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GEOLOGY AND GROUND WATER RESOURCES OF CIMARRON COUNTY, OKLAHOMA

by

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with a Section on

MESOZOIC STRATIGRAPHY

by

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

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CONTENTS

Abstract 7

Introduction
- Purpose and scope of this investigation 10
- Location of the area 12
- Previous investigations 13
- Method of this investigation 17
- Acknowledgments 19

Geography 20
- Topography and drainage 20
- Climate 25
- Economic development 32
- Population 33

General geology 34
- Stratigraphic summary 34
- Structural summary 34
- Economic geology 38
  - Oil and gas 41

Stratigraphy of the Cimarron valley (Mesozoic rocks), by J. W. Stovall 43
- Triassic system 43
  - Dockum group 43
- Jurassic system 51
  - Exeter sandstone 51
  - Morrison formation 57

- Cretaceous system 71
  - Lower Cretaceous series 71
    - Purgatoire formation 71
      - Cheyenne sandstone member 74
      - Kiowa shale member 76
  - Upper Cretaceous series 81
    - Dakota sandstone 81
    - Colorado group 94
      - Graneros-Greenhorn beds 94

- Tertiary and Quaternary systems, by S. L. Schoff 100
  - Pliocene and Pleistocene, undifferentiated 100
    - "Ogallala" formation 100
    - Basalt 118

- Quaternary system, by J. W. Stovall and S. L. Schoff 120
  - Pleistocene and Recent 120
    - Deposits in caves 121
    - Basketmaker culture in the Oklahoma Panhandle, by Forrest E. Clements 122
    - Stream deposits 124
    - Dune sand 131

Water-Bearing properties of the rock formations, by S. L. Schoff 133

- Laboratory tests 150

Observation wells 163
- Water level fluctuations 163

Ground water supplies and development 173
Shape and slope of the water table and movement of the ground water 173
Chemical character of the water 178
Fluoride content 181
Water for irrigation 188
Present development of water supplies from wells 189
Domestic and stock wells 189
Wells used for public and railroad supplies 191
Wells used for irrigation and commercial purposes 197

Well drilling methods 201

Possibilities of additional supplies for irrigation 202

Irrigation supplies in other parts of the southern high plains 205

Ground water conditions in Cimarron County, by localities 207
Upland plains 207
Central upland 209
Area of buried red bed ridge 210
Griggs deep water area 211
Midwell school deep water area 212
Sturgis deep water area 213
Willowbar shallow water area 213
Liberty school shallow water area 214
Wheeless shallow water area 215
Mexhoma area 215
Other areas 218
Cieneguilla (Seneca)—North Canadian upland 219
Southern upland 220
Felt shallow water area 220
Delfin school deep water area 222
Beaver school deep water area 222

Valleys 223
Cimarron valley 223
Flood plains 223
Broken lands 224
North Canadian valley 226
Western shallow water area 226
Eastern shallow water area 227

Recharge and Discharge of ground water 228
Recharge from local rainfall on the uplands 228
Recharge through sand dunes 233
Recharge through lakes 234
Recharge from streams 235
Recharge from precipitation on the "Ogallala" formation in outside areas 236
Recharge to the "Ogallala" formation from the Dakota sandstone 238
Recharge estimated from water level fluctuations 240
Summary—amount of annual recharge 242
Discharge of ground water 243
Natural discharge 243
Discharge from wells 245
Total annual discharge 246
Adequacy of the ground water supply 246

