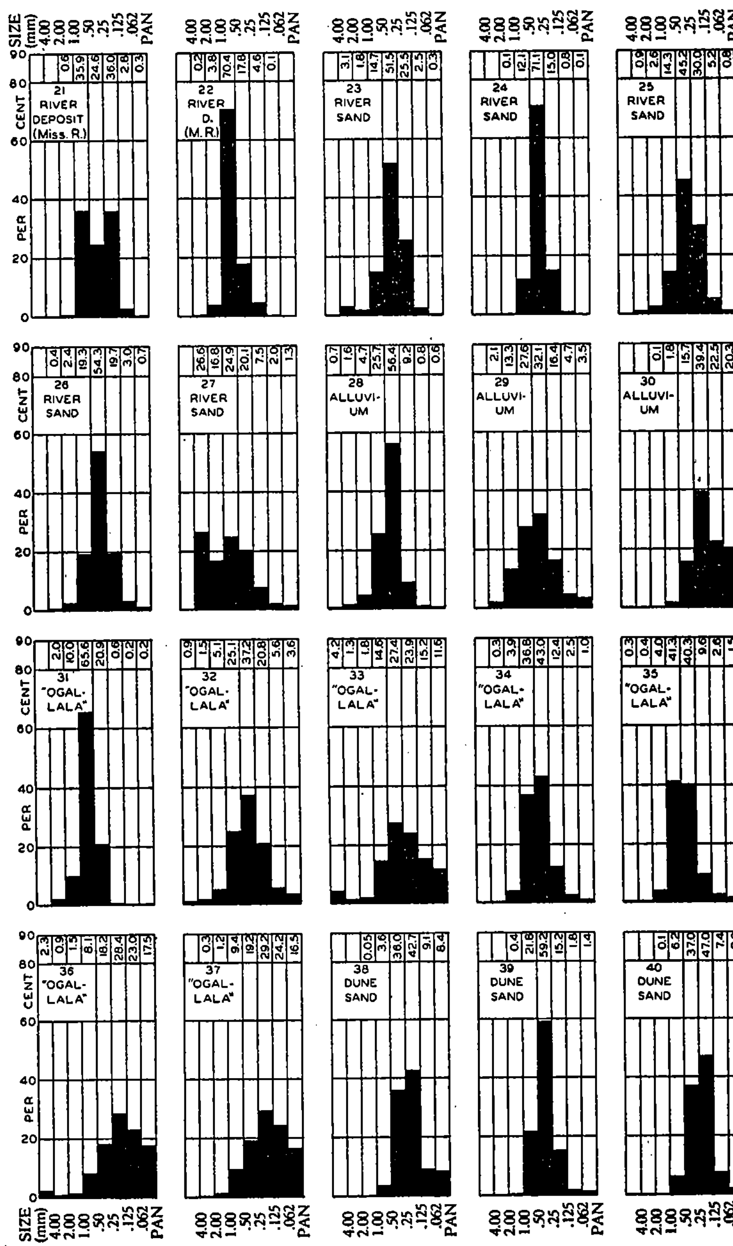


FIG. 12. Histograms showing results of mechanical analysis of Mississippi River deposits, river sand, alluvium, materials from the "Ogallala" formaation, and dune sand. Materials from Cimarron County unless otherwise indicated.

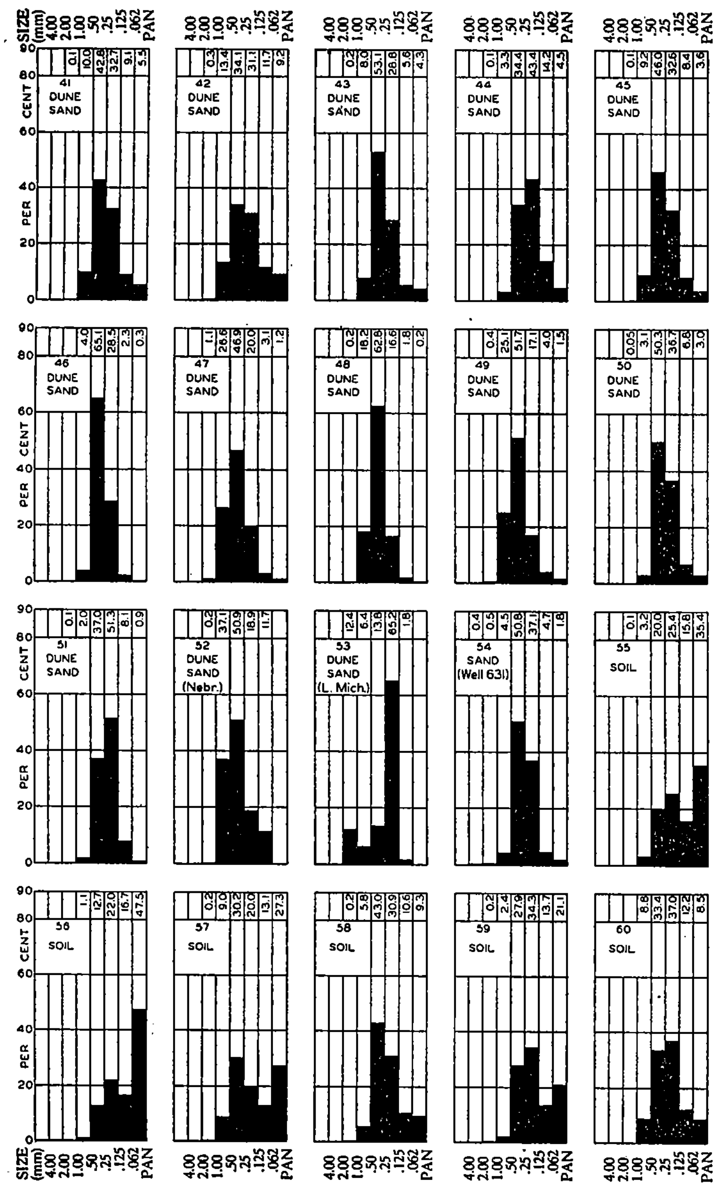


FIG. 13. Histograms showing results of mechanical analysis of dune sand and soil from Cimarron County, Oklahoma; dune sand from Nebraska and Lake Michigan; and sand from well No. 631, Cimarron County.

A few of the samples were treated with 20-percent hydrochloric acid and heated on a hot plate, to remove carbonates, but this step in the procedure was of doubtful value. Where the carbonate was the cementing material, it should have been removed if the analysis was to represent correctly the distribution of mineral grains of different sizes. On the other hand, some of the Tertiary and Quaternary deposits contain fragments of limestone that were deposited along with the quartz and other mineral grains and should be included with them in the mechanical analysis. Furthermore, some of the samples may have contained carbonates both as cementing materials and as detrital fragments. Histograms 34-37 (fig. 12) show the effect of removal of carbonate from two samples, one containing relatively little carbonate and the other containing considerable carbonate.

The mechanical analyses are presented graphically as histograms on which the percentage in each size is indicated in figures. Because two of the samples were analyzed both before and after removal of carbonate, the 49 histograms for Cimarron County materials represent 47 samples. Analyses of 11 similar or related materials, as reported by other authors, are given for comparison with the Cimarron County materials (figs. 11-13).

TABLE XVI.

SOURCE OF MATERIALS REPRESENTED BY HISTOGRAMS

Histogram No.	Description
1	Exeter sandstone, near base, NW¼ sec. 29, T. 5 N., R. 6 E.C.M.
2	Exeter sandstone, north side of U. S. Highway 64 at east end of bridge over Carrizo Creek, near W ¼-cor. sec. 18, T. 5 N., R. 1 E.C.M., after removal of soluble carbonates (13.62%).
3	Cheyenne sandstone, road cut on U. S. Highway 64 on east side of 101 pass, NE¼ sec. 15, T. 5 N., R. 1 E.C.M., represents zone 3.8 to 9.2 feet above base.
4	Cheyenne sandstone, same location as No. 3, 10.3 to 16.6 feet above base.
5	Cheyenne sandstone, same location as No. 3, 16.6 to 44.6 feet above base.
6	Cheyenne sandstone from well 376, sec. 8, T. 4 N., R. 4 E.C.M. Drill-cuttings from depths 133-136 feet.
7	Cheyenne sandstone, same well as No. 6. Drill-cuttings from depths 141-144 feet.
8	Dakota sandstone, south side of Cieneguilla Creek, sec. 10, T. 1 N., R. 1 E.C.M. Represents zone 0 to 10 feet above base.
9	Dakota sandstone, same location as No. 8. Represents zone 10 to 19.5 feet above base.
10	Dakota sandstone, same location as No. 8. Represents zone 19.5 to 31.5 feet above base.

Histogram No.	Description
11	Dakota sandstone, same location as No. 8. Represents zones 31.5 to 39 feet and 47 to 55 feet above base.
12	Dakota sandstone, same location as No. 8. Represents zone 39 to 47 feet above base.
13	Dakota sandstone, Flag Spring, (No. 513) sec. 32, T. 5 N., R. 5 E.C.M. Taken from point of issue of spring.
14	Dakota sandstone from lower 10 to 11 feet of a "classic section" in Sioux City, Iowa.[a]
15	Dakota sandstone, lower 3.5 feet of section about 2 miles south of Homer, Dakota County, Nebraska.[b]
16	Dakota sandstone, a zone 4 to 5 feet in thickness beginning about 11.5 feet above base, same location as No. 15.[c]
17	Dakota sandstone, zone 6 to 7 feet in thickness, near top of section, same location as No. 15.[d]
18	Beach sand, Lake Michigan, Michigan City, Indiana.[e]
19	Beach sand, Lake Michigan, Michigan City, Indiana.[e]
20	Quartz sand and shell fragments, on continental shelf, 30 miles south from Florida coast. Sample contained mostly quartz sand. Steamer Albatross; Station No. 2369; latitude 55°1′0″ N, longitude 160° 12′ 0″ W; depth, 26 fathoms. February 1885.[f]
21	Sand from beach of Mississippi River, Buffalo, Iowa.[g]
22	Sand from bottom of Mississippi River, Rock Island, Illinois.[h]
23	Saturated sand from test hole (142) in channel of North Canadian River near Harmer siding, NW¼ sec. 19, T. 2 N., R. 4 E. C. M. Depth 6.2 to 8.0 feet.
24	Saturated sand from test hole (150) in North Canadian River channel, NW¼ sec. 8, T. 2 N., R. 5 E.C.M. Depth, 2 to 2.5 feet.
25	Saturated sand from test hole (161) in North Canadian River channel, NE¼ sec. 20, T. 2 N., R. 6 E.C.M. Depth 2.2 to 4.0 feet.
26	Saturated sand from test hole (133) in North Canadian River channel at bridge north of Felt, SE¼ sec. 36, T. 2 N., R. 2 E.C.M. Depth 1.5 to 2.0 feet.
27	Saturated sand from test hole (166) in North Canadian River channel at Conrad station, NW¼ sec. 25, T. 2 N., R. 6 E.C.M. Depth 14.5 to 15.2 feet.
28	Alluvium from North Fork of Beaver Creek, SW¼ sec. 12, T. 2 N., R. 9 E.C.M.
29	Alluvium (?) from branch of North Fork of Beaver Creek, sec. 2, T. 2 N., R. 9 E.C.M.
30	Alluvium 4.5 feet above bed of North Canadian River, middle of sec. 10, T. 2 N., R. 5 E.C.M.
31	"Ogallala" formation. Sand bailed from well 278 (Cimarron Utilities Company), Boise City. Depth, probably between 147 and 167 feet.
32	"Ogallala" formation, zone 4.5 to 10 feet above bed of North Canadian River, about ⅛ mi. S. of middle of sec. 10, T. 2 N., R. 5 E.C.M.
33	"Ogallala" formation, upper part of 30-foot layer of sand, about 30 feet above bed of North Canadian River, NE¼NE¼ sec. 22, T. 2 N., R. 6 E.C.M.
34	"Ogallala" formation, from sand layer 14 to 25.5 feet above bed of North Canadian River, SE¼ sec. 10, T. 2 N., R. 5 E.C.M.
35	"Ogallala" formation, same sample as histogram 34 after removal of soluble carbonates (1.43% of the whole).
36	"Ogallala" formation, from 22.5-foot layer of sand, about 20.2 feet above bed of North Canadian River, SE¼SE¼ sec. 22, T. 2 N., R. 6 E.C.M.

Histogram No.	Description
37	"Ogallala" formation, same sample as histogram 36 after removal of soluble carbonates (15.52% of the whole).
38	Dune sand 5 feet below surface in cut on old road to Kenton via OTO ranch, near W ¼-cor. sec. 9, T. 3 N., R. 3 E.C.M.
39	Dune sand from surface of dune, SE¼SE¼SE¼ sec. 11, T. 3 N., R. 3 E.C.M.
40	Dune sand from surface of dune, SW¼ sec. 19, T. 3 N., R. 3 E.C.M.
41	Dune sand, SW¼NW¼ sec. 30, T. 3 N., R. 3 E.C.M.
42	Dune sand from surface of dune, SW¼ sec. 31, T. 3 N., R. 3 E.C.M.
43	"Dune" sand—drifted sand that accumulated at base of yucca plant in a sand dune area, NW¼ sec. 4, T. 2 N., R. 3 E.C.M.
44	Dune sand in an area largely covered by sage. NE¼ sec. 27, T. 1 N., R. 7 E.C.M.
45	Dune sand about 10 feet below surface in west side of cut on the road between Boise City, Oklahoma, and Dalhart, Texas, sec. 6, T. 1 N., R. 5 E.C.M.
46	Dune sand, sec. 27, T. 2 N., R. 1 E.C.M.
47	Dune sand from surface of dune, NW¼ sec. 34, T. 2 N., R. 1 E.C.M.
48	Dune sand, SW¼ sec. 33, T. 2 N., R. 1 E.C.M.
49	Dune sand, on east side of road on New Mexico state line, north of Cieneguilla Creek, SW¼ sec. 7, T. 1 N., R. 1 E.C.M.
50	Dune sand, 10 feet below surface, SW¼ sec. 12, T. 2 N., R. 1 E.C.M.
51	Dune sand from road cut on N. side of U. S. Highway 64, SE¼ sec. 10, T. 3 N., R. 3 E.C.M.
52	Dune sand, from rear slope of a dune near Alliance, Nebraska.[i]
53	Dune sand, near crest of a dune, Michigan City, Indiana.[i]
54	Sand from well 631, SW¼ sec. 23, T. 6 N., R. 7 E.C.M. Depth, 14.5-19.5 feet.
55	Soil, SE¼SE¼SE¼ sec. 13, T. 5 N., R. 7 E.C.M.
56	Soil, SE cor. sec. 30, T. 3 N., R. 8 E.C.M.
57	Soil, SW cor. sec. 30, T. 3 N., R. 7 E.C.M.
58	Soil, NE cor. sec. 19, T. 2 N., R. 7 E.C.M.
59	Soil from wheat field, NW cor. sec. 3, T. 3 N., R. 6 E.C.M.
60	Soil from a field last planted in row crop, sec. 13, T. 2 N., R. 2 E.C.M.

[a] Tester, A. C., "The Dakota Stage of the Type Locality": *Iowa Geol. Survey, Vol.* 35, Ann. Rept. for 1929, histogram 10, fig. 26, p. 239, 1931.
[b] Tester, *op. cit.*, histogram 17, fig. 26, p. 239.
[c] Tester, *op. cit.*, histogram 20, fig. 26, p. 239.
[d] Tester, *op. cit.*, histogram 23, fig. 26, p. 239.
[e] Udden, J. A., "Mechanical Composition of Clastic Sediments": *Geol. Soc. America, Bull. Vol.* 25, samples 106 and 110, pp. 667, 703, 1914.
[f] Udden, *op. cit.*, sample 136, pp. 670, 707.
[g] Udden, *op. cit.*, sample 99, pp. 666, 701.
[h] Udden, *op. cit.*, sample 83, pp. 666, 700.
[i] Udden, *op. cit.*, samples 204 and 218, pp. 678, 681, 714, 715.

Uniformity coefficients. The mechanical analyses show the degree of sorting, or uniformity, of the sediments. Samples that have few sizes represented, and with most of the grains in one size, are well sorted; those with many sizes, no one of which contains a notable preponderance of the grains, are poorly sorted. The degree of sorting can be expressed mathematically by the uniformity coefficient, which is an arbitrary value defined as the ratio of the diameter of a grain that has 60 per cent (by weight) of the sample finer than itself, to the diameter of the grain that has 10 percent finer than itself.[190] The smaller the number representing the uniformity coefficient, the more uniform is the sample.

The uniformity coefficients of the different Cimarron materials are given in Table XVIII. They range from 1.3 to 12, and are discussed in connection with the water-bearing properties of the formations.

Permeability. The permeability of a water-bearing material is its capacity to transmit water under hydraulic head, and the coefficient of permeability, as defined by Meinzer[191], is the rate of flow of water, in gallons a day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60° F.

The coefficient of permeability may be determined by a variety of methods, either in the field or in the laboratory[192]. In this investigation, the variable-head type of discharging permeability apparatus described by Fishel[193] was used, according to standard procedure. The samples ranged from consolidated sandstones to loose dune sand, and included the Exeter, Cheyenne and Dakota sandstones, the alluvium and river-channel sands, the "Ogallala," drill-cuttings from wells, soils, and the dune sand. The soils and the dune sands were tested to determine their relative effectiveness in absorbing rain water that may ultimately reach the water table, and are discussed further under *Recharge of the ground-water reservoir.* Results of the permeability tests are given in Table XVIII.

Porosity and apparent specific gravity. Tests of the porosity and the apparent specific gravity of some of the samples from Cimarron County were made in the hydrologic laboratory in

190. Meinzer, O. E., "The Occurrence of Ground Water in the United States": *U. S. Geol. Survey Water Supply Paper* 489, p. 7, 1923.
191. Stearns, N. B., "Laboratory Tests on Physical Properties of Water-Bearing Materials": *U. S. Geol. Survey Water Supply Paper* 596, p. 148, 1928.
192. Wenzel, L. K., "Method for Determining Permeability of Water-Bearing Materials, with Special Reference to Discharging-Well Methods": *U. S. Geol. Survey Water Supply Paper* 887, 1942.
193. Wenzel, L. K., *op. cit.*, pp. 59-62.

Washington. The procedure was essentially that described by Stearns[194].

Specific yield, specific retention, and moisture equivalent. The specific yield is the amount of water that will drain out of a saturated water-bearing material under gravity, expressed as a percentage of the total volume of the material. It is a measure of the quantity of water that a formation will yield when it is drained by a lowering of the water table, or of the amount of water that has been added when the water table rises. It is less than the porosity of the material because some of the water in a saturated material adheres to the mineral grains. This retained water, when expressed as a percentage of the total volume of the material, is the specific retention. The porosity minus the specific retention is the specific yield.

In this investigation, values for specific retention were obtained by determining the moisture equivalent, correcting it to make it correspond more closely with the specific retention, and subtracting the latter from the porosity. The moisture equivalent is determined by subjecting saturated samples of the material to a centrifugal force approximately 1,000 times the force of gravity. The samples are weighed, then dried and re-weighed. The difference in weight represents the weight of the moisture retained after centrifuging. The moisture equivalent by weight is computed by dividing the weight of the moisture retained after centrifuging by the weight of the dry soil, and the moisture equivalent by volume is computed by multiplying the moisture equivalent by weight by the apparent specific gravity of the material.[195]

If the moisture-equivalent is fairly large, it is nearly equal to the specific retention, and the approximate specific yield may be obtained simply by subtracting the moisture equivalent by volume from the porosity of the material. If the moisture-equivalent is small, a correction must be applied. A graph prepared by Piper[196] to show the relation between the moisture-equivalent and the spe-

194. Stearns, N. D., *op. cit.*, pp. 123-124, 131-133.
195. Stearns, N. D., *op. cit.*, pp. 131-137.
196. Piper, A. M., "Notes on the Relation Between the Moisture-Equivalent and the Specific Retention of Water-Bearing Materials": *Amer. Geophys. Union, Trans.* 14th Ann. Meeting, pp. 481-487, 1933.

cific retention can be used for this purpose, as described by Wenzel[197].

The porosity and the moisture-equivalent were determined in the hydrologic laboratory of the Geological Survey, U. S. Department of the Interior, for 20 samples from Cimarron County. These represent the Exeter, Cheyenne, and Dakota sandstones, the "Ogallala" formation, saturated alluvial sands from the channel of the North Canadian River, and dune sand. As the moisture-equivalents are low, the specific retention was determined from Piper's graph and subtracted from the porosity to obtain the specific yield (Table XVII).

TABLE XVII.

SPECIFIC YIELD OF MATERIALS FROM CIMARRON COUNTY, OKLAHOMA, BY FORMATIONS.

Formation	Number of determinations	Minimum	Maximum	Average
Dune sand	1	33.1	33.1	33.1
Alluvium (N. Canadian R.)	5	29.9	59.2	38.9
"Ogallala"	1	33.1	33.1	33.1
Dakota	6	19.3	35.9	26.8
Cheyenne	5	13.1	32.3	25
Exeter	2	14.8	25.0	20

The sample representing the "Ogallala" consisted of sand bailed from one of the wells of the Cimarron Utilities Company at Boise City, and may or may not be fairly representative, but its specific yield of 33.1 percent is between the average specific yields for the alluvium and the Dakota, and therefore is plausible. It is somewhat higher than the average specific yield for the Cheyenne and Exeter sandstones as might be expected because the latter are rather fine-grained and well indurated. On the other hand, it is much higher than the average specific yield of 13 percent for four samples from outcrops of the "Ogallala" in Beaver County. Although the latter samples may have tested low because of partial cementation on the outcrop, they should not be ignored.

197. Wenzel, L. K., "Geology and Ground Water Resources of South-Central Nebraska": *U. S. Geol. Survey Water Supply Paper* 779, pp. 89-94, 1938.

TABLE XVIII.

LABORATORY TESTS OF OUTCROP AND WELL SAMPLES FROM CIMARRON COUNTY, OKLAHOMA.
(For sources of samples analysed by screening, see corresponding histogram number in Table XVI).

Formation	Laboratory No. [1]	Histogram No.	Uniformity coefficient	Permeability coefficient	Apparent specific gravity	Porosity (percent)	Moisture equivalent (percent by vol.)	Specific yield (percent)
Exeter	2453	1	11	5	1.75	35.0	8.1	25.0
do.	2546	...	...	20	2.06	22.6	5.6	14.8
do.	8965	2	1.5	...	...	...	...	...
Cheyenne	2435	3	2.0	3	2.15	19.1	4.0	13.1
do.	2436	4	1.6	50	2.02	34.9	1.2	32.3
do.	2437	5	1.9	55	2.05	22.9	2.1	19.3
do.	2439[2]	6	2.0	280	1.68	37.8	4.5	31.3
do.	2441[2]	7	2.2	875	1.61	35.2	4.4	28.9
Dakota	2429	8	1.6	255	1.94	27.8	6.5	19.3
do.	2430	9	1.6	50	1.69	37.1	2.8	32.6
do.	2431	10	1.7	155	1.87	30.8	2.7	26.4
do.	2432	11	1.9	30	1.95	27.9	5.5	20.3
do.	2433	12	1.3	90	1.83	39.4	1.9	35.9
do.	2434	13	1.8	50	1.96	35.6	7.6	26.1
Tertiary-Quaternary ("Ogallala")	2421[2]	31	2.2	3050	1.65	36.6	2.0	33.1
do.	C-41	32	3.8	140	...	...	...	...
do.	C-42	33	6.4	14	...	...	...	...
do.	C-44(A)	34	2.7	315	...	...	...	...
do.	C-44(B)	35	2.7	...	...	...	...	...
do.	C-45(A)	36	6.7	15	...	...	...	...
do.	C-45(B)	37	4.0	...	...	...	...	...
Alluvium	2422	23	2.7	350	1.61	38.7	3.5	33.4
do.	2423	24	2.0	760	1.62	38.6	1.9	35.1
do.	2424	25	2.7	270	1.61	63.2	2.4	59.2
do.	2425	26	2.7	420	1.65	40.7	2.3	37.0
do.	2426	27	5.0	44	1.75	37.7	5.6	29.9
do.	C-38	28	2.0	205	...	...	...	...
do.	C-39	29	3.9	165	...	...	...	...
do.(?)	C-40	...	...	95	...	...	...	...
do.	C-43	30	6.0	12	...	...	...	...
Dune sand	C-1	38	3.4	17	...	...	...	...
do.	C-2	...	...	75	...	...	...	...
do.	C-3	39	2.5	270	...	...	...	...
do.	C-4	...	...	2	...	...	...	...
do.	C-5	...	...	100	...	...	...	...

TABLE XVIII.
(Continued)

LABORATORY TESTS OF OUTCROP AND WELL SAMPLES FROM CIMARRON COUNTY, OKLAHOMA.
(For sources of samples analysed by screening, see corresponding histogram number in Table XVI).

Formation	Laboratory No.[1]	Histogram No.	Uniformity coefficient	Permeability coefficient	Apparent specific gravity	Porosity (percent)	Moisture equivalent (percent by vol.)	Specific yield (percent)
do.	C-6	....	....	260	......	......	......	......
do.	C-7	....	....	55	......	......	......	......
do.	C-8	....	....	135	......	......	......	......
do.	C-9	....	....	65	......	......	......	......
do.	C-10	....	....	225	......	......	......	......
do.	C-11	40	2.2	95	......	......	......	......
do.	C-12	41	3.5	70	......	......	......	......
do.	C-13	42	4.8	35	......	......	......	......
do	C-14	43	2.7	225	......	......	......	......
do.	C-16	....	....	70	......	......	......	......
do.	C-20	44	2.7	170	......	......	......	......
do.	C-23	45	2.9	45	......	......	......	......
do.	C-26	....	....	465	......	......	......	......
do.	C-29	46	1.6	405	......	......	......	......
do.	C-30	47	2.7	260	......	......	......	......
do.	C-31	48	2.3	605	......	......	......	......
do.	C-32	49	2.7	210	......	......	......	......
do.	C-33	50	2.5	160	......	......	......	......
do.	C-34	....	....	90	......	......	......	......
do.	2427	51	2.1	120	1.52	42.1	7.0	33.1
Sand	C-36[2]	54	1.9	235	......	......	......	......
Soil	C-15	....	....	45	......	......	......	......
do.	C-17	55	8.0	11	......	......	......	......
do.	C-18	....	....	22	......	......	......	......
do.	C-19	56	7.5	4	......	......	......	......
do.	C-21	57	12.0	18	......	......	......	......
do.	C-22	58	4.0	50	......	......	......	......
do.	C-25	59	7.0	60	......	......	......	......
do.	C-27	....	....	145	......	......	......	......
do.	C-28	....	....	25	......	......	......	......
do.	C-35	60	3.7	85	......	......	......	......
do.	C-37	....	....	30	......	......	......	......

[1] Laboratory numbers pre-fixed with "C", and number 8965, were tested in the Oklahoma Geological Survey laboratory; the rest were tested in the U. S. Geological Survey laboratory.
[2] Sample bailed from well.

OBSERVATION WELLS

To obtain a record of the fluctuations in water level that occur normally, 24 wells in different parts of Cimarron County were selected for observation, and periodic measurements of water levels in them were begun in July 1938. (figures 14-16). Subsequently, 7 other wells were added to the observation program, but 7 wells of the original group had to be dropped as they caved in, were put into regular use by owners, were sealed so as to be inaccessible, or otherwise proved unsatisfactory. The total number of observation wells at the end of 1941 therefore was the same as at the beginning.

Descriptions of the observation wells and records of the water-level measurements in them, with summaries of the average changes of water level, have been published in the series of annual reports by the Geological Survey, United States Department of the Interior, entitled "Water levels and artesian pressure in observation wells in the United States"[198].

Topographic and geologic relations. The observation wells represent a variety of topographic conditions. Of the 31 wells that have been used for observation, 18 are on the upland plains; 6 are on the upland plains near a lake or pond; 1 is in an area of sand dunes; 4 are in river valleys; and 2 are on the slopes intermediate between the upland plains and the valley bottoms. Geologically, 22 of the wells tap water in the "Ogallala" formation or the Dakota sandstone, or both; 2 in the alluvium of the North Canadian and Cimarron Rivers; 2 in the alluvium and underlying rocks; 4 in rocks of pre-Cretaceous age, probably the Morrison formation; and 1 in the Dockum.

WATER-LEVEL FLUCTUATIONS

Fluctuations caused by precipitation. When the soil is saturated, a part of the precipitation seeps down through it and is added to the water stored in the zone of saturation. The added water raises the water level in the reservoir, and, of course, raises the water level in wells. In general, recharge from precipitation occurs more frequently where the water table is near the surface

198. *U. S. Geol. Survey Water Supply Papers* 840, 845, 886, 909.

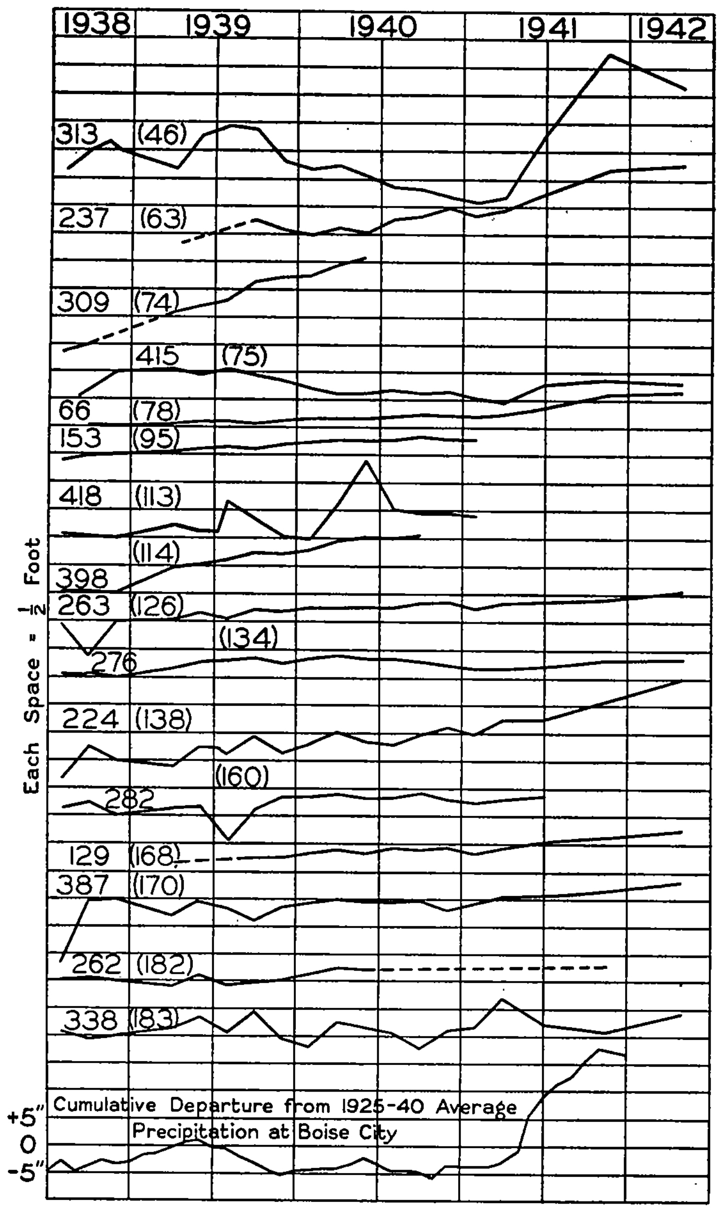


Fig. 14. Hydrographs for observation wells in the "Ogallala" formation compared with precipitation at Boise City. Figures in parenthesis are approximate depths to water at beginning of record.

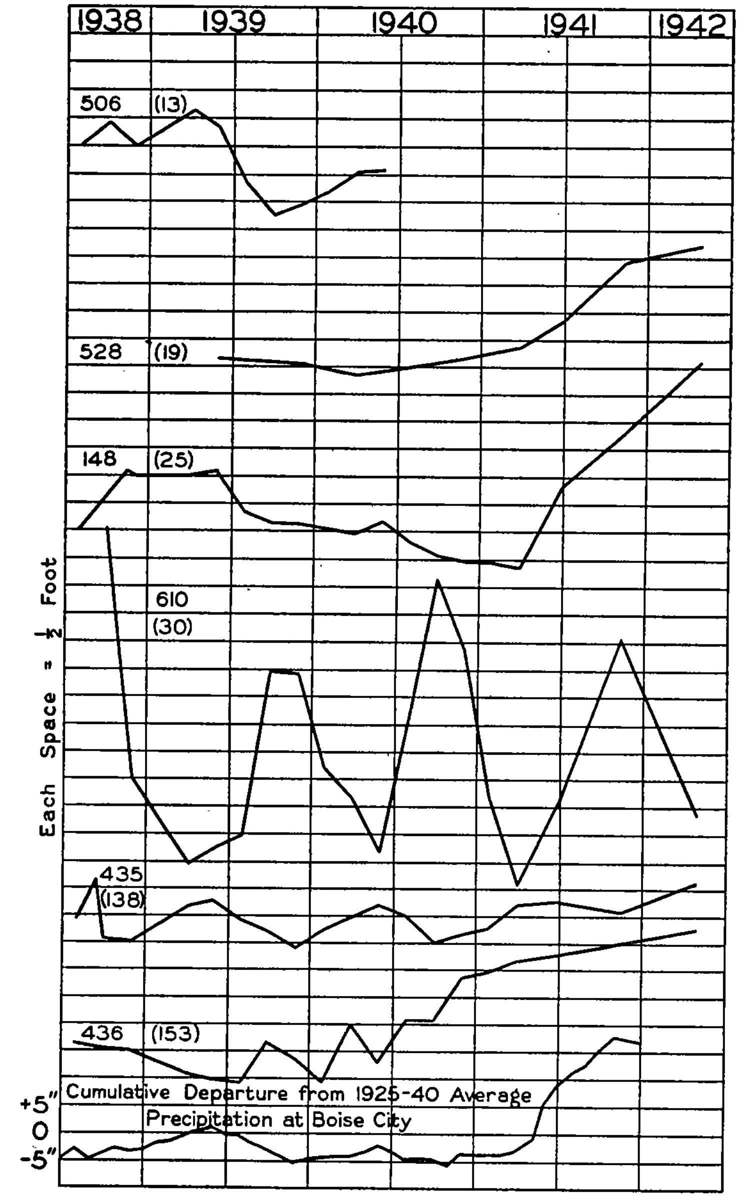


Fig. 15. Hydrographs for observation wells in alluvium (Nos. 506, 528, and 148), in the Morrison formation (No. 610), and in red-beds (Nos. 435 and 436) compared with precipitation at Boise City. Figures in parenthesis are approximate depths to water at beginning of record.

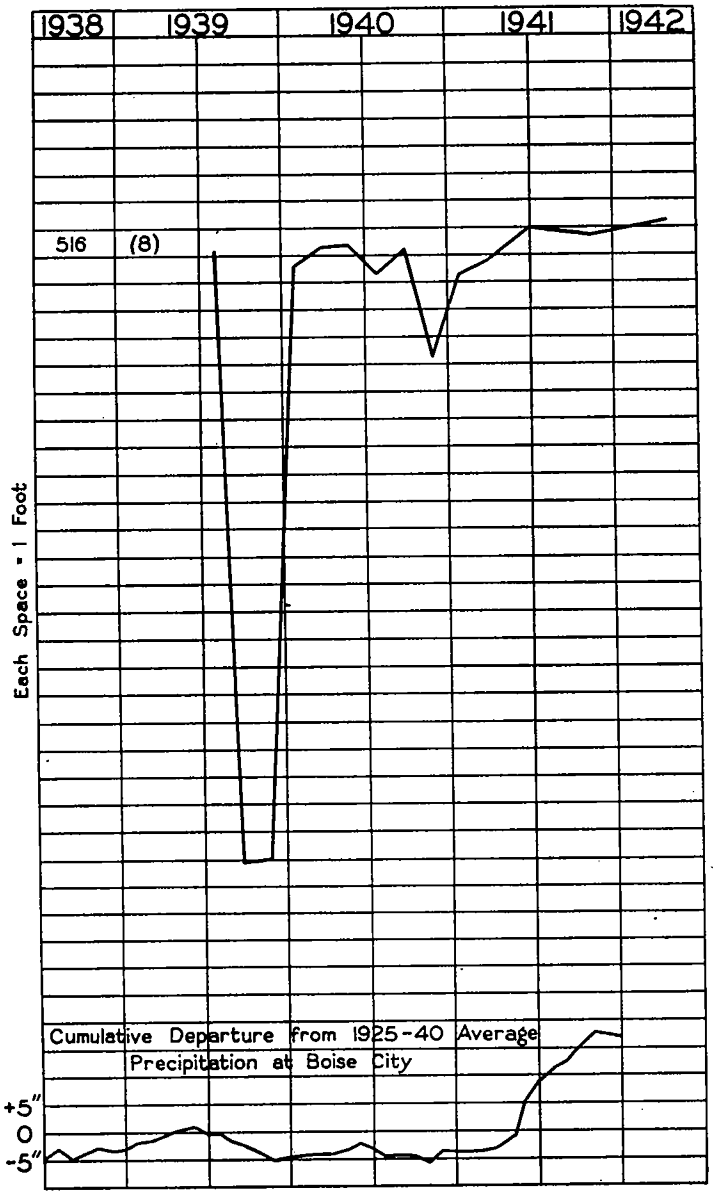


Fig. 16. Hydrograph for observation well 516, in the Dockum formation, compared with precipitation at Boise City. Figure in parenthesis is approximate depth to water near beginning of record.

than where it lies deep. The water levels in shallow wells along the rivers of Cimarron County rose several feet in response to the heavy precipitation of 1941, but water levels in deep wells have risen much less and have shown no evident relation to individual rains. Over the period of record, however, the water levels have risen in most of the observation wells and the weighted averages of water levels have shown that recharge has occurred.

Fluctuations caused by discharge. The natural discharge of ground water into effluent streams and through springs, and by the transpiration of plants or by evaporation, decreases the amount of water in storage and lowers the water table. Discharge is opposed by recharge, and whether the water level rises or declines depends on which is greater. Effects of natural discharge are likely to appear most promptly and to be largest where the water table is near the surface, as along streams.

Discharge by pumping wells has the same effect as natural discharge, and will lower the water levels for some distance in all directions. Cimarron County observation wells 240, 262, 276, 309, and 387 are windmill wells in use, and water levels in them may show some effect of the pumping although as a rule the measurements have been made only when the windmills have been idle for several hours. Well 275 is about 300 feet from a deep well with a pumping capacity of about 100 gallons a minute, which, however, has been used but little since water level measurements were begun. It is about 80 feet from a windmill well, also, but the measurements have shown no obvious effect of the pumping because they have generally been made when the mill had been idle for long periods. Well 528 is an irrigation well that has been used somewhat during the period of record, and the autumn water levels in it may show slight effects of the pumping.

Fluctuations caused by changes of atmospheric pressure. Where an impervious confining bed overlies the zone of saturation, the water levels in wells that penetrate the water-bearing formation may fluctuate in response to changes in atmospheric pressure. The pressure on the water surface in a well increases with an increase of atmospheric pressure. If this increase in pressure is transmitted freely through the interstices of the soil and other materials above

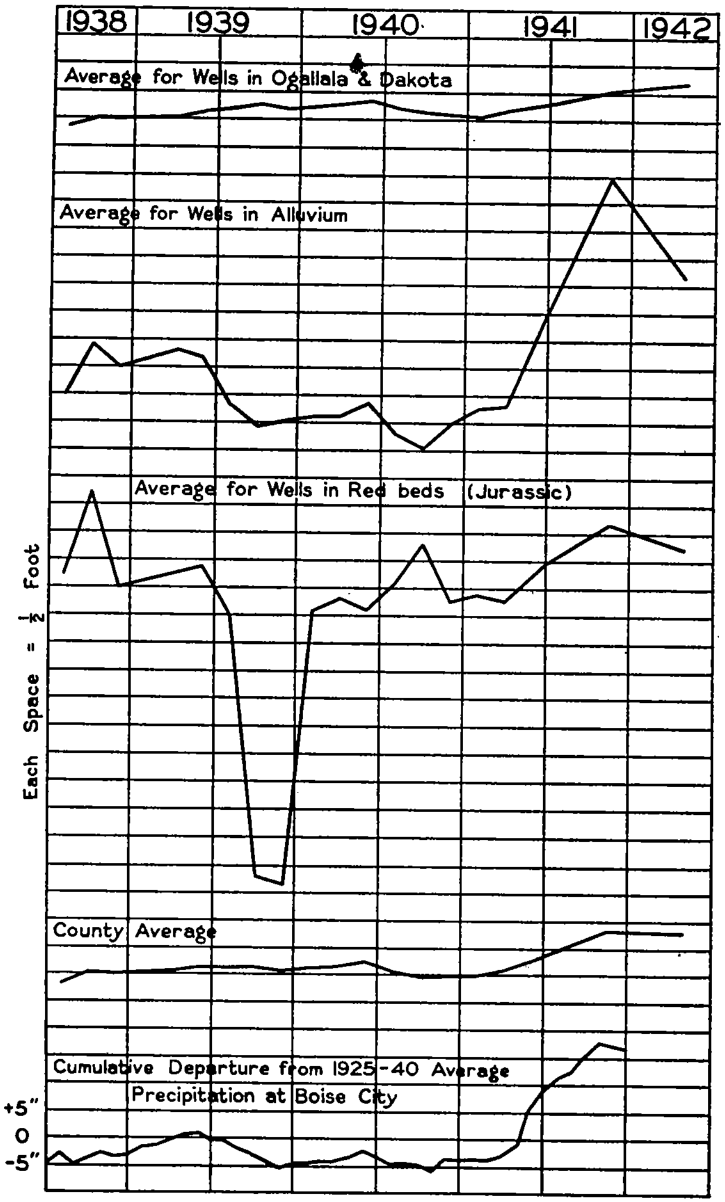


FIG. 17. Hydrographs showing averages of water levels in observation wells in different aquifers, and a weighted county average, compared with precipitation at Boise City. The county average does not include the "red bed" wells.

the zone of saturation, the pressure will be no greater on the water surface in the well than on the ground-water surface elsewhere in the vicinity, and no fluctuation of water level will occur in the well.

On the other hand, if the pressure is not transmitted to all of the ground-water surface, but acts only on the exposed water surface in the well, the water level in the well will decline with an increase in atmospheric pressure, and will rise with a decrease in pressure. In some parts of the United States where the ground water is confined under pressure, the water levels in wells have been observed to fluctuate several feet in response to changes in atmospheric pressure.

Moderate to large fluctuations of water level may occur in wells in Cimarron County that tap the older formations, such as the Cheyenne, the Morrison, and the Exeter, but they have not been observed. Measurements of water level were made in well 224 over a period of 7.5 hours during which readings of an aneroid barometer showed a decline of 0.108 inches in atmospheric pressure. In a well showing perfectly the effects of change in at-

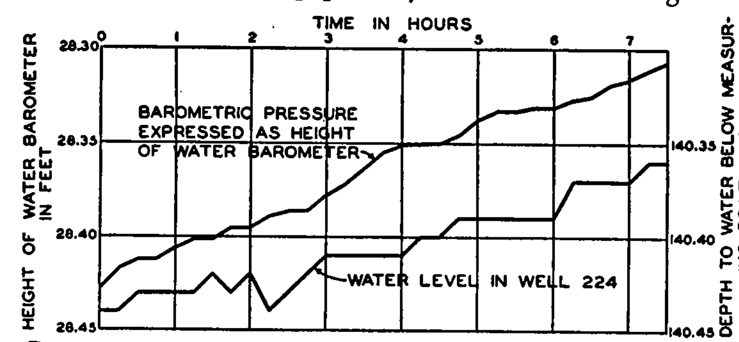


FIG. 18. Fluctuation of water level in well 224 compared with fluctuations of barometric pressure.

mospheric pressure, the corresponding water-level fluctuation should have been about 13.5 times greater than the barometric fluctuation as measured in inches of mercury, or about 0.12 foot (1.46 inches). The water-level fluctuation in well 224, however, was 0.08 foot, indicating that the well is about 66 percent efficient as a barometer (fig. 18). This response of the water level in the well to changes in atmospheric pressure indicates clearly that the water is under artesian pressure.

The water level in the well showed a rise that was similar to, but less than, the atmospheric pressure expressed in terms of height of a water barometer. It also appears to be less regular, perhaps because the water level responds imperfectly to changes in atmospheric pressure, but more probably because the water levels could not be measured as accurately as the barometer could be read.

A similar test was made in well 418, but was inconclusive. Over a period of 2 hours and 20 minutes, the atmospheric pressure declined only 0.04 inch. The corresponding decline for a water barometer would be 0.54 inch, or .045 foot. Meanwhile the water level in the well remained essentially stationary.

Magnitude of fluctuations. Water-level fluctuations in the individual observation wells ranged from 0.25 foot to about 23 feet during the period July 1938 to April 1942. In general, the water levels have fluctuated more widely in the shallow wells than in the deep wells. The widest range in water-level fluctuation was recorded in well 516, which penetrates thin alluvium and the underlying Dockum group in a shallow tributary to the Cimarron River. From August 1939 to the end of April 1942, the water level in this well generally stood between 5 and 10 feet below the surface, but in September and November 1939 it was nearly 25 feet below the surface (fig. 16). The following explanation of this large fluctuation in water level is offered:

The alluvial fill in the valley is a perched reservoir of limited capacity (fig. 19). The water table in it is independent of the water table in the underlying Dockum group, because the Dockum is relatively much less permeable and the water seeping into it from the alluvial fill is insufficient to raise the water table in it to the base of the alluvial fill. The fill consists only of a thin, narrow strip down the axis of the valley, and the water in it is slowly percolating downstream by underflow. This water maintains the spring about 100 feet west of the well, usually stands at a level high enough to enter the well, and doubtless contributes to the Dockum through the well. The last half of 1939, however,

was very dry, and the water level in the alluvial fill became so low, as indicated by low flow observed in the spring, that the fill near the well may have been entirely dry. Under such conditions, the water level in the well would decline to the level of the water table in the Dockum formation.

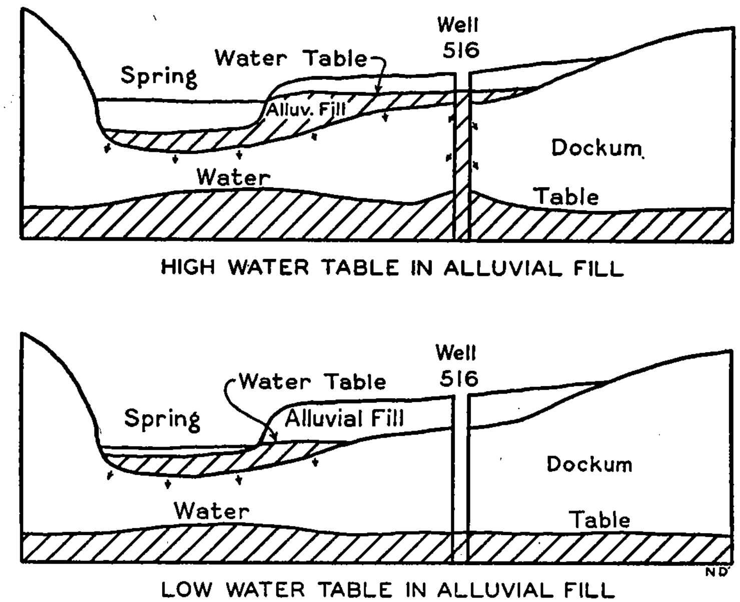


Fig. 19. Relation of the water level in well 516 to the water tables in the alluvium and in the Dockum.

