# OKLAHOMA GEOLOGICAL SURVEY

CARL C. BRANSON, Director

## Bulletin 72

# GROUND-WATER RESOURCES

OF

# OTTAWA COUNTY, OKLAHOMA

BY

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This report is a cooperative product of the United States Geological Survey and the Oklahoma Geological Survey. The classification and nomenclature of the rock units accords, for the most part, with that of the two surveys, but it differs somewhat from that of the United States Geological Survey.

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# GROUND-WATER RESOURCES OF OTTAWA COUNTY, OKLAHOMA

By EDWIN W. REED, Engineer,

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## ABSTRACT

Ottawa County, in the northeastern corner of Oklahoma, is nearly square, has an area of 504 square miles, and has a population of about 32,000 (1950). Miami, the county seat, had a population of 11,703 in 1950.

The southeastern half of the county is in the Ozark plateau, is hilly and well timbered, and has a surface relief of several hundred feet. The northwestern half is in the Osage section of the Central Lowlands and is largely flat prairie. The county is drained by the Neosho (Grand) and Spring Rivers.

The mining and milling of lead and zinc ores ranked as the most important industry in the county until 1944, when The B. F. Goodrich Co. established a tire-manufacturing plant at Miami. This industry is about equal in importance to mining and milling, and its large requirement for cooling water emphasized the need for an appraisal of ground-water resources.

Limestone, chert, shale, and sandstone, of Paleozoic age, underlie the surface of Ottawa County. Those exposed, in ascending order, are divided into the Boone formation, Hindsville limestone, Batesville sandstone, and Fayetteville shale, of Mississippian age, and the Krebs group, of Pennsylvanian age. These formations are overlain along the larger streams by alluvium and at other places they are overlain by terrace deposits. Locally, also, they are overlain by gravel and clay thought to be of Pleistocene age. Of these formations, the Boone offers the most promise as an aquifer. The water in it has been used mainly on farms.

Subsurface sedimentary rocks comprise more than 1,000 feet of cherty, oolitic, or sandy dolomite, and sandstone, of Cambrian and Ordovician age; eight formations are recognized, the lower three being assigned to the Upper Cambrian and the upper five to the Canadian series of the Ordovician system. The Seneca fault, Miami syncline, and local structural features modify the regional dip, which is 15 to 20 feet per mile northwestward on the flank of

the Ozark uplift. Granite of pre-Cambrian age has been encountered below the sedimentary rocks.

Rocks of the Canadian series are the source of all municipal water supplies in the county. Their intake area is in the Ozarks, many miles to the east, and wells tapping them are generally 1,000 to 1,300 feet deep and are cased and cemented to exclude water from overlying strata. Within the series, the Roubidoux formation is the most prolific. It consists of dolomite containing two or three sandy zones, and in wells it ranges from 105 to 180 feet in thickness. The top of it has been found at depths from 880 to 1,020 feet. Most of the water appears to come from the sandy zones, and some wells yield up to 600 gallons per minute. Although rather hard, the water has a relatively low total mineral content.

When wells first tapped the water in the rocks of the Canadian series, about 1900, the artesian pressure was sufficient to make them flow. By 1918 most wells had stopped flowing, and by 1947 the lift was more than 500 feet in some wells. The greatest decline in water levels has occurred near Miami.

Three controlled pumping tests on wells of The B. F. Goodrich Co. were analyzed according to the Theis nonequilibrium formula, and yielded 13 values for coefficient of transmissibility. These range from 22,200 gallons per day per foot to 59,400, and average 38,100. Because the wells used in the tests are near the axis of the Miami syncline, this average is believed to be somewhat lower than normal for the Canadian series, and a value of 40,000 gallons per day per foot is used in further computations. From the same tests, 12 values for the coefficient of storage were obtained and $1 \times 10^{-4}$ is regarded as average for this coefficient.

The Miami syncline and Seneca fault are believed to be barriers that obstruct the flow of ground water from remote parts of the aquifer to the Miami area, thereby increasing the drawdown in pumping wells. It is estimated that if one well were to be pumped at 400 gallons per minute, and if six other nearby wells were to be pumped at a combined rate of 2,200 gallons per minute, the total drawdown in the first well at the end of 5 years of continuous pumping would be about 450 feet.

The rocks of the Canadian series of Ottawa County appear to function as a huge reservoir. Water levels will decline as long as pumping continues. The rate of decline will diminish if the pumping rate remains unchanged, but will increase if the pumping rate is materially increased. If present rates of withdrawal are to be maintained, pump bowls ultimately will have to be lowered. The reservoir still should furnish many millions of gallons of water, although at increasing cost occasioned by increasing pumping lift. If an economical and practical method could be found to recharge the reservoir artificially, the trend might be reversed.

# INTRODUCTION

By Edwin W. Reed and Stuart L. Schoff

## PURPOSE AND SCOPE OF INVESTIGATION

Water for municipal and industrial use in Ottawa County, Oklahoma, is obtained principally from beds of water-bearing sandstone, limestone, and dolomite, of Cambrian and Ordovician age, at depths ranging from 450 to 1,700 feet below the surface. The water is under artesian pressure, and when wells first were drilled, about at the turn of the century, the pressure was sufficient to make them flow at the surface.

As more wells were drilled and the withdrawals of water increased, the artesian head declined until by 1918 most of the wells had stopped flowing. By 1947 the water was being lifted more than 500 feet in some wells. Although the greatest decline in water levels has occurred near Miami, Oklahoma, the water levels also have dropped alarmingly in adjacent parts of southeastern Kansas and southwestern Missouri.

It has been necessary to lower pump bowls periodically in most wells to keep pace with the declining water levels. Some wells have been deepened, others have been "shot" with nitroglycerine to increase their productivity, and others have been enlarged by reaming to permit lowering of pump bowls. Some cities and towns have experienced shortages of water during summer and may have more serious difficulty in the future if population and water demands increase. Nevertheless, the occurrence, the quantity, and the quality of the available ground water have been but slightly understood.

An investigation of the ground water available for The B. F. Goodrich Co. tire plant at Miami was among the problems of ground-water supply in Oklahoma studied during World War II by the United States Geological Survey in cooperation with the Oklahoma Geological Survey, under terms of an agreement initiated in 1937 and renewed each year since. In this investigation, which was begun at the request of the War Production Board, pumping tests made in the water wells of The B. F. Goodrich Co. led to an understanding of the declining water levels. Further investigation since the war has added a wealth of information, making possible the preparation of this report, the purpose of which is to evaluate the ground-water resources of the entire county.

## LOCATION AND EXTENT OF THE AREA

Ottawa County is in the northeastern corner of Oklahoma, being bounded on the north by Kansas, on the east by Missouri, and on the south and west, respectively, by Delaware and Craig Counties, Oklahoma (fig. 1). The county is approximately 22.5 miles square and has an area of 504 square miles. It is in the lands once assigned to the Cherokee Nation. Later, the part east of the Spring River was withdrawn from the Cherokees and at different times it was parceled out to the Senecas, Shawnees, Quapaws, Peorias, Wyandottes, and Modocs. The present county boundaries were established in 1907 when Oklahoma and Indian Territories were combined to form the State of Oklahoma (Gittinger, 1917).[1]

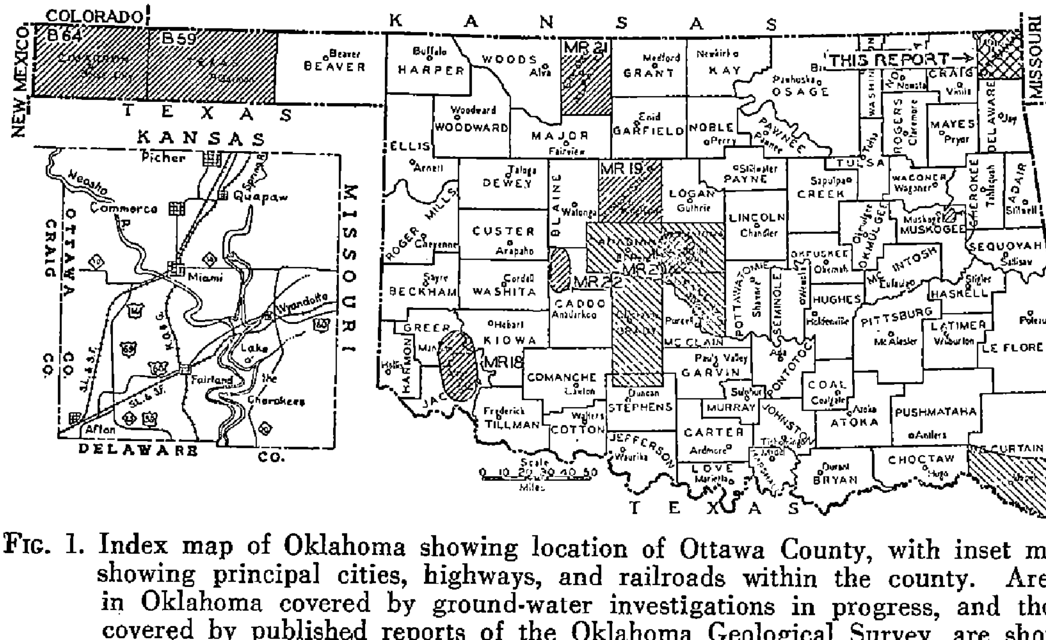


FIG. 1. Index map of Oklahoma showing location of Ottawa County, with inset map showing principal cities, highways, and railroads within the county. Areas in Oklahoma covered by ground-water investigations in progress, and those covered by published reports of the Oklahoma Geological Survey, are shown by ruled patterns. B, Bulletin; C, Circular; MR, Mineral Report.

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[1] See references, p. 191.

## PREVIOUS INVESTIGATIONS

Geologists who have investigated the mineral resources of Ottawa County have mentioned ground water, and several small-scale attacks have been made on some phases of the ground-water problems. Siebenthal (1908) included a section on ground water in a report on the mineral resources of northeastern Oklahoma, and in a later report (1915) he mentioned several flowing wells. In a report on the occurrence of lead and zinc in Ottawa County, Snider (1912, p. 16) commented on the difficulty of controlling ground water in the mines. Ireland (1930, p. 35; 1930a, p. 501) listed 18 water wells in Ottawa County, giving parts of 11 drillers' logs. Reporting on the lead and zinc mines of the county, Weidman (1932, p. 11, 12, 67) referred to many of the same wells and added a few others.

In 1936 and 1937 the State Mineral Survey, which was a project of the Works Progress Administration sponsored and directed by the Oklahoma Geological Survey, made a survey of the mineral resources of the State, including an inventory of water wells used for domestic and public supply. Tables summarizing the water-well data for Ottawa County, previously available to the public only through the files of the Oklahoma Geological Survey, are published in this report (appendix D).

Cady (1938) included Ottawa County in a short report on ground water for domestic use in northeastern Oklahoma. Reed and Jacobsen (1944) summarized in a report to the War Production Board the results of the pumping tests made in 1944 at The B. F. Goodrich Co., and Jacobsen (1944) supplemented their report by reviewing the ground-water conditions in the Mississippian rocks of the Miami area. The essential facts and conclusions of the papers by Reed and Jacobsen and by Jacobsen are incorporated in the present report.

## THIS INVESTIGATION

The senior author and Mr. Jacobsen spent about 6 weeks in Ottawa County in 1944 obtaining information on existing deep water wells, collecting samples of water, and conducting pumping tests. The senior author spent several weeks in the fall of 1947 and the spring of 1948 collecting additional water samples and gathering data on wells in areas and in aquifers not previously covered. At that time he also revisited all the municipal and heavily pumped industrial wells in order to bring their histories forward from 1944. Where possible, depths to water were measured, discharge rates were verified, and total pumpage figures were obtained.

Samples of water collected during this investigation were analyzed by standard methods. Most of the analyses were made in laboratories of the Quality of Water Branch, U. S. Geological Survey, in Austin, Texas, Stillwater, Oklahoma, and Washington, D. C. Samples collected from six wells by C. C. Williams, of the U. S. Geological Survey, were analyzed by the Kansas State Board of Health. Analyses for five samples from public water supplies in Ottawa County, collected in 1951 by the Oklahoma State Department of Health and analyzed in the laboratory of the U. S. Geological Survey at Stillwater, are included in the table of water analyses.

The surface geology of Ottawa County was covered by Siebenthal and Messler in mapping the Wyandotte quadrangle in 1907, but their map was not published because the quadrangle was not completed. Nevertheless, their map has been the basis for maps published by Snider (1915), Miser (1926), Ireland (1930, 1930a), and Weidman (1932). Each author made modifications to adapt the map to his scale of publication or to conform to his own ideas on specific localities, but the net result was, in each case, a map having the main features of the original. For this report the map by Siebenthal and Messler is again used for the eastern two-thirds of the county, but unlike the previously published maps the present one (pl. I) shows the subdivisions of the Chester series. Mapping of the Pennsylvanian rocks, done in 1950 and 1953 by Carl C. Branson for the Oklahoma Geological Survey, has been added, and cultural features have been brought up to date. The trace of the Short Creek oolite is shown from the manuscript map by Speer (1951a). Descriptions of the rocks and the structural geology of the area are based mainly on published reports.

The investigation was carried out under the general supervision of O. E. Meinzer and A. N. Sayre, former and present Chiefs, respectively, Ground Water Branch, U. S. Geological Survey, and Robert H. Dott, former Director, Oklahoma Geological Survey.

## ACKNOWLEDGMENTS

Without the cooperation of many individuals who supplied information or aided in the collection of field data, this report would not be possible. It is not practical to mention all contributors, but special thanks are due H. G. Freehauf, superintendent, Department of Public Utilities, and the late W. W. Dobson, former member of the Board of Public Utilities, of Miami, Oklahoma, and John R. Paugh, formerly construction engineer of The B. F. Goodrich Co., for arranging the pumping tests in the wells at the Goodrich plant. Mr. Freehauf also furnished information on the water wells and pumpage of the city of Miami. Records of wells and of pumpage and drillers' logs were furnished by city officials of Picher, Commerce, Quapaw, Fairland, and Afton, and by R. K. Stroup, chief engineer of the Eagle-Picher Mining and Smelting Co. Drill cuttings submitted by well drillers to the Missouri Division of Geological Survey and Water Resources were examined by members of that organization. The logs of wells prepared by them are given in this report (appendix A).

## GEOGRAPHY

By EDWIN W. REED and STUART L. SCHOFF

### TOPOGRAPHY AND DRAINAGE

Ottawa County includes parts of two physiographic provinces as classified by Fenneman (1938). The southeastern half belongs in the Ozark Plateau, is hilly and well timbered, and has many springs, some of them rather large. The relief is several hundred feet and most of the timber is oak. The northwestern half belongs to the Osage section of the Central Lowlands and is flat prairie with little relief except along streams.

Ottawa County is drained by the Grand (Neosho) River and its tributaries. The Neosho rises in east-central Kansas, enters Oklahoma at the northwest corner of Ottawa County, and flows southeastward two-thirds of the way across the county to the vicinity of Wyandotte, where it is joined by the Spring River. From this confluence its course is generally southward to a point about 12 miles east of the southwest corner of the county. The U. S. Board of Geographic Names recognizes the name Neosho for this stream all the way to its mouth near Muskogee, but in Oklahoma the name Grand is widely used and understood for the stretch downstream from the mouth of the Spring River. The Oklahoma Geological Survey has adopted this usage of the name Grand for its official publications, and the name is so used in this report. A gaging station has been maintained by the U. S. Geological Survey on the Neosho River near Commerce since June 1939. The records show a maximum discharge of 267,000 cubic feet per second (1951), a minimum of 0.5, and an average of 4,584.

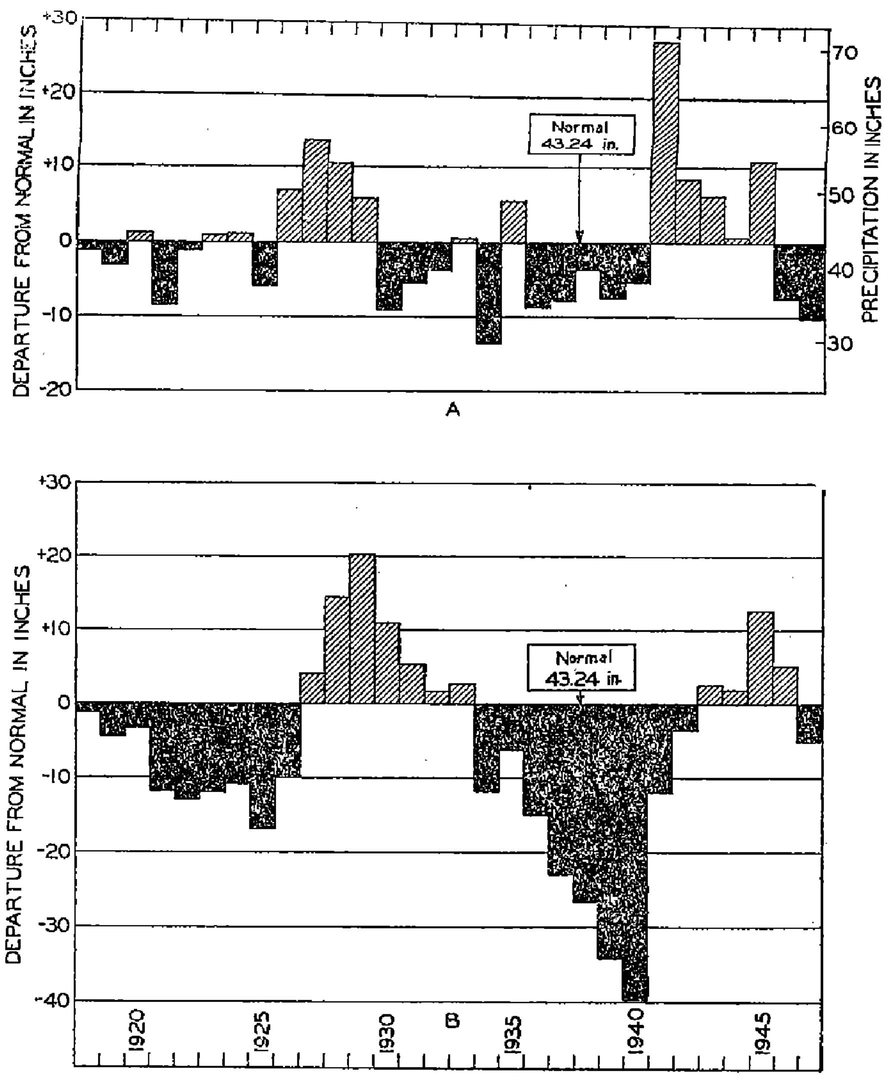
The Spring River rises in southwestern Missouri, flows westward into Kansas, turns south, enters Oklahoma about 5 miles west of the Missouri State line, and follows a generally southward course through northeastern Ottawa County to join the Neosho near Wyandotte.

Some of the more important tributaries of the Neosho River are Mud, Cow, Coal, and Hudson Creeks, which enter from the west; Tar, Elm, and Fourmile Creeks, which enter from the north; and Sycamore and Council Hollow Creeks, which enter from the east (fig. 5). Lost Creek, Warren Branch, and Fivemile Creek drain into the Spring River from the east. Horse Creek drains about 50 square miles of the southwestern part of Ottawa County and empties into the Grand (Neosho) River 7 miles south of the Ottawa-Delaware county line.

The Grand has been dammed near Pensacola, Oklahoma, about 50 miles downstream from the southern boundary of Ottawa County, forming Lake o' the Cherokees. Widely known, also, as Grand Lake, this reservoir has a capacity of 2,197,200 acre-feet, of which 525,000 acre-feet is reserved for flood control, 1,492,000 acre-feet is allocated for hydroelectric power, and the remaining 180,-200 acre-feet is storage. The lake extends upstream into Ottawa County beyond the confluence of the Neosho and Spring Rivers, forming what are known locally as the Grand River and Spring River arms of Grand Lake. Although power and flood control were the primary objectives behind its construction, Lake o' the Cherokees offers many possibilities for recreation, and its environs are being developed into one of the largest resort areas of the Southwest.

## CLIMATE

Ottawa County is in the humid zone (Thornthwaite, 1941, pl. 3). The normal annual precipitation at Miami, based on records beginning in 1918 (U. S. Weather Bureau, 1930, 1931-49), is 43.24 inches, but yearly totals have ranged from 27.64 (1953) to 71.01 (1941) inches (table 1). The heaviest precipitation comes during the spring, but September and October also are wet. On the average, more than 3 inches of rain falls in both July and August, mostly as local thundershowers. Winter is the driest season, and February is the driest month, having an average precipitation of only 1.53 inches. Figure 2 summarizes graphically the annual precipitation at Miami over the period 1918-1947.




B

FIG. 2. Precipitation at Miami, 1918-47. A, annual precipitation, and annual excess or deficiency with respect to normal annual precipitation of 43.42 inches. B, Cumulative departure from normal. (From records of U. S. Weather Bureau.)

TABLE 1.

MONTHLY PRECIPITATION IN INCHES AT MIAMI, OKLAHOMA, 1918-53.

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 2.10 | 0.65 | 1.24 | 4.44 | 4.01 | 1.37 | 1.68 | 4.26 | 5.35 | 6.87 | 6.28 | 3.81 | 42.06 |
| 1919 | 0.05 | 2.19 | 2.10 | 5.24 | 2.84 | 4.90 | 0.89 | 4.31 | 0.85 | 13.15 | 3.05 | 0.42 | 39.99 |
| 1920 | 1.68 | 0.00 | 8.13 | 1.44 | 6.08 | 4.69 | 1.12 | 8.35 | 5.12 | 5.82 | 0.62 | 1.43 | 44.48 |
| 1921 | 2.51 | 0.24 | 6.05 | 4.75 | 1.49 | 7.09 | 1.51 | 4.69 | 2.74 | 0.55 | 1.57 | 1.54 | 34.73 |
| 1922 | 1.12 | 1.20 | 9.64 | 4.68 | 4.67 | 3.34 | 8.96 | 0.96 | 1.76 | 0.64 | 4.19 | 0.93 | 42.09 |
| 1923 | 2.63 | 1.20 | 2.42 | 3.00 | 5.45 | 9.37 | 0.79 | 0.15 | 3.10 | 7.67 | 3.51 | 4.91 | 44.20 |
| 1924 | 1.06 | 2.69 | 1.91 | 4.27 | 6.24 | 4.56 | 4.17 | 6.82 | 5.16 | 2.04 | 2.93 | 2.46 | 44.31 |
| 1925 | 2.20 | 1.54 | 1.30 | 4.97 | 1.44 | 5.12 | 7.46 | 2.53 | 3.94 | 3.38 | 2.84 | 0.55 | 37.27 |
| 1926 | 2.55 | 1.43 | 1.91 | 1.67 | 3.49 | 6.86 | 2.82 | 4.88* | 11.58 | 6.43 | 3.78 | 2.72 | 50.12* |
| 1927 | 2.75* | 0.78* | 6.88 | 10.43 | 2.42 | 6.51 | 6.79 | 5.48 | 2.99 | 5.77 | 4.50 | 1.91 | 57.21* |
| 1928 | 0.49* | 3.03* | 2.30* | 6.28* | 3.33* | 12.24 | 6.42* | 5.63* | 0.63* | 4.05 | 3.41 | 5.80 | 53.61* |
| 1929 | 4.68 | 1.42 | 2.05 | 7.72 | 9.05 | 7.01 | 3.78 | 3.68 | 3.62 | 4.08 | 1.50 | 0.42 | 49.08 |
| 1930 | 4.29 | 1.89 | 0.69 | 4.56 | 3.27 | 4.57 | 1.38 | 1.81 | 6.29 | 2.39 | 2.17 | 0.63 | 33.94 |
| 1931 | 0.22 | 3.35* | 2.17 | 3.15 | 4.22 | 2.55 | 5.21 | 4.11 | 0.50 | 4.71 | 7.00 | 0.48 | 37.67* |
| 1932 | 4.74 | 1.06 | 1.23 | 3.49 | 2.43 | 8.96 | 2.78 | 0.97 | 1.56 | 4.00 | 1.75 | 6.54 | 39.51 |
| 1933 | 2.78 | 0.98 | 2.19 | 5.71 | 7.43 | T | 4.76 | 4.75 | 6.83 | 3.14 | 1.88 | 3.25 | 43.70 |
| 1934 | 1.59 | 0.99 | 1.08 | 3.01 | 2.39 | 1.82 | 1.01 | 2.15 | 7.70 | 0.95 | 5.71 | 0.99 | 29.39 |
| 1935 | 2.00 | 1.94 | 5.15 | 2.69 | 7.21 | 14.10 | 0.02 | 1.21 | 3.35 | 6.74 | 2.82 | 1.58 | 48.81 |
| 1936 | 0.30 | 1.01 | 0.90 | 3.22 | 2.12 | 0.79 | 2.07 | 0.76 | 13.16 | 6.76 | 0.53 | 2.78 | 34.40 |
| 1937 | 4.34 | 0.69 | 2.59 | 2.33 | 4.12 | 4.84 | 6.23 | 0.51 | 4.56 | 1.83 | 1.78 | 1.49 | 35.31 |
| 1938 | 2.00 | 3.31 | 7.51 | 2.49 | 7.89 | 5.74 | 3.26 | 2.50 | 0.70 | 0.39 | 2.86 | 0.90 | 39.55 |
| 1939 | 1.85 | 1.85 | 3.23 | 1.18 | 8.39 | 5.36 | 2.96 | 4.94 | 0.33 | 2.06 | 2.26 | 1.25 | 35.66 |
| 1940 | 1.08 | 1.49 | 1.23 | 5.91 | 2.15 | 5.76 | 1.63 | 5.94 | 2.79 | 2.02 | 5.86 | 1.93 | 37.79 |
| 1941 | 3.59 | 1.33 | 0.75 | 10.00 | 2.50 | 8.82 | 0.99 | 4.51 | 14.77 | 19.59 | 1.86 | 2.30 | 71.01 |
| 1942 | 1.43 | 2.73 | 0.33 | 6.39 | 3.70 | 8.51 | 0.77 | 6.18 | 11.39 | 4.46 | 2.35 | 2.40 | 51.64 |
| 1943 | 0.03 | 0.80* | 2.93* | 3.78* | 23.95 | 4.60 | 0.00 | 0.42 | 5.70 | 4.05 | T | 3.10 | 49.36* |
| 1944 | 0.20 | 4.65 | 5.00 | 6.70 | 4.35 | 3.15 | 0.70 | 6.60 | 3.60 | 2.86 | 2.50 | 2.20 | 42.51 |
| 1945 | 0.90 | 2.50 | 5.90 | 7.39 | 5.95 | 5.40 | 4.40 | 2.61 | 14.90 | 3.40 | T | 0.65 | 54.00 |
| 1946 | 3.96 | 2.87 | 1.01 | 1.90 | 7.51 | 2.84 | 0.04 | 3.20 | 1.40 | 1.13 | 7.88 | 1.97 | 35.71 |
| 1947 | 1.03 | 0.68 | 2.89 | 8.78 | 6.40 | 5.06 | 1.50 | 0.50 | 3.59 | 0.75 | 1.45 | 0.25 | 32.88 |
| 1948 | 0.42 | 2.14 | 4.98 | 2.08 | 5.62 | 12.60 | 6.29 | 4.68 | 0.03 | 0.91 | 1.40 | 1.40 | 42.55 |
| 1949 | 6.44 | 2.52 | 3.40 | 2.17 | 5.70 | 3.60 | 7.81 | 0.28 | 4.85 | 2.75 | 0.28 | 2.29 | 42.09 |
| 1950 | 1.51 | 1.70 | 1.11 | 2.38 | 5.86 | 5.39 | 7.07 | 7.81 | 2.48 | 3.05 | T | 0.15 | 38.51 |
| 1951 | 1.18 | 4.52 | 1.36 | 1.87 | 3.34 | 5.76* | 0.93* | 2.39 | 6.24 | 6.07 | 4.47 | 0.85 | 38.98* |
| 1952 | 1.28 | 2.66 | 2.41 | 2.66 | 6.20 | 1.34 | 2.34 | 6.83 | 0.29 | 0.09 | 3.22 | 1.04 | 30.36 |
| 1953 | 1.25 | 0.85 | 4.20 | 6.38 | 2.06 | 1.47 | 2.87 | 1.14 | 2.11 | 3.11 | 0.68 | 1.52 | 27.64 |
| Normal | 2.04 | 1.53 | 2.98 | 4.49 | 5.09 | 5.75 | 3.06 | 3.56 | 4.86 | 4.75 | 2.96 | 2.17 | 43.24 |

* Incomplete
T Trace

The mean annual temperature at Miami is 59.6°F. (table 2). July is the hottest month, and January the coldest. Temperatures exceeding 100°F have been recorded in each of the four months June, July, August, and September, and subfreezing temperatures have been recorded in each of the months from October through May, inclusive. The average length of growing season, from the last killing frost in the spring to the first in the fall, is 207 days. Winter temperatures are low enough so that some of the precipitation comes as snow, but snowstorms usually are of short duration and the snow remains on the ground only a few days.

TABLE 2.

Average Temperatures, at Miami, Oklahoma, in Degrees Fahrenheit, based on Available Records Through 1943

| | | | |
|---|---|---|---|
| January | 36.0 | July | 81.4 |
| February | 41.1 | August | 80.9 |
| March | 49.7 | September | 73.5 |
| April | 59.4 | October | 62.2 |
| May | 67.5 | November | 48.1 |
| June | 76.9 | December | 39.0 |
| | | Annual | 59.6 |

## POPULATION

The population of Ottawa County according to the 1950 Census was 32,218, representing a decline of 3,631 persons (10 percent) since 1940. On the other hand, the population of Miami increased 41.5 percent during the 1940's, from 8,345 to 11,801 (table 3).

TABLE 3.

POPULATION IN OTTAWA COUNTY, 1930-1950.

| | 1950 | 1940 | 1930 |
|---|---|---|---|
| Ottawa County | 32,218 | 35,849 | 38,542 |
| Afton | 1,252 | 1,261 | 1,219 |
| Commerce | 2,442 | 2,422 | 2,608 |
| Fairland | 699 | 786 | 679 |
| Miami | 11,801 | 8,345 | 8,064 |
| North Miami | 486 | 393 | 503 |
| Peoria | 201 | 227 | 189 |
| Picher | 3,951 | 5,848 | 7,773 |
| Quapaw | 938 | 1,054 | 1,340 |
| Wyandotte | 242 | 348 | 271 |

## TRANSPORTATION

Ottawa County is served by three railroads and several bus and truck lines, and it has three Federal highways, two State highways, and a network of rural roads.

The St. Louis-San Francisco Railway has one line running through Miami and Quapaw to Kansas City, and another through Fairland and Wyandotte to St. Louis, Missouri. Afton is the junction point for these two lines. The Northeastern Oklahoma Railroad serves principally the mining district. The Kansas, Oklahoma, and Gulf Railroad has a main line from its northern terminus at Baxter Springs, Kansas, through Quapaw, Miami, and Fairland to Denison, Texas.

U. S. Highway 66 crosses the county from northeast to southwest. It enters near the northeast corner, passes through Quapaw, Commerce, North Miami, Miami, and Afton, and leaves near the southwest corner. U. S. Highway 69 enters from the north and passes through Picher and Cardin to Commerce, from which point southward it coincides with U. S. 66. U. S. Highway 60 enters the county from the east via Seneca, Missouri, and passes southwestward through Wyandotte and Fairland to a junction with U. S. Highways 66 and 69 about 5 miles north of Afton.

State Highway 10 runs north along the east side of Lake o' the Cherokees through Wyandotte to a point 4 miles north of that town. There it turns west through Miami to the west boundary of the county. State Highway 25 enters the county from the south near the west shore of Lake o' the Cherokees and turns west to Afton. The Federal and State highways are either paved or gravel-surfaced. Most of the rural section-line roads are surfaced with chat or gravel.

## AGRICULTURE

Agriculture is practiced throughout the county. The principal crops are wheat, soybeans, and corn (table 4), but many others are grown also. According to County Agricultural Agent Tom Autrey (oral communication, 1952), cattle can be put out to pasture 11 months of the year, and the raising of both beef and dairy cattle is increasing, the most rapid increase being among dairy cattle. Many of the small-farm herds in the county are Herefords.

On the other hand, one of the leading herds of Aberdeen-Angus cattle in the United States is in Ottawa County, and from it many of the herds of this breed in other parts of the country have had their start.

TABLE 4.

AGRICULTURAL PRODUCTS OF OTTAWA COUNTY, OKLAHOMA, 1949.
(From 1950 Census of Agriculture, U. S. Department of Commerce).

| | | | |
|---|---|---|---|
| A. | Value of products sold: | | |
| | Field crops, other than vegetables, fruits, and nuts | $ 773,362 | |
| | Vegetables | 3,700 | |
| | Fruits and nuts | 17,516 | |
| | Horticultural specialties | 53,990 | |
| | All crops | | $ 848,568 |
| | Dairy products | 655,140 | |
| | Poultry and poultry products | 260,824 | |
| | Livestock and livestock products, other than dairy and poultry | 1,490,959 | |
| | All livestock and livestock products | | 2,406,923 |
| | Forest products | | 7,184 |
| | All farm products | | $3,262,675 |
| B. | Some principal crops, in acres: | | |
| | Wheat | | 22,341 |
| | Corn | | 20,881 |
| | Hay | | 19,929 |
| | Oats | | 12,160 |
| | Soybeans | | 6,074 |
| | Sorghum (excluding sorghum for syrup) | | 4,100 |
| | Barley | | 742 |
| | Flaxseed | | 227 |
| | Cowpeas | | 119 |
| | Rye | | 56 |

## MINERAL INDUSTRIES

The principal industries of Ottawa County are the mining and milling of zinc and lead ores and the manufacture of tires.

Ottawa County is the only county in Oklahoma that produces zinc and lead, and mining has been an important source of income through the years. The mining area is part of the Tri-State mining district, which includes also parts of southwestern Missouri and southeastern Kansas. In 1952 the district produced 90,512 short tons of zinc (recovered metal) and 27,356 tons of lead, valued at about 31 and 8 million dollars, respectively. The Oklahoma part of the district produced 54,916 short tons of metallic zinc valued at $18,232,112, and 15,137 short tons of lead valued at $4,874,114 (Netzeband, 1953). In terms of both zinc and lead, Oklahoma produced about 60 percent, Kansas about 26 percent, and Missouri about 14 percent.

According to Dale and Beach (1951, p. 24, 33), the production of lead in Oklahoma was first reported for 1891 and the value was $500. The production of zinc began about 1894, and the value was $3,272. Peak production of both these metals was reached in 1925, when zinc totaled 283,371 tons valued at $13,910,604 and lead was 79,946 tons valued at $43,072,392. By 1949 the production of zinc had declined to 44,033 tons and that of lead to 18,858 tons. The total recorded since the beginning of mining until 1949 is 4,800,487 tons of zinc and 1,167,208 tons of lead. The average ratio of zinc to lead from Ottawa County mines has been about 4.1 to 1, but the ratio has varied considerably from year to year. Byproducts of the smelting of the zinc and lead ores are cadmium, germanium, and indium. The first two are produced commercially but indium has been produced only on an experimental basis. All the cadmium, germanium, and indium produced from Oklahoma ores comes from Ottawa County.

At one time nearly every mine had its own mill, but in recent years the trend has been toward the treatment of ores at large central mills. Most of the small mills, therefore, have ceased operations. The central mill of the Eagle-Picher Co., near Cardin, has a capacity of 15,000 tons daily and is the largest in the Tri-State district. Several smaller central mills also are operated in Ottawa County.

A waste-product of the milling of the ores is chat, or broken chert. Some of it is shipped from the mining district for use as concrete aggregate, ballast, and road material. Only a small fraction of the available chat is marketed, however, and the mining district is dotted with huge piles, many of which cover several acres.

Limestone for agricultural use has been quarried near Wyandotte and east of Quapaw. The quarries were inactive in 1951. Limestone from five localities in Ottawa County has been tested in the Industrial Research Laboratory of the Oklahoma Geological Survey and found suitable for the manufacture of rock wool (Wood, 1939, p. 18-19).

Tripoli is quarried from several pits in the east-central part of the county, whence it is shipped to a mill at Seneca, Missouri. It is used principally as an abrasive in polishing and buffing compounds. Other uses include filler, foundry facing, and rotary drilling mud.

Tar, or bitumen, has been encountered locally in some mines. Weidman (1932, p. 69) reports that in one mine it was collected for commercial sale as roofing material.

The coal seams that occur in the Krebs group in the western part of the county are too thin to be of economic importance under present conditions.

### OTHER INDUSTRIES

The B. F. Goodrich Co. in 1944 established a plant at Miami for the manufacture of automobile and truck tires of all sizes, and in 1951 employed 1,200 to 1,300 people. In 1952 additions were being constructed that were expected to make the plant one of the largest of its kind in the world and to increase the working force to about 1,600.

Miami has an ice plant, a cheese factory, several dairies, the shops of the Northeastern Oklahoma Railroad, and a factory manufacturing work clothes. Late in 1951 or early in 1952 the Edson Furniture Co. was established in Miami, with the expectation of employing about 75 people.

The St. Louis-San Francisco Railway has a roundhouse at Afton. Metal products, such as pitcher pumps, are manufactured at Quapaw, and many small machine shops and supply establishments in the northern part of the county serve the mining industry. Several small lumber mills are operated in the eastern part of the county.

The Milnot Co. manufactures a filled-milk product in a plant astraddle the Oklahoma-Missouri State line at Seneca, Mo. Part of the milk processed in this plant comes from Ottawa County farms.

## GENERAL GEOLOGY

By Stuart L. Schoff

### STRATIGRAPHIC SUMMARY

Limestone, chert, shale, and sandstone of Paleozoic age crop out at the surface of Ottawa County. In ascending order, these rocks are divided into the Boone formation, Hindsville limestone, Batesville sandstone, and Fayetteville shale, of Mississippian age, and the Krebs group, of Pennsylvanian age (table 5). The Boone has several members, of which only one, the Short Creek oolite, is differentiated on the geologic map accompanying this report (pl. I.) The Krebs group has in it the Hartshorne, McAlester, Savanna, and Boggy formations. Members are the Warner and Bluejacket sandstones, and the Doneley limestone. Along streams these formations are overlain by alluvium, and at other places they are overlain by terrace deposits. At places, also, they are overlain by a deposit of gravel and clay, the age of which is not accurately known. Possibly it is Tertiary, but more probably it is Quaternary.

TABLE 5.