Appendix A, Measured Stratigraphic Sections 247

Appendix B, Well Logs 264

Appendix C, Tables of Records of Wells and Springs 280

TABLES

I. Monthly and Annual Temperatures 25
II. Frost Data at Boise City and Kenton 26
III. Monthly and Annual Precipitation at Boise City 27
IV. Monthly and Annual Precipitation at Kenton 28
V. Relative Acreage Devoted to Different Crops 32
VI. Test wells Drilled for Oil and Gas 40
VII. Formations in Gulf Oil Corp. Test Well 42
VIII. Subdivisions of Dockum Group 43
IX. Classification of Triassic in Northeastern New Mexico 44
X. Section of the Morrison Formation at Labrier (Tate) Butte 63
XI. Section of Morrison Formation at Robbers' Roost 64
XII. Section of Morrison Formation North of Boise City 67
XIII. Fossils from the Morrison formation 69
XIV. Materials below the water table in the "Ogallala" Formation 147
XV. Specific Capacities of Wells in the "Ogallala" 148
XVI. Source of Materials Represented by Histograms 155
XVII. Specific Yield of Materials 160
XVIII. Laboratory Tests of Outcrop and Well Samples 161
XIX. Fluctuations of Water Levels in Observation Wells 172
XX. Average Changes in Observation Wells 173
XXI. Analyses of Water from Wells and Springs 186
XXII. Safe and Unsafe Water for Irrigation 188
XXIII. Ground Water Areas in Cimarron County 207
XXIV. Depths to Water in Felt Shallow Water Area 221

ILLUSTRATIONS

Frontispiece—Cimarron Valley From Black Mesa.

Plate
I. Map of Cimarron County, Oklahoma, Showing Geology and Depths to Water in Wells ..... in pocket
II. Geologic Map of Northwestern Cimarron County, by J. W. Stovall ..... in pocket
III. Blow-out in Sand Dunes ..... following p. 32
IV. Upper Dockum Beds and Exeter Sandstone, near Foot of Labrier (Tate) Butte 64
V. Exeter Sandstone Overlying Upper Dockum Beds 64
VI. A. Morrison Formation, North of Kenton 64
B. Morrison Formation Near Robbers' Roost 64
VII. Mesozoic Formations in Labrier (Tate) Butte 64
VIII. Cheyenne Sandstone 64
IX. A. Upper Sandstone of Kiowa Shale, 101 Hill 64
B. Contact of Kiowa and Dakota 64
X. A. Lower Sandstone Member of the Dakota 96
B. Cliff of Dakota Sandstone 96
XI. The "Three Sisters" 96
XII. Sand and Gravel of "Ogallala" formation 112
XIII. Sandy Clay, Sand and "Caliche"; Limestone at Top "Ogallala" Formation 112
XIV. Soft Caliche Grading Upward into Limestone 112
XV. Nodular, Jointed Caliche 112
XVI. Hard, Dense Limestone, Overlying Nodular Caliche 112
XVII. Hard Limestone Weathering into Rounded Blocks 112
XVIII. "Concretionary" Zone in Caliche, Just Below Limestone 112
XIX. Limestone Resembling the "Algal" Limestone 112
XX. Jointing in Basalt on Black Mesa 224
XXI. Discharge from Irrigation Well 224
XXII. Kohler's Ditch 224
XXIII. Cedar Trees Growing on Dakota Sandstone 224

LIST OF FIGURES

Figure		Page
1.	Index map	9
2.	Topographic map of Cimarron County	21
3.	Pattern of cracks developed in recent sink hole	23
4.	Cumulative departure from normal and annual precipitation	31
5.	Structural Features of eastern Colorado and adjacent parts of Kansas, Oklahoma, and New Mexico	36
6.	Structure contour map of northwestern Cimarron County	37
7.	Relations of the Morrison at Labrier (Tate) Butte, Robbers' Roost, and across Cimarron River, 1.5 miles southeast	60
8.	Thickness of Tertiary and Quaternary formations in eastern Cimarron County	102
9.	Sketch indicating erosion in the Cimarron Valley since Pliocene (?) lava flow	120
10.	Cross-section to show occurrence of water in the "Ogallala"	145
11.	Mechanical analysis of materials from the Exeter, Cheyenne, and Dakota sandstones, and beach sand	152
12.	Mechanical analysis of materials from river sand, alluvium, "Ogallala" formation, and dune sand	153
13.	Mechanical analysis of materials from dune sand, sand from well No. 631, and soil	154
14.	Hydrographs for observation wells in the "Ogallala" compared with precipitation	164
15.	Hydrographs for observation wells in alluvium, Morrison, and red beds, compared with precipitation	165
16.	Hydrograph for observation well 516, in the Dockum formation, compared with precipitation	166
17.	Hydrographs showing averages of water levels in different aquifers, and a weighted county average, compared with precipitation	168
18.	Fluctuations of water level in well 224 compared with fluctuations in barometric pressure	169
19.	Relation of water level in well 516 to water tables in the alluvium and Dockum	171
20.	Contour map of the water table in the "Ogallala"	174
21.	Fluoride in parts per milllion in water from wells and springs	182
22.	Rate at which water in windmill wells rose after pumping	192
23.	Principal Ground Water Areas in Cimarron County	208
24.	Deep- and shallow-water in Mexhoma area	217
25.	Ground Water in a Mesa	224
26.	Intake area in the High Plains	237
27.	West-east cross section to show how the "Ogallala" may be partly recharged from the Dakota sandstone	239