The second widest fluctuation in water level (6.48 feet) occurred in well 610, which appears to tap water in the Morrison formation. An adequate explanation for the fluctuations is not at hand, but they may in part be related to the low specific yield of the Morrison in the vicinity of the well.

Aside from wells 516 and 610, described in the two preceding paragraphs, the greatest fluctuations of water level have occurred in the shallower wells. This relation between the depth to the water and the magnitude of the water-level fluctuations is brought out by Table XIX. As the shallower wells are also the wells that tap water in the alluvium along the major streams, it may also be said that the greater water-level fluctuations occurred in the alluvium.

TABLE XIX.

FLUCTUATIONS OF WATER LEVEL IN OBSERVATION WELLS, IN RELATION TO AQUIFERS AND TO THE DEPTH TO WATER, JULY 1938 THROUGH APRIL 1941.

Aquifer	Depth to Water (feet)	No. of Wells	Maximum fluctuations of water level in feet. Minimum	Maximum	Average	Mean
Alluvium-Dockum[1]	6 -	1	......	23.20	23.20	23.20
Alluvium[2]	13-25	3	1.86	3.73	2.66	2.79
"Ogallala"[3]	46-100	6	0.43	2.70	1.26	1.56
"Ogallala"[3]	100-150	6	0.40	1.84	1.06	1.12
"Ogallala"[3]	150-183	7	0.25	1.51	0.85	0.88
Morrison?	30 -	1	......	6.48	6.48	6.48
Red beds (Morrison?)	138-153	2	1.24	2.84	2.04	2.04

1 Well 516.
2 Includes 2 wells that penetrate beds below the alluvium.
3 Observation wells in the western part of the county that probably tap water in the Dakota sandstone are considered with those in the Ogallala.

Average changes in water level. The water levels in the observation wells in Cimarron County have been averaged in groups according to aquifers. The largest group consists of wells tapping the "Ogallala" formation and, locally, the Dakota sandstone. The other groups represent the alluvium along the major streams, the pre-Cretaceous rocks, and the combined alluvium-Dockum in well 516 (Table XIX).

Weighted averages to represent the average changes in groundwater levels in the county have been prepared by assigning to the wells in the "Ogallala"-Dakota and to wells in the alluvium values corresponding to the relative areas in which these formations are significant aquifers. For this purpose, the "Ogallala"-Dakota group of wells has been counted as 90 percent, and the alluvium group as 10 percent. (Table XX, column 5). The group representing the pre-Cretaceous rocks has been omitted in averaging because these rocks are relatively unimportant as aquifers, and the water-level fluctuations in two of the observation wells in them have been so great that they would completely mask the changes occurring in the other aquifers, even if very small values were assigned to them.

TABLE XX.

AVERAGE CHANGES IN WATER LEVEL IN OBSERVATION WELLS, IN FEET ABOVE DATUM PLANES[1].

Date	Wells tapping Ogallala and Dakota	Wells tapping alluvium	Wells tapping pre-Cretaceous rocks	Weighted County average[2]
July 1938	99.86	99.51	100.25	99.82
Sept.	100.00	100.43	101.76	100.04
Nov.	100.00	100.00	100.00	100.00
April 1939	100.03	100.32	100.24	100.06
May	100.15	100.20	100.40	100.15
July	100.19	99.33	99.50	100.10
Sept.	100.28	98.96	94.82	100.15
Nov.	100.19	99.05	94.68	100.08
Jan. 1940	100.23	99.12	99.62	100.12
Mar.	100.29	99.12	99.86	100.17
May	100.34	99.38	99.63	100.24
July	100.21	98.81	100.12	100.07
Sept.	100.13	98.57	100.85	99.97
Nov.	100.10	99.01	99.78	99.99
Jan. 1941	100.07	99.28	99.91	99.99
Apr.	100.19	99.31	99.81	100.10
June	100.32	101.08	100.53	100.40
Nov.	100.56	103.47	101.21	100.85
Apr. 1942	100.70	101.66	100.74	100.80

1 Figures shown in this table differ slightly from those published in similar tables in U. S. Geol. Surv. Water-Supply Papers 886 and 909, because well 435, which originally was thought to tap water in the "Ogallala" formation, has been withdrawn from the "Ogallala"-Dakota group of wells and added to the pre-Cretaceous group.
2 Wells tapping "Ogallala" and Dakota, 90 percent; wells tapping alluvium, 10 percent.

GROUND WATER SUPPLIES AND DEVELOPMENT

SHAPE OF THE WATER TABLE AND MOVEMENT OF THE GROUND WATER

The general shape of the water table under the upland plains of Cimarron County is indicated on the map (figure 20), by means of lines of equal elevation on the water table, referred to sea level. Together they show the configuration of the water table just as contour lines on the land surface show the topography. The direction of movement of the ground water is ordinarily at right angles to these lines in the direction of maximum slope.

The water-table contour lines show only the altitude of the water table in the "Ogallala" formation. They have not been extended into the Cimarron Valley because the "Ogallala" has been stripped from that area by erosion, and the water levels measured

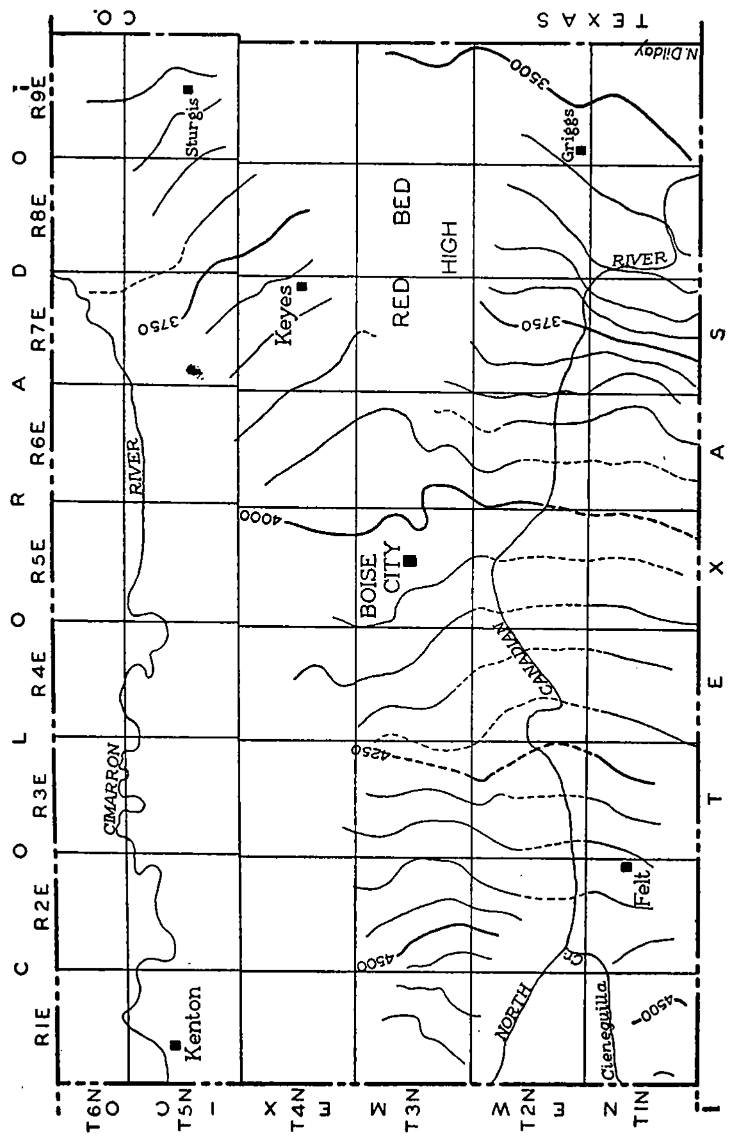


FIG. 20. Water table in the "Ogallala" formation under the upland plains in Cimarron County, Oklahoma. Contour interval, 50 feet.

in wells there represent several different formations. Some of the ground water in this area may occur under water table conditions, but some is under artesian pressure and the water levels in wells tapping this water show the pressure, or piezometric, surface, not a water table. A contour map showing these water levels as a single water table obviously would be erroneous. No attempt has been made to draw water table or piezometric contours for water in the pre-"Ogallala" formations because the wells in the Cimarron Valley are widely scattered and the data obtained are therefore inadequate.

As shown by the map, the average slope of the water table is 25 or 30 feet per mile in an easterly direction, but it is far from uniform. The maximum slope shown on the map is 60 feet per mile in the central part of T. 1 N., R. 7 E.; the minimum, immediately east of Boise City, is 11 feet per mile. The average slope is about 30 feet per mile between Wheeless and Boise City, but it decreases to about 17 feet per mile between Boise City and Sturgis. From Felt to the eastern part of T. 1 N., R. 6 E., the average slope is about 21 feet per mile, but eastward toward the North Canadian River it steepens abruptly. From Boise City southeastward to Griggs the average slope of the water table is 25 feet per mile, just about equal to the county average.

The general easterly slope of the water table is interrupted in T. 3 N., Rs. 7-8 E., T. 4 N., R. 9 E., and parts of adjacent townships by a "red bed" hill or ridge that rises above the level at which the water table in the Ogallala might otherwise occur. The red beds act as a buried obstruction and interrupt the movement of the water. Ground-water levels are about 100 feet higher in most of T. 4 N., R. 7 E., on the northwest side of the obstruction, than on the south side, and suggest that ground water is "ponded" behind the obstruction. More or less irregularity in the water table is to be expected around the red bed area because the hill or ridge was not smoothly rounded.

Local irregularities on the water table may be caused by unequal addition of water to the ground-water reservoir at different places. The water added to the reservoir tends to build up mounds because the resistance offered by the sands and gravels prevents it from spreading out as rapidly as it would on the surface of a lake. No clear-cut mounds traceable to this cause appear on the map, although it seems that there should be one under the sand hills in T. 3 N., R. 3 E. The contour lines in this locality are bowed slightly to the east, but not significantly more so than at other places in the area.

Other high areas in the form of water-table ridges are to be expected under dry ravines and tributaries that flow only when storm waters are to be carried away. The channels of such streams are above the water table and part of the water seeps into them. Descending to the under-ground reservoir, this water builds up a ridge on the water table, which slopes away from the stream rather than toward it. Such streams are termed "influent" because water is added to the reservoir through them. Water-level measurements in wells along the streams of Cimarron County are too meager to show such water-table ridges on the map. It is believed that the North Canadian River is influent at times, at least, in some stretches, but detailed data on the altitude of the water table near the stream are not available.

Discharge of ground water into streams has the opposite effect on the water table. If a valley has been cut below the general level of the water table, the water table is depressed along it, and slopes toward it. Ground water moves into the stream, and the stream is said to be "effluent." Between Keyes and Sturgis the water-table contour lines trend northwest-southeast with a suggestion of a bend in an upstream direction with reference to the Cimarron River, indicating slopes toward the Cimarron. Although the river often does not flow in T. 5 N., R. 6 E. and T. 6 N., R. 7 E., the water probably is always within a few feet of the river bed. Underflow in the channel sands, together with evaporation and use of water by plants, may be sufficient discharge to produce a shallow water-table depression along this part of the river.

The North Canadian River doubtless is influent in places and effluent in other places, and these conditions change from time to time. Effluent conditions were suggested by observations at two places along the North Canadian, in T. 2 N., Rs. 5 and 6 E. In

section 5 and 8, T. 2 N., R. 5 E., the general slope of the water table seems to be southward toward the river. The water level in well 149, which is on the upland, and 0.75 miles north of the river, is about 19 feet higher than the water level in well 148, which is on the flood plain about 0.25 mile north of the river channel; and about 21 feet higher than the water level of a test hole in the channel at the bridge for state highway 78. The slopes thus indicated averaged about 20 feet per mile, toward the river.

Likewise, in sec. 20, T. 2 N., R. 6 E., a hand-level measurement showed that on October 27, 1938, the water level in the channel sands was 2 feet lower than the water level in well 162, about 350 feet west of the channel.

On the other hand, the water level in the channel in sec. 21, T. 2 N., R. 6 E., on October 14, 1938, was about 1 foot above the water level in well 163, situated 1,000 feet to the north, indicating a slope away from the river, and local influent conditions at that time.

Discharge of water through a well lowers the water table in the immediate vicinity and forms a cone of depression, the size of which depends partly on the rate of discharge. A well that flows or is pumped continuously will always be in a cone of depression, but if withdrawal is stopped long enough, refilling will take place until the depression essentially disappears. Although there undoubtedly are many cones of depression on the water table in Cimarron County at any given time, they are too small and, as a rule, probably too transitory to show on the water-table map.

Other irregularities in the water table are due to differences in the permeability of the deposits. The continuity of the water table is broken where impermeable materials occur at the level where the water table otherwise would be. A well being drilled through the impermeable materials will be dry until it enters a permeable bed beneath, and then water will quickly rise in it about to the level of the normal water table.

Water table slopes steepen in the direction of ground-water movement where the permeability of the sediments decreases. Many differences in permeability are to be expected in deposits as heterogeneous as the "Ogallala," and they probably cause many abrupt changes of slope of the water table in Cimarron County. It is unlikely, however, that any of the irregularities shown on figure 20 are entirely due to this cause, because irregularities due to differences in permeability are probably less than the contour interval of the map.

In summary, the water table in the Ogallala formation under Cimarron County has a general eastward slope of 25 or 30 feet per mile. The shape of the water table depends on the uniformity of the subsurface materials, and the local conditions affecting recharge and discharge of the reservoir. The water table appears to be somewhat depressed below the general level along the upper part of the North Canadian River and the eastern part of the Cimarron. It probably is elevated in ridge form under the eastern part of the North Canadian. Probably several more or less independent water tables or piezometric surfaces exist in the Mesozoic formations of the Cimarron Valley area. The water table in the alluvium of the Cimarron may be continuous with that in the "Ogallala" east of Range 6, but in the western part of the valley it is separated from the "Ogallala" and is independent of water tables or piezometric surfaces in the Mesozoic formations. It rises westward with the gradient of the river, and also rises into the alluvium of the main tributaries of the Cimarron.

Chemical Character of the Water

The chemical character of the ground water in Cimarron County is indicated by 50 analyses of waters from formations ranging from Triassic to Quaternary in age. The analyses indicate the general chemical character of the waters and their suitability or unsuitability for industrial use, for irrigation, and for domestic use as far as this is affected by the dissolved mineral matter; they do not show the sanitary condition of the waters. Tests of the sanitary condition of many of the waters used for public supplies in the Panhandle are being made, however, by the Oklahoma Department of Public Health, through its district office at Guymon.

The "Ogallala" formation is the principal aquifer in Cimarron County. The analyses of samples from 28 wells indicate that the waters in this formation are rather uniform in chemical character

and mineral content. They are hard, calcium bicarbonate waters, usually having between 200 and 300 parts per million of bicarbonate, between 175 and 275 parts of total hardness, and between 250 and 400 parts of dissolved solids. Most of the "Ogallala" waters contain low to moderate amounts of sulfate, chloride, silica, calcium, magnesium, and sodium. Ratio of magnesium to calcium is higher than in most calcium bicarbonate waters.

Of the nine analyses of waters from the Dakota sandstone, eight represent calcium bicarbonate waters that are very similar to those from the "Ogallala" formation. The total hardness ranges between somewhat wider limits—135 to 318 parts per million—but the concentrations of most of the other constituents lie between the maximum and the minimum for the same constituents in "Ogallala" waters. One analysis, representing a 48-inch dug well on the outcrop of the Dakota (well No. 123), contains higher amounts of all the constituents that were determined and is unlike both Dakota and "Ogallala" waters. The very high NO_3 content of this water which is from a very shallow well (23 feet) indicates that the well receives surface drainage.

The one sample from the Cheyenne sandstone (well No. 385) is similar to those from the Dakota and Ogallala.

The analyses for well 364, which may draw water from both the Dakota and Cheyenne, and for well 227, which may draw water from either the Dakota or the "Ogallala," are comparable in chemical content with waters from the formations suggested.

The sample from the Morrison formation (No. 461) was about as hard as the hardest of the waters from the "Ogallala" formation, and contained more bicarbonate than the average waters from the "Ogallala," the Cheyenne, or the Dakota. It also contained more sulfate than those waters, but less than some of the samples from the red beds, the alluvium, and the Exeter.

Samples 89, 308, 331, 339, and 446 were taken from wells tapping red beds that underlie a thin covering of "Ogallala" in the eastern part of the county and perhaps are to be correlated with the Morrison. The samples differed considerably, possibly indicating that different types of water are contained in different zones in the red beds, or Morrison. Samples 89, 339, and 446 resembled waters from the "Ogallala" except that the last two were relatively soft. On the other hand, sample 308 contained a great deal of dissolved mineral matter, with large proportions of sodium and sulfate. Sample 331 also contained much sulfate.

Sample 469 is from an uncased well that probably draws water chiefly from the Exeter sandstone, but doubtless receives some also from the overlying Morrison. This was by far the softest water that was tested, but contained large amounts of sodium-potassium, bicarbonate, and sulfate, and had the highest total solids—1,649 parts per million. This water may be compared with that from well 480, which is a core hole that was drilled about 2 miles southwest of well 469. As reported by F. A. Devin[199], this well encountered a flow of water in the Exeter sandstone at a depth of about 150 feet. Water from the well flowed a considerable distance down the road ditch, but the flow stopped when the well was deepened. Later, it was cased and the water again flowed, leaving a white encrustation where it evaporated. A sample taken on November 17, 1941, when the flow was barely enough to rise over the top of the casing, was tested in the chemical laboratory of the Oklahoma Geological Survey, and was found to contain 10 parts per million of chloride, and about 4,800 parts per million of sulfate. This is about one-fifth as much chloride as was found in sample 469, but about 7 times as much sulfate. The high sulfate may indicate that the well was not effectively plugged at the base of the Exeter, and that waters from the underlying Triassic and perhaps Permian rocks are mixing with those from the Exeter.

The one sample (No. 614) that is definitely known to come from the Triassic (Dockum) seems to be similar to the "Ogallala" waters. The constituents that were determined in the analysis fell between the high and the low for the same constituents in the "Ogallala" waters.

The four samples from wells in the alluvium differed considerably in hardness and in bicarbonate. No. 507 was analysed more completely than the others and contained a total of 1162 parts per million of dissolved solids, with 571 parts of bicarbonate, and 420

199. Devin, F. A., oral communication.

parts of sulfate, but with hardness of only 149. This sample, however, is not typical. The others contained much less sulfate but were harder.

Ground waters in Cimarron County are used chiefly for municipal supplies and for domestic and stock purposes. There is little demand for water for industrial or irrigation use. The quality of water that may be considered satisfactory for drinking and for other domestic uses depends on the locality and the individual. However, some of the ground waters in Cimarron County contain in excess of 250 parts per million of sulfate, the upper limit of this constituent suggested by the United States Treasury Department as permissible in waters used for drinking on interstate carriers. Sulfate in excess of this limit tends to make the water unpalatable, although many waters exceeding this limit have been used for long periods without harmful effects. The only Cimarron County waters reported as unpalatable are those from a few of the wells in the Jurassic and from wells penetrating red beds in the east-central part of the county. The waters from the "Ogallala" formation and the Dakota and Cheyenne sandstones are entirely satisfactory for drinking, but they are hard and require excessive amounts of soap when used for laundry purposes and they form a scale in teakettles.

Fluoride content. Attention should be called to the fluoride content of the ground waters of Cimarron County. Of the 50 samples that were analysed, only 1 contained no fluoride and 1 other only, contained less than 1.0 part per million. Analyses for 25 of the samples, representing all the water-bearing formations, show from 1 to 2 parts per million of fluoride; 16 show from 2 to 3 parts; 5 show from 3 to 4 parts; and 2 show more than 4 parts. Figure 21 shows the distribution of the samples over the county and the fluoride content of each.

The relation between fluoride in water and the dental defect known as mottled enamel has only recently been generally recognized. Dr. H. Trendley Dean, Dental Surgeon of the U. S. Public Health Service has found that:

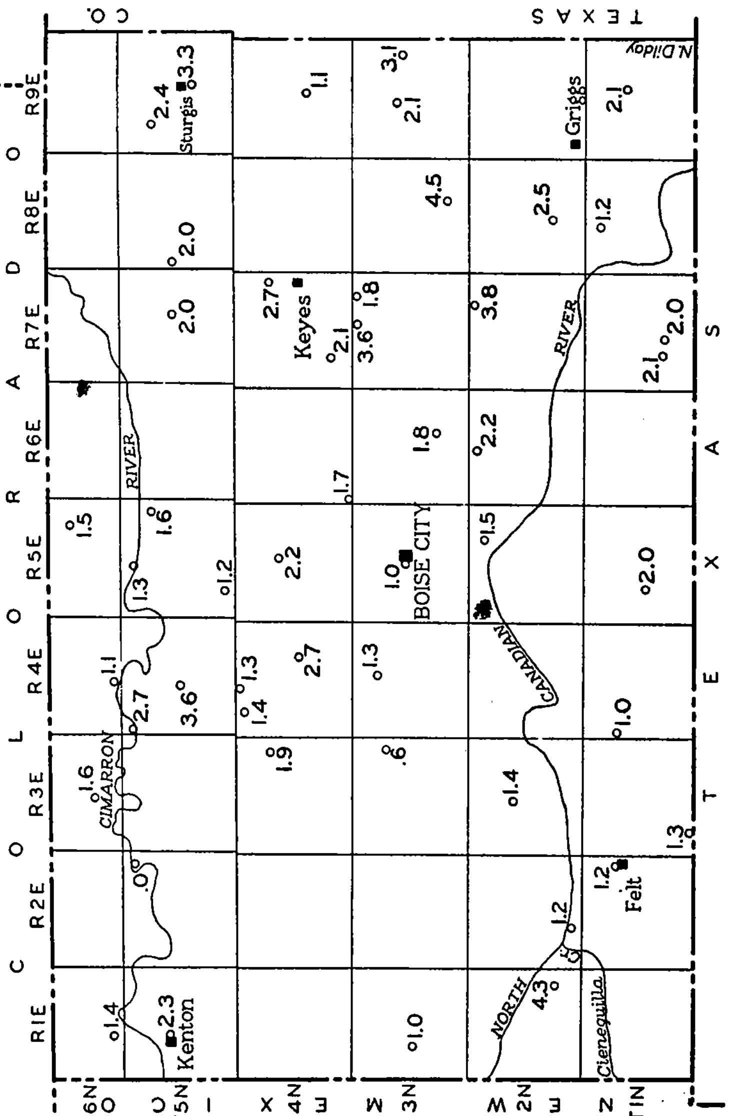


FIG. 21. Fluoride, in parts per million, in water from wells and springs in Cimarron County, Oklahoma.

"In surveys made of cities having the requisites for quantitative evaluation and even where these requisites are closely approximate, there is a definite quantitative relation between the fluoride concentration and the clinical effect. Although a prognosis with respect to any one individual is obviously unwarranted, it is felt that a prognosis relative to the group response to waters of varying fluoride concentration may be tentatively made at this time. From the continuous use of water containing about 1 part per million, it is probable that the very mildest forms of mottled enamel may develop in about 10 percent of the group. In waters containing 1.7 or 1.8 parts per million, the incidence may be expected to rise to 40 or 50 percent, although the percentage distribution of severity would be largely of the 'mild' or 'very mild' types. At 2.5 parts per million an incidence of 75 to 80 percent may be expected, with possibly 20 to 25 percent of all cases falling into the 'moderate' or a severer type. A scattering few may show the 'moderately severe' type.

"At 4 parts per million the incidence is in the neighborhood of 90 percent, and as a rule 35 percent or more of the children are generally classified as 'moderate' or worse. In concentrations of 6 parts per million or higher an incidence of 100 percent is not unusual."[200]

The interference with the normal development of the enamel apparently takes place during the period of its formation. Once a tooth is mottled, it never loses the disfigurement, even though the cause is eliminated. On the other hand, normally formed teeth have never been known to become mottled later and persons moving into an endemic area after the second teeth have developed are not affected. It is important, therefore, that children should not use water containing more than 1.0 part per million of fluoride. Because of the undesirable effect of fluoride in water on the enamel of the teeth of children, the Oklahoma Department of Public Health is giving special attention to the fluoride content of the waters. The logical solution of the problem is to avoid the use by children of water containing fluoride in excess of 1.0 part per million. In some instances this can be done by using a nearby water that does not contain harmful amounts of fluoride. Where this is not feasible it may be possible in some cases to provide distilled or cistern water for drinking and cooking purposes for the

200. Dean, H. Trendley, "Chronic Endemic Dental Fluorsis": *Jour. Amer. Medical Assoc.* Vol 107, pp. 1269-1272, Oct. 17, 1936.

portion of the population (children between birth and 8 years) needing protection.

A method for removing fluorine from domestic or small school supplies of water, by use of virgin bone charcoal, in small installations, has been developed by an Oklahoma oil company, and has been in successful use at several of the company's lease camps. The method is efficient and cheap, and the equipment extremely simple. A five gallon glass bottle, or similar container may suffice. This method of fluorine-removal will be described in a forthcoming publication of the Oklahoma Geological Survey.

The occurrence of fluoride in public water supplies of Oklahoma, including ground water supplies in Cimarron County, was investigated by Dr. Dean, assisted by Mr. E. C. Warkentin, Assistant Engineer, Oklahoma State Health Department, in 1936. Results of this survey, and results of tests for fluoride content by the State Health Department, are included in a forthcoming report on chemical characteristics of Oklahoma water supplies.[201] Some of the data relative to Cimarron County, are included here for sake of completeness.

Clinical examinations were made of small children in 35 communities. Sixteen of these had a common water supply, and a sufficent number of clinical examinations were made to warrant the computation of a "tentative" and "approximate" community mottled enamel index.

Boise City is the only Cimarron County community in the list, and 15 children were examined, who declared they had used city water continuously since birth; the incidence was 33.3; and the index is "Border line (tentative)". "An index is listed as 'tentative' when the sample of children examined consists of not less than 10, but not more than 24 . . ."

Nineteen communities and rural school districts are listed as "Communities with no common supply, or communities with a common water supply where the number examined was insufficient to compute a mottled enamel index. . ." Among these are the following in Cimarron County:

201. Warkentin, E. C., manuscript on "Mottled Teeth and Fluorosis": part of report on Chemical Characteristics of Oklahoma Water Supplies. Published by Oklahoma A. and M. College, Stillwater. *In press.*

Place	Common Water Supply	Remarks
Kenton	No	A few sporadic cases
Wheeless	No	Negative
Keyes	Yes	Moderate degree of affection in Keyes and its consolidated school District No. 11, which embraces about 100 sq. miles. More marked than any other area in western Oklahoma.

The following determinations of fluoride content of water supplies from Boise City, Felt, and Keyes, were made by the State Health Department:

Place	Fluoride P.P.M.	Date	Well	Depth (Feet)
Boise City	1.8	10/24/32	No. 3	165-382
	2.0	10/24/32	A.T. & S.F. RR.	
	2.0	10/24/32	do.	
	1.3	12/31/37	Cim. Utilities	
	1.2	12/31/37	Air Lift	
	0.8	1/ 5/38		
	1.3	4/16/38		
	1.2	9/—/38		165-382
Felt	1.3	5/—/32		125-132
	1.2	12/31/37	School	
	1.4	12/31/37	A.T. & S.F. RR.	
	1.4	1/21/38		125-132
	1.4	1/ 5/38		
	0.9	4/16/38		
	1.4	9/—/38		125-132
Keyes	4.5	10/24/32	Buck	165
	3.5	10/—/32		
	1.6	1/ 5/38		200-210
	1.7	4/16/38		
	1.6	9/—/38		200-210

Supplies for Boise City, Felt, Keyes, and Wheeless are from the "Ogallala" formation, and wells in Kenton draw water from the Morrison formation and possibly the Exeter sandstone.

The occurence of fluoride in water in Cimarron County is in common with occurrences in Texas and Beaver Counties, Oklahoma, the Panhandle of Texas, and other portions of the High Plains, ". . . from southeastern North Dakota to the 'Big Bend Distrist' of Texas, on the Rio Grande." In the Texas and Oklahoma Panhandles, at least, there seems to be a correlation between the presence of fluoride, and the "Ogallala" formation as the source of the water.

TABLE No. XXI.

ANALYSES OF WATER FROM WELLS AND SPRINGS in CIMARRON COUNTY, OKLAHOMA

(Analyzed by Margaret D. Foster and N. A. Talvitie, except No. 374, which was analyzed by E. W. Lohr. Numbers correspond to well numbers in table of well records, Appendix C. Results are in parts per million.)

Well or spring number	Owner	Depth (feet)	Date of collection	Total dissolved solids	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)		Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$	Geologic Formation	Well or spring number
18	Cimarron Utilities Co.	[1] 132	Nov. 10, 1938	234	52	35	19		10		196	14	4.6	1.2	3.8	165	Ogallala	18
41	James Dove	[1] 59	do.	273	31	46	21		20		223	36	10	1.3	7.5	201	Dakota	41
49	State of Oklahoma	122	Apr. 14, 1939	......	....	....	....		....		219	54	14	1.0	7.5	237	Ogallala	49
63	Fred Brakhage	78	Nov. 9, 1938	299	30	46	24		27		243	45	13	2.0	4.1	213	"	63
89	State of Oklahoma	221	do.	366	50	41	35	32		3.8	269	54	24	2.0	5.2	246	Red beds	89
90	W. P. Foreman	158	do.	346	53	39	35		29		273	44	18	2.1	4.1	241	Ogallala	90
98	Ernest Tatman	300+	Apr. 15, 1939	......	....	....	....		....		230	40	13	1.2	3.2	204	"	98
109	E. R. Blake	[1] 300	Nov. 10, 1938	307	46	39	25		27		207	49	18	2.1	9.0	200	"	109
123	J. C. Lujan	23	Apr. 14, 1939	......	....	....	....		....		402	[2] 112	145	4.3	638	1,088	Dakota	123
132	J. G. Mayhan	[1] 7½	do.	......	....	....	....		....		221	[2] 80	14	1.2	5.2	231	Alluvium	132
140	J. E. Heatley	120	do.	......	....	....	....		....		259	[2] 60	22	1.4	7.2	273	Ogallala	140
147	Prudential Life Ins. Co.	125	Apr. 18, 1939	......	....	....	....		....		225	34	19	1.5	7.7	228	"	147
158	W. B. Sizemore	141	Nov. 9, 1938	319	39	43	26		28		228	46	20	2.2	9.0	214	"	158
174	C. J. Taggert	152	do.	383	31	26	38		58		240	79	32	3.8	15	221	"	174
200	Plainview Con. School	263	Nov. 10, 1938	305	48	36	25		27		204	47	17	2.5	6.5	192	"	200
227	Mexhoma School	184	do.	432	26	60	25		47		220	127	26	1.0	4.5	252	Dakota?	227
255	Guy W. Slack	120	Nov. 18, 1938	333	28	62	20		19		239	45	21	.6	6.3	237	Ogallala	255
261	Sandy View Cons. School	182	Nov. 10, 1938	322	30	51	25		19		226	39	20	1.3	18	230	"	261
278	Cimarron Utilities Co.	[1] 167	Nov. 9, 1938	328	34	46	27	24		3.2	213	57	24	1.0	9.7	226	"	278
299	Thomas Potts	[1] 160	Apr. 18, 1939	......	....	....	....	—		....	247	26	9.0	1.8	4.5	258	"	299
308	T. F. Phillips	[1] 320	Nov. 10, 1938	1,185	15	31	36		322		293	519	94	1.8	9.2	225	Red beds	308
309	Mrs. Wesley Burch	100	do.	293	46	27	31		36		256	35	10	3.6	4.9	195	Ogallala	309
331	Frank Outhier	242	Apr. 15, 1939	......	....	—	....		....		210	[2] 360	107	4.5	17	381	Red beds	331
337	Roy Hanes	198	do.	......	....	....	....		....		251	44	10	3.1	7.2	219	Ogallala	337
339	A. M. Payne	206	Nov. 10, 1938	241	31	26	26		27		234	21	3.9	2.1	7.7	172	Red beds	339
364	J. L. Donley	[1] 205	Nov. 13, 1938	277	11	24	20		60		276	30	6.5	1.9	.0	142	Dakota and Cheyenne	364
373	J. A. James	Spring	Nov. 11, 1938	337	28	50	25		39		292	45	15	1.3	2.7	228	Dakota	373
374	....	do.	Nov. 13, 1938	264	....	50	22		21		252	34	11	1.4	.90	215	"	374
379	M. M. Adee	116	Apr. 14, 1939	......	....	....	....		....		279	16	6.0	2.7	8.0	237	Ogallala	379
385	H. A. Schneider	215	Nov. 17, 1938	392	14	35	29		73		313	75	16	2.2	3.0	206	Cheyenne	385
400	Bruce Wood	149	Apr. 18, 1939	......	....	....	....		....		206	48	29	1.7	14	270	Ogallala	400
406	Atchison, Topeka & Santa Fe R.R.	[1] 199	Nov. 9, 1938	274	37	33	31	18		2.8	213	43	15	2.7	3.5	210	"	406
419	Mrs. Lewis Bruning	103	Apr. 18, 1939	......	....	....	....	—		....	200	50	19	2.1	3.5	249	"	419
446	N. W. Ford	273+	Nov. 9, 1938	412	17	25	21		99		301	89	8.0	1.1	12	149	Red beds	446
461	Kenton School, U.G. Dist. 1	[1] 80	Apr. 13, 1939	......	....	....	....	—		....	496	[2] 160	42	2.3	6.1	270	Morrison	461
469	J. A. Whittenburg Estate	[1] 96	Nov. 18, 1938	1,649	17	5.4	4.7		571		556	708	57	.0	1.7	33	Exeter	469
492	H. G. Wilson	18	Apr. 14, 1939	......	....	....	....		....		724	[2] 72	32	2.7	8.6	682	Alluvium	492
495	George W. Gillis	Spring	do.	......	....	....	....		....		286	[2] 72	30	3.6	18	318	Dakota	495
505	B. N. North	13	Apr. 13, 1939	......	....	....	....		....		338	[2] 72	13	1.3	11	348	Alluvium	505
507	Mrs. J. Martin Ford	15	Nov. 17, 1938	1,162	23	44	9.5		375		571	420	35	1.6	5.5	149	"	507
513	....	Spring	Apr. 13, 1939	......	....	....	....		....		242	48	14	1.2	9.7	231	Dakota	513
530	John Cooper	143	Apr. 15, 1939	......	....	....	....		....		224	24	13	2.0	5.1	225	Ogallala	530
542	Edward Jermyn	[1] 280	Apr. 15, 1939	......	....	....	....		....		218	46	13	2.0	5.5	264	"	542
552	W. H. Greaser	[1] 295	Nov. 9, 1938	272	27	36	29		21		229	41	10	2.4	4.4	209	"	552
556	G. A. DeHaan	239	Apr. 15, 1939	......	....	....	....		....		245	24	6.0	3.3	4.5	234	"	556
570	Myrtle Tharp	Spring	Apr. 13, 1939	......	....	....	....		....		213	44	13	1.4	3.1	217	Dakota	570
591	Cowboy College	do.	do.	......	....	....	....		....		134	40	11	1.6	3.6	135	"	591
605	Harry Clark	do.	do.	......	....	—	....		....		120	52	17	1.1	2.2	156	"	605
614	A. S. Parker	[1] 205	do.	......	....	....	....		....		245	[2] 72	18	1.5	6.4	243	Dockum	614

[1] Reported.
[2] Approximate.

Water for irrigation. The successful use of water for irrigation depends on a number of factors in addition to the mineral content of the water. Some of these factors are the character of the soil, the amount of water used, rainfall, and drainage. Scofield[202] in 1932 suggested limits for certain mineral constituents in waters used for irrigation. The suggested limits are shown in the following table:

TABLE XII.

SUGGESTED LIMITS FOR SAFE AND UNSAFE WATERS FOR IRRIGATION

Constituents	Safe Less than	Unsafe More than
Total dissolved solids (parts per million)	700	2,000
Sodium (Na) (percent)	50	60
Sulphate (SO_4) (parts per million)	192	480
Chloride (Cl) (parts per million)	142	355

The percentage of sodium is obtained by dividing 100 times the milligram equivalent of sodium in the water by the sum of the milligram equivalent of calcium, magnesium, and sodium in the water:

$$\frac{\text{Milligram equivalents Na} \times 100}{\text{Milligram equivalents Ca} + \text{Mg} + \text{Na}} = \text{Percent Na}$$

Waters within the lower set of limits are not likely to be harmful when used in ordinary irrigation; waters above the upper limits, however, are very likely to be unfit for irrigation, either because of their effects on the plants or because of their effects on the soil. Waters between the lower and upper limits may or may not cause injury to crops or soil, depending on the composition of the water, the characteristics of the land, and the manner in which the water is used.

The waters in the "Ogallala", Dakota and Cheyenne that were examined were, with one exception, well within the lower limits suggested above. Similar waters have been used successfully in other parts of the High Plains. Some of the waters from the Dockum, Morrison, and the alluvium may, however, be mineralized in excess of the upper limits.

202. Scofield, C. S., "Quality of Irrigation Waters": *Calif. Dept. Public Works, Div. of Water Resources Bull.* 40, 1933.

PRESENT DEVELOPMENT OF WATER SUPPLIES FROM WELLS

Much more than half of the water used in Cimarron County for farm, municipal, industrial, railroad, and irrigation purposes is supplied from wells. Springs and streams furnish important supplies of water for household use and for stock in the Cimarron Valley, but even in this area windmill wells are common.

In the present ground-water investigation, records of 432 water wells in the county were obtained. Of these, 160 are farm and ranch windmill wells used for domestic and stock purposes, 74 are windmill wells used only for stock, 10 are wells used for public supplies including rural school wells, 12 are railroad wells including test wells that are not in use, 6 are irrigation wells, and 170 are windmill wells that appeared to be unused at the time the investigation was made. These are all listed in the *Tables of Well Records,* (Appendix C), which also include 13 wells drilled for oil or gas, 6 soil-auger and shovel holes in the channel of the North Canadian River, and 37 springs.

DOMESTIC AND STOCK WELLS

Most of the farm wells used for domestic and stock purposes, and the private wells used for domestic purposes in the towns, are of the drilled type and are from 4 to 6 inches in diameter. Most are cased with galvanized iron casing, but some are cased with heavy iron. Except on the flood plains of the major streams and nearby on the lower slopes of the valley bluffs, the wells generally are more than 100 feet deep. They are equipped with windmills capable of pumping a few gallons of water per minute, and some also are equipped with pump jacks for operation with small gasoline engines when the wind is inadequate.

In upland farming areas there is about one well on each section of land, but in the smaller towns, where many people have their own windmills, there are many wells per section. On the other hand, the wells are widely separated in the ranch lands along the major valleys, especially where springs are abundant or the streams are perennial. From the fact that many of the wells on the uplands are abandoned, either permanently or temporarily, it is evident that fewer wells are in use now than formerly.

Discharge of windmill wells. Measurements of the discharge of 28 windmill wells were made when samples of water for chemical analysis were taken, or in connection with routine measurements of depth to water in the wells. The maximum discharge obtained was 15 gallons a minute from a shallow dug well about 1 mile west of Cowboy College, in the alluvium of a canyon tributary of the Cimarron. The other discharges ranged from 0.5 gallon to 4 gallons a minute. The average of all the wells tested is 2.5 gallons a minute. Obviously, these discharges represent only the output under conditions that obtained when the tests were made. Somewhat higher figures doubtless would have resulted if tests had been restricted to wells in good repair at times of high wind.

The Panhandle Experiment Station[203] at Goodwell has measured wind velocity at crop level since 1925, and in connection with this work measured also the quantity of water pumped by a windmill used for irrigation of a garden. The windmill is a 12-foot mill on a 30-foot tower, with a 2¼-inch cylinder. It operates on a 6-inch stroke and the pumping lift is 140 feet. The water is metered as it passes through a pipe from the well to a storage tank. The record as published is not continuous because data for periods when the windmill was not in reasonably good working condition were discarded, but the record extends over several years. The average number of gallons of water pumped per day ranged from 1,033 for August to 2,087 for April. The year-around average, based on the published monthly averages, is 1490 gallons a day, or about a gallon a minute.

Drawdown and recovery in windmill wells. When a well is pumped the water level is lowered in it and for some distance in all directions from it. This lowering of the water level in the well is known as drawdown. It is least for properly constructed wells in good repair that tap water in coarse clean gravel, and is greatest for poorly constructed wells, or wells in poor condition, that tap water in fine-grained materials. It is the difference between the depth to the water level in the well before pumping

203. Finnell, H. H., "Agricultural Significance of Climatic Features at Goodwell, Oklahoma": *Panhandle Agri. Exper. Sta., The Panhandle Bulletin,* No. 40, pp. 26-30, 1932.

starts and the depth to the water level while pumping is in progress. In windmill wells it ordinarily can be obtained only in an approximate manner because variations in the rate of pumping produce fluctuations in the pumping water level. The drawdown was not measured in windmill wells in Cimarron County, but an estimate of it can be obtained from the recovery of water levels after pumping stops.

When pumping stops, the water level in a well rises, at first rapidly, then more and more slowly, until it nearly reaches the original, or static level. Water levels in several of the windmill wells in Cimarron County were first measured while pumping. The windmills were then shut off, and measurements of the water level were made at approximately 5-minute intervals until the water levels stopped rising, or until the rate of rise became slow. In a few wells, the water level continued to rise so rapidly, even an hour after pumping stopped, that it was inexpedient to continue measurements to the logical end-point.

By plotting the amount of recovery against time, a curve representing the rate and amount of recovery for a well may be obtained. Figure 22 shows 12 recovery curves, for 12 different wells tapping water in 3 different aquifers, in Cimarron County. These show total recoveries ranging from a little over 1 foot to more than 18 feet, and indicate drawdowns of equal or greater magnitude.

WELLS USED FOR PUBLIC AND RAILROAD SUPPLIES

The larger towns are supplied with water from wells through water-works including power-driven pumps, elevated storage tanks, and water mains. The wells are deeper on the average, and are of larger size and yield than the farm and stock wells. The following paragraphs summarize the significant data regarding the public supplies in each town.

The Atchison, Topeka, and Santa Fe Railway owns and operates wells at strategic points along its lines in Cimarron County. Some are windmill wells used to supply station houses or stock yards, and the rest are wells of larger diameter with power-driven pumps and are used to supply boiler water to locomotives.[204]

204. Data from files of the Atchison, Topeka, and Santa Fe Railroad.

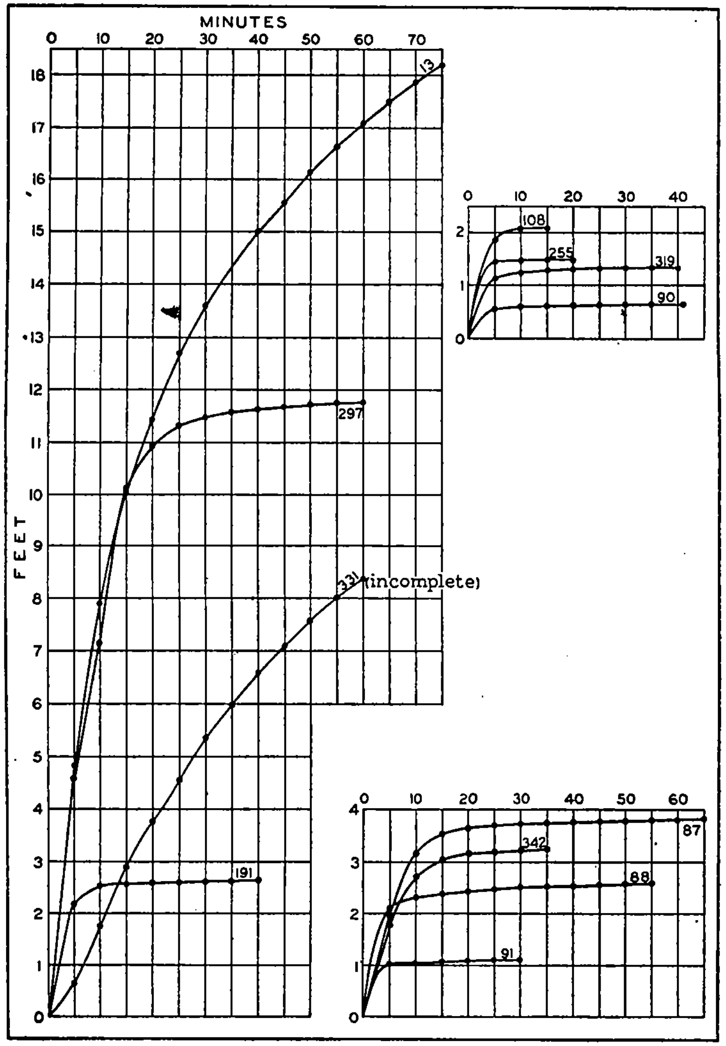


FIG. 22. Recovery curves, showing rate at which water levels in windmill wells in Cimarron County rose after pumping stopped. Well 13 may tap water in the "Ogallala" formation, but probably draws chiefly from Cretaceous formations. Wells 191, 319, 331, and 342 tap water in red beds. The others tap the "Ogallala" formation.

Boise City. Boise City is supplied with water by the Cimarron Utilities Company, which has three wells about a block southwest of the court house. Well No. 278 (Company No. 1) was drilled in 1926, is 167 feet deep, and is cased to the bottom with 8-inch iron casing, the lower part of which is perforated. It is equipped with a cylinder pump driven by a 5-horsepower electric motor, and is reported to yield about 21 gallons per minute. It is in use most of the time. For a chemical analysis of water from this well, see No. 278 in table of water analyses.

Well No. 279 (Company No. 2) was completed in 1928, is 176 feet deep, and is cased to the bottom with 7-inch iron casing with a 35-foot sand screen. It is equipped with a cylinder pump driven by a 5-horsepower electric motor, is reported to yield about 21 gallons per minute, and is used only occasionally. The water level as measured in May 1938 by the writer was about 147.5 feet below the land surface, but probably was somewhat below true static level because well 280 was pumping at the time. This water level, however, may be accepted as a reasonable approximation for the water level in the three wells ownd by the company.

Well No. 280 (Company No. 3) was completed in 1928, is 382 feet deep (see log, Appendix B), and draws most of the water from fine sand and coarse gravel between depths of 150 feet and 212 feet. This well is equipped with an air-lift pump driven by a 15-horsepower electric motor, and is reported to yield 111 gallons per minute with a drawdown of 9.2 feet.

The Santa Fe Railway operates three wells at Boise City. The stockyard well (No. 276) and the station-house well (No. 277) are pumped with windmills. Details on them are given in the *Table of Well Records,* and logs are reported in Appendix B.

Well 284 supplies boiler water for locomotives. It was drilled to a depth of 265 feet (see log 284, Appendix B), but was filled back with 2.97 cubic yards of crushed rock. The static water level is reported as 147 feet below the land surface. The well is cased to a depth of 161 feet with 14-inch casing, the lower 10 feet of which was perforated, and is equipped with a 5¾ x 64-inch cylinder pump set at a depth of 170 feet and operated with a 5-horsepower electric motor. When tested, the well produced 65 gallons a minute with a drawdown of 8 feet.