GEOLOGIC FORMATIONS EXPOSED AT THE SURFACE OR ENCOUNTERED IN WELLS IN OTTAWA COUNTY, OKLAHOMA.

| System | Series | Group | Formation | Member | Thickness (feet) | Lithology and Water-bearing Properties |
|---|---|---|---|---|---|---|
| QUATERNARY | | | Alluvium | | 0-35 | Stream-laid gravel, sand, and clay; may be capable of yielding water freely but is essentially untested. |
| UNCONFORMITY | | | | | | |
| TERTIARY (?) OR QUATERNARY (?) | Pleistocene (?) or Pliocene (?) | | Unnamed gravel and clay | | 0-30 | Unconsolidated gravel and clay; pebbles up to 5 inches across, mostly of chert; yields little or no water to wells. |

UNCONFORMITY

| | | | | | | |
|---|---|---|---|---|---|---|
| PENNSYLVANIAN | DES MOINES | KREBS | Boggy formation | Bluejacket sandstone | ? | Light buff, cross-bedded, medium-grained sandstone. Oldest member and only one remaining in Ottawa County. Not an aquifer. |
| | | | Savanna formation | Unnamed member | 78 | Black fissile shale with clay-ironstone lenses; and dark gray shale, sandy in part. Doneley limestone member is dark, carbonaceous and fossiliferous. Sandstone 12 feet thick occurs 15 feet above limestone and 51 feet below top of formation. Only meager supplies of water available. |
| | | | | Doneley limestone | 3.8 | |
| | | | | Unnamed member | 2.5 | |
| | | | | Rowe coal | 0.3 | |
| | | | | Unnamed member | 15+ | |
| | | | McAlester formation | Unnamed member | 39.3 | Dark gray to black, laminated to fissile shale with layers of clay-ironstone concretions and coal zones. Little or no ground water. |
| | | | | Warner sandstone | 10 | Light buff, cross-bedded, thin-bedded, medium-grained sandstone. May yield small quantities of water to rural wells. |
| | | | Hartshorne formation | | 36 | Black, dark gray and light gray shale, laminated to fissile; coal; underclay; clay-ironstone; gray platy siltstone; and basal conglomerate 1.2 feet thick. Only meager supplies of water available. |

TABLE 5.—(Continued)
GEOLOGIC FORMATIONS EXPOSED AT THE SURFACE OR ENCOUNTERED IN WELLS IN OTTAWA COUNTY, OKLA.

| System | Series | Group | Formation | Member | Thickness (feet) | Lithology and Water-bearing Properties |
|---|---|---|---|---|---|---|
| UNCONFORMITY | | | | | | |
| MISSISSIPPIAN | CHESTER | | Fayetteville shale | | 40-50 | Gray or black fossiliferous shale; not known to yield water to wells. |
| | | | Batesville sandstone | | 10 | Calcareous fossiliferous fine-grained sandstone, grayish yellow, yellowish orange, and iron-stained grayish red. Locally may yield small supplies of water to rural wells. |
| | | | Hindsville limestone | | 20-51 | Alternating fossiliferous limestone and shale. May yield small quantities of water, which locally may contain hydrogen sulfide. |
| | UNCONFORMITY | | | | | |
| | OSAGE | | Boone formation | | 367 | Limestone, fine-, medium-, and coarse-grained; gray, light gray, bluish, and bluish gray; much chert; fossiliferous; locally dolomitic and oolitic; glauconite. Yields up to 1,000 gpm in places but openings in the rock are not uniformly distributed and yields are correspondingly erratic. |
| | UNCONFORMITY | | | | | |
| | KINDERHOOK | | Northview shale<br>Compton limestone | | 5-10 | Shale and limestone identified in well logs and possibly, also, unnamed beds that may have been exposed at surface before flooding by Lake o' the Cherokees. Not water bearing. |

| | | | | | | |
|---|---|---|---|---|---|---|
| DEVONIAN AND MISSISSIP-PIAN | | | Chattanooga shale | | 1-30 | Black thin-bedded bituminous and carbonaceous shale. Not water bearing. |
| UNCONFORMITY | | | | | | |
| ORDOVICIAN | CANADIAN | | Cotter dolomite | Unnamed | 123-163 | Dolomite and magnesian limestone with cherty lenses in surface exposures. Drill cuttings show chert, shale fragments, and oolite in the insoluble residues. May yield moderate volume of water. |
| | | | | Swan Creek zone | 20 | |
| | | | UNCONFORMITY | | | |
| | | | Jefferson City dolomite | | 270-340 | Cherty dolomite; may contribute water to wells penetrating it, but its ground-water potential is not known independently of the rest of the Canadian series. |
| | | | UNCONFORMITY | | | |
| | | | Roubidoux formation | | 105-180 | Dolomite and two or three layers of sandstone. Principal aquifer tapped by deep wells in Ottawa County; yields up to 600 gpm with large drawdowns. Water hard but otherwise of good quality. |
| | | | UNCONFORMITY | | | |
| | | | Gasconade and dolomite Van Buren formation | | 240 | Dolomite, limestone, and chert; Gunter sandstone member yields moderate quantity of water to public supply well at Quapaw. Beds above Gunter not known to yield significant amount of water. |
| | | | | Gunter sandstone | 60 | |

TABLE 5.—(Continued)

GEOLOGIC FORMATIONS EXPOSED AT THE SURFACE OR ENCOUNTERED IN WELLS IN OTTAWA COUNTY, OKLA.

| System | Series | Group | Formation | Member | Thickness (feet) | Lithology and Water-bearing Properties |
|---|---|---|---|---|---|---|
| UNCONFORMITY | | | | | | |
| CAMBRIAN | UPPER CAMBRIAN | | Eminence dolomite | | 105-140 | Dolomite, with chert, pyrite, oolites, and glauconite. Penetrated by two wells in Ottawa County; yield of water, if any, not known. |
| | | | UNCONFORMITY | | | |
| | | | Bonneterre dolomite | | 95-185 | Dolomite, with chert, sand, pyrite, and glauconitic shale fragments. Penetrated by two wells in Ottawa County; yield of water, if any, not known. |
| | | | UNCONFORMITY | | | |
| | | | Lamotte sandstone | | 40 | White sandstone with sand grains made irregular by secondary regeneration; igneous detrital material; low porosity. Penetrated by one well in Ottawa County; yielded no water. |
| UNCONFORMITY | | | | | | |
| PRE-CAMBRIAN | | | Granite | | ? | Granite encountered at depths from 1,045 to 1,770 feet in wells in Ottawa County. Not water bearing. |

Plate I (in pocket) shows the distribution of the exposed rock formations of Ottawa County. It is based on an unpublished geologic map of the Wyandotte quadrangle prepared about 1907 by Siebenthal and Messler, modified to show Lake o' the Cherokees (Grand Lake), the outcrops of the units of the Krebs group

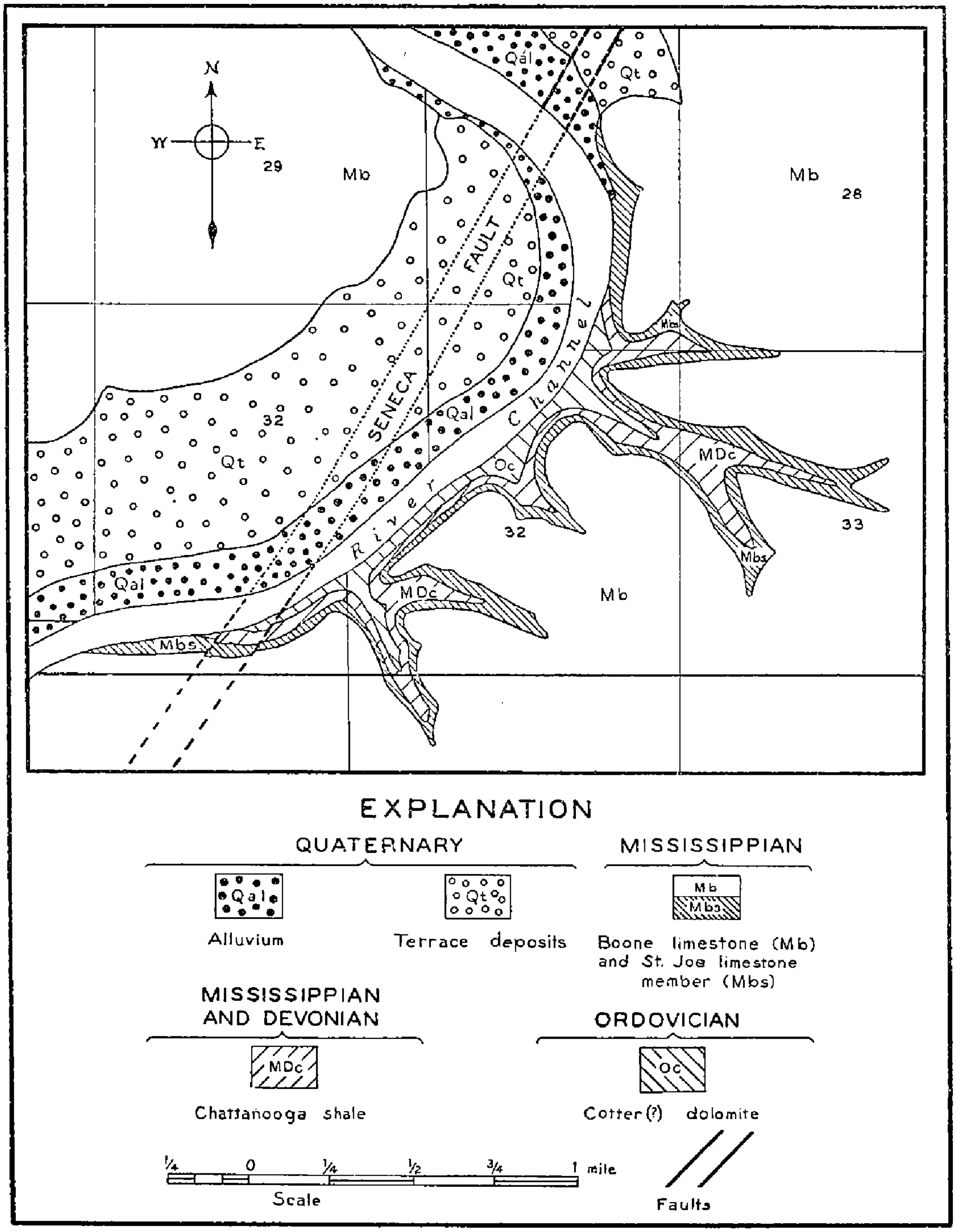



FIG. 3. Map of part of T. 26 N., R. 24 E., showing former outcrops of Ordovician, Devonian, and Mississippian formations along the Grand (Neosho) River, as mapped by Siebenthal and Messler.

as mapped by Branson, and the Short Creek oolite member of the Boone limestone as mapped by Speer (1951a).

Before flooding by Lake o' the Cherokees, the Chattanooga shale, of Devonian and Mississippian age, and dolomite beds of Ordovician age were exposed in the southern part of the county along the Grand (Neosho) River. These rock formations are not shown on plate I, but they are significant in the geological history of Ottawa County, and their former outcrops, as mapped by Siebenthal and Messler, are shown in figure 3.

A dolomite of Ordovician age shown on figure 3 is only the upper few feet of a thick sequence of dolomite, cherty dolomite, oolitic dolomite, sandy dolomite, and sandstone extending from Upper Cambrian into Lower Ordovician. Below is granite of pre-Cambrian age, which was encountered in the John Beaver well (28N23E-19)[1] at a depth of 1,770 feet below the surface. In one of the wells of The B. F. Goodrich Co., however, it was found at a depth of only 1,045 feet and five of the older formations were missing. In the John Beaver well the formations of Late Cambrian age are, in ascending order, the Lamotte sandstone, the Bonneterre dolomite, and the Eminence dolomite, and those of Early Ordovician are the Van Buren formation, Gasconade dolomite, Roubidoux formation, Jefferson City dolomite, and Cotter dolomite (Ireland and Warren, 1946, fig. 3). The Oklahoma Geological Survey classifies the formations of Early Ordovician age as the Canadian series.

## STRUCTURAL SUMMARY

Ottawa County is on a westward bulge of the southwest flank of the Ozark uplift, which is a dissected dome centered in Missouri. Erosion has stripped the sedimentary rocks from a part of the dome, exposing crystalline rocks of pre-Cambrian age. The crystalline core is surrounded, in surface exposures, by large areas of Cambrian and Ordovician rocks. Ottawa County is many miles from the middle of the dome and the rocks therefore dip in general to the northwest at low angles of only 15 to

[1] The well-numbering system is explained on p. 141.

20 feet per mile. Irregularities in the prevailing dip are related to local structural features, among them the Seneca fault, the Miami syncline, and the Horse Creek anticline.

The Seneca fault begins several miles northeast of the former settlement of Spurgeon, Missouri, which was about 8.5 miles east of the Missouri-Oklahoma State line, passes through Seneca, Missouri, and there enters Ottawa County, Oklahoma. It extends southwestward across Ottawa County (pl. I), northwestern Delaware County and diagonally across Mayes County, and has been identified in northwestern Wagoner County (Ireland, 1930, p. 30-31; 1930a, p. 496-497). Siebenthal (1908, p. 197-198) described it as consisting in part of a graben made by a simple pair of opposed breaks, with strong dips in the outer blocks toward the axial trough; and in part as a faulted syncline whose limbs consist of distributive faults having a cumulative throw toward the axis. He reported the displacement as ranging from 90 to 140 feet. Ireland (1930, p. 31; 1930a, p. 497) stated: "The greater part of the fault is double, letting down a graben, but south of Pryor Creek [now Pryor, Mayes County] there is only a single displacement. For 30 miles from where the fault enters Oklahoma, the Chester formations are let down into the Boone chert. . . . . The throw is about 100 to 200 feet." Weidman (1932, p. 35; and 1939, p. 51) referred to it as the Seneca "fault or syncline," expressing the view that it is "more of a syncline than a double fault, although faulting to a variable extent is associated with it." Speer (1951a, p. 43-44) called this structural feature a syncline because "the faulted character is not pronounced" and "most of the displacement [is] due to folding . . . . marked only by slight changes in dip of the Boone along [the] axis."

The Miami syncline is considered by Weidman (1932, p. 31-37; and 1939, p. 51-52) to be the most prominent structural feature in the northern part of the county (Miami-Picher district). He describes it as trending approximately N. 25° E. across Ottawa County from southwest of Afton through Picher and 15 miles into Kansas (pl. I). At different points along this general course its strike ranges from N. 20° E. to N. 30° E. It is about 0.5 mile wide, ranges from 100 to 200 feet deep, and has a bottom that is uneven, probably because of minor folds or small faults crossing its axis. Faulting is common along it, having been observed in the Angora mine and also near Afton, where the apparent displacements range from 50 to 100 feet. The west limb of the syncline is steeper than the east limb. Weidman points out that this structural feature has been called the Miami "fault", "trough," and "shear zone" as well as the "Commerce trough." He expressed a preference for the name Miami syncline, although recognizing that the structure is synclinal only part of the way. Speer (1951a, p. 45) reports, "The axis of the syncline crosses the Neosho River just west of Miami and at times of low water crumpled and broken strata of the Mayes (Chester) can be found in the bed of the river."

Regardless of the exact geologic nature of these two structural features—whether mostly fault or mostly fold—they are significant hydrologically. As will be demonstrated in the discussion of pumping tests, they are believed to be barriers to the movement of ground water in the rocks of the Canadian series.

Other and smaller folds in Ottawa County are described by Speer (1951a, p. 46) under the names Lincolnville syncline and Dripping Springs anticline. Evidence for these structures is found in exposures along the Spring River.

A northeast-trending fault has dropped the Warner sandstone member of the McAlester formation and higher beds to a position opposite the Hindsville limestone at Steppe Ford (sec. 5, T. 28 N., R. 21 E.). The Warner is dragged up on the fault plane and dips 3 degrees northwest. The throw is about 30 feet. The fault is named Steppe Ford fault for the Neosho River ford at the Hindsville exposure. The fault trace can be followed about 3.5 miles by stereoscopic examination of aerial photographs, but the only exposure of bedrock is that at Steppe Ford.

Several minor faults parallel to and adjacent to the axis of the Miami syncline are identifiable by drainage alignment. Two small faults with northwest orientation offset Chesterian rocks east of the syncline.

Within the region, other structural features superimposed on the flank of the Ozark dome are the Joplin anticline in Missouri nearby to the north and the Horse Creek anticline to the south. The Joplin anticline is described by Smith and Siebenthal (1907, p. 9) as trending northwestward approximately through Joplin. They state that the southwestern limb is the steeper, that the structural relief is at least 150 or 200 feet, and that between Joplin and Smithfield the structure may pass into a fault. The Horse Creek anticline is described by Siebenthal (1908, p. 198), Ireland (1930, p. 30, and 1930a, p. 496), and Speer (1950a, p. 42-43). It strikes northeastward from near the point where Cabin Creek enters Mayes County past Cleora and Bernice to the Grand River near the mouth of Elk River—where it crosses the Seneca fault—and thence eastward past Tiff City, Missouri. The north limb has a low northward dip averaging 2°. Dips on the steeper south limb range from 5° to 18°.

## GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTER

By Stuart L. Schoff

On pages that follow, the geologic formations are described in ascending order, from oldest to youngest, beginning with the pre-Cambrian granite. The descriptions are based principally on the published work of Weidman (1932) and Ireland (1930, 1930a, 1944), supplemented by information from other sources as indicated.

### PRE-CAMBRIAN ROCKS

Several wells in Ottawa County have entered the pre-Cambrian igneous rocks which underlie the sedimentary Paleozoic strata. Only granite has been found, although elsewhere in the region other types of crystalline rocks have been encountered. In Ottawa County the granite has been found at depths ranging from 1,045 to 1,770 feet. The depth may be greater or less at untested locations because the upper surface of the granite seems to be highly irregular, much like a hilly area. One of the wells of The B. F. Goodrich Co., for example, penetrated granite at 1,055 feet below the surface, but in two others less than a quarter of a mile to the west and to the north no granite was found, although depths of 1,200 and 1,465 feet were attained. Further evidence indicating an irregular surface on the granite is the absence of some of the lower sedimentary strata in the vicinity of the granite "peaks"—as if the peaks had been islands in the sea while the oldest sediments were being deposited. An alternate interpretation advanced by Weidman (1932, p. 78-80) is that the granite is a dike intruded into the sedimentary rocks. If so, the granite is not pre-Cambrian, but is younger than the sedimentary rocks.

Small outcrops of granite near Spavinaw in Mayes County, Oklahoma, are probably similar to the granite buried under Ottawa County. The several published views of the age and relationships of the granite are summarized by Ireland (1930, p. 12-15, and 1930a, p. 478-481) and by Tolman and Landes (1939, p.

76-81). Ham and Dott (1943, p. 1626-1631) have presented evidence to show that detritus from the granite at Spavinaw was incorporated in the lower beds of the overlying dolomite, and, hence, that the granite is older than the dolomite and so probably is of pre-Cambrian age.

### UNCONFORMITY AFTER PRE-CAMBRIAN

Sedimentary rocks older than Late Cambrian have not been identified in the drill cuttings from wells in Ottawa County and are presumed not to have been deposited. Erosion seems to have cut deeply, stripping away considerable thicknesses of the pre-Cambrian rocks and making an uneven surface having several hundred feet of relief.

### CAMBRIAN SYSTEM

The Cambrian system is represented by rocks belonging to the Upper Cambrian series, which nowhere in Ottawa County crop out at the surface but are identified in drill cuttings from deep wells. In ascending order, the formations of the Upper Cambrian are the Lamotte sandstone, the Bonneterre dolomite, and the Eminence dolomite.

## Upper Cambrian Series

#### LAMOTTE SANDSTONE

*Character and thickness.*—Ireland (1944) described the Lamotte sandstone on the basis of insoluble residues examined microscopically, as follows:

> "The Lamotte sandstone at the base of the Cambrian section is a white sandstone. Some of the sand grains are rounded, frosted 'snowball' sand, but most of them are irregular, having been regenerated by secondary growth. In most places the sand is tight and has little porosity. Igneous detrital material with pink feldspar and black or dark green crystalline fragments is found in a zone 5 to 50 feet thick in the basal part of the Lamotte sandstone. . . ."

The Lamotte sandstone was identified in the insoluble residues of drill cuttings from the John Beaver well (29N23E-19-2) on examination by the Missouri Geological Survey. The top was found at a depth of 1,730 feet, and the bottom at 1,770 feet below the land surface. Thus its thickness is 40 feet. It overlies pre-Cambrian granite. No other well in Ottawa County is known to have penetrated the Lamotte.

*Water supply.*—The low porosity mentioned by Ireland is an indication that little water can be expected from the Lamotte sandstone. The only well reported to have penetrated it did not obtain water from it.

### BONNETERRE DOLOMITE

*Character and thickness.*—Ireland described the Bonneterre thus:

> "The Bonneterre dolomite has a small percentage of residue near the top, but an increasingly greater percentage downward in the dolomite. Small amounts of chert and pyrite occur but the chief residue is sand and granular glauconitic gray shale fragments. The shale fragments are less argillaceous and more granular and silty in the middle and lower parts than in the upper parts. The sand increases downward and the basal bed, 20 to 40 feet thick, is composed altogether of sand in some wells. The dolomite thins westward from southwestern Missouri."

The Bonneterre dolomite was identified by the Missouri Geological Survey in the insoluble residues of drill cuttings from two wells in Ottawa County, the top being found at 1,410 and 1,545 feet, respectively, below the surface. Thicknesses are 95 and 185 feet (appendix A).

*Water supply.*—The Bonneterre dolomite is not a major aquifer in Ottawa County. It is not clear whether the wells that penetrate it derive significant amounts of water from it.

### EMINENCE DOLOMITE

*Character and thickness.*—The Eminence dolomite is the uppermost formation of the Upper Cambrian series encountered in wells in Ottawa County and adjacent Missouri. Ireland's description:

> "The Eminence dolomite is the top formation of the Cambrian. Residues from it are chiefly pyrite with some finely crystalline chert, dolocastic chert, and oolites. Except where oolites occur the residues make up less than 5 percent of the original samples, but most of the samples leave less than one percent residue. Glauconite is found in

> the Eminence dolomite, but is not as abundant as in the underlying Bonneterre dolomite. Little or no glauconite is found in the part of the Arbuckle group above the Cambrian, though it is abundant in the overlying Simpson group and Mississippian beds. The Eminence dolomite has been found only in wells in Ottawa and Craig Counties. The thickness decreases from Missouri southwestward into Oklahoma."

The Eminence dolomite was identified in the insoluble residues of drill cuttings from two wells in Ottawa County, the top being found at depths of 1,360 and 1,405 feet below the surface. The thicknesses are 105 and 140 feet.

*Water supply.*—No wells in Ottawa County are known to derive water from the Eminence dolomite, although possibly some water from it enters the wells that penetrate it.

## ORDOVICIAN SYSTEM

The Eminence dolomite is overlain by several hundreds of feet of dolomite and sandstone of Early Ordovician age, which with the Eminence are classified as the Arbuckle group by Ireland (1944). The formations identified in this sequence of strata are those distinguished in Missouri, not those of the Arbuckle Mountains, and the term Arbuckle group therefore is not used in this report. They are, instead, regarded as belonging to the Canadian series.[1] In ascending order, the formations of the Canadian in Ottawa County are the Van Buren formation with Gunter sandstone member, Gasconade dolomite, Roubidoux formation, Jefferson City dolomite, and Cotter dolomite. Ordovician rocks younger than the Cotter were eroded if they were ever present.

The Cotter dolomite formerly was exposed in the lower part of the east bluff of the Grand (Neosho) River in T. 26 N., R. 24 E., but has been concealed through flooding by Lake o' the Cherokees (Grand Lake). As the published account of this exposure is very brief, the description of this as well as other formations of the Canadian series is quoted from Ireland (1944), who made studies of insoluble residues from drill cuttings from deep wells along a line extending from Creek County near Tulsa, Oklahoma, northeastward beyond Joplin, Missouri. Although his descriptions were

[1] Canadian has been adopted as a series name by the Oklahoma Geological Survey, but the U. S. Geological Survey uses Lower Ordovician as the series name.

written to fit a large area, they are in the main applicable to Ottawa County. Ireland wrote, "Unconformities are placed in the geologic section to accord with those on the outcrop area of Oklahoma, Missouri, and Arkansas." His sections show unconformities at the base of the Gunter sandstone member of the Van Buren formation, the Jefferson City dolomite, and the Cotter dolomite.

### Canadian Series

#### VAN BUREN FORMATION AND GASCONADE DOLOMITE (UNDIFFERENTIATED)

*Character and thickness.*—Ireland described the Gasconade dolomite and the Van Buren formation together:

> "The sequence consisting of the Gasconade dolomite and Van Buren formation is identified by white, smooth, porcelaneous chert, chert with small dolocasts, and gray or dark chert generally in relatively large proportions. The upper part of the sequence in many wells has a zone with a small percentage of sand. In some places a zone of cryptocrystalline chert is found about 50 feet below the top of the sequence and is used by the Missouri Geological Survey as a marker for the top of the lower Gasconade of that Survey . . . . The Gunter is a basal member of the Van Buren formation and is generally a sandy dolomite in Oklahoma, though in Missouri it is in some places a sandstone."

The Missouri Geological Survey identified the Gasconade dolomite in the insoluble residues of drill cuttings from 10 wells in Ottawa County, in which the top is at depths ranging from 1,050 to 1,130 feet below the surface. In most of the wells the Gasconade could be divided into an upper part ranging from 50 to 70 feet in thickness, and a lower part 25 to 60 feet thick and between 1,100 and 1,200 feet below the surface. In three wells the combined thickness of the lower part of the Gasconade dolomite and the underlying Van Buren formation was 220 to 280 feet. In four wells the basal Gunter sandstone member of the Van Buren formation was 15 to 40 feet thick, and its top was 1,310 to 1,380 feet below the surface.

*Water supply.*—The Gasconade dolomite probably is not a major aquifer. It is doubtful whether it would yield freely enough to justify drilling to it if no water were available in other formations. Abernathy (1943, p. 104) indicates that the 20 feet of Gasconade penetrated in a well at the Jayhawk Ordnance Works, in Kansas, yielded water, but he evidently considered it of minor importance. Records of wells in Ottawa County that penetrate the Gasconade do not show how much water came from it, and the yield from the underlying Van Buren formation is nearly as unknown. The only producing wells in the county that tap the Gunter sandstone member of the Van Buren are the well of the General Power Co. at Quapaw (29N23E-35-3) and Miami municipal well 5 (28N23E-32). The well at Quapaw initially yielded only a few gallons per minute, a part of it doubtless coming from the Roubidoux formation. Acidizing the Gunter increased this yield to 30 gallons per minute. The Gunter sandstone member is rather widely tapped for water supplies in Missouri, where perhaps it is more permeable than it is in Oklahoma. It may be expected to have greater permeability where it is sandstone than where it is sandy dolomite, and the effect of acidizing it in the Quapaw well suggests that it has a considerable amount of dolomite (or carbonate rock of some kind) at that place.

### ROUBIDOUX FORMATION

*Character and thickness.*—Ireland's description of the Roubidoux formation follows:

> "The top of the Roubidoux formation is characterized by a distinctive brown quartzose oolite having many clusters of oolite grains and many free grains. In many places the oolite makes up the entire residue sample which may be 20 to 40 percent of the original sample. The Roubidoux has many very cherty zones as well as zones with large amounts of sand. In some wells a very sandy zone occurs near the top. A sandy zone near the middle of the formation and another near the base have as high as 80 percent sand and they are 15 to 30 feet thick. The sandy zone at the base of the formation generally serves as a marker for the top of the Gasconade."

The thickness of the Roubidoux formation in Ottawa County, as indicated by 11 logs based on microscopic examination of insoluble residues (appendix A), ranges from 105 to 180 feet and averages 160 feet. In three other wells 110 to 140 feet of the Roubidoux was penetrated, but the base may not have been reached. The average penetration of the Roubidoux in the 14 wells is 153 feet. The top of the formation was reached at depths ranging from 880 to 1,020 feet below the surface in the different wells.

*Water supply.*—All the public water supplies and most of the industrial supplies in Ottawa County come from wells drilled into the rocks of the Canadian series, among which the sandstone layers in the Roubidoux formation are the principal aquifers. The usual practice in completing such wells is to set and cement casing to some point below the Mississippian rocks—that is, a point in the upper part of the Cotter dolomite—leaving the rest of the hole uncased. Thus the waters of the Boone formation, which in places may be acidic, and the waters of the Chattanooga shale, which are small in volume but may introduce hydrogen sulfide, are cased out, but the waters from all the older formations are free to enter the well. These are hard but have relatively low concentrations of dissolved solids and are suitable for many uses. The temperature of the water ranges from 63° to 69° Fahrenheit. Wells yield as much as 600 gallons per minute, but drawdowns are large and water levels have declined progressively, making it necessary to lower pumps or deepen wells.

The hydraulic properties of the Roubidoux and associated formations, the performance of wells penetrating them, and the recharge to and discharge from them are discussed under the heading "Occurrence and behavior of ground water." The mineral content of the ground water is discussed under the heading "Chemical character of the ground water."

### JEFFERSON CITY DOLOMITE

*Character and thickness.*—Ireland described the Jefferson City dolomite thus:

> "The Jefferson City dolomite contains much chert whose proportion generally exceeds 10 percent and occasionally reaches 50 percent. Much of the chert is brown or tan, and most of it is smooth, but much of it is brown, sucrose, or finely crystalline. A dark brown sucrose oolitic zone, about 60 to 100 feet below the top, is an unusually good marker which the Missouri Geological Survey uses as the top of the lower Jefferson City dolomite of that Survey. Other oolitic zones occur farther down . . . . Very little sand is found in the Jefferson City. In Oklahoma the dolomite thickens southwestward to the maximum

within the area, but northeast of Vinita it has a relatively uniform thickness from 285 to 320 feet.''

As identified in the insoluble residues of drill cuttings from 13 wells in Ottawa County (appendix A), the Jefferson City is 270 to 340 feet thick. The average is 295 feet. The top was reached at depths of 540 to 675 feet below the surface.

*Water supply.*—The Jefferson City dolomite may contribute some water to wells penetrating it, but the magnitude of this contribution is not known separately from the contributions of other formations of the Canadian series. For the water-bearing properties of the Jefferson City dolomite, see the quotation from Abernathy in the section on the Cotter dolomite.

COTTER DOLOMITE

*Character and thickness.*—The dolomite exposed in the east bluff of the Grand (Neosho) River was described by Siebenthal (1908, p. 189) as " . . . . dolomite and magnesian limestones with oolitic, opalescent chert lenses. . . . From 10 to 13 feet of the formation is shown above low water." His unpublished geologic map of the Wyandotte quadrangle indicates that he considered these beds to be the Jefferson City limestone, but H. D. Miser (1950, oral communication) says they are much more likely to be part of the Cotter dolomite. Miser's interpretation is used here, especially as the Cotter is identified in several of the deep wells in Ottawa County.

Ireland's description of insoluble residues of drill cuttings is:

''Residues of the Cotter dolomite are sandy chert, translucent milky chert, dead white chert, very fine dolocastic fragments, fine silt aggregates, fine porous or dolocastic white or light green shale fragments, porous or finely dolocastic brown shale fragments, and quartzose oolite and oolitic chert. Many beds of quartzose and oolitic chert are found in the lower half of the formation. The oolites are generally white or brown in a matrix of chert with a different color, blue, gray, tan, brown, or white. Oolites occur as clusters or free spheres having a frosted appearance that is due to the fine coating of minute quartz prisms. The centers of the oolites are, in many wells, sand grains surrounded by concentric bands or shells. Oolites with a center of indeterminate material have radial structure most commonly, with a few concentric shells. The base of

> the Cotter in most places contains a sandy zone. The sand in this zone is uniformly very fine-grained and is generally less than 10 percent of the residue. The zone is rarely over 20 feet thick in thickness. It is called the Swan Creek zone and is fairly well developed in Missouri but less so in Oklahoma."

In 13 logs based on examination of insoluble residues of drill cuttings, thicknesses of the Cotter ranged from 143 to 183 feet and averaged about 165 feet. The top of the formation in these wells is 380 to 512 feet below the surface. As identified in some of these logs, the basal Swan Creek zone is 15 to 40 feet thick and its top is 520 to 620 feet below the surface.

*Water supply.*—Deep water wells in Ottawa County generally are uncased below the Chattanooga shale—that is, through the Cotter and underlying formations. The Cotter, therefore, may contribute more or less water to such wells, but the magnitude of this contribution is not known. The water is regarded by most observers as coming from the Roubidoux formation, which is the principal objective of most deep water-well drilling. Abernathy (1941, p. 232) considered the Cotter and underlying Jefferson City together as a significant aquifer, pointing out that the water occurs in solution cavities along an erosional unconformity, and that after entering the rocks in the outcrop area in the Ozarks it moves slowly westward down the dip. He wrote: "Several hundred deep wells have penetrated the water-bearing zone of the Jefferson City-Cotter beds in eastern Kansas and northern Oklahoma, and every such well finds an abundance of water in it. The water . . . . contains appreciable amounts of hydrogen sulfide, probably derived from the [overlying] Chattanooga black shale . . . . . Several municipal water plants derive their water supply from this formation and remove the hydrogen sulfide by use of an air lift or by aeration after pumping."

## POST-CANADIAN UNCONFORMITY

Rocks representing the Middle and Upper Ordovician, all the Silurian, and the Devonian below the Chattanooga shale are absent in Ottawa County, both at the surface and below. Their absence implies a long period of emergence during which sediments of these ages may or may not have been deposited. Any that were deposited in this time were eroded before deposition of the Chattanooga shale.

## DEVONIAN AND MISSISSIPPIAN SYSTEMS

### CHATTANOOGA SHALE

*Distribution, age, and character.*—A black shale near the boundary between the Devonian and Mississippian systems has been recognized in much of the Mississippi Valley. Named from Chattanooga, Tennessee, by C. W. Hayes (1891, p. 143), it has borne a variety of local names, such as Sylamore formation, Eureka shale, and Noel shale, from Arkansas and Missouri, and it has been widely correlated—for example, with the Woodford chert of the Arbuckle Mountains and the upper part of the Ohio shale of Ohio. Controversy has arisen over the age of the black shale, because in some regions the fossil evidence indicates Devonian age, whereas in others Mississippian age is implied.

The Chattanooga shale of Tennessee and vicinity, long classified by the U. S. Geological Survey as Devonian and Carboniferous, is now considered to be Devonian; that in the Batesville area of Arkansas is regarded as Devonian on the basis of fossil evidence; and that in the rest of Arkansas and northeastern Oklahoma—lacking fossils but much nearer to Batesville than to the type locality in Tennessee—as Devonian(?). The Chattanooga is generally regarded as a correlative of the Arkansas novaculite, from the middle member of which Hass (1951, p. 2535-2539) reports conodonts of both late Devonian and Mississippian (Kinderhook) age. Accordingly, Miser (1951, oral) in preparing the State geologic map of Oklahoma, has classified the Chattanooga as Devonian and Mississippian. This classification is used in the present paper.

The Chattanooga shale was exposed along the Grand (Neosho) River in the southern part of T. 26 N., R. 24 E. (fig. 3) before that stretch of the valley was flooded by Lake o' the Cherokees (Grand Lake). This was the northernmost exposure of the formation in Oklahoma and the only one in Ottawa County. Siebenthal (1908, p. 189) gave the thickness at this locality as 26 feet, and Ireland (1930, p. 19; 1930a, 485) and Weidman (1932, p. 10-11) reported 25 feet. According to the latter, it consisted of black thin-bedded bituminous and carbonaceous shale with well-defined joints trending about N. 50° E. and N. 60° W. He added that the shale is found in deep wells northward to the Kansas State line; that it is thin under the Picher area; and that it often has not been recognized by well drillers, although generally it can be identified if drill cuttings are examined carefully. Weidman (table 4, p. 11) lists 9 wells in which the Chattanooga shale was found to range from 1 to 35 feet in thickness, and Ireland (1930, p. 36; 1930a, p. 502) lists 10 wells in which it ranged from 1 to 30 feet in thickness. Based on their figures, the average is about 11 feet. According to Weidman's table the top of the Chattanooga was found at depths ranging from 370 to 538 feet below the surface, and the bottom at depths from 375 to 550 feet.

In the present investigation only two drillers' logs were obtained that seemed to record the Chattanooga shale. These are for the Lucky Syndicate well (No. 29N23E-17), in which 5 feet of black shale was logged between 475 and 480 feet, and the Scout Camp well (No. 28N24E-31), in which 10 feet of "brown lime and Chattanooga shale" was logged at 390 to 400 feet.

The logs of six wells drilled for The B. F. Goodrich Co. were prepared by the Missouri Geological Survey on the basis of microscopic examination of drill cuttings. These logs show 6 to 8 feet of the Chattanooga shale, the top lying at depths ranging from 430 to 462 feet below the land surface.

All the wells considered in the above paragraphs are in an area 5 to 8 miles wide extending northeastward from Afton through Miami to Picher. The relation of Chattanooga shale to the beds reported as Northview shale in three wells, cuttings of which were examined by the Missouri Geological Survey, is not clear.

*Water supply.*—The Chattanooga shale is not an aquifer from which to obtain even moderate supplies of water, and no wells in Ottawa County are known to tap water in it. The hydrologic importance of the Chattanooga rests mainly on the fact that, being relatively impermeable, it stops the downward movement of most of the ground water in the Boone formation and confines the water in the underlying dolomites. Ireland (1930, p. 18; 1930a, p. 484) pointed out that springs are common at the top of the Chattanooga shale because of its impervious character. Although Weidman 1932, p. 10-11) thought that the Chattanooga shale could be identified in the cuttings from most wells drilled to its horizon if samples were examined carefully, he also described the Chattanooga as thickening southward in Ottawa County and mentioned the absence of the formation farther east. Moore (1939, p. 5) states that the Chattanooga shale is absent "throughout the mineralized area of the Tri-State district." Hence, it is likely that the Chattanooga is absent in parts of northern Ottawa County, as many drillers' logs indicate. If so, there is no apparent impervious seal separating the Boone formation from the rocks of the Canadian series, and the ground water may be able to move from the one into the other. It is obvious that the waters may mingle where wells and test holes pass through the Chattanooga into the lower rocks and remain uncased or unplugged.

## MISSISSIPPIAN SYSTEM

### Kinderhook Series

#### NORTHVIEW SHALE AND COMPTON LIMESTONE

*Distribution and character.*—Snider (1915, p. 22-24) and Ireland (1930, p. 20; 1930a, p. 486) described the occurrence in northeastern Oklahoma of a greenish-black or dull blue soft or earthy shale and shaly limestone between the St. Joe member of the Boone formation and the underlying Chattanooga shale. This shale is unfossiliferous but was thought because of its stratigraphic position to represent the Kinderhook series. None of the localities mentioned by Snider and Ireland is in Ottawa County, and Weidman (1932, p. 11) did not discuss Kinderhook strata in his report on the county. Such beds probably will not be found at the surface in Ottawa County now that the only exposure likely to include them is concealed by the waters of Lake o' the Cherokees.

In southwestern Missouri the Kinderhook series includes the Northview shale and an underlying limestone, the Compton. The relationship between them is a gradational transition (Weller, 1901, p. 140; Moore, 1928, p. 60, 108-109, 111, 118-122, 131, 158). These two formations were identified in cuttings from four wells in Ottawa County by the Missouri Geological Survey, as follows: John Beaver (29N23E-19), 5 feet of Northview at depths of 440-445 feet below the surface; town of Quapaw (No. 29N23E-35), 5 feet of Northview at 370-375 feet; Eagle-Picher central mill, well 2 (No. 29N23E-31), 10 feet of Northview and Compton at 485-495 feet; and McCoy greenhouse (No. 28N22E-24-6), 25 feet of Northview and Compton at 430-455 feet. The log for the last-mentioned well records 5 feet of the Chattanooga shale underlying the Compton limestone. It is the only log that mentions the Chattanooga as well as the Northview and Compton, and so is the only one in Ottawa County that gives the stratigraphic relations of these units.

*Water supply.*—The Kinderhook strata have neither the lithologic characteristics of a good aquifer nor the thickness to afford much storage capacity. No water wells in Ottawa County are known to tap water in them.

**Meramec and Osage Series**

The bedrock at the surface in most of the eastern half of Ottawa County is the Boone formation. Much of this formation is referred to the Osage series, but the upper part may belong to the Meramec series. The Boone is not a single lithologic unit but includes several subdivisions, which have much in common lithologically and therefore are not easily differentiated at all places, although some of them have been widely recognized. Boundaries between some of the subdivisions signify periods of erosion, not deposition, and these periods have a bearing on the occurrence of ground water.

The Boone formation includes parts of two series within which are five units. Where recognized these have formation rank (Hopkins, 1893, p. 253; Smith, 1903, p. 198; Smith and Siebenthal, 1907, p. 5; Snider, 1914, p. 615-618; 1915, p. 25-26; Siebenthal, 1915, p. 26-27; Purdue and Miser, 1916, p. 10; and Weidman, 1932, p. 11-17). Moore and others (1939, p. 2-4) have summarized the stratigraphic relationships of these formations, giving lithologic descriptions, showing the positions of members known from outcrops, and listing the lettered beds recognized in the mining area. The following table is condensed from their tabulation.

TABLE 6

SUBDIVISONS OF THE BOONE FORMATION AS OUTLINED BY MOORE AND OTHERS.

MERAMEC series
- *Unconformity*
- Warsaw limestone (comprises upper part of the Boone formation as this term is employed in the Tri-State area)
- *Unconformity*

OSAGE series (comprises middle and lower part of the so-called Boone formation)
- Keokuk limestone, including the Short Creek oolite member
- *Unconformity*
- Burlington limestone (absent in the mining area)
- *Unconformity*
- Reeds Spring limestone
- *Unconformity*
- St. Joe (or Pierson) limestone
- *Unconformity*

KINDERHOOK series

### BOONE FORMATION

The Warsaw, Keokuk, Burlington, and Reeds Spring have not been distinguished in the geologic mapping thus far done in Ottawa County, and the name Boone is therefore retained in this report for the whole sequence of cherty limestone strata. Siebenthal and Messler distinguished the St. Joe limestone member on their unpublished map of the Wyandotte quadrangle, and their mapping of its outcrop along the Grand River in the southern part of T. 26 N., R. 24 E. is shown in figure 3. At normal stages of Lake o' the Cherokees, this outcrop is under water (Speer, 1951a, p. 43), but at low stages, such as that of March 1954, it is temporarily exposed (Speer, oral communication). It was the only outcrop of the St. Joe in the county.

The Short Creek oolite has been mapped by Speer (1951a), and its outcrop as shown on plate I of this report is from his work. The Grand Falls chert member, described by Siebenthal (1915, p. 27) as occurring about 100 feet below the Short Creek oolite member and assigned by Moore and others to a position in the lower part of the Keokuk, may be merely a weathered phase of cherty limestone rather than a stratigraphic unit. Weidman (1932, p. 17) found much irregularity in the cherty zones, there being in some places several zones of abundant chert and in other places no well defined single zone of it. The Green limestone of Weidman (1932, p. 15) is a unit of uncertain relationship. Described as 5 to 20 feet thick and 25 to 30 feet above the Short Creek oolite member of the Boone formation, it has been mentioned only by Ireland (1930, p. 21; 1930a, p. 387) among the later authors. Possibly it is the glauconitic limestone (bed J) at the base of the Warsaw limestone as described by Moore and others (1939, p. 3, 9). The name is not acceptable in geologic literature because it is taken from a color peculiarity of the rock, not a geographic locality.

*Distribution, character, and thickness.*—The Boone formation crops out in the eastern half of Ottawa County from the Missouri State line westward to where it is covered by younger rocks. The boundary between these rocks and the Boone is an irregular line that roughly parallels and is from 0.2 mile to 2.5 miles west of the Spring River. The contact line crosses the Neosho River near Miami, passes about 2 miles east of Fairland, and skirts the east side of Afton. The outcrop in Ottawa County is part of a large outcrop extending into southeastern Kansas, southwestern Missouri, and northwestern Arkansas. In Oklahoma the outcrop extends southward across Delaware and Mayes Counties into Cherokee and Adair Counties.