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

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.

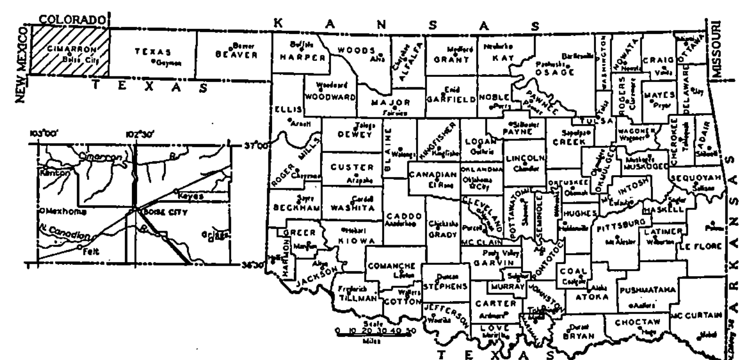

FIG. 1. Index Maps showing Location of Cimarron County, Oklahoma, and Principal Features in the County.

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.

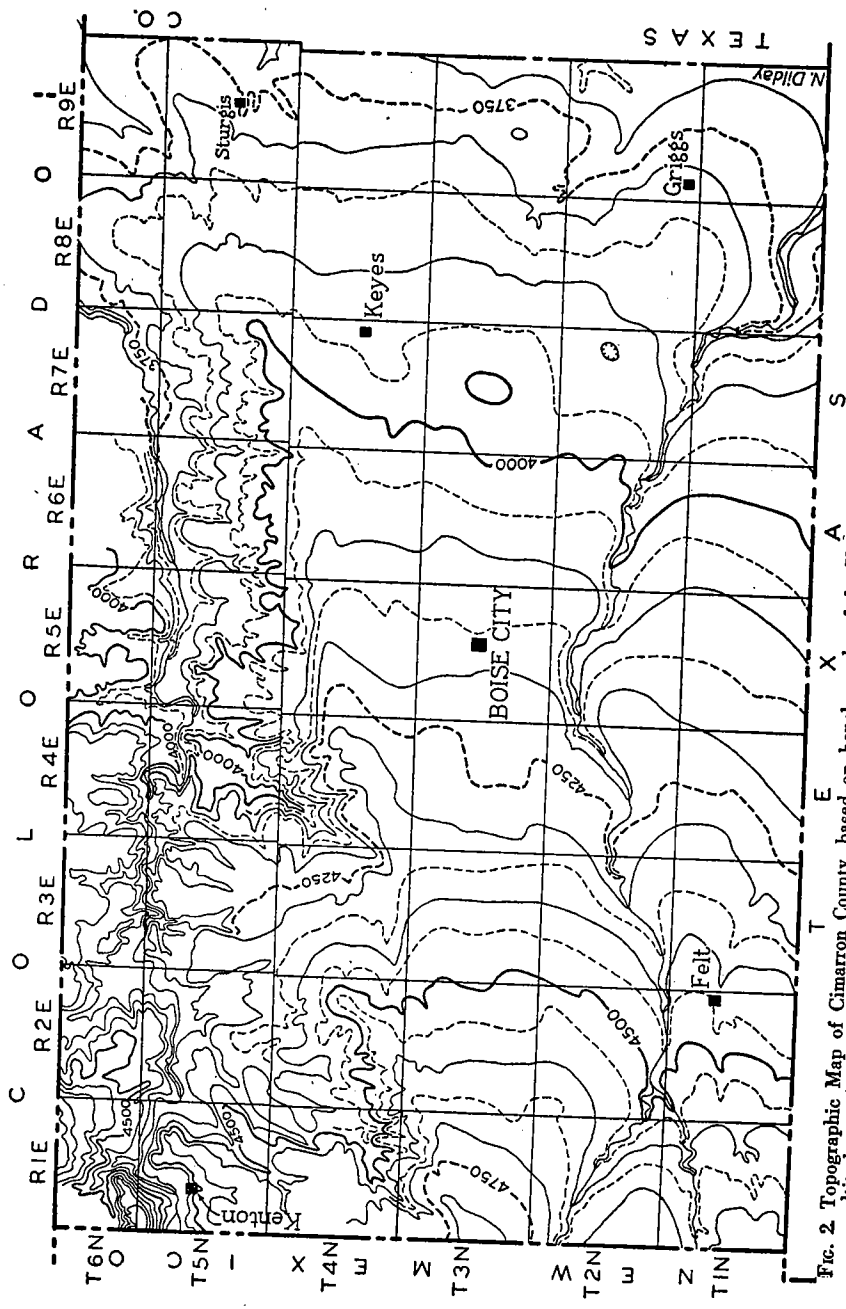

Fig. 2 Topographic Map of Cimarron County, based on bench marks of the U. S. Coast and Geodetic Survey, plane-table and