Felt. The Cimarron Utilities Company furnishes water for the town of Felt from a well 132 feet deep. As reported by the company, this well (No. 18) is cased to the bottom with 8-inch iron casing that is perforated for an unknown length at the bottom and is fitted with a screen. The well is equipped with a cylinder pump operating on a 9-inch stroke and driven by a 1½-horsepower electric motor. It is estimated to yield about 20 gallons a minute. The temperature of the water was measured as 59° F. on November 10, 1938. For an analysis of water from this well, see No. 18 in the table of analyses. The log is reported in Appendix B, under the same number.

The Santa Fe Railway drilled six wells in search of water near Felt, and of these one is used to supply boiler water for locomotives. This well (Railway well 1, reported in tables as No. 17) was drilled to a depth of 282 feet, and was cased with 14-inch casing from a depth of 16 feet to 154 feet, and with 10-inch casing from 62 feet to 218 feet. It was equipped with six 10-inch strainers, each 10 feet long, and a 5¾ x 80-inch cylinder pump. The log of this well is reported in Appendix B.

Well 20 is equipped with a cylinder pump and a windmill, and is being used by F. A. Burrows to furnish water for household purposes and for stock. The others—Nos. 11, 15, 16, and 19—were abandoned, but records for them are given in the *Table of Well Records* (Appendix C).

Kenton. Private windmill wells supply water for Kenton. The school well (No. 461) is reported to be 80 feet deep, and probably taps water in the Morrison formation. It is cased with 6-inch casing and is pumped with a windmill. For an analysis of water from this well, see No. 461 in the table of water analyses.

Keyes. The principal source of water for the town of Keyes is a well owned by the Santa Fe Railway and leased to and operated by the Cimarron Utilities Company. This well (No. 406) is in SE¼SE¼SW¼ sec. 12, T. 4 N., R. 7 E. It is 199 feet deep and is cased to the bottom with 14-inch iron casing. The casing

is perforated between depths of 139 and 189 feet and is surrounded by a gravel wall 10 inches thick. The log (No. 406, Appendix B) indicates that the water comes from coarse sand between depths of 146 and 154 feet and between 178 and 185 feet, and from fine sand between depths of 176 and 178 feet. This well could not be measured, but the water level in an abandoned test well (No. 405) that is 100 to 200 feet distant was measured as 134 feet below the land surface.

The well is equipped with a double-acting 7¾ by 80-inch cylinder pump and a 15-horsepower electric motor. It is reported that on test the well yielded 90 gallons a minute with a 10-foot drawdown, but in normal operation the yield is about 70 gallons a minute. The water is pumped from the well to an elevated tank beside the railroad tracks about a half mile to the south, and thence is pumped to a smaller elevated tank in the town. For an analysis of water from this well, see No. 406 in the table of water analyses.

Water to supply the school and a few neighboring families is obtained from a well owned and operated by A. E. Buck (No. 416). This well is 165.5 feet deep and is cased with 8-inch galvanized iron casing, the lower 12 or 16 feet of which is perforated. The water is reported to come from coarse gravel and sand between depths of 136 and 165.5 feet. The well is equipped with a 2¾-inch cylinder and a 1½-horsepower electric motor. A 5-horsepower gasoline engine is available for use in emergencies.

The railway drilled six test wells at Keyes in seeking the most favorable location for a well. Well 406 (company well 2) is the present source of water for the railway and town, is leased to the Cimarron Utilities Company, and has been described.

Well 407 (company well 1) was drilled to a depth of 289 feet, but after being shot with dynamite was only 182 feet deep. Three sizes of casing were used in it: 14-inch casing between depths of 20 and 127.5 feet; 10-inch casing from the surface to 159 feet, with a 22½-foot strainer on the end; and 6-inch casing from the surface to 168 feet. Water was obtained in joint clay and sand between depths of 155 and 165 feet (see log 407, Appendix B), and the static water level was reported as 137 feet below the land surface. This well was equipped with a 4¾ by 36-inch cylinder set at a depth of 171 feet, and when tested it yielded a maximum of 45 gallons a minute. This rate could not be maintained, however, because the water level was soon drawn down below the strainer. This difficulty was not experienced at a pumping rate of 35 gallons a minute. The well was used only during construction of the railroad.

Test wells 405, 408, 409, and 433 are reported in the *Table of Well Records,* and logs for them are given in Appendix B. They are not equipped with pumps.

Sturgis. The settlement of Sturgis is supplied with water from a community windmill well in the NE¼NW¼NE¼ sec. 22, T. 5 N., R. 9 E., on land belonging to G. A. DeHaan (well 556). Water also is hauled in a tank mounted on a trailer from this well to Harmony School, District 12.

As measured by the writer, the well is 239 feet deep, and the static water level in July 1938 was about 196 feet below the land surface. The well is cased with 8-inch iron casing and is equipped with a cylinder pump on the end of a 2-inch drop pipe. For a partial analysis of water from this well, see No. 556 in table of analyses.

Nieto, Conrad, and Castaneda. The Santa Fe Railway has windmill wells at Nieto, Conrad, and Castaneda stations. The well at Nieto (No. 6) furnishes water for a stockyard, and the well at Conrad (No. 167) furnishes water for the station house. Both are listed in the *Table of Well Records.* The well at Castaneda furnishes water for the station house. No data are available for it.

Kerrick, Texas; and *Campo, Colorado.* The Santa Fe Railway has wells at Kerrick, Texas, about 0.5 mile south of the Texas State line, and at Campo, Colorado, about 8 miles north of the Colorado State line. Logs of these wells are listed in Appendix B as T-1 and C-1, respectively.

The well at Kerrick is 334 feet deep and entered "red beds" at 330 feet. The materials above the "red beds" are chiefly sand

and gravel, probably all in the "Ogallala" formation, and the static water level in the well is reported at 264 feet below the surface. The well was drilled 16 inches in diameter, and was cased with 230.75 feet of 14-inch casing; 289 feet of 10-inch casing; and 310 feet of 8-inch casing. An 8-inch well screen 24 feet in length was used. A 5¾-inch cylinder pump was set at a depth of 307 feet, and the well yielded 63 gallons a minute on a 24-hour test, with a drawdown of 21 feet.

The well at Campo was drilled to a depth of about 430 feet. It appears to have entered the Dakota sandstone at a depth of 247 feet, the Kiowa shale at 291 feet, the Cheyenne sandstone at 355 feet, and sandstones in the upper part of the Morrison at 402 feet. It was cased with 14-inch casing from the surface to a depth of 314 feet, and with 10-inch casing from 314 to 426 feet. The lower 90 feet of the 10-inch casing was perforated, and therefore it is probable that the principal water-bearing stratum is the Cheyenne sandstone. The well was equipped with an 11-stage deep-well turbine pump with 7¼-inch bowls, and on test yielded 100 gallons a minute with a drawdown of 12 feet.

WELLS USED FOR IRRIGATION AND COMMERCIAL PURPOSES

The development of wells for irrigation in Cimarron County has been largely through local initiative, and although irrigation of river-bottom lands with flood-waters has been carried on successfully for several years, there has been little interest in deep irrigation wells on the uplands. The first large irrigation well on the uplands, drilled near the Texas State line in 1935 by C. K. Womack, has been abandoned, but is described below. The second large well was drilled in the Cimarron River valley in the winter of 1937-38 by the Alliance Insurance Company, and was used in the summers of 1938-41. In addition, a few small wells pumped with windmills or small engines are being used to irrigate small fields and gardens.

So far as the writer knows, the only well in Cimarron County used for a commercial purpose—excluding railroad wells and privately-owned wells used for municipal supplies—is the well formerly pumped by O. A. Showalter to supply water for a swimming pool. Recently it has been used chiefly to irrigate trees.

The irrigation and commercial wells of Cimarron County are described in the following paragraphs.

C. K. Womack. Sec. 34, T. 1 N., R. 5 E. (well 66). The well drilled in 1935 by Mr. Womack is on the upland south of Boise City and just north of the Texas State line. It was put down by the owner himself, and is said to have reached a depth of 150 feet, but when measured in 1938 by the writer, it was only 127 feet in depth. It is cased between depths of 80 and 120 feet with oil drums whose diameter as placed in the well was about 13 inches. Water was encountered in gravel and fine sand between depths of 84-88 feet, 110-120 feet, and 130-150 feet, with white clay or caliche in the intervening zones. The static water level as measured in 1938 by the writer was about 78 feet below the land surface, and subsequent measurements made in connection with the observation-well program have shown only very small fluctuations of water level. The well was equipped with a turbine pump driven by a gasoline tractor. The yield was estimated as 150 gallons a minute by W. N. White[205], who saw the well in operation in 1936. The well was not used in 1937 and 1938, and the pump was removed in 1939.

Alliance Insurance Company. NW¼ sec. 4, T. 5 N., R. 7 E. (well 528, Pl. XXI). Early in 1938 a well on the flood plain about 0.5 mile south of the Cimarron River channel north of Keyes was completed for the Alliance Insurance Company by the Well Works Manufacturing Company, of Garden City, Kansas. The well was drilled by the hydraulic-rotary method to a depth of 330 feet and according to the driller it entered sandstone at a depth of about 40 feet below the surface. During a visit by the writer, the drill passed through many feet of sandstone from this level down to 145 feet. The rest of the drilling was not observed, but the samples taken by the driller at 10-foot intervals indicate a predominance of very fine-grained sandstones and siltstones, with medium to coarse sand materials at 300-310 feet. The driller also reported coarse sand between 320 and 330 feet, but saved no sample. The driller's log was not made available. The well is 18 inches in diameter, and for the most part is uncased. The static water level in July 1938 was about 20 feet below the land surface, and measurements made at intervals ranging from 2 to 8 months beginning in November 1939 have shown only moderate fluctuations of water level for the non-pumping periods, and no significant net change in water level as a result of pumping. The well was equipped with a 16-stage turbine pump set at a depth of 160 feet, with 20 feet of suction pipe, for operation with a 43-horsepower gasoline engine. The yield was estimated by the writer as about 300 gallons a minute. In 1938 the well was pumped to irrigate about 40 acres of corn and feed crop, and comparable irrigating was done in 1939, 1940, and 1941.

205. White, W. N., "Ground Water in the Oklahoma Panhandle (Cimarron, Texas, and Beaver Counties)": *U. S. Geol. Survey Mimeographed Memorandum*, p. 4, 1936.

Dan Eiland, Sr., SE¼ sec. 12, T. 5 N., R. 4 E. (well 500). In 1940, Dan Eiland, Sr., and his son dug a well to a depth of about 26 feet on the flood plain of the Cimarron River about a mile south of Garrett School. The well was cased with 10½-inch iron casing, and was equipped with a cylinder pump and a small gasoline engine. It taps water in the valley fill, and in the summer of 1940 was pumped about once a week to irrigate an acre of garden. According to the owner, the drawdown is very small, as might be expected in a large well in alluvial gravel under the operating conditions described. The yield of the well is not known, but obviously is moderate. The static water level as measured in November 1940 by the writer was about 11 feet below the land surface. Further measurements were begun in connection with the observation-well program, but the well was flooded from the river and clogged with mud in 1941. An attempt to clear it by shooting with dynamite ruined the well.

C. Brookhart. NE¼ sec. 29, T. 6 N., R. 3 E. (well 593). The windmill well on the east side of the road opposite the C. Brookhart ranch house is mentioned here because it seems to be used chiefly for irrigation of a small garden, and because it suggests the possibilities for small-scale irrigation in the alluvial fill of the flat-bottomed canyons that are tributary to the Cimarron. This well is about 1.25 miles from the head of the canyon, about 1.75 miles from where the canyon joins the Cimarron River, and 100 feet or more above the Cimarron. It is a dug well about 30 inches in diameter, with rock walls, and is about 13 feet in depth. When observed in April 1939 it was pumping only spasmodically in a light, erratic wind, but a few turns of the wheel were sufficient to produce about 15 gallons of water a minute. Under these pumping conditions the water level was about 10 feet below the surface.

The high yield of this windmill well probably is due to the fact that the well affords a large reservoir capacity. With a large cylinder pump, it would yield water readily until the reservoir was nearly empty. Test drilling would show whether a considerable thickness of saturated pervious material is present, and should precede the selection of other well-sites in this or other canyons. Because of the relatively small volume of alluvial fill in such canyons it is probable that the quantity of water is not large, but the depth to water is not great, and small, scattered wells to irrigate gardens of 1 to 5 acres might be developed in the canyons without exceeding the safe yield of the reservoirs.

S. Strong. NW¼ sec. 18, T. 5 N., R. 5 E. (wells 518 and 518-a). Two windmill wells tapping water in the Morrison formation, and perhaps also in the valley fill, are used for irrigating a 1.5-acre garden and orchard at the Si Strong ranch. The wells are 93 and 113 feet in depth, are cased with 8-inch casing, and pump into two wooden storage tanks, each of which holds about 18,000 gallons. The eastern well is reported to yield about 10 gallons a minute, and as the water is thought to be less alkaline than that from the western well, it is used in the house as well as for irrigation. The western well is reported to yield about 7 gallons a minute, and is used only for irrigation. Among the products of the irrigated garden and orchard are apples, peaches, grapes, plums, onions, and watermelons.

Other irrigation wells. Other windmill wells that are used partly or entirely for irrigating gardens and trees are well 578, west of the house at the J. J. Willson Ranch (Regnier P. O., NW¼ NW¼NW¼ sec. 16, T. 6 N., R. 2 E.), which apparently taps water in both the alluvial fill of a small canyon and in the underlying Morrison formation; and well 590, at the northwest corner of the yard at the A. L. Brookhart ranch (NW¼ SW¼ sec. 26, T. 6 N., R. 3 E.). Also, many of the farm windmill wells on the upland plains of the county are used for irrigation of small gardens in addition to their principal use in supplying domestic and stock water.

O. A. Showalter swimming-pool well. SW¼NW¼NW¼ sec. 11, T. 3 N., R. 5 E. (well 281). The well used to furnish water for the swimming pool at the Showalter Park was drilled in 1931 by E. B. Witten. It is reported to be 315 feet deep, and to have encountered water in sand between depths of 147 and 207 feet, and in red beds below that depth. It is cased with 7-inch casing from the surface to a depth of 208 feet, and with 5⅝-inch casing from there to the bottom. The lower 53 feet of the 7-inch casing and the lower 86 feet of the 5⅝-inch casing were perforated. The well is equipped with an air-lift pump operated by tractor power, and yields about 100 gallons a minute. The well could not be measured, but comparison with a nearby windmill well (No. 275) suggests that the static water level is about 147 feet below the surface. The well is used to irrigate about 3 acres of trees in addition to its use in filling the swimming pool.

WELL DRILLING METHODS

Most of the domestic and stock wells in Cimarron County have been drilled with percussion tools operated from portable drilling rigs. The chief exceptions are a few dug wells in the valley bottoms. The drilled wells range from 25 feet to more than 300 feet in depth, and generally are from 4 to 6 inches in diameter. A few of the windmill wells are as much as 8 inches in diameter. Some of the first wells in the county are reported to have been drilled by hand or by horsepower, but gasoline engines are commonly used in present day drilling equipment.

Because the sands and gravels of the "Ogallala" formation are generally unconsolidated, it is necessary to case most wells to the bottom to prevent caving. A common practice has been to drill through the water-bearing bed or beds and set the casing on a layer of clay. Galvanized iron casing has been used widely in small diameter wells and usually has been perforated for 10 or 20 feet by means of hack-saw cuts, the length of the perforated section corresponding approximately to the thickness and depth of the water-bearing bed. Iron, steel, and oil-well casing are also used. The dug wells generally are walled with stone.

The drop pipe is ordinarily held in place by a wooden clamp consisting of two 4 x 4-inch wooden blocks tightly bolted to the pipe and resting on top of the casing. Iron clamps are also used. Some wells have an iron or steel cover over the casing and under the clamp to prevent contamination from the surface. Burlap sacking in the space between the blocks of the wooden clamp is also used to plug the top of wells.

The irrigation, railroad, and municipal wells are cased with galvanized or wrought iron casing 6 to 18 inches in diameter, part of which is perforated below the top of the first water-bearing bed. Well 406, owned by the Santa Fe Railway and operated by the Cimarron Utilities Company to supply water for Keyes, is gravel-packed. It was drilled 38 inches in diameter and cased with 14-inch casing, and the space outside of the casing was filled with gravel. Some of these wells have been drilled with percussion tools, and others by the hydraulic-rotary method. For details regarding the types of pumps and kind of power used in the larger wells, see the descriptions of existing municipal, railroad, irrigation, and industrial wells, and the well tables.

Possibilities of Additional Water Supplies for Irrigation

The feasibility of developing additional water supplies from wells for irrigation in Cimarron County depends upon complex hydrologic, economic, and agricultural factors that can be considered here only in part. From the hydrologic point of view, successful irrigation from wells depends on (1) the depth to the water, (2) the permeability and thickness of the water-bearing materials, and (3) the amount of water that can be pumped from the underground reservoir without permanently depleting the supply.

The first factor—depth to water—largely determines the depths of wells and the costs of drilling, of pumping equipment, and of operation. The importance of the pumping lift is discussed at length by Rohwer,[206] who states:

206. Rohwer, C., "Putting Down and Developing Wells for Irrigation": *U. S. Dept. of Agri. Circ.* 546, pp. 4-5, 1940.

> The limit of the lift against which water may be profitably pumped for irrigation varies with the cost of pumping and the value of the crops grown. As greater care is being used in the design of pumping plants and as the efficiency of pumps is being constantly increased and the cost of power reduced, the cost of pumping an acre-foot of water per foot of lift has been correspondingly reduced. . . Low-priced agricultural products and small yields, however, reduce the economical pumping lift.

Rohwer gives a table showing, among other things, the estimated economic limit of lift for pumping water from wells in 12 of the western states. Oklahoma is not included, but the estimates given for Kansas and Nebraska are 50 feet, and that for Texas is 60 to 100 feet.

The second factor—permeability and thickness of saturated materials—also has a bearing on the depth and construction of wells and on installation and operating costs. Obviously, a single thick bed of clean gravel can be tapped at less expense than many thinner beds of poorly sorted sand separated by layers of clay, because the well need not penetrate as far below the water table, and gravel-packing will not be necessary. Furthermore, the drawdown and, hence, the total pumping lift, will doubtless be less in the well in gravel than in the well in the sands.

The third factor—safe yield of the reservoir—depends on the capacity of the reservoir and on the amount of annual recharge. It limits the total amount of development in a given area, and in the long run it also determines the success of the individual pumping plant.

Plate I shows that depths to water differ greatly in Cimarron County, even from one part of the uplands to another. Depths to water under the uplands generally are more than 40 feet, and for a very large part of the area are more than 100 feet. Therefore, deep-well irrigation probably is not economically practical for a large part of the upland. On the other hand, the water table is less than 100 feet below the surface near old Willowbar post office, near Liberty school, near Wheeless, in about 200 square miles south of the North Canadian River in the western half of the county, and along the main streams. The practicability of developing well irrigation differs from one shallow-water area to another because of differences in the depth to the water, in the thickness of saturated materials, in the topography of the surface, and in the soils. Their relative merits are discussed further under the heading *Ground Water Conditions Described by Localities.*

The principal water-bearing formations in Cimarron County that probably will yield water in quantities large enough for irrigation are Tertiary and Quaternary sands and gravels (chiefly the "Ogallala" formation) under the uplands, and the alluvium in the major valleys. These materials are all very heterogeneous, and some wells are likely to encounter more good water-bearing material than others. The sands and gravels generally are nearly or entirely unconsolidated, so that wells must be cased to the bottom to prevent caving, and may require screens or gravel-packing. Sieve analyses of carefully selected samples of water-bearing sands obtained from preliminary test holes should indicate whether gravel packing is necessary, and if not, what type of screen should be used.

The thickness of the saturated portion of the Tertiary-Quaternary deposits of the uplands differs greatly from place to place, ranging from little or nothing over the buried red bed ridge south of Keyes to perhaps 50 feet. Evidence to indicate areas of unusually thick saturated materials is lacking. The thickness of the zone of saturation in the alluvium also ranges within wide limits, the maximum along the axis of the Cimarron Valley being perhaps 40 feet.

The yield of the larger municipal and railroad wells indicates moderate permeability for the water-bearing materials, but is less encouraging than the yields of the large wells at the Panhandle Agricultural Experiment Station and elsewhere in Texas County—perhaps because no wells comparable to those in Texas County, or so favorably situated, have been drilled in Cimarron County. When test drilling is undertaken, the depth, thickness, and character of all the beds encountered should be logged, and the water-bearing beds should be sampled carefully as a preliminary to laboratory tests of their hydrologic properties.

Irrigation Supplies in Other Parts of the Southern High Plains

Interest in the possibility of irrigating with water pumped from deep wells in the Oklahoma Panhandle was aroused by the drought of 1931-1940. Much of the development to date has occurred in Texas County, where it was hoped that the gas field in the central part of the county would furnish fuel at a cost low enough to offset the obvious disadvantage of high pumping lifts. Although in most parts of that county the gas has not been made available to farmers, several irrigation wells are in use, both on the uplands and in the valleys.

The Panhandle Agricultural and Mechanical College, at Goodwell, took the lead in 1937 by putting down two gravel-packed wells in which the static water levels are about 118 and 135 feet below the surface. Both are equipped with deep-well turbine pumps. The well on the Experimental Farm is operated by a natural-gas engine, and the one on the college campus by an electric motor. In 1939, the Soil Conservation Service, of the United States Department of Agriculture, acting under provisions of the Water Facilities Act of 1937, [207] co-operated with the college in drilling a second large well on the Experimental Farm. The Soil Conservation Service has also given considerable aid to Texas County farmers who have installed irrigation wells in the valleys of Paloduro Creek and the North Canadian River. The development of ground-water supplies in Texas County through 1937 was described by the writer[208] in a previous report, in which details of the irrigation wells and their equipment are given.

Ground water has been pumped for irrigation in parts of the Southern High Plains in the Texas Panhandle and in southwestern Kansas for many years. In general, most of this irrigation has been developed in localities where the depth to the water table is moderate. The average depth to water in the irrigated areas near Plainview, Lubbock, Muleshoe, Hereford, and Texline, Texas, is 60 to 65 feet. The depth is 20 to 70 feet near Scott City, Kansas, and 20 to 60 feet near Garden City, Kansas. Deep-well irri-

207. Public—No. 723—75th Congress. Chap. 681—3rd Session. H. R. 10851.
208. Schoff, S. L., "Geology and Ground Water Resources of Texas County, Oklahoma": *Okla. Geol. Survey Bull.* 59, 1939.

gation has been tried where static water levels are 100 feet or more below the surface, but in general seems not to have been successful. Further details regarding well irrigation in these areas are summarized in a previous report by the writer,[209] and comprehensive reports are being prepared by the Geological Survey of the U. S. Department of Interior, in cooperation with State agencies.

The Texas State Board of Water Engineers, in cooperation with the Geological Survey, U. S. Department of Interior, has made well-inventories in part or all of 25 counties in the High Plains in Texas, and has issued mimeographed tables of the well records, wells logs, and chemical analyses of water, by counties. A progress report on the cooperative investigation was issued in July 1938,[210] and a memorandum for the press, summarizing the history of the development of ground water supplies and the effects of pumping on the water table was issued in April 1939.[211] A more comprehensive preliminary report giving the principal results obtained from the investigation to April 1, 1940, was released in December 1940.[212]

The Kansas Geological Survey, in cooperation with the Geological Survey of the U. S. Department of the Interior, has issued reports on ground water in Ford,[213] Meade,[214] Stanton,[215] and Morton[216] Counties.

209. Schoff, S. L., *op. cit.*, pp. 120-124.
210. White, W. N., Broadhurst, W. L., and Lang, J. W., "Ground Water in the High Plains in Texas": *U. S. Geol. Survey Mimeographed Prog. Rept.*, 11 pp., July 26, 1938.
211. "Ground Water in the High Plains": *Texas State Board of Water Engineers, Memorandum for the Press*, mimeographed, April 12, 1939.
212. White, W. N., Broadhurst, W. L., and Lang, J. W., "Ground Water in the High Plains in Texas": *Texas State Board of Water Engineers*, mimeographed, 56 pp. including maps, Dec. 1940.
213. Lohman, S. W., "Water Supplies from Wells Available for Irrigation in the Uplands of Ford County, Kansas": *State Geol. Survey of Kans. Mineral Res. Circ.* 9, 1938.
Waite, H. A., and Hess, R. H., "Geology and Ground-Water Resources of Ford County, Kansas": *State Geol. Survey of Kans. Bull.* 43, 1942.
214. Frye, J. C., "A Preliminary Report on the Water Supply of the Meade Artesian Basis, Meade County, Kansas": *State Geol. Survey of Kans. Bull.* 35, 1940.
Frye, J. C., "Geology and Ground-Water Resources of Meade County, Kansas": *State Geol. Survey of Kans. Bull.* 45, 1942.
215. Latta, Bruce H., "Geology and Ground-Water Resources of Stanton County, Kansas": *State Geol. Survey of Kans. Bull.* 37, 1941.
216. McLaughlin, T. G., "Geology and Ground-Water Resources of Morton County, Kansas": *State Geol. Survey of Kans. Bull.* 40, 1942.

GROUND-WATER CONDITIONS IN CIMARRON COUNTY DESCRIBED BY LOCALITIES

In the following paragraphs the ground-water conditions in Cimarron County are described by localities that are classified primarily on the basis of the depth to the water table as determined by the water-level measurements made in wells (fig. 23). These areas fall into two main groups, (1) upland plains, and (2) valleys:

TABLE XXIII.

Ground Water Areas in Cimarron County

- Upland Plains
  - Central upland
    - Area of buried red bed ridge
    - Griggs deep-water area
    - Midwell school deep-water area
    - Sturgis deep-water area
    - Willowbar shallow-water area
    - Liberty school shallow-water area
    - Wheeless shallow-water area
    - Mexhoma area
    - Other areas
  - Cieneguilla-North Canadian upland
  - Southern upland
    - Felt shallow-water area
    - Delfin school deep-water area
    - Beaver school deep-water area
- Valleys
  - Cimarron Valley
    - Flood plains
    - Broken lands
  - North Canadian and Cieneguilla Valleys
    - Western shallow-water area
    - Eastern deep-water area

Upland Plains

The uplands make up about 60 percent of the area of Cimarron County, and range from flat or gently undulating, in localities where the High Plains surface has been little affected by erosion, to hilly in the sand dune areas. They are cut into three unequal parts by the major streams, as follows: (1) the central upland, between the North Canadian and Cimarron Rivers; (2) the upland between the North Canadian River (i.e., Currumpa Creek) and its tributary, Cieneguilla Creek; and (3) the southern upland, south of Cieneguilla Creek and the North Canadian River.

The flatness of the greater part of the upland plains encourages the farming of large areas with tractors and favors the easy

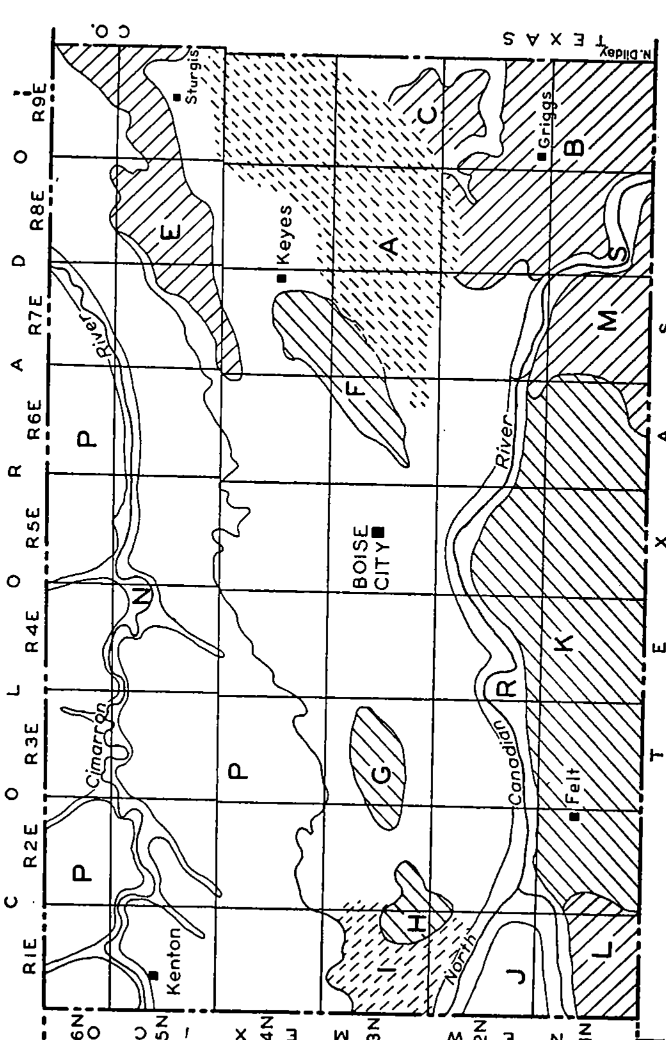


FIG. 23. Principal ground-water areas in Cimarron County, Oklahoma. A, area of buried red bed ridge; B, Griggs deep-water area; C, Midwell school deep-water area; E, Sturgis deep-water area; F, Willowbar shallow-water area; G, Liberty school shallow-water area; H, Wheeless shallow-water area; I, Mexhoma area (two water levels); J, Cieneguilla-North Canadian upland; K, Felt shallow-water area; L, Delfin school deep-water area; M, Beaver school deep-water area; N, flood plains; and P, broken lands in Cimarron Valley; R, western shallow-water, and S, eastern deep-water areas in North Canadian-Cieneguilla Valleys.

spreading of irrigation water. The upland soils in general are probably good. A soil-survey of the county has not been made, but as the uplands are similar to and continuous with those of Texas County, and are underlain by the same kind of rocks, it is likely that the soils are similar to the upland soils of Texas County, which are excellent over large areas.[217] The sand dune areas, obviously, are not favorable for irrigation because of large losses of water by seepage into the sand, and because of difficulty in spreading water and cultivating over hilly ground.

CENTRAL UPLAND

The central upland is the largest of the three upland plains. Tributaries of the Cimarron have etched their way headward into this plain, making its northern boundary very irregular, especially in the west half of the county, but the North Canadian River has so few tributaries that the southern boundary is a fairly smooth curve. The surface displays all of the characteristics of upland plains mentioned above—flat, undulating, and hilly areas. The hills are found principally in the sand dunes west of Boise City and northeast of Keyes. Large areas are uninterrupted by valleys of any kind, but are diversified by many more or less circular depressions. The northeastern part of the plain, near Sturgis, has been trenched by the headwaters of Goff Creek, and an area in the eastern part, to the northeast of Griggs, has been somewhat dissected by headwaters of Beaver Creek. Both creeks empty into the North Canadian River in Texas County.

This plain supports a large part of the population of the county. The County Seat—Boise City—is centrally located on it. All of the main highways in the county cross it, and it contains more than half of the arable land.

The depth to water in the central plain ranges from less than 50 feet below the surface to about 300 feet. In two moderate-sized areas the depth to water is less than 100 feet, in one it is just about 100 feet, and in four localities it exceeds 200 feet. Evidence of two more or less independent water tables was found in the extreme western part, near Mexhoma. A buried red bed ridge

217. Fitzpatrick, E. G., and Boatright, W. C., "Soil Survey of Texas County, Okla.": *U. S. Dept. Agri., Bur. Chem. and Soils*, Ser. 1930, No. 28, Map.

rising nearly to the surface partly controls the hydrology of the eastern part of the plain, and therefore is described first.

Area of buried red bed ridge. The red bed ridge appears to underlie most of T. 3 N., Rs. 7 and 8 E., T. 4 N., R. 9 E., and parts of adjacent townships (fig. 23). The red beds are not exposed at the surface in this area, but logs of many seismograph shot-holes and the reports of well drillers and others indicate that they are not far below the surface. They extend above the level at which the water table otherwise would occur, and the principal water-bearing formation of most of the rest of the central plain—the "Ogallala"—is therefore nearly or entirely dry.

The wells in use in the area range from 200 to more than 300 feet in depth, and many of them seem to have passed through the "Ogallala" without obtaining adequate supplies of water. Reports indicate that many more wells have been drilled, some to depths of 300 feet or more, but that a large proportion of them failed. Farm houses are few in T. 3 N., Rs. 7 and 8 E., a fact suggesting that part of the land is worked by farmers who live in other localities where ground water is more readily obtainable.

The red beds consist chiefly of impervious red shales, but sandstones are interbedded with them and probably furnish the water to most of the wells that are in use. For example, the Gladys Belle oil-test in sec. 25, T. 3 N., R. 7 E. penetrated several water-bearing beds (see log 318). The water well that furnished the drilling water for this test well is reported by the driller[218] to have obtained an abundant supply of water from sand between depths of 420 and 428 feet, and the log of the oil well suggests that this sand extends down to 440 feet. It is said, further, that the water rose to the 200-foot level within a few hours after the sand was penetrated. Reports indicate that much of the water obtained from the red beds in the southwestern part of this area is more or less mineralized, but the existing wells in T. 4 N., R. 9 E. seem to obtain moderately abundant supplies of water of satisfactory quality. The chemical analysis of water from well 446, (sec. 22, T. 4 N., R. 9 E.), shows considerable dissolved mineral matter,

218. Witten, E. B., Boise City, oral communication, 1938.

but otherwise is rather similar to analyses of water from the Tertiary-Quaternary rocks.

The high pumping lifts that would necessarily prevail, the difficulty in obtaining water at all in some places and the small yields in others, and the probably high mineral content of much of the water make it exceedingly unlikely that deep wells for irrigation can be developed successfully in this area.

The buried red bed ridge is probably the subsurface extension of the red beds that crop out at several places in Texas County along the North Canadian River and its tributary, Tepee Creek, and appears to be the higher parts of an east-west ridge of the pre-Tertiary topography.[219] Other evidence bearing on this buried ridge has been presented under *Thickness* and *Stratigraphic Relations* of the Ogallala formation, and a cross section showing it is given on Plate I.

Griggs deep-water area. Tps. 1 and 2 N., Rs. 8 and 9 E. The largest deep-water area is in the southeastern corner of the county near Griggs postoffice (fig. 23). In an area of about 110 square miles the depth to the water table is more than 200 feet below the surface, and in an area of about 45 square miles it is more than 250 feet. In six wells the static water levels were more than 275 feet below the surface. In one well a 300-foot tape failed to reach the water, and it is therefore probable that in a few square miles the water table lies more than 300 feet below the surface. This is the greatest depth to water recorded in the county, and in the entire Oklahoma Panhandle.

Residents in this area and drillers who have worked there report no difficulty in obtaining good supplies of water of good quality. The available chemical analyses indicate that the ground waters from this area are similar to waters from the "Ogallala" formation and definitely are unlike many of the waters from the red beds.

The great depth to the water table in this area probably is partly due to the buried red bed ridge adjoining it on the north-

219. Schoff, S. L., "Ground Water in the Oklahoma Panhandle": *Econ. Geol.*, Vol. 35, p. 543, 1940. Illustrated by Isopach lines on fig. 3.

west, which probably acts as an obstruction to retard ground water from moving into the Griggs area. As shown by the water-table contour map (fig. 20), the general movement of ground water in the eastern part of the county is eastward. The water-table contours north of the red bed ridge, however, trend northwest-southeast and are offset several miles to the east compared with contours south of the ridge. This condition suggests that ground waters moving eastward or southeastward have been "ponded" on the north side of the buried ridge, raising the water table and decreasing the water-table gradient locally. Although a little of the "ponded" ground water may escape around the west end of the buried ridge into the Griggs area, and some more may come around the eastern end or over low points in the crest of the ridge, the principal movement of the water is northeastward toward Sturgis. As a result of this diversion, the 300 feet or more of the "Ogallala" formation in the Griggs area, on the "lee" side of the ridge, is undersaturated, and the water table is far below the surface.

The great depth to the water table in the Griggs area will prevent the development of deep-well irrigation unless a high-priced crop and a sure market can be found. The soils, the flat surface, and the character of the ground water, however, are favorable. As no wells are known to penetrate the full thickness of the "Ogallala," the thickness of the zone of saturation in the formation is a matter of conjecture, but it probably is not more than 50 feet in most of the area.

Midwell school deep-water area. (Tps. 2 and 3 N., R. 9 E.) In an area of about 17 square miles immediately southwest of Midwell school (fig. 23) the water table is more than 200 feet below the surface. In about 4 square miles of this area, the depth to water exceeds 250 feet. The maximum measured depth is about 265 feet. From the shape of the water-table contours shown on figure 20, it seems probable that this area lies just southeast of the eastern end of the high crest of the buried red bed ridge. This area probably would be continuous with the Griggs deep-water area if it were not for the intervening valley of the North Fork of Beaver Creek, along which depths to water are appreciably less than 200 feet. The surface topography, soils, and chemical character of the ground-water are comparable to those in the Griggs area.

Sturgis deep-water area. (Parts of Tps. 4-6 N., Rs. 7-9 E.) The Sturgis deep-water area is elongate and trends east-northeast from the vicinity of Pioneer and Excelsior schools into Texas County. It is bounded on the north by the valley of the Cimarron. On the south it is partly bounded by a fork of Goff Creek, and partly is unmarked by any topographic feature. The depth to the water table is more than 200 feet in an area of about 59 square miles, and is greater than 250 feet in about 9 square miles. The maximum slope of the water table and the direction of movement of the ground water are northeastward.

In part, the surface of this area is rather strongly undulating. Locally the soils seems to be more sandy than in some other parts of the county. The available chemical analyses indicate that the water is of good quality. Reliable information from which to estimate the thickness of the zone of saturation in the "Ogallala" formation is not available, but it is likely that the thickness nowhere exceeds 100 feet, and in much of the area may be less than 50 feet.

Willowbar shallow-water area. The Willowbar shallow-water area is an elongate strip trending southwestward from the vicinity of Keyes (fig. 23), and covering about 28 square miles. It is named for the former post office and trading center, Willowbar, and includes Willowbar Lake. The wells that were measured in the area range from 55 to 125 feet deep, and static water levels in them are generally between 75 and 100 feet below the surface, although a minimum depth to water of 46 feet was measured in well 313. This well is in a depression near a small intermittant pond, and the area in which the depth to water is less than 50 feet is obviously small.

Two factors account for this shallow-water area. First, the area is a broad, shallow depression of the upland surface, and second, the water table along its southern edge may rise somewhat as a result of the "ponding" of the ground water by the buried red bed ridge, as described under the *Griggs deep-water* *area.* This is not the largest shallow-water area on the uplands, but because of its relatively flat surface, favorable soil, and good quality of ground water, it may be better adapted for irrigation from wells than the others. It does not offer a first rate opportunity, however, because the zone of saturation in the pervious water-bearing strata is rather thin. As estimated from the water levels that were measured in wells and from the logs of seismograph shot-holes, the thickness of the zone of saturation in the Tertiary and younger formations ranges from 15 to 75 feet and averages about 50 feet in the southern third of T. 4 N., R. 7 E.; and ranges from about 20 to 30 feet in the northwestern part of T. 3 N., R. 7 E. Test-drilling to determine the thickness and character of the zone of saturation should precede the sinking of large wells in this area.

Liberty school shallow-water area. The few wells that were available for measurement in the sand dunes of the central part of T. 3 N., R. 3 E. suggest an area about 7 miles long and 3.5 miles wide where the depth to ground water is moderate. The area covers about 17 square miles, and trends roughly east-west across the township into the eastern part of T. 3 N., R. 2 E. near Liberty school (fig. 23), for which it is named. Water levels of 79 and 85 feet below the surface were measured in two wells in the western part of the area, a level of 98 feet was obtained at the east end, and a level of 105 feet was obtained to the south. From these water levels it appears that the depth to the water table is 80 to 100 feet in the western part and is very close to 100 feet in the eastern part.

This shallow-water area may be an indication that rainwater percolates downward through the dune sands and builds up a mound on the water table. If water-level measurements could have been made in several times as many wells in the area, such a mound might appear on the water-table contour map, but the data actually obtained are sufficient only to suggest a slight and inconclusive eastward bending of the contour lines (fig. 20).

No well logs or other data are available to suggest the thickness of the zone of saturation in the "Ogallala" formation, or whether the Dakota sandstone or other water-bearing Mesozoic

formations are present under cover at reasonable depths. The sand dunes, obviously, are not favorable to the development of irrigation.

Wheeless shallow-water area. Water levels measured in six wells south of Wheeless range from 63 to 97 feet below the surface and suggest the third shallow-water area of the central upland. This area lies in parts of Tps. 2 and 3 N., Rs. 1 and 2 E., and covers about 10 square miles (fig. 23). As mapped, it is separated from the Liberty school shallow-water area by a 2-mile strip where depths to water slightly in excess of 100 feet are reported but no measurements could be made. The surface is undulating, and the minimum depth to water—53 feet—was obtained in a well in the bottom of a depression and represents only a small area. On the whole, the depth to the water probably is between 75 and 100 feet. The depths of the measured wells ranged from 69 to 149 feet. The water probably comes from the "Ogallala" formation.

Mexhoma area. (T. 3 N., R. 1 E., and adjacent parts of T. 3 N., R. 2 E.) Ground water at two levels is revealed by the water-level measurements in the vicinity of Mexhoma and Wheeless. In addition to the shallow wells of the Wheeless shallow-water area, described above, a few shallow wells were found associated with deeper wells. For example, well 220, about 1.25 miles northwest of Wheeless, is 135 feet deep and the water level in it was measured as 86 feet below the surface. Well 221 is just across the road to the east—less than 0.25 mile away and within a foot of the same altitude—but is 239 feet deep and has a static water level of 187 feet. Thus the water levels in these two wells are about 100 feet apart in altitude.

The difference in section 30, T. 3 N., R. 1 E., is less pronounced, but appears to be significant. The depth to water in well 235, in the NW¼ of the section, is about 200 feet, whereas in well 234, in the SE¼, it is only 83 feet. The latter well, however, begins at an elevation about 70 feet lower, and the difference in altitude of the water surface in the two wells is therefore only about 48 feet. If the two wells were assumed to tap the same body of ground water, the water-table gradient between them would be about 43 feet per mile westward—a lower gradient than was found in some localities (See *Shape and Slope of the Water Table,* etc., and fig. 20), but opposite to the regional slope of the water table.

Contour lines representing the two sets of water levels in the Mexhoma area are shown in figure 24. The division of the wells into two groups is based on (a) the depth to the water, applicable without question where the depth is either exceptionally shallow or deep, and (b) the altitude of the water level above sea level. As the interval between the two levels seems to decrease eastward into T. 3 N., R. 2 E., the assignment of some of the wells to one group or the other has been somewhat uncertain, but the grouping on the map is thought to be at least plausible.

Positive identification of the aquifers represented by these two water levels is not possible because no well logs are available for this area. The upper level doubtless represents the water table in the "Ogallala" formation, which in this locality ordinarily is water-bearing, and directly underlies the land surface. Presumably it is thick enough so that its base is below the upper water level. The lower water level may well represent water in the Dakota sandstone, which crops out along South Carrizo Creek in the northern part of T. 3 N., R. 1 E., and along the North Canadian River a few miles south of the south line of the map. If the Dakota is fully saturated, the deeper water levels may represent a surface of artesian head, although the head must be relatively low or the water would rise higher. If the Dakota is not fully saturated, the lower water levels are a water table. An impermeable zone—perhaps the upper part of the Graneros-Greenhorn, or possibly fine-grained materials in the lower part of the "Ogallala"—separates the saturated Dakota from the saturated "Ogallala". Otherwise the upper water would move downward to the lower level, and only one water table would be found.

The higher set of contours shows a low nose trending northeastward in the SE¼ T. 3 N., R. 1 E., and the lower set shows a flattening of the gradient somewhat farther west. The reasons for these irregularities are not apparent, but two suggestions for the nose at the upper level are offered:

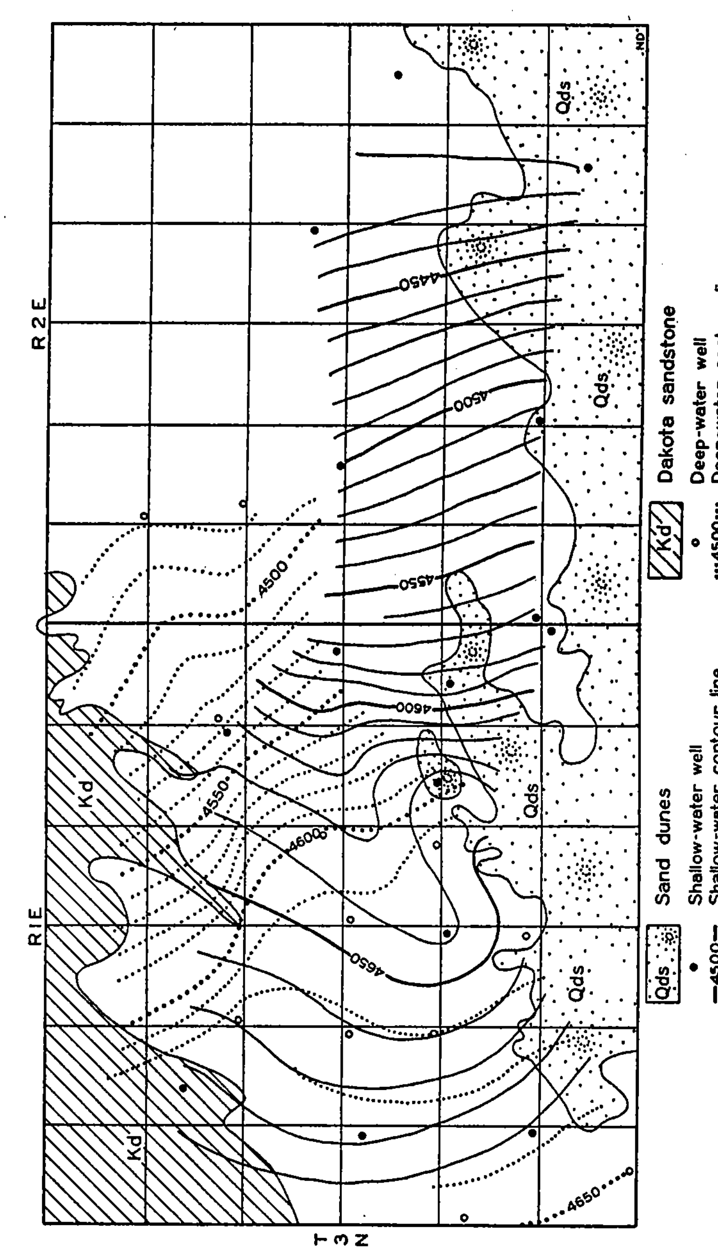


FIG. 24. Deep- and shallow-water levels in the Mexhoma area shown by contour lines. The upper level is a water-table in the Ogallala formation; the lower one may be either a water-table or a piezometric surface, and probably represents water in the Dakota sandstone. Contour intervals, 10 feet.

(a) Recharge of the ground-water from rain taken in by the dunes along the southern edge of the area may be concentrated to produce a low mound on the water-table. Unfortunately for this explanation, no really convincing recharge-effect for the entire dunes area is evident from the map; and if the same cause is responsible for the flattening of the slope at the lower level, it is necessary to assume considerable leakage through the "impermeable" zone between the two aquifers.