The Boone consists of bluish gray to light gray limestone and gray to white chert. Weidman (1932, p. 13-14) determined the amount of the rock that is insoluble in hydrochloric acid, and found that it ranges from 16 to 80 percent at different horizons within the formation. He stated that the residue consists "mainly of quartz in the form of chert or flint, a small part being mainly clastic quartz grains and fine clay particles. The quartz grains and the clay particles are considered of primary origin being deposited with the limestone strata, but the insoluble residue in excess of 10 or 15 percent . . . . . was apparently introduced as secondary chert, a product of silicification." His study of samples from the well of the Ottawa County Welfare Home (well 27N22E-12) led to the conclusion: "The lower half of the Boone in this well contains more chert than the upper half, the upper half being mostly limestone, and the lower half mostly chert." Weidman noted the occurrence at several horizons in the Boone of thin seams and lenses of black shale. These range from 1 to 6 feet in thickness. The characteristics of the St. Joe limestone member and the Short Creek oolite member are described in paragraphs that follow. The records of 15 wells indicate that the thickness of the Boone in Ottawa County ranges from 329 to 393 feet and averages about 367 feet (Weidman, 1932, p. 12).

*St. Joe limestone member.*—The basal member of the Boone is the St. Joe limestone. According to Ireland (1930, p. 20; 1930a, p. 486) the former outcrop along the Grand River was about 15 feet thick, and about 5 feet above the base there was a soft blue shale 3 or 4 inches thick. For several localities south of Ottawa County he gave thicknesses ranging from 8 to 20 feet. Weidman (1932, p. 15) stated that the St. Joe as recognized in the mining district ranges from 30 to 40 feet in thickness and consists of shaly and sandy dolomitic limestone with little or no chert; outside the mining district he found little dolomite in it. The St. Joe member is equivalent to the "Pierson" and Sedalia limestones of Missouri and the Fern Glen limestone (Moore and others, 1939, p. 7-8).

*Grand Falls chert member.*—The Grand Falls chert member described by Siebenthal (1915, p. 27) as occurring about 100 feet below the Short Creek oolite, appears not to have been identified in surface exposures in Ottawa County. Weidman (1932, p. 17) found much irregularity in the cherty zones of the Boone, there being, in some places, several zones of abundant chert and in other places no well-defined single zone of it. He concluded that the cherty portion of the Boone is not a definite stratigraphic horizon.

*Short Creek oolite member.*—The Short Creek oolite member was reported by Siebenthal (1908, p. 190) to be present in the eastern half of Ottawa County, but to pinch out or lose its oolitic character west of the Neosho and Spring Rivers. It is widely recognized in prospect holes in the mining district. According to Speer (1951; 1951a), the Short Creek occurs in the southern and eastern parts of the county, its northernmost exposure being 7 miles east of Miami near Dripping Springs on the Spring River. At the base it grades upward from dense gray limestone, but at the top the change from oolite to chert is rather abrupt. The upper part of the Short Creek generally contains very little chert. On the other hand, only a few oolites occur in the overlying chert and these are confined to the basal inch. The size of the oolitic spherules in the Short Creek is rather uniformly 0.02 to 0.03 inch, except in the upper part where they are slightly larger. The rock is gray when fresh, becoming white on weathering. It is a solid layer with few joints or other fractures, and in outcrops it ranges from 2 to 10 feet in thickness. Greater thicknesses reported from test holes may be exaggerated because of inaccuracies inherent in methods of sampling drill cuttings.

*Water supply.*—Next to the Roubidoux formation, the Boone formation is the most important source of ground water in Ottawa County, but the water in it has been utilized only to a small extent. As is the case in limestones generally, the water in the Boone occupies and moves through an intricate system of fractures and solution openings. Where such passageways are numerous, large, full of water, and readily replenished, an abundant water supply is obtainable. Where the passageways are few and small, the water supply may suffice only for domestic use on a farm. Where the rock is solid throughout, a well will prove to be a dry hole. Which condition is true of a given location often cannot be ascertained before drilling, but a statement of the controlling geologic factors may be helpful.

The openings in the Boone formation have been localized both vertically and horizontally by the geologic processes that have been active in the area. Especially significant are the periods of erosion that interrupted the deposition of the Boone. These are represented by the uneven surfaces—known as unconformities—separating the Warsaw limestone from the Keokuk limestone, and the Keokuk from the Reeds Spring limestone. Possibly, also, the Reeds Spring may be separated from the St. Joe limestone member of the Boone formation by an unconformity. In the geologic past these formations, beginning possibly with the St. Joe, were successively exposed at the surface, subject to weathering and to the dissolving action of percolating water, and they therefore were made more or less porous and permeable, especially in their upper parts. Then they were submerged again in the sea and buried under sediments of the next younger rock unit. Thus as the drill penetrates the rocks known collectively as the Boone it passes alternately through solid and porous strata.

The structural history of the region also has a bearing on the localization of porosity and of ground water. During several periods of regional deformation the Ozark Mountains were uplifted, and in this process the rocks were considerably sheared and shattered. To a marked degree the shattering was localized along certain zones, the most important of which, in Ottawa County, is the Miami syncline, or "shear trough". Joint and fissure zones and local structures along the syncline have combined to permit the solution and removal of large amounts of limestone by circulating ground water, so that in their present condition these fracture zones are excellent ground-water reservoirs. Some beds, such as the Grand Falls and other cherty members, were relatively competent and reacted to the mountain-building stresses by fracturing rather than by bending, even at places outside the zones of most intense shearing. The Grand Falls chert member is known locally as the "water flint" because of the abundance of water in it.

The fractured condition of the rocks along the northern part of the Miami syncline is especially well known because some of the natural openings have been partly filled with lead and zinc minerals, and the rocks have been studied in hundreds of mine shafts and tunnels and thousands of test holes. Conceivably, similar conditions of fracturing and solution may prevail in the Boone formation along the Seneca fault and Horse Creek anticline, which seem to lack mineral deposits and therefore offer little incentive for mineral prospecting.

Because ground water must be removed from the mines if mining operations are to go forward, the best available evidence of the hydraulic properties of the Boone formation is from the mining area. This area probably is not typical of the Boone generally, but the testing done in it is worth mentioning as a suggestion of what to expect under favorable conditions.

In 1932 C. F. Williams (1932, p. 105) stated: "A recent survey showed that 43 stations in the Oklahoma-Kansas field were lifting an average of more than 9,000 gallons per minute over a 24-hour period." This is about 13 million gallons per day. Jacobsen (1944) reported that the unprecedented wartime demand for lead and zinc had led to the reopening of some mines and the deepening of others to levels previously considered uneconomical, with consequent multiplication of mine-dewatering problems. He was certain, therefore, that the total pumpage exceeded 9,000 gallons per minute. The Eagle-Picher central pumping station at Picher alone was said to be pumping nearly 5,000 gallons per minute. Two wells of the United Zinc Smelting Corp. on the Park-Walton lease were pumping more than 2,000 gallons per minute, and many smaller pumping plants were making significant contributions to the total. By 1948, however, the demand for lead and zinc had fallen off, mining activity had decreased, and the total withdrawal of ground water from the Boone formation probably was less than 9,000 gallons per minute.

Williams described mine dewatering thus: "The common practice is to drain the underground water to a sump, usually at the shaft, either by means of ditches along the drifts or by pumping. From this point the water is raised to the surface by electrically driven centrifugal or triplex pumps. In one mine. . . . a natural cave is utilized as a reservoir for temporary storage during the daily pumpage period. In some mines strong acid water is encountered and special acid-resisting pumping equipment has been installed."

In addition to the water discharged from the mines, a considerable volume of water is discharged naturally from the Boone formation through many springs in the eastern part of Ottawa County, and rural wells withdraw water for domestic and stock use. It is estimated that in 1948 the total discharge of water from the Boone was more than 28 million gallons per day. Only a small fraction, however, was discharged for beneficial use. As Jacobsen (1944) pointed out, the aim of the mining companies is not to pump a specified quantity of water but only to keep the water level low enough to permit mining. Heavy pumping nearby for any other purpose would contribute to this objective and would allow the mining companies to reduce their own pumping. Thus new pumpage for purposes other than dewatering would salvage water that otherwise would go to waste. Whether such salvage will be practiced depends in part on the chemical quality of the water to be salvaged. Salvage of some of the water discharged from springs appears entirely feasible.

Despite the large volume of water discharged from the Boone formation, the water table remains high in the Boone in Ottawa County except in the mining district, and evidence of excessive withdrawal is lacking. The withdrawal of additional large amounts of water without overdraft of the ground-water reservoir should be possible. It should not be forgotten, of course, that most of the reports of large yields originate in the mining district, where geologic processes may have been especially effective in creating openings in the rock, and therefore that much smaller yields may be the rule in other localities. The erratic occurrence of water in the Boone makes it difficult to predict accurately the yields of individual wells. The desirability of adequate test drilling prior to constructing large and costly wells is evident, but the cost of testing may be offset by the dependability of the supply once it has been developed, by the relatively low pumping lifts compared with the lifts in the deep wells, and by the somewhat lower temperature of the water where cooling is the objective. The possibilities of "shooting" and acidizing to increase the yields of wells in the Boone merit consideration.

Except in the mining district, the water from the Boone is of good quality and is suitable for most uses (table 12). A serious drawback to the utilization of the ground water of the Boone for public supplies is the danger of contamination. Polluted surface waters may enter it readily through fractures, some of which have been enlarged by solution, and through sinkholes. The Boone, like limestones generally, effects little filtration of the water that passes through it, and water drawn from it for human consumption should be tested for bacterial contamination before use is begun, and regularly thereafter.

The opportunities for replenishment of the ground water in the Boone appear to be good. They are discussed in detail in the section headed "Recharge and discharge, by aquifers." The springs that issue from the Boone are discussed in a separate section elsewhere in this report. A 7-month pumping test in Cherokee County, Kansas, and an elaborate test made on the Park-Walton property, both tests relating to the ground water of the Boone, are discussed in the section on pumping tests.

## Post-Boone Unconformity

The upper boundary of the Boone formation is generally regarded as an unconformity (Snider, 1914, p. 618; 1915, p. 26-27; Moore and others, (1939, p. 11). Weidman (1932, p. 12, 30) noted that within Ottawa County the thickness of the Boone, as recorded in the logs of 16 water wells, differs from place to place, the maximum difference being 64 feet. Recognizing that part of the difference in thickness might be due to original differences in deposition, he estimated that 40 to 50 feet of strata had been eroded. He pointed to the chert-pebble conglomerate in the lower beds of the overlying Chester series as further evidence of the unconformity.

## Chester Series

Rocks belonging to the Chester series, of Mississippian age, overlie the Boone formation. The principal outcrop is a band ranging from 1 mile to 7 miles in width, which is widest near Narcissa and Fairland and narrowest near the Kansas State line. Both boundaries of this band are sinuous, but the eastern one is especially so because the Chester extends eastward or southeastward down ridges, notably the one between the Neosho and Spring Rivers. Many outliers of rocks of the Chester series occur east of the main outcrop, among them a large, elongate outlier just north of the Delaware County line in T. 26 N., Rs. 24 and 25 E. Several smaller outliers occur east of the Spring River in Tps. 27-29 N., Rs. 24 and 25 E. The Chester rocks will be found in wells that begin on the outliers, in the main area of outcrop, or on the outcrop of the rocks of the Krebs group. Elsewhere in Ottawa County the Chester rocks have been eroded.

Siebenthal (1907, p. 190; 1915, p. 28) described what he called the Chester group of Ottawa County as consisting of the Batesville sandstone below and the Fayetteville formation above. The Pitkin limestone, mentioned by him as occurring above the Fayetteville in the Wyandotte quadrangle, does not extend into the county. He mapped as the basal member of the Batesville a limestone which later proved to be the same as a limestone in Arkansas which was named the Hindsville limestone member by Purdue and Miser (1916, p. 12). Referring to the Wyandotte quadrangle, these authors pointed to the similarity in lithology and stratigraphic position, at the same time stressing the absence in Oklahoma of small pelecypods and gastropods. Miser (oral communication) has proposed that in Ottawa County the Hindsville be ranked as a formation, and this classification has been accepted by the U. S. Geological Survey. In the Joplin area, Smith and Siebenthal (1907) used the name Carterville formation for the rocks of Chester age, which they found to be closely related faunally to the Batesville sandstone and the Fayetteville shale.

Snider (1914, p. 618-620) considered as a unit all the beds in northeastern Oklahoma that occur between the top of the Boone formation and the base of the Fayetteville shale. Although he recognized the stratigraphic units mapped by Siebenthal, he expressed doubt as to their correlation. He considered the name Batesville to be not applicable to rocks in the Wyandotte quadrangle [including Ottawa County] because "the Batesville sandstone of Arkansas does not extend into Oklahoma on the south side of the [Ozark] uplift." Nevertheless, he pointed out that the Batesville sandstone as identified by Siebenthal "occupies practically the same stratigraphic position as the typical Batesville," and that the limestone below it "is almost certainly the northward continuation of the unnamed Chester limestone" observed by him elsewhere in the region.

In 1915 Snider (p. 27) proposed the name Mayes formation, taken from Mayes County, Oklahoma, for the zone including the "unnamed limestone," Siebenthal's Batesville, and older beds that occur farther south. This name has been widely used (Miser, 1926; Ireland, 1930, p. 22; 1930a, p. 488; and Weidman, 1932, p. 18, 21). The U. S. Geological Survey accepts the name Mayes for use in Mayes County and some other parts of northeastern Oklahoma, but retains the older names and subdivisions where they can be distinguished, as in Ottawa County. On the pages that follow the name Mayes has been used in places because the authors quoted used it, and to substitute the nomenclature of the present report would amount to misquoting them. What an author wrote about the Mayes formation is interpreted and applied to the rock units distinguished in this report. The interpretations are the junior author's.

Ireland (1930, p. 25; 1930a, p. 491) and Weidman (1932, p. 18) stated that the beds of the Chester, or Mayes formation, do not terminate in northern Ottawa County, as indicated by Siebenthal's map, but extend into Kansas. This conclusion was based on exposures of these beds in Cherokee County, Kansas, near Baxter Springs and farther north along the Spring River and Brush Creek. Weidman added that the "basal limestone member of the Mayes" (i.e., the Hindsville) had been identified in drillers' logs in the Kansas mining area.

### HINDSVILLE LIMESTONE

*Character and distribution.*—The oldest formation in the Chester series of Ottawa County is the Hindsville limestone. It was mapped but not named by Siebenthal, who described it as consisting of 20 to 40 feet of flaggy crystalline limestone, in places massive, in part oolitic, and arenaceous toward the top. Siebenthal expressly stated that it is "free of chert," but Weidman (1932, p. 19) found it to be much silicified, as well as dolomitized, near the ore deposits in the mining district. He states that the cherty (silicified) phase of the limestone "is not exactly like the Boone chert, but closely resembles it in many places."

The Hindsville limestone crops out as an irregular band extending from near Afton northeastward beyond Miami. This outcrop is widest—about 5 miles—between Fairland and Narcissa. The Hindsville occurs also in outliers east of the Grand (Neosho) and Spring Rivers.

Snider (1915, p. 31) considered this zone of limestone to be part of the Mayes formation of northeastern Oklahoma, and he described a hill near the NE cor. sec. 3, T. 27 N., R. 23 E. (Ottawa County), where the Mayes consists of 60 feet of limestone capped by coarse sandstone. These beds had been mapped as the Batesville sandstone and an underlying unnamed limestone (Hindsville) by Siebenthal. Snider stated that the limestone is "partly siliceous and platy, but the greater part is a coquina-like mass of comminuted fossils," and he added that it is very porous.

Weidman (1932, p. 61) gives a 61-foot section of the Mayes formation in the NE¼NE¼ sec. 35, T. 28 N., R. 24 E., which begins at the contact with the underlying Boone and extends upward to include 10 feet of sandstone mapped by Siebenthal as an outlier of the Batesville. The 51 feet below the sandstone represents the Hindsville and consists of alternating shale and limestone, the total thickness of shale being 27 feet and the total of limestone 24 feet.

Weidman (1932, p. 18) described an exposure of the basal limestone of the Mayes formation at the bridge of the Kansas, Oklahoma, and Gulf Railroad over the Neosho River downstream from Miami. He stated that 15 feet was exposed, beginning about 15 feet above the lower-water stage of the river, that a thin conglomerate of chert pebbles in a limestone matrix is included at the base, and that quartz grains are abundant in both the basal conglomerate and the overlying coquinalike fossiliferous limestone.

*Water supply.*—If the porosity noted by Snider is widespread in the limestone beds of the Hindsville, this formation may be capable of yielding moderate quantities of water to wells intended for farm use. Such porosity, however, is likely to be related to the opportunities afforded for leaching by water from the outcrop, and it is therefore unlikely that large quantities of ground water are available in limestones of the Hindsville generally. No information is available to show whether the limestones have fissures or openings along bedding planes that have been enlarged by solution and extend to considerable depths. It may be safe to assume that below the surface at relatively short distances from the outcrop these limestones are solid and essentially impermeable. Even if they were highly porous and permeable, the quality of the water in them is dubious. G. G. Huffman (oral communication) reports that at some localities the water in this formation is sulfurous and has a bad odor and taste, probably because of the decomposition of the pyrite ($FeS_2$) and carbonaceous matter contained in the rocks. The shale in the Hindsville is no more likely to yield large volumes of water than is the shale of other formations.

## BATESVILLE SANDSTONE

*Character and distribution.*—The Batesville sandstone is the middle formation of the Chester series in Ottawa County. It crops out as a band 0.25 mile wide, or less, between the Hindsville limestone and the Cherokee formation, except south of Narcissa where the formation adjacent on the west is the Fayetteville shale. The outcrop is interrupted at the Neosho River, where the formation is overlain by terrace deposits and alluvium. Between the river and Narcissa the outcrop is discontinuous, and farther south it consists of two areas west of Fairland and north of Afton, which in places are nearly 1 mile wide, together with many outliers on hills to the east. Likewise, many outliers ranging from a few acres to 1 or 2 square miles in area dot the northeastern quarter of the county (pl. I). Inliers of the Batesville occur along Tar Creek between Miami and Picher and on one tributary of Tar Creek.

Two samples of sandstone were collected by the junior author of this report from outcrops mapped as Batesville. Both are noncalcareous. One is pale yellowish brown on the exposed surface, and is grayish yellow, dark yellowish orange, and white on fresh surfaces. The adjective "fresh" should be regarded as of relative value, because the effect of weathering doubtless extends into the rock beyond the limit of the sample. The sample is composed of very fine quartz sand together with a few flakes of colorless mica and a few black grains having a low luster and no obvious cleavage. Most of the quartz grains are colorless and white; some are liberally stained yellow.

The other sample also is very fine grained and composed mainly of quartz, but nearly all the grains are stained dark red. The weathered and "fresh" surfaces both are grayish red, although differing slightly in shade. The rock is well cemented.

According to Weidman (1932, p. 19-20), the sandstone in the Mayes formation (Batesville) generally is "fine grained and friable except in the vicinity of the ore deposits, where it is extensively silicified into hard, quartzitic sandstone. Thin sections of both friable and quartzitic phases contain a variable amount of clastic feldspar grains. Analysis of the sandstone from the top of the hill 2 miles east of Miami shows 7 percent soluble calcareous material, 67 percent quartz sand, and 26 percent feldspar sand. In addition a few grains of tourmaline, zircon, and muscovite are present."

Field observations in 1950 led G. G. Huffman (oral communication) to suggest that the Batesville is a sandy facies of the Hindsville, and that several sandstone beds of the Batesville are present at some places because of interfingering of the sandy and limy lithologies. The typical Batesville sandstone is generally found on top of hills, at which location the circulation of both surface and ground waters is fairly rapid and the lime therefore could have been leached out, leaving mostly sand. The occurrence of the sandstone at or near the tops of hills is evident both from the descriptions by previous writers and from the great number of outliers of the Batesville mapped by Siebenthal (pl. I). Huffman states that according to well drillers the Batesville where encountered below younger formations is hard and "drills like lime."

Referring to the sandstone cap rock, Weidman (1932, p. 19-20) wrote that the thickness of the sandstone in the Mayes is 10 feet. The sandstone is the Batesville. Huffman (oral communication) likewise says that the thickness is not more than 10 feet.

*Water supply.*—The Batesville sandstone is not an aquifer of major rank in Ottawa County. In general, the available records do not indicate whether wells obtain water from it. It may be adequate as a source of water supply for farms where its thickness has not been greatly reduced by erosion, where it has been made porous by leaching, and where it is so situated that not all the water entering it is soon drained out. Such conditions may be met on some of the larger outliers. At depth and below younger formations the Batesville may not be water bearing.

### FAYETTEVILLE SHALE

*Character and distribution.*—The youngest formation of the Chester series exposed in Ottawa County is the Fayetteville shale, named for Fayetteville, Arkansas (Simonds, 1891, p. 42-48). Near that place it consists of two shale members separated by the Wedington sandstone member, and it totals about 120 feet in thickness.

In Ottawa County the Fayetteville shale is present only in the vicinity of Afton, Narcissa, and Fairland. The principal outcrop extends northeast-southwest across the middle of T. 26 N., R. 22 E., between the outcrops of the underlying formations of the Chester series and the overlying Des Moines series (pl. I). This outcrop is less than 0.1 mile wide at the Craig County line about 2 miles west of Afton. It widens northeastward to a maximum of about 1.5 miles in the northeastern quarter of T. 26 N., R. 22 E., and it ends about 1 mile southeast of Narcissa. An outlier just north of Fairland covers about 1.75 square miles and another 0.5 mile southeast of the same town covers less than 0.25 square mile. The latter probably is the "small conspicuous knoll of earthy and platy limestone" that Snider (1915, p. 37) and Ireland (1930, p. 23; 1930a, p. 482) described as the "northernmost" exposure. Ireland added: "To the north of this point the formation has been removed by erosion." Both Siebenthal (pl. I) and Weidman, however, show the outcrop extending somewhat farther north—that is, nearly to Narcissa.

Siebenthal (1915, p. 28) described the Fayetteville of northeastern Oklahoma as "black fissile unfossiliferous shale, which in places, especially toward the north, gives way to a soft, drab clay shale crowded with the characteristic fossils of the Fayetteville formation."

According to Ireland (1930, p. 23; 1930a, p. 489), the Fayetteville shale of southern Ottawa County is similar to the Fayetteville in northern Mayes County, which he described as thin-bedded limestone below, gray shale rather than black, and thin platy, earthy, fossiliferous limestone above.

Weidman (1932, p. 21) stated that the Fayetteville consists of shale and interbedded limestone and sandstone, some of the shaly beds containing abundant Bryozoa similar to *Archimedes*. He gave the thickness of the formation in Ottawa County as between 40 and 50 feet.

*Water supply.*—The lithologic descriptions of the Fayetteville shale indicate relative impermeability. No records were obtained of water wells in the Fayetteville yielding more than enough water for farm use.

## POST-CHESTER UNCONFORMITY

The formations underlying the Des Moines series progressively disappear northward. In northeastern Oklahoma the uppermost formation of the Chester series disappears somewhere in southern

Mayes County. The formation next below it (the Fayetteville shale) thins northward and disappears in southwestern Ottawa County, although equivalent beds seemingly reappear in the Joplin area (Smith and Siebenthal, 1907, p. 6). These relationships, together with the occurrence of conglomerate in the basal beds of the Cherokee formation, were regarded by Ireland (1930, p. 29; 1930a, p. 489), Weidman (1932, p. 22, 30) and Moore and others (1939, p. 12) as evidence for an unconformity, except that Weidman saw nondeposition rather than erosion in the disappearance of the Fayetteville.

## PENNSYLVANIAN SYSTEM

By Carl C. Branson

Rocks of Pennsylvanian age are the bedrock at or near the surface of approximately a fifth of the county, entirely in the western and northwestern parts, and at no place are they more than 200 feet thick. All these rocks are deposits of the stable shelf which extends northward from the McAlester basin. They rest unconformably upon Fayetteville shale and limestone in the southwestern part of the county, upon the Hindsville limestone near Miami, and upon the Boone formation in adjacent parts of Kansas. Only rocks of late middle Pennsylvanian age (Des Moines series) are represented, for the rocks of Springer, Morrow, and Atoka age are overlapped southwest of Ottawa County.

### Des Moines Series—Krebs Group

The Krebs group was defined by Oakes (1953, p. 1523) to include the Hartshorne, McAlester, Savanna, and Boggy formations. On the northeastern Oklahoma platform these rocks and those of the superjacent Cabaniss group are the "Cherokee shale" or "Cherokee group" of authors, terms which have been dropped from formal nomenclature by the Oklahoma Geological Survey.

#### HARTSHORNE FORMATION

The lowest Pennsylvanian rocks exposed are those below the Warner sandstone member of the McAlester formation. They are exposed at few localities, and no section is complete at any one locality. A composite section compiled from the exposure in the

SW¼ sec. 3, T. 27 N., R. 22 E., the exposure along Elm Creek east of the center of sec. 10, T. 28 N., R. 22 E., and from observations in adjacent Craig County follows.

| | Thickness (feet) |
|---|---|
| Warner sandstone member of McAlester formation | 10.0 |
| Hartshorne formation | |
| Riverton coal | 0- 0.8 |
| Underclay | 1.5 |
| Shale, dark gray, to black, fissile | 19.0 |
| Clay-ironstone, calcareous, fossiliferous | 0.7 |
| Shale, dark gray, laminated to fissile | 8.0 |
| Siltstone, gray, platy, carbonaceous, with *Taonurus* | 3.6 |
| Shale, light gray, silty | 0.8 |
| Coal | 0.3 |
| Underclay | 2.2 |
| Conglomerate, limestone cobbles in part | 1.2 |
| Total | 36.1 |
| Hindsville limestone | |

The writer is using the name Hartshorne in a different sense from that of earlier writers. In the McAlester basin, the name Hartshorne sandstone has been used for the lowest sandstone of the Des Moines series. Beneath it is an unnamed shale containing at places the Lower Hartshorne coal and resting upon rocks of Atokan age. Above it and at places separated from the sandstone by shale is the Upper Hartshorne coal, customarily placed in the base of the McAlester formation. It is here proposed that the name of Hartshorne be that of the formation which embraces the rocks from the top of the Atoka formation to the top of the Upper Hartshorne coal. At the type locality, Hartshorne, in Pittsburg County, the formation consists of the Upper Hartshorne coal, the "Hartshorne sandstone," the Lower Hartshorne coal and underclay, and shale tongues locally developed between those members. The specific sandstone bed called Hartshorne is given its older but seldom used name, Tobucksy sandstone, conferred upon it by Chance (1890, p. 658, 659). In Ottawa County, the Hartshorne formation consists of the rocks from the top of the Mississippian to the top of the Riverton coal, or where the coal is absent, to the base of the Warner sandstone member of the McAlester formation.

Newell (1937, p. 34, 184) considered the portion of this section containing the *Taonurus* siltstone as probably equivalent to the

Blackjack School sandstone member of the Atoka formation. Too much emphasis on *Taonurus* as an index to the Atoka is dangerous. The fossil occurs above the Warner at one place in Ottawa County and at the top of the Spaniard limestone member of the Savanna formation in Mayes County. It is a facies fossil associated with dirty siltstones. There are, perhaps, no more abundant specimens anywhere than in the siltstones of the Northview and Hannibal formations, Kinderhook, in Missouri.

The writer suggests that the Riverton coal of Craig and Ottawa Counties and adjacent parts of Kansas is the equivalent of the Upper Hartshorne coal of the McAlester basin, and that the unnamed coal near the base of the section may be equivalent to the Lower Hartshorne coal.

The limestone or clay-ironstone 16 feet above the base of the Hartshorne formation was named the Elm Creek limestone by Weidman (1932, p. 25). The type locality and type section are on Elm Creek in the west bank about 100 yards downstream from the bridge on the east-west road that bisects sec. 10, T. 28 N., R. 22 E. This outcrop lies about 20 feet below the Warner sandstone member of the McAlester exposed in the rim of the valley southwest of the limestone exposure. The writer and Charles D. Claxton dug a pit below the limestone and found only clay shale to a depth of 3½ feet. The outcrop on Fourmile Creek mentioned by Weidman was not found. The outcrop which Weidman called typical of the Elm Creek and located erroneously in sec. 15, T. 29 N., R. 21 E. (it is in sec. 14) is not Elm Creek, but is clearly an outcrop of the Doneley limestone member of the Savanna formation. The name Elm Creek was stillborn, for it had been used by Drake (1893, p. 421) for what is now called the Elm Creek limestone member of the Admiral formation. The name had also been used by Böse (1918, p. 18) for a limestone in the Canyon group of Texas. It is here considered that Weidman's invalid name should not now be replaced. The limestone is known only at the type locality and at one undescribed locality in Craig County.

## MC ALESTER FORMATION

The McAlester formation of the platform is a much thinner equivalent of the formation in the type area near McAlester. The basal unit there is the McCurtain shale member, a dark shale up to 150 feet thick. This shale can be no more than inches thick in Ottawa County, and for mapping purposes the base of the Warner sandstone member is regarded as the base of the McAlester formation. The remarkably uniform sandstone called the Warner has been traced into Ottawa County from the type locality near Warner. Newell (1937, p. 40) traced the bed from Warner to near Vinita and reached the conclusion that it is continuous with the Little Cabin sandstone of Ohern, Weidman, and others. His mapping enabled him to reach the correct conclusion, although he incorrectly carried his line through much of Mayes County on an Atoka sandstone member. The writer and his students have traced the Warner through Wagoner, Mayes, Craig, and Ottawa Counties, and there is no doubt but that the Little Cabin sandstone is Warner. Ohern named the Little Cabin in an unpublished manuscript, but Cooper first published the name (1928, p. 160). Weidman incorrectly quoted Ohern as having named it the Cabin Creek sandstone, called it the Narcissa sandstone on his map, and used the name Little Cabin sandstone in his text (Weidman, 1932, p. 23, pl. 1).

The Warner sandstone member is uniformly about 10 feet thick. It consists of rounded quartz grains of medium size, and contains a minor percentage of iron oxides. On the surface it is a light buff, cross-bedded, thin-bedded sandstone. The sandstone is the only resistant layer in a thick shale and supports a low but distinct cuesta, or at places is expressed as a sandy ridge. South of the Neosho River opposite Miami are numerous outliers supported by the Warner and these extend southward beyond Narcissa. All are on the east side of the Miami syncline. The Warner occurs as broad low hills which extend northeastward through the mining district, and there is a prominent hill capped by Warner in the town of Baxter Springs, Kansas.

The rocks of the McAlester formation above the Warner sandstone member are dark gray to black, laminated to fissile shales with layers of clay-ironstone concretions, and with three coal zones, one of which is represented only by the underclay. These beds can be seen in the east bank of the Neosho River above Steppe Ford bridge in the drag zone on the downthrown side of the Steppe

Ford fault. The locality is in the center of the south half of the part of irregular sec. 5 on the north side of the river in T. 28 N., R. 22 E. The strata exposed here as measured by the writer in July 1953 are:

| | Thickness (feet) |
|---|---|
| McAlester or basal Savanna formation | |
| Shale, black, fissile, with clay-ironstone lenses | 11.5 |
| McAlester formation | |
| Coal | 0.2 |
| Underclay | 2.3 |
| Shale, black, fissile, with layers of clay-ironstone concretions | 22.9 |
| Underclay | 1.2 |
| Siltstone, light buff, platy, with *Taonurus* | 0.6 |
| Shale, black, fissile | 0.8 |
| Coal | 0.2 |
| Underclay | 1.6 |
| Warner sandstone member | 9.5 |

SAVANNA FORMATION

The position of the base of the Savanna formation cannot be accurately determined from surface exposures in Ottawa County. In Craig County and southwestward, the base of the Savanna is drawn at the base of the Spaniard limestone member, but this member has not been found north of central Craig County. The writer believes that the upper 11.5 feet of beds exposed at Steppe Ford bridge are at the horizon of the Spaniard, and that the coal just below those beds is the coal that occurs at the base of the Spaniard farther south. The Sam Creek limestone member, the next higher mappable bed, also pinches out in Craig County and is not known in Ottawa County.

The highest of the three limestones of the Savanna is well exposed during low water in the south bank of the cut-off meander of the Neosho River in NW¼ sec. 14, T. 29 N., R. 21 E. The limestone is dark, carbonaceous, fossiliferous, and is 3.8 feet thick. It has been named the Doneley limestone member of the Savanna formation by the writer (1954, p. 192). The member can be traced from south of Warner, Oklahoma, across Muskogee, Mayes, Craig, and Ottawa Counties, Oklahoma, and across Cherokee County, Kansas. Beneath the Doneley is 2.5 feet of dark, calcareous, fossiliferous shale resting upon the Rowe coal. The coal is 4 inches thick at this exposure, and has 1½ feet of underclay. Rowe coal was once dug in the slopes of Potato Hill in sec. 29, T. 28 N., R. 21 E., and it has been reported in the side of Blue Mound 3 miles north of Picher, Oklahoma, in Kansas. Below the underclay 4 feet of dark shale is exposed, but the interval from the base of this exposure to the top of the shale exposed at Steppe Ford bridge is unknown.

The Savanna beds above the Doneley consist of dark gray to gray shales, silty to sandy at places in some strata, and with a bed of sandstone 12 feet thick occurring 15 feet above the limestone. This sandstone is exposed in the sides of Potato Hill and in Dawes Hill, 1 mile west of Potato Hill. The top of the sandstone is 51 feet below the top of the Savanna formation.

The rocks of the Savanna above the 12-foot sandstone are not exposed in Ottawa County except as weathered shale. In adjacent parts of Craig County, the upper part includes a thin coal (Drywood coal) and its underclay. The coal and underclay probably occur in Ottawa County, but have not been found.

#### BOGGY FORMATION

The Oklahoma Geological Survey has defined the Boggy formation as those strata from the base of the Bluejacket sandstone member to the unconformity at the base of the rocks of the Cabaniss group. The only unit of the Boggy remaining in Ottawa County is the Bluejacket sandstone member, and this is the youngest Paleozoic rock in the county. It is exposed at a few places along the axis of the Miami syncline in the mining district, as remnants of the original cap of Dawes Hill (sec. 30, T. 28 N., R. 22 E.), and as a small area littered with pieces of sandstone at the summit of Potato Hill (sec. 29, T. 28 N., R. 22 E.). The sandstone is light buff, cross-bedded sandstone of medium grain size. It is an escarpment-forming bed in Craig County and in the counties southward into the McAlester basin, and therefore is readily mappable. It is the Bartlesville sand of some oil fields.

### Water Supply in the Des Moines Series

By Stuart L. Schoff

The rocks of the Des Moines series are not a likely source of ground water in large quantities. Shales generally are poor aquifers, because they are very fine grained and water can move between the mineral particles only very slowly. Shales may, however, yield moderate quantities of water through cracks, thus meeting farm requirements for domestic and stock water. Although the Warner sandstone member of the McAlester formation may be somewhat more permeable than the surrounding shale beds, its fine texture probably means relatively low permeability and the narrowness of its outcrop means small opportunity for replenishment from precipitation. Wells drilled west of the Miami syncline should encounter the Warner sandstone member at progressively greater depths as the Craig County line is approached. The available drillers' records do not show whether wells find water in it, or what yields or quality of water may be expected. The Bluejacket sandstone member of the Boggy formation is not a source of ground water in Ottawa County. It occurs as a cap rock on hills where the water that may enter it is readily drained away through springs and seeps, or is evaporated near the margin of the outcrop. It underlies only small areas and therefore has small reservoir capacity.

## POST-DES MOINES UNCONFORMITY

No record remains of the rocks that may have been deposited in Ottawa County during the long interval from middle-Pennsylvanian time until the Pleistocene (or, at the earliest, Tertiary). The upper part of the Pennsylvanian, all the Permian, all the Mesozoic, most if not all of the Tertiary, and much of the Pleistocene are unrepresented. Judged by the record, erosion was the dominant geologic process during this interval.

## TERTIARY(?) OR QUATERNARY(?) SYSTEM

### UNNAMED GRAVEL AND CLAY

*Character and distribution.*—Weidman (1932, p. 27-28) recognized a surface formation of unconsolidated gravel and clay which he described as widely distributed over both the uplands and the lowlands in the mining district. This he considered to be of Tertiary age, but known deposits of that age appear to be restricted to the High Plains of northwestern Oklahoma. On the other hand, some of the gravel deposits in the State occurring in topographic situations similar to that in Ottawa County have yielded Pleistocene fossils. Therefore the probabilities favor Pleistocene age for the gravels described by Weidman. Neither Weidman nor Siebenthal mapped this deposit, but Branson did so, and plate I shows his mapping, which is confined to the western third of the county. He classified these materials as terrace deposits.

The gravel ranges from 1 to 10 feet in thickness and is best exposed on the higher hills and ridges at altitudes 50 to 100 feet above present stream levels. The pebbles in the gravel are as much as 5 inches across and consist mostly of chert.

The clay overlies the gravel and is present in the lowlands but has been eroded from the uplands. It is sandy, generally is yellow or brown, and ranges from 10 to 30 feet in thickness. Weidman concluded that the gravel and sandy clay were deposited by streams that drained west and northwest from the Ozarks, not southeastward as at present.

*Water supply.*—The deposit is unimportant as an aquifer. In general, the gravel is above the water table, and the water seeping into the deposit from rain on the surface quickly drains away.

## QUATERNARY SYSTEM

### ALLUVIUM AND TERRACE DEPOSITS

*Character and distribution.*—Alluvium is the material deposited by streams. It may consist of gravel, sand, and clay in any proportion, and it underlies the flood plains, or "bottoms." It is generally thickest near the middle of a valley, and thinnest at points remote from the channel. Also, it is thicker along major rivers than along small creeks.

Terrace deposits also are stream-laid materials. They are the alluvium deposited longer ago, and are called terrace deposits because they underlie benches that stand above the lowest bottom lands. Since depositing them, the stream has shifted its channel laterally and has cut deeper. Hence in many places the terrace deposits are adjacent to and topographically higher than the present stream.

At many places, alluvium and terrace deposits are good aquifers. The coarser beds in them as a rule will transmit water freely, and the alluvium, especially, is well situated for replenishment of ground water. In Ottawa County, however, the alluvium and terrace deposits appear to be aquifers of only minor importance, at least from the standpoint of present utilization. They may be minor from the standpoint of potential yield also.

In mapping the alluvial deposits along the main streams of Ottawa County, Siebenthal distinguished the alluvium of the flood plain from the alluvial sediments underlying the first bench above the flood plain, and designated the latter as terrace deposits. This distinction is not retained on plate I of the present report because these alluvial sediments probably function as a single aquifer. The water table doubtless passes from one into the other without a great change in slope. Upstream from Miami along the Neosho River, these deposits underlie an area ranging from less than a mile to nearly 4 miles in width. Much of this part of the valley is subject to flooding. It is rather sparsely settled, is largely uncultivated, and therefore is heavily wooded. In consequence, little information is available regarding the water-bearing properties of the alluvial sediments. The indications are that these sediments consist largely of clay and generally are less than 30 feet thick.

Elsewhere in Ottawa County, the alluviated areas are much narrower. The Neosho River downstream from Miami and the Spring River also have alluvial bottoms from 0.2 mile to 1.1 miles wide. Their larger tributaries have alluvial bottoms from 0.1 to 0.75 mile wide, but the small and medium-sized creeks in the outcrop area of the Boone formation have narrow, V-shaped valleys and little or no alluvium. When Lake o' the Cherokees (Grand Lake) is full, the alluvium is partly under water along the Neosho from Miami to the mouth of the Spring River, and along the Spring River below the mouth of Warren Creek. Along the Grand River (below the Spring River), the alluvium is almost entirely under water. The alluvium in the lower reaches of Lost and Sycamore Creeks also is flooded, but Warren and Fivemile Creeks are entirely above the highest lake level. In part of its course in both Kansas and Oklahoma, the Spring River crosses the outcrop of the Boone, which is cherty and on erosion yields chert gravel which may be incorporated in alluvial deposits.

*Water supply.*—The few dug wells on the sparsely settled bottoms of the Neosho and Spring Rivers yield small quantities of water, chiefly for domestic and stock use on farms. Where the alluvium of the Spring River contains chert gravel, it may be capable of yielding water rather freely, but its possibilities are essentially untested.

The potentialities of the alluvium of the Neosho River are suggested by test drilling and test pumping in the Neosho River valley in northeastern Labette County, Kansas. As reported by Williams (1944), the alluvium there is about 35 feet thick, and the upper 10 to 30 feet is generally silt and clay. The underlying sand and gravel are poorly sorted. A test well was pumped for 98 hours at an average rate of 90 gallons per minute, and the specific capacity was 3.9 gallons per minute per foot of drawdown. The coefficient of permeability of the saturated part of the alluvium was about 420 gallons of water per day for each section of the aquifer 1 mile wide and 1 foot thick, under a hydraulic gradient of 1 foot per mile.

Tributaries entering the Grand (Neosho) and Spring Rivers from the east cross the Boone formation, and at places their alluvium may contain water-bearing chert gravel. Some of the smaller ones, however, have little or no alluvium, at places running directly on the bedrock. Tributaries that enter the Neosho upstream from Miami cross formations consisting mainly of shale, and their alluvium therefore is likely to consist mostly of impervious, fine-grained material incapable of yielding large quantities of water to wells.

## OCCURRENCE AND BEHAVIOR OF GROUND WATER

By Edwin W. Reed

The basic principles of the occurrence of ground water have been discussed in detail by Meinzer (1923), from whose report the following summary is adapted in order that the reader may have a better understanding of the ground-water conditions in Ottawa County.

### ROCKS AS RESERVOIRS

The rocks that form the outer crust of the earth—and this includes all the rocks within reach of drilling machines—are solid throughout at few places, if anywhere; they contain many open spaces, called voids or interstices. These open spaces are the receptacles that hold the water that is found below the surface of the land and is recovered in part through wells and springs. There are many kinds of rocks, and they differ greatly in the number, size, shape, and arrangement of their interstices and hence in their properties as containers of water. The occurrence of water in the rocks of any region is, therefore, determined by the character, distribution, and structure of the rocks it contains—that is, by the geology of the region—together with the climate and topography.