altimeter altitudes, and surveys for the proposed Kenton Dam. Scale, 1:500,000. Contour interval, 50 feet.

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 northeastern 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.

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).

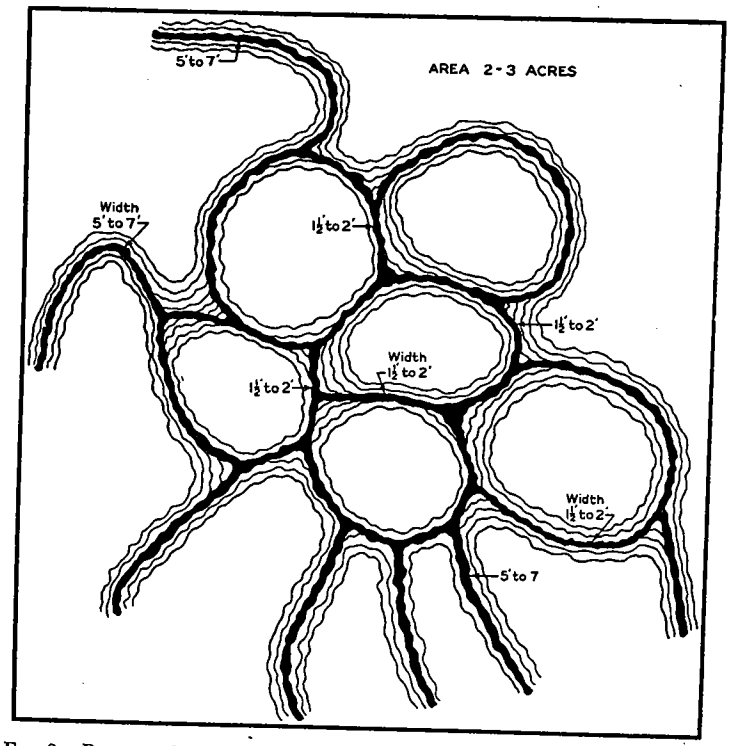

FIG. 3. Pattern of cracks developed in recent sink hole activity, based on sketch by land owner.

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