(b) The water level in the well near the S¼ cor. sec. 23, T. 3 N., R. 1 E., which is the chief basis for drawing the nose, may not belong with either group of water levels, but may instead represent a perched water table higher than either. Information on which to evaluate this possibility is lacking.

Other areas. The wells in the rest of the central upland are of intermediate depth, and the static water levels in them range from 100 to 200 feet below the land surface. The deep- and shallow-water areas described in the preceding paragraphs represent the extremes in depth to the water table. They are like hills and basins on a plain, and are separated by areas where intermediate depths to water prevail.

The water-level measurements obtained in 1938-39 indicate that the depth to water near Boise City is about 150 feet, increasing northward and northwestward to about 200 feet, and decreasing eastward toward the Willowbar shallow-water area. Near Sandy View school and northward to the margin of the Cimarron Valley, the depth to water generally is between 170 and 200 feet. The depth to water near Keyes is 100 to 150 feet; near Burton siding and northeastward to Harmony school, 150 to 200 feet; near Garlington school and southwestward to the North Canadian Valley, 100 to 150 feet; in a belt marginal to the North Canadian from the New Mexico State line eastward to Range 7, including large areas north of Harmer siding and near Victory school, 100 to 150 feet.

A perched water table of limited extent is indicated by the record of the M. M. Adee well (No. 379) in the NW¼ sec. 23, T. 4 N., R. 4 E. The well is about 116 feet in depth, and the water level in it was measured as about 98 feet below the surface, in contrast with water levels of 185 to 225 feet below the surface in wells nearby.

The ground water tapped by wells in the intermediate localities probably is derived chiefly from the "Ogallala" formation, but few well logs are available for geological identification of the water-bearing strata. It is possible, therefore, that the Dakota sandstone, which extends under cover southward from the Cimarron Valley and eastward from eastern New Mexico, is tapped by more wells than the records show. Here and there, also, wells may tap water in older sandstones. The H. A. Schneider well (No. 385) in the NW¼ sec. 15, T. 4 N., R. 5 E. is within a mile of the south margin of the Cimarron Valley, and begins only a few feet above the top of the Dakota sandstone, which is exposed in the Santa Fe Railway cut about 0.25 mile to the west. The well is 215 or 220 feet in depth, and therefore must penetrate all of the Dakota sandstone and probably also the Kiowa shale, the Cheyenne sandstone if present, and perhaps part of the Morrison. Both the Dakota and the Cheyenne thin eastward in Cimarron County, and the Cheyenne is absent at Wolf Mountain only 3.5 miles north of the Schneider well. The static water level in the well in October 1938 was about 128 feet below the surface, at an altitude appreciably higher than the water levels in other wells on the plains to the south. This fact, together with the large depth of water standing in the well, suggests that the water is under artesian pressure, and therefore, that the aquifer is either the Cheyenne or sandstones in the Morrison.

CIENEGUILLA (SENECA)-NORTH CANADIAN UPLAND

The upland between Cieneguilla Creek and the part of the North Canadian known locally as Currumpa Creek is an upland in the sense that it is higher than the adjacent valleys. It is not, however, an upland plain. Tributaries of both streams have cut into it from the north and the south, and sand dunes have mantled part of it, so that it is a moderately hilly and sandy area useful mainly for grazing. The "Ogallala" formation is either thin or absent in this area, and furnishes little or no water to wells. The Dakota sandstone crops out along the valleys on both the north and south sides of the area, in places extending high above the streams. It also crops out several miles from the streams in secs. 21 and 28, T. 2 N., R. 1 E. Several springs issue from it in the canyons around the margin of the area, and most of the scattered windmill wells probably tap water in it. Well 122, at the Rufus Wright ranch, begins on the Kiowa shale and probably taps water in the underlying Cheyenne sandstone. The depths to water as measured in wells in this area range from 25 or 50 feet near the valleys to 127 feet in the western part.

SOUTHERN UPLAND

The upland south of the North Canadian River and its tributary Cieneguilla Creek is about 46 miles long and has a maximum width of about 10 miles. Between one-third and one-half of it is covered with sand dunes, and much of it, therefore, is used chiefly for grazing. The water table lies deep beneath the land surface at both the east and west ends, but in the middle ranges from about 40 feet to somewhat more than 100 feet below the surface.

Felt shallow-water area. The Felt shallow-water area, named for the settlement of Felt in the southwestern part of the county, is the northward extension of the shallow-water district centering around Texline, in Dallam County, Texas, where 25 wells were pumped for irrigation in 1939[220]. It includes most of T. 1 N., Rs. 2 to 6 E., inclusive, and the land between these townships and the valley of the North Canadian River—an area of about 218 square miles. The western third of it, in the vicinity of Felt, is rather flat or mildly undulating except where it is trenched by the shallow valley of Coldwater Creek. The eastern two-thirds is largely covered with sand hills that begin as broad, gentle swells near the Texas State line, and become higher northward toward the North Canadian River. Deep depressions, some containing lakes in wet seasons, characterize the surface in T. 1 N., R. 4 E. southeast of New Hope school, making a sink-hole type of topography.

220. White, W. N., Broadhurst, W. L., and Lang, J. W., "Ground Water in the High Plains of Texas": *Texas Board of Water Engineers, Mimeographed Rept.*, p. 15, 1940.

On the basis of the water-level measurements obtained in this area in 1938, the depth to the water table ranges from about 40 to about 100 feet beneath the surface. It is estimated that the depth to water is somewhat more than 100 feet in an area of about 11 square miles in the northern part of T. 1 N., Rs. 3 and 4 E., and in about 6.5 square miles in Tps. 1 and 2 N., R. 6 E.

The depth to the water table is less than 100 feet in an area of about 200 square miles. The minimum observed depth to water, 42 feet, was in a well in a large depression, at New Hope school (NE¼ sec. 28, T. 1 N., R. 4 E.), but ground water may be obtainable locally at even lesser depths. It is reported that a well about 0.75 mile southeast of the school, lower in the depression and beside a lake, is only 20 or 25 feet in depth. Unfortunately, a water-level measurement could not be made in it. In the valley of Coldwater Creek at the Texas state line, the water level in well 42 (sec. 33, T. 1 N., R. 3 E.) was measured as about 43 feet. The water-level measurements obtained in depressions and in Coldwater Creek valley, however, represent only a small part of the area. In general the depth to the water table probably is between 75 and 100 feet.

TABLE XXIV.

DEPTHS TO WATER TABLE IN FELT SHALLOW-WATER AREA, BY TOWNSHIPS

Township	*Measured Depth to Water (Feet)*
T. 1 N., R. 2 E.[a]	75-100
T. 1 N., R. 3 E.	43[b]-100
T. 1 N., R. 4 E.[c]	42[d]-108
T. 1 N., R. 5 E.	65-78
T. 1 N., R. 6 E.[e]	69-108
T. 2 N., Rs. 3-6 E.[f]	75-100

[a] Eastern two-thirds of township.
[b] In valley of Coldwater Creek.
[c] Measurable wells confined to western half.
[d] In a large depression.
[e] Excluding about 3 square miles in extreme southeast corner.
[f] Ranch lands; few wells measurable.

The "Ogallala" formation appears to be the principal aquifer in most of the Felt shallow-water area, but the Dakota sandstone may supply water to a few of the wells in the western part. The Dakota is not clearly indicated in the logs of the wells drilled near Felt by the Santa Fe Railway, although the black shales and slates reported at depths ranging from 115 to more than 200 feet probably can be interpreted as the underlying Kiowa shale. This lack of conclusive evidence for the Dakota may arise from the fact that the Dakota sandstone, in places at least, is so very friable that drillers would not be likely to distinguish it from the relatively unconsolidated "Ogallala" sands.

Well logs are entirely lacking in the eastern two thirds of the area but the oral report of Mr. Womack[221] that his irrigation well passed through alternating layers of gravel, fine sand, and clay or caliche to a depth of 150 feet suggests that the "Ogallala" is the principal source of ground water in at least part of it. On the other hand, the report of a Cimarron County well driller[222] that five wells drilled in T. 1 N., Rs. 6 and 7 failed because they encountered red beds at shallow depths indicates that in places the saturated part of the "Ogallala" may be thin and ground water difficult to get.

Delfin school deep-water area. (T. 1 N., R. 1 E., and western part of T. 1 N., R. 2 E.) The deep-water area near Delfin school occupies about 28 square miles of undulating upland south of Cieneguilla Creek. Coldwater Creek heads in the southwestern part of it, and cuts northeastward across it, but makes only a shallow trough in the upland surface. The depth to the water table as measured in 9 wells in 1938 ranged from about 100 feet below the surface in the eastern part to 172 feet in the western part near Nieto siding. The Dakota sandstone crops out high in the walls of Cieneguilla Creek valley on the north, and therefore probably underlies the area at moderate depths and furnishes more or less water to wells.

Beaver school deep-water area. (T. 1 N., R. 7 E., and parts of adjacent townships.) East of Range 6, the gradient of the water table becomes considerably greater than the slope of the land surface, and the depth to the water increases abruptly to about 250 feet in the vicinity of Beaver school. Depths to water in 7 wells measured in 1938 ranged from 147 to 265 feet below the surface. This deep-water area occupies about 43 square miles of land that is largely covered with sand dunes and therefore is not especially suitable for irrigation. The log of the Santa Fe

221. Womack, C. K., oral communication.
222. Witten, E. B., oral communication.

Railway well at Kerrick, Texas, (log T-1, Appendix B), about 0.5 mile south of this area, suggests that the "Ogallala" in this vicinity is 300 feet or more in thickness, is the source of the ground water obtained by some of the wells, and overlies the red beds directly. On the other hand, the logs of seismograph shot holes indicate that wells in the central part of T. 1 N., R. 7 E. draw water from the pre-Tertiary red beds.

VALLEYS

The Cimarron and North Canadian Rivers cross parts of Cimarron County. Ground-water conditions in the valleys of these rivers and their tributaries are described in the paragraphs that follow.

CIMARRON VALLEY

The Cimarron River and its tributaries have more or less dissected a wide strip of country (See *Topography and Drainage*) in which the depths to water are diverse because of the strong topographic contrast between the flood plains along the streams and the intervening divides, and in which the existing wells tap water in several different geological formations. Accordingly the ground-water conditions in the Cimarron Valley will be described under two headings, (a) flood plains, and (b) broken, or dissected, lands.

Flood plains. Along the Cimarron and its major tributaries the flood plains range from a fraction of a mile to nearly two miles in width. They are relatively flat lands on which irrigation water could be spread rather easily, and on parts of which the soils are satisfactory. The productivity of some of these bottom lands has been amply demonstrated by the surface-water irrigation carried on by Kohler in the Cimarron Valley and by Tucker in the North Carrizo Creek valley. Except near the upper ends of the tributary valleys, the water table everywhere is less than 50 feet below the surface of the flood plains, and in most places less than 25 feet. The principal water-bearing stratum of the flood plains is the alluvium, the water-bearing properties of which are described in a previous section. The quality of the water from the alluvium is described under the heading *Chemical Character* *of the Ground Water.* Irrigation with ground water as developed in the valley by Strong, Eiland, and the Alliance Insurance Company is described under *Wells used for Irrigation.*

Broken lands. West of Range 5, much of the area between the Cimarron River and the edge of the upland consists of broken lands—canyons, mesas, buttes, and narrow, tabular inter-stream divides. Farther east, V-shaped valleys are separated by broadly rounded divides. These are ranch lands, and springs and perennial streams are used as the source of stock water wherever possible. As such natural water supplies are moderately abundant in the western canyon-and-mesa part of the valley, water wells are spaced far apart. Many of the wells are used for domestic supplies at ranches, are in the canyon bottoms, and therefore are properly classified under the previous heading, *Flood plains.*

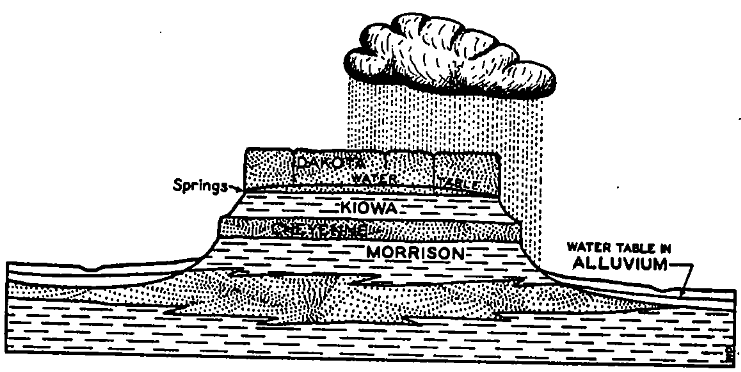


Fig. 25. Ground water in a mesa. The intake area of the Dakota is limited to the top of the mesa, and water descends in it to the top of the Kiowa shale. The water table in it is drawn down near the margin of the mesa because of discharge by springs. The Cheyenne sandstone is essentially dry because its intake area is limited to the narrow band of its outcrop. Water in the sands of the Morrison can be reached most easily by drilling in the canyons.

In general, wells have not been drilled on top of the mesas or table lands, although they probably would encounter some water in the Dakota sandstone. The intake area for the Dakota capping of a mesa is obviously limited to the top of the mesa (fig. 25), and the annual recharge can be only a fraction of the annual rainfall at that place. The base of the Dakota is exposed entirely around many of the mesas, and the water in the sandstone is

Plate XX. Basalt at the north end of Black Mesa is extensively jointed.

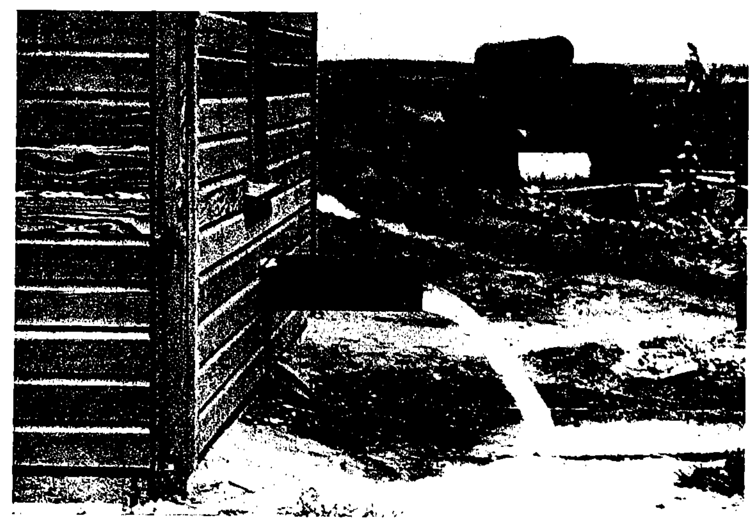


Plate XXI. Irrigation well of Alliance Insurance Company (No. 528), showing discharge after drawdown had been stabilized.

therefore free to escape as springs or seeps, drawing the water table down near the margins of the mesa. Probably the saturated part of the Dakota under the middle of a mesa is relatively thin. The Kiowa shale underlying the Dakota is relatively impervious and would prevent all but a little water from moving downward beyond the base of the Dakota. The Cheyenne sandstone, under the Kiowa, crops out as a steep bluff or cliff on the sides of the mesas, therefore has a very small catchment area, and probably is nearly or quite dry under the mesas and the more nearly isolated table lands. A. C. Brown reported drilling a well near the northeastern end of Black Mesa, starting from the top of the Cheyenne sandstone (as interpreted by the writer from Mr. Brown's statement), which was found to be dry. The lenticular sandstones in the Morrison may contain water under mesas, but can be reached at shallower depths by drilling in the valleys. The principles outlined here for a mesa capped by Dakota can be applied, with variations in detail, to mesas capped by other formations. Ground-water conditions in the tabular divides between canyons are similar to those in mesas, except, perhaps, near their heads where they join the uplands. The chances for obtaining ground water in either the Dakota or Cheyenne under small, isolated buttes are negligible.

More water is probably to be had under the broader, flatter divides farther east. Some divides of this sort are found on the south side of the river as far west as Range 2, but on the north side they are restricted to the area east of U. S. highway 287. Where the Dakota underlies such divides, water may generally be found in it, and the record of the Donley flowing well (No. 364) indicates that water also may be obtainable in the Cheyenne sandstone. The water in the Cheyenne in many localities may be under artesian pressure, although generally the pressure is not strong enough to cause the water to flow at the surface.

In most of the Cimarron Valley east of U. S. highway 287, the Dakota and Cheyenne are absent. Wells on the upper parts of the sloping valley bluffs, near the edge of the upland, may reach good water supplies in the lower part of the "Ogallala" formation, but wells on the lower slopes generally must be drilled into the red shales and fine, silty sandstones of the Dockum group. In places, wells beginning above the base of the "Ogallala" obtain water supplies in the Exeter sandstone.

NORTH CANADIAN VALLEY

The North Canadian River has only one important tributary —Cieneguilla (Seneca) Creek—in Cimarron County. Goff, Tepee, and Beaver Creeks head in the eastern part of the county and drain eastward to join the North Canadian in Texas County. Their valleys have been cut 50 feet or more below the High Plains surface in places, but their flood plains are narrow, and the alluvial fill in them is relatively thin. Wells in these valleys tap water in the "Ogallala" formation at depths generally between 100 and 150 feet—less than in wells on the adjacent uplands but still too great for successful pumping for irrigation of the small bottom lands.

Other tributaries of the North Canadian River and Cieneguilla Creek are dry ravines or gulleys, generally less than a mile in length. There is no large dissected area comparable to the broken lands bordering the Cimarron. Most of the wells in the valleys are on the flood plains, which in many places are hardly 0.25 mile in width.

Western shallow-water area. (Rs. 1 to 6 E.) From the New Mexico State line nearly to Conrad station, in R. 6 E., the alluvium of the North Canadian and Cieneguilla Valleys is saturated almost to the bed of the channel. The North Canadian (Currumpa Creek part) is said to be perennial for several miles in the central part of T. 2 N., R. 1 E., and a few pools of standing water were found along the channel of Cieneguilla Creek in T. 1 N., R. 1 E. In April 1941 water was flowing in the channel of the North Canadian in the E. ½ sec. 21, T. 2 N., R. 6 E. In places, also, the sands of the channel are often moist although no water is to be seen at the surface. The measurements made in wells on the flood plains showed water levels somewhat below the level of the channel at places where the channel sands were dry, and test holes dug in the channel with a shovel and hand

augur in the autumn of 1938 encountered water at depths ranging from a few inches to 6 feet.

The depth of the water table below the stream channel increases sharply in the eastern part of T. 2 N., R. 6 E. A hand-augur test hole was bored in the channel in the NW¼ of sec. 25 of this township in October 1938, and reached a depth of about 14 feet before water stood in it.

Shallow wells on the flood plains all along this part of the valley tap water in the alluvium, but the deeper wells also tap older formations. In Cieneguilla Creek valley and the upper 8 miles of the North Canadian Valley (i.e., "Currumpa Creek") they may enter the Dakota, Kiowa, or Cheyenne after passing through the alluvium. One or more of these formations may also be penetrated by wells that start on the sloping valley bluffs above the flood plains. Along the lower part of the North Canadian—downstream from the mouth of Cieneguilla Creek—the deeper wells on the flood plain penetrate more or less of the "Ogallala" below the alluvium. Few wells along this part of the valley have been drilled on the sloping valley bluffs, but wells so situated should draw water from the "Ogallala".

Eastern deep-water area. Few wells are in use along the 15 miles of the North Canadian Valley between Conrad station and the point where the river enters Texas. The available evidence indicates that the water table lies deep beneath the surface. Along much of this part of the valley it is more than 100 feet below the stream channel. As the valley is only about 1 mile in width and the flood plain is very narrow, it is unlikely that the alluvium is as much as 100 feet thick. Hence the existing wells probably pass through it to obtain water in the underlying "Ogallala" formation.

RECHARGE AND DISCHARGE OF GROUND WATER

The addition of water to the underground reservoir is known as recharge, and the natural loss of water from the reservoir through seeps, springs, stream channels, evaporation, and use by plants, and the amount withdrawn through wells, is known as discharge. As more water is pumped from a reservoir through wells, the natural discharge will decline, but because it usually is not possible to salvage all of the natural discharge, some water will continue to escape through natural outlets after the safe yield of the reservoir is exceeded. It follows, then, that the amount of water that can be pumped annually from the reservoir without causing a permanent and continuing decline of water levels is approximately the amount of the annual recharge, minus the part of the natural discharge that cannot be salvaged.

The ground water is derived chiefly from the water that falls as rain or snow, and the water table normally fluctuates in response to variations in rainfall, evaporation, and other climatic conditions. Once the water is in the reservoir, it moves down the slope of the water table. Thus water which is added at a locality where it is of no immediate value may ultimately reach a place where it can be pumped profitably from the reservoir. The following paragraphs outline the ways in which recharge may be accomplished in Cimarron County.

Recharge from Local Rainfall on the Uplands

The amount of recharge over such a large area as Cimarron County is probably far from uniform because of differences in the amount of precipitation from one place to another, and because of differences in the disposal of the precipitation. The average annual precipitation of Cimarron County is about 15 inches. Of this amount, part is returned to the atmosphere through evaporation, part is used by plants, and part is lost through immediate run-off as flood waters. The remainder seeps downward through the soil and the underlying rocks to the zone of saturation. Most of the water in this zone eventually returns to the surface, either within the county or in outside areas, through seeps, springs, river channels or wells, or is discharged by plants or by evaporation from the soil where the water table is near the surface.

The part of the precipitation that is lost by evaporation varies with the seasons, and is largest in the summer, when temperatures are highest (Table I). Finnell[223] states that 39 per cent of the water that falls near Goodwell, Oklahoma, during a wet period in the spring may become soil moisture, but as little as 22 per cent becomes soil moisture during the summer. As the conditions governing penetration of rainfall into the soil in Cimarron County are probably similar to, although not identical with those at Goodwell, Finnell's figures afford a basis for a quantitative estimate. He does not state how much of the fall and winter precipitation becomes soil moisture, but it probably is not over 50 per cent, and this may be a fair figure to use. The average of the annual precipitation for Boise City and Kenton is about 15 inches; the average for the three spring months (April-June) is 5.20 inches; the average for summer (July-September) is 5.74 inches; and the average for fall and winter (October-March) is 3.92 inches. From these figures it appears that the average amount of rainfall which may become soil moisture in the spring in Cimarron County is equivalent to about 2 inches; in the summer, 1.3 inches; and in fall and winter, 2 inches. The total for the year is about 5.3 inches. These figures probably are too high rather than too low. Finnell specifies "wet periods", in spring and summer, possibly meaning to exclude occasional light showers from his estimates.

Only a part of the soil moisture, however, penetrates to the water table. Much of it is used by plants, and this part is obviously greatest during the growing season. Although the water so used cannot be considered lost from the standpoint of human needs, it is lost so far as recharge of the ground water reservoir is concerned.

The part of the precipitation lost through immediate run-off depends on the intensity and duration of the rain, the slope of the land, the porosity of the soil, and the amount of vegetation on the land. Other factors being equal, a much larger percentage of the water is lost through run-off during a heavy downpour

223. Finnell, H. H., "Agricultural Significance of Climatic Features at Goodwell, Oklahoma": *Panhandle Agri. Exp. Sta., The Panhandle Bulletin*, No. 40, pp. 22-23, 1932.

than during a gentle rain. Moderate and steep slopes where soils are "tight" and there is little or no vegetation favor a large loss through run-off. About 40 percent of the area of Cimarron County has been dissected, and much of this part consists of flat but sloping flood plains and moderate slopes, both fairly well sodded over, on which the immediate run-off probably is moderate. Only a small proportion of the area is steep, rocky slopes and cliffs with little vegetation, where the run-off is large. Hence, large losses through immediate run-off occur in much less than half the county. On the uplands, little run-off results from light rains, and even in heavy rains much of the water must stay near where it falls unless it can drain readily into the closed depressions. Finnell[224] estimated that in the vicinity of Goodwell, in Texas County, Oklahoma, the average run-off is 2.43 inches, or about 13.5 per cent of the total annual precipitation. The uplands in Cimarron County are roughly similar to the Goodwell locality, although probably more diversified than the area referred to by Finnell. If a similar percentage of run-off applies, the loss by run-off from the uplands of Cimarron County would be about 2 inches of precipitation annually.

The conditions that favor the downward percolation of water through the soil and into the underground reservoir are in general opposite to those which favor a large immediate run-off. The large, nearly flat uplands in Cimarron County are areas where immediate run-off is small and the water is either used by plants, evaporated, or absorbed by the soil. Whether much water penetrates to the water table under uplands devoted to wheat and other crops is a matter of controversy. Farmers generally have observed that the water from rains in the High Plains seems to penetrate only a few feet. This observation apparently is borne out by quantitative experiments of the U. S. Department of Agriculture, in which the amount of moisture in the soil at different depths down to 6 feet, and at times 10 and 15 feet, was measured shortly before the beginning of the growing season and after harvest. These experiments were made at Havre, Montana; Hays and Colby, Kansas; North Platte, Nebraska; and Mandan, North

224. Finnell, H. H., *op. cit.*, p. 41.

Dakota. The average annual precipitation at these places ranged from 12.02 inches (Havre) to 21.35 inches (Hays). The soils ranged from heavy to light. At each station, one plot of land was continuously cropped in wheat, and two others were alternately cropped and fallowed, one being cropped in even years and the other in odd years. The tests suggested the following conclusions regarding the penetration of water to the water table:

"In general it may be said that under sod or under continuous cropping to small grain, infiltration of water to depths not reached by roots has been so rare and so limited at the stations under study that the addition of any appreciable quantity of water to the water table is a matter of centuries.

"At Havre, Colby, Hays, and on the south field at Mandan it is questionable whether water has even penetrated beyond the reach of wheat roots on land continuously cropped to wheat. At North Platte and on the main field at Mandan, water has penetrated beyond the reach of wheat roots. At Mandan, this occurred only once in 25 years, and then under a precipitation not duplicated during the period 1878 to 1936. At North Platte the indications are that it is not likely to occur as often as once in 10 years.

"At both North Platte and Mandan the indications are that under native sod water seldom penetrates to depths beyond the reach of the deep-rooted perennial plants that make up a part of the vegetation.

"Under a system of alternate fallow and crop, water infiltrated to depths greater than under continuous cropping, but even under this system infiltration beyond the reach of crop roots was very limited and infrequent. At Havre and Colby, there was little or no infiltration beyond the reach of wheat roots. At Hays, North Platte, and on the main field at Mandan, there was infiltration beyond the reach of roots, and after the soil below the feeding range of crop roots became wet it remained continuously so. At Hays, soil-moisture determinations made to a depth of 20 feet in 1935 showed that the soil at depths between 10 and 20 feet was much wetter on alternately cropped than on continuously cropped land. Even under an alternate fallow and crop system it would require many years for water to reach the water table.

"The conclusion must be reached that, at the stations under study, material additions of water to the water table are not made by penetration of surface water on the upland. The existing water tables or channels must be due to infiltration of water from streams or other places of water concentration, or to the penetration through permeable strata probably located long distances away from the points under study. . .

> "If very wet years occurred successively, the extent of infiltration into the subsoil would be materially increased. The residue of water remaining after harvest, as it does in the wettest years at some stations, would reduce the quantity of water necessary to saturate the section of soil occupied by crop roots, and more water would be available for deeper penetration. As a general rule, however, wet years occur following years when the crop has exhausted all the moisture within reach of its roots. The entire dry zone must be saturated before water penetrates below it.[225] . . ."

From the above quotation it would seem that recharge to the ground-water reservoirs occurs rarely, if ever, in semi-arid areas devoted to wheat-raising. Ground-water hydrologists, however, have generally held that such recharge must occur, for if it did not the water table would decline progressively after the beginning of pumping. All of the water that apparently went out of the upper 2 or 3 feet of the soil between the spring and harvest measurements in the experiments may not have been used by plants. A part may have gone down to lower depths. For the Mandan station it is stated that heavy rainfall in June 1914 wet the soil to a depth of more than 6 feet, that heavy rainfall in 1915 wet it again, and that, although the wheat used the water in the upper 3 feet, the lower 3 feet remained wet, and "all the available water from the fifth and sixth foot sections was not removed until 1919."[226] This statement implies that the water simply stayed in the lower two feet until 1919, but similar results would have been obtained if a fraction of the water in the upper part of the soil had been moving downward very slowly. Cady[227] has presented the case for the ground-water hydrologists, using three lines of evidence: (1) fluctuations of water level in deep and shallow wells; (2) perched water tables, the very existence of which implies the downward movement of water from the surface to the water table; and (3) the fact that the major streams are below the water table and are draining, not recharging, the

225. Cole, J. S., and Mathews, C. R., "Subsoil Moisture under Semiarid Conditions": *U. S. Dept. Agri. Tech. Bull.* No. 637, pp. 68-69, April, 1939.
226. Cole and Mathews, *op. cit.*, p. 14.
227. Cady, R. C., "Ground Water Recharge in Areas of Deep Water-Table in the Great Plains": *Amer. Geophys. Union, Trans.*, Pt. II, pp. 570-574, 1940.

ground-water reservoir, whereas small highs on the water table show local areas of recharge. Further, Cady offers an estimate of the recharge in Box Butte County, Nebraska, based on the configuration of the water table.

Once the water has gone below the reach of plant roots and the zone where it can be evaporated from the soil, it will, in all probability, continue downward to the water table. The route followed is likely to be very circuitous because of the obstacles presented by impervious rock materials. Caliche underlies the soil in many parts of the county, and the upper part of it is locally dense and impervious. On encountering such caliche the water can only move laterally or diagonally until it finds a crevice or joint leading downward, and because no single joint or crevice extends through the entire thickness of the caliche, the water must follow a zig-zag course downward. Below the caliche the route of movement is likely to be indirect because the impervious silts that are bedded with the sands also cause the water to move laterally for longer or shorter distances.

Some situations offer better opportunities for the water to begin this journey to the water table than others. As in the High Plains in Texas[228], the sand dune areas, and the temporary lakes and streams are especially favorable.

Recharge through sand dunes. Sand dunes cover many square miles in Cimarron County—south of the North Canadian River, in T. 3 N., R. 3 E. and adjacent townships, and near the Cimarron River in the northeastern part of the county. The porous and pervious sands absorb much of the water that falls on them as rain or snow, and part of this water then moves downward beyond the reach of plant roots and the influence of evaporation. Laboratory tests show that the permeability coefficients of dune sands in Cimarron County range from about 2 to 605, and average about 160 (Table XVIII). This is a moderate average permeability in comparison with the more productive aquifers, but is higher than the permeability of ordinary upland soils in Cimarron

228. White, W. N., Broadhurst, W. L., and Lang, J. W., "Ground Water in the High Plains in Texas": *U. S. Geol. Survey Mimeographed Rept.*, p. 4, July 26, 1938.
"Ground Water in the High Plains in Texas": *Texas Board of Water Engineers, Mimeographed Report*, pp. 6-9, Dec., 1940.

County. The permeability coefficients of 11 miscellaneous soils from ploughed fields range from 4 to 145, the most permeable sample coming from a field in a sand dune area. The average for the soils is 45. If the permeability is taken as a rough index of the infiltration capacity of a soil, it appears that the sand dunes will absorb several times as much water as most upland soils. How much of the water so absorbed will penetrate to the water table depends on the vegetation. The relatively shallow depth to the water table, and a slight eastward bending of the water-table contour lines on figure 20, suggest, but do not prove, that recharge through the dunes in T. 3 N., R. 3 E. has built up a low water-table mound. The water that moves down through areas of sand dunes and sandy soils contributes chiefly to the water supply in the "Ogallala" formation, although possibly some of it ultimately may enter the Dakota sandstone where the latter directly underlies the "Ogallala." Where sand dunes are on flood plains, the water absorbed by them will go into the alluvium.

Recharge through lakes and ponds. The many shallow depressions that dot the upland plains often contain temporary lakes or ponds after heavy rains, and may be the sites of significant additions to the underground reservoir. Some of the lakes probably are floored with clay as in Texas County,[229] but the water generally stands in them long enough so that a considerable thickness of underlying beds can be saturated, or mud cracks which form as the lake dries up may later allow the water to move downward to more pervious materials. Water was standing in the depression adjacent to well 313 when water-level measurements were begun in Cimarron County in 1938, but the pond has been dry most of the time since May 1939. The water level in the well rose from July to November 1938, while the lake level was high; declined through the winter until April 1939; rose again when spring rains filled the pond; reached a high level in July 1939, a few weeks after the lake became dry; declined, at first slowly, and then more rapidly, until January 1941; rose about 2.5 feet to a record high level in November; and then declined about 0.5 foot until April

229. Fitzpatrick, E. G., and Boatright, W. C., "Soil Survey of Texas County, Oklahoma": *U. S. Dept. Agri., Bur. Chem. and Soils*, Ser. 1930, No. 28, p. 24. Map shows Randall clay in the bottoms of many of the temporary lakes.

1942. The range in fluctuation of water level was 2.7 feet. The record of the water level in well 415, which is beside Willowbar Lake, is similar except that the range of the water-level fluctuations was less—only 0.60 foot. The lake seems to have been dry since May 1940. Recharge water moving down through lake beds contributes chiefly to the reservoir in the "Ogallala" formation.

Recharge From Streams

At times of low flow, perennial streams do not contribute to ground-water reservoirs, but instead receive water from them. During floods, more or less water from such streams enters the alluvium as bank storage, but a large part drains back into the channel after the flood has passed. The principal contribution of perennial streams under natural conditions, therefore, is made where they cross the outcrop of a pervious stratum that dips steeply enough to allow the water absorbed from the stream to move downward below the level of the stream. Because of the dip, the intake areas of such formations are relatively small, but the continuous addition of water, in dry seasons as well as wet, may be significant.

Streams that head in regions of abundant precipitation, such as mountains, will either dwindle or disappear entirely as they cross arid and semi-arid regions because of evaporation of the water and seepage into their channels. The seepage goes to the ground-water reservoir, and where the streams are large or numerous the total recharge in the arid or semi-arid region may be many times greater than that which could normally come from local rainfall. Likewise, streams that flow only after rains and have cut their valleys through part or all of the caliche, especially through the denser and less permeable upper part, can contribute some of their flow to the water table by percolation through the coarse fill in their bottoms.

Two major rivers enter Cimarron County from outside areas —the Cimarron and the North Canadian. Neither carries a large continuous flow that disappears within the county, but both carry floods resulting from rains in upstream areas. As stated elsewhere, the Cimarron is essentially perennial in the western half of the county, and therefore may contribute recharge water to the Exeter sandstone and to the sandstones in the Morrison formation where it crosses their outcrops, and may make temporary additions to the water in the alluvium through bank storage.

The North Canadian River from Conrad station downstream to where it leaves the county probably contributes water to the "Ogallala" formation. As pointed out in a previous section, the water table along this part of the valley is far below the bed of the stream, and probably far below the bottom of the alluvium.

The Cimarron River east of R. 6, and at times east of R. 5 also, is often dry, but the water table is only a few feet below the surface. Similar conditions prevail along the North Canadian west of R. 7, and along its major tributary, Cieneguilla Creek. These streams maintain a flow along some stretches during part of the year and have permanent water holes and moist channel sands along others. They may be classed as "nearly perennial." Adjacent to them the water table at times may be essentially flat; at times it may slope gently toward the streams on both sides, so that water moves into the channel producing a flow; and at other times it may have a low ridge beneath the channel as a result of recharge from floods.

Recharge From Precipitation on the "Ogallala" Formation in Outside Areas

The Southern High Plains is a great table-land—something like the mesa illustrated in figure 25, but covering 70,000 square miles instead of only a square mile or two, and capped by the "Ogallala" formation instead of the Dakota. The major rivers have cut down through this great table-land, dividing it into smaller table lands which themselves cover many thousands of square miles. The ground water in the "Ogallala" in these table-lands must come largely from precipitation in the immediate area, just as the water in the Dakota on the mesa of figure 25 must come from local precipitation. Because the water slowly moves through the formation to discharge at its lower edge, the water absorbed in a locality especially favorable to recharge may become available to wells in areas where local intake is low but the demand for water is high. The general movement of the ground water in the "Ogallala" formation in Cimarron County is east-

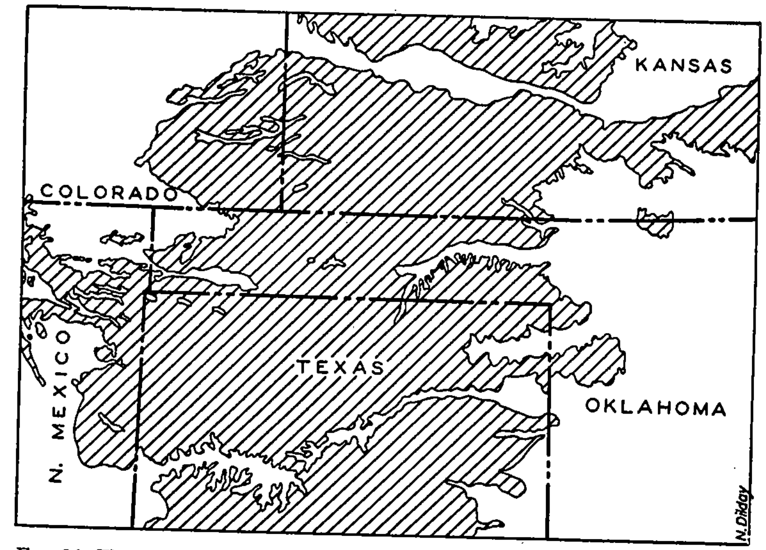


Fig. 26. The intake of the Tertiary and Quaternary rocks in the High Plains is equal to their outcrop area. Blank areas are underlain by older formations. (From the Geologic Map of the United States.)

ward (See fig. 20), and as figure 26 shows, the outcrop of the "Ogallala" extends only short distances west, northwest, and southwest of the county, into areas where the precipitation is no higher than within the county. Therefore, little water received by the formation in outside areas can move underground into Cimarron County. Even if large additions of water were made in southeastern Colorado and the ground water moved southeastward, the Cimarron River would intercept the water before it could reach the main body of the "Ogallala" formation in the county.

Water that falls on the outcrop in outside areas and reaches Cimarron County by moving underground is probably offset by that which falls on the outcrop within the county and moves out of it into adjacent areas to the east. Thus, in the absence of large additions of water from especially favored outside areas, it is safe to conclude that recharge through precipitation on the outcrop at adjacent places does not materially increase the total recharge of the ground-water reservoir above that which normally takes place by precipitation on the outcrop within the county.

Recharge to the "Ogallala" Formation From the Dakota Sandstone

In a report on ground water in Texas County[230], Oklahoma, it was suggested that ground water moving eastward down the dip in the Dakota sandstone might help to recharge the "Ogallala" by migrating into the latter near the eastern limit of the Dakota under cover, where the Dakota ought to be thinner than in its intake area. The illustration used in that report is repeated here as figure 27.

The Dakota sandstone crops out near Des Moines, New Mexico, at an altitude of about 6,500 feet and is exposed for about 50 miles to the east, passing under the "Ogallala" formation a few miles west of the Oklahoma-New Mexico State line at an altitude of about 4,700 feet. The area of this outcrop is 800 or 900 miles, and over it a considerable amount of water, if available, could be taken into the sandstone. The average annual precipitation in this area, however, is relatively low—about the same as in Cimarron County. All of the water taken into the sandstone, of course, does not reach Oklahoma by underground percolation. Much of it is discharged in one way or another, but a fraction of it may cross the state line under cover. Where the Dakota under cover is thin as a result of erosion before the "Ogallala" was deposited, its capacity is less, and the water in it must migrate to another formation—not downward, because underlying materials in general are not sufficiently pervious, but upward into the lower part of the "Ogallala."

In the report on Texas County it was suggested that this migration of the water into the "Ogallala" might take place in western Texas County or eastern Cimarron County, but evidence obtained in the present investigation indicates that it probably is restricted to western Cimarron County. The buried red bed ridge in T. 3 N., Rs. 7 and 8 E., and T. 4 N., R. 9 E., described in a previous section, is evidence that the Dakota does not extend into eastern Cimarron County. The Dakota is exposed along the Cimarron River as far east as R. 5 E., but farther east it appears to have been removed by erosion in pre-"Ogallala" time. It is ex-

230. Schoff, S. L., *op. cit.*, pp. 157-158.

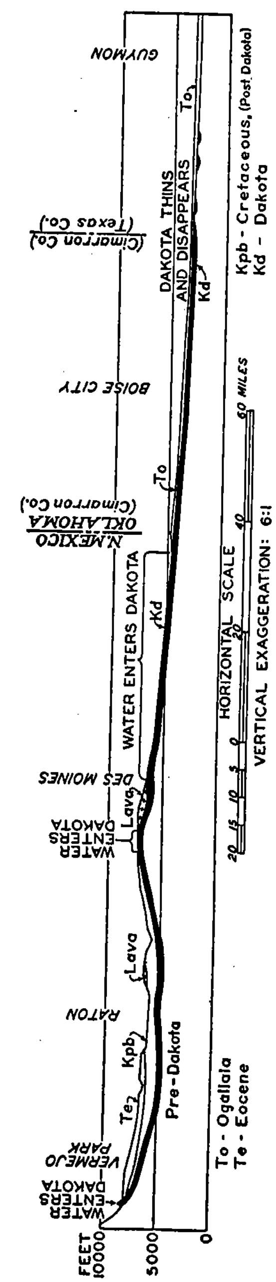


Fig. 27. West-to-east cross section from the vicinity of Vermejo Park, New Mexico, to Guymon, Oklahoma, used in "Geology and Ground-Water Resources of Texas County, Oklahoma" to show how the ground-water supply of the "Ogallala" formation may be partly recharged by water from the Dakota near the eastern limit of the Dakota under cover, where it is thin and in contact with the basal Ogallala. Evidence obtained in Cimarron County suggests that such recharge may be confined to the area west of Boise City.

posed also, along Cieneguilla Creek and the North Canadian River in R. 1 E., and on the south side of the latter in the eastern part of R. 3 E. The logs of wells in Boise City leave doubt as to the presence of buried Cretaceous there, and the log of a well at Kerrick, Texas, appears to record "Ogallala" directly overlying red beds. Hence the eastern limit of the Dakota under cover probably is in the western half of Cimarron County, and recharge from the Dakota to the "Ogallala" can only occur in that part of the county.

Recharge Estimated From Water-level Fluctuations

The water level in the underground reservoir is continually fluctuating in response to recharge to, or discharge from, the reservoir. The fluctuations of water level, therefore, are a measure of the changes in the quantity of water in storage.

The amount of rise of the water table depends on the character of the water-bearing material, and is always greater than the amount of rise produced by the addition of an equal quantity of water to a surface reservoir of the same volume, because mineral grains occupy much of the available space. The rise due to the addition of water will be greater in fine-grained materials of low porosity and permeability than in coarse, highly permeable material. The property that governs the amount of rise in a given material is the specific yield, which is the amount of water that will drain out of the material under gravity. The method used in determining the specific yield of water-bearing materials from Cimarron County is described in the section on Laboratory Tests, and the results are given in Table XVIII.

The average specific yield of the samples from the river channel, the "Ogallala", and the Dakota, which are the formations represented in the weighted average water levels, is about 32 percent, but the "Ogallala", which is the principal aquifer, is represented by only one sample. The low values obtained from the samples of this formation from Beaver County suggest that it may be both fair and conservative to use 25 percent as the specific yield of the formations represented in the weighted averages of the water levels. This is comparable to the results obtained by Wen-

zel[231], who reports average specific yields ranging from 17 to 30 percent for loess, the Ogallala formation, and Pleistocene sand and gravel from Nebraska. His averages are for groups of samples representing different classes of material.

The water-level record for Cimarron County extends from July 1938, which was near the end of a protracted drought, to April 1942, and includes the exceptionally wet year of 1941. Although this record is too short for a conclusive statement of the annual recharge, it can be used for a preliminary estimate. During the 46 months covered by this record, the weighted average of the water levels in the observation wells in the Dakota sandstone, "Ogallala" formation, and alluvium in Cimarron County rose 0.98 foot, or an average of 0.255 foot per year. This average rise multiplied by the suggested specific yield (25) indicates an average recharge equivalent to 0.064 foot of rainfall annually, or 0.77 inch. This calculation assumes that no water escapes from the groundwater reservoir. It would be fair, therefore, to add the amount of the discharge, which on another page has been estimated as about 1600 acre-feet annually. Distributed uniformly over the area in which the Dakota, "Ogallala", and alluvium are exposed at the surface, this discharge amounts to less than 0.02 inch, and brings the estimated total recharge to about 0.79 inch per year.

It should be pointed out that this estimate involves several assumptions, and it may require considerable future revision. If it is correct, the quantity of water added annually to the groundwater reservoir in Cimarron County averages about 70,000 acre-feet. The great difference between the recharge estimated from the water-level fluctuations and the amount of the natural discharge may be partly explained by the fact that the water taken into the reservoir in Cimarron County need not be discharged within the county, but may instead move by underground circulation to adjacent areas, such as Texas County, Oklahoma, and the state of Texas.

231. Wenzel, L. K., "Methods for Determining Permeability of Water-Bearing Materials, with Special Reference to Discharging-Well Methods": *U. S. Geol. Survey Water Supply Paper* 887, pp. 90-94, 1942.

Summary—Amount of Annual Recharge

From the foregoing discussion it appears that much of the annual recharge to the ground-water reservoir in the "Ogallala" formation in Cimarron County comes from local precipitation, and probably enters the ground through the areas of sand dunes and sandy soils, through the channels and flood plains of streams that ordinarily are dry, and through temporary lakes. A significant part of the flood water that comes down the North Canadian River probably reaches the ground-water reservoir by seepage through the river channel, especially in the eastern part of its course. The Cimarron, however, cannot contribute flood water to the "Ogallala" except, perhaps, in the lower dozen miles of its course in Cimarron County, because most of its valley has been cut below the base of the "Ogallala."

Precipitation is probably as effective in recharging the Dakota sandstone where it crops out as in recharging the "Ogallala". The pre-Dakota sandstones have such small outcrop areas that they can receive little water directly from precipitation, but they may receive some from the streams crossing them.

The hydrologists who have been studying the ground-water resources of the High Plains in recent years are of the opinion that the average annual recharge is only a very small fraction of the average annual rainfall. White, Broadhurst, and Lang[232], in discussing conditions in the High Plains in Texas, state "In depth over the entire area, the average recharge probably amounts to only a fraction of an inch." Theis[233] made several sets of computations based on (a) the rate of ground-water flow through a selected cross section; (b) the fluctuations of the water table as indicated by average water levels in observation wells; and (c) the shape of the water table in the Llano Estacado. His conclusion, applicable to northeastern New Mexico and the western part of the Texas Panhandle, was that the average annual recharge is less than 0.5 inch. Cady[234] estimated the amount of water moving through selected cross sections of the aquifer in Box Butte County, Nebraska, and concluded that the recharge in that area is between 0.75 and slightly more than 1 inch per year.

232. White, W. N., Broadhurst, W. L., and Lang, J. W., "Ground Water in the High Plains in Texas": *U. S. Geol. Survey Mimeographed Rept.*, p. 5, July 26, 1938.
233. Theis, C. V., "Amount of Ground-Water Recharge in the Southern High Plains": *Amer. Geophys. Union Trans.* 564-568, 1937.
234. Cady, R. C., *op. cit.*, p. 573.