Most rocks have numerous interstices of very small size, but some are characterized by a few large openings, such as joints or caverns. In most rocks the interstices are connected, so that the water can move through the rocks by percolating from one interstice to another; but in a few types of rock the interstices are largely isolated and there is little opportunity for the water to percolate. The interstices are generally irregular in shape, but different types of irregularities are characteristic of different kinds of rocks.

The amount of water that can be stored in any rock depends upon the volume of the rock occupied by open spaces—that is, the porosity of the rock. Porosity is expressed as the percentage of the total volume of rock that is occupied by interstices. A rock is said to be saturated when all its interstices are filled with water. The porosity of a sedimentary rock is controlled by (1) the shape and arrangement of its constituent particles; (2) the degree of assortment of its particles; (3) the cementation and compaction to which it has been subjected since its deposition; (4) the removal of mineral matter through solution by percolating waters; and (5) the fracturing of the rock resulting in joints and other openings. Well-sorted deposits of unconsolidated silt, sand, or gravel have a high porosity, regardless of the size of the grains. Poorly sorted deposits have a much lower porosity because the small grains fill the voids between the large grains, thus reducing the amount of open space. The pore space in some well-sorted deposits of sand or gravel may be filled partially with cementing material, reducing the porosity. Solution channels and fractures may be large and of great practical importance in transmitting water, but they are rarely abundant enough to give an otherwise dense rock a high porosity.

## ROCKS AS CONDUITS

Although the capacity of a rock to contain water is determined by its porosity, its capacity to yield water is determined by its permeability. The permeability of a rock may be defined as its capacity for transmitting water under hydraulic head. It is measured by the rate at which the rock will transmit water through a given cross section under a given difference of head per unit of distance. Rocks that will not transmit water, or transmit it only very slowly, may be said to be impermeable. Some deposits, such as well-sorted silt or clay, may have a high porosity but because of the minute size of the pores will transmit water only very slowly. Other deposits, such as well-sorted gravel containing large openings that communicate freely with one another, will transmit water very readily. Part of the water in any deposit is not available to wells because it is held against the force of gravity by molecular attraction—that is by the cohesion of the water itself and by its adhesion to the walls of the pores. The ratio of (1) the volume of water that a saturated rock will yield by gravity to (2) its own volume is known as the specific yield of the rock.

## THE WATER TABLE

Below a certain level the interstices of the permeable rocks are generally saturated with water under hydrostatic pressure. These rocks are said to be in the zone of saturation. Water entering the rocks from the surface is drawn down by gravity to the zone of saturation except as it is held by molecular attraction of the walls of the interstices through which it descends. The permeable rocks above the zone of saturation are said to be in the zone of aeration, which includes a relatively thin belt of soil water.

The upper surface of the zone of saturation in ordinary permeable soil or rock is called the "water table" except where the upper surface is formed by impermeable rock. When a well is sunk, it remains empty until it enters a saturated permeable bed—that is, until it enters the zone of saturation. Then water flows into the well. If the rock through which the well passes is all permeable the first water that is struck will stand in the well at about the level of the top of the zone of saturation—that is, at about the level of the water table. If the rock overlying the bed in which the first water is struck is impermeable, the water is generally under pressure which will raise it in the well to some point above the level at which it was struck. In such a place there is no water table, and confined (artesian) conditions are said to exist. (See section on confined (artesian) water.)

The water table is not a level surface but has irregularities comparable with and related to those of the land surface, although it is less rugged. It does not remain in a stationary position but fluctuates up and down. The irregularities are due chiefly to local differences in gain and loss of water, and the fluctuations are due to variations from time to time in gain or loss.

The water table is not to be regarded as a single continuous surface, but rather as a great many small and interconnected surfaces. Each impervious mineral grain that happens to be at the level of the water surface breaks the continuity of the water table. It is only in the voids or pores that the water table is present. In sandstone the water surfaces are numerous, small, and close together. Where the ground water is in fractures in rocks that otherwise are solid and impervious, the water table consists of small, irregular, rather widely separated water surfaces. This is probably the nature of the water table in the shale formations of Ottawa County.

Where fractures have been enlarged by solution, some of the water surfaces are larger than those in shale, but they are similarly irregular and widely separated. This probably is the nature of the water table in the Boone formation of Ottawa County. Taken all together, such openings are a small fraction of the entire volume of the rock—that is, the porosity is low.

The amount of water available to wells depends on the saturated thickness and extent of the aquifer and on the permeability and specific yield of the water-bearing materials. The amount of water that can be pumped perennially without progressive depletion of ground water in storage depends on the replenishment of water from precipitation and from the influent seepage from streams in the area of outcrop. These latter factors will be considered further in the section on recharge and discharge of ground water.

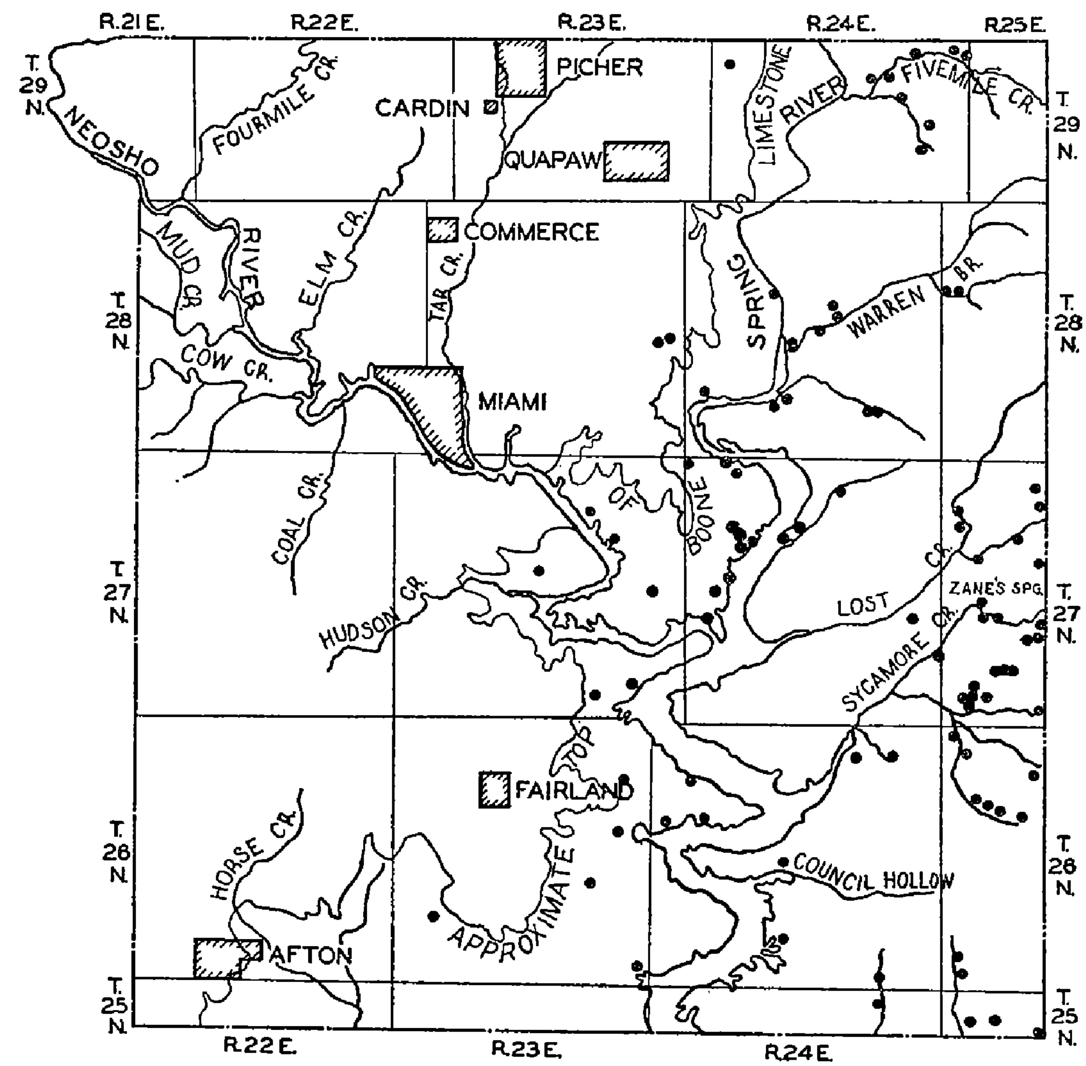



FIG. 4. Map showing locations of springs in Ottawa County.

## SPRINGS

The State Mineral Survey of 1937 obtained records of 98 springs in Ottawa County, most of them in the eastern half of the county and in the outcrop area of the Boone formation (fig. 4). Their flow was reported to range from less than 1 to more than 2,000 gallons per minute each, and the total discharge of all of them was nearly 10,000 gallons per minute.

Most of them appear to be gravity springs. The larger ones are of the fracture type which issue from fractures or fissures. The smaller ones are mainly of the depression type, in which water comes to the surface simply because the land surface extends down to the water table (Meinzer, 1923, p. 51). Water falling on the outcrop of the Boone formation enters sinkholes or other openings and moves underground through cracks and openings along bedding planes, some of which have been enlarged by the dissolving action of water on limestone. It travels down the slope of the water table, issuing in springs or seeps along ravines, gullies, and creeks that have been eroded down to the water table. In at least short stretches along nearly every creek in the limestone area the flow is due chiefly to the springs or seeps. In general, the water probably travels underground only a few miles at the most before returning to the surface, and in some places its underground route may be measured in hundreds of feet.

As the creeks and ravines are eroded deeper, the water table adjacent to them is lowered and springs issue from lower openings. Along Warren Branch, for example, the present outlets for a series of small springs are only slightly above stream level, but some of the abandoned outlets may be seen about 8 feet higher. One of them is known as "wind cave" because a current of air having approximately the temperature of the rocks flows from it. This temperature is about the same as that of the spring water and about equal to the average annual air temperature of the locality.

Zane's Spring on Zane's Ozark Ranch (SE¼NE¼ sec. 19, T. 27 N., R. 25 E.), is one of the largest springs in the county. It has been improved by blasting a wide-mouthed, shallow semicircular cave about 30 feet deep, 50 feet high, and 100 feet wide in the limestone bluff. The water emerges from several cracks in the Boone formation at the north end of the cave near the floor level, flows through an open concrete-walled channel along the back of the cave, over a weir at the south end, under a house (which it cools in summer), and through a meadow. Farther east it is augmented by the flow from several smaller springs, and a stock pond has been made by damming the channel. An estimate of the discharge was obtained on July 24, 1946, by timing the progress of a wooden chip down a measured section of the channel. This indicated more than 2,000 gallons per minute. At that time the owner considered the flow to be relatively low, and reported a maximum of 5,000 gallons per minute during some wet seasons. As a discharge of only 1,700 gallons per minute was indicated by a similar measurement made on April 30, 1948, it is evident that the flow varies widely, doubtless in response to variations in precipitation. The temperature of the water as it emerges from the rock is 59° F., and the cave therefore is a cool retreat for even the hottest summer days. Accordingly, it has been partly floored with concrete for use as an outdoor living room. A smaller nearby spring has been walled up and covered to make a safe source of water for domestic use.

The springs of Ottawa County are widely used as sources of stock and domestic water supplies on farms, but they have not been put to municipal, industrial, or irrigation use. It is probable that seeps and small springs issue in places from some of the sandstone and limestone layers in the rocks above the Boone formation, especially from the Batesville sandstone, but water supplies adequate for more than stock use are not likely to come from such sources.

## CONFINED (ARTESIAN) WATER

Artesian or confined conditions are said to exist where a water-bearing bed is overlain by an impermeable or relatively impermeable bed and where the top of the aquifer is below the level of the water table in the intake area. Water enters the water-bearing bed at the intake area and percolates slowly downward to the water table and then down the dip in the water-bearing bed beneath the overlying confining bed. Down the dip from the intake area the water exerts considerable pressure against the confining bed, so that when a well is drilled through the confining bed into the water-bearing bed the pressure is released and the water rises in the well. Because of loss in head resulting from friction as the water percolates down the dip, the water level will not rise to an elevation as high as that of the water table in the intake area. Where the land surface is low enough the artesian pressure may be sufficient to raise the water above the surface, and flowing wells may be obtained.

Because the upper surface of the saturated zone is formed by an impermeable bed and the water in wells will rise above it, this portion of the aquifer has no water table. The imaginary surface defined by the height to which artesian water will rise in wells is known as the piezometric surface. Where a water-bearing bed having a water table occurs above the impermeable confining layer, the piezometric surface of the artesian aquifer may be above or below or at the same level as this water table. Where there is a substantial degree of interconnection between two such aquifers—that is, where the confining bed is interrupted or leaky, the relative positions of the piezometric surface and water table may be significant. If the piezometric surface is above the water table, the artesian water may be escaping into the unconfined aquifer; where it is lower, the artesian aquifer may be receiving water from the unconfined aquifer. Such interchange might occur through the confining layer if it is not entirely impermeable, or it might occur through the well itself if the casing is not effectively sealed against leakage. Where there is no interconnection between aquifers, the relative positions of the piezometric surface and water table have no particular significance.

Under natural conditions, recharge to artesian aquifers generally occurs principally in the areas of outcrop, where water-table conditions prevail. The lag between the time of precipitation and the corresponding rise of water level in wells is greater under artesian than under water table conditions, and increases with distance from the outcrop. Where this distance is great, the fluctuations due to precipitation are small or nonexistent, and only those due to pumping or to variations in atmospheric pressure are readily evident. Changes in atmospheric pressure may cause changes in water level of a foot or more in artesian wells, the level rising when the air pressure is low and declining when it is high.

In Ottawa County the Chattanooga shale is effective as an impermeable confining bed. It and the underlying rocks of the Canadian series are at altitudes considerably below their outcrops in the Ozarks to the east. As the land surface also is lower than the outcrop, or intake area, the conditions for flowing wells are met, and the first wells drilled in the county had heads high enough to overflow. Subsequently the withdrawal of water by flow and by pumping has so reduced the hydrostatic pressure that the water in wells in the area of most intensive use no longer rises to the surface.

The artesian head probably is different in the different water-bearing zones of the Canadian series, but as most of the wells are open to all zones from near the base of the Chattanooga shale down through the Roubidoux formation, the water levels observed in them are the result of a balance—an equilibrium—of the different pressure heads, plus the effect of withdrawals. Few wells have penetrated the water-bearing strata below the Roubidoux, and therefore only a little is known about the pressure head in those strata. It seems, for example, to be higher in the Gunter sandstone member of the Van Buren formation than in the Roubidoux formation. It is reported that, when the Gunter was penetrated in the Quapaw municipal well, the water level rose 18 feet—from a depth of 276 feet to a depth of 258 feet.

## RECHARGE AND DISCHARGE OF GROUND WATER

The principal source of water in the earth is precipitation on the outcrops of permeable rocks. Other sources are influent seepage from streams crossing the outcrop, and movement underground from outside areas. The replenishment of ground water is known as recharge. It is often expressed as a percentage of the annual precipitation, or as equivalent to a layer of water, usually measured in inches of depth, spread uniformly over the area. It may range from a small fraction of an inch in some areas to many inches in others. It may equal only a small percentage of the annual precipitation, or more than 50 percent. In the same county, it will differ from township to township, from section to section, and from acre to acre, but the movement of water underground tends to equalize the recharge for large areas and to make estimates of average recharge useful.

The amount of water entering the ground depends first on the amount of precipitation. Obviously, little rain means little opportunity for recharge. If rain comes as gentle to moderate showers, a larger fraction of the water can go into the soil and rock than if it comes in heavy or protracted storms that quickly fill the uppermost openings and furnish water faster than it can be absorbed. Light, loose, sandy soils will absorb more of the water than will heavy clay soils. The absorption will be relatively high on gentle slopes but much less on steep slopes where runoff is dominant. Vegetation favors absorption by retarding runoff and by loosening the soil so that it is more permeable, but it uses part or all of the water, transpiring it to the atmosphere instead of letting it percolate to the water table. In winter a larger fraction of the precipitation will reach the zone of saturation than in the heat of summer because evaporation is less and transpiration ceases. The first rain after a prolonged drought will add little or nothing to the ground-water supply because the soil must be largely saturated before any water can sink below it. Thick rock formations that dip at low angles have more surface exposed to receive water from precipitation than formations of equal thickness that dip at steep angles, and rocks of coarse, uniform texture, or with extensive systems of joints and fissures, will take in water faster than rocks that are fine-grained, uneven textured, or unbroken.

Streams crossing the outcrop will contribute water if their channels are above the water table, but otherwise will receive water from the underground reservoir. Recharge may be accomplished artificially by putting water into aquifers through infiltration beds or through wells drilled especially for the purpose. The practice of artificial recharge in the United States is still rather uncommon, but it is growing.

Ground water moves slowly through the rocks from the places of recharge, or intake, to points of discharge at lower levels. Although the path followed by any given molecule of water may be very circuitous, the net result is movement down the slope of the water table, or, in the case of confined water, in the direction of the slope of the piezometric surface. Discharge of ground water occurs naturally through springs, into channels of effluent streams, through use by plants that can send their roots down to the water table, and by evaporation where the water table is near the surface. It occurs artificially through wells by pumping or artesian flow, or by drainage into ditches or other man-made excavations.

Under natural conditions, the recharge to an underground reservoir is approximately balanced by the discharge from it. Hence, a measure of the natural discharge is a rough measure of the recharge. Pumping or artesian flow from wells upsets this balance and may divert toward the wells a part of the natural discharge of springs and streams. This diverted discharge is said to be salvaged. The lowering of the water table by pumping makes room in the normally saturated part of the aquifer for water that otherwise might go as surface runoff. Thus, where precipitation is more than adequate, withdrawal of water by pumping may increase recharge by increasing the receptiveness of the aquifer.

## Recharge and Discharge by Aquifers

### CANADIAN SERIES

The ground water in the rocks of the Canadian series is replenished from precipitation in areas where those rocks crop out and from influent seepage from streams crossing them. In Ottawa County these rocks formerly were exposed in one small inlier along the Grand (Neosho) River in the southwestern part of T. 26 N., R. 24 E. (fig. 3). Now covered by the waters of Lake o' the Cherokees, the rocks of the Canadian series at this place have an abundant source of continuous recharge. How much they take in depends on the number, size, and underground connections of their openings, and perhaps on the extent to which these openings have been sealed with mud settling out of the lake water. The effect of recharge at this locality on the ground-water supply in the strata of the Canadian series in the heavily pumped parts of Ottawa County may be negligible. The beds exposed to the lake waters are the upper part of the series, not the "sands" of the Roubidoux formation from which most of the water is pumped and their area of contact with the lake waters is small relative to the storage capacity of the Canadian series as a whole.

Other small inliers in southwestern Missouri and northwestern Arkansas likewise may take in some water but, here again, only the upper strata of the Canadian series are exposed, from which the wells in Ottawa County derive only minor quantities of water. The principal outcrop is in the central part of the Ozark Mountains in south-central Missouri and north-central Arkansas, 50 to 150 miles east of Ottawa County and at a considerably higher altitude. This area is large and well watered and is crossed by many streams. In it many springs are, obviously, places of ground-water discharge, but just as obviously they are evidence that the rocks receive, contain, and transmit water. The average annual recharge here probably is large, but the amount reaching Ottawa County is insignificant compared with the withdrawal, mainly because of the slow progress made by the water in its journey through the rocks.

Discharge from the rocks of the Canadian series in Ottawa County is essentially limited to the water pumped from wells, which in 1948 was estimated as about 4 million gallons per day. Of this, more than 2 million gallons per day was used by industry, about 1.75 million gallons per day was for public supply, and the rest was for institutional and other purposes. The B. F. Goodrich plant was then using about 1.7 million gallons per day, mainly for cooling, but it subsequently has reduced its draft upon the underground reservoir through use of a cooling tower. Unless other users of ground water have increased their pumpage and so have offset the saving achieved by the Goodrich Co., the discharge for 1948 probably is the maximum to date. From the time that the first well was drilled into the Canadian series, the discharge of ground water has increased, except perhaps during the depression of the 1930's when the production of lead and zinc was drastically curtailed and the population declined. According to the State Mineral Survey, the total pumpage was about 1.75 million gallons per day in 1937. An estimate made in 1944 by Reed and Jacobsen indicated pumpage of 2.25 to 2.5 million gallons per day.

### BOONE FORMATION

The ground water in the Boone formation in Ottawa County is replenished mainly from precipitation. To a large degree, this replenishment comes from within the county, although some of the water in the deeper strata may have traveled many miles from intake areas located to the east and northeast in adjacent Missouri and Kansas. The smaller streams, especially those known as "disappearing" streams, may make large contributions to the ground-water reservoir, but as their drainage areas are largely within the county it is evident that the water they contribute is just a part of the local precipitation. The Neosho and Spring Rivers bring into the county water from outside areas, but these streams usually gain water from the underground reservoir by effluent seepage. Only during floods are they likely to contribute water to the aquifer, and then only temporarily as bank storage.

The outcrop of the Boone formation is, on the whole, favorable to ground-water recharge. The cherty soil is porous, and the underlying bedrock is more or less fractured. Although slopes are steep in parts of the outcrop area, the trees, grass and other vegetation tend to hold the water, reducing the loss through runoff. Sinkholes in parts of the area are capable of large intake from "disappearing" streams.

Abandoned mine shafts and test holes also may afford entrance for water. Even in the outcrop areas of the Chester series or the Krebs group, such openings penetrate the Boone. At one time tailings from the mills so clogged Tar Creek that heavy rains flooded large areas, overflowing into shafts and necessitating the pumping of millions of gallons of water from the mines. In the 1930's the Works Progress Administration, under the direction of the Mining Division of the U. S. Geloogical Survey, cleaned out the channel of Tar Creek and other creeks, filled several sinkholes and abandoned deep wells, and covered the abandoned shafts. This program achieved a substantial reduction in the pumping required to keep ground-water levels below the mine workings. It also demonstrated the effectivneess of recharge through man-made openings.

It is easier to describe how water enters the Boone than to determine how much enters. The long-term records of ground-water levels and of ground-water discharge needed for a reasonably accurate measurement of the average recharge to the Boone are not available, but an analysis of the meager data now in hand may suggest the order of magnitude of that recharge.

As stated elsewhere in this report, large quantities of water are pumped from the Boone in order to keep the lead and zinc mines dry enough for work. In addition, many springs in the eastern part of the county discharge much ground water—reportedly some 10,000 gallons per minute or 14,400,000 gallons per day—and many rural wells tap the Boone for domestic and stock-water supplies. Despite this seemingly large discharge, ground-water levels remain high in the Boone in Ottawa County except locally in the mining areas. Evidence of overdraft is lacking, and a condition of approximate equilibrium between recharge and discharge therefore may be assumed to exist.

The total of pumpage and spring discharge from the Boone formation in Ottawa County is estimated as about 28 million gallons per day. This is about 10,220 million gallons per year, or 31,359 acre-feet. Very roughly, the outcrop of the Boone in Ottawa County is 211 square miles or about 135,000 acres, and the discharge, hence, is about 0.23 acre-foot of water from each acre of outcrop. In terms of rainfall this equals about 2.7 inches or about 6.4 percent of the annual precipitation at Miami.

This estimate, obviously, ignores the invisible effluent discharge into perennial streams, the discharge by vegetation, and the discharge by evaporation directly from the water table. Clearly, therefore, it is a conservative estimate.

### ALLUVIUM AND TERRACE DEPOSITS

The alluvium receives water mainly from precipitation, although at times of high water the streams may make substantial but temporary contributions by way of bank storage. When the streams overtop their banks and spread across the flood plains, the percolation of water into the alluvium may be so general that a relatively large increase in stored ground water results. Considerable time may elapse before this increment of water can drain into the channel or be dissipated otherwise.

Alluvium underlies flat, nearly level areas where infiltration can be high because the runoff is low. On the other hand, the vegetation in alluvial areas is likely to be heavy and will return large quantities of water to the atmosphere. Also, the water table is near the surface and direct evaporation may take a relatively high toll. Under present conditions, the withdrawal of ground water from alluvium in Ottawa County is very small compared with the possibilities for replenishment.

The terrace deposits shown on plate I are unlikely to receive temporary contributions of water as bank storage. Being higher above the streams than the alluvium, they are not subject to flooding. Therefore they receive recharge mainly from precipitation directly on their surfaces. The higher terrace deposits, especially where thin, are readily drained of the water entering them, and therefore they are not important aquifers in Ottawa County, regardless of their opportunities for recharge.

#### OTHER FORMATIONS

The recharge to the formations of the Chester series and to those of the Krebs group is limited mainly by the ability of these formations to receive and transmit water. Where the sandstones are porous they may take in a fairly large fraction of the water falling on them, but the shales and dense limestones will reject all but a little. Runoff, therefore, is relatively high despite the flatness of the areas underlain by these formations, and evaporation and transpiration take a heavy toll. The sandstone beds in the Krebs group can receive but little water because their outcrops are very narrow. If wells in the bedrock formations above the Boone fail, it is because of inability of the formations to receive and transmit water, not because of deficient precipitation on their outcrops.

## EFFECT OF PUMPING OR ARTESIAN FLOW

The effect of pumping on the water table, or piezometric surface, is described by Wenzel (1942, p. 98-100) and Meinzer and Wenzel, (1942, p. 466-467), from whose works the following paragraphs are taken.

### Cone of Depression

As soon as a pump begins discharging water from a well that penetrates an aquifer having a water table, the water table is lowered around the well and a hydraulic gradient from all directions is established toward the well. The water table soon assumes a form that is comparable to an inverted cone, although it is not a true cone. Where the water-bearing material is homogeneous the base of this cone of depression, or area of influence, will be circular if the water table is initially horizontal, but somewhat elliptical if the water table has an initial slope. Some water-bearing material will be unwatered by the decline of the water table, and the water drained from this material will percolate toward the pumped well. Thus for a short time after pumping is begun most of the water that is pumped may be obtained from unwatered sediments comparatively close to the pumped well, and temporarily very little water may be drawn to the well from greater distances. However, as pumping is continued a hydraulic gradient that is nearly an equilibrium gradient will be established close to the well, and water will be transmitted through the water-bearing material close to the well at nearly the rate at which it is being pumped.

The decline of the water table and the resultant unwatering of material in this area will then proceed at a much slower rate. This necessitates the percolation of more water from greater distances, and hence the cone of depression will expand, gradually draining material farther away. Thus, as the pumping of the well continues, more of the formation will gradually be unwatered, and an equilibrium gradient that will transmit to the well approximately the amount of water that is being pumped will be established at increasing distances from the well. Such an equilibrium gradient can be established only by an increase in drawdown. The water table near the well, in order to maintain an approximate equilibrium form, will therefore continue to lower indefinitely but at a decreasing rate.

If no water is added to the formation, the water table will continue to decline so long as the well is pumped, and the cone of depression will eventually extend to the limits of the formation. Recharge to the formation, however, may halt the development of the cone of depression by furnishing additional water that will become a supply for the pumped well.

The piezometric surface under artesian conditions behaves in a manner very similar to the behavior of a water table. Water is at first removed from storage, not by the unwatering of a part of the formation but rather by the compaction of the aquifer and of the included and associated beds of silt and clay, and by slight expansion of the water, as the head is reduced. The squeezing out of water by compaction delays the development of the cone of depression in much the same way as the development under water-table conditions is delayed by the unwatering of part of the formation. However, the quantity of water removed by compaction is generally much less than the quantity removed by the unwatering of a part of a formation, and consequently the drawdown of the water levels in the observation wells and the development of the cone of depression are usually more rapid.

### Interference Between Wells

When two wells tapping the same aquifer are pumped, each sets up its own cone of depression, and if they are close enough so that these cones overlap the wells are said to interfere with each other. Neither well can draw water from the portion of the aquifer beyond the line where the two cones meet. If the discharge of the wells remains constant, the cones must expand more rapidly in the remaining free directions, and the drawdowns will be greater than if only one well were pumping. If the drawdown remains the same as it would be without interference, the discharge must decrease. Under actual conditions, the effect usually is a decrease in discharge and an increase in drawdown. Mathematically, the total drawdown in either well is the drawdown caused by its own pumping plus the drawdown caused by the other well at a distance from that well equal to the distance between the wells.

If more than two wells interfere with each other, each affects all the others. The total drawdown in each well is increased by the sum of the drawdowns in it caused by all the other wells. The net result of interference is an increase in pumping lift and a consequent increase in pumping cost. Where interference causes large general lowering of the water table or of the piezometric surface and associated reduction in discharge, the aquifer is said to be locally overdeveloped. Local overdevelopment may go so far, for example, that half as many wells, properly spaced, would yield as much water as the number actually being pumped.

Under artesian conditions, the cones of depression are broad and deep because only a small amount of water comes from storage close to the well and a condition of equilibrium cannot be established until the cone of depression expands to the outcrop. Theoretically, therefore, if two wells equidistant from the outcrop are to be pumped at the same rate without mutual interference, the distance between them would have to be more than twice the distance to the outcrop. In most artesian aquifers the distances from wells to outcrops are measured in miles, and well spacing on the indicated basis is impractical. To utilize the available ground water, therefore, more or less interference between wells must be tolerated. Where the distance to the outcrop is great and the time required for the cones of depression to reach it is long, the aquifer may function primarily as if it were a reservoir receiving little or no recharge. Many millions of gallons may be pumped from it, but with progressive lowering of the piezometric surface and increase in cost of pumping.

The spacing of wells is in part an economic problem beyond the scope of this report and in the field of the designing engineer. The increase in cost of pumping occasioned by increase in drawdown where wells are close together must be balanced against the cost of longer pipelines, power lines, and other factors where the wells are farther apart. In artesian aquifers at locations far from the outcrop, mutual interference cannot be eliminated. Drawdown and pumping cost are certain to increase if the yield is maintained or increased, but a careful analysis of the many factors involved can lead to an appropriate well spacing and eliminate the drilling of wells whose useful life will be short because of excessive interference.

### Decline of Artesian Pressure in the Canadian Series

It is evident that in the first decade of the 20th century the piezometric surface of the ground water in the rocks of the Canadian series was above the land surface in all but the highest parts of the county. Siebenthal (1908, p. 225-228) reported wells that were flowing in the summer of 1907 at Miami and Afton, Ottawa County; at Vinita, Welch, and Bluejacket in Craig County; and at other places. It is evident, also, that some decline in artesian pressure had already occurred, for he mentioned a well northwest of Afton, "which at one time had a small flow but in which the water now stands from 1 to 20 feet below the surface." Regarding two wells in Miami he wrote: "These two wells affect each other decidedly, though half a mile apart." Siebenthal's data indicate that the piezometric surface over the area was more than 800 feet above mean sea level except at Miami, where it was slightly lower.

After additional field work done prior to 1912, Siebenthal (1915, p. 165, 166) again described some of the same wells together with new ones, indicating that most still flowed at the surface. His evidence does not imply that no decline in head had occurred between his visits, only that the decline had not cut off flows by taking water levels below the land surface.

Most of the wells that originally flowed at the surface are reported to have ceased flowing "when the mines opened," probably in the period from 1916 into the early 1920's, when the production of lead and zinc ores increased rapidly. The mining operations could not have directly affected the artesian head of the water in the rocks of the Canadian series because the ore is found in rocks separated from them at most places by the essentially impervious Chattanooga shale. The hydrologic connection if any, is very poor. The effect of increasing production of lead and zinc was a considerable increase in water use. The milling operations required large amounts of water, and, although most of it was obtained from surface ponds, many deep wells were drilled to supplement the ponds. At the same time, the cities and towns of the mining area doubled and even trebled in population, most of the municipal wells were drilled, and municipal pumpage increased sharply. As the original artesian head was not much more than 30 feet above the land surface and the decline already was in progress, the increased draft caused the piezometric surface to fall below the land surface and the wells stopped flowing. This occurrence was unusual enough to be remembered and to be associated with other significant events, such as the opening of the mines.

In 1936 and 1937 the State Mineral Survey, a Works Progress Administration project sponsored and directed by the Oklahoma Geological Survey, made an inventory of the mineral resources of Oklahoma. One objective was the collection of information on the water resources of the state. The records for Ottawa County and adjacent counties obtained in this inventory indicate that the water levels in the deep wells were then about 100 feet below the surface, or about 700 feet above mean sea level. This survey was made during the depression period when pumpage was less than previously because most of the mines had suspended operations and much of the population dependent on mining had drifted away. Presumably this decrease in pumpage was accompanied by a rise in water level; or, at least, by lessening of the rate of decline.

In 1942 C. C. Williams, of the U. S. Geological Survey, supplemented his work in southeastern Kansas by making an inventory of some of the municipal wells in northern Ottawa County. As reported to him, the water levels at that time were 200 to 300 feet below the surface, or approximately 600 to 500 feet above mean sea level.

When the wells for The B. F. Goodrich Co. were completed northwest of Miami in April 1944, measurements in them showed the water levels to be about 250 feet below the surface, or about 530 feet above mean sea level.

The Eagle-Picher Mining and Smelting Co. has kept a record of the water level in the well at its Central Mill near Cardin since it was drilled in 1932. Measurements were made at irregular intervals by means of an air line, both while the well was being pumped and while the pump was idle. A hydrograph based on the company's records shows a clear-cut downward trend (fig. 5).

Declines in water level have been noted also in adjacent parts of Kansas and Missouri, but the magnitude has been less than in Ottawa County.

Table 7 summarizes the reported and measured water levels in several deep wells in Ottawa County, and figure 5, which is based on the same data, illustrates graphically the decline of water level.

**Depth To Water Below Land Surface**

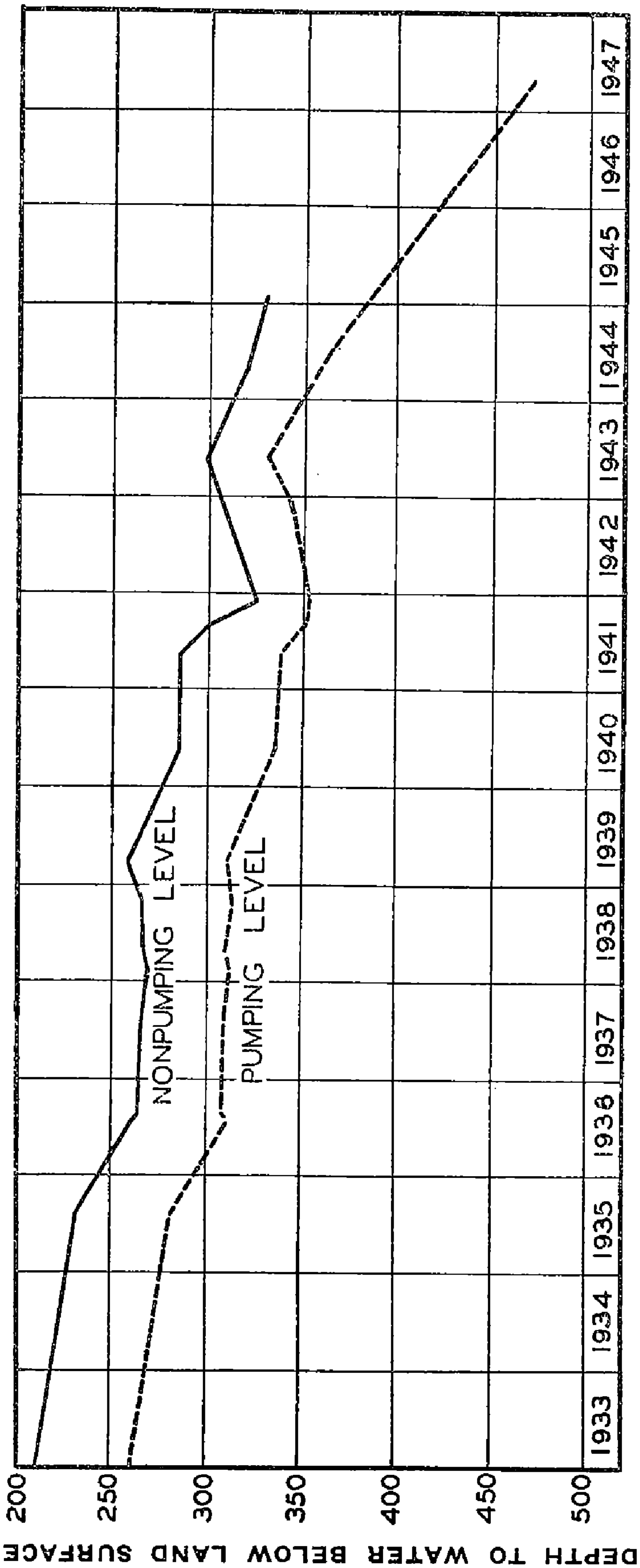



Fig. 5. Pumping and nonpumping water levels, in feet below land surface, in well at Eagle-Picher central mill (well 29N23E-31-1), 1933-1947.

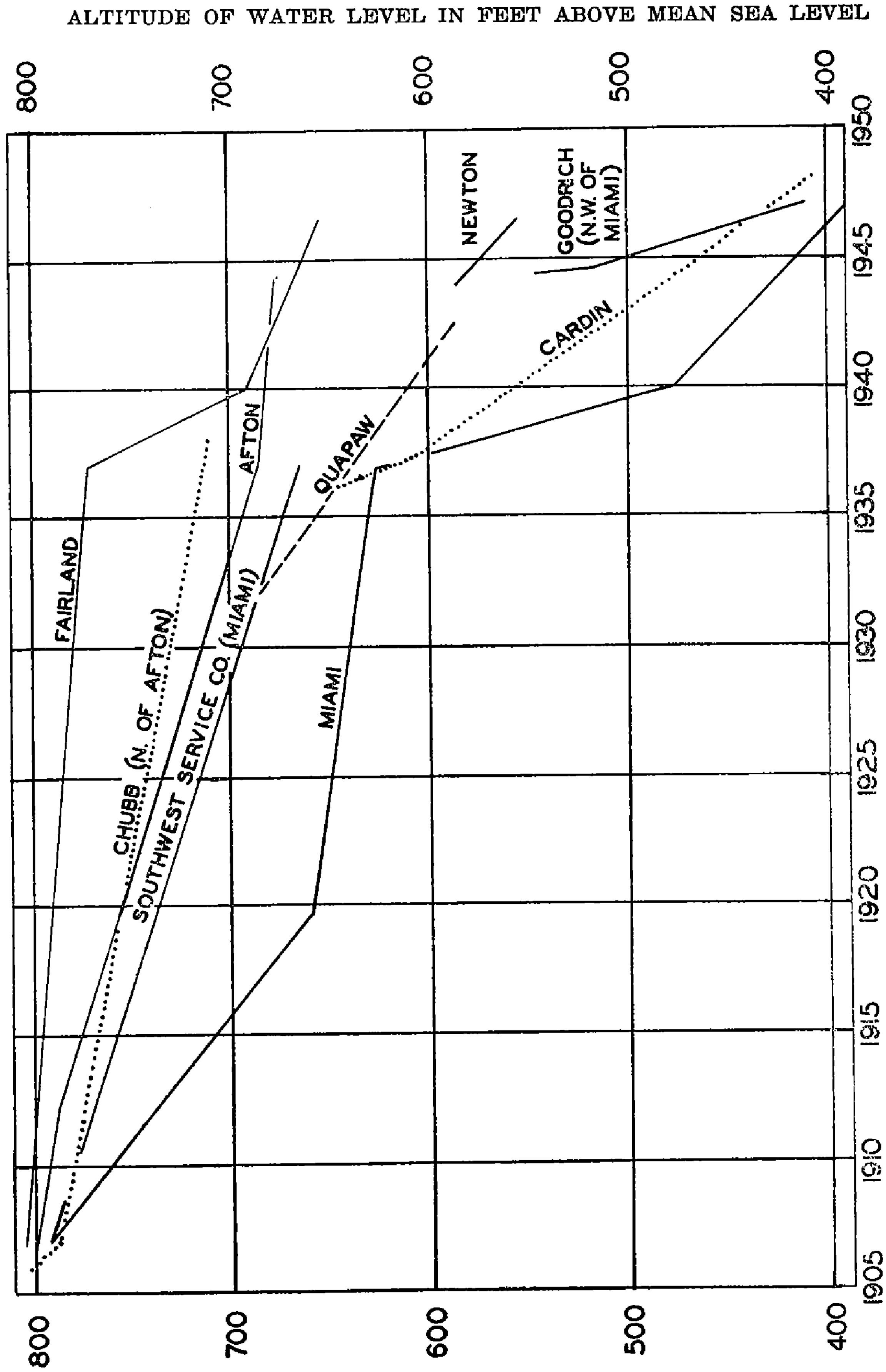



FIG. 6. Graphs showing decline of water levels in deep wells in Ottawa County.