If the recharge averages as much as an inch per year over the 1,172,480[235] acres of Cimarron County, the annual addition of water to the underground reservoirs in the county would amount to about 97,700 acre-feet. If it were 0.1 inch, the annual accretion would still be 9,700 acre-feet; but if it is only 0.01 inch, the annual accretion would be only about 970 acre-feet.

Discharge of Ground Water

Natural discharge. Before pumping started, the average annual recharge of the ground-water reservoirs in Cimarron County was balanced by an approximately equal discharge. Much water is still discharged through natural outlets. Measurements were made of the flow of many springs, estimates were made for others, and reports were obtained for springs not visited. This information is neither complete nor fully accurate, but it indicates that the natural discharge of ground water through springs and seeps is about 640 acre-feet per year.

At high stages of the water table, some of the ground water probably discharges into the Cimarron River and leaves the county as surface flow. The quantity of water discharged in this manner is not accurately determinable with the information available, but an estimate may be suggestive. The discharge measurements made by the U. S. Army Engineers at the bridge on U. S. highway 287, north of Boise City, show that in the two years from October 1, 1938, through September 30, 1940, a total of 81,226 acre-feet of water passed the gaging station. Most of this was flood water, but small flows were recorded during many of the periods between floods. A curve showing the fluctuation in the total flow of the river was prepared, and the low points on this curve were connected to form a second curve representing the ground-water flow, which appears to have been about 1,440 acre-feet. This is an average of 720 acre-feet per year, and is less than 2 per cent of the total flow.

235. Based on area of 1,832 square miles reported in 1940 census.

This procedure was first used by Houck[236] in a study of the Mad River basin, in Ohio. Meinzer and Stearns[237] applied it in a study of the intake and discharge of ground water in the Pomperaug Basin, Connecticut, and discussed in detail the sources of uncertainty and possible errors inherent in it. The uncertainties doubtless are greater for an intermittent stream like the Cimarron, which at times carries great floods and at others is completely dry, than for a perennial stream in a humid region, but it is thought that the estimate of the ground-water flow of the Cimarron obtained in this manner is at least conservative.

Seepage into the channel of the Cimarron increases downstream from the gaging station, and therefore much of the ground-water flow passing the station becomes ground water again within the county. The river is often dry at the bridge north of Keyes, and at other times between floods it carries only a small flow. This bridge is about 3 miles from the place where the river leaves the county, and it is therefore likely that only half, or less, of the ground-water flow at the gaging station actually flows from the county. This is 360 acre-feet a year, on the average.

The North Canadian carries water from the county only during floods. Therefore the ground-water discharge in this valley is restricted to transpiration and evaporation losses in the western part where the water table is close to the surface. The river is said to flow perennially along 3 or 4 miles of the "Currumpa Creek" part of the valley. If the average length of this perennial stretch is 3.5 miles, the average width of the stream of water is 5 feet, and the average annual evaporation from the free-water surface is 5.5 feet as at Goodwell[238], the evaporation loss from the stream would be about 12 acre-feet per year.

The evaporation from the perennial parts of the Cimarron and its tributaries is much more because the length of the free water surface is many times greater. The length of the perennial part of the Cimarron is about 45.5 miles, and the length of the perennial tributaries is about 38.5 miles. The width of the water

236. Houck, I. E., "Rainfall and Run-Off in Miami Valley, State of Ohio": *Miami Conservancy District Tech. Repts.* Pt. 8, 1921.
237. Meinzer, O. E., and Stearns, N. D., "A Study of Ground-Water in the Pomperaug Basin, Connecticut": *U. S. Geol. Survey Water Supply Paper* 597-B, pp. 73-146, 1929.
238. Finnell, H. H., *op. cit.*, p. 40.

surface, of course, differs considerably both from place to place and from time to time. If it averages 10 feet for the Cimarron and 5 feet for the tributaries, and the average annual evaporation is 5.5 feet, the annual evaporation loss from these streams would be about 430 acre-feet.

The total of these estimates is about 1,442 acre-feet of water discharged annually through natural outlets. Nothing has been included for the ground water transpired by vegetation or evaporated from the ground itself where the water nears the surface.

Much of this discharge comes from the Dakota sandstone, supplemented to a limited extent by water from the older Mesozoic formations. Nearly all of the springs and seeps issue from the Dakota, and the streams that are perennial begin to flow after crossing the outcrop of the Dakota. In contrast, the discharge from the "Ogallala" formation seems to be negligible—a surprising and perhaps significant fact when the good yields of the wells in it are considered. Few springs are known to issue from the "Ogallala," but it should be observed that the water in the "Ogallala" may move downward into the Dakota where the two are in contact, and issue as a "Dakota" spring. The extent to which this process takes place, of course, cannot be estimated, but the scarcity of springs in the eastern Cimarron Valley, along part of which the "Ogallala" overlies the relatively less permeable rocks of pre-Cretaceous age, suggests that it is relatively unimportant.

Discharge from wells. The quantity of water discharged from wells is only a small fraction of the quantity discharged naturally. The principal users of ground water are the towns, the railroad, and the irrigators. From the reports on municipal water consumption furnished by the Cimarron Utilities Company, and from other data, it is estimated that the annual pumpage for these purposes during the eight years 1932-1940 has ranged from about 62 acre-feet to about 89 acre-feet, and has averaged about 74 acre-feet.

In addition, windmill wells on farms and ranches withdraw much water. Adequate information from which to estimate the total annual discharge of such wells is not available, but it is evident that a large volume of water is involved. Records were obtained of about 400 windmill wells in Cimarron County, of which about 60 percent were in use for stock and domestic purposes. These records, however, probably include less than half the total of the windmill wells in the county. Because in general the unused wells could be measured more readily than others, the percentage of used wells in the records probably is lower than would be the case if all windmill wells in the county had been considered. Hence it is probable that at least 500 windmill wells are in use in the county. Such wells produce from a fraction of a gallon to 3 or 4 gallons a minute. Some pump for only a few hours a day two or three times a week, whereas others are always turned on, ready to pump whenever the wind blows. If, on the average, 500 windmills were to pump 1 gallon a minute each for 3 hours each day, they would discharge nearly 33,000,000 gallons of water in the course of a year, or about 100 acre-feet. Hence the pumpage from windmill wells may easily exceed that for municipal, railroad, and stock purposes, and bring the total annual pumpage to about 175 acre-feet of water.

Total annual discharge. In many respects the estimates for the annual discharge of ground water in Cimarron County are inadequate, especially in view of the fact that data on transpiration losses are not available, but they indicate the order of magnitude of the actual discharge. The total is a little over 1,600 acre-feet of water—1,442 acre-feet discharged naturally, and 175 acre-feet pumped from wells.

Adequacy of the Ground-Water Supply

From the foregoing estimates, it is evident that the volume of ground-water perennially available in Cimarron County is appreciable when expressed in terms of acre-feet, but is small when expressed as depth of water over the area. The present pumpage seems to be only about 175 acre-feet a year, which is a small fraction of the natural discharge and also is only a small fraction of the possible annual recharge, even if that recharge is an exceedingly conservative 0.01 inch, which would mean about 980 acre-feet a year. Hence it appears that considerable additional pumpage is possible. The water available is probably adequate for all of the irrigation development that is practical under present economic conditions, but the ground-water supply of Cimarron County should be conserved.

APPENDIX A

MEASURED STRATIGRAPHIC SECTIONS IN CIMARRON COUNTY

BY S. L. SCHOFF AND J. W. STOVALL

TOWNSHIP 1 NORTH

1. SEC. 10, T. 1 N., R. 1 E., ALONG CIENEGUILLA (SENECA) CREEK*

	Feet
Cretaceous	
Dakota sandstone	
5. Sandstone, brown to buff; beds 2″ to 6″ thick; contains dark brown concretions; very hard in places	27.0
4. Sandstone, platy, and shale, brown, purple, and grayish	8.0
3. Sandstone, buff to brown, massive, cross-bedded; crops out in bluffs on south side of creek	20.0
Purgatoire formation	
Kiowa shale member	
2. Sandstone, buff, platy, in beds ½″ to 6″ thick; grades downward into shale	5.0
1. Shale, grayish, streaked with brown on bedding planes; contains numerous *Gryphaea corrugata* in dense, dark brown, sandy shale; base not exposed	8.0
Bed of creek	

2. SEC. 6, T. 1 N., R. 8 E., NEAR W.¼ COR., IN ROAD CUT.

	Feet
Tertiary-Quaternary	
"Ogallala" formation	
5. Limestone, hard, dense, broken by curved joints into biscuit-like blocks; may be algal; makes ledge	1.0
4. Caliche, arenaceous (mortar bed); weathers rough and jagged	1.5
3. Rubble-covered slope	11.0
2. Caliche, soft, earthy or chalky, easily cut with shovel; best exposed between 16 and 20 feet above base of section	22.0
1. Sand, brown, fine, with scattered white, calcareous nodules and pipes; grades upward into (2)	11.3

3. SE¼ SEC. 26, T. 1 N., R. 8 E., CUT ON WEST SIDE OF ROAD

	Feet
Tertiary-Quaternary	
"Ogallala" formation	
7. Approximate level of upland flat	
6. Limestone, pink to white, hard, dense, arenaceous; locally chalky and porous; abundant rounded, biscuit-like forms	1.5
5. Caliche hard, arenaceous, rather hard, bedding irregular to absent; thin, hard, algal limestone beds like part of (6) in upper part	5.5
4. Covered; large blocks of arenaceous caliche scattered over surface	9.0
3. Caliche, brown, soft, somewhat chalky, arenaceous, partly capped by irregular, harder layer	7.5
2. Covered; large blocks of arenaceous caliche scattered over surface	45.0
1. Sand, fine, soft; and silt; with soft, calcareous nodules	16.0

Note: Exposure includes a pipe of hard, arenaceous caliche in somewhat softer arenaceous caliche. The pipe consists of nearly vertical walls 1 to 2 inches thick.

* Formations arranged in descending order, youngest at top.

TOWNSHIP 2 NORTH

4. S½SW¼ SEC. 3, T. 2 N., R. 5 E., IN NORTH CANADIAN RIVER CLIFF, AND TRIBUTARY GULLEYS, IMMEDIATELY EAST OF BOISE CITY DUMP GROUND.

	Feet
Tertiary-Quaternary	
"Ogallala" formation	
10. Gentle slope rising to upland plain; no rocks exposed. About	25.0
9. Limestone, hard, with pink and red banding that suggests algal origin; caps a bench, but poorly exposed; blocks and slabs abundant on top of bench, and scattered down the slope	0.3
8. Slope covered with rubble from above	13.6
7. Limestone, gray, possibly of algal origin	0.2
6. Mortar bed	2.0
5. Sand, reddish; irregular horizontal zones and many pipes are well cemented with calcium carbonate	5.5
4. Covered slope on east side mouth of gully. At "waterfall" is left fork of gully, this interval is only 4.6 feet thick and consists of mortar bed containing a 1.5-inch layer of siliceous limestone about 1.5 feet below top	9.3
3. Mortar bed and irregularly-nodular, fractured or cracked caliche, grading upward into hard limestone (Algal?)	2.0
2. Silt and sand, calcareous, locally hard and irregularly nodular; grades upward into (3)	15.0
1. Covered. About	5.0
Bed of North Canadian River.	

5. NEAR SW COR. NW¼ NE¼ SEC. 10, T. 2 N., R. 5 E., EAST SIDE OF NORTH CANADIAN RIVER.

	Feet
Quaternary	
4. Dune sand	15.0
Tertiary-Quaternary	
"Ogallala" formation	
3. Limestone, gray, hard, rough-weathering, in irregular layers 0.2-0.4 foot thick	1.0
2. Mortar bed, grading laterally and vertically into irregularly nodular, much jointed or cracked caliche. Nodules average about 1 inch in diameter, and many have pebbles of ferruginous sandstone as nuclei	8.3
1. Sand, calcareous, with a few hard, calcareous nodules	1.5
Bed of North Canadian River	

6. NEAR MIDDLE N½ OF S½ SEC. 10, T. 2 N., R. 5 E., IN CLIFF ON WEST SIDE OF NORTH CANADIAN RIVER

	Feet
A. Southern part of cliff	
Tertiary-Quaternary	
"Ogallala" formation	
11. Limestone, gray with orange to pink bands, probably algal; grades upward from material below	2.0
10. Caliche, irregularly nodular, much jointed or cracked	12.5
9. Sand, medium grained, with stringers and layers of granules and pebbles; horizontal layers or zones are irregularly cemented with calcium carbonate	12.5
8. Sand and gravel, rather even-bedded; locally contains a lens of reddish-brown siltstone and chocolate brown sandy clay; gravel-filled channels at base show scouring of underlying sandstone	5.5
7. Sandstone, massive, fine-grained, bonded with clay; weathers in rounded faces; crops out just above the bed of the river along the southern part of the cliff, but seems to be 8 feet above the channel in the northern part of the cliff	4.5
B. Northern part of cliff	
Tertiary-Quaternary	
"Ogallala" formation	
6. Mudstone, hard, calcareous	0.3
5. Sand, light brown, loose	1.4
4. Sandstone, massive, calcareous, poorly sorted	0.5
3. Limestone, gray-brown; dense, impure, 0.3 foot to	0.6
2. Even-bedded sandstone, siltstone, and sandy reddish-brown clay in layers 0.2-0.5 foot thick; 2.2 feet to	2.4
1. Clay, chocolate brown, partly sandy, partly free of grit; 0.5 foot to	2.7
Bed of North Canadian River	

7. NEAR MIDDLE SE¼ SEC. 10, T. 2 N., R. 5 E., IN CLIFF ON SOUTH SIDE OF NORTH CANADIAN RIVER

	Feet
Tertiary-Quaternary	
"Ogallala" formation	
9. Gentle covered slope rising to upland level, about	30.0
8. Sandy clay and clayey sand, poorly exposed; fragments and possibly pebbles of caliche mixed with fine gravel on surface	11.0
7. Caliche, irregularly nodular, much jointed or cracked, grading upward into mortar bed, with a cap of hard, irregular, pink limestone (algal?). The capping limestone grades upward from the material below and is uneven, bending down as if to fill cracks and making large rounded forms	11.7
6. Sand, yellow-brown, medium, with stringers and layers of granules and pebbles, irregularly cemented with calcium carbonate to form approximately horizontal white layers 1.5-2 feet thick. Upper 6-8 inches is reddish brown and clayey.	11.5
Sharp, irregular contact	
5. Clay, chocolate brown; sandy, calcium carbonate content increases upward; upper 2.3 feet weathers blocky	5.1
4. Sand, brown; clayey	0.5
3. Clay, chocolate brown; sandy	4.2
2. Sand, brown, clayey	1.3
1. Clay, chocolate brown, sandy, containing irregular, discontinuous light gray zone 0.1-0.15 foot thick and 0.6 foot below top	3.0
Bed of North Canadian River	

8. NEAR MIDDLE N½ S½ SEC. 21, T. 2 N., R. 6 E., IN CLIFF ON SOUTH SIDE OF NORTH CANADIAN RIVER

	Feet
Tertiary-Quaternary	
"Ogallala" formation	
10. Covered slope to upland plain. 7 feet to	12.0
9. Slope liberally covered with coarse gravel, possibly a terrace deposit	8.0
8. Limestone, gray or white with pink to red bands; also with saucer-like forms that suggest sun-cracking of a calcareous mud on an exposed lacrustine flat	0.8
7. Mortar bed, grading upward from (6) into irregularly-nodular, much jointed or cracked, rather hard caliche at top	10.8

	Feet
6. Sand, somewhat case-hardened at surface, but mostly rather loose, with big calcareous nodules and "boulders"; calcium carbonate cement increases upward, changing color from brown to gray	13.0
5. Sand, brown, fine-grained, with little calcium carbonate	2.7
4. Sand, brown, fine-grained, somewhat cemented with calcium carbonate; surface slightly case-hardened by calcium carbonate washed down from above, making surface white	13.5
3. Sand, brown, poorly sorted, with calcareous pipes and nodules; calcium carbonate increases upward so that this unit grades into (4)	4.8
2. Mortar bed, with many coarse sand grains and some pebbles; white; porous appearance may be due to weathering out of sand grains; probably a continuation upward of (1), but with different appearance because heavy, case-hardened shell remains	7.2
Irregular "contact"—rises and falls 2-3 feet; due to spalling off of case-hardened shell	
1. Mortar bed, pinkish, with abundant coarse grains of quartz	4.7
Bed of North Canadian River	

9. NE¼ NE¼ SEC. 22, T. 2 N., R. 6 E., CLIFF ON EAST SIDE OF NORTH CANADIAN RIVER

Tertiary-Quaternary	
"Ogallala" formation	
3. Limestone, gray below with pink bands and nodules at top (algal?)	1.3
2. Sand, soft, somewhat cemented by calcium carbonate, with few nodules, grading upward into irregularly-nodular, much jointed or cracked, rather hard caliche. Large concretionary or "algal" structures about 3.5 feet below top	44.0
1. Sand, fine-grained, with calcareous nodules and pebbles of ferruginous sandstone; in lower part the nodules are in horizontal zones resembling layers, but in the upper part they are scattered irregularly	30.0
Bed of North Canadian River	

10. NORTHERN PART OF SE¼ SE¼ SEC. 22, T. 2 N., R. 6 E., CLIFF ON SOUTH SIDE OF NORTH CANADIAN RIVER

Tertiary-Quaternary	
"Ogallala" formation	
6. Even-bedded silts and sands, weathering with many vertical cracks; lenses of medium gravel	10.0
5. Limestone, with pink bandings at top; 0.7 foot to	1.5
4. Mortar bed, with pebbles	28.0
3. Sand, brown, fine-grained, with scattered calcareous nodules and ferruginous pebbles; slightly cemented by calcium carbonate	4.5
2. Sand and gravel with some calcareous nodules, partly cemented by calcium carbonate. Some of the calcareous nodules may be pebbles re-worked from limestone or caliche	6.0
1. Sand, brown, fine-grained, with a few nodules; only slightly cemented by calcium carbonate	22.5
Bed of North Canadian River	

11. NEAR MIDDLE SE¼ SEC. 23, T. 2 N., R. 6 E., IN SANTA FE RAILROAD CUT, AND ADJACENT CLIFF ON EAST SIDE OF NORTH CANADIAN RIVER. THE TWO SECTIONS REVEAL ALMOST IDENTICAL PARTS OF THE FORMATION, AND VERY SIMILAR MATERIALS EXCEPT THAT THOSE IN THE RIVER BLUFF ARE HARDER, INDICATING GREATER INDURATION OR CASE-HARDENING, AS A RESULT OF LONGER EXPOSURE.

A. Exposure in southwest side of railroad cut, southeast end

	Feet
Tertiary-Quaternary	
"Ogallala" formation	
9. Silt and sand, brown, clayey; calcareous in lower part; upper 4-6 inches is medium to dark gray; exposed only on northeast side of cut	3.7
8. Limestone, irregular, gray with many wavy pink bands and abundant algal or concretionary nodules. The nodules consist of a core of dense, hard, gray-brown, sandy limestone surrounded by a zone of concentric but wavy alternating pink to red and white bands. The bands are about a millimeter wide and occupy only the outer 20 percent—the larger the nodule the larger the dense limestone core. Nuclei were not found in the nodules	1.5
7. Mortar bed, ledgy	3.0
6. Sand, light brown, fine-grained, partially cemented by calcium carbonate; mostly soft, but locally hard; calcium carbonate carried down from above makes the unit appear more calcareous than it is	4.0
5. Sand, reddish, soft to hard, only partly cemented with calcium carbonate. 0.5 foot to	0.6
4. Mortar bed; rather thoroughly impregnated with calcium carbonate, but softer than on outcrop. Sand grains are mostly fine, but more are medium and coarse than in (2). Makes a smooth-faced layer in southeastern part of cut but locally is much fractured and near the middle of cut is nearly indistinguishable from (2), which seems to extend up to unit 6 or 7	3.0
3. Sand, reddish, soft to hard, only partly cemented by calcium carbonate. 0.5 foot to	1.0
2. Sand, light brown, fine-grained, partly cemented by calcium carbonate; mostly soft, but locally hard; nodules and concretions scarce or absent; pronounced vertical structure, perhaps accentuated by shovel work in the cut. Face of exposure covered with calcium carbonate washed down from above, making the unit look white. This surface wash, together with the vertical structure, give this unit a superficial resemblance to the irregularly nodular, much jointed or cracked variety of caliche	9.0
1. Covered with rubble slumped down from above. Digging indicates that this unit probably is a downward continuation of (2)	2.2
Bottom of cut	

B. Exposure in cliff on east side of North Canadian River

Tertiary-Quaternary	
"Ogallala" formation	
4. Limestone, grading upward from (3) at base to nodular, banded red and white at top. Same as (8) of preceding section	1.2
3. Caliche, irregularly nodular, much jointed or cracked. Approximately equal to (7) of preceding section	4.6
2. Mortar bed, rather soft; prominent vertical structure in lower part, followed at 6 feet above base by an irregular zone of reddish sand; upper 10 feet smooth faced; locally with large concretions or "boulders" in upper 2-3 feet. Approximately equal to units 2-6 of preceding section	16.4
1. Covered	39.2

TOWNSHIP 3 NORTH

12. NE¼NW¼NE¼ SEC. 18, T. 3 N., R. 4 E., CALICHE EXPOSED IN OLD CELLAR. DIMENSIONS OF CELLAR, 8.5 FEET NORTH-SOUTH, 12 FEET EAST-WEST, AND 5 FEET DEEP.

	Feet
Tertiary-Quaternary	
"Ogallala" formation	
3. Soil, sand, silty, fine, brown color	1.4
2. Soil, as above, but with streaks and soft "nodules" of lime. Top and bottom of this zone are uneven in detail; at southwest corner of cellar, the bottom dips down into zone (1), making a soft, earthy pipe in caliche	0.8
1. Caliche, ranging from soft and powdery to hard and nodular, mostly fine and porous; nodular near middle, with largest nodules (4 to 6 inches) at west end of cellar, where nodules extend to bottom; locally contains a thin, hard, irregular limestone at top	2.7
Bottom of cellar.	

TOWNSHIP 4 NORTH

13. SECS. 17 AND 18, T. 4 N., R. 2 E., NEAR SWEDE CREEK; OUTLIERS IN SECS. 12, 21, 22, AND 28, T. 4 N., R. 1 E.; AND SECS. 20 AND 33, T. 4 N., R. 1 E. GENERALIZED SECTION OF SEVERAL INCOMPLETE EXPOSURES.

Cretaceous	
Colorado group	
9. Limestone, bluish-white, marly, a few hard beds, some shale	62.5
8. Limestone, buff to yellow, marly, fossiliferous	22.0
7. Limestone, dark brown, fossiliferous	0.5
Units 7-9 are exposed in secs. 17 and 18, T. 4 N., R. 2 E., from Swede Creek to the SW¼ sec. 18.	
6. Shale, buff to cream	17.5
5. Shale, chocolate brown	12.0
4. Sandstone, buff to brown	20.5
Units 4-7 are exposed in outliers in secs. 12, 21, and 22, T. 4 N., R. 1 E., with the greatest thickness in sec. 12.	
Dakota sandstone	
3. Sandstone, massive, cross-bedded, conglomeratic. Upper sandstone member of the Dakota	53.0
2. Shale, grayish; contains ferruginous sandstone; 1-foot bed of lignite at base. Middle shale member of the Dakota	47.0
Units 2 and 3 were measured in sec. 20, T. 4 N., R. 1 E.	
1. Sandstone, buff, massive, cross-bedded, conglomeratic. Lower sandstone member of the Dakota. Measured in sec. 33, T. 4 N., R. 1 E.	85.0

14. SEC. 32, T. 4 N., R. 2 E.

Tertiary-Quaternary	
"Ogallala" formation	
6. Limestone, gray, dense	1.0
5. "Mortar beds", grading into sand	6.3
4. Sand, buff	8.0
3. Conglomerate	7.5
2. Shale, brown, sandy	1.0
1. Sand, brown, with lime inclusions	3.0

15. SECS. 2, 10, AND 11, T. 4 N., R. 2 E., AND SECS. 34 AND 35, T. 5 N., R. 2 E., ALONG COTTONWOOD CREEK

	Feet
Top of hill	
Cretaceous	
Colorado group	
Greenhorn formation	
19. Limestone, gray, crystalline, and shale, buff, in alternating thin beds; poorly exposed; limestone at top of section is finely and evenly laminated, apparently unfossiliferous	21.3
18. Covered interval between base of steep slope of hill and nearest exposure in creek bank to southeast	22.5
17. Shale, clayey when wet, contains small aggregates of selenite, weathers buff; exposed at intervals in creek bank	20.2
16. Limestone, dark gray, finely crystalline, platy, with veinlets of calcite, and partings of shale, very fossiliferous. Contains *Gryphaea* and *Inoceramus*	0.9
15. Shale, gray, thinly and evenly bedded, with irregular layers of limestone a fraction of an inch thick	0.6
14. Limestone, light brown, platy, fossiliferous; with fragments of carbonized wood	0.7
Units 14-16 are probably equivalent to the Lincoln limestone member of the Greenhorn formation.	
Graneros formation	
13. Bentonite, lower 0.1 to 0.2 foot is white, upper part dark gray, stained brown along bedding planes. This bed resembles similar bed at top of Graneros in Kansas, according to Folger	0.6
12. Limestone, dark gray, fucoidal, sandy-looking; in beds ¼ to 1 inch thick; weathers buff	1.8
11. Shale, carbonaceous, thinly, but regularly bedded, fissile, with thin nodular layers of limestone.	3.0
10. Covered	5.0
9. Shale, weathers buff	3.0
8. Covered along 0.25 mile or more of creek	30.0
7. Shale, weathers buff, thin-bedded, fissile	3.6
6. Limestone, weathers buff, impure	0.9
5. Shale, gray, thin-bedded, fissile, contains several layers of iron concretions; several sandy or limy layers in upper part	6.6
4. Limestone, gray, weathers buff, platy, fossiliferous, with iron-stained concretionary masses in upper part; and three layers 1 to 3 inches thick that are stained dark brown to black by iron	3.6
3. Limestone, platy, like above, but containing one layer of buff limestone 2 inches thick that is dark when fresh, mottled with light colored, rounded masses arranged parallel with bedding. Apparently non-fossiliferous; includes layer of gray shale 2 inches thick, 0.5 foot below top	2.2
2. Limestone, dark to light gray, sandy looking, thin-bedded	1.1
1. Covered, along creek; estimated at	5.0
Top of Dakota sandstone (near E¼ cor. sec. 34, T. 5 N., R. 2 E.)	

16. SECS. 4, 9, AND 16, T. 4 N., R. 5 E., IN RAILROAD CUT NORTH OF BOISE CITY

Cretaceous	
Dakota sandstone	
17. Sandstone, buff, blocky; bottom of syncline	1.3
16. Sandstone, buff to brown, and shale and caliche	3.7
15. Sandstone, buff, blocky	2.0
14. Sandstone, buff, alternating with yellow shale; caliche cuts into it; contact gradational	4.0

Feet

13. Sandstone, buff, blocky to platy 1.7
12. Shale, grayish 4.0
11. Shale, grayish to blue 3.7
10. Sandstone, gray-white to buff, sugary; massive 2-foot layer to thin beds 10.0
9. Shale, grayish 2.0
8. Sandstone, white to cream, sugary, massive 7.3
7. Shale, grayish, with some buff at top and bottom 10.0
6. Sandstone, cream to gray, sugary; locally in 4-foot ledges.... 17.0
5. Shale, gray, with thin seams of buff sandstone 3.0
4. Sandstone, buff, thin-bedded, with small lenses of shale 2.0
3. Shale, gray, sandy, fossiliferous 2.0
2. Sandstone, buff, very thin-bedded 11.0
1. Sandstone, buff, massive, cross-bedded 12.0

Bottom of cut

TOWNSHIP 5 NORTH

17. SE¼ SEC. 4, T. 5 N., R. 1 E., 1.5 MILES NORTHEAST OF KENTON.

Cretaceous
Dakota sandstone
7. Sandstone, typical development of lower Dakota; buff sandstone, which weathers red; has very hard surface; joint lines extend north of east 32.0

Purgatoire formation
Kiowa shale member
6. Shale; contains gray to variegated, thin, platy sandstone.... 47.8

Cheyenne sandstone member
5. Sandstone, white, massive, cross-bedded, pitted weathered surface 46.3

Angular unconformity

Jurassic
Morrison formation
4. Sandstone, friable, with thin ledges cropping out on talus slope 33.1
3. Sandstone, purple to gray, friable; upper contact distinct, lower contact covered by talus 28.2
2. Sandstone, cream to white, many brown flecks, massive 13.7
1. Covered slope, upper part covered with sandstone rubble, and a few outcrops of buff sandstone 52.1

18. SEC. 8, T. 5 N., R. 1 E., 1 MILE NORTHWEST OF KENTON

Cretaceous
Dakota sandstone
7. Sandstone, typical development of lower Dakota; contains many wood fragments, one being 8 inches by 6 feet........ 45.1

Purgatoire formation
Kiowa shale member
6. Shale, forms typical talus slope below Dakota cap; contains thin, platy, vari-colored sandstone 36.7

Cheyenne sandstone member
5. Sandstone, buff on fresh surface, shows many brown specks; contains rounded pebbles, mostly quartzite, much petrified wood 37.6

Unconformity

Jurassic
Morrison formation
4. Shale, sandy, greenish-gray and purple in alternating layers 17.4

Feet

3. Sandstone, upper part massive, white to cream, containing many tiny brown specks; lower part covered with talus of fragments of thin sandstone. 39.5
2. Sandstone, buff, massive, showing tiny brown specks and small marble-shaped concretions on weathered surfaces; joints extend north of east 21.5
1. Covered, talus slope 59.7

Valley Floor

19. SEC. 18, T. 5 N., R. 1 E., AT BRIDGE ON CARRIZOZO CREEK, WEST OF KENTON.

Cretaceous
Dakota sandstone
15. Sandstone, buff, massive, conglomeratic 15.3

Purgatoire formation
Kiowa shale member
14. Sandstone, buff, stained with purple, vermillion, brown, and black, thin-bedded, grades downward into typical Kiowa shale 6.8
13. Shale, gray, black, with *Gryphaea* near base 55.6

Cheyenne sandstone member
12. Sandstone, cream to white, massive, 6-foot bed of conglomerate at base 30.2

Unconformity

Jurassic
Morrison formation
11. Shale, purple and gray, with sandstone partings 36.0
10. Sandstone, buff, brown flecked, massive, coarse 25.6
9. Shale, purple, gray, with sandstone partings 23.7
8. Sandstone, buff, brown flecked, massive, coarse 2.8
7. Shale and sandstone, purple, gray, yellow, covered slope, but rocks visible in a few places 98.3

Exeter formation
6. Sandstone, white, cross-bedded, very fine-grained, upper portion marked with tints of gray, green, and brown 27.5

Unconformity

Triassic
Dockum group
5. Shale, purple, with gray splotches 1.5
4. Shale, gray, splotched with purple. Has 1- to 2-inch layer of ashy gray sandstone that weathers readily 2.0
3. Marl, purple, mottled with gray on fracture planes 3.9
2. Shale, brick red, slightly mottled with gray 1.3
1. Shale, red, mottled with gray 1.8

Bed of creek

20. SEC. 15, T. 5 N., R. 2 E., DINOSAUR QUARRY NO. 1, NORTH SIDE HIGHWAY 64, 8 MILES EAST OF KENTON, JUST EAST OF BRIDGE OVER SOUTH CARRIZO CREEK

Cretaceous
Purgatoire formation
Cheyenne sandstone member

Unconformity

Jurassic
Morrison formation
6. Sandstone, buff, almost quartzitic in places, separated from the underlying clays by a very irregular surface 2.0
5. Shale, cream, banded with light purple 1.0
4. Shale, purple, banded with lenses of lighter colored, harder material 2.3

	Feet
3. Shale, purple, dense, hard, forming a distinct band, with irregular upper and lower surfaces	1.4
2. Shale, gray, contains dinosaur bones, and many concretions; concretions occur throughout, but there are two distinct bands or layers 3 inches thick, occurring about 1.3 feet below top of unit	8.5
1. Shale, alternating layers of purple, gray, and buff, a few inches to 6 feet thick; the lowest is greenish-gray, and crops out in bed of South Carrizo Creek	35.0
Bed of Creek	

21. SEC. 1, T. 5 N., R. 5 E., ¾ MILE NORTH OF CIMARRON RIVER, AT EDGE OF VALLEY.

	Feet
Jurassic	
Morrison formation	
10. Quartzitic boulders, dominantly pink but is buff or brown locally. The boulders are generally float, but a small area can be measured in place	3.5
Disconformity	
Exeter sandstone	
9. Sandstone, talus covered	2.0
Disconformity	
Triassic	
Dockum group	
8. Sandstone, cream, brown specked, cross-bedded; occurs in small ledges that are separated by gentle slopes	64.7
7. Sandstone and shale, generally cream colored but with a 1-foot ledge of fine-grained, red sandstone near the top; a 2-foot bed of white sandstone near the middle, and a 2-foot bed of brown, cross-bedded, platy sandstone at the bottom	10.8
6. Shale, red, generally slope-forming but has a 3-foot ledge of brown, red mottled, fine-grained sandstone 2.5 feet below the top	11.7
5. Shale, red, with a 2-foot bed of brown, cross-bedded, fine-grained, platy sandstone at the top and a similar sandstone 1 foot thick near the bottom	9.6
4. Sandstone, cream, banded with brown, fine-grained	2.0
3. Shale, red, slope forming	5.5
2. Sandstone, buff, fine-grained	3.8
1. Sandstone, buff, mottled with red, cross-bedded, platy	3.2

All of the above sandstone exposures are very much alike and have a shingled appearance on exposed surfaces.

22. SECS. 9 AND 16, T. 5 N., R. 5 E., RAILROAD CUT NORTH OF BOISE CITY

	Feet
Jurassic	
Morrison formation	
35. Limestone cap of hill	3.0
34. Covered to top of hill	14.0
33. Sandstone, gray, platy	0.1
32. Shale, gray-purple	0.3
31. Sandstone, gray, fine-grained, blocky	0.3
30. Clay, purple-gray	0.3
29. Marl, gray, fine-grained	0.2
28. Clay, purple	0.5
27. Marl, gray to purple	0.3
26. Shale, maroon and gray	1.7
25. Marl, gray	0.3
24. Clay, purple to gray	0.3
23. Marl, purple to gray	0.2

	Feet
22. Clay, gray and purple	0.3
21. Marl, light gray	0.3
20. Clay, purple to gray	0.8
19. Marl, pinkish	0.4
18. Clay, purple to gray	1.2
17. Marly nodules, gray and purple	0.3
16. Clay, purple, some gray	3.2
15. Clay, purple, with gray zones, platy	0.8
14. Clay, purple, with 2-inch nodular layer at top	2.0
13. Sandstone, purple, thin-bedded; forms ledge	0.9
12. Sandstone, purple and gray, thin-bedded, alternating with clay	3.5
11. Clay, purple and gray	1.5
10. Sandstone, purple and gray, even-bedded, in beds 1-inch or less	1.2
9. Clay, purple and gray, in alternating thin beds	7.5
8. Sandstone, purple, calcareous, in thin, regular beds, with partings of purple clay; mottling on clay	2.8
Disconformity	
Exeter sandstone	
7. Sandstone, white, fine-grained, massive, hard; flecked with minute red and black specks; contains quartz pebbles a few millimeters in diameter; case-hardened	2.2
Unconformity	
Triassic	
Dockum group	
6. Clay, dark purple-brown, with bands of greenish-gray clay and yellowish sandstone; bands 1 inch thick. Triassic strata are truncated by Exeter sandstone above	2.1
5. Clay, purple, with white band 2 inches thick, 1.5 feet above base of unit	5.2
4. Sandstone, brown, hard, thick and regular beds; thicker beds in lower part, making ledge	3.3
3. Clay, purple, with few gray markings	3.4
2. Limestone, brown, fine-grained, hard, dense; leached along cracks	1.7
1. Covered to bottom of railroad cut	3.0
Bottom of cut.	

23. SE¼ SEC. 34, T. 5 N., R. 5 E., FOURTH HILL SOUTH OF WOLF MOUNTAIN

	Feet
Cretaceous	
Dakota sandstone	
4. Sandstone capping hill	thin
Purgatoire formation	
Kiowa shale member	
3. Shale	25.0
Cheyenne sandstone member	
2. Sandstone	15.0
Unconformity	
Jurassic	
Morrison formation	
1. Shale	5.0

24. SEC. 34, T. 5 N., R. 5 E., IN SHORT RAILROAD CUT SOUTHWEST OF WOLF MOUNTAIN

	Feet
Cretaceous	
Dakota sandstone	
6. Sandstone, yellow, cross-bedded, with brown lines	8.0
5. Sandstone, brown, dense	4.0
4. Sandstone, purplish; contains wood stems and fucoids	0.1

	Feet
3. Shale, gray-brown	2.0
2. Sandstone, buff, thick-bedded, silt-like	11.0
Purgatoire formation	
Kiowa shale member	
1. Shale, dark, typical; contains many fine specimens of *Gryphaea*; base not exposed	18.0
Bottom of cut	

25. SEC. 35, T. 5 N., R. 5 E.

Jurassic	
Exeter sandstone	
3. Sandstone, white, sugary, brown on weathered surface; exposed surfaces hard	5.0
Unconformity	
Triassic	
Dockum group	
2. Sandstone, pink, platy; has masses of nodules of platy sandstone apparently formed around organic matter	6.0
1. Clay, reddish-pink	7.0
Dip is to northwest, 12 feet per 100 feet.	

26. SEC. 36, T. 5 N., R. 5 E., CUT-BANK IN TRUJILLO CANYON, 0.2-0.25 MILE EAST OF WELL 515.

Quaternary	
18. Gravel	3.0
Unconformity	
Triassic	
Dockum group	
17. Shale, mostly red, but with thin white layers	4.0
16. Sandstone, fine, white with brown veins; massive except in upper 0.1 foot	1.0
15. Shale, white, with red layer ¼ to ½ inch in thickness at top	0.5
14. Sandstone, fine, gray, and red shale, in thin irregular beds	0.4
13. Shale, somewhat silty or sandy, pale pinkish and yellowish; includes discontinuous yellow streaks in lower part, continuous yellow layer near middle that thickens and thins, and elliptical white masses in upper part	1.8
12. Shale, dark red (like No. 10)	0.5
11. Shale, medium red, makes smooth-faced ledge	0.7
10. Shale, deep red	0.8
9. Shale, red, with white streaks and splotches	1.8
8. Shale, white, sandy, soft, powdery	0.5
7. Shale, red, somewhat silty or sandy	0.2
6. Sandstone, fine-grained, silty or shaly, red splotched with yellow; lower part massive, upper 0.5 foot thin-bedded	2.0
5. Shale, red below grading to purplish toward top, with very little white; less silty or sandy than No. 1, and less concretionary; along cracks the iron oxide has been altered to yellow in pencil-fine lines	4.3
4. Sandstone, very fine, pale pink and white; makes ledge	1.0
3. Shale, red, soft, weathers back under the overlying sandstone	1.0
2. Layer of nodules or concretions of fine, pale pink sandstone; maximum thickness of concretionary zone	0.5
1. Shale, red, sandy or silty, irregularly bedded; strongly concretionary or "biscuit-like" in structure, weathering into broadly rounded surfaces; contains much white material in approximately horizontal stringers, splotches, and spots	5.0
Bottom of channel of Trujillo Creek	

27. NE¼ SEC. 18, T. 5 N., R. 6 E.

	Feet
Triassic System	
Dockum group	
2. Sandstone and conglomerate, buff and yellow; bones of *Buettneria* and *Phytosaur* were found in this unit	20.0
1. Sandstone and conglomerate, mostly red but locally yellow, part is evenbedded, part cross-bedded, and part very irregularly bedded, with pockets where clay balls have been weathered out. Part of the red sandstone is splotched with yellow. The conglomerate is fine-grained, red, and composed of many small, soft pebbles. The top of the unit is especially conglomeratic	14.7
Channel of Trujillo Creek.	

28. NW¼ SEC. 18, T. 5 N., R. 6 E.
¼ MILE SOUTHWEST OF ROCK CROSSING ON TRUJILLO CREEK.

Triassic System	
Dockum group	
3. Sandstone, buff to gray, cross-bedded, grading upward into fine-grained buff to yellow sandstone	15.0
2. Conglomerate, pink, white, gray, with pebbles of sandstone, limestone, shale, rounded to slabby and 2 inches across. Lower 3.4 feet coarse, upper is fine and cross-bedded	6.8
1. Sandstone, yellow, mottled with red, fine-grained, irregularly bedded, marked with white veinlets. Upper part is mottled with large dark red patches. Includes a lens of fine conglomerate, soft, pink on fresh surfaces, has limestone or shale pebbles	8.8

29. NE¼ SEC. 18, T. 5 N., R. 6 E.

Triassic	
Dockum group	
7. Sandstone, buff, black-flecked, friable, cross-bedded	5.0
6. Talus slope but contains 3 layers of buff, fine-grained sandstone; and 2.5 feet of fine-grained, red sandstone in lower part. Covered parts may be shale	9.5
5. Sandstone, buff, fine-grained, friable, shingly	4.4
4. Talus slope, probably sandy shale	7.5
3. Sandstone, buff, locally mottled with red; has gray specks; has several thin beds	4.0
2. Shale, buff, splotched with red, soft at top and has some sandstone	3.5
1. Sandstone, conglomeratic, magenta	2.0
Bottom of draw.	

TOWNSHIP 6 NORTH

30. SECS. 20 AND 29, T. 6 N., R. 1 E., LABRIER (TATE) BUTTE.

Cretaceous	
Dakota sandstone	
37. Sandstone, buff, thin-bedded, fine-grained	8.0
36. Sandstone, buff to cream, fine-grained, cross-bedded	22.5
35. Sandstone, buff, conglomeratic, irregularly bedded	5.0
Purgatoire formation	
Kiowa shale member	
34. Sandstone, brown, thin-bedded	7.0
33. Shale, ashy gray to buff	42.5
Cheyenne sandstone member	
32. Sandstone, buff, friable	40.0
31. Sandstone, conglomeratic, variable	9.0
30. Sandstone, buff, friable	1.0

	Feet
Unconformity	
Jurassic	
Morrison formation	
29. Shale, emerald green. Similar to top bed of Morrison at 101 Pass, and just above water level at Robbers' Roost	1.0
28. Shale, green; and sandstone, buff to brown; in alternating beds; considerable talus cover	53.0
27. Limestone, with shale partings of about equal thickness; limestone is dove-colored, contains many lenses of chert; layers about 8 inches thick. Surface of limestone layers irregular; limestone at top of unit grades upward into sandstone	40.0
26. Sandstone, white, massive	34.0
25. Sandstone and shale; sandstone is locally thin-bedded, but becomes more massive within 100 yards, and thick sandstone ledge occurs at this horizon on south part of Butte	21.0
24. Dolomite, dove to pink, contains many small dolomite rhombs, varies in thickness from 8 to 20 inches. Average	1.0
23. Sandstone, buff, thin-bedded; has numerous easily-eroded bands	8.0
Unconformity	
Exeter sandstone	
22. Sandstone, white, massive, coarse-grained, cross-bedded	37.0
21. Sandstone, brownish, fairly coarse, differentially hard	1.2
20. Sandstone, white to brownish, with dark brown and black flecks; medium fine; erodes readily	3.5
19. Sandstone, gray, friable, fine, erodes readily	2.0
18. Sandstone, brownish, with many brown or black flecks; heavy bed	0.9
17. Sandstone, cream-colored with grayish lines, very fine-grained	0.5
16. Sandstone, gray, slightly purple on fresh surface, more friable than unit (15)	1.0
15. Sandstone, white with greenish tint, friable, thin-bedded	9.5
Unconformity	
Triassic	
Dockum group	
14. Sandstone, bluish-gray	1.5
13. Shale, purplish-red, with greenish mottlings	6.0
12. Sandstone, buff, flecked with iron stains	3.8
11. Clay, light green; shows conchoidal fracture in very thin beds; contains many small sandstone lenses near base	4.7
10. Shale, bright green, platy, soapy to touch, weathers readily	4.8
9. Shale, brownish	6.5
8. Shale, gray	3.0
7. Shale, brick red, closely jointed, conchoidal fracture	4.2
6. Marl, light gray, stained purple along cracks	5.0
5. Marl, brick red, gray-streaked	18.0
4. Marl, greenish-gray to purple, much jointed	2.3
3. Sandstone, grayish, contains some lime	2.8
2. Marl, grayish, purple-stained	1.0
1. Marl, pink, weathers into ¼- to ½-inch blocks	3.5
Bed of North Carrizo Creek	

31. SEC. 34, T. 6 N., R. 1 E., VICINITY OF ROBBERS' ROOST. FROM WATER LEVEL OF NORTH CARRIZO CREEK, WEST OF OLD FOUNDATION, UP TO THE HILL TO THE NORTHEAST.