TABLE 7

WATER LEVELS IN DEEP WELLS IN OTTAWA COUNTY, OKLAHOMA, 1907-48

| Well no. | Owner's name | Date | Position of water level (ft. above or below pt.)[1] | Altitude above sea level (feet) | | Source[3] |
|---|---|---|---|---|---|---|
| | | | | Reference point[2] | Water level | |
| 26N22E-29 | James S. Chubb | Pre-1907 | (4) 0 | 800 | 800+ | A |
| | | 1907 | 1-20 | 800 | 799-780 | A |
| | | 1936 | 90 | 800 | 710 | C |
| 32-2 | Town of Afton | Pre-1907 | (4) 0 | 785 | (4) 785+ | A |
| | | 1912? | +3 | 785 | 788 | B |
| | | 1937 | 100 | 785 | 685 | C |
| | | 1944 | 108 | 785 | 677 | E |
| 26N23E- 9 | Town of Fairland | 1907 | 30 | 835 | 805 | A |
| | | 1937 | 65 | 835 | 770 | C |
| | | 1940 | 145 | 835 | 690 | E |
| | | 7/25/1946 | 180 | 835 | 655 | E |
| 27N22E-12 | County Welfare Home | 1936 | 150 | 850 | 600 | C |
| 27N23E-28-2 | Newton | 1944 | 225 | 810 | 585 | E |
| | | 7/25/1946 | 255 | 810 | 555 | F |
| 28N22E-24-1 | B. F. Goodrich Co. | 5/19/1944 | 241 | 786 | 545 | F |
| | | 8/ 2/1944 | 252 | 786 | 534 | F |
| | | 7/ 9/1946 | 352 | 786 | 434 | F |
| | | 1/18/1947 | 377 | 786 | 409 | F |
| 28N23E- 6-1 & 2 | City of Commerce | 1936 | (5) 200 | 810 | (5) 610 | E |
| | | 8/—/1945 | (5) 370 | 810 | (5) 440 | E |
| 18 | B. F. Goodrich Co. | 8/ 3/1944 | 245 | 777 | 532 | F |
| | | 7/ 9/1946 | 322 | 777 | 455 | F |
| 30-1 | City of Miami | Pre-1907 | (4) 0 | 792 | (4) 792+ | A |

TABLE 7 (Continued)

WATER LEVELS IN DEEP WELLS IN OTTAWA COUNTY, OKLAHOMA, 1907-48

| Well no. | Owner's name | Date | Position of water level (ft. above or below pt.)[1] | Altitude above sea level (feet) | | Source[3] |
|---|---|---|---|---|---|---|
| | | | | Reference point[2] | Water level | |
| 28N23E-30-2 | Southwest Service Co. | Pre-1907 | +28 | 765 | 793 | A |
| | | 1937 | 100 | 765 | 665 | C |
| | | 1944 | 150 | 765 | 615 | E |
| 31-3 | City of Miami | 6/—/1919 | 116 | 776 | 660 | |
| | | 1937 | 150 | 776 | 626 | C |
| | | 1940 | 300 | 776 | 476 | E |
| | | 1/—/1947 | 385 | 776 | 391 | F |
| 29N22E-25-1 | Powerhouse | 3/—/1945 | 233 | 835 | 602 | D |
| | | 10/22/1945 | 235 | 835 | 600 | D |
| 36 | Scammon Hill Mine | 10/19/1923 | 190 | 825 | 635 | D |
| 29N23E-15-1 | Brewster | 4/11/1947 | 295 | 840 | 545 | F |
| | | 11/20/1947 | 296 | 840 | 544 | F |
| | | 4/29/1948 | 297 | 840 | 543 | F |
| 18-1 | Pelican Mine | 4/27/1948 | 265 | 840 | 575 | D |
| 19-1 | Masters (town of Cardin) | 2/—/1936 | 180 | 825 | 645 | C |
| | | 5/—/1937 | 220 | 825 | 605 | C |
| | | 9/12/1942 | (6)420 | | | |
| | | 4/30/1948 | (6)450 | | | |
| 19-2 | Eagle-Picher, M. & S. Co. (John Beaver) | 1938 | 285 | 833 | 548 | D |
| 19-4 | Eagle-Picher M. & S. Co. (Lion Mine) | 4/29/1948 | 256 | 830 | 574 | F |
| 20 | Netta Mine | 5/31/1915 | 50 | 830 | 780 | D |
| 23 | Bob Cropp | 1933 | 215 | 855 | 640 | D |
| 24 | Ontario Smelter | 1/ 3/1918 | 104 | 850 | 746 | D |

TABLE 7 (Continued)

WATER LEVELS IN DEEP WELLS IN OTTAWA COUNTY, OKLAHOMA, 1907-48

| Well no. | Owner's name | Date | Position of water level (ft. above or below pt.)[1] | Altitude above sea level (feet) | | Source[3] |
|---|---|---|---|---|---|---|
| | | | | Reference point[2] | Water level | |
| 29N23E-30 | Blue Goose Mine | 1927 | 200 | 832 | 632 | D |
| 31-1 | Eagle-Picher M. & S. Co. | 1/ 9/1932 | 210 | 834 | 624 | D |
| | (central mill) | 12/—/1932 | 210 | 834 | 624 | D |
| | | ......do...... | (5)286 | 834 | (5)548 | D |
| | | 7/—/1935 | 230 | 834 | 604 | D |
| | | ......do...... | (5)280 | 834 | (5)554 | D |
| | | 7/—/1936 | 260 | 834 | 574 | D |
| | | ......do...... | (5)310 | 834 | (5)524 | D |
| | | 8/—/1936 | 264 | 834 | 570 | D |
| | | ......do...... | (5)308 | 834 | (5)526 | D |
| | | 6/—/1937 | 264 | 834 | 570 | D |
| | | ......do...... | (5)308 | 834 | (5)526 | D |
| | | 2/—/1938 | 268 | 834 | 566 | D |
| | | ......do...... | (5)312 | 834 | (5)522 | D |
| | | 4/—/1938 | 266 | 834 | 568 | D |
| | | ......do...... | (5)310 | 834 | (5)524 | D |
| | | 10/—/1938 | 264 | 834 | 570 | D |
| | | ......do...... | (5)316 | 834 | (5)518 | D |
| | | 3/—/1939 | 258 | 834 | 576 | D |
| | | ......do...... | (5)310 | 834 | (5)524 | D |
| | | 5/—/1940 | 285 | 834 | 549 | D |
| | | ......do...... | (5)335 | 834 | (5)499 | D |
| | | 5/—/1941 | 285 | 834 | 549 | D |
| | | ......do...... | (5)338 | 834 | (5)496 | D |
| | | 8/—/1941 | 298 | 834 | 536 | D |
| | | ......do...... | (5)350 | 834 | (5)484 | D |

TABLE 7 (Continued)

WATER LEVELS IN DEEP WELLS IN OTTAWA COUNTY, OKLAHOMA, 1907-48

| Well no. | Owner's name | Date | Position of water level (ft. above or below pt.)[1] | Altitude above sea level (feet) | | Source[3] |
|---|---|---|---|---|---|---|
| | | | | Reference point[2] | Water level | |
| 29N23E-31-1 | Eagle-Picher M. & S. Co. (central mill), cont'd. | 11/—/1941 | 325 | 834 | 509 | D |
| | | ......do...... | (5)353 | 834 | (5)481 | D |
| | | 1/29/1943 | (5)340 | 834 | (5)494 | D |
| | | 5/28/1943 | 298 | 834 | 536 | D |
| | | ......do...... | (5)330 | 834 | (5)504 | D |
| | | 5/23/1944 | 320 | 834 | 514 | D |
| | | ......do...... | (5)360 | 834 | (5)474 | D |
| | | 1/27/1945 | 330 | 834 | 504 | D |
| | | 7/—/1946 | 368 | 834 | 466 | D |
| | | ......do...... | (5)384 | 834 | (5)450 | D |
| | | 4/17/1947 | (5)430 | 834 | (5)404 | D |
| | | 4/27/1948 | (5)497 | 834 | (5)337 | D |
| 35-2 | Town of Quapaw | 1932? | 160 | 845 | 685 | C |
| 35-3 | ............do............ | 7/23/1942 | 258 | 845 | 587 | E |

1 Water levels above reference point indicated by "+"; all others are below reference point.
2 Altitudes of reference points approximated from topographic map.
3 Source of data: A—Siebenthal, C. E., U. S. Geol. Survey Bull. 340-C.
B—Siebenthal, C. E., U. S. Geol. Survey Bull. 606.
C—Records of the State Mineral Survey.
D—Company records.
E—Reported to U. S. Geol. Survey during this investigation.
F—Tape or air-line measurement.

(4) **Water level at surface or higher.** Wells that were reported to have overflowed may have had several feet of positive **head, but amount** is not known.
(5) Water level while pumping.
(6) Position of pump bowls.

## PUMPING TESTS

Three controlled pumping tests were made on wells of The B. F. Goodrich Co., under the direct supervision of the senior author of this report. They reveal the hydraulic properties of the rocks of the Canadian series. In addition, two protracted pumping tests were made by others on wells tapping the Boone formation. Although these two do not yield coefficients of transmissibility and storage, they clearly indicate that in some localities, at least, the Boone can yield water in very substantial quantities. All five tests are described in the pages that follow.

### Purpose and Definitions

The amount of water a well will yield depends primarily on the hydraulic properties of the aquifer. These include the permeability, the coefficient of storage, and the extent and thickness of the aquifer. The permeability[1] is the ability of the water-bearing material to transmit water, and usually is expressed as the number of gallons of water per day that can percolate through each mile of the water-bearing bed (measured at right angles to the direction of flow) for each foot of thickness of the bed and for each foot per mile of gradient. In dealing with a single aquifer, it often is more convenient to multiply the permeability by the thickness of the aquifer to obtain the coefficient of transmissibility, which represents the ability of the aquifer as a whole to transmit water. Pumping tests generally give the transmissibility directly. The coefficient of storage is equal to the amount of water, expressed as a fraction of a cubic foot, released from each vertical column of the aquifer having a base 1 foot square as the piezometric or water level declines 1 foot. Measurements of the permeability, the coefficient of transmissibility, and the coefficient of storage can be made by means of controlled pumping tests.

### Tests in Canadian Series (Goodrich Plant)

In the first test, well 28N22E-24-3 was pumped at an average rate of 421 gallons per minute from 11:20 a.m. on March 25, 1944, to 2:30 p. m. on April 2, a period of 8 days, 2 hours, and 10 minutes. Measurements of water level made in the well by the wetted-tape

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[1] Field permeability, determined at the prevailing temperature of the water. The laboratory coefficient is the permeability at 60 degrees F.

method after the pump had been shut down gave the rate of recovery of the water level. Periodic measurements of water level in well 28N22E-24-5 starting the day before the pump was shut down gave part of the drawdown and the recovery of water level at a distance of 2,000 feet from the point of withdrawal. The discharge of the pumped well was measured by means of a Sparling meter, which was checked against an orifice meter.

Methods used in subsequent tests were similar, but periods and rates of pumping differed. In the second test, well 28N22E-24-1 was pumped at an average rate of 450 gallons per minute from 10:05 a.m. on May 19, 1944, to 8:22 a. m. on May 21, a period of 46 hours and 17 minutes. The water levels were observed in wells 28N22E-24-3 and -5 before, during, and after the pumping, and in well 28N22E-24-2 during the latter part of the test. These wells were 2,575, 3,358, and 2,470 feet, respectively, from the point of withdrawal.

In the third test, well 28N22E-24-4 was pumped at an average rate of 500 gallons per minute from 10:41 a. m. on August 3, 1944, to 10:45 a. m. on August 5, a period of 48 hours and 4 minutes. Observations of water levels were made in wells 28N22E-24-1 and -3 and 28N23E-18-1. These wells were 5,400, 4,090, and 2,507 feet, respectively, from the point of withdrawal. The drawdown and recovery of water level in well 28N22E-24-1 during the third test are illustrated in figure 7.

### ANALYSIS OF DATA

Hydrographs of water level plotted against time, similar to figure 7, were prepared for each observation well to show the drawdown and the recovery of water level in that well caused by the pumping. The drawdown and recovery of water level were then analyzed separately for each well, according to the Theis nonequilibrium formula, to derive coefficients of transmissibility and storage. In all, 13 determinations for transmissibility and 12 for storage were made.

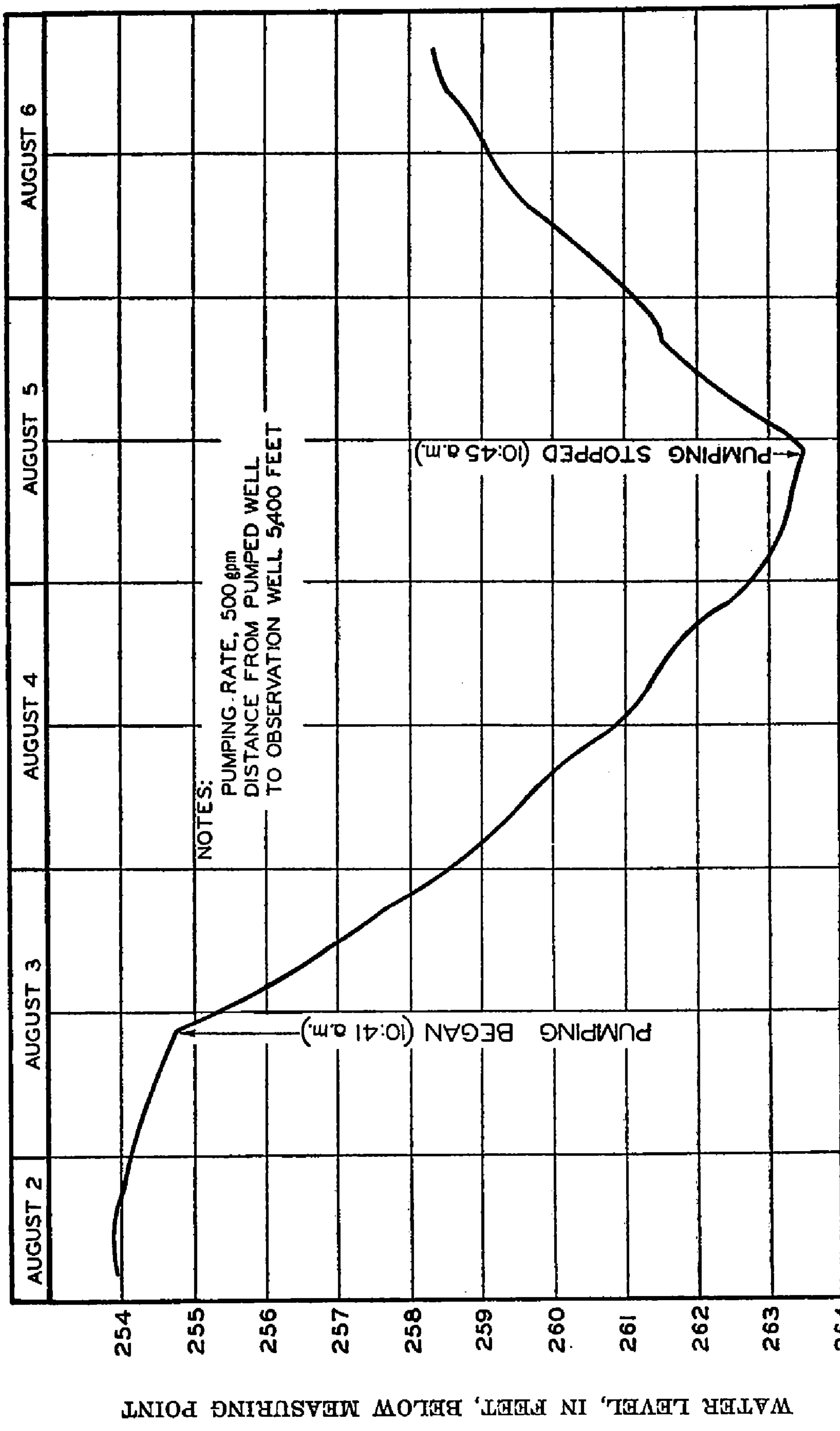


FIG. 7. Graph showing drawdown and recovery of water level in well 28N22E-24-1 during and after test in which well 28N22E-24-4 was pumped, August 1944. Pumping rate 500 gallons per minute. Distance from pumped well 5,400 feet.

The Theis nonequilibrium formula (Theis, 1935, p. 519-524) is an equation that describes the cone of depression created in the piezometric surface by the withdrawal of water. As applied in pumping tests, the observed drawdown and the rate of pumping are substituted in the formula, which then is solved for the coefficients of transmissibility and storage. Future drawdowns at specified rates of withdrawal may be estimated by using these coefficients of transmissibility and storage in the same formula as a basis for extrapolating new drawdown curves. The formula assumes that the aquifer is infinite in extent, bounded by impermeable beds above and below, and homogeneous and isotropic; and further that water is released from storage instantaneously with decline in head. These ideal conditions are not fully realized in nature. If they were, coefficients of transmissibility and storage would be identical throughout the aquifer, but in actuality they differ widely. In applying the Theis formula, therefore, consideration should be given to the deviations from the assumed conditions.

For the tests at the Goodrich plant, the Theis formula was first solved using the graphical method (Wenzel, 1942, p. 88), which consists of plotting drawdown against the reciprocal of time on logarithmic paper and matching the curve so obtained to a standard type curve. It was found that although the curves matched for the early part of the test, they diverged with the passage of time. That is, the drawdown in the latter part of the test was excessive, owing perhaps to competitive pumping from other wells, or to an obstacle in the aquifer preventing uniform, normal extension of the cone of depression. The nearest competing wells were those of the city of Miami, but the pumping periods in them did not correspond with the time of excessive drawdown in the Goodrich wells. The Miami syncline therefore was considered as a possible barrier to the movement of underground water.

The effectiveness of this inferred barrier is suggested but by no means proved by comparison of analyses of water from wells on opposite sides of the synclinal axis (table 8). The dissolved solids in waters from three wells west of the syncline averages nearly two and a half times as much as in waters from seven wells east of the syncline, which is the side nearer the intake area. Most of the increase is in chloride, which averages about six times as concentrated in the waters from west of the syncline. The difference is greater than the normal increase in mineralization observable as aquifers are followed down the dip to the depths where flushing and freshening by water from the outcrop ceases and the formation contains undiluted sea water trapped in the sediments at the time of deposition.

TABLE 8

COMPARISON OF DISSOLVED SOLIDS AND CHLORIDES IN WATERS FROM THE ROCKS OF THE CANADIAN SERIES ON OPPOSITE SIDES OF THE MIAMI SYNCLINE.

| Well name | Well number[1] | Depth (feet) | Chlorides (ppm) | Dissolved solids (ppm) |
|---|---|---|---|---|
| A. *Wells west of syncline* | | | | |
| Pelican | 29N23E-18-1 | 1,229 | 260 | 583 |
| Gordon | 29N23E-18-2 | 1,176 | 94 | 300 |
| Bird Dog | 29N22E-13-1 | 1,267 | 259 | ...... |
| Powerhouse | 29N22E-25-1 | 1,229 | 212 | 495 |
| *Average* | | *1,225* | *204* | *459* |
| B. *Wells east of syncline* | | | | |
| Picher | 29N23E-21-1 | 1,066 | 16 | 158 |
| Picher | 29N23E-21-2 | 1,125 | 23 | 178 |
| Central Mill | 29N23E-31-1 | 1,175 | 16 | 158 |
| Commerce | 28N23E- 6-1 | 1,050 | 7 | 144 |
| Goodrich | 28N22E-24-4 | 1,235 | 32 | 201 |
| Miami | 28N23E-31-3 | 1,250 | 78 | 264 |
| Ballard (Wilson) | 27N23E- 7-1 | 1,055 | 54 | 265 |
| *Average* | | *1,136* | *32* | *195* |
| *Ratio, East:West* | | *1:1.08* | *1:6.3* | *1:2.4* |

[1] Well numbers indicate location. See section on Well-numbering system.

It is not clear how flushing and freshening to depths of about 1,200 feet in Ottawa County are accomplished. For one thing, the intake area is remote and much time would be required for slow-moving ground water to travel to Ottawa County. During this time much mineral matter could be dissolved from the rocks traversed. Then, too, circulation implies outlet as well as intake, and the points of discharge are unknown. They are, indeed, difficult to conceive in view of the fact that the water-bearing rocks under consideration continue to descend westward whereas the land surface rises. Nevertheless when the first well was drilled into these rocks the water in them was fresh enough to use and to warrant extensive development. The important consideration, therefore, probably is the rate of circulation, or the lack thereof, in different parts of the aquifer. Feeble or negligible circulation across the synclinal axis could conceivably lead to a relatively stagnant "pool" on its west side, the water being less diluted or freshened than it might be otherwise.

As the effect of a folding movement is compressive along a synclinal axis, the porosity and permeability of the rocks in the Miami syncline may be less than elsewhere in the region. Furthermore, the folding was accompanied by faulting, and the faults may have offset permeable beds against impermeable beds, or crushed and broken rock along the faults may be an obstacle to the movement of water. Thus, the syncline may constitute an impermeable barrier preventing or impeding the movement of ground water from the west toward the wells that were pumped in the tests.

The axis of the Miami syncline passes about 0.5 mile west of the Goodrich plant and it is noteworthy that the Goodrich well nearest to it proved to be the well showing the lowest yield and the lowest coefficient of transmissibility. Confirmation is furnished by drillers' reports of low yields from other wells drilled near the axis of the syncline. To translate this idea into quantitative terms and check its validity, the extra drawdowns that would be caused by such an obstruction were computed for the first and second pumping tests according to the Theis image-well theory, which is explained on a later page. Subtracting these extra drawdowns from the observed drawdowns and replotting yielded new but hypothetical curves that closely matched the type curve. These new curves, therefore, approximated those that would have been obtained if no hydraulic barrier were present—that is, if the ground water were free to move toward the wells uniformly from all sides.

The syncline would be a barrier to the movement of ground water toward a pumped well as soon as the cone of depression reached it, and its influence on yield and drawdown would increase with continued pumping until the cone expanded eastward to the outcrop area—if it could—allowing establishment of a condition of equilibrium. For this reason, it is believed that the coefficient of transmissibility derived from the first part of the curves is more typical of the aquifer in the area as a whole than is the coefficient of transmissibility from the latter part of the tests. At C. E. Jacob's suggestion (personal communication) modified type curves assuming that the Miami syncline is an absolute barrier on the west were prepared, and the actual curves based on the tests were matched to them. Values for the coefficient of transmissibility based on this procedure are thought to be reasonably reliable and realistic (table 9).

TABLE 9

ADJUSTED COEFFICIENTS OF TRANSMISSIBILITY AND STORAGE OF THE ROCKS OF THE CANADIAN SERIES AS DETERMINED FROM PUMPING TESTS IN WELLS AT THE GOODRICH PLANT, MIAMI, OKLAHOMA

| Discharge well[1] | Observed well[1] | Coefficient of transmissibility (gpd/ft) | Coefficient of storage | Based on |
|---|---|---|---|---|
| *Test 1.* | | | | |
| | 28N22E-24-3 | 23,800 | | Recovery |
| 28N22E-24-3 | | | | |
| | -5 | 47,400 | $8.43 \times 10^{-5}$ | Recovery |
| *Test 2.* | | | | |
| | 28N22E-24-2 | 22,200 | $1.02 \times 10^{-4}$ | Recovery |
| | -3 | 32,950 | $6.85 \times 10^{-5}$ | Drawdown |
| 28N22E-24-1 | -3 | 40,400 | $6.07 \times 10^{-5}$ | Recovery |
| | -5 | 32,200 | $7.87 \times 10^{-5}$ | Drawdown |
| | -5 | 31,500 | $7.69 \times 10^{-5}$ | Recovery |
| *Test 3.* | | | | |
| | 28N22E-24-1 | 36,400 | $4.23 \times 10^{-5}$ | Drawdown |
| 28N22E-24-4 | -1 | 59,400 | $6.17 \times 10^{-5}$ | Recovery |
| | -3 | 41,200 | $5.77 \times 10^{-5}$ | Drawdown |
| | -3 | 43,900 | $6.10 \times 10^{-5}$ | Recovery |
| | 28N22E-18-1 | 35,600 | $1.27 \times 10^{-4}$ | Drawdown |
| | -1 | 48,800 | $1.41 \times 10^{-4}$ | Recovery |
| Over-all average | | 38,100 | $8.00 \times 10^{-5}$ | |

1 Well numbers indicate location. See section on Well-numbering system, p. 141.

These adjusted coefficients of transmissibility range from 22,200 gallons per day per foot to 59,400, and average 38,100; and the coefficients of storage range from $4.23 \times 10^{-5}$ to $1.41 \times 10^{-4}$, and average $8.00 \times 10^{-5}$. The wide range in values for these coefficients is thought to be due principally to lack of uniformity within the aquifer—more precisely, to low porosity and permeability along the Miami syncline, perhaps attributable to cementation and faulting. Well 28N22E-24-2 is the nearest of the Goodrich wells to the axis of the syncline, and the lowest figure for transmissibility was obtained from the recovery of water level in it after pumping was stopped in well 28N22E-24-1, the next nearest to the syncline. On the other hand, the highest figures for transmissibility were obtained when well 28N22E-24-4 was pumped. Of the pumped wells, this was the farthest from the synclinal axis. Even within the group of six determinations based on this test the range is from 36,400 to 59,400 gallons per day per foot, a spread of 23,000. The average for this group of determinations is about 44,200 gallons per day per foot.

The second lowest value for the coefficient of transmissibility was obtained from the recovery of water level in well 28N22E-24-3 after pumping in it had stopped. This well entered the pre-Cambrian granite at a depth of 1,050 feet and is the shallowest of the Goodrich wells. The lower 592 feet is uncased, and all this zone is assumed to have contributed water to the well. This is 174 feet less than the average length of open hole in the other five Goodrich wells. The well went through 155 feet of the Roubidoux formation, which is thought to be the principal source of ground water. Among the Goodrich wells, this is not the thinnest section of the Roubidoux by 5 feet, but it is 15 feet less than the average. As the coefficient of transmissibility is equal to the permeability multiplied by the thickness of the aquifer, it is evident that less thickness means lower transmissibility. Even more important, perhaps, is the fact that the lower sandstone member of the Roubidoux formation—thought to be one of the more productive zones—is much thinner in this well than in the other Goodrich wells.

It appears probable that the transmissibility of the aquifer gradually decreases from the east toward the Miami syncline. As the Goodrich wells are rather close to the synclinal axis, it is likely that the average of 38,100 gallons per day per foot is lower than the normal transmissibility of the Canadian series in Ottawa County. For this reason, and for convenience in further computations, 40,000 gallons per day per foot for the coefficient of transmissibility and $1 \times 10^{-4}$ for the coefficient of storage have been adopted as representative of the area.

## FUTURE DRAWDOWNS

The Theis nonequilibrium formula can be used to predict future drawdowns in an aquifer if the coefficients of transmissibility and storage are known, and if the effects of the boundaries can be evaluated. Curves representing the theoretical drawdown of water level at distances ranging from 1 to 155,000 feet from a well being pumped at a rate of 400 gallons per minute for periods of 100 days, 6 months, 1 year, 2 years, 5 years, 10 years, and 50 years have been prepared for an aquifer of infinite extent having a coefficient of transmissibility of 40,000 gallons per day per foot and a coefficient of storage of $1 \times 10^{-4}$ (figs. 8 and 9). These coefficients are approximately those of the rocks of the Canadian series in Ottawa County.

Because the drawdown is proportional to the rate of pumping, drawdowns at rates other than 400 gallons per minute can be determined from the curve by multiplying the indicated drawdown by the appropriate ratio. For example, a well pumping 200 gallons per minute will cause half the drawdown shown on the curve and a well pumping 500 gallons per minute will cause one-fourth more —that is, 1.25 times as much. The total drawdown at a given point caused by pumping from several wells is equal to the sum of the drawdowns produced individually by the wells. For example, if two wells were to pump 400 gallons per minute each for a period of 100 days, the drawdown at a point 600 feet from one well and 2,000 feet from the other would be 12 feet plus 9 feet, or 21 feet at the end of the period.

The Theis formula is not directly applicable to the problem of determining the drawdown in a well due to its own pumping, because several factors, among them the entrance losses into the well and changes in transmissibility of the formation adjacent to the well caused by the drilling or development of the well, cannot be evaluated mathematically. An approximate solution is obtained by determining the specific capacity (gallons per minute per foot of drawdown) for a 24-hour period of pumping and from it estimating what the drawdown at the end of the first day would be at the pumping rate selected for the computations. The estimated drawdown normally is greater than the drawdown computed strictly

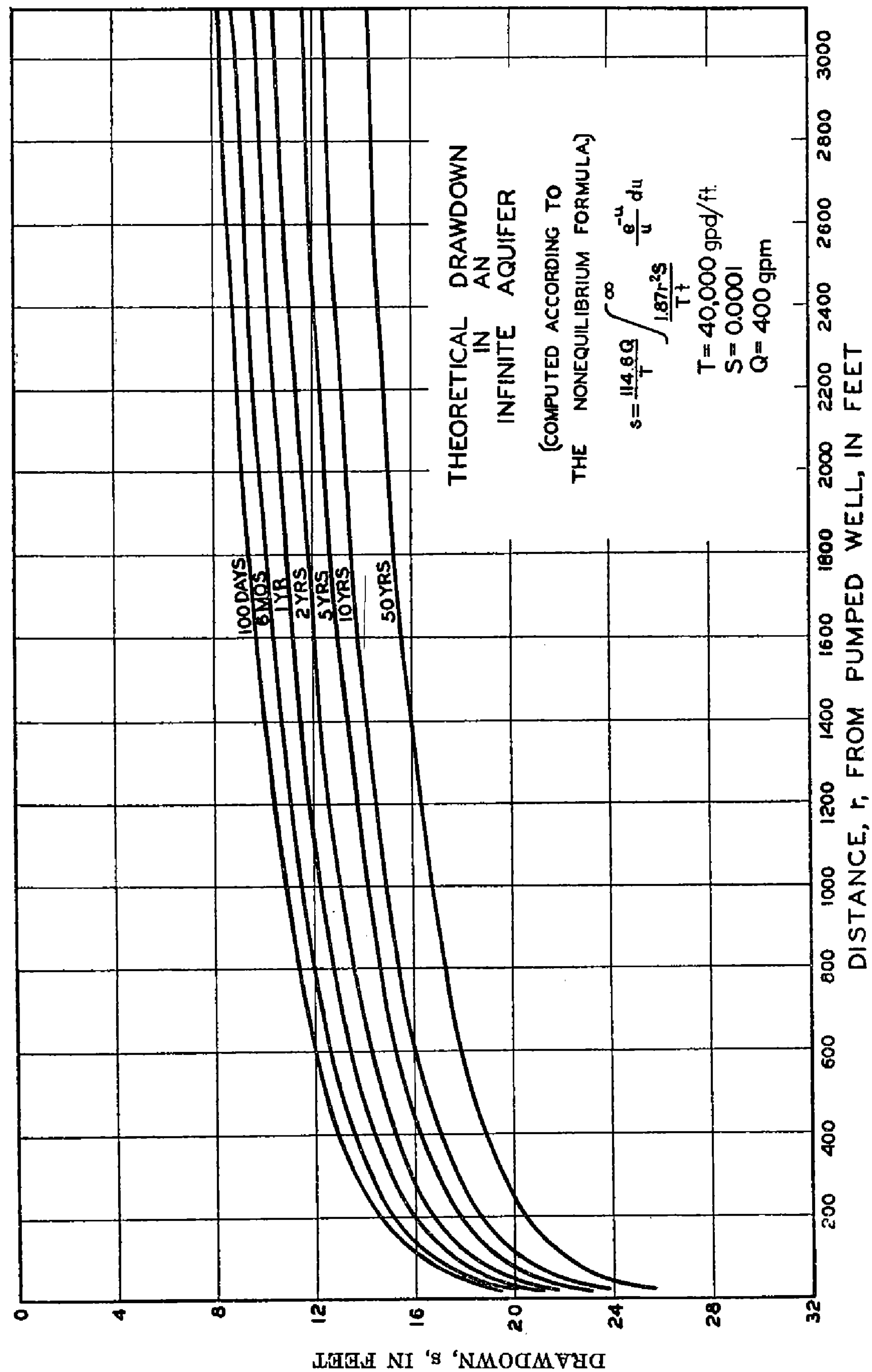


FIG. 8. Theoretical drawdown in an aquifer of infinite lateral extent having hydraulic properties approximating those of the Canadian series of Ottawa County, Oklahoma, for periods from 100 days to 50 years and at distances up to 3,100 feet from the pumped well.

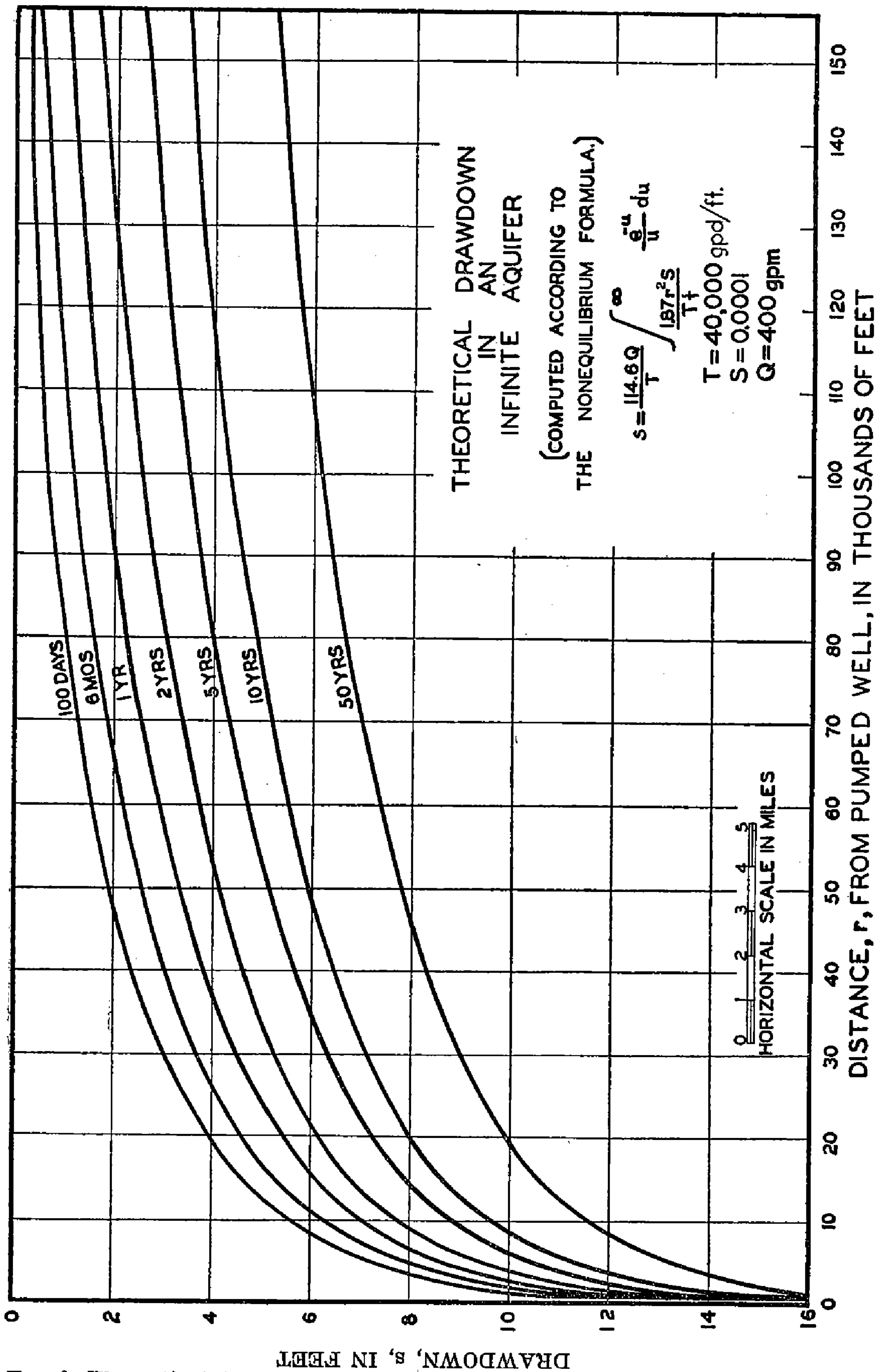


FIG. 9. Theoretical drawdown in an aquifer of infinite lateral extent having having hydraulic properties approximating those of the Canadian series of Ottawa County, Oklahoma, for periods from 100 days to 50 years and at distances up to 155,000 feet (about 30 miles) from the pumped well.

according to the Theis formula. The difference between the estimated drawdown and the drawdown computed by the formula is then used as a constant correction, being added to the drawdowns for future days as computed by the formula.

### EFFECT OF BOUNDARIES

The Theis formula, and therefore the curves of figures 8 and 9, are based on the assumption that the aquifer is of infinite lateral extent, but the pumping tests showed the Miami syncline to be a barrier to the flow of ground water. Presumably the Seneca fault is a barrier also. The effect of a barrier on the drawdown in pumped wells can be evaluated by the use of the image-well theory of Theis (1939), which translates the hydraulic effect of the barrier into the drawdown that would be caused by other, hypothetical, pumped wells.

The simplest case is that of one pumped well and one barrier. The well is regarded as reflected across the barrier as if the barrier were a mirror. The reflection, or "image," well is an assumed well pumping at the same rate and for the same period of time as the real well and located at the same perpendicular distance from the barrier as the real well, but on the opposite side. Because the real well and the image well are identical and equidistant from the barrier, their cones of depression are identical and will reach the barrier at the same time. Therefore, a reversal of gradient—a "drainage divide"—will occur there. Under these assumed conditions, ground water would be no more able to cross the "drainage divide" than it is able in nature to cross the hydraulic barrier. Hence, the computed drawdown in the pumped well caused by the "pumping" of the image well is equal to the effect of the barrier.

If several pumped wells are to be considered, the theory assumes for each an image well reflected across the barrier, and the total drawdown at any point equals the sum of the drawdowns produced by all the real pumped wells plus the drawdowns produced by the image pumped wells at that point.

In the case of a single well and two parallel barriers, the systems of the image wells become infinite—the pumped well is reflected to the first image across the first barrier, this image well is reflected to a second image across the second barrier, which in turn is reflected back across the first barrier, and so on ad infinitum. Similarly, a second system is set up starting with an image of the pumped well reflected across the second barrier, then across the first barrier, and so on. As the successive image wells of the same system are progressively farther from the starting point, the drawdown effect ultimately becomes negligible. Where several pumped wells are considered, each has its own infinite system of image wells and affects all the others. Thus the analysis may become very complicated, but for practical purposes a distance may be selected beyond which the effect of additional image wells would be negligible during the period under consideration.

If the two barriers are not parallel, the system of image wells becomes finite, and a rigid mathematical solution is possible under some situations but not under others. If the angle of intersection of the two barriers, measured in degrees, can be multiplied by an even whole number to yield 360 degrees, the problem can be solved. Thus, if the angle of intersection is 60 degrees, multiplying 60 times 6 (an even whole number) yields 360 and a solution should be obtainable. On the other hand, if the angle of intersection is 72 degrees, an odd whole number (5) is required as multiplier to get 360 degrees, and a solution is possible only if the well (or wells) lies on the bisector of the angle of intersection. For practical purposes, however, the computations for a few sets of images generally will suffice to determine the drawdown within the barriers, because the drawdown effect decreases markedly as the images become more and more distant.

The rocks of the Canadian Series of Ottawa County are an aquifer having several pumped wells and perhaps two hydraulic barriers. The Miami syncline on the west and probably the Seneca fault on the east are barriers for at least parts of their lengths, and they doubtless contribute to the drawdowns in the wells between them. To illustrate, a partial analysis was made of the drawdown to be expected in well 28N22E-24-5 caused by its own pumping plus pumping in six other wells at the Goodrich plant. Continuous pumping at 400 gallons per minute was assumed for all wells except 28N22E-24-2, for which 200 gallons per minute was assumed. Both barriers were regarded as vertical planes. The calculations were simplified by considering the first set of image wells reflected across the Miami syncline to be a single well pumping at a rate of 2,600 gallons per minute. Because the reflection of this image well and those of the real wells across the Seneca fault are relatively close together, the calculations were simplified further by assuming these image wells to be a single well pumping 5,200 gallons per minute. Figure 10 illustrates the relative positions of the group of actual wells, the barriers, and the several sets of image wells. Table 10 summarizes the theoretical drawdown after 100 days, 6 months, 1 year, 2 years, and 5 years of continuous pumping. The indicated total drawdown after 5 years is about 450 feet.

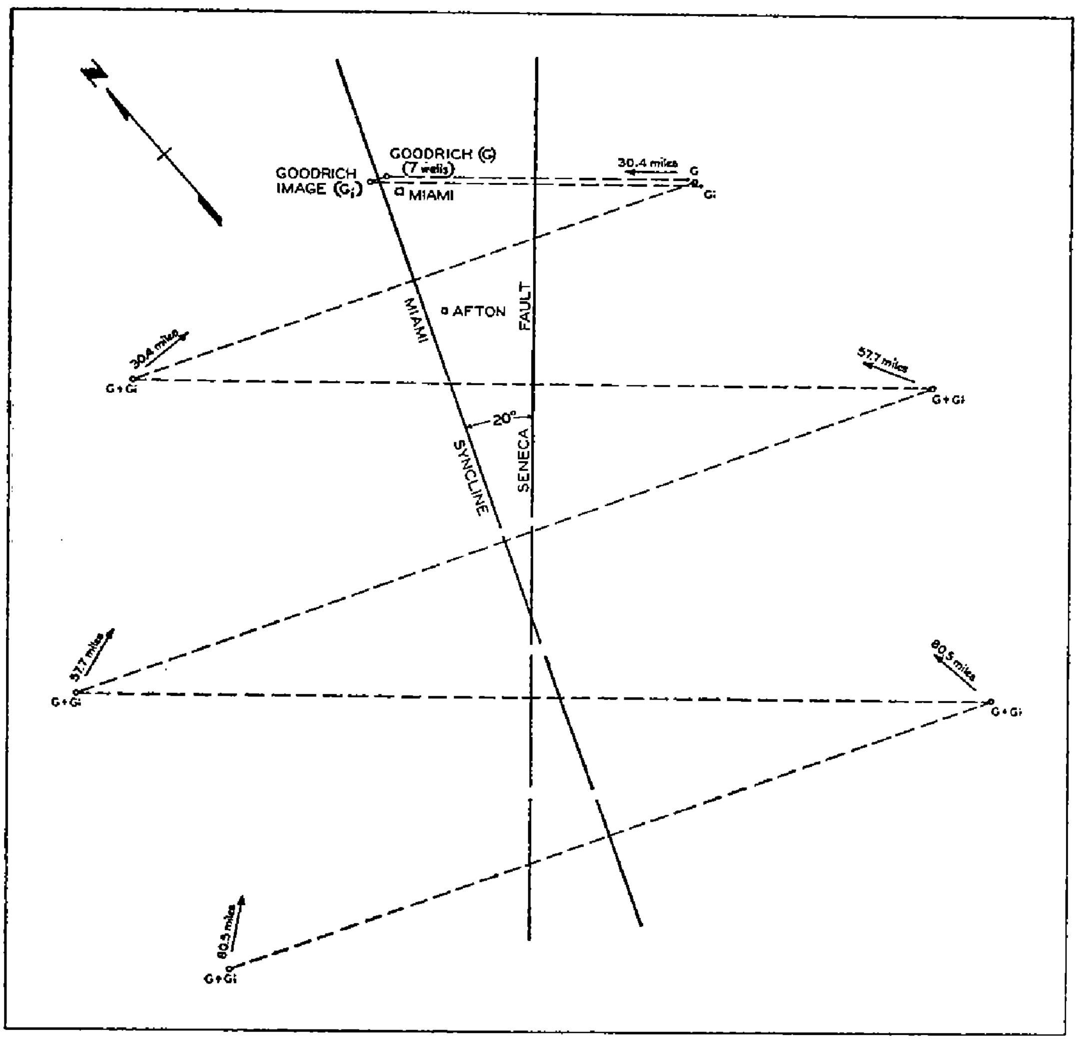


Fig. 10. Application of the image-well interpretation to the Canadian series of the Miami, Oklahoma, area.

TABLE 10

THEORETICAL DRAWDOWN OF WATER LEVEL IN THE CANADIAN SERIES IN FEET, AFTER CONTINUOUS PUMPING FOR PERIODS FROM 100 DAYS TO 5 YEARS, AS ESTIMATED FOR A WELL AT THE PLANT OF B. F. GOODRICH CO. (28N22E-24-5), MIAMI, OKLAHOMA.

| Drawdown from | Length of Pumping Period | | | | |
|---|---|---|---|---|---|
| | 100 days | 6 months | 1 year | 2 years | 5 years |
| Pumping in well 28N22E-24-5 (at 400 gpm) | 204 | 206 | 207 | 208 | 209 |
| Interference of 6 other wells (at 2,200 gpm, total) | 38 | 41 | 44 | 48 | 53 |
| First reflection, all 7 wells on Miami syncline (2,600 gpm) | 38 | 42 | 47 | 52 | 59 |
| First set, double reflections (2 on each barrier, 10,400 gpm) | 5 | 12 | 25 | 41 | 66 |
| Second set, double reflections (10,400 gpm) | 0 | 1 | 5 | 14 | 32 |
| Third set, double reflections (10,400 gpm) | 0 | 0 | 1 | 5 | 18 |
| Fourth set, double reflections (10,400 gpm) | 0 | 0 | 1 | 4 | 15 |
| Total drawdown in well 28N22E-24-5 | 285 | 302 | 330 | 372 | 452 |

It is obvious that several sources of error are involved in this analysis. First, the municipal wells of Miami and possibly, also, other wells in the area would increase the drawdown. To include them, however, would complicate the calculations and their explanation beyond the needs of this report. Second, the Theis formula, on which the analysis is based, assumes that the coefficient of transmissibility is uniform throughout the aquifer, but the pumping tests gave rather uneven results. To some extent the error due to this factor is thought to be offset by the use of average coefficients of transmissibility and storage in the computations. Third, the formula assumes an unchanging coefficient of storage and instantaneous release of water from storage, whereas under natural conditions the release will be gradual and the coefficient of storage probably will increase slowly with the passage of time. The effect will be that more water will come from storage than is assumed in the computations and the drawdown will be lessened correspondingly, but even if the coefficient of storage should become several times that indicated by the rather brief pumping tests, the drawdowns would not be significantly smaller.

The assumption that the coefficient of transmissibility will be constant is not entirely valid. Although theoretically the coefficient should decrease somewhat as the formation is dewatered, such dewatering is an impossibility so long as pumps in the area remain at their present levels, which are far above the zones yielding the bulk of the water. Also, if actual dewatering occurred the change from artesian to water-table conditions would be accompanied by a relatively large increase in coefficient of storage that would more than offset the decrease in the coefficient of transmissibility.

In the computations it is assumed that both the Miami syncline and the Seneca fault are impermeable barriers throughout, whereas the pumping tests demonstrated impermeability only along the Miami syncline adjacent to the Goodrich well field. Many additional pumping tests at other locations would be required to test the validity of the assumptions regarding the barriers. If the ground water leaks across them locally or moves around the ends, the estimated future drawdowns are too large. The computations have ignored the possible effect of other faults and folds both within and outside Ottawa County. Likewise, the effect of recharge in the outcrop area has been ignored, mainly because the nearest large outcrop is more than 100 miles away.

From this analysis it is evident that the rocks of the Canadian series in Ottawa County act principally as a huge underground reservoir, which for all practical purposes is not being replenished. Water levels, hence, will decline as long as pumping continues. If the pumping rate remains the same, the rate of decline will diminish as time passes, but any large increase in the rate of pumping will increase the rate of decline. In any case, pump bowls will have to be lowered in many wells if the discharge is to be maintained.

A very large quantity of water remains in the reservoir, which still should furnish many millions of gallons of water, although at increasing cost occasioned by increasing lift. The water levels have declined more than 400 feet in some places during the past quarter of a century, and there is no reason to expect a reversal in this trend at present or anticipated rates of withdrawal. If an economical and practical method could be found to recharge the reservoir artificially, however, the trend might be reversed.

### Tests in Boone Formation

Pumping tests have not been made that offer data for the determination of the coefficients of transmissibility and storage for the Boone limestone. Something of the hydraulic properties of the Boone may be learned, however, from the records of protracted pumping at the Garrett and Park-Walton mines. The objective of the pumping was to dewater the mines so that work could go forward in them.

#### GARRETT LEASE

Abernathy (1941, p. 234-235) reported a 7-month pumping test made by the Eagle-Picher Mining and Smelting Co. at its Garrett lease, in sec. 36, T. 34 S., R. 23 E, Cherokee County, Kansas, between August 9, 1938, and March 7, 1939. Two deep-well turbine pumps having a maximum total capacity of 8 million gallons per day were used to pump from a shaft 5 by 9 feet in cross section and 465 feet deep. The aquifer was the Reeds Spring limestone (Boone). During a 67-day period near the end of the test 482 million gallons of water was withdrawn, the average daily pumpage being 7.2 million gallons. The water in the shaft was lowered from an initial static level of 180 feet to a level 324.8 feet below the surface. Thus the drawdown was 144.8 feet, and the specific capacity was about 34 gallons per minute per foot of drawdown. From Abernathy's table of monthly pumpage it appears that the total for the period of the test was about 1,196 million gallons, for an average of about 5.7 million gallons per day. Abernathy concluded: " . . . . Although the drawdown was very great, water might be withdrawn at this rate (8 million gallons per day) without serious injury to the Reeds Spring ground-water reservoir. Similar conditions favorable for ground-water development probably exist at most localities in the Miami fault area."

#### PARK-WALTON PROPERTY

To obtain an estimate of the cost of removing water under the Park-Walton zinc-lead property of the United Zinc Smelting Corp. (sec. 13, T. 29 N., R. 21 E.), the U. S. Bureau of Mines made a pumping test lasting from May to December 1943. Three wells drilled by the corporation were used. From the surface to 200 feet these were drilled 15 inches in diameter and were cased with 12¼-inch casing; from 200 feet to the bottom at about 370 feet they were drilled 12¼ inches in diameter and were uncased. The wells passed through an "open" or fractured zone from 270 to 315 feet, below which the rocks proved relatively "tight."

Identical deep-well turbine pumps having rated capacities of 1,200 gallons per minute against a 360-foot head at 1,760 revolutions per minute were installed in the wells. These were driven by 150-horsepower electric motors. The first pump was started in May, the second in June, and the third in July, and pumping in each well was nearly continuous. During 6.5 months a total of 741,180,000 gallons of water was pumped at an average rate exceeding 1,000 gallons per minute per well. The water level was lowered 208 feet in the immediate vicinity and to lesser but significant amounts in a surrounding area of about 6 square miles.

A contour map of the water surface based on water-level measurements made on November 15, 1943, in outlying open drill holes shows that the cone of depression was far from cone shaped (fig. 11). Its base was more nearly triangular than oval, with the pumping wells near the northwest apex of the triangle. It extended east and south nearly 3 miles, but north and west only short distances. This irregular shape is due to the irregular permeability of the water-bearing formation—that is, to the irregular size, distribution, and interconnections of the fissures and related openings through which the ground water moves.

The irregular distribution of water-bearing openings in the rock is further illustrated by the fact that, despite the inability of the pumps to lower the water below the 316-foot level, the company sank two "dry" shafts to the depth of 350 feet in "tight" limestone a short distance west of the ore deposit. At the 350-foot level, water in large volume was first encountered, not in the shaft, but in a cross cut 60 feet east of the bottom of the first shaft. Nearly complete drainage of the ore deposit was attained when cross cuts had been driven east from the bottom of the shafts to connect with the wells.

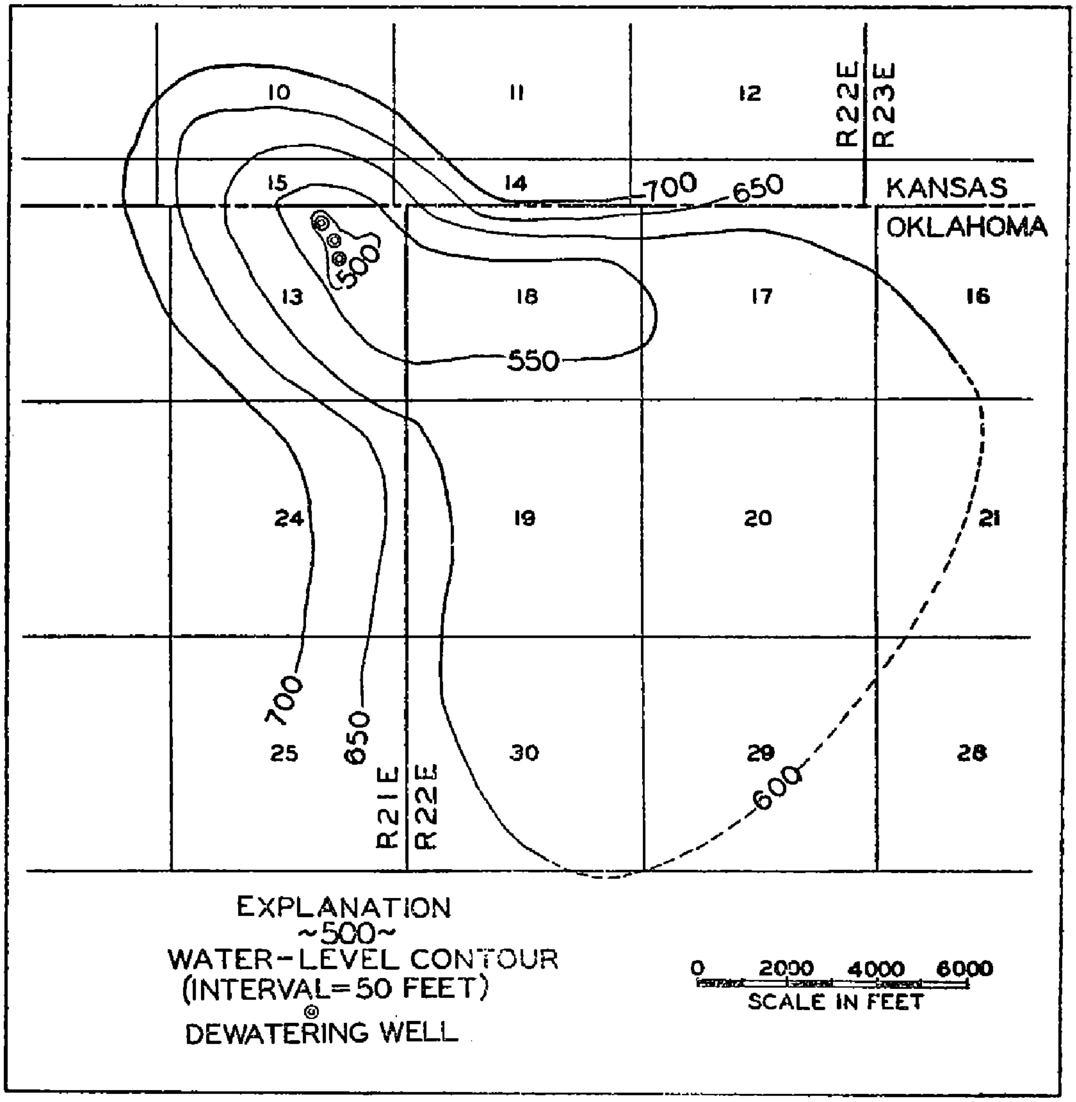


FIG. 11. Cone of depression created in the water table in the Boone formation after pumping continuously for about 6 months at the Park-Walton tract. Contours show altitude of water table in feet above sea level.

As mining operations moved southward, a fourth well south of the original three was drilled and the pump from the north well was installed in it. In May 1948 the pumpage from the three wells was about 2,750 gallons per minute. Meanwhile, two more mines had been opened nearby and the pumping in them brought the total for the locality to nearly 5,000 gallons per minute.

## UTILIZATION OF GROUND WATER

By Edwin W. Reed

Ground water is the source of most domestic, stock, municipal, institutional, and industrial water supplies in Ottawa County. The largest use is for public supply, but the total amount of water pumped for industrial purposes is exceeded in only two other counties in Oklahoma, Tulsa County and Oklahoma County.

### DOMESTIC AND STOCK WATER SUPPLIES

Practically all the water supplies for domestic and stock use in rural areas are obtained from wells and springs. The wells generally are shallow, tapping only the surface formations, and are equipped with rope and bucket or hand-operated cylinder pumps. Most of the wells and springs yield more than enough water for rural use but some are reported to be depleted perceptibly or to go dry during periods of drought.

### PUBLIC WATER SUPPLIES

All the incorporated cities and towns in Ottawa County have public water-supply systems that depend on deep wells drilled into the rocks of the Canadian series. Deep-well turbine pumps are generally used to lift the water to surface reservoirs, from which centrifugal pumps transfer it to the water mains or, in some cases, to elevated tanks. The water is given no special treatment, but the incidental aeration received when entering surface reservoirs serves to remove most, if not all, of the hydrogen sulfide common in waters from deep wells of the area. A few of the smaller towns lack surface reservoirs, depending entirely on the deep-well turbine pumps to lift the water into elevated tanks.

#### MIAMI

The city of Miami relies on five deep wells. One of these (No. 28N23E-30-1) is at the site of the old waterworks 1 block north of the St. Louis-San Francisco Railway Station. It is reported to be 1,250 feet deep. Details as to equipment and yield are lacking. There is also at this site an abandoned well which presumably is the city well mentioned by Siebenthal (1908, p. 225).

Two of the wells are at the present waterworks and municipal power plant, Fourth and D Streets NE. The well in the northeast corner of the property is reported to be 1,250 feet deep, 10 inches in diameter, and cased from the surface to a depth of 450 feet (Well 28N23E-31-2). The well in the southeast corner is similar in construction and is 1,247 feet deep (Well 28N23E-31-3). Each is equipped with a deep-well turbine pump driven by a 75-horsepower electric motor and is reported to yield about 350 gallons per minute.

TABLE 11

PUMPAGE OF GROUND WATER FOR MUNICIPAL SUPPLY, MIAMI, OKLAHOMA, 1948-51.[1]

| Month | 1948 | (Millions of gallons) 1949 | 1950 | 1951 |
|---|---|---|---|---|
| January | 29.101 | 22.939 | 23.020 | 23.592 |
| February | 28.845 | 22.596 | 20.785 | 22.621 |
| March | 29.224 | 23.656 | 24.892 | 23.050 |
| April | 30.053 | 24.954 | 26.769 | 22.644 |
| May | 25.867 | 26.222 | 28.474 | 26.856 |
| June | 30.570 | 28.052 | 31.987 | 28.396 |
| July | 31.492 | 35.301 | 30.022 | 38.654 |
| August | 29.998 | 35.574 | 28.810 | 36.318 |
| September | 30.421 | 26.399 | 25.689 | 28.704 |
| October | 27.138 | 26.824 | 24.884 | 26.304 |
| November | 26.284 | 25.717 | 22.034 | 24.538 |
| December | 24.704 | 24.954 | 22.802 | 24.682 |
| Total | 343.697 | 323.188 | 310.168 | 326.359 |
| Daily average | .94 | .88 | .85 | .89 |

[1] Data furnished by H. G. Freehauf. Water-main construction requiring the flushing of new lines, together with an unusually hot summer, made 1948 the peak year, which should be regarded as abnormal. Pumpage was abnormally high in July and August 1951 because some water lines were broken in the Neosho River flood of that year, and much water was used in cleaning up.

The fourth well is about 0.5 mile south of the municipal waterworks in the city park near the Neosho River. (Well 28N23E-31-1). Drilled in 1936, it is 1,116 feet deep and is reported to yield 480 gallons per minute.

The fifth well was drilled in 1948 about 1 mile east of the municipal waterworks, outside the city limits (NW¼NE¼NW¼ sec. 32, T. 28 N., R. 23 E). It is 11 ¾ inches in diameter, is 1,345 feet deep, and is cased from the surface to a depth of 500 feet. It is the deepest of the municipal wells and is the only one to tap the Gunter sandstone member of the Van Buren formation. It was "shot" with 120 quarts of nitroglycerine in the zone from 975-1,005 feet; 100 quarts at 1,060-1,085 feet; and 20 quarts at 1,130-1,140 feet. The well is equipped with a 24-stage submersible turbine pump driven by a 100-horsepower electric motor. With the top of the bowls set 700 feet below the surface, this well yields 550 gallons per minute.

The annual pumpage of ground water for the Miami municipal system in the 4 years 1948-51, inclusive, averaged nearly 326 million gallons (table 11).

#### NORTH MIAMI

North Miami purchases water from Miami, delivery being made through a water main laid along U. S. Highway 66.

#### PICHER

The city of Picher has three wells at the municipal waterworks on the east side of U. S. Highway 69 at the north edge of the business district. They are within 200 feet of each other. Well 29N23E-21-1 is 1,077 feet deep and the other two are 1,125 feet (Wells 29N23E-21-2 and -3). All are 8 inches in diameter and are cased from the surface to a depth of about 400 feet. Below that depth they are 6 inches in diameter and uncased. They are equipped with deep-well turbine pumps driven by 30-, 35-, and 40-horsepower electric motors, respectively, and their combined yield is reported to be about 250 gallons per minute. This is barely enough to meet the peak summer demand.

#### COMMERCE

Two wells about 100 feet apart, reported to be 1,050 and 1,110 feet deep, furnish the water supply for the city of Commerce (Wells 28N23E-6-1 and -2). They are at the waterworks 1 block south and 2 block east of the turn in U. S. highway 66 at the west edge of the city, are 6¼ inches in diameter, and are cased from the surface to a depth of 355 feet. Electrically driven turbine pumps are reported to withdraw about 125 gallons per minute.

### QUAPAW

The public water supply of Quapaw is obtained from a well at the plant of the General Power Co., at the south edge of town (Well 29N23E-35-3). Drilled in 1942, the well is 1,325 feet deep and penetrates not only the Roubidoux formation but also the Gunter sandstone member of the Van Buren formation. Several strings of casing were set in the hole—37 feet of 15-inch casing, 280 feet of 10-inch casing, and 635 feet of 8-inch casing, this last extending from the surface to a depth of 635 feet. The 8-inch casing was cemented in place. The hole is 8 inches in diameter from 635 feet to 1,100 feet, and 6.5 inches in diameter from the 1,100-foot level to the bottom. A 40-horsepower electric motor drives a deep-well turbine pump which is reported to yield 250 gallons per minute.

### AFTON

The municipal water supply for the town of Afton is obtained from two wells about 1 block southwest of the railway station, between U. S. Highway 66 and the tracks of the St. Louis-San Francisco Railway (Wells 26N22E-32-1 and -2). They are about 75 feet apart, 1,066 feet deep and 8 inches in diameter, and cased to an unrecorded point below the Chattanooga shale. The southeast well is equipped with an electrically driven deep-well turbine pump, which is reported to yield 150 gallons per minute. The northwest well is equipped with an electrically driven cylinder pump having a capacity of 125 gallons per minute. Normally one well is adequate to meet the needs of the town.

### FAIRLAND

The public water supply of Fairland is obtained from one well at the elevated tank in the central part of town (Well 26N23E-9). The depth of this well was reported to be 1,100 feet deep (Laine, Schoff, and Dover, 1951, p. 95), but H. T. Lawrence (oral communication, 1953) stated that its depth was measured as 1,244 feet. He also stated that the casing is 8 5/8 inches in diameter, and that according to an old record it extends to a depth of 400 feet. In the absence of a log of the strata penetrated by the well, it is not clear whether the water of the Boone formation and Chattanooga shale are cased out, but this probably is the case. The analysis of a sample of water from the well shows it to be similar to water from the rocks of the Canadian series, and to have none of the characteristics of the water from the younger rock formations. In 1946 a new turbine pump having a rated capacity of 70 gallons per minute was installed, replacing a turbine rated at 50 gallons per minute. According to Mr. Lawrence, the latter was dropped to the bottom of the well, and was left there. In 1953 both these turbine pumps were removed, the well was cleaned out, its depth was measured, and a new pump was installed, but the yield was only 60 gallons per minute and ways of increasing the water supply were being sought.

### CARDIN

A privately owned well furnishes the water supply of Cardin (Well 29N23E-19-1). All records for it were lost about the time the town ceased to be incorporated (1938), but according to reports the well is more than 1,100 feet deep. Presumably the water in formations above the Canadian series is cased out, for the analysis of the water is fairly typical of water from the Canadian (table 12). An electrically driven turbine pump said to discharge 152 gallons per minute is installed in the well.

### NARCISSA

The community of Narcissa receives water from a well on the Gaines brothers' farm about 650 feet west of the school. The well (No. 27N22E-27-1) is reported to be 1,000 feet deep and to be cased only to a depth of 20 feet. It is equipped with a cylinder pump driven by a 3-horsepower electric motor and serves 13 homes and the owners' farm, silo and grain elevator.

### OTHER COMMUNITIES

Most of the other communities in the county are supplied with water from privately owned wells, although a few get water from nearby mine wells. Residents of some of the smaller settlements depend on water hauled from sources several miles away.

## INDUSTRIAL WATER SUPPLIES

Ottawa County is one of the more highly industrialized counties of Oklahoma. Initially its industry was based principally on its rich resources of lead and zinc, but in recent years several new industries not dependent on local natural resources have been established. Water for industrial use, therefore, is an important factor in the economic well-being of the county.

### WATER FOR MINING

Relatively little water is needed for mining the lead and zinc ores, and getting rid of water generally is more of a problem than obtaining it. Water is used, however, for sprinkling the haulage-ways and ore piles to control dust. Most of this water is obtained from the mines themselves, although deep wells drilled into the rocks of the Canadian series supply a small part of it. Water from deep wells is used for drinking and sanitary purposes by the miners, and in a few cases is supplied to nearby houses for domestic use.

### WATER FOR MILLING

Until the early 1930's a mill was operated on nearly every lease, more than 100 of them being in operation during one period of peak production. As the water requirement for milling is about 40 gallons per minute per ton milled (Weidman, 1932, p. 126), it is evident that a large amount of water was necessary, although reuse of the water reduced somewhat the amount taken from ultimate sources. Most of it was pumped from creeks or from the mines themselves into storage ponds, and thence to the mills, and part was pumped from deep wells. With the advent of central mills, all but a few of the smaller mills were shut down and the wells for them were abandoned. Records of the total amount of water pumped from deep wells for milling purposes during the height of mining operations are not available. An estimate based on the tonnage milled and the reported average water requirement indicates that the total may have exceeded 2 million gallons per day.

The Eagle-Picher central mill is by far the largest in the Tri-State district. It handles most of the ore from the district. It has two wells that supply water for drinking and sanitary needs and part of the water for milling. The well at the elevated tank south of the mill is 1,175 feet deep, and is pumped continuously at about 150 gallons per minute (Well 29N23E-31-1). The second well (No. 29N23E-31-2) is about 650 feet west of the first, is 1,505 feet deep, and is used intermittently to supplement the first well. Both wells are equipped with electrically driven turbine pumps.

The Beck mill, east of Picher, obtains water from a well 6 inches in diameter and 675 feet deep, which is equipped with an air-lift pump. Other mills depend mainly on surface sources for milling water.

### WATER FOR ELECTRIC POWER

The Eagle-Picher powerhouse, 1 mile west of Cardin, generates electricity for the central mill and other mining activities. Its water supply comes from one well (No. 29N22E-25-1), which is 1,229 feet deep, is equipped with a deep-well turbine pump driven by 25-horsepower electric motor, and yields about 70 gallons per minute. The largest use of the water is for cooling, but some water is used for drinking and sanitary purposes.

### WATER FOR SHELL PIPE LINE CORP.

The Shell Pipe Line Corp. operates a pumping station on its gasoline pipeline about a mile west of Fairland. Water for cooling, drinking and sanitary purposes is pumped by air-lift from one well on the property, which is reported to be 1,100 feet deep.

### WATER FOR B. F. GOODRICH CO.

The B. F. Goodrich Co. has six wells to supply cooling water for a large tire plant. These wells are 10 inches in diameter, are cased through the Chattanooga shale, and are 1,055 to 1,465 feet deep. Equipped with electrically driven turbine pumps, they yield 200 to 500 gallons per minute. The pumping tests described elsewhere in this report were made in them. The Goodrich plant is the largest industrial user of water in the county. Although a possible peak water demand of 5 million gallons per day was contemplated in planning for the plant, the actual pumpage has not exceeded about 2 million gallons per day, and this has been cut to about 400,000 gallons per day by reuse of the water after passing it through a cooling tower.

#### WATER FOR OTHER INDUSTRIES

The Milnot Co., on the Missouri State line at Seneca, Missouri, obtains water from a deep well tapping the Canadian series. Several dairies having relatively low water requirements have their own water wells. Other industries in Ottawa County get water from public-supply systems.

### INSTITUTIONAL WATER SUPPLIES

#### COUNTY WELFARE HOME

The Ottawa County Welfare Home, 2 miles southwest of Miami, obtains water for all institutional needs, including drinking, sanitary purposes, and sprinkling of lawns, from a well 1,055 feet deep (No. 27N22E-12). This well is equipped with an electrically driven cylinder pump and a pressure tank.

#### SENECA INDIAN SCHOOL

The Seneca Indian School at Wyandotte has a well 8 inches in diameter, 1,040 feet deep, and cased from the surface to a depth of 250 feet (Well 27N24E-21). A cylinder pump driven by a 10-horsepower electric motor is reported to discharge 80 gallons per minute. The water is used for drinking, sanitary purposes, sprinkling the school grounds, and watering livestock.

#### NORTHEASTERN OKLAHOMA A. AND M. COLLEGE

The Northeastern Oklahoma Agricultural and Mechanical College gets water from the Miami public-supply system.

### METHODS OF CONSTRUCTING WELLS

#### DUG WELLS

Wells dug by hand are common in Ottawa County, especially in the eastern part in the outcrop area of the Boone formation. Such wells generally are several feet in diameter or several feet square. Although some are reported to be 40 feet or more deep, most are less than 20 feet. They are generally lined with field stone, although brick has been used in a few such wells. The water is withdrawn by hand-operated cylinder pumps or by rope and bucket. Yields are small but generally are sufficient for domestic and farm needs. Some dug wells are reported to decline in yield or to fail entirely during drought, probably because the water table declines below the bottom of the well. The wells generally are dug only a few feet into the zone of saturation, and a few feet of decline in water level, therefore, is enough to make them go dry. More by accident than intent, dug wells completed in time of drought may go below the lowest level of the water table and so may not fail completely. Those completed in wet years, on the other hand, may not extend below the lowest water level and so may go dry. They might be deepened successfully.

### DRILLED WELLS

Most of the wells in the county are of the drilled type. The percussion method is used almost exclusively in their construction, being preferred for penetrating the hard, dense rocks of the area. By this method, the mining companies have drilled thousands of holes in prospecting for lead and zinc ore. Even with modern methods and equipment, the drilling of wells for public or industrial water supplies is expensive and time consuming, for in general the wells must be 1,000 to 1,200 feet deep. Those drilled recently have been larger, deeper, and better constructed than the earlier wells, and larger yields have been obtained from them.

The construction of a deep well is generally begun with the drilling of a hole to accommodate the surface casing, which extends to bedrock and serves to keep unconsolidated materials from falling into the well. The pipe used for this purpose ordinarily is 16 to 20 inches in diameter and 20 to 40 feet long. When it is in place, a somewhat smaller hole, generally 10 to 12 inches in diameter, is drilled to a point below the Chattanooga shale, at which level the permanent casing is to be set. The hole is then continued with a smaller bit into or through the principal aquifer. This generally is the Roubidoux formation, although a few wells have been continued into the Gunter sandstone member of the Van Buren formation. Next a packer is cemented in the hole just below the casing point and the main string of casing is set and cemented from the surface to the packer. The cased section is tested for leaks and if results are satisfactory the packer is drilled out, the hole is cleaned, and a pump is installed for testing. If the yield proves unsatisfactory, the aquifer then may be "shot" or "acidized." The surface casing sometimes is pulled from the well, but more commonly it is left because it cannot be removed after cementing the main string.

In a few of the deeper wells it has been necessary to reduce the diameter of the hole several times as drilling progresses. If a hole larger than 10 inches in diameter is desired, it may be obtained by drilling a small hole and enlarging it by reaming.

The casing shuts out the water that may be in the Chattanooga shale, and also the harder and perhaps acidic waters of the Mississippian rocks, principally the Boone formation. In most deep wells, all the hole below the casing is open and all the formations in this zone may contribute water.

### SHOOTING AND ACIDIZING

Many deep wells in Ottawa County have been "shot" with nitroglycerine to break up the hard sandstone and limestone aquifers so that the ground water may move more readily through them and yields may be increased. The practice of shooting wells is common in the oil fields, and those specializing in such work may contract to do it in water wells. In the deep water wells of Ottawa County, solidified-nitroglycerin torpedoes are placed opposite the sandstone members of the Roubidoux formation. They are connected one to another by liquified nitroglycerin "anchors" so that the shooting at all desired depths may be accomplished in one operation. The resulting broken rock is removed from the well by bailing, and pieces several inches in diameter are commonly recovered. From the size of the pieces and the volume of the material bailed from wells after shooting, it is apparent that large cavities are created in the sandstone, thereby increasing the effective diameter and the specific capacity of the well. Presumably the sandstone beyond the cavity is more or less shattered.

Shooting has more than doubled the yield of several wells and has been moderately effective in others. The yield of one of the wells at the Goodrich plant was increased from 235 gallons per minute before shooting to 500 gallons per minute afterward, and the yield of another was raised from 110 to 210 gallons per minute—an increase of 90 percent. The yield of the Quapaw municipal well was increased from 150 to 250 gallons per minute, or 66 percent. The last two wells drilled for the city of Miami were "shot" as a matter of routine drilling procedure without previous tests of the yield.

Another method of increasing the yield of a well is to add hydrochloric acid under pressure to the water-bearing section of rocks. Like shooting, this procedure is a practice developed in the oil fields. It is effective on rocks that are soluble in acid, especially limestones and dolomites, and also on sandstones in which the principal cementing material is calcium carbonate. The acid removes the soluble parts of the rock, enlarging the existing openings and making connections from one to another. The porosity of the rock reached by the acid is increased and so, also, is the effective diameter of the well.

In Ottawa County only the Quapaw municipal well (No. 29N23E-35-3) has been acidized. This well was drilled to the Gunter sandstone member and initially yielded only a few gallons per minute. Acidizing the Gunter increased the yield to 30 gallons per minute. Subsequent acidizing of the Roubidoux formation increased the yield to 150 gallons per minute, and, still later, shooting the Roubidoux with nitroglycerin brought the yield to 250 gallons per minute.

A well at the Jayhawk Ordnance Works in Cherokee County, Kansas, about 8 miles north of the Oklahoma-Kansas State line, at first yielded 154 gallons per minute with a drawdown of 323 feet. After acidizing it yielded 678 gallons per minute with a drawdown of 287 feet (Abernathy, 1943, p. 97 and 99). Thus the yield was increased 3.4 times. Even more significant is the increase in specific capacity of the well, from 0.48 gallon to 2.36 gallons per minute per foot of drawdown.

Shooting will be more effective than acidizing in the sandstones but acidizing is likely to be more effective in limestones and dolomites. Acidizing, however, tends to increase the mineralization of the water, principally the hardness, because it admits more water from the calcareous or magnesian rocks. Analyses of water taken from the Jayhawk well before and after acidizing indicate an increase of 151 parts per million in total solids, and an increase of 109 parts per million in hardness. Acidizing may have had a similar effect in the Quapaw well, but proof is lacking, there being no analysis of the water for the period before the job was done. It is noteworthy that the Quapaw water is the hardest from the Canadian series in Ottawa County (420 parts per million). The well is the deepest for which an analysis is available, having penetrated the Gunter sandstone member. It should be observed that high hardness may be due in part to tapping a different and deeper aquifer, and hence not entirely due to the acid treatment.

## CHEMICAL CHARACTER OF THE GROUND WATER

All natural waters contain mineral matter dissolved from the rocks and soils with which they have come in contact. The quantity of dissolved mineral matter in the water depends primarily on the type of rock or soil through which the water has passed, the length of time of contact, and pressure and temperature conditions. In addition to these natural factors are others connected with human activities, such as use of streams and wells for disposal of sewage and industrial waste, diversion and use of water for many purposes, and drainage from oil fields.

The mineral constituents and physical properties of ground waters reported in the analyses of table 12 are those having a practical bearing on the value of the waters for most purposes: silica, iron, calcium, magnesium, sodium, potassium (or sodium and potassium reported together as sodium), carbonate, bicarbonate, sulfate, chloride, fluoride, nitrate, dissolved solids, hardness, pH, specific conductance, and temperature.

The source and significance of these different constituents and properties of ground water are discussed in the following paragraphs, which are adapted from publications of the Quality of Water Branch of the U. S. Geological Survey. Figure 12 illustrates by means of bar diagrams the mineral content of the water from 9 wells and 1 spring.

### DISSOLVED SOLIDS

The figures given under "dissolved solids" show approximately the total quantity of dissolved mineral matter as determined by evaporating a given quantity of water and weighing the residue after it has been dried. In some of the analyses, where the figure for dissolved solids is large and no determination of weight has been made, only the sum of the determined constituents has been shown in table 12.

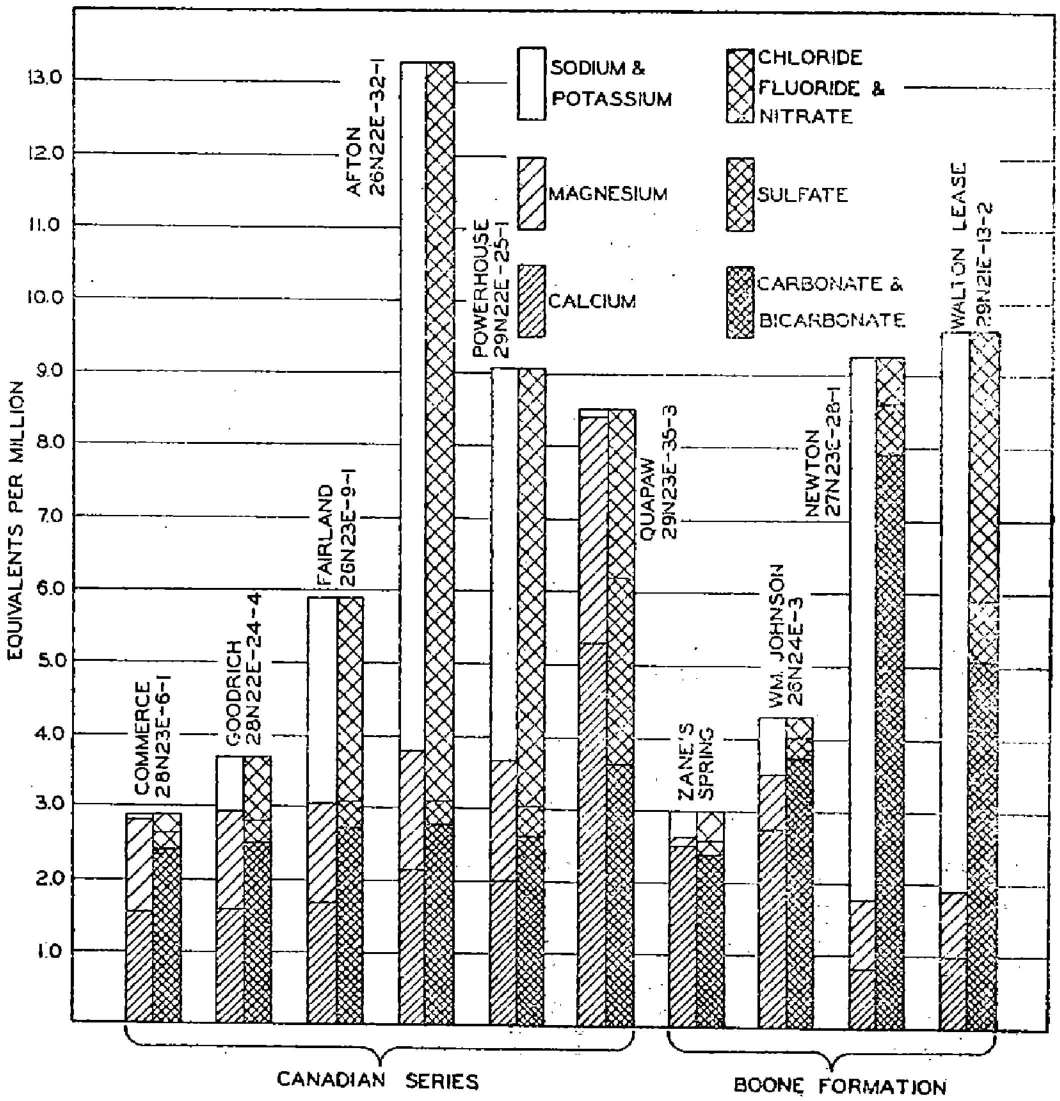


FIG. 12. Bar diagrams illustrating mineral content of waters from 9 wells and 1 spring in Ottawa County, Oklahoma.

## HARDNESS

The hardness of a water is the calcium carbonate ($CaCO_3$) equivalent of the calcium and magnesium and all other cations individually determined that cause hardness in water. It is the characteristic of water that receives the most attention with reference to industrial and domestic use, and it is usually recognized by the increased quantity of soap required to produce lather. Hard water is objectionable because of the formation of scale in boilers, water heaters, radiators, and pipes, with the resultant decrease in the rate of heat transfer, possibility of boiler failure, and loss of flow. Hardness is caused almost entirely by compounds of calcium and magnesium. Other constituents, such as iron, man-

## TABLE 12.

### ANALYSES OF GROUND WATERS FROM OTTAWA COUNTY, OKLAHOMA, M IN LABORATORIES OF THE U. S. GEOLOGICAL SURVEY AND THE KANSAS STATE BOARD OF HEALTH.