Cretaceous	
Dakota sandstone	
67. Sandstone, buff, thin-bedded, fine-grained	22.0
Purgatoire formation	

	Feet
Kiowa shale member	
66. Sandstone, buff, platy, grades downward into shale	4.0
65. Shale, gray, forms upper talus slope of hill	26.0
Cheyenne sandstone member	
64. Sandstone, white, irregularly-bedded, conglomeratic. Measured on north side of high point of hill	38.0
Angular Unconformity	
Jurassic	
Morrison formation	
63. Sandstone, white, cross-bedded	114.6
62. Sandstone, buff, brown-flecked, conglomeratic	15.2
61. Shale, red	6.5
60. Sandstone, brown, fissile, ledge-forming	4.0
59. Shale, red, grades into green shale toward top	5.0
58. Sandstone, brown; forms ledge	1.5
57. Shale, purplish red	2.0
56. Sandstone, buff, flecked with brown, thin layers	3.0
55. Shale, red to gray	3.7
54. Sandstone, brown	1.5
53. Shale, purplish	2.5
52. Sandstone, brown	4.5
51. Shale, purple	2.0
50. Sandstone, brown	2.7
49. Sandstone, white, flecked with brown; shows a decided inclination toward cross-bedding	6.0
48. Shale, purple	1.7
47. Sandstone, white, cross-bedded	6.0
46. Sandstone, white, brown-flecked, cross-bedded	4.0
45. Sandstone, white, brown-flecked, shows ledges	4.6
44. Sandstone, white, brown-flecked	0.6
43. Sandstone, very platy, gray, lenticular	0.2
42. Sandstone, white, brown-flecked, dense	0.4
41. Sandstone, white, with brown flecks	0.3
40. Sandstone, white, fine-grained, dense	0.5
39. Sandstone, ash-colored, very platy, fine-grained, recess-forming, friable	0.5
38. Sandstone, buff, dense, ledge-forming	1.1
37. Shale, greenish	1.0
36. Shale, purple; on exposure slakes into paper-thin particles	1.0
35. Sandstone, white	1.8
34. Shale, gray	0.1
33. Sandstone, white, very fine-grained, containing calcium carbonate; stained with brown along fractures and outer surface; flecked with brown throughout; tough and ledge-forming	1.8
32. Shale, greenish-gray	1.5
31. Sandstone, purple, very friable, platy	2.5
30. Dolomite, buff, arenaceous	0.5
29. Sandstone, buff, friable	0.1
28. Dolomite, buff, "bird's-eye"	0.2
27. Shale, white, limy, contains calcite partings ⅛-inch thick	0.2
26. Dolomite, buff	0.2
25. Shale, varies between gray, lavender, and pink, calcareous; contains ¼-inch calcite partings	0.4
24. Dolomite, cream colored	0.9
23. Covered, talus slope	2.1
22. Sandstone, buff, with parallel, closely-spaced fractures	0.5
21. Sandstone, buff, thin, platy	0.2
20. Sandstone, light to dark brown, with white stain along bedding planes; fractures into blocks from ½ inch to 14 inches in width, and of unknown length; blocks from	

	Feet
the same stratum which have been entirely exposed by erosion were 5 to 6 feet long, suggesting fence posts	0.3
19. Sandstone, buff, platy	0.3
18. Dolomite, cream, dense	0.2
17. Dolomite, sandy, friable	0.3
16. Shale, gray	0.4
15. Limestone, dove-colored	0.9
14. Shale, gray	0.3
13. Limestone, dove-colored; has a slaty character in lower 2 inches	1.3
12. Limestone, mottled	0.3
11. Shale, gray	0.1
10. Limestone, dove to buff, mottled, "bird's eye"	0.3
9. Shale, greenish	0.1
8. Dolomite, buff	0.3
7. Shale, brown	0.3
6. Limestone, dove-colored, slightly banded	0.4
5. Shale, slate-gray	0.5
4. Limestone, dove-gray	0.5
3. Shale, light brown to buff	0.4
2. Dolomite, light-dove layer, weathers readily into small blocks which show rounded corners	1.0
1. Shale, green; slakes into more or less rectangular pieces. This bed is correlated with bed 29 of the Labrier (Tate) Butte section, and with the uppermost bed of the Morrison in the section exposed at 101 Pass, sec. 15, T. 5 N., R. 1 E.	1.5
Bed of North Carrizo Creek	

32. SE¼ SEC. 31, T. 6 N., R. 6 E.

Triassic	
Dockum group	
7. Sandstone, buff, platy, ledge forming	3.1
6. Shale, red and buff, talus covered	27.0
5. Sandstone, buff, grades laterally into red	2.3
4. Shale, pink to red	4.7
3. Sandstone, buff to red, ledge forming	5.0
2. Sandstone, buff, ledge-forming	8.2
1. Sandstone, red, massive, ledge forming, contains gypsum veinlets. Upper surface is weathered white and is smooth but contains solution pits. This bed rests on a red shale of indeterminate thickness	6.7

33. SE¼ SEC. 33, T. 6 N., R. 6 E.

Triassic System	
Dockum group	
7. Sandstone, buff to red, shingly	3.0
6. Shale, buff, mostly talus covered	22.0
5. Sandstone, buff, grades laterally into red, shingly	3.0
4. Shale, buff and red, forms talus slope	12.0
3. Conglomerate, pink, coarse, contains 8-inch quartzite schist boulders, 2-inch by 8-inch by 12-inch blocks of fine-grained, shingly sandstone, clay balls, white, gray, red pebbles of river-worn material. The whole mass is extremely cross-bedded	5.0
2. Marl, magenta, weathers slightly	4.0
1. Marl, variegated, dense, not readily weatherable. Base not exposed.	

34. NE¼ NW¼ SEC. 30, T. 6 N., R. 8 E., NORTH SIDE OF TRIBUTARY TO CIMARRON RIVER

	Feet
Tertiary-Quaternary	
"Ogallala" formation	
7. Sand, fine, reddish, with irregular white limy layer less than 1 foot above base. About	3.0
6. Conglomerate, coarse, moderately well cemented; boulders 1 foot and more in diameter; balls of light colored clay up to 5 inches in diameter; abundant ferruginous sandstone pebbles of Dakota type; red scoria cobbles; pebbles range from slabby, to angular, to well rounded	7.0
Uneven contact	
5. Sand and sandstone, coarse and gravelly, pinkish, with rather regular stratification; includes just below the top (a) scattered boulders and cobbles; (b) a few limy lenses 1 to 2 inches thick and from a few inches to a foot long, and (c) three large chunks of very fine brown sandstone, more or less shattered, largest 1 foot square; unit makes smooth vertical face	11.5
Uneven contact	
4. Silt or clay, sandy, chocolate brown; like (2) is much jointed or "checked", and on outcrop is in shattered condition; joint faces are partly stained black, possibly by desert varnish but not in dendritic pattern; includes abundant white calcareous nodules; unit as a whole is a lens that pinches out east-west in a distance of 110 to 120 feet	1.1
3. Sand, very fine, light brown, containing in upper few inches rather abundant nodules like those in (4)	1.5
2. Silt or clay, sandy, gray, more or less jointed or "checked"; as exposed, a lens about 150 feet long with the west end truncated by erosion at the end of the cliff	1.5
1. Sand, unconsolidated, fine to medium, locally coarse, light brown; in places shows fine lamination, but mostly has little stratification and makes a smooth, nearly vertical face; at west end of exposure a channel has been cut nearly to bottom of it and re-filled with coarse gravel and boulders, including abundant ferruginous sandstone of the Dakota type, some fine-grained igneous rocks and scoria. Base not exposed	10.0

APPENDIX B

LOGS OF WELLS

BY S. L. SCHOFF

In the following pages the logs of 28 wells in Cimarron County are given, including 15 wells drilled by the Santa Fe Railroad at Felt, Boise City, and Keyes. There are 2 logs for wells owned by the Cimarron Utilities Co., 2 for private wells, and 1 for a hand-augur test hole in the Beaver River channel. Logs of 6 of the deep test wells drilled in prospecting for oil show one or more water-bearing beds, and the upper parts of these logs—1,000 to 2,000 feet—are given.

In addition to the logs of Cimarron County wells, the logs of a well at Kerrick, Texas, on the Texas State line, and one a few miles north of Cimarron County at Campo, Colorado, are given. Both wells belong to the Santa Fe Railroad.

In general, these logs are given as recorded by the driller except for minor changes in word order. "Gyp" probably means caliche if it occurs within the upper 200 or 300 feet, but may be true gypsum if reported in association with red shale or "red rock" at greater depths.

WELLS NEAR FELT

Wells in the vicinity of Felt obtain water chiefly from sands. These sands may be the lower part of the Ogallala formation, which is the surface formation at Felt, or they may be the Dakota sandstone, which is well exposed at Seneca Creek about 6 to 9 miles west of Felt and also on Beaver River about 5 to 7 miles east of Felt. The Dakota sandstone at the exposure on Seneca Creek is extremely friable, and in drilling operations such a rock would be indistinguishable from the relatively unconsolidated Ogallala sands. Hence there is uncertainty in identifying the Dakota-Ogallala boundary in the logs.

The wells for which logs are available near Felt penetrate a total of 824½ feet of beds below the water table. Of this total, 204½ feet (25 percent) is logged as "sand", "gravel", "sand and gravel", or "sand rock"; 423 feet (51 percent) is logged as clay

or other impervious beds; and 195 feet (24 percent) is logged as mixtures of clay with sand or gravel or both. The permeability and water-bearing properties of this last 24 percent depend on the mutual relations of the clay and the sand or gravel.

WELLS AT BOISE CITY

Logs are available for 3 railroad wells and 1 Cimarron Utilities Co. well at Boise City. The wells penetrate a total of 424 feet of beds below the water table, of which 224 feet (54 percent) is logged as sand or similarly pervious beds; 140 feet (33 percent) is clay or other impervious beds; 43 feet (10 percent) is logged as mixtures of clay with sand or gravel; and 12 feet (3 percent) is not recorded. The lower 170 feet of the Cimarron Utilities Co. well (No. 280) is in red beds, of which about half is recorded as sands.

WELLS AT KEYES

The 5 railroad wells at Keyes penetrate 402 feet of beds below the water table. Of this total 70 feet (18 percent) is sand, gravel, etc.; 266½ feet (66 percent) is clay or other impervious material; and 65½ feet (16 percent) is reported as mixtures of clay with sand or gravel or both. However, no sands or gravels are recorded below the water table in wells 408 and 409 and only 6 feet (4 percent) are recorded in well 407, as against 50 feet (69 percent) in well 405 and 14 feet (22 percent) in well 433. These facts suggest lateral variation of the various lithologies within short distances horizontally. Most of the materials reported in these wells appear to belong to the Ogallala formation.

WELL NO. 11.
A. T. AND S. F. RAILROAD, TEST NO. 5 AT FELT.
NE¼ NE¼ SW¼ Sec. 1, T. 1 N., R. 2 E.

	Thickness (feet)	Depth (feet)
"Ogallala" formation		
Soil	3	3
Sand and clay	42	45
Sand, dry	12	57
Sand and gravel	18	75
Sand and clay	7	82
Static water level		*82*
Sand and clay	18	100
Struck water at		*100*
Sand and clay	20	120
Sand, fine, muddy	20	140
Sand, fine, muddy, with a little clay	23	163
Clay, white tinted with blue	12	175

WELL NO. 15.

A. T. and S. F. Railroad, Test No. 2 at Felt.
SW¼ SW¼ SW¼ sec. 12, T. 1 N., R. 2 E.

	Thickness (feet)	Depth (feet)
"Ogallala" formation		
Loam	2	2
Gyp	2	4
Gyp rock	8	12
Gyp rock, mostly boulders	28	40
Clay, white	35	75
Static water level		*75*
Clay, white	5	80
Small flow of water at		*80*
Joint clay, yellow, tight	34	114
Sand rock	2	116
Kiowa? shale		
Shale, black, "light" flow of water	2	118
Slate, black, with layers of rock	37	155
Slate, black	20	175

WELL NO. 16.

A. T. and S. F. Railroad, Test No. 1 at Felt.
SE¼ NW¼ Sec. 12, T. 1 N., R. 2 E. (Compare with No. 17)

	Thickness (feet)	Depth (feet)
"Ogallala" formation		
Loam	2	2
Clay, white	75	77
Static water level		*77*
Clay, white	3	80
Struck water at		*80*
Joint clay with traces of sand	44	124
Sand rock	2	126
Quicksand, very fine	2	128
Clay and sand	6	134
Clay, white, and fine sand	12	146
Sand rock	2	148
Sand and clay	17	165
Sand, fine, and clay; very little water	31	196
Clay, yellow	12	208
Kiowa? shale		
Shale, black	15	223
Cheyenne? sandstone		
Sand, fine, water-bearing	5	228

WELL NO. 17.

A. T. & S. F. Railroad, Well No. 1 at Felt.
SE¼ NW¼ Sec. 12, T. 1 N., R. 2 E. (Compare with No. 16)

	Thickness (feet)	Depth (feet)
"Ogallala" formation		
Loam	2	2
Clay, white	75	77
Static water level		*77*
Clay, white	3	80
Struck first water at		*80*
Joint clay	44	124
Sand rock	2	126
Clay, yellow	39	165
Sand, brown and some sandstone, water-bearing	4	169
Clay, sandy	20	189
Clay, yellow	15	204
Clay, sandy	4	208
Dakota? sandstone		
Sand rock, brown, water-bearing	20	228
Kiowa? shale		
Shale, black	20	248
Clay, yellow	10	258
Slate, black	21	279
Sand, black	3	282

WELL NO. 18.

Cimarron Utilities Co., Felt.
NW¼ SE¼ Sec. 12, T. 1 N., R. 2 E.

	Thickness (feet)	Depth (feet)
Dirt and clay	5	5
Caliche	16	21
Sand rock, hard	4	25
Caliche or soft sand rock. Reported water level at 85′.	64	89
Clay, soft, white	6	95
Sand rock, hard	5	100
....	2	102
Quicksand	8	110
Sand and gravel, water-bearing	5	115
Sand rock, yellow	6	121
Sand rock, white	11½	132½

WELL NO. 19.

A. T. & S. F. Railroad, Test No. 3 at Felt.
SE¼ SE¼ NE¼ Sec. 14, T. 1 N., R. 2 E.

	Thickness (feet)	Depth (feet)
"Ogallala" formation		
Loam	5	5
Clay with layers of rock	65	70
Static water level		*70*
Clay with layers of rock	10	80
Struck water at		*80*
Clay with gravel and layers of rock	30	110
Clay, yellow	15	125
Kiowa? shale		
Slate, black	20	145

WELL NO. 20.

A. T. & S. F. Railroad, Test No. 4 at Felt.
SE¼ NE¼ SE¼ Sec. 14, T. 1 N., R. 2 E. (Used by F. A. Burrows)

	Thickness (feet)	Depth (feet)
Loam	2	2
Clay, yellow	3	5
Sand and clay	5	10
Clay, white	25	35
Sand and clay	20	55
Static water level measured 1938, about		*55*
Sand and clay, little water	17	72
Struck water at		*72*
Sand and clay	48	120
Sand and clay with layers of sand rock	20	140
Rock, hard, dry	6	146
Sand rock, hard	15	161
Flowing sand	1	162
Sand rock, hard, dry	7	169
Sand, fine, muddy	7	176
Sand rock	2	178
Sand, fine, muddy	7	185
Clay, yellow	4	189

WELL NO. 31.

G. L. JACOBS, SW¼ NW¼ SW¼ SEC. 1, T. 1 N., R. 3 E.

	Thickness (feet)	Depth (feet)
Soil	8	8
Caliche, chalky	42	50
Sand, dry	44	94
Gravel, dry	4	98
Clay, blue	35	133
Static water level (reported)		*133*
Clay, sandy, yellow, water-bearing	16½	149½
Sand rock		149½

WELL NO. 166.

SOIL AUGUR TEST HOLE BEGINNING ON BEAVER RIVER CHANNEL, NW¼ Sec. 25, T. 2 N., R. 6 E.

Sand, medium to coarse	1.5	1.5
Sand, gravelly—pebbles ½ to 1½ inches	0.5	2.0
Sand	3.5	5.5
Sand, gravelly—pebbles ¼ to ½ inch	1.4	6.9
Sand	0.5	7.4
Clay, sandy	0.3	7.7
Sand, clayey	0.2	7.9
Sand	4.6	12.5
Pebbles, maximum 2 inches	0.35	12.85
Sand, very coarse, and gravel; pebbles mostly smaller than ¾ inch, maximum 1 inch	1.15	14.0
Gravel, pebbles mostly smaller than ½ inch, maximum 1½ inch; some coarse sand. Saturated	1.2	15.2

WELL NO. 204.

GULF OIL CORP., No. 1 COX, CEN. SE¼ SEC. 35, T. 2 N., R. 8 E.

Well drilled as an oil test, total depth 6,168 feet. Correlations from sample examination by Charles Ryniker, geologist, Gulf Oil Corp.; details from samples by Ted Voiles and others.

Tertiary and Quaternary		
"Ogallala" formation		
Sand, yellow-white, medium polished, caliche cement. Arkose 90-411, increasing downward; coarse arkose and hematite 250-280; fragments of *Inoceramus* shells 300-320; hematite streak 340-350; trace of basalt fragments 360-370	411	411
Unconformity		
Triassic and/or Permian		
Red beds	168	579
Permian		
Dolomite; anhydrite; fine, micaceous, dolomitic sand; green shale, DAY CREEK	21	600
Shale, pale red, waxy	190	790
Shale, red, gypsiferous; streaks of red, sandy shale 830-930; fine, orange sand 930-940	120	910
Gypsum, BLAINE	180	1090
Sand, bright orange, polished, irregularly rounded; red clay 1285-1300	250	1340
Shale, red; trace green shale 1360, sand 1425-1445	280	1620
Shale, red, gypsiferous	80	1700
Dolomite, STONE CORRAL	50	1750
Shale, red, sandy, traces of salt; green shale streaks	375	2125
Sand, white, gypsiferous	75	2200
Shale, red, sandy; some gypsum	360	2560
Limestone, conglomeratic, dolomitic, arkosic	20	2580

	Thickness (feet)	Depth (feet)
Shale, red, sandy in upper part; traces green shale; gypsum	170	2750
Limestone, sandy, conglomeratic, dolomitic	140	2890
Shale, red; limestone 2945-2950	130	3020
Conglomerate, quartz, limestone pebbles; little red shale	30	3050
Limestone, somewhat cherty; especially at base; interbedded red shale; streaks of green shale.	166	3216
Pennsylvanian (Top indefinite)		
Virgil series		
Wabaunsee group		
Limestone, dense, dolomitic, cherty, sandy at base	217	3433
Shawnee group		
Limestone, cherty, sandy, arkosic, oolitic near base, TOPEKA	427	3860
Unconformity		
Des Moines series		
N.B.: Rocks of Missouri series and Marmaton group of Des Moines series are missing; Pennsylvanian rocks below this point are classified as "Cherokee". In wells in southwestern Kansas, there is definite evidence that the Morrow series is represented, and Morrow beds probably are present in this test.		
Cherokee formation		
Limestone; red and green shale at top, oolitic in lower part; green shale streaks; sandy zones; some arkose	390	4250
Limestone, oolitic and cherty in part; gray to dark shale breaks; small amounts of sand; arkosic, conglomeratic limestone at base	260	4510
Shale, dark; zones of sandstone, green shale, and limestone; sand, coarse, arkosic 4510-4580; green-red shale 4650-4715; limestone and shale 4755-4855; arkosic sandstone 4855-4875	573	5083
Mississippian		
Limestone, fine, gritty, micaceous at top; generally cherty; oolitic zones	587	5670
Dolomite, cherty; sand zone 5800-5825	155	5825
Ordovician		
Limestone and dolomite, cherty, VIOLA-GALENA	90	5915
Limestone; dolomite; sand zones 5950-5995, SIMPSON	80	5995
Dolomite, some oolitic chert at top; cherty at top, middle, and near base, COTTER (ARBUCKLE)	173	6168

WELL NO. 276.

A. T. & S. F. RAILROAD, STOCKYARDS WELL AT BOISE CITY, NW¼ SW¼ Sec. 14, T. 3 N., R. 5 E.

		Total Depth
Loam	2	2
Sand, white	4	6
Clay, sandy	14	20
Lime, white	7	27
Sand (pack)	3	30
Lime, soft, white	10	40
Clay, sandy, brown	17	57
Sand, hard	5	62

	Thickness (feet)	Depth (feet)
Clay, sandy	25	87
Sand (pack)	38	125
Sand, coarse	5	130
Sand, hard, tight	4	134
Static water level, measured 1938		*134*
Sand, hard, tight, some water	13	147
Sand, fine, yellow, water-bearing	13	160
Sand, coarse, water-bearing	5	165
Clay, sandy, no water	8	173

WELL NO. 277.

A. T. & S. F. Railroad, Well to Supply Station at Boise City.
SE¼ SE¼ SW¼ Sec. 15, T. 3 N., R. 5 E.

Loam	3	3
Adobe clay	6	9
Clay	7	16
Clay, sandy	32	48
Clay, hard	22	70
Shale, sandy	7	77
Sand rock	2	79
Boulders	15	94
Clay and boulders	6	100
Clay, sandy	28	128
Sand	18	146
Struck water at		*146*
Clay	6	152
Sand	2	154
Quicksand	19	173
Clay	1	174
Quicksand	4	178

WELL NO. 280.

Cimarron Utilities Company Well No. 3 at Boise City.
SW¼ NW¼ Sec. 15, T. 3 N., R. 5 E.

Soil	6	6
Clay	4	10
Sand	4	14
Clay	46	60
Sand	8	68
Clay	46	114
Sand, dry	33	147
Static water level		*147*
Sand	1	148
Shale	2	150
Sand, grading from fine, white sand at top to coarse gravel at bottom, water-bearing	62	212
Red bed	3	215
Red clay	35	250
Sand, red	35	285
Sand rock	15	300
Sand rock, red	22	322
Sand rock, white	10	332
Sand, fine, white, water not over 2 gallons a minute	4	336
Not logged	12	348
Clay, red	5	353
Clay, red, sandy	7	360
Clay, red	15	375
Sand, red	7	382
Shale, red		382

WELL NO. 284.

A. T. & S. F. Railroad Well to Supply Locomotives, at Boise City.
SE¼ NE¼ NE¼ Sec. 21, T. 3N., R. 5 E.

	Thickness (feet)	Depth (feet)
Soil	3	3
Gumbo	5	8
Caliche	12	20
Sand, white, and clay	15	35
Sand, white (pack)	17	52
Limestone, white, and phosphate	18	70
Sand, brown (pack)	20	90
Sand, brown, and clay	19	109
Sand, fine, brown	33	142
Clay, yellow, and fine gravel	5	147
Static water level		*147*
Clay, yellow, and fine gravel	8	155
Mixed gravel, water-bearing	1	156
Limestone, soft, moist	6	162
Clay, yellow, and lime gravel	25	187
Soft rock, yellow clay, water-bearing 5 gals. a min.	4	191
Clay, yellow, and lime shale	4	195
Sandstone, brown, soft	16	211
Clay, brown	16	227
Clay, blue	2	229
Clay, brown	13	242
Clay, brown, and lime gravel	6	248
Red beds	17	265

WELL NO. 318.

Gladys Belle Oil Company, SW¼ SW¼ NE¼ Sec. 25, T. 3 N., 7 E.
Water-supply well for Israel No. 1 oil test. Log reported from memory by E. B. Witten, driller.

Dirt and clay	70	70
Red bed, soft, sticky	205	275
Sand, hard, white, fine grained, water-bearing. *Water rose 85 feet.* Cased off.	5	280
Red bed	140	420
Sand, loose, fine, water-bearing. *Water rose 200 feet in 40 minutes.*	8.5	428.5

WELL NO. 318-A.

Gladys Belle Oil Co., Israel No 1. SW¼ SW¼ NE¼ Sec. 25, T. 3 N., R. 7 E.
This well reached a total depth of 4,392 feet.

Sand	66	66
Sand, yellow	24	90
Gypsum	4	94
Red rock	36	130
Lime	20	150
Red rock	50	200
Sand, yellow	20	220
Static water level (approximate; water rose from 420 feet.)		220
Red rock	52	272
½ bbl. water		*272*
Mud, yellow	13	285
Red rock	15	300
Clay, yellow	19	319
Lime	4	323
Clay, yellow	12	335
1 bbl. water		*335*

	Thickness (feet)	Depth (feet)
Lime	6	341
Red rock	10	351
Gumbo	14	365
Red rock	55	420
Sand (hole full of water)	*20*	*440*
Red rock	235	675
Lime	25	700
Red rock	65	765
Gypsum	15	780
Red rock	192	972
Sand, 12 bbls. of water	*23*	*995*
Lime	35	1030
Red rock	10	1040
Lime	45	1085
Rock salt	75	1160
Salt sand	40	1200
Lime	12	1212
Red rock	33	1245
Lime	20	1265
Hole full of water at 1265 feet		*1265*
Sand, red	120	1385
Lime	5	1390
Sand	15	1405
Red rock	65	1470
Hole full of water		*1470*
Sand, red	30	1500

WELL NO. 350.

SEGREGATED OIL CO., SW¼ SW¼ NE¼ Sec. 22, T. 4 N., R. 1 E.
Well begins on outcrop of Dakota sandstone.

Lime	8	8
Blue slate	10	18
Red mud	5	23
Slate	60	83
Lime	5	88
Sand	10	98
Slate	22	120
Sand	65	185
Slate	15	200
Sand, water-bearing	*10*	*210*
Slate	25	235
Sand	80	315
White slate	25	340
White sand	15	355
White slate	20	375
White sand	25	400
Red rock	38	438
Sand	67	505
Red mud	20	525
Slate	17	542
Lime	8	550
White shale	17	567
Lime	25	592
White shale	57	649
Lime	16	665
White shale	181	846
Sand	14	860
Red bed	800	1660
Red sand	40	1700

	Thickness (feet)	Depth (feet)
Red slate	20	1720
Hard lime	25	1745
Red slate	45	1790
Red sand	30	1820
Red slate	40	1860
Red sand and slate	60	1920
Red lime, hard	20	1940
Red slate, soft	50	1990
Hard lime	10	2000
Lime	30	2030

WELL NO. 355.

W. R. AND W. E. RAMSEY, NEAR CENTER SE¼ SEC. 34, T. 4 N., R. 1 E.
WELL BEGINS ON OUTCROP OF DAKOTA SANDSTONE.
This well reached a total depth of 4,306 feet.

Soil	1	1
White sandstone	11	12
Blue shale	5	17
Yellow sandstone	23	40
Sand rock	60	100
Blue shale	20	120
White sand, soft	55	175
White sand, water-bearing	*30*	*205*
Shale	10	215
Red rock	65	280
Lime	5	285
Lime, sandy	5	290
Sand rock	50	340
Red rock	10	350
Red sand rock	30	380
White slate	17	397
Hard sand rock	3	400
Red sand rock	20	420
Red rock, hard	3	423
Sand rock	47	470
White mud	10	480
White sandy shale	65	545
Sand rock, hard	5	550
Sandstone, hard	3	553
Blue slate	15	568
Blue mud	72	640
Shale, sandy	25	665
Grey sandy shale	10	675
Red rock	18	693
Red sandy lime	5	698
Red rock	41	739
Red sand rock	8	747
Lime	5	752
Red sand rock	2	754
Lime	2	756
Red rock	19	775
Sand, water-bearing	*13*	*788*
Red sand	6	794
Red rock	14	808
Red sand rock	47	855
Lime, sandy	7	862
Lime, some sand	8	870
Red rock	53	923
Lime, sandy	12	935
Red rock	73	1008

WELL NO. 364.

J. L. Donley, SW¼ Sec. 12, T. 4 N., R. 3 E.

	Thickness (feet)	Depth (feet)
Ogallala formation		
Soil, with some caliche layers	10	10
Caliche, sandy; caves	54	64
Dakota sandstone		
Sand rock, white	16	80
Sand rock, varicolored	50	130
Shale, varicolored	5	135
Quicksand, coarse, water-bearing	6	141
Clay brown, with white layers at base	18	159
Sand, fine 25% granite wash, water-bearing	2	161
Kiowa shale		
"Cap", black, hard	3	164
Shale, blue, some clay	29	193
"Cap", hard	1	194
Cheyenne sandstone		
Sand, cemented; well remains open though uncased; artesian water	7	201
Sand rock, coarse, white, water-bearing	4	205

WELL NO. 376.

J. L. Donley. NW¼ Sec. 8, T. 4 N., R. 4 E.
0-43 feet, as reported by driller; 48-144 feet, from well cuttings.

	Thickness (feet)	Depth (feet)
Soil	12	12
Caliche	8	20
Static water level		*20*
Caliche	10	30
Dakota sandstone		
Sandstone	2	32
Quicksand	11	43
Not reported	5	48
Sandstone, ferruginous, conglomeratic	22	70
Kiowa shale		
Shale, blue	11	81
Sand, fine, bluish; probably some shale	15	96
Shale, gray	37	133
Cheyenne sandstone		
Sandstone, medium gray	11	144

WELL NO. 405.

A. T. & S. F. Railroad, Test No. 4 at Keyes, SW¼ SW¼ SE¼ Sec. 12, T. 4 N., R. 7 E. (Compare with No. 406).

	Thickness (feet)	Depth (feet)
Loam, sandy	3	3
Clay, hard	37	40
Sand and clay	7	47
Clay, hard	5	52
Gyp rock	3	55
Sand and clay	10	65
Clay, hard	10	75
Sand and clay	15	90
Clay, hard	10	100
Sand and clay	16	116
Clay, sticky	9	125
Sand and clay	9	134
Static water level measured 1938		*134*
Sand and clay	6	140
Sand, loose, flowing	4	144
Struck first water at		*144*

	Thickness (feet)	Depth (feet)
Sand, loose, flowing	1	145
Sand, fine	20	165
Sand and gravel with some clay	20	185
Sand, water-bearing	5	190
Sand and clay	8	198
Clay, hard, probably red beds	6	204
Clay, very hard. Probably red beds	2½	206½

WELL NO. 406.

A. T. & S. F. Railroad, Well No. 2 at Keyes. SE¼ SE¼ SW¼ Sec. 12, T. 4 N., R. 7 E. (Compare with No. 405.)

	Thickness (feet)	Depth (feet)
Clay, some sand	40	40
Clay	4	44
Rock	6	50
Clay	4	54
Rock, sandy, soft	16	70
Rock, gyp, some sand	13	83
Clay, hard	10	93
Clay, yellow	10	103
Clay, hard	4	107
Clay, sandy	8	115
Clay, hard, white	13	128
Rock, hard, white	5	133
Static water level, estimated from No. 405, 1938		*133*
Rock, hard, white	5	138
Rock, white, some sand	8	146
Sand, coarse, water-bearing	8	154
Clay, yellow	9	163
Sand, dry	9	172
Clay	4	176
Sand, fine, water-bearing	2	178
Sand, coarse, water-bearing	7	185
Sand, some clay	10	195
Red beds, hard	8	203

WELL NO. 407.

A. T. & S. F. Railroad, Well No. 1 at Keyes. NW¼ NE¼ SE¼ Sec. 13, T. 4 N., R. 7 E.

	Thickness (feet)	Depth (feet)
Clay	3	3
Gyp	4	7
Clay, brown	16	23
Sand and clay	7	30
Clay, yellow	15	45
Sand, dry	16	61
Sand and gravel	59	120
Gyp rock	8	128
Gravel and boulders	9	137
Static water level		*137*
Gravel and boulders	6	143
Clay, white	12	155
Joint clay, yellow, with sand	29	184
Joint clay, yellow, changing to red bed	20	204
Red bed	24	228
Joint clay	2	230
Red bed	59	289

WELL NO. 408.

A. T. & S. F. Railroad, Test No. 1 at Keyes. SE¼ SE¼ Sec. 13, T. 4 N., R. 7 E.

	Thickness (feet)	Depth (feet)
Soil	4	4
Clay, sandy	48	52
Sand	37	89
Gyp rock	39	128
Joint clay with trace of sand	7	135
Struck water at		*135*
Joint clay with trace of sand	34	169
Red bed	27	196

WELL NO. 409.

A. T. & S. F. Railroad, Test No. 2 at Keyes. SW¼ SW¼ SW¼ Sec. 13, T. 4 N., R. 7 E.

Soil	3	3
Gyp and clay	72	75
Sand, dry	15	90
Clay	15	105
Sand and clay	15½	120½
Static water level		*120½*
Sand and clay	34½	155
Sand and clay, wet	17	172
Red bed	2	174

WELL NO. 433.

A. T. & S. F. Railroad, Test No. 3 at Keyes, NW¼ NE¼ Sec. 18, T. 4 N., R. 8 E. (T. C Schneider property).

Soil	2	2
Clay and gyp	14	16
Clay, yellow, hard	17	33
Sand and clay with hard layers	17	50
Gyp and clay	12	62
Sand and clay	23	85
Clay, sticky	7	92
Gyp and clay	16	108
Clay, sand	36	144
Static water level		*144*
Clay, sandy	1	145
Clay, sandy, soft	17	162
Clay with a little sand, but not much water	30	192
Sand and gravel, water-bearing	14	206
Clay, hard, tinted with red	1	207

WELL NO. 503.

Barnsdall Oil Company. State School Land No. 1. NW¼ SE¼ 35, T. 5 N., R. 5 E. Well begins on outcrop of Morrison formation.

Surface and lime	50	50
Lime shells and red rock	290	340
Hard lime	20	360
Quicksand and red rock	10	370
Sandy red rock and lime	580	950
Sand	5	955
Sandy red rock and gyp	260	1215

Total depth reached by this well, 5,503 feet.
No water reported.

WELL NO. 509.

Magnolia Petroleum Co., SE¼ SE¼ NE¼ Sec. 22, T. 5 N., R. 5 E. Well begins on outcrop of Dockum formation (Triassic). This well reached a total depth of 4,356 feet.

	Thickness (feet)	Depth (feet)
Soil	8	8
Red rock	17	25
Water-bearing sand	9	34
Sand, hard	24	58
Quicksand	8	66
Red sand, hard	129	195
Shells and sand	30	225
Lime, sandy	30	255
Sand	20	275
Lime	20	295
Red sand	30	325
Lime, sandy	10	335
Sand	15	350
Lime, shell	3	353
Red rock	12	365
Lime	15	380
Red sand	64	444
Gravel	14	458
Lime	7	465
Sand and lime shells	29	494
Lime	6	500
Sand	60	560
Pack sand	20	580
Lime	20	600
Sand	35	635
Lime	15	650
Gypsum	30	680
Sand	20	700
Lime, sandy	18	718
Red rock	12	730
Gypsum	22	752
Lime	48	800
Sand	22	822
Lime	13	835
Sand rock, hard	7	842
Red rock	25	867
Sand	23	890
Lime, sandy	40	930
Gypsum	20	950
Red rock	40	990
Lime	15	1005

WELL NO. 510.

Empire Gas and Fuel Co. SW¼ SW¼ NW¼ Sec. 22, T. 5 N., R. 5 E. Well begins on outcrop of Morrison formation or Exeter sandstone.

Red shale, soft	130	130
Grey sand, soft	40	170
Grey lime, soft	15	185
Red sand, soft	20	205
Red shale, soft	60	265
Lime, hard	15	280
Lime, soft, sandy	22	302
Red sand, soft	217	519
Red rock, soft	23	542
Sand, bearing fresh water	*10*	*552*
Red rock	15	567

	Thickness (feet)	Depth (feet)
Red clay	20	587
Red rock	98	685
Lime	37	722
Red rock	192	914
Shale	3	917
Lime	3	920
Red rock	63	983
Red clay, gravel	8	991
Red clay	42	1033
Red clay, gyp	5	1038
Red clay	20	1058
Red clay, gyp	42	1100
Gypsum	30	1130
Sand, gyp	20	1150
Gypsum	20	1170
Clay, gravel, gyp	60	1230
Fine sand, shale	45	1275
Sand, shale	30	1305
Sand, shale, gyp	30	1335
Sand	9	1344
Fine sand	15	1359
Sand	15	1374
Fine sand	26	1400
Sand, clay	15	1415
Sand	10	1425
Clay, sand, gravel	15	1440
Sand, gyp	20	1460
Sand	30	1490
Sand, clay	15	1505
Sand	70	1575
Sand, clay	8	1583

WELL NO. 520.

W. R. AND W. E. RAMSEY, SE¼ SE¼ SEC. 4, T. 5 N., R. 6 E.

This well begins on the Dockum formation (Triassic) and reached a total depth of 4,200 feet.

Red rock	4	4
Red rock, hard	12	16
Red rock, sandy	4	20
Red rock	25	45
Red sand, water-bearing	*65*	*110*
Red rock	25	135
Red sand, hole full of water	5	140
Red rock	15	155
Red rock	120	275
Sand	30	305
Sand, hole full of water	45	350
Sand	25	375
Red rock	175	550
Sand, water-bearing	*10*	*560*
Red rock	15	575
Gyp	25	600
Red rock	30	630
Red rock	220	850
Red sand, ½ blr. wtr.	*20*	*870*
Red sand	15	885
Red rock	115	1000
Gyp rock, hard	50	1050
Red rock	45	1095
Water		1095

WELL NO. C-1.

A. T. & S. F. RAILROAD, STATION WELL AT CAMPO, COLORADO.

	Thickness (feet)	Depth (feet)
Soil	2	2
Clay, yellow, sandy	6	8
Clay, yellow, and gyp	22	30
Sand, clean, 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, some water	9	209
Clay, brown	6	215
Sand and gravel	20	235
Clay, sandy	12	247
Sand, white	6	253
Static water level		*253*
Sand, white, some water	9	262
Sandstone, gray, soft	8	270
Joint clay	14	284
Sand, white, water-bearing	7	291
Shale, black	28	319
Sand, white, water-bearing	4	323
Joint clay, yellow	3	326
Shale, blue	4	330
Sand rock, soft	8	338
Joint clay and gray shale	17	355
Sandstone, soft	45	400
Gravel, coarse	2	402
Sandstone, soft	12	414
Sandstone, hard	4	418
Sandstone, soft	4	422
Sandstone, hard	4	426
Shale, gray, very hard		426

WELL NO. T-1.

A. T. & S. F. RAILROAD, STATION AT KERRICK, TEXAS.

Soil, sandy	7	7
Sand, red, and clay	5	12
Sand, white, and clay	16	28
Sand, yellow, and clay	27	55
Sand, white	15	70
Sand, brown	12	82
Sand and clay	28	110
Sand, light yellow	20	130
Sand, gray	61	191
Sand	10	201
Sand and coarse gravel	35	236
Sand and gravel	24	260
Sand, very fine	4	264
Static water level		*264*
Sand, very fine, water-bearing	16	280
Sand and gravel, water-bearing	20	300
Clay, yellow	3	303
Sand, coarse, water-bearing	7	310
Clay, brown	20	330
Red beds	4	334

APPENDIX C

TABLES OF RECORDS OF WELLS AND SPRINGS

BY S. L. SCHOFF

The tables on the following pages summarize the information that was obtained regarding all kinds of wells and springs in Cimarron County. The number in the first column corresponds with the number appearing on the map (Pl. I) beside the well or spring symbol. The depths of the wells are given to the nearest even foot as measured below the land surface. They may differ from the original depth obtained by the driller if the well has partly filled in or if some obstacle prevented the measuring tape from reaching the bottom. The water levels are given as measured below some definite and reasonably permanent object at the well, such as the pipe clamp or the top of the casing. Usually the measuring point was above the land surface. To find the depth to which the water stands in a well, subtract the figure for water level from the figure for depth and add the height of the measuring point above the surface unless the latter is preceded by a negative sign, when it should be subtracted. Water-level measurements that were considered accurate to a hundredth of a foot are reported to the second place to the right of the decimal; those accurate to a tenth of a foot are recorded to the first place to the right of the decimal; and those less accurate, or reported, are recorded in even feet. The reported water levels and well depths are indicated by a reference to a footnote at the end of the table.

Where the accuracy of some of the information, such as well-diameters and the nature of the water-bearing materials, was in doubt, a question mark (?) has been used. The use of the water is generally the principal use or uses. Many of the farm windmill wells are used for the irrigation of gardens, but only small quantities of water are involved, and this use has not been indicated in the table. Wells near farmhouses generally supply the water for both the house and the stock; those in pastures generally are used only for stock water. In the absence of information to the contrary, wells at unoccupied farm houses have been recorded as unused.

Where the nature of the water-bearing material is known, either by observation, or report, the material is briefly described in the column headed "Remarks", and reference is made to the well log, if one is available. The water-bearing material is also identified by geological name, such as Dakota or "Ogallala", in the column headed "Probable aquifer". For the wells in the east-central part of the county that tap water in rocks of pre-Tertiary age, the designation "red beds" has been used because the geologic formation represented by the water-bearing beds is not known with certainty. It is considered likely, however, that these "red beds" are of Dockum age.

WELL TABLES

Record of Wells and Springs in Cimarron County, Oklahoma.

(All wells are drilled unless otherwise stated under "Remarks")

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
	T. 1 N., R. 1 E													
1	SE¼SE¼SE¼ sec. 15	J. I. Johnson	....	Upland flat	4645	162	....	0.5	151.36	11-14-38	Dakota	C,W	N	
2	SE¼SE¼SE¼ sec. 21	P. H. Schroeder	....	do.	4672	156	....	0.5	142.28	do.	do.	C,W	D,S	
3	NW¼NW¼NW¼ sec. 22	W. D. Smith	....	do.	4668	182	....	1.2	159.12	do.	do.	C,W	N	
4	SW¼SW¼SE¼ sec. 25	Henry Johnson	1918	do.	4609	140	....	1.3	124	do.	Dakota?	C,W	D,S	
5	SW¼ SW¼ sec. 28	Siler Faulkner	....	do.	4687	183	4½	1.0	157.03	11-15-38	Dakota	C,W	N	
6	W½ NE¼ sec. 30	A. T. & S. F. R. R.	....	do.	4724	205	6	1.0	173.15	do.	do.	C,W	S	Stockyard well at Nieto.
7	SW¼ SW¼ sec. 8	H. E. Saunders	....	Creek bottom	4638	36	5	0.5	26.20	4-20-39	Alluvium?	C,W	S	
8	SW¼ NW¼ sec. 10	do	....	Ravine	....				Sp.	do.	Dakota			Estimated 4 gals. a min.
	T. 1 N., R. 2 E.													
11	NE¼NE¼SW¼ sec. 1	R. W. Willard	....	Upland flat	4469	175	5	......	82[5]	....	Ogallala?	None	N	A. T. & S. F. test No. 5 at Felt. See log.
12	SE¼SE¼SE¼ sec. 3	H. O. Pillett	....	do.	4497	94	....	1.0	91.10	11- 8-38	Ogallala	C,W	N	

[1] Measuring point was usually top of casing, water pipe clamp, or coupling.
[2] Pumps: C, cylinder; T, turbine; B, bucket and rope. Power: W, windmill; H, hand; A, air-lift; G, Gasoline engine; O, oil engine; E, electric motor. Number indicates horse power.
[3] Use: D, domestic; S, stock; I, irrigation (number indicates acres); P, public; RR, railroad; N, not used.
[4] For analysis of water see table on pp. 186-187.
[5] Reported.
[6] Water level estimated from nearby measured well.
[a] Altitude determined by Paulin altimeter.