[Analytical results in parts per million except as indicated]

| Well No.[1] | Depth (feet) | Aquifer | Date of collection | Temperature (°F) | Silica ($SiO_2$) | Total iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) |
|---|---|---|---|---|---|---|---|---|---|
| 25N24E- 4 | 200 | Boone | 4-29-48 | ........ | ........ | ........ | ........ | ........ | ........ |
| 26N22E-29 | 1,100 | Canadian | 7-25-46 | ........ | ........ | ........ | 39 | 19 | 179 |
| -32-1 | 1,200 | ......do...... | 7-29-44 | ........ | ........ | ........ | 43 | 20 | 218 |
| -32-1 | 1,200 | ......do...... | 9- 6-51 | ........ | 9.1 | 0.02 | 39 | 18 | 220 |
| 26N23E- 8 | 1,100 | ......do...... | 7-25-46 | ........ | ........ | ........ | 45 | 16 | 86 |
| - 9 | 1,253 | ......do...... | 7-29-44 | 68 | ........ | ........ | 34 | 16 | 66 |
| - 9 | 1,253 | ......do...... | 9- 6-51 | ........ | 9.4 | .02 | 32 | 15 | 71 |
| 26N24E- 3 | 437 | Boone | 7-24-46 | 60 | ........ | ........ | 55 | 9.3 | 18 |
| 27N23E- 4 | 1,033 | Canadian[2] | 5- 1-48 | ........ | ........ | ........ | 30 | 16 | 61 |
| - 7 | 1,055 | ......do...... | 7-25-46 | 67 | ........ | ........ | 33 | 14 | 36 |
| -28-2 | 245 | Boone | 7-24-46 | 61 | ........ | ........ | 16 | 12 | 172 |
| 27N24E-21 | 1,040 | Canadian | 7-24-46 | 66 | ........ | ........ | 32 | 14 | 9 |
| 27N25E-19 | Spring | Boone | 7-24-46 | 59 | ........ | ........ | 50 | 1.7 | 8 |
| 28N22E-11-2 | 1,150 | Boone and Canadian | 7-25-46 | 62 | ........ | ........ | 28 | 13 | 20 |
| -24-4 | 1,235 | Canadian | 8- 5-44 | 67 | 11 | .06 | 32 | 16 | 16 |
| -35-1 | 1,130 | ......do...... | 7-26-46 | 63 | ........ | ........ | 30 | 14 | 17 |
| [3]28N23E- 6-1 | 1,050 | ......do...... | 9- 3-42 | ........ | ........ | 0 | 32 | 15 | 1.8 |
| - 6-1 | 1,050 | ......do...... | 9- 6-51 | ........ | 9.8 | .01 | 28 | 13 | 9.6 |
| ([3]) -31-2 | 1,247 | ......do...... | 9- 3-42 | ........ | ........ | .02 | 37 | 16 | 42 |
| -31-2 | 1,247 | ......do...... | 5-20-52 | 69 | 10 | 0 | 32 | 15 | 63 |
| 28N24E-12 | 185 | Boone | 4-27-48 | 57 | ........ | ........ | 52 | 5.3 | 1 |
| 29N21E-13-2 | 367 | ......do...... | 7-28-44 | ........ | ........ | ........ | 20 | 11 | 178 |
| -23-1 | 182 | McAlester | 4-28-48 | 61 | ........ | ........ | 12 | 4.6 | 230 |
| -23-2 | 12 | Alluvium | 4-28-48 | 56 | ........ | ........ | 54 | 19 | 37 |
| 29N22E-13 | 1,267 | Canadian | 10-14-37 | ........ | ........ | ........ | ........ | ........ | ........ |
| -25-1 | 1,229 | ......do...... | 4-15-47 | 69 | ........ | ........ | 40 | 20 | 124 |
| 29N23E-15-4 | 675 | ......do......[4] | 4-29-48 | ........ | ........ | ........ | ........ | ........ | ........ |
| 29N23E-18-1 | 1,080 | ......do...... | 4-29-48 | ........ | ........ | ........ | 45 | 24 | 146 |
| -18-2 | 1,176 | ......do...... | 10-14-37 | ........ | ........ | ........ | 33 | 16 | 61 |
| ([3]) -19-1 | 1,100 | ......do...... | 9-12-42 | ........ | ........ | .06 | 34 | 16 | 4.8 |
| ([3]) -21-1 | 1,077 | ......do...... | 9- 3-42 | 67 | ........ | .03 | 34 | 16 | 3.7 |
| -21-1 | 1,077 | ......do...... | 9- 6-51 | ........ | 9.8 | .02 | 29 | 14 | 12 |
| -21-2 | 1,125 | ......do...... | 4-28-48 | 67 | ........ | ........ | 30 | 16 | 14 |
| ([3]) -31-1 | 1,175 | ......do...... | 9-12-42 | 69 | ........ | .0 | 29 | 14 | 12 |
| ([3]) -35-3 | 1,325 | ......do...... | 11- 3-42 | 67 | ........ | 4.6 | 106 | 38 | 2.3 |
| -35-3 | 1,325 | ......do...... | 9- 6-51 | ........ | 9.7 | .01 | 29 | 14 | 4.4 |

[1] For significance of well numbers, see section on well numbering system.
[2] Cased to Roubidoux formation of Canadian series.
[3] Analysis by Kansas State Board of Health.
[4] Well drilled to Cotter formation of Canadian series.

| car-nate (CO₃) | Car-bonate ($CO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluo-ride (F) | Nitrate ($NO_3$) | Dissolved solids: Residue on evap-oration at 180°C | Dissolved solids: Sum | Hardness as $CaCO_3$: Calcium, mag-nesium | Hardness as $CaCO_3$: Noncar-bonate | Per-cent sod-ium | Specific conduct-ance (micro-mhos at 25°C) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 76 | ...... | 5.0 | 61 | ...... | ...... | ...... | ...... | 89 | 0 | ...... | 460 | ...... |
| 82 | 16 | 18 | 205 | ...... | 0.2 | 578 | 615 | 175 | 0 | 6.9 | 1,060 | ...... |
| 68 | 0 | 16 | 359 | ...... | 2.8 | ...... | 742 | 190 | 52 | 71 | ...... | 8.2 |
| 67 | 0 | 18 | 348 | 1.8 | .9 | 758 | 739 | 172 | 34 | 73 | 1,420 | 7.8 |
| 82 | 10 | 16 | 130 | ...... | .2 | 374 | 393 | 178 | 13 | 51 | 663 | ...... |
| 64 | ...... | 17 | 101 | ...... | .2 | ...... | 315 | 151 | 16 | 49 | ...... | 8.4 |
| 66 | 0 | 15 | 104 | .7 | .2 | 320 | 333 | 142 | 6 | 51 | 613 | 8.1 |
| 03 | 13 | 13 | 10 | ...... | ...... | 225 | 218 | 175 | 0 | 19 | 359 | ...... |
| 48 | ...... | 15 | 94 | .2 | 4.5 | 287 | 294 | 141 | 19 | 49 | 541 | ...... |
| 56 | 7 | 21 | 54 | ...... | .2 | 265 | 241 | 140 | 0 | 36 | 476 | ...... |
| 19 | 32 | 32 | 24 | ...... | .2 | 494 | 494 | 89 | 0 | 81 | 819 | ...... |
| 38 | 8 | 17 | 10 | ...... | .2 | 162 | 159 | 137 | 11 | 13 | 276 | ...... |
| 26 | 9 | 9.5 | 9 | ...... | 11 | 188 | 160 | 132 | 14 | 12 | 266 | ...... |
| 50 | 7 | 17 | 11 | ...... | .2 | 183 | 170 | 123 | 0 | 27 | 298 | ...... |
| 51 | ...... | 15 | 32 | .2 | .2 | 201 | 200 | 146 | 22 | 19 | ...... | 8.4 |
| 37 | 10 | 16 | 17 | ...... | .2 | 189 | 172 | 132 | 4 | 22 | 303 | ...... |
| 46 | ...... | 12 | 7 | .5 | 2.2 | 144 | ...... | 142 | 22 | 3 | ...... | ...... |
| 46 | 0 | 16 | 8 | .5 | .2 | 149 | 159 | 123 | 4 | 14 | 277 | 7.9 |
| 52 | ...... | 12 | 78 | .5 | 2.6 | 264 | ...... | 158 | 34 | 37 | ...... | ...... |
| 48 | 0 | 18 | 103 | .7 | ...... | 320 | 318 | 142 | 20 | 48 | 592 | 7.9 |
| 50 | ...... | 18 | 9.5 | .05 | .5 | 197 | 161 | 152 | 29 | 3 | 336 | ...... |
| 08 | 0 | 42 | 132 | ...... | .2 | ...... | 535 | 95 | 0 | 80 | ...... | 8.1 |
| 10 | 15 | 28 | 53 | 1 | ...... | 588 | 595 | 49 | 0 | 91 | 982 | ...... |
| 94 | 12 | 68 | 14 | .1 | 30 | 335 | 329 | 213 | 34 | 28 | 534 | ...... |
| 68 | ...... | 12 | 259 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 61 | ...... | 19 | 212 | .5 | ...... | ...... | 495 | 182 | 50 | 60 | 918 | ...... |
| 80 | ...... | 65 | 14 | ...... | ...... | ...... | ...... | 128 | 0 | ...... | 459 | ...... |
| 64 | ...... | 21 | 260 | .6 | 4.0 | 583 | 582 | 211 | 77 | 60 | 1,070 | ...... |
| 58 | ...... | 18 | 94 | ...... | ...... | ...... | 300 | 148 | 19 | 47 | ...... | ...... |
| 44 | ...... | 28 | 8.5 | .3 | 1.8 | 166 | ...... | 151 | 33 | 7 | ...... | ...... |
| 48 | ...... | 12 | 16 | .4 | 1.7 | 158 | ...... | 151 | 30 | 5 | ...... | ...... |
| 45 | 0 | 16 | 16 | .3 | .2 | 157 | 170 | 130 | 11 | 16 | 300 | 8.1 |
| 47 | ...... | 18 | 23 | .1 | ...... | 178 | 173 | 141 | 20 | 18 | 303 | ...... |
| 44 | ...... | 13 | 16 | .4 | 1.6 | 158 | ...... | 130 | 12 | 17 | ...... | ...... |
| 20 | ...... | 124 | 80 | .3 | 2.2 | 467 | ...... | 420 | 240 | 1 | ...... | ...... |
| 45 | 0 | 18 | 4 | .3 | ...... | 142 | 152 | 130 | 11 | 7 | 262 | 8.0 |

ganese, aluminum, barium, strontium, and free acid also cause hardness, but they are not usually found in appreciable quantities in most natural waters. Water that has a hardness of less than 50 parts per million is usually rated as soft, and its treatment for removal of hardness is seldom justified. Hardness between 50 and 150 parts per million does not seriously interfere with the use of water for most household uses, but its removal by softening processes may be profitable for laundries and other industries. When the hardness exceeds 150 parts per million, treatment for its removal is usually desirable for most uses.

### IRON

Iron is present in most ground waters, but generally only in small amounts. Water containing more than a few tenths of a part per million is objectionable because of its reddish appearance after exposure and because the iron stains fabrics and porcelain, enameled ware, and plumbing fixtures. Such water may, therefore, require treatment. Excessive iron may interfere with the efficient operation of exchange-silicate water softeners.

### CALCIUM AND MAGNESIUM

Calcium and magnesium in water contribute to hardness and boiler scale, as discussed above.

### SODIUM AND POTASSIUM

Moderate quantities of sodium and potassium have little effect on the suitability of water for most industrial or domestic uses. More than 50 parts per million of the two may cause foaming in the operation of steam boilers. Generally, if the equivalents per million of sodium exceed the sum of the equivalents per million of calcium and magnesium in water used for irrigation, there is some danger of damage to the soil.

### CARBONATE AND BICARBONATE

Carbonate and bicarbonate affect the usability of water mainly in combination with other dissolved matter. Bicarbonate is the principal radical in most natural waters, especially those from limestone aquifers, such as the rocks of the Canadian series and the Boone formation of Ottawa County. A high concentration of sodium bicarbonate will cause foaming in boilers.

### SULFATE

Sulfate may be dissolved in water passing through gypsum. It also may be formed by the oxidation of the sulfides of lead, zinc, and iron, and so it is present in large quantities in the mine waters. When combined with calcium and magnesium, sulfate contributes to noncarbonate hardness, and hence, to hard scale found in boilers and heating equipment. Sulfate in excess of 500 parts per million has a laxative effect, particularly when in combination with magnesium.

### CHLORIDE

Chloride combined with sodium is common salt, and both generally are present in ground water. Chloride in small amounts has little effect on the usefulness of water, but concentrations of 300 parts per million and higher give water a salty taste perceptible to most people, making the water unpalatable and, therefore, undesirable for domestic use. Still higher concentrations of chloride may make water corrosive, requiring frequent replacement of water pipe or measures to prevent corrosion, such as the lining of pipe with a noncorrosive material.

### FLUORIDE

The principal effect of fluoride in water is on dental health, and it is beneficial or detrimental depending on the concentration. In concentrations of 0.5 to 1.0 part per million, fluoride is believed by many health authorities to lessen dental caries (decay), but higher concentrations contribute to a dental defect known as mottled enamel, which appears in teeth in the formative stage, that is, in the teeth of children up to about 12 years. Although concentrations of 1 to 2 parts per million in drinking water cause few and relatively light cases of mottled enamel, concentrations above 4 parts per million will cause the defect in 90 percent of the children using the water, and 35 percent of the cases will be classifiable as "moderate" or worse (Dean, 1936, p. 1269-1272; Dean, Arnold, and Elvolve, 1942, p. 1155-1179).

### NITRATE

Nitrate in water is considered a final oxidation product of nitrogenous material and, in some instances, may indicate previous contamination by sewage or other organic matter. Water containing an excessive amount of nitrate has been suspected of causing a form of cyanosis ("blue babies") when used in the preparation of formulas for feeding infants. The Oklahoma State Health Department now considers water containing less than 10 parts per million nitrate nitrogen (approximately 45 parts per million when reported as nitrate) as safe for use. There still are many uncertainties regarding the danger of using water containing large amounts of nitrates, as there are numerous instances of high-nitrate water being used without apparent ill effects.

### HYDROGEN SULFIDE

Hydrogen sulfide in water causes a disagreeable taste and odor ("rotten eggs"), and in large amounts it is corrosive, but fortunately it is rather easily removed by aeration of the water. The amount of hydrogen sulfide in water is difficult to ascertain with accuracy because it readily passes off into the atmosphere. The usual practice has been to test for it as the water is pumped from the well. The analyses made for this investigation do not include determinations of hydrogen sulfide.

### CHARACTER OF WATER FROM THE CANADIAN SERIES

Water from the rocks of the Canadian series is generally of the calcium bicarbonate type, moderately hard, and rather low in dissolved solids. Most of the water pumped from deep wells appears to come from the sandstone in the Roubidoux formation. This conclusion is suggested by the analysis of the water from the Fred De Mier well (No. 27N23E-4-1), which is similar to that from other deep wells in the county, although the De Mier well, unlike the others, is cased down to the Roubidoux and therefore receives only water from the Roubidoux.

The water from the Canadian series of rocks in Ottawa County is generally suitable for most industrial and domestic purposes. The hardness is mostly carbonate ("temporary") hardness, and the water can be softened rather easily, if necessary. Hydrogen sulfide is common in the water but can be removed by aeration. Nearly all wells discharge into storage reservoirs on the ground, which, although covered, are vented to allow escape of hydrogen sulfide gas. The chloride content of the water from most wells is relatively low.

Initially, the water from the Quapaw well (29N23E-25-3) was considerably more mineralized than the water from other deep wells of the same part of the county, but it has changed with the years until it does not differ greatly from them. The analysis of a sample of water collected in November 1942, about 3 months after completion of the well, showed rather high hardness and relatively large amounts of iron, calcium, magnesium, sulfate, and chloride. In September 1951, after the well had been in service about 9 years, the Oklahoma Department of Health collected another sample of water from the well, and the analysis of it showed an appreciable decrease in the concentration of several of the constituents, so that the water rather closely resembled the water from the city of Commerce well (No. 28N23E-6-1). The latter is regarded as fairly typical of waters from the Roubidoux formation (Canadian series) in northern Ottawa County.

The explanation for this change in the character of the water from the Quapaw well can only be surmised. In the first place, the Quapaw well is the deepest producing water well in the county, and it taps both the Roubidoux formation and the Gunter sandstone member of the Van Buren formation. The greater depth and additional aquifer may partly account for the greater initial mineralization of the water, and the shooting and acidizing of the well may be partly responsible also. The acidizing would open the dolomites and limestones, admitting more water from them, and such water probably would be harder than that from sandy strata. If with the passage of time the water supply in the Gunter has been partly exhausted or the openings made by acidizing have become clogged, the water from these sources in 1951 may have been a relatively smaller fraction of the whole. Correspondingly, the contribution of water from the Roubidoux would be relatively larger, and the water withdrawn from the well would be more like waters from the wells tapping only the Roubidoux.

Geologic structures and related changes in the hydraulic properties of the rocks affect the mineral content of the water. As demonstrated elsewhere in this report, the permeability of the water-bearing strata of the Canadian series seems to be greatly reduced along the Miami syncline, the axis of which may be regarded as a barrier to the westward movement of ground water. Water coming from the outcrop doubtless is diverted southward along the barrier; ground water west of the barrier may be more or less stagnant, and being less readily replenished and freshened, is more mineralized (table 8).

### POSSIBLE CONTAMINATION BY MINE WATERS

When mines are shut down, pumping of water from them is stopped, and they fill with water. If all mining ceases in Ottawa County a situation may arise that will endanger the potable ground water from which the municipal water supplies are drawn, and the time may not be far in the future when this may happen. The production of ore from the mines of Ottawa County has been declining since 1925, and it is anticipated that in a few more years all the ore that can be mined profitably under present economic conditions will have been extracted (Blessing, Ernest, 1953, Oral communication).

Metallic sulfides of no value will be left in the mines, and will have been oxidized through exposure to the air while the mines were pumped free of water. The water that comes in contact with these oxidized sulfides will become acidic. In this connection it is worth noting that some of the mine water being pumped in 1953 was highly acidic. Where the Chattanooga shale is missing and possibly no impervious layer exists under the mines, the acidic waters may work their way down into the water-bearing strata of the Canadian series.

The acidic waters will have easy access to those strata wherever the mines have intersected deep wells penetrating them, unless the artesian pressure in them is high enough to prevent downward movement of water from the Boone. It is reported that about 100 wells have been intersected in this way (Blessing, Ernest, 1953, Oral communication). These wells could probably be plugged provided that the work could be done in the mines before mining is stopped, but after the mines fill with water the cost would doubtless be prohibitive even if the work could be accomplished. The effectiveness of a program of plugging such wells would depend in part on what percentage of the wells could be found and in part on how easily the acidic waters may be able to descend in the areas between wells. Periodic tests of the water used for public supplies should show whether or not the acidity is increasing.

### CHARACTER OF WATER FROM THE BOONE FORMATION

Water from the Boone formation normally is of the calcium bicarbonate type, moderately hard but low in dissolved solids. In a general way, the hardness and the total mineral content increase with the depth but, owing to the erratic occurrence of the ground water in limestone, no simple relationship between depth and mineral content is observable.

The waters from the Park-Walton and Newton wells (29N21E-13-2 and 27N23E-28-2, respectively) differ from other waters from the Boone in being unusually soft for water from limestone—less than 100 parts per million—and in having rather high dissolved solids of about 500 parts per million. The major constituent is sodium bicarbonate, which, together with the softness and the high dissolved solids, suggests that base exchange occurs as the water moves through the rock. In this process the calcium dissolved from limestone is exchanged for sodium or potassium, the source of which may be glauconitic sands in the Boone. The analyses indicate that the water has picked up sodium bicarbonate, also. The Newton well is near the contact of the Boone limestone with the overlying rocks of the Chester series (sec. 28, T. 27 N., R. 23 E.) and is 245 feet deep. The Park-Walton well, which is 375 feet deep, is 14 miles to the northwest and about 7 miles farther down dip. The glauconitic sands have been found in many places in the mining district, and although the occurrences do not appear to represent a continuous layer it is likely that these sands have had a "zeolitic" effect in parts of the area not represented by analyses.

## TEMPERATURE OF GROUND WATER

By Stuart L. Schoff

The temperature of the ground water as discharged at 17 wells and 1 spring in Ottawa County was measured with a pocket thermometer (table 12). For 11 deep wells tapping the rocks of the Canadian series it ranged from 63° F to 69°F and averaged 67°F. For four wells in the Boone formation it ranged from 57°F to 61°F and averaged 59°F. The water of one spring issuing from the Boone formation had a temperature of 59°F. In one well thought to draw water from both the Boone and the Canadian series, the water temperature was 62°F. In one well probably tapping the McAlester formation, the water temperature was 61°F, and in a well in alluvium it was 56°F, the lowest recorded.

Where static water levels are near the surface or where the water issues as a spring, the water temperature may fluctuate somewhat with the seasonal variations of air temperature. Thus, of the wells tapping the Boone formation, the one having the lowest water temperature is the shallowest and had a static water level only 20 feet below the land surface when the temperature was measured in April.

At moderate depth the temperature of the rocks (and of the ground water) is likely to be a degree or two higher than the mean annual air temperature (Van Orstrand, 1935, p. 88). McCutchin (1930, p. 20) found that in Kansas and Oklahoma the excess of soil temperature over air temperature ranges from 1°F to 4°F, and that the lowest temperature in a well generally is about 100 feet below the surface. At that depth the temperature does not change materially from season to season. Below the 100-foot level the temperature of the ground water increases with depth because the temperature of the rocks of the earth increases downward. This increase is shown in a general way by the fact that the average temperature of the water from 11 wells in the Canadian series is about 8°F higher than for 4 wells in the Boone. The wells in the Canadian series average 1,180 feet deep; those in the Boone about 300 feet.

## CONCLUSIONS

The principal aquifers of Ottawa County are the dolomites and sandstones of Cambrian and Ordovician age, and the Boone formation, of Mississippian age. The alluvium along the main streams may contain substantial quantities of ground water in places but it is an unproved reservoir, having been tapped only in a few places and for only small amounts of water. Other formations yield meager supplies of water, generally adequate only for rural domestic and stock use.

Pumping to dewater mines indicates high yields of ground water from the Boone in some localities, but high yields are not necessarily characteristic of the Boone throughout the area of its occurrence. Outside the mining district the water level in the Boone remains high, indicating that considerably more water could be pumped without overdraft. A serious drawback to the utilization of the ground water of the Boone is that surface pollution may enter it readily through fractures enlarged by solution and through sinkholes; and, further, that the Boone, like limestones generally, effects little or no filtration of the water that passes through it.

The Roubidoux formation of the Canadian series is the principal aquifer tapped for municipal, industrial, and institutional water supplies. Wells that once flowed at the surface no longer do so, and water levels have been lowered 250 feet or more below the surface. Analysis of the geologic and hydrologic factors governing the occurrence and movement of the ground water in this and related formations of the Canadian series indicate that a large volume of water still is available in the formation but that it can be obtained only at progressively increasing cost occasioned by progressively increasing pumping lifts.

Coefficients of transmissibility and storage for the rocks of the Canadian series, derived from three pumping tests at The B. F. Goodrich Co. plant, differ appreciably. The differences may be traceable to the proximity of the Miami syncline. After an adjustment in which the Miami syncline was regarded as an absolutely impermeable barrier, coefficients of transmissibility were calculated that range from 22,200 gallons per day per foot to 59,400 and average 38,100. For convenience in computation and because the wells at the Goodrich plant may be too close to the Miami syncline to be fully representative of the aquifer, a coefficient of 40,000 gallons per day per foot is taken as normal for transmissibility. Correspondingly, the normal coefficient of storage is $1 \times 10^{-4}$. By use of the image-well theory, it is estimated that drawdown in a well at The B. F. Goodrich Co. plant, after 5 years of pumping 400 gallons per minute while six other nearby wells pump at a combined rate of 2,200 gallons per minute, would be about 450 feet.

Chemical analyses show that the waters from both the Boone formation and the Canadian series are of the calcium bicarbonate type, moderately hard but low in dissolved solids. Waters from wells in the Canadian series west of the axis of the Miami syncline are more highly mineralized than those from wells east of the axis. This fact is interpreted as indicating that the syncline is a barrier to the westward movement of ground water, substantiating the conclusion to this effect based on results of test pumping the wells of The B. F. Goodrich Co.

## WELL-NUMBERING SYSTEM

The well-numbering system is based on the township system of the General Land Office. The first part of the well number is the township number, the second is the range number, and the third is the section. Thus 25N23E-15 designates a well in sec. 15, T. 25 N., R. 23 E. Where several wells are recorded in the same section, serial numbers are added to distinguish one from another. For example, well 25N23E-15-2 is the second well recorded in sec. 15.

In table 13, the wells are grouped by townships set off by a center heading. The well numbers are given in the first, or left-hand, column. The part of the well number derived from the township and range is given once, at the left in bold-face type, with only the section and serial elements of the number showing on the line describing the well, thus:

**25N23E**

**-15-1**

**-15-2**

Locations within the sections are given in the second column of the well tables, following the usual pattern of land descriptions: NW¼NW¼NW¼. In this example, the smallest fractional unit is given first, and the location is the northwesternmost 10 acres of the section. This part of the location is not repeated in other tables, and in most cases it is not mentioned in the text.

# APPENDIX A.

## WELL LOGS BASED ON MICROSCOPIC EXAMINATION OF DRILL CUTTINGS

The following logs of water wells in Ottawa County are based on the microscopic examination of drill cuttings according to procedures worked out by the Missouri Division of Geological Survey and Water Resources. Samples of the cuttings are collected at short intervals, normally representing about 5 feet of drilling. A weighed fraction of each sample is boiled in hydrochoric acid to remove all carbonate material. This procedure indicates the percentages of both the soluble and insoluble portions of the rock. The character of the insoluble residue is then studied under the microscope, and the different formations are identified by differences in the proportion and character of their insoluble content. Strip logs, on which the different constituents of the samples are represented by colors, usually are prepared to facilitate interpretation and correlation with other wells, but as these are not readily reproduced, only the thicknesses and depths of the named geologic units are given in the pages that follow. Except as noted, the logs were prepared by the Missouri Division of Geological Survey and Water Resources and are reproduced here through the courtesy of that organization.

### 27N22E-12, Ottawa County Welfare Home

Log through Chattanooga from Weidman, (1932, p. 67); from Chattanooga to bottom based on Weidman's determinations of percentage and character of insoluble residues.

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Cherokee[1] | 60 | 60 |
| Chester | 60 | 120 |
| Boone | 377 | 497 |
| Chattanooga | 15 | 512 |
| Cotter | 163? | 675? |
| Jefferson City | 270 | 945 |
| Roubidoux | 110 | 1,055 |

[1] Krebs group of this report.

### 27N23E-7, Dave Wilson Well (Owner, Ed Ballard)

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Not reported | 445 | 445 |
| Chattanooga | 15 | 460 |
| Cotter | 135 | 595 |
| Swan Creek zone | 30 | 625 |
| Upper Jefferson City | 55 | 680 |
| Lower Jefferson City | 235 | 915 |
| Roubidoux | 140 | 1,055 |

## 28N22E-24-1, The B. F. Goodrich Co. Well 1

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 15 | 15 |
| Chester | 40 | 55 |
| Warsaw | 135 | 190 |
| Short Creek oolite member of Boone limestone | 10 | 200 |
| Keokuk-Burlington | 145? | 345? |
| Reeds Spring-Fern Glen | 105? | 450? |
| Chattanooga | 8 | 458 |
| Cotter | 142 | 600 |
| Swan Creek zone | 30 | 630 |
| Jefferson City | 300 | 930 |
| Roubidoux | 150 | 1,080 |
| Upper Gasconade | 60 | 1,140 |
| Lower Gasconade | 60 | 1,200 |

## 28N22E-24-2, The B. F. Goodrich Co. Well 2

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 25 | 25 |
| Chester | 30 | 55 |
| Warsaw | 140 | 195 |
| Short Creek oolite member of Boone limestone | 10 | 205 |
| Keokuk-Burlington | 135 | 340 |
| Reeds Spring-Fern Glen | 110 | 450 |
| Chattanooga | 7 | 457 |
| Cotter | 163 | 620 |
| Swan Creek zone | 20 | 640 |
| Jefferson City | 280 | 920 |
| Roubidoux | 180 | 1,100 |
| Upper Gasconade | 70 | 1,170 |
| Lower Gasconade | 30 | 1,200 |

## 28N22E-24-3, The B. F. Goodrich Co. Well 3

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Not reported | 5 | 5 |
| Surface and Chester | 40 | 45 |
| Warsaw | 123 | 168 |
| Short Creek oolite member of Boone limestone | 7 | 175 |
| Keokuk-Burlington | 105 | 280 |
| Reeds Springs-Fern Glen | 155 | 435 |
| Chattanooga | 7 | 442 |
| Cotter | 118 | 560 |
| Swan Creek zone | 25 | 585 |
| Jefferson City | 305 | 890 |
| Roubidoux | 155 | 1,045 |
| Pre-Cambrian (granite) | 10 | 1,055 |

## 28N22E-24-4, The B. F. Goodrich Co. Well 5

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface and Chester | 65 | 65 |
| Warsaw | 120 | 185 |
| Short Creek oolite member of Boone limestone | 10 | 195 |
| Keokuk-Burlington | 145 | 340 |
| Reeds Spring-Fern Glen | 115 | 455 |
| Compton | 7 | 462 |
| Chattanooga | 8 | 470 |
| Cotter | 150 | 620 |
| Swan Creek zone | 30 | 650 |
| Jefferson City | 290 | 940 |
| Roubidoux | 180 | 1,120 |
| Upper Gasconade | 70 | 1,190 |
| Lower Gasconade | 45 | 1,235 |

## 28N22E-24-5, The B. F. Goodrich Co. Well 4

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 40 | 40 |
| Chester | 30 | 70 |
| Warsaw | 118 | 188 |
| Short Creek oolite member of Boone limestone | 7 | 195 |
| Keokuk-Burlington | 105 | 300 |
| Reeds Spring-Fern Glen | 150 | 450 |
| Compton | 8 | 458 |
| Chattanooga | 7 | 465 |
| Cotter | 145 | 610 |
| Swan Creek zone | 20 | 630 |
| Jefferson City | 290 | 920 |
| Roubidoux | 160 | 1,080 |
| Upper Gasconade | 60 | 1,140 |
| Lower Gasconade-Van Buren | 180 | 1,320 |
| Gunter sandstone member of Van Buren | 40 | 1,360 |
| Eminence | 105 | 1,465 |

## 28N22E-24-6, McCoy Greenhouse Well

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Chester | 55 | 55 |
| Warsaw | 130 | 185 |
| Keokuk, Burlington, Reeds Spring | 245 | 430 |
| Northview and Compton | 25 | 455 |
| Chattanooga | 5 | 460 |
| Cotter | 150 | 610 |
| Jefferson City | 295 | 905 |
| Roubidoux | 140 | 1,045 |
| First sand, 960-980 feet | | |
| Second sand, 1,035-1,045(?) feet | | |

## 28N23E-18, The B. F. Goodrich Co. Well 6

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 15 | 15 |
| Chester | 20 | 35 |
| Warsaw | 110 | 145 |
| Short Creek oolite member of Boone limestone | 10 | 155 |
| Keokuk-Burlington | 145 | 300 |
| Reeds Spring-Fern Glen | 130 | 430 |
| Chattanooga | 6 | 436 |
| Cotter | 134 | 570 |
| Swan Creek zone | 30 | 600 |
| Jefferson City | 290 | 890 |
| Roubidoux | 180 | 1,070 |
| Upper Gasconade | 50 | 1,120 |
| Lower Gasconade | 25 | 1,145 |

## 29N22E-25-1, Eagle-Picher Mining & Smelting Co., Powerhouse Well[1]

Log through Chattanooga from Weidman (1932, p. 67); from there to bottom based on Weidman's determinations of percentages and character of insoluble residues.

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Cherokee[2] | 110 | 110 |
| Chester | 25 | 135 |
| Boone | 365 | 500 |
| Chattanooga | 5 | 505 |
| Cotter | 115 | 620 |
| Swan Creek zone | 40 | 660 |
| Jefferson City | 300 | 960 |
| Roubidoux | 170 | 1,130 |
| Upper Gasconade | 60 | 1,190 |
| Lower Gasconade | 39 | 1,229 |

1 For driller's log of this well, see Appendix B.
2 Krebs group of this report.

## 29N23E-19-2, Eagle-Picher Mining & Smelting Co. (John Beaver) Well

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Not reported | 295 | 295 |
| Grand Falls chert member of Boone limestone and Reeds Spring | 145 | 440 |
| Northview | 5 | 445 |
| Cotter | 165 | 610 |
| Swan Creek zone | 15 | 625 |
| Upper Jefferson City | 70 | 695 |
| Lower Jefferson City | 220 | 915 |
| Roubidoux | 160 | 1,075 |
| Upper Gasconade | 50 | 1,125 |
| Lower Gasconade-Van Buren | 250 | 1,375 |
| Gunter sandstone member of Van Buren | 30 | 1,405 |
| Eminence | 140 | 1,545 |
| Bonneterre | 185 | 1,730 |
| Lamotte | 40 | 1,770 |
| Pre-Cambrian | 2 | 1,772 |

## 29N23E-31-1, Eagle-Picher Mining & Smelting Co. (Central Mill), Well 1

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface and Cherokee | 61 | 61 |
| Chester | 29 | 90 |
| Warsaw | 120 | 210 |
| Keokuk | 40 | 250 |
| Burlington | 85 | 335 |
| Grand Falls chert member of Boone limestone | 45 | 380 |
| Reeds Spring | 80 | 460 |
| Fern Glen | 25 | 485 |
| Cotter and Jefferson City | 535 | 1,020 |
| Roubidoux | 105 | 1,125 |
| Gasconade | 50 | 1,175 |

## 29N23E-31-2, Eagle-Picher Mining & Smelting Co. (Central Mill), Well 2

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Chester | 130 | 130 |
| Warsaw | 120 | 250 |
| Keokuk-Burlington | 90 | 340 |
| Grand Falls chert member of Boone limestone | 25 | 365 |
| Reeds Spring-Fern Glen | 120 | 485 |
| Northview-Compton | 10 | 495 |
| Cotter | 175 | 670 |
| Jefferson City | 300 | 970 |
| Roubidoux | 150 | 1,120 |
| First sand, 1,040-1,060 feet | | |
| Second sand, 1,080-1,120 feet | | |
| Gasconade-Van Buren | 260 | 1,380 |
| Gunter sandstone member of Van Buren | 30 | 1,410 |
| Bonneterre | 95 | 1,505 |

## 29N23E-35-3, Town of Quapaw

| Formation | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil and shale | 15 | 15 |
| Chester | 100 | 115 |
| Warsaw | 65 | 180 |
| Keokuk | 60 | 240 |
| Grand Falls chert member of Boone limestone | 20 | 260 |
| Reeds Spring-Fern Glen | 110 | 370 |
| Northview | 5 | 375 |
| Compton | 5 | 380 |
| Cotter | 140 | 520 |
| Swan Creek zone | 20 | 540 |
| Upper Jefferson City | 85 | 625 |
| Lower Jefferson City | 255 | 880 |
| Roubidoux | 170 | 1,050 |
| Upper Gasconade | 50 | 1,100 |
| Lower Gasconade-Van Buren | 210 | 1,310 |
| Gunter sandstone member of Van Buren | 15 | 1,325 |

## APPENDIX B.

### DRILLERS' LOGS OF DEEP WATER WELLS IN OTTAWA COUNTY

On the following pages are given logs of deep wells in Ottawa County, essentially as written by the well drillers. They were obtained from several sources, but most came from the files of the Eagle-Picher Mining and Smelting Co., through the courtesy of R. K. Stroup, Cardin, Oklahoma.

Having been written by several different men who were not geologists, these logs differ considerably in the amount of detail given and they diverge markedly from standard geologic terminology. The drillers worked for the mining companies, and their drilling, sampling, and logging procedures were those of the mining area, where the standard practice in prospecting is to drill through the rocks of the Krebs group before taking samples. Through the ore-bearing Mississippian rocks samples are collected at 5-foot intervals, and in this zone, therefore, the logs are rather detailed and contain many references to showings of lead and zinc ores.

To make the logs similar in style and to emphasize the lithologic character of the materials, the rock type named by the driller is given first followed by other distinguishing characteristics such as color and hardness, and then by such other materials as were described with it. Thus, if the driller wrote "soft white limestone, flint, and jack shines," the edited log reads "limestone, white, soft, and flint and jack shines." Also, if several 5-foot intervals were given the same description, they have been consolidated as one unit embracing the larger interval. Terminology peculiar to the area is retained because it is felt that editorial interpretation would be of doubtful value. The following glossary indicates the usual meanings.

Cotton rock—soft fine-grained rock, generally limestone
Flint—chert
Hogchaw or hogchow—chalky, porous chert
Jack—sphalerite or calamine
Lead—galena
Lime—limestone or dolomite
Mundic—pyrite
Sandspar—silicified sandy limestone
Selvage—a layer of clay or decomposed rock, also called "gouge"
Shines—a showing of ore
Silicate—calamine or smithsonite
Soap or soapstone—shale
Spar—dolomite
Tar—bitumen
Tiff—calcite[1]

[1] According to Foy, "A glossary of the mining and mineral industry," U. S. Bur. of Mines Bul. 95, "tiff is a common name for calcite in the zinc fields of Wisconsin and Missouri, but means barite in southeast Missouri."