T. 1 N., R. 2 E.—(Cont'd)

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P. (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift	Use of water	Remarks
13	SE¼ SE¼ sec. 5	J. C. Lemon, et al	....	Gentle slope	4521	276	5	0.5	90.	11- 8-38	Ogallala & older	C,W	S	Measured yield, 2.3 gals. a min. Water level rose 18.21 ft. in 1 hr. 15 min. after pumping stopped.
14	SE¼SW¼SE¼ sec. 10	J. C. Bergner	....	Upland flat	4492	117	5	1.3	95.3	do.	Ogallala	C,W	D,S	
15	SW¼SW¼SW¼ sec. 12	N. W. Willard	....	do.	4458.4	175	8	......	75[5]	....	do.	None	N	A. T. & S. F. test No. 2 at Felt. See log. Water reported in black shale, 116-118 ft., and small flow at 80 ft.
16	SE¼ NW¼ sec. 12	A. T. & S. F. R. R.	....	do.	4454	228	....	......	77[5]	....	do.	None	N	A. T. & S. F. R. R. Test No. 1 at Felt. See log.
17	SE¼ NW¼ sec. 12	A. T. & S. F. R. R.	....	do.	4454	282	10	......	77[5]	....	Ogallala & Dakota?	C	RR	A. T. & S. F. R. R. well No. 1 at Felt. See log. First water at 80 feet, 2nd at 224 ft. 14 in. casing 16-154 ft., 10-in casing 62-218 ft. 6 strainers, 10 ft. by 10-in. Cylinder 5¾ in. x 80 in.
18[4]	NW¼ SE¼ sec. 12	Cimarron Utilities Co. (Felt)	....	do.	....	132	8	......	83[5]	....	Ogallala	C,E,1½	D	Water in sand and gravel. See log. 8-in. casing to 130 ft., perforated, with screen. Reported yield, 20 gal. a min. Water temp. on 11-10-38, 59° F.
19	SE¼SE¼NE¼ sec. 14	F. A. Burrows	....	do.	4438	145	8	......	70[5]	....	Ogallala?	None	N	A. T. & S. F. R. R. test No. 3 at Felt. Water in gravel bedded with clay and "rock", 80-110 ft. See log.
20	SE¼NE¼SE¼ sec. 14	do.	....	Creek bottom	4433	189	4	0.3	55	11-14-38	do.	C,W	D,S	A. T. & S. F. R. R. test No. 4 at Felt. Water in sand and clay. See log.
21	SE¼SW¼SW¼ sec. 19	A. Decker	....	Upland flat	4597	125	....	1.2	120.90	11- 8-38	Ogallala? Dakota?	C,W	N	
22	SW¼SW¼SW¼ sec. 20	Porter Reeves	....	do.	4571	118	....	......	101.89	do.	do.	C,W	N	
23	NE¼SE¼NE¼ sec. 22	C. M. Howell	1917	do.	4479	106	....	0.3	94.95	do.	Ogallala	C,W	D,S.	
24	SW¼NW¼SW¼ sec. 31	J. D. Marsh	....	do.	4592	140	....	1.0	117.48	11-14-38	Dakota?	C,W	N	
25	NW¼ NW¼ sec. 32	C. J. Rhodes, et al.	....	Slope	4525	90	5	1.5	64.26	do.	Ogallala?	C,W	N	6.5 ft. above channel of ephemeral creek.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
	T. 1 N., R. 3 E.													
31	SW¼NW¼SW¼ sec. 1	G. L. Jacobs	1916	Upland flat	....	149	3½	......	133[5]	1916	Ogallala	C,W	D,S	Water in sandy yellow clay, 133-149 ft. Water level draws down below cylinder if pumped fast. See log.
32	SW¼SE¼SE¼ sec. 4	T. J. O'Neal	1908	do.	4395	109	5½	......	91.14	11- 4-38	do.	C,W	N	Water in gravelly sand, 96-114 ft. Iron casing to 100 ft.
33	NE¼NW¼NW¼ sec. 7	Frank Donley	....	do.	4437	130	5	0.5	72.55	11- 2-38	do.	C,W	N	
34	NW¼NE¼NW¼ sec. 8	Mary H. Hewitt Est.	....	do.	4423	95	....	0.5	87.22	do.	do.	C,W	N	
35	SE¼ SW¼ sec. 12	Julia Richardson	....	do.	4328	110	....	......	99.85	11- 4-38	do.	C,W	D,S	Uncased
36	NW¼NW¼NW¼ sec. 15	Robert G. Faim	Old	do.	4375	102	....	1.25	96.	do.	do.	C,W	D,S	
37	NW¼NE¼NE¼ sec. 18	American Nat. Life Ins. Co.	1929	do.	4419	117	3½	1.0	75.65	11- 5-38	do.	C,W	D,S	1/3 mi. N. of Coldwater Creek.
38	SE¼SW¼SE¼ sec. 20	Richard F. Reed	1913	do.	4371	74	6	0.3	67.71	11- 7-38	Dakota?	C,W	N	Reported depth 79 ft. Drilled in sandstone 3 to 76 ft. Water in gravel 76 to 79 ft. Uncased.
39	NE¼NE¼NE¼ sec. 23	Eva J. Young	....	do.	4323	114	....	......	95.83	11- 4-38	Ogallala	C,W	N	
40	SW¼SE¼SE¼ sec. 24	Grant Black	....	Low hill on upland	4270	73	6	0.3	61.20	11- 7-38	do.	C,W	N	
41[4]	NE¼SW¼SW¼ sec. 32	James Dove	1913	Gentle slope	4376	59[5]	8	......	51[5]	....	Dakota	C,W	D,S	Sand, clay and caliche, 0-9 ft; sandstone 9-59 ft. Casing 0-9 ft. Measured yield 3 gals. a min. Temp. on 11-10-38, 59.5° F.
42	SW¼SW¼SE¼ sec. 33	J. L. Joy	....	Gentle slope	4290	62	....	0.3	43.40	11- 7-38	Dakota?	C,W	S	Water probably from Dakota sandstone.
43	SW¼SW¼SE¼ sec. 34	John Glatthart	....	Upland flat	4288	80	....	......	69.82	do.	Dakota? Ogallala?	C,W	N	
44	SE¼SE¼SE¼ sec. 9	M. G. Morgan	....	do.	4379	129[5]	4½	1.0	99.13	4-14-39	Ogallala	C,W	D,S	

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P. (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift	Use of water	Remarks
	T. 1 N., R. 4 E.													
49[4]	SW¼SW¼SW¼ sec. 7	State of Oklahoma	....	Upland flat	4314	122	5	0.5	99.90	11- 7-38	Ogallala	C,W	D,S	
50	SE¼SE¼SW¼ sec. 8	W. E. Summers	1931	do.	4308	129	4	1.0	108.91	11-18-38	do.	C,W	D	Measured drawdown 3.5 ft. at 1.1 gals. a min.
51	SE¼SE¼SE¼ sec. 9	R. C. C. Thatcher	....	do.	4250	82	....	......	71.72	10-28-38	do.	C	N	In area of dunes.
52	SE¼SW¼SE¼ sec. 18	Wm. A. McDaniel	....	Low hill on upland	....	114	....	0.5	89.50	11- 7-38	do.	C,W	N	
53	SW¼SW¼SW¼ sec. 21	Farm Mtg. Holding Co.	....	Upland flat	4250	74	....	1.5	67.84	do.	do.	C,W	N	
54	NE¼NE¼NE¼ sec. 28	New Hope School District C-12	....	do.	4214	55	....	0.3	42.18	11- 5-38	do.	C,H	D,S	School transferred. Well used by neighbors.
55	SE¼SE¼SE¼ sec. 30	R. C. Hutton	....	do.	4246	67	....	0.7	52.46	do.	do.	C,W	N	
56	SW¼SE¼NW¼ sec. 31	W. A. Cross	....	do.	4243	55	5	1.5	45.85	11- 7-38	do.	C,W	N	
	T. 1 N., R. 5 E.													
61	SE¼SW¼NE¼ sec. 9	Edmund B. Rogers	....	do.	4154a	105	4	5.5	81.84	11- 1-38	Ogallala	C,W	N	2 wells 150 feet apart. Measured N. well. In area of dunes.
62	SW¼SW¼SE¼ sec. 19	I. L. Barnett Est.	....	Hill on upland	4168a	77	4½	3.5	67.93	7-23-38	Ogallala	C,W	N	
63[4]	NE¼NE¼NE¼ sec. 20	Fred Brakhage	1915	Upland flat	4149a	78	6	0.6	72.30	10-28-38	do.	C,W	D,S	Water in coarse gravel, 74-81 ft. Measured yield 2.2 gals. a min.
64	SW¼SW¼SW¼ sec. 28	E. Wilkins School	....	do.	4139	80	4½	1.5	72.06	do.	do.	C,W	D	
66	NW¼SE¼SE¼ sec. 34	C. K. Womack	1935	do.	4095	127	13	6.0	84.08	9-17-38	do.	T,G	Obs.	Reported depth 150 ft. Drilled for irrigation water in gravel and sand; 1st, 84-88 ft.; 2d, 110-120 ft.; 3d, 130-150 ft. Cased with oil drums to 140 ft. Estimated yield, 150 gals. a min.
	T. 1 S., R. 5 E.													
70	NE¼NE¼NW¼ sec. 6	....	....	Upland flat	4159	73	4	0.3	64.12	10-28-38	Ogallala	C,W	N	

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
						T. 1 N., R. 6 E.								
71	NE¼NW¼NW¼ sec. 5	State of Oklahoma	....	Upland flat	4081a	126	5	1.0	108.73	10-27-38	Ogallala	C,W	N	Water in gravel.
72	NE¼NE¼NE¼ sec. 9	Mrs. C. W. Briles	....	do.	4030a	130	....	1.0	90.55	10-26-38	do.	C,W	N	
73	SE¼SW¼NW¼ sec. 16	Wm. L. Chenault	1911	do.	4042a	111	....	1.0	92.52	do.	do.	C,W	S	Water in sand.
74	W cent. NW¼ sec. 23	J. J. Perkins	1884	do.	4006a	90	6	0.5	75.42	do.	do.	C,W	S	Water in sand.
75	SW¼SW¼SW¼ sec. 25	do.	....	Upland flat	3964a	109	....	0.5	104.20	10-26-38	do.	C,W	N	Water in sand.
76	SE¼SE¼SE¼ sec. 27	do.	....	do.	3998a	115	....	1.0	104.81	do.	do.	C,W	N	
77	Center sec. 32	W. L. Chenault	....	do.	4025a	78	4½	4.0	72.78	10-28-38	do.	C,W	N	
78	SE¼SE¼ sec. 36	J. J. Perkins	....	do.	3952	146	....	......	130	10-25-38	do.	C,W	S	Water in sand.
						T. 1 N., R. 7 E.								
83	NW¼NW¼SW¼ sec. 1	J. J. Perkins	....	Slope	3832a	222	4¾	1.3	184.20	10-24-38	Ogallala	C,W	S	Water in sand.
84	SE¼ NE¼ sec. 4	do.	....	Flood plain	....	81	....	......	61.18	10-13-38	do.	C,W	S	14 ft. above N. Canadian R. channel.
85	SW¼ NW¼ sec. 14	S. M. Weldon	1922	Upland flat	3893a	254	4½	1.0	235.37	10-24-38	Red beds	C,W	D,S	Water in coarse gravel, 230-255 ft.
86	SW¼NE¼NW¼ sec. 15	J. J. Perkins	....	do.	3911a	230	6	0.7	206.60	do.	do.	C,W	S	Water in coarse sand.
87	SW¼SW¼SE¼ sec. 18	Andy A. James	....	do.	3962	104	4½	0.3	90.75	10-25-38	Ogallala	C,W	D,S	Water level rose 3.84 ft. in 65 min. after pumping stopped.
88	SW¼SW¼SW¼ sec. 26	Ella M. Shrayer	....	Low hill on upland	3892a	280	5	......	267.32	do.	do.	C,W	D,S	Water in sand. Red beds 275-280 ft. Water level rose 2.61 ft. in 55 min. after pumping stopped.
89[4]	SE¼NE¼NW¼ sec. 28	State of Oklahoma	....	Upland flat	3931a	221	4½	1.0	201	10-26-38	Red beds	C,W	D,S	Measured while pumping slowly. Measured yield, 1.3 gals. a min.; water temp. 61° F. on 11-9-38.
						T. 1 N., R. 7 E.—(Cont'd)								
90[4]	NE¼NE¼NE¼ sec. 29	W. P. Foreman	Old	do.	3926a	158	....	1.0	147.07	do.	Ogallala	C,W	D,S	Water in gravel. Measured yield, 1.4 gallon a min., and water temp. 61° F. on 11-9-38. Water level rose 0.66 ft. in 36 min. after pumping stopped.
91	SE¼SW¼SE¼ sec. 36	Joe W. Taylor	1928	Upland flat	3860a	280	....	0.3	265.28	10-25-38	do.	C,W	D,S	Water in sand and gravel. Water level rose 1.12 ft. in 25 min. after pumping stopped.
						T. 1 N., R. 8 E.								
96	NW¼NW¼SW¼ sec. 1	Prudential Ins. Co.	....	Upland flat	3837a	300+	4½	1.0	300+	10-11-38	Ogallala	C,W	N	No water, no bottom at 300 ft.
97	SE¼SE¼SW¼ sec. 3	W. H. Douglas	....	do.	3860a	296	4	0.5	288.83	do.	do.	C,W	N	
98[4]	SE¼SW¼SW¼ sec. 4	Ernest Tatman	1918	Upland flat	3860a	300+	4½	1.5	292.45	10-11-38	Ogallala	C,W	D,S	Measured yield, 3.2 gals. a min.; water temp. 63° F. on 4-15-39.
99	SE¼NE¼SW¼ sec. 18	J. J. Perkins	....	Flood plain	3739a	157	....	1.5	141.45	do.	do.	C,W	S	9 ft. above N. Canadian R. channel.
100	SW¼NE¼NE¼ sec. 28	do.	....	Slope	3695a	145+	4½	1.0	143	9-15-38	do.	C,W	D,S	19 ft. above N. Canadian R. channel. Measured while pumping.
101	SE¼NW¼NE¼ sec. 32	do.	....	Flood plain	3703a	242	....	......	167.98	10-11-38	do.	C,W	S	26.5 ft. above N. Canadian R. channel
102	SE¼SE¼SE¼ sec. 34	do.	....	Upland flat	3758a	255	5	0.5	241.44	do.	do.	None	N	
						T. 1 N., R. 9 E.								
106	NE¼NE¼SE¼ sec. 6	D. M. Kindred	....	do.	3810a	298+	6	1.2	292.20	9-15-38	Ogallala	C,W	N	
107	SE¼SW¼SW¼ sec. 9	Maude New Est.	....	do.	3762a	287	5	0.2	256.22	do.	do.	C,W	D	
108	NW¼NW¼NW¼ sec. 12	N. American Life Ins. Co.	Old	do.	3706a	242	....	0.5	232.44	8-25-38	do.	C,W	D,S	Water level rose 1.11 ft. in 10 min. after pumping stopped.
109[4]	NW¼NE¼NW¼ sec. 15	E. R. Blake	....	do.	3736a	300[5]	5	0.3	236.5	do.	do.	C,W	D,S,P	Measured after pumping. Water in coarse gravel. Measured yield 2.2 gals. a min.; water temp. 63° F., 11-10-38. Water for Griggs school.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
	T. 1 N., R. 9 E.—(Cont'd)													
110	NW¼NW¼NW¼ sec. 21	Levi Combs	Old	do.	3743a	300[5]	5	0.6	241	do.	do.	C,W	D,S	Measured while pumping. Water in med. to coarse sand, 245-300 ft.
111	SW¼SE¼SW¼ sec. 27	P. A. Combs	1916	do.	3707a	232	5	0.7	230	do.	do.	C,W	D,S	Water in coarse gravel. Water level rose 0.28 ft. after mill was shut off, but pumping did not entirely stop.
112	SE¼ NW¼ sec. 31	R. S. Roberts	....	Slope	3714a	231	....	1.4	213.50	do.	do.	C,W	N	Reported 250 ft. deep, water in clay rose 15 ft. when reached by drill. A feeble well.
	T. 2 N., R. 1 E.													
115	NE¼ sec. 7			Flood plain	....	18	60	0.5	16.5	11-15-38	Alluvium	C,W	N	Dug well, near Currumpa Creek (N. Canadian R.)
116	E½ SE¼ sec. 8	State of Oklahoma	....	Ravine	4616	33	5	1.5	31.7	4-19-39	Dakota	C,W	S	Dug well. Measured while pumping slowly.
117	SE¼SE¼SW¼ sec. 15	Will May	1892	Terrace	4570	14	66	......	11.41	4-21-39	Alluvium	C,W	D,S	Dug well, walled with rock. Soft water, in quicksand and gravel. A weak well.
118	SW¼ NW¼ sec. 15	J. C. Lujan	....	do.	4573	14	15	......	11.30	4-11-39	do.	C,W	N	Dug well, cased with planks.
119	NW¼ NE¼ sec. 16	Mrs. Lorenzo Lujan	Old	Flood plain	4585	83	6	2.2	3.18	do.	Cheyenne?	C,W	D,S	15 ft. above cr. level. Rept. orig. depth 200 ft.
120	do.	do.	Old	do.	4579	10	30	0.7	8.72	do.	Alluvium	B	D	Dug well, 9 ft. above cr. channel. Tree roots make water bitter.
121	NE¼ NW¼ sec. 22	J. D. Lujan	1929	Creek bottom	4579	30	5	2.0	19.50	4-21-39	do.	C,W	S	
122	NW¼ SW¼ sec. 23	R. Wright	....	Bench 27′ above cr.	4564	50	4½	......	39.46	do.	Dakota	C,W	D,S	Measured 1 hour after pumping. Waters 10 head of stock. Inadequate.
123[4]	SW¼ NW¼ sec. 25	J. C. Lujan	1900	Steep slope	4529	23	48	......	17.90	4-11-39	do.	C,W	D,S	Dug well. Natural rock wall. Water temp. 52° F. on 4-14-39.
	T. 2 N., R. 1 E.—(Cont'd)													
124	NE¼ SW¼ sec. 27	H. E. Saunders	1938	Sand dunes	4689	108	5 ?	1.0	98.31	4-20-39	do.	C,W	S	
125	NW¼ SE¼ sec. 34	....	....	Slope	4658	69	6	1.5	55.31	4-11-39	Dakota?	C,H	D	
126	NW¼ NW¼ sec. 36	....	....	Creek bottom	....	......	....	......	Sp.	do.	Dakota & (?) Alluvium	....	—	25-30 gals. a min.
127	NE¼ NE¼ sec. 36	Guy C. Saunders	....	Gulley	....	......	....	......	2 Sp.	4-21-39	Dakota	......	—	Estimated 1 to 5 gals. a min.
128	SW¼ sec. 32	State of Oklahoma	....	Dunes	....	136	....	0.3	127.8	8-12-40	Dakota?	C,W	S	Water level, measured after some pumping, was constant.
	T. 2 N., R. 2 E.													
129	NE¼NE¼SE¼ sec. 2	Geo. Camilli	1910	Hill	4553	179	4½	2.2	170.00	4-22-39	Dakota? Ogallala?	None	Obs.	
130	NW¼NW¼NE¼ sec. 7	Citizen's Home Bank	....	Upland flat	4655	114	....	......	96.87	do.	Ogallala	C,W	D,S	
131	NE¼NE¼NE¼ sec. 14	Reed Burton	1932	do.	4520	156	....	......	146.85	do.	Dakota? Ogallala?	C,H	D,S	
132[4]	SW¼ NW¼ sec. 33	J. G. Mayhan	1934	Flood plain	....	7.5[5]	2	6.3	11.55	11- 8-38	Alluvium	H	D,S	Water in sand. Dug well, 20-in. sand point. Waters 30 head of stock. Water temp. 56° F. on 4-14-39.
133	SE¼NW¼SE¼ sec. 36	....	1938	River channel	4376	2	12	......	1.5	11- 2-38	do.	None	N	Test hole.
	T. 2 N., R. 3 E.													
135	SE¼SE¼SE¼ sec. 1	D. C. Ottinger	1918	Upland flat	4347	142	6	1.0	138.03	10-22-38	Ogallala	C,W	D,S	
136	NE¼NE¼SE¼ sec. 3	Joe Doskocil	....	do.	4399	159	4½	1.2	154.74	10-31-38	do.	C,W	D,S	
137	SE¼SE¼NE¼ sec. 4	Louis Simmer	....	do.	4432	174	....	1.0	145.47	do.	do.	C,W	N	
138	NE¼NE¼NW¼ sec. 5	Otto Taub	....	Low hill	4488	187	4½	0.3	126.60	do.	do.	C,W	N	In area of dunes.
139	SE¼SE¼SE¼ sec. 6	do.	....	Upland flat	4477	138	4	1.0	120.16	11- 4-38	do.	C,W	N	
140[4]	SE¼NE¼NE¼ sec. 16	John E. Heatley	....	do.	4409	120	....	0.5	103.89	11- 2-38	do.	C,W	D,S	In area of dunes. Water temp. 61° F. on 4-14-39.

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Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
							T. 2 N., R. 4 E.							
142	NE¼NW¼NW¼ sec. 19	....	1938	River channel	4243a	8	4	......	6.2	10-31-38	Alluvium	None	N	Soil augur test hole.
143	SE¼SE¼SW¼ sec. 24	R. C. C. Thatcher	....	Upland flat	4218a	?	....	......	80	11- 1-38	Ogallala	C,W	S	Measured while pumping.
144	SW¼ NE¼ sec. 36	do.	....	Dunes	4217a	92	4	4.5	78	do.	do.	C,W	S	Measured while pumping.
							T. 2 N., R. 5 E.							
146	SW¼NW¼SW¼ sec. 1	J. D. Paul	....	Upland flat	4141a	121	....	0.2	113.43	10-19-38	Ogallala	C,W	D,S	Water in gravel.
147[4]	SW¼NW¼SW¼ sec. 2	Prudential Life Ins. Co.	1914	do.	4153a	125	....	1.5	109	do.	do.	C,W	D,S	Water in gravelly sand. Water temp. 58° F. on 4-18-39.
148	SE¼SE¼SW¼ sec. 5	T. A. Peters	1937	Flood Plain	4105	78	9	0.5	25.13	7-23-38	Alluvium	C,W	Obs.	22.5 ft. above N. Can. R. channel. Water in gravel at 30 ft.
149	SW¼ NW¼ sec. 5	do.	1909	Upland flat	4208	121	5	......	109.07	do.	Ogallala	C,W	D,S	Water in mixed gravel and clay. Waters 75 head of stock.
150	SE¼NW¼NW¼ sec. 8	....	1938	River channel	4088	2½	4	......	1.80	10-30-38	Alluvium	None	N	Soil augur test hole.
151	SE¼NW¼NW¼ sec. 9	Edmund B. Rogers	....	Flood plain	4081	22	5	1.0	15.91	10-30-38	Alluvium	C,W	N	13 ft. above N. Canadian R. channel.
152	NE¼SE¼SE¼ sec. 14	....	1938	River channel	4032a	3	15	......	2.2	10-19-38	do.	None	N	Test dug with shovel.
153	SE¼SE¼SE¼ sec. 32	Edmund B. Rogers	....	Upland flat	4183a	117	5	2.5	97.72	7-23-38	Ogallala	C,W	S	
154	SW¼SW¼SW¼ sec. 23	do.	....	do.	4132a	127	....	2.5	90.21	10-27-38	do.	C,W	S	In an area of dunes.
155	SW¼SW¼SW¼ sec. 25	do.	....	do.	4112a	103	6	7.5	97.03	do.	do.	C,W	S	In an area of dunes.
							T. 2 N., R. 6 E.							
158[4]	W. cent. SE¼NE¼ sec. 4	W. B. Sizemore	1908	Upland flat	4067	141	5	0.6	135.79	10-14-38	Ogallala	C,W	D,S	Waters 40 head of stock. Measured yield 1.25 gals. a min., and temp. 61° F. on 11-9-38.
159	SW¼SE¼SW¼ sec. 10	Warren H. Lewis	....	do.	4054a	192	....	0.4	120.21	10-13-38	do.	C,W	N	Water in gravel.
160	NW¼NE¼NE¼ sec. 12	Andrew Harris	....	do.	3998	170	....	0.3	151.64	do.	do.	C,W	N	
161	Cent. NE¼ sec. 20	....	1938	River channel	3975a	4	4	......	2.2	10-27-38	Alluvium	None	N	Soil augur test hole.
162	SW¼NW¼NE¼ sec. 20	Edmund B. Rogers	....	Flood plain	3989a	28	6	0.3	14.20	do.	Alluvium	C,W	S	13.7 ft. above N. Can. R. channel.
163	SW¼SW¼NE¼ sec. 21	do.	....	do.	3974a	40+	4	0.5	28.30	10-14-38	do.	C,W	S	0.15 mi. N. of N. Can. R. and 27 ft. above channel.
164	NW¼SE¼SW¼ sec. 24	J. J. Perkins	....	Slope	3947	120	4	......	80.11	do.	Ogallala	None	N	52 ft. above N. Can. R. channel.
165	NW¼NE¼NW¼ sec. 25	do.	....	River terrace	3919	88	5	....	43.93	do.	do.	C,W	N	24 ft. above N. Can. R. channel.
166	NW¼NW¼NW¼ sec. 25	....	1938	River channel	3895	15	4	......	14.15	10-25-38	Alluvium	None	N	Soil augur test hole. Water in fine to medium gravel, 14.2-15+ ft. See log.
167	SW¼NW¼NW¼ sec. 25.	A. T. & S. F. R. R. (Conrad sta.)	....	Slope	3934	81	6	0.7	54.56	10-24-38	Ogallala	C,W	D,S	39 ft. above N. Can. R. channel
168	SW¼SW¼SE¼ sec. 34	J. D. Sanders	....	Upland flat	4024a	115	4	1.0	94.95	10-27-38	do.	C,W	D,S	
							T. 2 N., R. 7 E.							
173	SE¼SE¼SE¼ sec. 2	W. S. Taggert Est.	1930	Upland flat	3912	225	4½	0.5	205 (?)	10-13-38	Ogallala	C,W	D,S	Water in sand and fine gravel.
174[4]	NE¼NW¼NW¼ sec. 2	C. J. Taggert	1915	do.	3924	152	5½	1.0	139.59	9-14-38	Ogallala	C,W	D	Can water 100-150 head of stock. Water in gravel, 150-154 ft., overlying red beds. 2 unsuccessful wells were drilled 0.2 mi. east. Measured yield, 2 gals. a min., and temp. 60° F. on 11-9-38.
175	NW¼NW¼NW¼ sec. 9	C. C. Lucas	....	do.	3951	160	....	1.3	141.4	10-13-38	do.	C,W	N	
176	NE¼NE¼NE¼ sec. 12	Florence Richards	1907	do.	3919	253	....	1.0	247.43	8-31-38	Ogallala?	C,W	D,S	Water in sand rock.
177	SE¼SE¼SW¼ sec. 14	M. J. Nicholson	....	do.	3908	203	4(?)	......	184.13	9- 2-38	Ogallala	C,W	N	Water in sand and gravel.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
	T. 2 N., R. 7 E.—(Cont'd)													
178	SE¼NE¼SE¼ sec. 18	P. L. Ferguson	....	do.	3982	185	5	1.5	172.37	10-13-38	do.	C,W	D,S	Water in coarse gravel.
179	NW¼NW¼NE¼ sec. 22	F. A. Gilmer	Old	do.	3941	203	5	1.3	189.68	9- 2-38	do.	C,W	D,S	Water in gravel.
180	SW¼SW¼SW¼ sec. 22	J. J. Perkins	Old	do.	3946	211	....	1.0	185.5	10-12-38	do.	C,W	D,S	Water in gravel.
181	S½SW¼SE¼ sec. 24	A. C. Kincannon	1927	do.	3913	225	4¾	1.0	213.9	9- 2-38	do.	C,W	D,S	Water in sand. Waters 50 head of cattle.
182	NW¼NW¼SW¼ sec. 25	Louis E. Garver	....	Gentle slope	3885a	......	4½	1.3	174.44	10-12-38	do.	C,W	N	Water in gravel.
183	NE¼SE¼NE¼ sec. 30	James T. Cryer	1929	Slope	3933a	145	4½	1.3	113.39	do.	do.	C,W	D,S	Water in sand, 12-14 ft. thick, over gravel 6-8 ft. thick.
184	SE¼SE¼NE¼ sec. 35	State of Oklahoma	1917	Gentle Slope	3837a	130	4½	1.5	120.79	10-12-38	Ogallala	C,W	N	Water in gravel.
	T. 2 N., R. 8 E.													
191	SE¼SE¼SE¼ sec. 1	D. L. Todd	1920	Gentle slope	3778	258	5	1.2	215.86	8-30-38	Red Beds	C,W,	D,S	Water in sandstone 258-268 ft. Water level rose 2.66 ft. in 35 min. after pumping stopped.
192	SW¼SE¼SW¼ sec. 2	R. O. Renfrew	....	Upland flat	3830	210	....	1.2	200.36	do.	do.	C,W	N	Water in sand.
193	SW¼SE¼NW¼ sec. 10	A. S. Cupp	1920	do.	3853	239	5	......	224.26	8-31-38	Ogallala	C,W	S	Water in gravel. Originally drilled 5 ft, into red beds.
194	SW¼SE¼SW¼ sec. 13	Renfrew Investment Co.	....	do.	3839a	255	3	0.3	249.77	do.	do.	C,W	D,S	Bottom on red clay. Waters 63 head of stock. Water level rose 2.96 ft. in 18 min. after pumping stopped.
195	S½SW¼SW¼ sec. 15	G. W. Grabeal	1927	do.	3870	268	5	0.6	252.15	do.	do.	C,W	D	Water in gravel, 252-268 ft.
196	SE¼SE¼NE¼ sec. 19	P. L. Ullom	....	do.	3898a	245	5	0.5	230.04	do.	do.	C,W	N	
197	SE¼SE¼NE¼ sec. 25	G. C. Twombly	....	do.	3834	315[5]	5	0.7	280.69	9-15-38	do.	C,W	D,S	Water in sand and gravel.
	T. 2 N., R. 8 E.—(Cont'd)													
198	SW¼SW¼SW¼ sec. 25	Ben Cox	....	do.	3854	320[5]	....	1.0	293.32	do.	do.	C,W	D,S	Water in sand and gravel.
199	SE¼SE¼SE¼ sec. 27	Clarence Husky	Old	do.	3849	286	....	1.0	273.59	do.	do.	C,W	D,S	
200[4]	NE¼NE¼NE¼ sec. 28	Plainview School	....	do.	3866	263	....	0.3	255.45	8-23-38	do.	C,W	P	Water in sand and gravel. Measured yield 1.6 gals. a min. and temp. 63° F. on 11-10-38.
201	SW¼SE¼SW¼ sec. 30	Mrs. Frank Cavis	Old	Upland flat	3875	204	4½	0.7	198.18	9- 2-38	Ogallala	C,W	S	Water in gravel?
202	SW¼SW¼SW¼ sec. 31	J. E. Husky	....	do.	3858	251	....	1.75	240.75	10-12-38	do.	C,W	S	Near breaks, 95 ft. above N. Can. R. channel, which is 1¼ mi. south.
203	SE¼NE¼SE¼ sec. 32	Mrs. M. F. Burrow	1913	do.	3863a	300[5]	4½	1.2	280	9- 2-38	do.	C,W	D,S	Water in coarse gravel, 290-300 ft.
204	SE cor. sec. 35	Gulf Oil Corporation	1942	do.	3854	6168	....	......	....	....				Cox No. 1 oil test well. See log.
	T. 2 N., R. 9 E.													
209	SW¼SW¼NE¼ sec. 2	J. W. Smalts	....	Flood plain	3648a	135	5	0.5	120.99	8-24-38	Ogallala	C,W	S	8 ft. above channel of ephemeral crk. Water in coarse gravel, 129-135 ft.
210	SW¼NW¼NW¼ sec. 3	C. A. Pugh	....	Upland flat	3780a	255	5?	0.7	240.65	8-23-38	do.	C,W	N	Measured eastern well. Water in gravel.
211	NE¼ SE¼ sec. 8	Floyd Cunningham	....	Slope	3738a	200	....	0.5	196	do.	Red beds	C,W	N	Water in gravel.
212	NE¼NE¼ sec. 17	W. W. Shields	....	Flood plain	3685a	156	4½	0.9	143.47	do.	do.	C,W	N	Water in sand and gravel.
213	SW¼SW¼NE¼ sec. 25	C. A. Twombly	....	Upland flat	3670	230	....	......	206	8-24-38	Ogallala	C,W	N	Water in gravel.
214	SW¼NW¼SW¼ sec. 33	Mrs. M. E. Crone	....	do.	3777	300[5]	4.0	0.3	270.52	do.	do.	C,W	D,S,P	Supplies part of water for Griggs School.
	T. 3 N., R. 1 E.													
217	SE¼ NW¼ sec. 8	Geo. E. Hincke	1939	Slope	4704	47	4½	......	21.00	4-21-39	Ogallala?	C,W	S	Pumps dry in 5 min.
218	SE¼ NW¼ sec. 8	Geo. E. Hincke	....	Creek bottom	4685	......	....	......	Sp.	4-21-39	Alluvium	....	.....	Permanent water hole; no flow.
219	SW¼SW¼SW¼ sec. 9	E. R. Morse	....	Upland flat	4802	185	5	1.7	178.25	4-26-39	Dakota?	None	N	Probably uncased.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
						T. 3 N., R. 1 E.—(Cont'd)								
220	NE¼SE¼SE¼ sec. 11	L. H. Snider	......	do.	4712	135	......	......	86.32	4-19-39	Ogallala	C,W	N	Compare no. 221.
221	SW¼NW¼SW¼ sec. 12	do.	......	do.	4712	239	6	......	187.3	do.	Dakota?	None	N	Compare no. 220.
222	SE¼SE¼SE¼ sec. 13	Wheeless School	1925	Upland flat	......	130[5]	4½	......	115[6]	......	Ogallala	C,W	D	Water in quicksand.
223	SE¼NE¼NE¼ sec. 19	E. C. Jones	......	do.	4821	180	4½	0.8	141.67	7-21-38	do.	C,W	D,Obs.	
224	NE¼SE¼SE¼ sec. 15	Walter R. Wood	......	do.	4744	156	5	2.7	140.94	do.	Dakota?	W	Obs.	
225	SE¼SW¼SE¼ sec. 13	F. S. Wood	......	Undulating upland	4690	133	5½	0.2	116.17	do.	Ogallala	C,W	D,S	Can water 100 head of stock.
226	SE¼SE¼SE¼ sec. 20	F. F. Bourk	......	Upland flat	4786	195	......	0.5	166.39	do.	Dakota?	C,W	N	
227[4]	NE¼NE¼NE¼ sec. 20	Mexhoma School	......	do.	4792	184	......	3.0	170.12	do.	do.	C,W	P	Yield very small. Measured temp. 60° F., 11-10-38.
228	SW¼SE¼SE¼ sec. 22	E. R. Sherrod	......	do.	4729	120	......	1.0	113.4	4-19-39	do.	C,W	N	
229	NW¼NW¼NW¼ sec. 22	F. F. Wood	......	do.	4765	173	4¾	0.6	152.16	do.	do.	C,W	D,S	
230	SE¼SE¼SW¼ sec. 23	H. B. Green	......	do.	4709	69	5	......	65.31	do.	Ogallala	None	N	
231	NE¼NE¼NW¼ sec. 25	do.	......	do.	4677	105	4½	0.7	93.75	9-16-38	do.	None	N	
232	NE¼NE¼NE¼ sec. 28	E. D. Phillips	......	do.	4757	167	......	0.5	117.49	4-19-39	do.	C,W	N	
233	SE¼ SE¼ sec. 28	Estella Wooten	1914	Dunes	4744	150	5¼	1.0	130.42	do.	Dakota?	C,W	D,S	Water in white sand rock, 150-155 ft.
234	SE¼SE¼SE¼ sec. 30	Everett W. Petro	......	Upland flat	4776	88	......	1.5	84.63	do.	Ogallala	C,W	N	Compare wells 223, 226, 235, and 236.
235	NW¼SW¼NW¼ sec. 30	American Nat'l Life Ins. Co.	......	do.	4845	225	5	0.5	200.37	11-16-38	Dakota?	C	N	
236	SW¼SW¼SE¼ sec. 31	H. B. Green	......	do.	4756	125	......	0.9	106	11-16-38	do.	C,W	S	Measured while pumping 2.5 gals. a min.
237	NE¼NE¼NE¼ sec. 36	Central Life Assurance Soc	......	Depression	4640	83	5	4.0	67.26	4-19-39	Ogallala	None	Obs.	
						T. 3 N., R. 2 E.								
240	SE¼SW¼SW¼ sec. 8	J. E. Benson	......	Upland flat	4634	185	......	0.7	160.27	7-21-38	Dakota?	C,W	D,S Obs.	
241	SE¼NE¼NE¼ sec. 2	L. C. Smith	......	do.	4518	140	......	0.6	131.18	4-24-39	do.	C,W	S	
242	SW¼SW¼SW¼ sec. 5	State of Oklahoma	......	do.	4642	175	......	0.3	164.28	do.	do.	C,W	N	
243	SE¼SE¼SE¼ sec. 12	W. A. McKnight	Old	do.	4507	156[5]	5½	......	128[5]	do.	Ogallala?	C,W	D,S	Water in gravel, 140-156 ft. Owner measured water level about 1-1-39. Plentiful supply.
244	NW¼NW¼NW¼ sec. 12	C. J. Bivens	1921	do.	4516	144	5	1.0	136.03	4-24-39	Dakota?	C,W	D,S	
245	SE¼NE¼SE¼ sec. 15	John Atkins	Old	do.	4562	153	6	2.0	137	do.	Ogallala	C,W	D,S	Measured while pumping.
246	SW¼SW¼SE¼ sec. 17	W. T. Rice	Old	do.	4625	166	5	......	125	do.	do.	C,W	D,S	Rept. 182 ft. deep, water in sand. Only upper part cased. Measured while pumping.
247	sec. 24	Fred Jenny	Old	do.	4501	113	4½	0.5	85.55	4-22-39	do.	C,W	D,S	
248	SW¼SW¼SW¼ sec. 28	State of Oklahoma	......	Dunes	4604	149	5	......	88.88	do.	do.	C,W	N	
249	SW¼SW¼SW¼ sec. 30	H. B. Green	......	Upland flat	4645	80	5	......	73.79	do.	do	None	N	
250	sec. 35	State Land Commission	Old	do.	4540	149	4	1.0	120	do.	do.	C,W	D,S	Measured while pumping.
						T. 3 N., R. 3 E.								
255[4]	SE¼SE¼SW¼ sec. 12	Guy W. Slack	1929	Upland flat	4342	120	5	0.7	98.33	11- 2-38	Ogallala	C,W	D,S	On east edge of dunes area. Water level rose 1.51 ft. in 15 min. after pumping stopped. Waters 10 head of stock.
256	SW¼SW¼SW¼ sec. 18	Lena Brown	......	Upland flat	4492	106	......	......	79.25	7-20-38	Ogallala	C,W	N	Water in gravel.
257	NE¼NE¼NE¼ sec. 34	Mrs. C. P. Lewis	......	do.	4396	134	4	3.2	108.62	11- 4-38	do.	C,W	D	
						T. 3 N., R. 4 E.								
261[4]	NW¼NW¼NW¼ sec. 10	Sandy View Con. Sch. Dist. 8	......	Upland flat	4279	182	5	1.0	174.34	10-20-38	Ogallala	C,W	P	Water in gravel. Measured yield, 1.2 gals. a min., water temp. 60.5° F., on 11-10-38.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
				T. 3 N., R. 4 E.—(Cont'd)										
262	SE¼SE¼SW¼ sec. 12	H. W. and Z. B. Stone	....	do.	4250	189	....	0.5	182.16	7-20-38	do.	C,W	D,S,Obs.	
263	SE¼SW¼SW¼ sec. 15	John Ohnich, Jr.	....	do.	4249	134	4½	3.2	129.03	7-21-38	do.	C,W	N,Obs.	Water in gravel.
264	NE¼NW¼NW¼ sec. 17	Ben Jameson	....	do.	4299	152	....	0.2	134.38	do.	do.	C,W	D,S	Water in "rock."
265	SE¼SE¼SE¼ sec. 29	Carrie Knopp	....	do.	4272	128	4½	1.6	114.58	10-22-38	do.	C,W	N	Water in gravel
266	NW¼NE¼NW¼ sec. 29	Carl D. Myers	....	do.	4286	150[5]	5	1.0	126.91	10-21-38	do.	C,W	D,S	Water in fine sand, 132-150 feet.
267	SW¼SW¼NW¼ sec. 30	Ernest Williams	....	do.	4315	144	6	1.0	138.44	10-22-38	do.	C,W	D,S	
268	SW¼SW¼SW¼ sec. 35	B. F. Houts	....	do.	4263	138	....	-5.0	119.82	do.	do.	C,W	D,S	Water in sand, 125-150 feet.
				T. 3 N., R. 5 E.										
273	SW¼SW¼SW¼ sec. 7	Ira D. Ralston	....	Upland flat	4229	177	....	0.5	174	7-20-38	Ogallala	C,W	N	
274	NE¼SE¼SE¼ sec. 8	C. Rollins	....	do.	4201	174	....	......	171.34	7-21-38	do.	C,W	D,S	Water in gravel.
275	NW¼ NW¼ sec. 11	O. A. Showalter	....	do.	4156	154	5	......	146.74	10-19-38	Ogallala	None	Obs.	
276	NW¼ SW¼ sec. 14	A. T. & S. F. R. R.	1931	do.	4144	173	6	0.5	134.02	7-20-38	Ogallala	C,W	S,Obs.	R. R. stockyard well at Boise City. Water in hard, tight sand 134-147 ft.; fine sand, 147-160 ft.; coarse sand 160-165 ft. See log. Reported 23.5 gals. a min. on test. Filled with gravel 163-173 ft.
277	SE¼SE¼SW¼ sec. 15	A. T. & S. F. R. R.	....	Upland flat	......	178	....	......	....	....	Ogallala	C,W	RR.	R. R. well No. 1 at Boise City. Supplies station house. Water in quicksand and sand 152-178 ft. See log.
				T. 3 N., R. 5 E.—(Cont'd)										
278[4]	SW¼ NW¼ sec. 15	Cimarron Utilities Co. (Boise City)	1926	do.	4163	167[5]	8	......	147[6]	....	do.	C,E,5	P	Company well No. 1. Reported yield, 20.8 gals. a min. Water temp. 61° F. on 11-9-38. See log 280.
279	SW¼ NW¼ sec. 15	do.	1927	do.	4163	176[5]	7	0.2	147.64	5-27-38	do.	C,E,5	P	Company well No. 2. Water in coarse sand. See log 280. Reported yield 20.8 gals. a min. 35-ft. sand screen.
280	SW¼ SW¼ sec. 15	do.	1928	do.	4163	382	....	......	147[5]	....	do.	A,E,15	P	Company well No. 3. Water in sand grading down into gravel, 150-212 ft. Reported yield, 111 gals. a min. with drawdown 9.2 ft. See log.
281	SW¼NW¼NW¼ sec. 11	O. A. Showalter	1931	do.	......	315[5]	5⅝	......	146[6]	....	Ogallala & Older	A,O	P,I,3	Water in sand, 147-207 ft.; in red beds between 207-315 ft. 7-in. casing to 208 ft., lower 63 ft. perforated; 5⅝-in. casing to 315 ft., perforated 230-315 ft. Supplies swimming pool. Reported yield 100 gals. a min., and drawdown 30-40 ft.
282	NE¼NW¼NW¼ sec. 20	Minnie Cook	....	do.	4227	172	....	......	160.04	7-23-38	Ogallala	C,W	Obs.	
283	NE¼ SW¼ sec. 22	C. O. Taylor	1928	do.	4173	195	5½	0.8	164.62	10-19-38	do.	C,W	D,S	Water in gravel.
284	SE¼NE¼NE¼ sec. 21	A. T. & S. F. R. R. (Boise City)	1931	do.	......	265	14	......	147[5]	....	do.	C,E,5	RR.	Supplies water for locomotives. Filled back from 273 ft. with 2.97 cu. yd. crushed rock. 14-in. casing to 161 ft., lower 10 ft. perforated. 5¾x64-in. cylinder at 170 ft. Reported yield 65 gals. a min. on test with 8 ft. drawdown. See log.
285	SE¼ NE¼ sec. 35	C. Scarbrough	....	do.	4144a	134	4½	......	123.58	10-19-38	do.	C,W	N	Water in sandstone.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
	T. 3 N., R. 6 E.													
291	NE¼NE¼NE¼ sec. 1	H. B. Nall	....	Upland flat	4019	97	....	0.4	93.21	10-15-38	Ogallala	C,W	D,S	Water in gravel.
292	SE¼SE¼NE¼ sec. 3	P. A. McLaughlin	1924	do.	4065a	117	5	2.0	105.52	do.	do.	C,W	D,S	Waters 4 head of stock.
293	NE¼SE¼NE¼ sec. 5	B. C. Bush	....	do.	4093a	125	....	1.0	122.39	do.	do.	C,W	D,S	
294	SW¼SW¼SW¼ sec. 12	Martha Moore	....	do.	4028	83	....	0.5	79.68	do.	do.	C,W	N	
295	SW¼NE¼SE¼ sec. 16	J. H. McMorran	....	do.	4067a	125	5	1.0	106.98	do.	do.	C,W	N	
296	SE¼SE¼SW¼ sec. 18	A. O. Pitzer	....	do.	4114a	130	5	0.3	121.97	10-14-38	do.	C,W	S	
297	SE¼SE¼SW¼ sec. 22	G. E. Tilton	Old	do.	4039a	113	6	0.3	99.72	10-15-38	do.	C,W	D,S	Water rose 11.78 ft. in 1 hr. after pumping stopped.
298	NW¼NW¼SW¼ sec. 25	Minnie L. Kimell	....	do.	4008a	119	4½	......	107.81	do.	Ogallala?	None	N	
299[4]	NW¼NE¼NE¼ sec. 27	Thomas Potts	Old	do.	....	160 [5]	....	......	100 [6]	....	Ogallala	C,W	D,S,P	Water for Garlington School. Measured yield, 1 gal. a min. Water temp. 59° F. on 4-18-39.
300	SW¼SE¼SW¼ sec. 28	James B. Curry	....	do.	4088	135	6	1.2	110.28	do.	Ogallala	C,W	D,S	Water in sandstone.
301	NE¼NE¼NE¼ sec. 30	Guy Lewis	....	do.	4106a	114	5	1.0	99.02	10-14-38	do.	C,W	D,S	
302	SW¼SW¼SW¼ sec. 31	T. J. Compton	....	do.	4131	137	....	0.5	119.33	do.	do.	C,W	D,S	Water in sandstone.
303	SE¼SE¼NW¼ sec. 36	Fred C. Aycock	1930	do.	4006a	172	....	1.0	152.03	10-15-38	Ogallala?	C,W	D,S	
	T. 3 N., R. 7 E.													
308[4]	NE¼NE¼NE¼ sec. 2	T. F. Phillips	Old	do.	3962	320 [5]	5	0.5	198.36	7-19-38	Red beds	C,W	D,S	1.75 mi. S. E. of Willowbar Lake. Measured yield 1.5 gals. a min., and temp. 61° F. on 11-10-38.
309[4]	NW¼NW¼NW¼ sec. 3	Mrs. Wesley Burch	1927	Hill on upland	3975	100	4½	......	74.09	7-18-38	Ogallala	C,W	D,S Obs.	2 mi. S. W. of Willowbar Lake. Measured yield 2 gals. a min. and temp. 62° F. on 11-10-38.
	T. 3 N., R. 7 E.—(Cont'd)													
310	NW¼NE¼NW¼ sec. 5	John Vannatta	1908	Upland flat	3996	94	6	0.3	78.11	9- 7-38	Ogallala	C,W	D	Water in gravel.
311	NW¼NW¼NW¼ sec. 8	W. D. Sanders	....	do.	4008a	110	....	0.5	78.25	9-13-38	do.	C,W	S	Water in sand.
312	NE¼ SE¼ sec. 9	E. L. Morford	....	do.	3994	126	....	......	81.45	9-14-38	Red beds	C,W	N	Poor well.
313	NW¼NW¼NW¼ sec. 9	E. J. Behrendt	1915	Slope	3954a	61	6	0.5	46.88	7-19-38	Ogallala	C,W	Obs.	Water in coarse sand and gravel, 50-67 ft. Mouth of well about 25 ft. above bottom of adjacent pond.
314	NE¼SE¼SE¼ sec. 13	Mrs. E. G. Israel	....	Upland flat	3944	274	....	0.7	182.83	9-14-38	Red beds	C,W	S	
315	NW¼NW¼NW¼ sec. 14	B. F. Aycock	1906	do.	3992	296	4½	0.5	223.16	do.	do.	C	N	Water in gravel.
316	SW¼SW¼NE¼ sec. 18	G. W. Marsh	1918	do.	3999a	75	5	1.0	67.61	9-13-38	Ogallala	C,W	D,S	Water tastes bad.
317	NE¼SE¼NE¼ sec. 19	Elmer Isom	....	Slope	3958	101	5	1.5	95.61	9-14-38	do.	None	N	
318	SW¼SW¼NE¼ sec. 25	Gladys Belle Oil Co.	1926	Upland flat	3592	428 [5]	....	......	220 [5]	....	Red beds	None	N	Supplied drilling water for 318-a. Water in sand, 420-428 feet. See log.
318-a	SW¼SW¼NE¼ sec. 25	do.	1926	do.	3592	4,392	....	......	....	....	....	None	N	Oil test, Israel No. 1. See partial log.
319	NW¼NE¼NW¼ sec. 29	W. D. Sanders	....	do.	3985a	162	5	0.3	152.06	9-14-38	Red beds	C,W	D,S	Water level rose 1.37 ft. in 40 min. after pumping stopped.
320	SE¼SW¼SE¼ sec. 31	C. A. Parker Est.	1907	do.	3976	143	6	......	137.98	10-13-38	Ogallala	C,W	D,S	Water in gravel.
321	SE¼SE¼SE¼ sec. 32	P. G. Steinberger Est.	1910	do.	3944	135	....	0.3	128.30	9-14-38	do.	C,W	D,S	
	T. 3 N., R. 8 E.													
327	NE¼NW¼NE¼ sec. 2	Stella McBride	Old	Upland flat	3864	253	....	0.3	156	8-30-38	Red beds	C,W	D	Water in sandstone. Water level rose 1 ft. in 15 min., although well had not been pumped for 3½ hrs.
328	SE¼SE¼NE¼ sec. 7	L. G. Miles	1920	Upland flat	3931a	300+	....	......	185.19	8-29-38	Red beds	C,W	S, Obs.	Poor water, in gravel.
329	SW¼SE¼SW¼ sec. 17	Virgil A. Nickell	....	do.	3922a	145	....	......	128.27	do.	do.	C,W	N	
330	NW¼NW¼NW¼ sec. 25	Marvin Reeves	Old	do.	3811a	206	....	0.3	199.27	do.	Ogallala	C,W	N	Water in gravel.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
						T. 3 N., R. 8 E.—(Cont'd)								
331[4]	SE¼SE¼SE¼ sec. 27	Frank Outhier	....	do.	3845a	242	5½	0.2	209.57	do.	Red beds	C,W	D,S	Poor water from red gravel. Water level rose 8.38 ft. in 1 hr. after pumping stopped, and 2.87 ft. more in an additional 15 hours and 40 min. Water temp. 61° F., on 4-15-39.
						T. 3 N., R. 9 E.								
337[4]	NW¼SW¼NW¼ sec. 13	Roy Hanes	1916	do.	3694a	198	6	......	182.35	8-25-38	Ogallala	C,W	D,S,P	Water in shale. Water for Midwell school. With pumpjack has supplied enough water for 500 head of stock. Measured yield 1 gal. a min., and water temp. 64° F. on 4-15-39.
338	SW¼SE¼NE¼ sec. 14	Federal Land Bank	Old	do.	3694a	210	....	0.3	183.50	7-16-38	do.	C,W	Obs.	
339[4]	NE¼NE¼NE¼ sec. 16	A. M. Payne	1917	do.	3789a	206	....	......	174	8-22-38	Red beds	C,W	D,S	Water level rose 1 foot during measurement although well had not pumped for 1 hr. or more. Measured yield 0.5 gal. a min., and temp. 62° F. on 11-10-38. In red beds.
340	NW¼NW¼NW¼ sec. 19	W. S. Spence	1910	do.	3817a	162	5	0.8	157.81	do.	Ogallala	C,W	D,S	Water in coarse sand and gravel 158-164 ft. Rept. 7 gals. a min. pumping with engine.
341	SW¼NW¼SW¼ sec. 25	J. S. Smalts	....	do.	3703a	273+	....	......	207	do.	do.	C,W	N	
						T. 3 N., R. 9 E.—(Cont'd)								
342	SW¼NE¼NW¼ sec. 27	J. W. Klaverweiden	1917	do.	3785a	300[5]	6	0.4	265.63	do.	Red beds	C,W	D,S	Water in red shale? 6-in. galv. iron casing to 200 ft., rest open hole. Water level rose 3.27 ft. in 35 min. after pumping stopped.
343	SW¼NE¼NE¼ sec. 31	Mary Schaffer	....	do.	3772a	243	4½	0.8	229.96	8-23-38	Ogallala	C	N	
344	SE¼NE¼NE¼ sec. 2	Bert McCracken	....	Upland flat	3711	300+	------	......	231.4	6-30-39	Red beds	C,W	S	
						T. 4 N., R. 1 E.								
346	NW¼ NE¼ sec. 9	State of Oklahoma	....	Slope	....	69	5	......	55.21	4-27-39	Cheyenne?	C,W	N	
347	NW¼ NW¼ sec. 9	John Regnier	....	do.	....	14	22	......	12.14	do.	Alluvium	C,W	S	Dug well, 13½ ft. above crk. channel.
348	NE¼ NE¼ sec. 13	Lucy Skelley	....	Flood plain	....	35	6	0.5	22.05	4-26-39	Dakota	C,W	D	Rept. 44 ft. deep, cased only to 28 ft.
349	NW¼ NW¼ sec. 14	do.	....	Canyon	....	90	6	......	77.09	do.	do.	C,W	S	Only first 10 to 20 ft. cased.
350	SW¼SW¼NE¼ sec. 22	Segregated Oil Co.	1918	....	3500	2,030	15½	......	---- ----	....	....	None	N	Oil test, state land No. 1. Water in sand 200-210 ft. See log.
351	SW¼ NW¼ sec. 25	Joe Brown	....	Slope	....	158	6	2.0	40.73	4-26-39	Cheyenne?	C,W	D	Irrigates orchard.
352	NE¼ SE¼ sec. 26	Joe Brown	....	Flood Plain	....	54	6½	2.0	20.55	4-26-39	Alluvium?	C	N	
353	SE¼ SE¼ sec. 32	C. A. Kirtley	1919	Slope	4603	57	12	1.5	10.78	4-26-39	Cheyenne? Dakota	C,W	D	Cased only to depth of 7 ft.
354	sec. 33	do.	....	Flood plain	....	19[5]	....	1.0	16.76	do.	Alluvium	C,W	N	Dug well, walled with rock.
355	SE¼ sec. 34	W. R. and W. E. Ramsey	1928	------	....	4,306	20 to 5	......	---- ----	-------	....	None	N	Oil test, State school land No. 1-D. Water in white sand, 175-205 ft. See partial log.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
					T. 4 N., R. 2 E.									
358	E½ sec. 8	R. Wright		Creek bottom					Sp.	4-19-39	Dakota		S	Estimated flow, 12-15 gals. a min.
359	SE¼ sec. 8	do.		Flood plain		37		0.6	14.15	4-25-39	Dakota	C,W	D,S	Drawdown, 3 ft. at 4 gals. a min.
360	SW¼SW¼SW¼ sec. 15	State of Oklahoma		Slope		129	5	0.5	41.83	do.	Dakota	C,W	S	
361	NE¼ NW¼ sec. 28	....		Slope		126		0.7	68.36	do.	Dakota	C,W	S	Uncased.
362	NE¼ NE¼ sec. 36	State of Oklahoma	Old	Flood plain		71	5	1.0	64	4-24-39	Ogallala?	C,W	S	Measured while pumping.
					T. 4 N., R. 3 E.									
363	SE¼ NW¼ sec. 8	OTO Ranch		Flat		187	4¾	1.0	152.42	4-18-39	Dakota?	C,W	S	
364[4]	SW¼ sec. 12	J. L. Donley	1938	Gentle slope		205	4½	1.3	0.49	9-26-38	Dakota & Cheyenne	flows	S	4½-in. casing to 164 ft., open hole 164-205 ft. Measured yield 3.5 gals. a min. Water temp. 67.5° on 11-13-38. See log.
365	SE¼ SE¼ sec. 15	J. L. Donley		Slope		90	5¼	0.5	44.63	4-18-39	Dakota	C,W	S	
366	NW¼ SW¼ sec. 22	OTO Ranch		Creek terrace		66			34	4-18-39	Dakota?	C,W	S	Water level measured while pumping about 3 gals. a min.
367	NW¼ NE¼ sec. 23	Guy W. Slack		Creek bottom			5			do.	Dakota or Cheyenne	Flows	S	Measured flow, 4 gals. a min.
368	NE¼ NE¼ sec. 28	OTO Ranch		do.					Sp.	do.	Dakota		S	Measured flow, 20 gals. a min.
369	SW¼ NW¼ sec. 32	OTO Ranch		do.	4384	67	4½	3.0	23.47	do.	Ogallala?	C,W	S	
					T. 4 N., R. 4 E.									
370	NE¼SW¼NW¼ sec. 1	J. G. Holden		do.		51	10-12	1.0	48.59	10-20-38	Dakota	C,W	N	Uncased.
371	NE¼ sec. 4	J. A. James		Creek					Sp.	do.	do.		S	Measured yield 12.5 gals. a min.
372	SW¼ sec. 4	do.		do.					Sp.	do.	do.		S	Measured yield 12 gals. a min. Water temp. 58° F. on 10-20-38.
373[4]	NE¼ NW¼ sec. 4	do.		Ss. cliff					Sp.	do.	do.		D,S	Measured yield 5.5 gals. a min and water temp. 62° F. on 11-11-38.
374[4]	NW¼ sec. 5	....		Ravine					Sp.	11-13-38	Dakota		S	Estimated yield, 12 gals. a min.
375	SE¼ NE¼ sec. 7	J. L. Donley		Creek					Sp.	11-13-38	Dakota?			Estimated yield 15 gals. a min.
376	SE¼ NW¼ sec. 8	do.	1938	Slope		144	5	0.6	20.81	do.	Dakota & Cheyenne			21 ft. above channel of Cold Springs Arroyo. See log.
377	SE¼SW¼SW¼ sec. 22	Neal D. Adee		Upland flat	4307	217	4½	1.0	185.18	10-21-38	Ogallala?	C,W	N	
378	NE¼NE¼NW¼ sec. 22	do.		do.	4326	270[5]		1.5	227.74	10-20-38	Dakota?	C,W	S	
379[4]	NW¼NW¼NW¼ sec. 23	M. M. Adee	1910	do.	4315	116	4½		97.92	do.	Ogallala	C,W	D	Water temp. 60° F. on 4-14-39.
380	NW¼SW¼NW¼ sec. 25	Adah Seehler et al		do.	4265a	200	5	1.0	190.82	10-21-38	do.	C,W	N	
381	SE¼ SE¼ sec. 31	Geo. E. Smith		do.	4306	173	5	0.4	164.20	do.	do.	C,W	N	
382	NW¼NW¼NW¼ sec. 33	H. B. Dixon	1915	Upland flat	4303	206		1.0	192.60	10-21-38	Ogallala	C,W	D,S	Water rose 2.02 ft. in 1 hr. after pumping stopped
383	NW¼NW¼NW¼ sec. 35	E. E. Ralston		do.	4279	200		1.5	193.70	10-20-38	do.	C,W	N	
					T. 4 N., R. 5 E.									
384	NW¼NW¼SW¼ sec. 13	R. A. Godown		do.	4159a	174			155.56	7-22-38	Ogallala?	C,W	Obs.	
385[4]	NW¼NW¼NW¼ sec. 15	H. A. Schneider		do.	4209	215	5.	0.2	127.92	10-18-38	Cheyenne	C,W	D,S	Measured yield 1.3 gals. a min., 11-17-38.
386	SW¼SW¼SE¼ sec. 25	Alpha I. Baker		do.	4142	155	6	0.4	149.46	do.	Ogallala?	None	N	
387	SE¼SW¼SE¼ sec. 28	F. M. Tudor		do.	4190	178		1.0	171.06	7-22-38	do.	C,W	D,Obs.	
388	SW¼SW¼SW¼ sec. 31	B. Eubanks		do.	4218a	175		0.3	170.51	10-18-38	Ogallala	C,W	N	
389	NW¼NW¼NW¼ sec. 31	A. D. Stassi		do.	4219a	170			163.11	do.	do.	C,W	N	
390	Near cent. sec. 32	J. M. Kincannon		do.	4201a	175	4	1.3	164.4	do.	do.	C,W	S	

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
	T. 4 N., R. 6 E.													
393	SW¼NW¼SE¼ sec. 1	Wm. S. Sellers	....	Upland flat	4065a	190	....	0.2	186.14	9-13-38	Ogallala	C,W	N	
394	SW¼SW¼SE¼ sec. 7	Geo. W. Snodgrass	....	do.	4127a	187	....	......	166.95	10-17-38	do.	C,W	N	
395	SW¼SW¼SW¼ sec. 10	John Huck	....	do.	4092	180	....	1.0	165.4	do.	do.	C,W	N	
396	NE¼SE¼SE¼ sec. 11	Excelsior School, Dist. 20	....	do.	4071	182	4½	0.8	170.14	do.	do.	C,W	N	School transferred.
397	SW¼NW¼SW¼ sec. 20	Lynn T. Miller	....	do.	4123a	169	4½	......	156.07	do.	do.	None	N	
398	SE¼SW¼SW¼ sec. 24	Central Life Assurance Soc.	....	Undulating upland	4041a	123	....	......	113.94	7-19-38	do.	C,W	S,Obs.	¾ mi. SE of Castor Lake.
399	NE¼SE¼NE¼ sec. 29	John F. Graham	....	Upland flat	4096a	137	....	......	132.31	10-17-38	do.	C,W	N	
400[4]	SW¼ SW¼ sec. 31	Bruce Wood	1910	Upland flat	4122a	149	5½	0.8	135.24	7-20-38	Ogallala	C,W	D,S	Reported 169 ft. deep, water in sand 140-169 ft. Measured yield, 1½ gals. a min., water temp. 60° F., on 4-18-39.
	T. 4 N., R. 7 E.													
403	SE¼SE¼SE¼ sec. 6	Floyd Music	1903	Upland flat	....	196[5]	5	......	189[5]	....	Ogallala	C,W	D,S	Water in coarse gravel.
404	NW¼NE¼NE¼ sec. 10	T. F. Phillips	....	do.	3981	172	4	......	157.56	9-13-38	do.	None	N	
405	SW¼SW¼SE¼ sec. 12	Otis R. Slimp	....	do.	3945	206	4½	13.7	147.90	8-22-38	do.	None	N	A. T. & S. F. R. R. test No. 4 at Keyes. Water in sand. See log. Well appears to have collapsed at 182 ft. Depth to water below land surface 134 ft.
	T. 4 N., R. 7 E.—(Cont'd)													
406[4]	SE¼SE¼SW¼ sec. 12	A. T. & S. F. R. R.	1928	do.	3945	203	14	......	133[6]	....	do.	C,E,15	RR,P	A. T. & S. F. R. R. well No. 2 at Keyes, supplies town. Water in coarse sand, 146-154 ft. and 178-185 ft. See log. 14-in. casing to 199 ft. perforated 139-189 ft. Gravel walls 10-in. thick. Double acting cylinder, 7¾x80-in. Reported yield on test, 90 gals. a min., with 10-feet drawdown. Normal yield about 70 gals.a min.
407	NW¼NE¼SE¼ sec. 13	A. T. & S. F. R. R.	....	do.	3938	289	6	......	137[5]	....	do.	None	N	A. T. & S. F. R. R. well No. 1 at Keyes. Dynamite shot raised bottom to 182 ft. Water in sand and joint clay, 155-165 ft. See log. 14-in. casing 20-127.5 ft.; 10″ casing, 0-159 ft., with 22.5 ft. strainer on end; 6-inch casing, 0-168 ft. Well was equipped with 4¾x36-in. cylinder set at 171 ft. and yielded average of 20 gals. a min. for construction use. At 45 gals. a min., water level lowered below strainer. Abandoned.
408	SE¼ SE¼ sec. 13	A. T. & S. F. R. R.	....	do.	3923	196	....	......	135[5]	....	do.	None	N	Railroad test No. 1 at Keyes. Water in sand and joint clay, 135-169 ft. Red beds at 169 ft.
409	SW¼SW¼SW¼ sec. 13	L. L. Slimp	....	Upland flat	3941	174	....	......	120.5[5]	....	Ogallala	......	N	A. T. & S. F. R. R. test No. 2 at Keyes. Water in sand and clay, 120-172 ft. Red beds, 172-174 ft. See log.
412	NW¼NW¼NW¼ sec. 18	H. J. Froning	....	do.	4047	171	5	......	162.67	9-13-38	do.	C,W	N	
413	SW¼SW¼NW¼ sec. 19	Lloyd H. Booth	....	do.	4038a	149	5	......	135.30	do.	do.	C,W	N	
414	Cent. SE¼ sec. 22	A. E. Buck	Old	Flat near lake	....	120[5]	8	......	74	8-22-38	do.	None	N	

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
						T. 4 N., R. 7 E.—(Cont'd)								
415	NW¼ SW¼ sec. 23	do.	Old	do.	3926	76	6	1.4	75.95	do.	do.	None	Obs.	Originally 96 ft. deep.
416	NW¼NW¼NE¼ sec. 24	do.	1927	Upland flat	....	165[5]	8	......	....	....	do.	C,E,1.5	D,P	Water in gravel, 136-165 ft. Water for Keyes school and neighbors.
417	SW¼NW¼NW¼ sec. 27	Frank Conner	1907	do.	....	100[5]	6	......	90[5]	....	do.	C,W	D	Water in sand. Has watered 100 head of stock.
418	NW¼NW¼NW¼ sec. 29	T. F. Phillips	Old	do.	4009a	128	....	......	112.89	7-19-38	do.	C,W	S,Obs.	
419[4]	SW¼SW¼SE¼ sec. 29	Mrs. Lewis Bruning	1922	do.	3985a	103	4	0.7	89.70	9-13-38	do.	C,W	D	Water in sand and gravel. Water temp. 60° F., 4-18-39.
420	NE¼SE¼NW¼ sec. 30	Hazel Vannatta	1913	do.	4010a	109	6	0.3	106.30	9- 7-38	do.	C,W	D,S	
421	SW¼NW¼SW¼ sec. 32	R. M. Vannatta	1912	Upland flat	4006	100	5	......	90.85	9- 7-38	do.	C,W	D,S	
						T. 4 N., R. 8 E.								
428	NE¼NE¼NE¼ sec. 3	Joe E. Barrick	....	Hill on upland	3905	205	....	1.2	194.43	8-27-38	Ogallala	C,W	D,S	
429	SW¼SE¼SW¼ sec. 5	T. F. Phillips	....	Upland flat	3906a	167	....	......	153.39	do.	do.	C,W	D,S	
430	SW¼SW¼SE¼ sec. 11	C. F. David	1913	Undulating upland	3875a	176	4	0.8	140.73	8-29-38	do.	C,W	D,S	Water in gravel?
431	SE¼NE¼NE¼ sec. 15	Clara A. Curlis	....	Hill on upland	3882a	160	5½	1.0	151.07	do.	do.	C,W	N	
432	NW¼NW¼NW¼ sec. 17	W. A. Harriman	1917	Upland flat	3908a	163	....	......	146.97	do.	do.	C,W	D	Water in gravel, 162-165 ft.
433	NW¼ NE¼ sec. 18	T. C. Schneider	....	do.	3910	207	....	......	144[5]	....	do.	None	N	A. T. & S. F. R. R. test No. 3 at Keyes. Water in sand and gravel, 192-206 ft. See log.
434	NW¼NW¼NW¼ sec. 19	W. A. Miller	Old	do.	3926	144	....	......	124.86	8-29-38	do.	C,W	D,S	Waters 5 head of stock.
435	SW¼SW¼SW¼ sec. 26	B. J. Wiggins	....	do.	3878a	213	....	0.5	138.08	7-18-38	Red beds	C,W	Obs.	
436	NE¼NE¼NE¼ sec. 32	Mrs. S. C. Cantrell	....	do.	3905a	296	4¼	......	153.06	do.	do.	None	Obs.	
						T. 4 N., R. 8 E.—(Cont'd)								
437	NE¼NE¼NE¼ sec. 20	W. W. Wiggins	....	do.	3908a	212	5½	......	156.44	do.	Ogallala	C,W	D,S	Water in medium gravel, 206-212 ft. Reported a weak well.
438	SW¼SW¼NE¼ sec. 20	do.	1940	do.	....	550[5]	12,10&8	......	180.93	11-17-41	do.	T,G	N	Water in gravel at 180 ft., sand rock at 230 ft. Red beds at 240 ft. 12-in. casing, 0-230 ft., perforated 115-230 ft.; 10-in. casing, 230-310 ft., all perforated; 8-in. casing, 310-550 ft., perforated 490-550 ft. Rept. yield, 250-300 gals. a min., inadequate for intended irrigation.
						T. 4 N., R. 9 E.								
441	NW¼SW¼NW¼ sec. 6	Charles Mobray	....	do.	3850a	191	....	2.5	172.62	8-20-38	Red beds	C,W	N	Water in thin sandstone at 191 ft. Seep in red beds, 160-165 ft.
442	SE¼SE¼NE¼ sec. 8	W. H. Spradlin	....	do.	3790a	226	6	0.5	204.73	do.	do.	C,W	D,S	Water in soft material, 225-229 ft.
443	SE¼SE¼NE¼ sec. 10	Charles Burkett	....	do.	3751a	236	....	......	224.63	do.	do.	C,W	N	
444	NE¼SE¼NE¼ sec. 11	T. P. Wason	....	do.	3736a	268	....	0.3	217.8	8-19-38	do.	C,W	D,S	
445	NW¼NW¼NE¼ sec. 13	John T. Jackson	....	do.	3715a	234	....	0.3	200.67	do.	Ogallala and red beds	C,W	N	
446[4]	SW¼SW¼NW¼ sec. 22	N. W. Ford	....	Upland flat	3767a	273+	....	0.5	232.19	8-20-38	Red beds	C,W	D,S,P	Water for Lone Star Sch. Dist. 31. Measured yield 1.8 gals. a min., and water temp. 61° F., on 11-9-38.
447	NE¼NW¼NE¼ sec. 26	T. M. Brydon	....	do.	3725a	273+	....	......	214.75	8-19-38	do.	C,W	N	
448	SE¼SW¼SW¼ sec. 32	Geo. L. Leppert	....	do.	3833	273+	....	1.1	253.09	8-23-38	do.	C,W	N	

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M.P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
						T. 5 N., R. 1 E.								
453	SW¼ sec. 2	Marcia B. Malm	....	Flood plain	....	28	5	1.5	18.81	4-27-39	Alluvium	B	D	
454	NW¼ sec. 4	Myrtle Tharp	Old	do.	....	35	6	1.3	27	4-28-39	do.	C,W	D,S	Measured while pumping. Water in sand and gravel, very hard, leaves white crust.
455	SW¼ sec. 8	T. J. Wiggins	....	Low hill	....	32	....	1.0	26	4-27-39	Morrison ?	C,W	D,S	Measured while pumping occasionally.
456	NE¼ sec. 9	R. J. Davidson	....	Slope	....	72	6	1.5	44.20	do.	Morrison	C,W	S	Water at 60 ft. in "soapstone."
457	SE¼ NW¼ sec. 9	R. J. Davidson	1903	Terrace	....	56	6	0.5	30.52	4-27-39	do.	C,W	D	Rept. 103 ft. deep.
458	NE¼ sec. 13	Geo. Wiggins	....	Slope	....	340[5]	5	0.7	27	do.	do.	C,W	D	Poor water; leaves white crust.
459	NE¼ sec. 13	do.	....	Flood plain	....	16	36	1.0	14.48	do.	Alluvium	C,H	D	Dug well.
460	SW¼ NW¼ sec. 16	Mrs. Andrew Drennon	....	Terrace	....	77	6	......	44.92	4-13-39	Morrison	C,W	D	Uncased. Water good, soft.
461[4]	SE¼ NW¼ sec. 16	Kenton School	1927	do.	....	80[5]	6	......	45[6]	....	do.	C,W	P	Water temp. 61° F., 4-13-39.
462	NE¼ NE¼ sec. 17	G. L. Bivens	....	Flood plain	....	90	4	......	15.7	4-28-39	Alluvium ? Morrison ?	C,W	D	Water soft, but leaves white crust.
463	SW¼ NW¼ sec. 26	....	....	do.	....	17	42	......	15.92	4-27-39	Alluvium	None	N	Dug well, walled with stone.
464	E½ sec. 35	Lucy Skelley	....	Canyon bottom	....	55	6	1.2	16.37	4-26-39	Morrison	C,W	S	
						T. 5 N., R. 2 E.								
468	SW¼ sec. 1	J. A. Whittenburg Est., (Walker Ranch)	....	Slope	....	69	6	1.0	31.	11-16-38	Morrison	C,W	D,S	700 ft. SE of Cimarron River and 20 ft. above it. Water rept. alkaline. Measured while pumping.
469[4]	SW¼ sec. 1	J. A. Whittenburg Est., (Walker Ranch)	....	Slope	....	96[5]	....	......	....	....	Exeter	C,W	S	About 15 ft. above Cimarron R. A weak well. Water in variegated shale between 46 and 96 ft., and in coarse sand rock at 96 ft.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M.P. (feet)	Below M. P. (feet)	Date Measured	Probable Aquifer	Method of lift	Use of water	Remarks
						T. 5 N., R. 2 E.—(Cont'd)								
470	SE¼ NE¼ sec. 7	A. C. Easley	Old	Flood plain	....	102	6	0.5	37	4-27-39	Alluvium and ? Morrison	C,W	D,S	Measured while pumping slowly. Cased only to depth of 20 ft.
471	SE¼ SE¼ sec. 8	Mrs. J. N. VanLeer	....	Canyon	....	......	....	......	6 Sp.	4-28-39	Dakota	....	D,S	Measured yield, 7 gals. a min.
472	NE¼ NE¼ sec. 22	Sinclair Oil & Gas Co.	1928	Slope	....	4,872[5]	15½ to 5-3/16	......	....	....	....	....	......	Oil test.
473	NE¼NW¼NE¼ sec. 25	Frank Yunker	....	Gentle slope	....	39	5½	0.5	12.10	4-27-39	Dakota	None	N	
474	SW¼ SW¼ sec. 28	G. A. Whittenburg	....	Flood plain	....	23	36	......	21.65	4-25-39	Alluvium	None	N	Dug well walled with rock.
475	NW¼ SW¼ sec. 28	do.	....	Gulch	....	......	....	......	Sp.	do.	Dakota	....	S	Estimated yield, 3 gals. a min.
476	SW¼ sec. 30	Thomas E. Jones	....	Flood plain	....	14	60	......	11.87	4-28-39	Alluvium	C	N	Uncased dug well.
477	SE¼ sec. 31	do.	....	Canyon	....	......	....	......	2 Sp.	4-25-39	Dakota	....	N	Estimated yield, 1 to 3 gals. a min.
478	SW¼ sec. 32	Rufus Wright	....	do.	....	......	....	......	2 Sp.	do.	do.	....	S	Estimated yield, 3 to 5 gals. a min.
479	SW¼ SW¼ sec. 32	do.	....	Flood plain	....	50	6	0.7	15.04	do.	Alluvium ?	C,W	D	
480	NW¼NW¼NW¼ sec. 14	State of Oklahoma	....	Gentle slope	....	150+	4	......	Flow	11-17-41	Exeter	....	N	Core hole, water rept. from Exeter at 150 ft. Sulfate, 4800 p. p. m.
						T. 5 N., R. 3 E.								
484	SW¼ SE¼ sec. 12	....	....	Canyon	....	......	....	......	Sp.	11-11-38	Dakota ?	....	S,I,9	Estimated yield 50 gals. a min.
485	SW¼ NW¼ sec. 26	State of Oklahoma	....	flat	....	122	6	2.0	113.87	5-10-39	do.	C,W	S	
						T. 5 N., R. 4 E.								
490	NE¼ SE¼ sec. 1	....	....	Flood plain	....	46	6	......	17.55	9-29-39	Alluvium	C,H	N	15 ft. above Cimarron R. channel.
491	NE¼ NW¼ sec. 3	....	....	Slope	....	45	4	0.3	36.62	9-30-39	Cheyenne or Morrison	None	N	Dug well, walled with stone; 16 ft. above channel of Cimarron R. Water in gravel. Water temp. 58° F., 4-14-39.
492[4]	SW¼ sec. 6	H. G. Willson	1907	Flood plain	....	18	20	2.0	15.43	11-11-38	Alluvium	B	D	Dug well walled with stone; 16 ft. above channel of Cimarron R. Water in gravel. Water temp. 58° F., 4-14-39.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M.P.[1] (feet)	WATER LEVEL Below M.P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
						T. 5 N., R. 4 E.—(Cont'd)								
493	NW¼ NE¼ sec. 11	Julius Kohler	....	do.	....	23	6	0.5	10.71	9-30-39	Alluvium	C,W	N	
494	NE¼ sec. 17	....	....	Ravine	....	......	....	......	Sp.	11-11-38	Dakota?	....	S	Measured yield, 2 gals. a min.
495[4]	NW¼ NE¼ sec. 21	Geo. W. Gillis	....	Slope	....	......	....	......	Sp.	do.	Dakota	....	D,S	Improved spring, yield small, estimated 1 to 5 gals. a min. Water temp. 55° F., 11-11-38.
496	SW¼ SW¼ sec. 22	Mrs. Dorsey Sparkman	....	Slope	....	83	36 & 6	0.5	23	4-14-39	Cheyenne	C,W	D,S	A dug well 36 inches in diameter to depth of 23 ft., walled with stone; drilled 6 in. diameter, 23 ft. to 83 ft.
497	SW¼ sec. 29	Rex Powelson	....	do.	....	......	....	.....	Sp.	....	Dakota?	....	S	Rept. yield 10 gals. a min.
498	NW¼ sec. 29	do.	....	Gulch	....	......	....	.....	Several Sp.	....	Dakota	....	S,I	Dam impounds flow, rept. as 60 gals. a min. before drought.
499	NW¼ sec. 29	do.	....	Slope	....	......	....	......	Sp.	....	do.	....	D	Improved spring. Rept. yield 2½ gals. a min. before drought; reduced to 1½; water temp. 59° F., 11-19-38.
500	SE¼ sec. 12	D. Eiland	1940	Flood plain	....	26	10½	-2.0	9.27	11-26-40	Alluvium	C,G	I,1+	Dug well. Destroyed 1941.
						T. 5 N., R. 5 E.								
503	NW¼ SE¼ sec. 35	Barnsdall Oil Co.	1938	Slope	4048	5503	....	......	---- ----	....	....	None	N	Oil test, school land No. 1. Begins on Morrison. No water reported. See partial log.
504	NE¼ sec. 4	G. F. Mabry	....	Slope	....	76	6	1.0	24.25	7-29-37	Morrison	C,H	N	
505[4]	S½ SE¼ sec. 4	B. N. North	1932	Flood plain	....	13	7	0.5	7.16	7-22-38	Alluvium	C,W	S	Dug well. 0.45 mi. N. of Cimarron R. Water in sand, 7-17 ft. Water temp. 57° F. 4-13-39.
						T. 5 N., R. 5 E.—(Cont'd)								
506	do.	do.	....	Terrace	....	16	48	......	12.60	do.	do.	None	Obs.	Dug well, walled with rock. At NE cor. of farm house. Water in sand.
507[4]	SW¼ sec. 12	Mrs. J. Martin Ford	Old	Flood plain	....	15	60	0.75	11.21	do.	do.	C,W	S,I,1	Dug well, walled with rock. Water in sand. Measured yield, 3 gals. a min.
508	NE¼SW¼SW¼ sec. 21	W. R. and W. E. Ramsey	1928	....	3996	4,360[5]	15½ to 6⅝	......	....	....	....	None	N	Oil test, School land A-2.
509	SE¼SE¼NE¼ sec. 22	Magnolia Petroleum Co.	1929	....	....	4,356	20 to 8⅝	......	....	....	....	do.	N	Oil test, School land 11-A. Water in sand 25-34 ft. See partial log.
510	SW¼SW¼NW¼ sec. 22	Empire Gas & Fuel Co.	1917	....	....	1,583	20 to 12½	......	....	....	....	do.	N	Oil test, School No. 1. Water in sand, 542-552 ft. See log.
511	NW¼ NE¼ sec. 27	W. R. and W. E. Ramsey	1928	....	3939	4,681[5]	20 to 5 3/16	......	....	....	....	do.	N	Oil test. State land No. 1.
512	SE¼SW¼NE¼ sec. 27	Magnolia Petroleum Co.	1930	....	....	4,758[5]	20 to 8⅝	......	....	....	....	do.	N	Oil test, School land No. 33.
513[4]	NW¼ sec. 32	Flag Spring	....	Creek	....	......	....	....	Sp.	10-18-38	Dakota	....	N	Measured yield, 7 gals. a min. and temp. 52° F. on 10-18-38.
514	SE¼ SE¼ sec. 34	State of Oklahoma	....	Creek bottom	....	......	....	....	Sp.	....	Alluvium?	....	S	A permanent water hole. No visible flow, but furnished water for drilling oil well.
515	NW¼NW¼ sec. 36	State of Oklahoma	....	Slope	4001a	106	4	....	39.17	7-22-38	Dockum	C,W	S	
516	SE¼ SE¼ sec. 34	....	1938	Slope	....	103	9	1.6	8.02	8- 5-39	do.	None	Obs.	Uncased. Rept. yielded 16 gals. a min. on test. Water level fluctuates widely.
517	NW¼ sec. 17	Julius Kohler	1939	Slope	....	79	....	0.8	74	5-18-40	Morrison	C,W	S	Water level measured while pumping about 4 gals. a min.
518	NW¼ sec. 18	S. Strong	1933	Terrace	....	93[5]	8	......	27	....	do.	C,W	D,S,I	Rept. yield 10 gals. a min.
518-a	do.	do.	1928	do.	....	113[5]	8	....	26	....	do.	C,W	S,I	Rept. yied 7 gals. a min. (max.); water alkaline.

T. 5 N., R. 6 E.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
519	NW¼ SW¼ sec. 3	T. D. Burnett	....	Flood plain	....	10	....	......	6	7-28-39	Alluvium	C,W	S	Measured while pumping. Rept. water level, 5 ft.
520	SE¼ SE¼ sec. 4	W. R. and W. E. Ramsey	1927	....	3830	4,200	20 to 5 3/16	......	....	....	....	None	N	Oil test, state No. 1-C. Water in sands, 45-110, 135-140, 305-350, 550-560 ft., etc. See partial log
521	SE¼ SW¼ sec 9	T. D. Burnett	....	Creek bank	....	25	5	0.9	9.35	7-29-39	Dockum	C,W	S	Cased only to depth of 10 ft. Begins in sandstone.
522	NW¼ NW¼ sec. 23	....	....	Gentle slope	....	70	5	0.5	65.67	do.	Exeter and Dockum?	C,W	N	
523	SW¼ SW¼ sec. 28	T. D. Burnett	....	Crk. bottom	3990a	113	....	1.0	66.72	11-17-38	Exeter	C,W	S	Water in yellowish-white sandstone, 20-135 ft. Drawdown, 7 ft. at moderate pumping rate.
524	SE¼SE¼NW¼ sec. 36	State of Oklahoma	Old	do.	....	60[5]	6	......	....	....	Alluvium or Ogallala	W	N	Has watered 1500 head of stock.

T. 5 N., R. 7 E.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
527	SE¼ SE¼ sec. 4	Alliance Ins. Co.	1912	Flood plain	3773a	51[5]	6	2.0	43	10-13-37	Ogallala	C,W	S	1.25 mi. S. of Cimarron R. Water in sand.
528	Cent. NW¼ sec. 4	do.	1937	Flood plain	3747a	330[5]	18	1.0	20.17	5-11-39	Alluvium or older	T,G,43	I,40; Obs.	16-stage turbine pump set at 160 ft. with 20-ft. suction. Measured yield 300 gals. a min., rept. drawdown 88 ft.
529	NW¼SW¼SE¼ sec. 10	J. R. Brinkley and H. D. Osborne	1932	Low hill	3836a	171	6	1.5	111.55	10-16-37	Ogallala	C,W	D,S	Water in gravel.
530[4]	SW¼SW¼SE¼ sec. 15	John Cooper	1917	Slope	3873a	143	6	1.0	134.75	9- 3-38	do.	C,W	D,S,P	Water for Burnett School, Dist. 7. Water temp. 61° F. on 4-15-39.
531	SW¼SE¼SE¼ sec. 19	Kate H. Ford et al	....	Creek bottom	....	172	....	0.8	149.30	do.	do.	C,W	S	
532	SW¼SE¼SE¼ sec. 23	Justine Barton	....	Upland flat	3997a	267	....	......	236	do.	do.	C,W	N	

T. 5 N., R. 7 E.—(Cont'd)

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
533	SW¼SW¼SE¼ sec. 26	Viola Young	....	do.	4001a	234	....	1.0	217.16	do.	do.	C,W	N	
534	SW¼SE¼SW¼ sec. 31	Floyd Music	1910	do.	....	227[5]	5	......	200[5]	....	do.	C,W	S	Water in fine gravel.
535	NW¼NW¼NE¼ sec. 36	Martin Beck	....	do.	3981a	211	5	0.3	208.69	9- 3-38	do.	C,W	D,S	Water in medium-grained sand, 200-226 ft.
536	NE¼NW¼NW¼ sec. 24	W. F. Hinds	....	do.	3984	280	....	......	274.84	5-11-39	do.	C	N	

T. 5 N., R. 8 E.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
539	SW¼SE¼SE¼ sec. 9	Bert Stewart	1925	Upland flat	3919	296[5]	5	......	260.66	8-27-38	Ogallala	C,W	D,S	Water in coarse gravel.
540	NE¼SE¼NE¼ sec. 11	Estelle Hoffman	....	do.	3847	238	....	......	231.02	8-26-38	do.	C,W	N	
541	NE¼NW¼NW¼ sec. 14	Minny E. Carlisle	....	Slope	3852	222	5	1.2	206.35	8-27-38	do.	C,W	N	
542[4]	SW¼SE¼SW¼ sec. 18	Edward Jermyn	Old	Upland Flat	3963	280[5]	....	......	262[5]	....	do.	C,W	D,S,P	Furnishes water for Berg School. Water temp. 59° F. on 4-15-39.
543	NW¼NW¼NW¼ sec. 21	Renfrew Investment Co.	....	Upland flat	3930	273+	....	0.3	240.19	do.	do.	C,W	N	
544	NW¼NW¼NE¼ sec. 24	Elwood Harriman	....	do.	3862	218	....	0.4	217.54	8-18-38	do.	C,W	N	
545	NE¼NE¼SE¼ sec. 25	Exxa Bennett	....	do.	3852a	207	....	0.3	188.02	do.	do.	C,W	N	

T. 5 N., R. 9 E.

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	Water level: Below M. P. (feet)	Water level: Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
549	SW¼SW¼SW¼ sec. 3	A. R. Greaser	....	Upland flat	3811a	270	....	1.3	259.87	8-18-38	Ogallala	C,W	N	
550	NE¼NE¼NE¼ sec. 5	J. N. VanLeer	....	do.	3747a	227	4½	0.5	185.40	do.	do.	C,W	N	
551	NE¼NE¼NE¼ sec. 7	R. L. Anderson	Old	Hill on upland	3797a	226	5	0.6	213.88	do.	do.	C,W	D,S	
552[4]	SW¼SE¼SW¼ sec. 8	W. H. Greaser	1908	Upland flat	3839a	295[5]	4	1.3	246.15	do.	do.	C,W	D,S	Measured yield 1 gal. a min., and temp. 60° F. on 11-9-38.
553	SE¼NE¼SE¼ sec. 10	J. W. Triplett	1917	do.	3784	265	4	1.3	239.44	8-16-38	do.	C,W	N	
554	SE¼SW¼SW¼ sec. 12	Mrs. E. J. Sackett	Old	do.	3755	256	4¾	......	226.00	do.	do.	None	N	
555	SW¼SW¼SE¼ sec. 18	Earl Swain	Old	do.	3843a	215	....	0.4	210.38	8-18-38	do.	C,W	N	

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
						T. 5 N., R. 9 E.—(Cont'd)								
556	NE¼NW¼NE¼ sec. 22	G. A. DeHaan	1926	do.	3760*a*	239	8	-4.5	191.85	8-15-38	do.	C,W	P	Water for Harmony Sch., Dist. 12 and residents of Sturgis. Water temp. 62° F., on 4-15-39.
557	SE¼SE¼SE¼ sec. 23	Wm. L. Sharp & Co.	....	Slope	3705*a*	120	....	1.0	112.86	8-19-38	Ogallala	C,W	N	30 ft. above Goff Creek channel.
558	SE¼SW¼SW¼ sec. 26	Mary E. Dresser	....	Upland flat	3755*a*	248	....	0.6	211.62	do.	do.	C,W	N	
559	NW¼SW¼NW¼ sec. 32	James Sparkman	Old	do.	3824*a*	261	5	0.8	194.43	do.	do.	C,W	N	
560	NW¼NW¼SW¼ sec. 34	J. M. Bracken	....	Creek terrace	3745*a*	228	....	0.5	144.07	do.	do.	C,W	N	12 ft. above crk. channel.
						T. 6 N., R. 1 E.								
566	sec. 8	....	....	Flood plain	....	17	....	1.0	13.73	4-28-39	Alluvium	C,W	S	Dug well, walled with rocks.
567	SW¼ sec. 27	H. C. Labrier	Old	Slope	....	55	5	1.3	23.50	4-29-39	Morrison	C,W	D,S	Described as soda water. Leaves white crust.
568	SW¼ sec. 29	S. J. Cooper	Old	Valley flat	....	25	7	0.5	21	4-28-39	Alluvium?	C,W	D	Dug well. Measured while pumping slowly.
569	SE¼ NE¼ sec. 33	Myrtle Tharp	....	Slope	....	......	....	......	2 sp.	....	Slump	......	D	Yield very small.
570[4]	SE¼ NW¼ sec. 33	do.	....	Steep slope	....	......	....	......	Sp.	4-13-39	Dakota	....	......	Improved spring. Measured yield, 0.7 gal. a min. Water temp., 54° F., on 4-13-39.
						T. 6 N., R. 2 E.								
578	NW¼ NW¼ sec. 16	J. J. Willson	1927	Valley flat	....	125 [5]	5½	0.5	18.97	4-29-39	Alluvium & Morrison	C,W	I	Dug well to depth of 37 ft.; drilled from 37 ft. to 125 ft. Mineralized.
579	NW¼ sec. 22	do. (Hughes Ranch)	....	Slope	....	52	....	1.5	23	do.	Morrison	C,W	D	13 ft. above adjacent crk. Measured while pumping.
580	SE¼SE¼NE¼ sec. 24	J. R. Phillips	1927	....	....	4,370 [5]	15½ to 6⅝	......	....	....	....	......	......	Oil test.
						T. 6 N., R. 3 E.								
588	SW¼ NW¼ sec. 14	....	....	Valley flat	....	14	45	......	9.09	4-29-39	Alluvium	C,W	S	Dug well, walled with rock.
589	NE¼ NW¼ sec. 20	G. H. Hallock	....	Steep slope	....	......	....	......	Sp.	do.	Dakota	....	D	Measured yield, 5 gals. a min. Irrigates garden.
590	NW¼ SW¼ sec. 26	A. L. Brookhart	....	Valley flat	....	13	27	0.5	10.78	do.	Alluvium	C,W	D	Dug well, walled with rock.
591[4]	NE¼ SE¼ sec. 28	Cowboy College	....	Canyon	....	......	....	......	Sp.	....	Dakota	....	P	Improved spring, supplies rural school. Water temp. 56° F., 4-13-39.
592	NE¼ sec. 29	C. Brookhart	....	Ravine	....	......	....	......	Sp.	4-29-39	Cheyenne	....	D,S	Improved spring. Measured yield, 0.5 gal. a min.
593	do.	do.	....	Flood plain	....	13	30	1.0	10	do.	Alluvium	C,W	I	Dug well, walled with rock, irrigates small garden. Measured while pumping.
594	SE¼ SW¼ sec. 32	J. J. Willson (Murray Ranch)	....	Canyon wall	....	......	....	......	2 Sp.	do.	Dakota	....	D,S	Measured yield, 1½ gals. a min.
595	S½ NE¼ sec. 33	H. W. Brookhart	....	Slope	....	21	48	1.0	16.60	do.	Cheyenne	B	D	Dug well, walled with rock to 6 ft.; rest natural rock.
596	S½ SW¼ sec. 35	Edwin Brookhart	1908	Flood plain	....	81	5½	1.5	25	do.	Alluvium or Morrison	C,W	D,S	Measured while pumping slowly.
						T. 6 N., R. 4 E.								
600	NW¼ SE¼ sec. 13	D. C. Sloan	....	Canyon	....	......	....	......	Sp.	....	....	....	S	Rept. yield 2 gals. a min.
601	NW¼ sec. 16	State of Oklahoma	....	Dunes	....	155	....	......	83.33	4-29-39	Dakota	C,W	S	
602	NE¼ SE¼ sec. 24	D. C. Sloan	1890	Valley flat	....	17	36 to 48	0.5	16.01	9-30-39	Alluvium	None	N	Dug well, walled with rock. Water in sand and gravel. Rept. water level was 2 ft. higher before drought.
603	SE¼ NW¼ sec. 25	do.	....	Canyon	....	......	....	......	Sp.	....	Dakota	....	S	Rept. yield 1 gal. a min.
604	NE¼ sec. 26	D. C. Sloan	....	Canyon	....	......	....	......	Sp.	....	Dakota?	....	......	Rept. yield, 1 gal. a min.
605[4]	SE¼ sec. 33	Harry Clark	....	Steep slope	....	......	....	......	Sp.	....	Dakota	....	D	Improved spring. Small flow.
606	do.	do.	....	Slope	....	38	5	1.8	32.6	9-30-39	Alluvium or Morrison?	C,W	D,S	

Well No.	Location	Owner or name	Date completed	Topographic situation	Altitude (feet)	Depth (feet)	Diameter (inches)	Height of M. P.[1] (feet)	WATER LEVEL Below M. P. (feet)	WATER LEVEL Date Measured	Probable Aquifer	Method of lift[2]	Use of water[3]	Remarks
						T. 6 N., R. 5 E.								
610	NW¼ sec. 21	A. S. Parker	....	Slope	....	74	8	......	28.66	9-17-38	Morrison	None	Obs.	Uncased. Water level fluctuates widely.
611	NE¼ SW¼ sec. 18	D. C. Sloan	....	Gulley	....	......	....	......	Sp.	....	Dakota	....	S	Rept. formerly flowed 5 gals. a min. but decreased in 1939 to 1½.
612	S½ NE¼ sec. 19	do.	....	Canyon	....	......	....	......	Sp.	....	do.	....	S	Rept. yield 5 gals. a min.
613	SE¼ SE¼ sec. 19	do.	....	do.	....	......	....	......	Sp.	....	do.	....	S	Rept. yield 1 gal. a min.
614[4]	NE¼ sec. 23	A. S. Parker	1938	Gentle slope	....	205[5]	....	0.5	100.69	4-13-39	Dockum	C,W	S	Measured yield 4 gals. a min. Water temp., 62° F., on 4-13-39.
615	sec. 30	Julius Kohler	....	Valley flat	....	19	5	0.8	16.15	9-29-39	Alluvium	None	N	
616	SE¼ SE¼ sec. 31	do.	1931	Flood plain	....	25	5	1.2	13.55	do.	do.	C,W	S	Water rept. "alkaline."
617	NW¼SE¼SE¼ sec. 31	do.	1903	Terrace	....	71	5	1.9	27.23	do.	Morrison	None	N	Rept. soft water in white sandstone between depths 63 and 81 ft.; cased only to 46 ft.
618	NW¼ sec. 21	A. S. Parker	....	Slope	....	90	5½	1.0	57.20	11-15-41	Morrison?	None	N	Water highly mineralized. Rept. yield 4 gals. an hr. Compare water level in No. 610, which is higher on slope.
619	do.	do.	1941	Slope	....	200[5]	....	......	....	....	do.	C,W	S	Drilled to replace No.618. Water in rock at 90 and 126 ft., casing perforated accordingly. Open hole, 140-200 ft. Water level pumps down below cylinder in about 3 hrs.
						T. 6 N., R. 6 E.								
622	SW¼ SE¼ sec. 15	Ford Estate	....	Gentle slope	....	33	6	1.0	14.85	7- 1-39	Ogallala?	C,W	S	
623	NW¼ sec. 20	do.	....	do.	....	70	6	......	60.30	do.	Ogallala	C,W	S	
						T. 6 N., R. 6 E.—(Cont'd)								
624	SW¼ sec. 31	do.	....	Slope	....	101	5	0.8	25.51	do.	Dockum	C,W	N	
625	NW¼ SW¼ sec. 31	do.	1937	Gentle slope	....	100	....	0.3	21	do.	Dockum	C,W	S	Measured while pumping.
						T. 6 N., R. 7 E.								
630	SE¼ SW¼ sec. 21	Alliance Ins. Co.	....	Slope	....	38	4	0.5	26.65	7- 1-39	Alluvium	C,W	S	
631	SW¼ SW¼ sec. 23	do.	1939	Dunes	....	19½	4¾	2.0	12.23	7- 1-39	Dune sand? Alluvium?	C,W	S	Dug well. Water in sand, 14½ to 19½ ft.
632	SW¼NE¼NW¼ sec. 24	Minnie Yunker	....	Flood plain	....	17	6	0.5	5.84	do.	Alluvium	C,W	N	
633	NE¼ SW¼ sec. 28	Alliance Ins. Co.	....	do.	....	38	6	0.5	6.18	do.	do.	C,W	D	
634	SE¼ NE¼ sec. 31	Ford Estate	....	do.	....	18	8	......	11.78	do.	do.	C,W	N	Dug (?) well.
635	SE¼ NW¼ sec. 31	do.	....	Dunes	....	15	6	......	10.73	do.	do.	C,W	S	
636	SE¼NE¼SE¼ sec. 35	Alliance Ins. Co.	....	Hill	3812a	146	....	1.0	113.33	8-26-38	Ogallala	C,W	N	
						T. 6 N., R. 9. E.								
645	NE¼ NE¼ sec. 13	O. O. Rawlings	....	Undulating upland	3708a	215	5	0.5	200	10-14-37	Ogallala	C,W	N	
646	SE¼NE¼SW¼ sec. 22	H. A. Whisenhand	....	Flat	3715a	209	4½	2.0	167.66	8-16-38	do.	C,W	S	
647	NE¼ NE¼ sec. 25	Elmer Isom	....	Low hill	3738a	238	....	1.0	228.67	10-14-37	do.	C,W	N	
648	NW¼ NW¼ sec. 29	A. Hargis, Est.	....	Flat	3709a	158	4½	0.6	145.49	8-16-38	do.	None	N	
649	NE¼ NE¼ sec. 32	E. C. Mingenback	....	Creek bottom	3700a	112	....	0.3	107.61	8-18-38	do.	C,W	S	
650	SE¼SE¼SW¼ sec. 35	Mrs. W. H. Kitner	....	Upland flat	3783a	262	....	1.5	252.70	8-16-38	do.	C,W	N	

[1] Measuring point was usually top of casing, water pipe clamp, or coupling.
[2] Pumps: C, cylinder; T, turbine; B, bucket and rope. Power: W, windmill; H, hand; A, air-lift; G, Gasoline engine; O, oil engine; E, electric motor. Number indicates horse power.
[3] Use: D, domestic; S, stock; I, irrigation (number indicates acres); P, public; RR, railroad; N, not used.
[4] For analysis of water see table on pp. 186-187.
[5] Reported.
[6] Water level estimated from nearby measured well.
a Altitude determined by Paulin altimeter.