## 25N24E-3, T. Tomlinson Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil and clay | 25 | 25 |
| Flint, light gray and gray | 5 | 30 |
| Flint, light gray | 35 | 65 |
| Flint, light gray and gray | 35 | 100 |
| Flint, light gray, and gray lime | 20 | 120 |
| Cotton rock, white, and flint | 55 | 175 |
| Flint, light gray, and gray lime | 25 | 200 |
| Lime, light gray, and gray flint | 45 | 245 |
| Lime, dark gray, and gray flint | 20 | 265 |
| Flint, dark gray, and gray lime | 25 | 290 |
| Flint, dark gray and blue | 30 | 320 |
| Flint, dark gray and some gray lime | 5 | 325 |
| Flint, light gray | 5 | 330 |
| Shale, mundic, lead trace | 35 | 365 |
| Flint, light gray, and gray lime | 20 | 385 |
| Lime, gray | 25 | 410 |
| Lime, dark gray, and gray lime | 45 | 455 |
| Lime, light gray and some dark gray | 30 | 485 |
| Lime, gray and brown | 25 | 510 |
| Lime, gray, sand, jack traces | 10 | 520 |
| Lime, gray | 20 | 540 |
| Lime, gray and brown | 50 | 590 |
| Lime, brown, and some gray lime | 25 | 615 |
| Lime, light gray and brown | 55 | 670 |
| Lime, flaky dark brown, and gray flint | 5 | 675 |
| Lime, gray | 10 | 685 |
| Lime, gray and brown | 5 | 690 |
| Lime, gray, and gray flint | 20 | 710 |
| Lime, gray, and blue flint | 5 | 715 |
| Lime, gray, and gray flint | 20 | 735 |
| Lime, gray and brown, and gray flint | 15 | 750 |
| Lime, gray, and gray and blue flint | 15 | 765 |
| Lime, gray, gray flint, selvage | 15 | 780 |
| Flint, gray, gray lime, mundic | 40 | 820 |
| Sand, white, and selvage | 40 | 860 |
| Sand, white, and some sandy lime | 70 | 930 |
| Sand, white | 30 | 960 |
| Sand, white, gray lime and some blue flint | 15 | 975 |
| Sand, white, and some green selvage | 10 | 985 |
| Sand, white, sandy gray lime, selvage | 25 | 1,010 |

## 26N23E-36, E. H. Offield Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 30 | 30 |
| Flint, brown and gray | 100 | 130 |
| Flint, white gray | 30 | 160 |
| Flint, gray, and gray lime | 60 | 220 |
| Flint, blue, and blue gray lime | 80 | 300 |
| Flint, gray, and shale | 5 | 305 |
| Flint, gray | 40 | 345 |
| Flint, gray, and zinc shines | 9 | 354 |
| Flint, gray, blue selvage, zinc shines | 6 | 360 |
| Flint, gray, and zinc shines | 14 | 374 |
| Flint, gray, and poor zinc shines | 8 | 382 |
| Flint, gray, and gray lime | 28 | 410 |

## 28N22E-35-2, Walter Tydings Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 8 | 8 |
| River gravel | 10 | 18 |
| Soapstone and lime boulders | 4 | 22 |
| Lime, brown | 48 | 70 |
| Flint, brown and blue | 10 | 80 |
| Lime, brown | 5 | 85 |
| Lime, brown, and some blue flint | 50 | 135 |
| Lime, white | 5 | 140 |
| Flint, blue, brown lime | 35 | 175 |
| Flint, blue, and black flint | 5 | 180 |
| Lime, brown | 5 | 185 |
| Lime, brown, and light blue flint | 10 | 195 |
| Lime, brown | 5 | 200 |
| Flint, white, and lime | 10 | 210 |
| Lime, brown | 30 | 240 |
| Lime, brown, and white flint | 5 | 245 |
| Flint, white, and white lime | 20 | 265 |
| Lime, brown | 5 | 270 |
| Lime, white | 25 | 295 |
| Lime, white and brown | 15 | 310 |
| Lime, white, and some flint | 45 | 355 |
| Lime, brown and white | 10 | 365 |
| Flint, white, and lime | 10 | 375 |
| Flint, light blue brown | 20 | 395 |
| Lime, brown, and tight ground | 5 | 400 |
| Flint, light blue, brown lime, tight ground | 7 | 407 |
| Flint, blue, and brown lime | 18 | 425 |
| Lime and selvage | 35 | 460 |
| Soapstone, and oil sand | 10 | 470 |
| Lime, brown | 50 | 520 |
| Lime, brown, and white flint | 75 | 595 |
| Flint, blue, and lime | 15 | 610 |

## 28N23E-31-3, City of Miami Well 2

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface material | 14 | 14 |
| Sand rock | 11 | 25 |
| Lime (rotten) | 25 | 50 |
| Lime and flint, medium | 10 | 60 |
| Lime, soft | 20 | 80 |
| Flint and lime, medium | 10 | 90 |
| Lime, soft | 15 | 105 |
| Lime and flint, medium | 5 | 110 |
| Lime and flint, hard | 10 | 120 |
| Flint and lime, hard | 35 | 155 |
| Lime and flint, hard | 10 | 165 |
| Lime and flint, medium | 10 | 175 |
| Lime, soft | 80 | 255 |
| Lime and flint, medium | 5 | 260 |
| Lime and flint, medium brown | 10 | 270 |
| Lime, soft, brown | 20 | 290 |
| Flint, blue, and soft lime | 10 | 300 |
| Flint, blue, and medium lime | 45 | 345 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Flint, hard, blue | 55 | 400 |
| Flint and lime, hard | 10 | 410 |
| Lime and flint, medium | 5 | 415 |
| Lime, soft | 10 | 425 |
| Lime and selvage | 7 | 432 |
| Shale, brown, soft | 14 | 446 |
| Lime, medium | 5 | 451 |
| Sand, hard, white | 10 | 461 |
| Lime, medium | 6 | 467 |
| Lime, medium, white | 111 | 578 |
| Lime, white | 24 | 602 |
| Lime, medium, gray | 18 | 620 |
| Sand and lime, medium | 12 | 632 |
| Lime, medium, brown | 36 | 668 |
| Lime, medium, gray | 37 | 705 |
| Lime and flint, medium | 15 | 720 |
| Lime, hard, gray | 18 | 738 |
| Lime, sandy, medium | 70 | 808 |
| Lime and flint, medium | 18 | 826 |
| Lime and flint | 6 | 832 |
| Lime and flint, shines, soft | 6 | 838 |
| Lime, black | 6 | 844 |
| Lime and flint, shines, medium | 6 | 850 |
| Lime and flint, medium | 12 | 862 |
| Lime and flint | 12 | 874 |
| Lime and flint, shines, medium | 16 | 890 |
| Lime and flint, shines | 6 | 896 |
| Lime, medium, brown | 6 | 902 |
| Lime, brown, and hard flint | 6 | 908 |
| Lime, hard, gray | 36 | 944 |
| Lime, hard, blue and gray | 6 | 950 |
| Lime, brown | 6 | 956 |
| Lime, hard, gray | 36 | 992 |
| Lime, gray, and sand | 6 | 998 |
| Sand, hard, white | 12 | 1,010 |
| Lime, hard, brown | 5 | 1,015 |
| Sand and lime | 10 | 1,025 |
| Lime, hard, gray | 85 | 1,110 |
| Lime and sand, medium | 6 | 1,116 |
| Water sand, medium | 15 | 1,131 |
| Sand and lime | 4 | 1,135 |
| Lime, medium gray | 20 | 1,155 |
| Lime, hard, gray | 40 | 1,195 |
| Sand and lime | 5 | 1,200 |
| Sand, white | 10 | 1,210 |
| Sand and lime | 5 | 1,215 |
| Lime, hard | 10 | 1,225 |
| Lime, medium | 22 | 1,247 |

## 28N24E-31, Scout Camp Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay and boulders | 28 | 28 |
| Lime, gray, and gray flint | 22 | 50 |
| Flint, dead gray | 10 | 60 |
| Lime, gray, and gray and white flint | 15 | 75 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Lime, brown, sandy, and gray and white flint | 5 | 80 |
| Lime, brown, and some gray flint | 10 | 90 |
| Lime, brown, and gray and white flint | 30 | 120 |
| Lime, brown and gray | 40 | 160 |
| Lime, brown | 15 | 175 |
| Lime, brown, and cotton flint | 5 | 180 |
| Cotton flint | 15 | 195 |
| Lime, brown, and cotton flint | 25 | 220 |
| Lime, brown, and gray flint | 15 | 235 |
| Flint, gray and blue, and some lime | 5 | 240 |
| Flint, gray, blue and brown | 20 | 260 |
| Lime, gray and brown, and dark blue and brown flint | 10 | 270 |
| Lime, brown, and gray and blue flint | 100 | 370 |
| Lime, gray and green, and some gray flint | 5 | 375 |
| Lime, brown | 5 | 380 |
| Lime, brown and green, and green selvage | 5 | 385 |
| Lime, brown and white | 5 | 390 |
| Lime, brown, and Chattanooga shale | 10 | 400 |
| Lime, gray, brown, and green | 5 | 405 |
| Lime, gray and brown, sandy, and gray flint | 5 | 410 |
| Lime, gray, and cotton flint | 5 | 415 |
| Lime, gray, with selvage seams | 5 | 420 |
| Lime, gray, sandy, and dark blue flint | 11 | 431 |

## 29N22E-23, Adams Mine Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface clay and shale | 110 | 110 |
| Lime, crystalline, brown, and medium gray flint | 12 | 122 |
| Flint, medium, gray, and crystalline brown lime | 8 | 130 |
| Flint, brown light gray | 4 | 134 |
| Flint, compact, light blue | 8 | 142 |
| Lime, compact, gray, and dark blue flint | 17 | 159 |
| Cavity lost cuttings | 4 | 163 |
| Flint, pale gray brown, and compact tan lime | 8 | 171 |
| Lime, soft, white, and white flint | 4 | 175 |
| Flint, white, and soft tan lime | 25 | 200 |
| Flint, light gray blue | 4 | 204 |
| Flint, blue brown mottled | 5 | 209 |
| Flint, dark brown gray | 12 | 221 |
| Crevices, lost cuttings | 29 | 250 |
| Flint, brown, white | 10 | 260 |
| Jasperoid, gray, white blue flint, tiff | 5 | 265 |
| Flint, pale gray white, and jack shines | 10 | 275 |
| Flint, medium gray, water-bearing | 5 | 280 |
| Flint, light gray white | 10 | 290 |
| Flint, partly leached, pale gray | 15 | 305 |
| Flint, pale gray, and compact medium gray lime | 10 | 315 |
| Flint, tan | 5 | 320 |
| Flint, dark gray brown, and little compact gray lime | 5 | 325 |
| Flint, dark light gray, and compact gray lime | 5 | 330 |
| Flint, medium gray, and compact brown lime | 15 | 345 |
| Flint, dark blue, and shelly compact medium gray lime | 15 | 360 |
| Flint, light gray, and shelly compact medium gray lime | 10 | 370 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Flint, medium dark gray, mottled | 5 | 375 |
| Flint, medium blue gray, and compact gray lime | 5 | 380 |
| Flint, medium blue gray | 5 | 385 |
| Flint, medium gray, compact gray lime | 5 | 390 |
| Lime, medium gray, and little blue flint | 10 | 400 |
| Flint, light gray brown, mottled, and compact medium gray lime | 6 | 406 |
| Lime, medium gray, and medium gray flint | 42 | 448 |
| Lime, compact, light gray, and light blue flint | 8 | 456 |
| Lime, pale green | 6 | 462 |
| Lime, finely crystalline, white, and green shale | 14 | 476 |
| Lime, medium gray, sandy | 8 | 484 |
| Lime, tan, and light gray flint | 24 | 508 |
| Dolomite, light gray, and clear white oolitic flint | 17 | 525 |
| Dolomite, light gray, snow white flint, green shale | 33 | 558 |
| Dolomite, finely crystalline, light gray | 18 | 576 |
| Dolomite, finely crystalline, light gray, and little clear white oolitic flint | 26 | 602 |
| Lime, finely crystalline, brown, and little clear white oolitic flint | 12 | 614 |
| Dolomite, finely crystalline, light gray, and light gray flint | 24 | 638 |
| Dolomite, finely crystalline, light gray, and dark gray flint | 8 | 646 |
| Lime, finely crystalline, tan, and gray sandstone | 20 | 666 |
| Lime, finely crystalline, tan, and white clear gray flint | 12 | 678 |
| Flint, white, clear gray, and sandy tan lime | 20 | 698 |
| Flint, white, clear gray, and compact gray dolomite | 8 | 706 |
| Lime, compact, brown, and sandy gray lime | 16 | 722 |
| Lime, compact, white, and clear gray flint | 8 | 730 |
| Lime, finely crystalline, brown, and brown gray flint | 12 | 742 |
| Lime, compact, white, and clear white flint | 12 | 754 |
| Lime, sandy, and green shale streaks | 12 | 766 |
| Lime, sandy, tan, and little gray white flint | 32 | 798 |
| Lime, finely crystalline, white, and white clear gray flint | 20 | 818 |
| Lime, crystalline, medium gray | 12 | 830 |
| Lime, crystalline, medium gray, and white clear gray flint | 80 | 910 |
| Lime, crystalline, medium gray | 12 | 922 |
| Lime, compact, brown, and white clear gray flint | 12 | 934 |
| Lime, crystalline, brown, and white clear gray brown oolitic flint | 24 | 958 |
| Lime, crystalline, brown, gray sandstone, white to gray flint | 16 | 974 |
| Lime, sandy, gray | 13 | 987 |
| Lime, crystalline, brown, and gray sandstone | 8 | 995 |
| Dolomite, crystalline, gray, and white clear gray flint | 16 | 1,011 |
| Dolomite, crystalline, gray, white clear gray flint, white sandstone | 12 | 1,023 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Dolomite, crystalline, gray, and little white sandstone | 41 | 1,064 |
| Dolomite, crystalline, gray, and white; gray to brown flint | 8 | 1,072 |
| Lime, crystalline, brown, gray sandstone, snow white flint | 11 | 1,083 |

## 29N22E-25-1, Eagle-Picher Mining and Smelting Co., Powerhouse Well[1]

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Shale | 105 | 105 |
| Lime, gray, and shale | 5 | 110 |
| Lime, gray, and little white flint | 5 | 115 |
| Lime, gray, light gray, and little gray flint | 5 | 120 |
| Lime, gray, light brown | 5 | 125 |
| Lime, gray, and gray white flint | 5 | 130 |
| Lime, gray | 5 | 135 |
| Lime, brown, and little white flint | 5 | 140 |
| Flint, light blue, and gray lime | 5 | 145 |
| Flint, coarse, gray | 5 | 150 |
| Flint, coarse, gray, and some gray lime | 5 | 155 |
| Lime, gray, and light gray flint | 5 | 160 |
| Flint, gray, white, and gray lime | 5 | 165 |
| Flint, gray, blue | 5 | 170 |
| Flint, gray, blue, and some gray lime | 5 | 175 |
| Flint, coarse, light gray | 5 | 180 |
| Flint, light gray | 15 | 195 |
| Flint, gray | 5 | 200 |
| Flint, gray, dark gray, and brown | 5 | 205 |
| Flint, white nodule, and gray brown flint | 10 | 215 |
| Lime, gray, and white flint | 5 | 220 |
| Lime, gray, and some white flint | 5 | 225 |
| Lime, gray, and little white flint | 5 | 230 |
| Lime, gray, and white gray flint | 5 | 235 |
| Lime, gray, and light gray flint | 5 | 240 |
| Flint, gray and light gray | 5 | 245 |
| Lime, gray, and light gray flint | 5 | 250 |
| Lime, gray | 5 | 255 |
| Lime, gray and light gray | 5 | 260 |
| Nodule flint, white, gray flint, gray lime | 5 | 265 |
| Lime, gray, and some gray flint | 5 | 270 |
| Nodule flint, white, gray flint, gray lime | 5 | 275 |
| Lime, white, and cotton rock | 10 | 285 |
| Flint, white, and little cotton rock | 5 | 290 |
| Flint, white and gray, and little cotton rock | 5 | 295 |
| Flint, clear white | 5 | 300 |
| Flint, white and gray | 5 | 305 |
| Flint, dark gray, and little light gray flint | 5 | 310 |
| Flint, dark gray, and some dark gray lime | 5 | 315 |
| Lime, dark gray, and little dark gray flint | 5 | 320 |
| Flint, light and dark gray, and little gray flint | 5 | 325 |
| Flint, dark gray, and dark gray lime | 10 | 335 |
| Flint, gray and dark gray, and dark gray lime | 15 | 350 |
| Flint, gray, brown and white, gray lime, trace zinc | 5 | 355 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Lime, gray, and gray and blue flint | 5 | 360 |
| Flint, dark gray and blue, and some gray lime | 5 | 365 |
| Lime, gray and dark gray, some dark gray and dark blue flint | 10 | 375 |
| Flint, gray and dark gray, and gray lime | 5 | 380 |
| Lime, gray and dark gray, and little dark gray flint | 5 | 385 |
| Lime, gray, dark gray | 5 | 390 |
| Lime, gray and dark gray, and little blue flint | 5 | 395 |
| Flint, gray and blue, and gray lime | 5 | 400 |
| Flint, gray blue, gray lime, brown flint, zinc shines above | 5 | 405 |
| Lime, gray and dark gray, and dark gray flint | 10 | 415 |
| Lime, gray and dark gray, and dark blue flint | 5 | 420 |
| Lime, gray, dark, and little blue flint | 5 | 425 |
| Lime, gray and dark gray, and dark gray blue flint | 5 | 430 |
| Flint, gray blue, and gray lime | 5 | 435 |
| Flint, blue, and gray and dark gray lime | 10 | 445 |
| Lime, gray, and blue flint | 5 | 450 |
| Lime, gray and dark gray, and little blue flint | 5 | 455 |
| Lime, gray and light gray | 5 | 460 |
| Lime, blue gray | 5 | 465 |
| Lime, gray blue | 5 | 470 |
| Lime, dark gray | 5 | 475 |
| Lime, gray, and little sandstone | 5 | 480 |
| Sandstone, fine, gray, and lime | 10 | 490 |
| Lime, light brown, and gray sandstone | 5 | 495 |
| Lime, light brown, and little sandstone | 5 | 500 |
| Lime, gray and light brown, and light gray sandstone | 5 | 505 |
| Lime, gray and light gray | 15 | 520 |
| Lime, gray | 10 | 530 |
| Lime, gray and dark gray | 10 | 540 |
| Lime, gray and some dark gray | 10 | 550 |
| Lime, light gray | 10 | 560 |
| Lime, light gray and light brown | 10 | 570 |
| Flint, gray, and little gray lime | 10 | 580 |
| Lime, gray and dark gray, and gray flint | 10 | 590 |
| Lime, gray | 10 | 600 |
| Lime, gray, and gray and dark gray flint | 10 | 610 |
| Lime, gray, and some gray flint | 10 | 620 |
| Lime, brown and little gray | 10 | 630 |
| Sandstone, gray | 10 | 640 |
| Lime, light blue, and some gray sandstone | 10 | 650 |
| Flint, white and light blue, and light brown lime | 10 | 660 |
| Lime, gray, and gray flint | 10 | 670 |
| Lime, gray and light brown | 10 | 680 |
| Lime, gray | 10 | 690 |
| Lime, dark gray | 20 | 710 |
| Lime, gray and light brown, and gray sandstone | 10 | 720 |
| Lime, fine, gray, and little sandstone | 20 | 740 |
| Lime, gray | 10 | 750 |
| Lime, brown, and gray flint | 20 | 770 |
| Lime, gray | 10 | 780 |
| Lime, brown, and little white flint | 10 | 790 |
| Lime, gray, and some white nodule flint | 10 | 800 |
| Lime, gray, and some white flint | 10 | 810 |
| Lime, brown, and brown flint | 10 | 820 |
| Lime, gray | 10 | 830 |
| Lime, gray, and gray white flint | 30 | 860 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Lime, gray, and some white flint | 10 | 870 |
| Lime, gray, and little white flint | 10 | 880 |
| Lime, gray, sandy | 10 | 890 |
| Lime, gray, sandy, and little white flint | 10 | 900 |
| Lime, brown | 10 | 910 |
| Lime, brown and dark gray | 10 | 920 |
| Lime, gray and light brown, and little white flint | 10 | 930 |
| Lime, gray, and little white flint | 10 | 940 |
| Sandstone, gray, limy | 50 | 990 |
| Sandstone, clear, fine, white | 10 | 1,000 |
| Sandstone, fine, slightly limy | 10 | 1,010 |
| Sandstone, fine, gray, limy | 20 | 1,030 |
| Lime, white, and sandstone | 20 | 1,050 |
| Lime, fine, light gray, sandy | 10 | 1,060 |
| Sandstone, white, slightly limy | 10 | 1,070 |
| Sandstone, white, and gray lime | 40 | 1,110 |
| Lime, white, and sandstone | 10 | 1,120 |
| Sandstone, white, light gray lime, and some white flint | 10 | 1,130 |
| Lime, light gray, and white flint | 10 | 1,140 |
| Lime, light gray, and some sandstone | 10 | 1,150 |
| Lime, white, sandstone | 10 | 1,160 |
| Lime, white, sandy | 10 | 1,170 |
| Lime, fine, white, and white sandstone | 20 | 1,190 |
| Lime, fine, white, and some white flint | 10 | 1,200 |
| Flint, white, and white lime | 20 | 1,220 |
| Lime, light gray, and white flint | 9 | 1,229 |

1 For a log of this well based on microscopic examination of drill cuttings, see Appendix A.

## 29N22E-25-2, Goodeagle Mine Well[1]

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soapstone | 105 | 105 |
| Lime | 35 | 140 |
| Flint | 35 | 175 |
| Flint and spar | 90 | 265 |
| Flint | 75 | 340 |
| Lime | 11 | 351 |
| Flint and lime | 124 | 475 |
| Lime and flint | 35 | 510 |
| Sand | 5 | 515 |
| Lime | 85 | 600 |
| Sand | 5 | 605 |
| Lime | 315 | 920 |
| Sand and lime | 97 | 1,017 |
| Sand | 8 | 1,025 |

1 This record taken from file of the Century Zinc Co..

## 29N22E-25-3, B. and R. Mining Company Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay | 30 | 30 |
| Soap | 90 | 120 |

| | (feet) Thickness | (feet) Depth |
|---|---|---|
| Lime, gray | 20 | 140 |
| Lime and flint | 35 | 175 |
| Flint | 20 | 195 |
| Lead shines | 30 | 225 |
| Flint, dark | 23 | 248 |
| Flint and zinc | 28 | 276 |
| Flint, dark | 24 | 300 |
| Flint, white | 35 | 335 |
| Flint, dark, and lime | 67 | 402 |
| Lime, dark, and zinc shines | 8 | 410 |
| Lime, dark, and flint | 51 | 461 |
| Zinc shines | 8 | 469 |
| Lime, gray | 281 | 750 |
| Sand rock | 10 | 760 |
| Lime, gray | 190 | 950 |
| Lime, sandy | 50 | 1,000 |
| Sand, white | 9 | 1,009 |
| Sand and lime | 48 | 1,057 |

## 29N22E-36, Scammon Hill Mine Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay | 30 | 30 |
| Shale | 160 | 190 |
| Lime, brown, and flint | 40 | 230 |
| Flint and fair lead | 25 | 255 |
| Flint and lead, shines | 15 | 270 |
| Flint, white | 10 | 280 |
| Lime and flint, lead jack, shines | 10 | 290 |
| Lime, brown, and flint | 15 | 305 |
| Lime and flint, jack, shines | 11 | 316 |
| Flint, good jack, shines | 9 | 325 |
| Water flint, fair jack | 10 | 335 |
| Lime and flint | 25 | 360 |
| Lime and flint, fair jack, shines | 10 | 370 |
| Flint, brown | 30 | 400 |
| Lime, brown, and flint | 15 | 415 |
| Flint, brown, lead jack, shines | 15 | 430 |
| Flint, black, lead jack, shines | 15 | 445 |
| Flint, black, thin lead jack, shines | 20 | 465 |
| Flint, brown, fair jack | 30 | 495 |
| Lime and selvage, open ground | 5 | 500 |
| Lime, brown | 10 | 510 |

## 29N23E-15-2, Beck Mining Company Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil and clay | 15 | 15 |
| Shale | 50 | 65 |
| Lime, gray | 35 | 100 |
| Flint, blue white | 30 | 130 |
| Cotton rock | 10 | 140 |
| Flint boulders | 20 | 160 |
| Flint, blue white, and gray lime | 10 | 170 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Flint, blue white, and fair shines of zinc | 10 | 180 |
| Flint, blue white, and zinc shines | 10 | 190 |
| Flint, blue white, and good lead shines | 10 | 200 |
| Flint, blue white | 25 | 225 |
| Flint, blue and brown | 5 | 230 |
| Flint, blue white | 40 | 270 |
| Flint, brown white | 25 | 295 |
| Flint, blue white, broken | 25 | 320 |
| Flint, blue brown | 15 | 335 |
| Flint, blue | 30 | 365 |
| Flint, blue, and gray lime | 30 | 395 |
| Flint, blue, and gray lime selvage | 50 | 445 |
| Flint, blue, and gray lime | 15 | 460 |
| Flint, blue white, and brown lime | 15 | 475 |

## 29N23E-15-3, Huttig Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay | 15 | 15 |
| Soapstone, gray | 15 | 30 |
| Limestone, gray | 50 | 80 |
| Limestone, gray, and white flint | 50 | 130 |
| Limestone, green, gray white flint, pyrite | 10 | 140 |
| Flint, blue gray white, pyrite and zinc | 7.5 | 147.5 |
| Flint, blue gray white, and pyrite | 7.5 | 155 |
| Flint, gray white, and white limestone | 25 | 180 |
| Flint, gray white, and brown limestone | 30 | 210 |
| Limestone, brown, and white flint | 25 | 235 |
| Limestone, brown white, and white flint | 80 | 315 |
| Flint, blue gray, and brown limestone | 25 | 340 |
| Limestone, brown, and gray flint | 45 | 385 |
| Selvage and gray limestone, and gray flint | 16 | 401 |

## 29N23E-16-1, Consolidated Lead & Zinc Co. Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Shale | 65 | 65 |
| Lime | 65 | 130 |
| Lime fissure, white | 10 | 140 |
| Flint, white | 42 | 182 |
| Flint, light blue | 8 | 190 |
| Flint, blue, open ground | 14 | 204 |
| Flint, light blue, open ground | 26 | 230 |
| Flint, light blue brown | 19 | 249 |
| Flint, dark blue, lower lime | 69 | 318 |
| Flint, dark blue, lime, zinc shines | 4 | 322 |
| Flint, light, and lime | 378 | 700 |
| Lime, brown | 160 | 860 |
| Lime, sandy | 113 | 973 |
| Water sand | 17 | 990 |
| Lime, sandy | 15 | 1,005 |
| Flint, blue, water sand | 14 | 1,019 |
| Sand, white, water-bearing | 14 | 1,033 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Opening | 1 | 1,034 |
| Sand, white, water-bearing | 13 | 1,047 |
| Opening | 2 | 1,049 |
| Sand, white, water-bearing | 11 | 1,060 |

## 29N23E-16-2, Victory Metals No. 2 Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay and shale | 65 | 65 |
| Limestone | 40 | 105 |
| Lime and tar, soft | 5 | 110 |
| Limestone | 50 | 160 |
| Flint, limestone | 25 | 185 |
| Flint, blue white, trace of zinc | 5 | 190 |
| Flint, blue white, and zinc shines | 15 | 205 |
| Flint, blue white | 10 | 215 |
| Flint, white | 30 | 245 |
| Lime, brown | 20 | 265 |
| Flint, white, and limestone | 36 | 301 |
| Flint, white, zinc, shines | 4 | 305 |
| Flint, white, and limestone | 25 | 330 |
| Lime, brown, and blue flint | 55 | 385 |
| Flint, brown blue, and zinc shines | 5 | 390 |
| Flint, blue brown | 15 | 405 |
| Lime, brown, and blue flint | 70 | 475 |
| Shale, blue | 1 | 476 |
| Sand, gray | 4 | 480 |
| Sandstone, gray | 5 | 485 |
| Sand and limestone | 85 | 570 |
| Sand, brown | 30 | 600 |
| Sand and limestone | 50 | 650 |
| Flint, black, and limestone | 15 | 665 |
| Sand, and limestone | 115 | 780 |
| Flint, blue, and limestone | 30 | 810 |
| Sand and limestone | 175 | 985 |
| Sand, gray | 15 | 1,000 |
| Sand, white, water-bearing | 15 | 1,015 |
| Sand and limestone | 10 | 1,025 |

## 29N23E-17, Lucky Syndicate Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soapstone | 90 | 90 |
| Lime | 50 | 140 |
| Lime and flint | 25 | 165 |
| Flint | 10 | 175 |
| Flint, some jack | 15 | 190 |
| Flint | 33 | 223 |
| Hog chow | 38 | 261 |
| Flint | 31 | 292 |
| Hog chow | 5 | 297 |
| Lime and flint | 143 | 440 |
| Lime | 5 | 445 |
| Lime and mud pockets | 30 | 475 |
| Shale, black | 5 | 480 |
| Lime | 120 | 600 |
| Lime and flint | 275 | 875 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Lime, little showing of sand | 77 | 952 |
| Sand, water-bearing | 8 | 960 |
| Lime | 47 | 1,007 |
| Sand, water-bearing | 10 | 1,017 |
| Lime and flint | 61 | 1,078 |
| Sand, water-bearing, crevice at 1085 | 17 | 1,095 |
| Lime and sand | 45 | 1,140 |
| Sand, some lime | 5 | 1,145 |
| Lime and flint | 9 | 1,154 |
| Lime and some flint | 13 | 1,167 |
| Lime | 12 | 1,179 |
| Flint, blue | 6 | 1,185 |
| Lime and flint | 12 | 1,197 |
| Lime | 10 | 1,207 |
| Flint | 7 | 1,214 |
| Lime | 38 | 1,252 |
| Flint | 10 | 1,262 |
| Lime, sand and flint | 25 | 1,287 |
| Lime and flint | 19 | 1,306 |
| Lime, flint, water sand | 8 | 1,314 |
| Lime | 26 | 1,340 |
| Lime, flint and sand | 30 | 1,370 |
| Sand, water-bearing | 10 | 1,380 |
| Lime | 40 | 1,420 |
| No cuttings | 73 | 1,493 |
| Sand | 17 | 1,510 |
| Lime and sand | 15 | 1,525 |

## 29N23E-18-1, Pelican Mine Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Shaft | 255 | 255 |
| Lime, brown, and flint | 195 | 450 |
| Lime, gray | 485 | 935 |
| Sand, gray | 35 | 970 |
| Lime, gray | 40 | 1,010 |
| Sand, white | 15 | 1,025 |
| Lime, dark gray | 55 | 1,080 |

## 29N23E-19-3, Eagle-Picher Mining & Smelting Co. (Beaver Mine) Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 35 | 35 |
| Soap | 50 | 85 |
| Lime, dark | 25 | 110 |
| Lime, gray | 40 | 150 |
| Lime, brown | 50 | 200 |
| Lime, gray, and flint | 35 | 235 |
| Flint | 35 | 270 |
| Flint, dark, lead and jack shines | 15 | 285 |
| Flint, dark | 25 | 310 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Lime, dark, and flint | 130 | 440 |
| Lime, gray, and flint | 145 | 585 |
| Sand, white | 25 | 610 |
| Lime with sand | 374 | 984 |
| Sand, white | 26 | 1,010 |
| Sand, gray | 103 | 1,113 |

## 29N23E-19-4, Eagle-Picher Mining & Smelting Co. (Lion Mine) Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil and yellow clay | 25 | 25 |
| Soapstone and shale | 44 | 69 |
| Sand rock | 3 | 72 |
| Soapstone and shale | 28 | 100 |
| Soapstone and mundic | 15 | 115 |
| Lime, gray | 10 | 125 |
| Flint, blue white, cavey | 48 | 173 |
| Flint, brown blue | 4 | 177 |
| Flint, white blue, and fair lead | 20 | 197 |
| Flint, white blue, fair lead, mundic | 6 | 203 |
| Flint, white blue, trace of lead and jack | 2 | 205 |
| Flint, white blue, and jack shines | 16 | 221 |
| Flint, white blue, and fair jack | 14 | 235 |
| Flint, hard, white, creviced | 47 | 282 |
| Flint, white, brown, and jack shines | 3 | 285 |
| Lime and flint | 10 | 295 |
| Lime and flint | 405 | 700 |
| Sand, white | 5 | 705 |
| Lime | 70 | 775 |
| Sand, white, brown | 5 | 780 |
| Lime | 10 | 790 |
| Sand, white, brown | 20 | 810 |
| Lime | 9 | 819 |
| Sand, hard, white | 18 | 837 |
| Lime, sand, little flint | 63 | 900 |
| Sand, white | 20 | 920 |
| Lime | 20 | 940 |
| Sand, white | 5 | 945 |
| Lime sand, little flint | 15 | 960 |
| Sand, pure white | 8 | 968 |
| Sand, white | 47 | 1,015 |
| Lime, sand, and little flint | 31 | 1,046 |
| Sand, white | 69 | 1,115 |
| Lime, sand, slight trace of flint | 20 | 1,135 |
| Lime, little sand, and flint | 3 | 1,138 |

## 29N23E-20, Netta Mine Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soapstone | 65 | 65 |
| Flint, blue, and lime | 10 | 75 |
| Lime, white | 5 | 80 |
| Lime, gray, and blue flint | 10 | 90 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Lime, brown and gray | 10 | 100 |
| Lime, brown | 10 | 110 |
| Lime, white | 5 | 115 |
| Flint, white and blue | 10 | 125 |
| Cotton rock | 30 | 155 |
| Flint, blue, and gray lime | 10 | 165 |
| Flint, blue and white | 5 | 170 |
| Flint, white, and blue lime | 20 | 190 |
| Flint, blue, and blue lime | 15 | 205 |
| Flint, blue, and gray lime | 25 | 230 |
| Flint, white, and zinc shines | 9 | 239 |
| Flint, white and blue | 5 | 244 |
| Flint, white and blue, good zinc, good lead | 8 | 252 |
| Flint, black and little blue, lime, good zinc, lead shines | 3 | 255 |
| Flint, white and black, zinc shines | 3 | 258 |
| Flint, white | 29 | 287 |
| Lime, blue and white | 37 | 324 |
| Lime and flint, blue | 34 | 358 |
| Lime, blue and gray | 47 | 405 |
| Lime, blue and gray, and white flint | 15 | 420 |
| Lime, brown | 5 | 425 |
| Lime, blue and gray, and white flint | 20 | 445 |
| Lime, blue, and white selvage | 5 | 450 |
| Lime, gray, white flint and blue flint | 25 | 475 |
| Lime, sandy, little flint, little water | 41 | 516 |
| Lime, white and blue | 14 | 430 |
| Lime, white, and little sand | 16 | 547 |
| Lime, gray, and water sand | 54 | 600 |
| Lime, brown, blue flint, and little sand | 20 | 620 |
| Lime, sandy | 27 | 647 |
| Sand, water-bearing | 5 | 652 |
| Lime, sandy, little blue flint | 44 | 696 |
| Lime, brown, and little flint | 13 | 709 |
| Lime, sandy, blue flint | 30 | 739 |
| Lime, brown, blue flint | 60 | 799 |
| Lime, brown, little blue flint | 5 | 804 |
| Lime, gray, and white flint | 10 | 814 |
| Lime, brown, and little sand | 50 | 864 |
| Lime, sandy, and blue flint | 30 | 894 |
| Flint, white and blue, brown lime | 10 | 904 |
| Lime, white, black | 10 | 914 |
| Lime, gray, and little sand | 35 | 949 |
| Lime, sandy, and little white flint | 15 | 964 |
| Sand | 40 | 1,004 |
| Sand, white | 15 | 1,019 |
| Sand, little white flint | 30 | 1,049 |

## 29N23E-21-1, City of Picher Well 1.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil | 2 | 2 |
| Clay, yellow | 18 | 20 |
| Soapstone | 40 | 60 |
| Lime and flint | 20 | 80 |
| No record | 18 | 98 |
| Crevice | 2 | 100 |
| Soapstone | 4 | 104 |

| | (feet) Thickness | (feet) Depth |
|---|---|---|
| Lime boulders | 10 | 114 |
| Lime, soft, white | 4 | 118 |
| Lime and flint boulders | 12 | 130 |
| Flint boulders formation | 10 | 140 |
| Hogchaw flint | 16 | 156 |
| Lime boulders | 14 | 170 |
| Lime and white flint | 20 | 190 |
| Zinc ore, very thin in blue flint | 10 | 200 |
| Flint, white | 30 | 230 |
| Hogchaw flint | 35 | 265 |
| Lime and flint, gray | 5 | 270 |
| Hogchaw flint, gray | 5 | 275 |
| Lime, brown | 45 | 320 |
| Lime, dark, softer | 10 | 330 |
| Lime, dark, dark flint | 45 | 375 |
| Lime, dark, some flint | 54 | 429 |
| Lime, dark, some light flint | 151 | 580 |
| Lime, dark, and flint | 365 | 945 |
| Lime and sand | 40 | 985 |
| Sand | 50 | 1,035 |
| Flint, blue, and very hard lime | 42 | 1,077 |

## 29N23E-21-2, City of Picher Well 2

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil and clay | 16 | 16 |
| Shale, blue | 19 | 35 |
| Shale, dark, medium hard | 15 | 50 |
| Lime, soft, white | 5 | 55 |
| Lime, hard, white | 20 | 75 |
| Lime and flint, hard | 62 | 137 |
| Lime and flint, extra hard | 33 | 170 |
| Flint, blue and white, hard | 8 | 178 |
| Flint, hard, white, and zinc shines | 15 | 193 |
| Flint, white, medium hard | 23 | 216 |
| Flint, white and blue, hard | 10 | 226 |
| Lime flint, light colored, hard | 104 | 330 |
| Flint, gray, extra hard | 30 | 360 |
| Flint, blue, extra hard | 25 | 385 |
| Flint, light blue, top of lower lime | 3 | 388 |
| Lime, white, hard | 80 | 468 |
| Sand, white, medium hard, water-bearing | 8 | 476 |
| Flint, limy, white, hard | 470 | 946 |
| Sand, lime, openings, and water | 54 | 1,000 |
| Sand, white, water-bearing | 35 | 1,035 |
| Flint and lime, very hard | 31 | 1,066 |

## 29N23E-21-3, City of Picher Well 3

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil, clay and shale | 55 | 55 |
| Limestone, white | 35 | 90 |
| Lime, coarsely crystalline, brown, with seams of green shale | 14 | 104 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Limestone, white, little light blue flint | 28 | 132 |
| Limestone, tan, blue white flint | 4 | 136 |
| Limestone, fine-grained, brown, and blue and white flint | 14 | 150 |
| Limestone, brown and white, and some white flint | 4 | 154 |
| Limestone, gray and white, and some white flint, jack shines | 15 | 169 |
| Flint, gray and white, jasperoid, jack shines | 4 | 173 |
| Flint, gray and white, glauconite, leached jasperoid | 4 | 177 |
| No cuttings, crevice | 4 | 181 |
| Jasperoid, white, 50-50 chatty jack shines | 2 | 183 |
| Flint, snow white, gray white water flint, little jasperoid, jack shines mostly free ore | 7 | 190 |
| Cotton rock, some unleached white flint | 26 | 216 |
| Cotton rock, light blue flint | 3 | 219 |
| Flint, white, blue and dark gray, glauconite in leached white flint | 4 | 223 |
| Limestone, crystalline, brown, ⅓ light blue flint | 4 | 227 |
| Limestone, crystalline, brown, ⅓ white flint | 4 | 231 |
| Limestone, crystalline, brown, little white flint | 19 | 250 |
| Limestone, crystalline, brown | 8 | 258 |
| Flint, snow white, cotton rock | 20 | 278 |
| Limestone, white, little gray flint | 8 | 286 |
| Flint, light brown | 14 | 300 |
| Jasperoid, brown, with cementing gray flint fragments, tan limestone | 25 | 325 |
| Limestone, dark gray, fine grained | 25 | 350 |
| Limestone, dark gray, fine grained, some gray flint | 10 | 360 |
| Limestone, dark gray, fine grained, ⅓ to ½ gray flint | 36 | 396 |
| Limestone, dark gray, compact, ¼ to ½ gray flint | 16 | 412 |
| Flint, dark gray to white, ⅓ compact gray limestone | 8 | 420 |
| Flint, dark gray, light gray, brown, ¼ gray to tan limestone | 10 | 430 |
| Limestone, white, light gray, little blue gray flint | 10 | 440 |
| Limestone, compact, light gray, and little blue and gray flint | 10 | 450 |
| Dolomite, crystalline, white, and green shale streaks | 10 | 460 |
| Dolomite, crystalline, brown, and ¼ gray and white flint | 40 | 500 |
| Limestone, light gray, sandy, white chert, green shale | 80 | 580 |
| Sandstone, calcareous, brown oolitic flint | 40 | 620 |
| Dolomite, compact, brown, clear blue and gray oolitic flint, and brown flint | 20 | 640 |
| Limestone, soft, white, and white sandstone, white chert | 20 | 660 |
| Dolomite, white and tan, clear white sandstone, oolitic white chert | 80 | 740 |
| Flint, brown, little oolitic white flint, white sandstone | 30 | 770 |
| Flint, clay, brown oolitic flint, some clear white sandstone | 30 | 800 |
| Dolomite, compact light gray | 20 | 820 |
| Dolomite, sandy, brown, white chert, gray flint, | | |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| little oolitic brown flint, quartz sandstone | 28 | 848 |
| Flint, gray, white chert, white sandstone, brown dolomite | 8 | 856 |
| Sandstone, white, brown oolitic flint, some brown dolomite, gray and white flint | 16 | 872 |
| Sandstone, gray, some brown dolomite, white chert | 24 | 896 |
| Dolomite, dark gray, sandy, and little white chert | 24 | 920 |
| Sandstone, white and gray, and clear gray flint | 24 | 944 |
| Dolomite, compact, gray, white sandstone, some white chert | 8 | 952 |
| Dolomite, gray, sandy, some gray and white clear bluish flint | 48 | 1,000 |
| Sandstone, white, clear quartz grains loosely cemented | 40 | 1,040 |
| Dolomite, gray, sandy, quartz, some gray flint and white flint | 28.5 | 1,068.5 |

## 29N23E-21-4, Cosmos Mine Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil and clay | 15 | 15 |
| Shale | 15 | 30 |
| Limestone | 50 | 80 |
| Flint | 105 | 185 |
| Flint and good jack | 50 | 235 |
| Lime and flint | 165 | 400 |
| Lime | 500 | 900 |
| Sand and lime | 200 | 1,100 |

## 29N23E-21-5, Mahutska Mining Co. Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 3 | 3 |
| Sandstone | 12 | 15 |
| Soapstone | 30 | 45 |
| Lime boulders | 20 | 65 |
| Lime flint | 140 | 205 |
| Crevice | 5 | 210 |
| Flint boulder ground | 20 | 230 |
| Flint jack and lead shines | 10 | 240 |
| Jack, good, and lead | 10 | 250 |
| Flint, water-bearing | 40 | 290 |
| Lime | 40 | 330 |
| Flint, brown | 20 | 350 |
| Flint, open ground with selvage, mundic, and water | 10 | 360 |
| Flint, blue | 10 | 370 |
| Lime, white, water-bearing | 160 | 530 |
| Lime and flint | 423 | 953 |
| Sand, white | 11 | 964 |
| Lime, white | 4 | 968 |

## 29N23E-22, Tulsa Lead and Zinc Co. Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay | 25 | 25 |
| Shale | 31 | 67 |
| Lime | 54 | 110 |
| Lime and flint | 40 | 150 |
| Lime and flint, selvage and pyrite | 10 | 160 |
| Lime, selvage, pyrite | 5 | 165 |
| Lime and flint, selvage and pyrite | 5 | 170 |
| Flint, blue | 10 | 180 |
| Flint, blue gray | 5 | 185 |
| Flint, blue white | 5 | 190 |
| Flint, white | 10 | 200 |
| Flint, white, blue, yellow | 10 | 210 |
| Flint, gray, and jack shines | 10 | 220 |
| Flint, gray and brown, spar and jack shines | 5 | 225 |
| Flint, gray and brown, and jack shines | 5 | 230 |
| Flint, gray, brown flint, spar, jack shines | 6 | 236 |
| Flint, grav | 9 | 245 |
| Flint, gray, and lime | 115 | 360 |
| Flint, blue, and lime | 31 | 391 |
| Lime and selvage | 49 | 440 |
| Lime and flint | 70 | 510 |
| Flint, black and blue | 5 | 515 |
| Lime, flint, selvage, pyrite | 10 | 525 |
| Lime and flint | 250 | 775 |
| Sand, gray | 20 | 795 |
| Lime and flint | 40 | 835 |
| Sand and lime | 10 | 845 |
| Sand, red | 10 | 855 |
| Sand, gray | 10 | 865 |
| Sand, gray, and blue flint | 5 | 870 |
| Sand, black | 10 | 880 |
| Sand, gray, flint | 5 | 885 |
| Sand, gray, water-bearing | 70 | 955 |
| Sand, white, water-bearing | 15 | 970 |
| Sand, gray and blue | 10 | 980 |
| Sand, gray | 15 | 995 |
| Sand, gray, flint | 10 | 1,005 |

## 29N23E-23, Bob Cropp Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil and clay | 30 | 30 |
| Shale | 22 | 52 |
| Lime, gray | 48 | 100 |
| Flint, white | 40 | 140 |
| Lime, gray | 15 | 155 |
| Flint, white | 25 | 180 |
| Flint, loose | 5 | 185 |
| No cuttings | 5 | 190 |
| Flint, black, good zinc shines | 5 | 195 |
| Lime, black | 4 | 199 |
| Flint, gray, and lime | 36 | 235 |
| Lime, brown | 25 | 260 |

| | (feet) Thickness | (feet) Depth |
|---|---|---|
| Flint, white, brown | 15 | 275 |
| Lime, flint | 170 | 445 |
| Lime, blue | 5 | 450 |
| Flint, brown and blue | 30 | 480 |
| Lime and flint | 45 | 525 |
| Lime, gray | 15 | 540 |
| Lime and flint | 140 | 680 |
| Lime, brown | 75 | 755 |
| Flint, gray, limy | 15 | 770 |
| Lime, brown, and gray flint | 80 | 850 |
| No cuttings | 5 | 855 |
| Sand, gray, water-bearing | 20 | 875 |
| Lime, brown, sandy | 10 | 885 |
| Sand, gray, water-bearing | 15 | 900 |
| Flint, white and gray, and brown lime | 15 | 915 |

## 29N23E-24, Ontario Smelter Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil and clay | 35 | 35 |
| Soapstone | 5 | 40 |
| Lime, white, flint | 115 | 155 |
| Cotton rock and brown lime | 27 | 182 |
| Flint, blue, and zinc shines | 28 | 210 |
| Flint, blue and white | 10 | 220 |
| Lime, brown | 130 | 350 |
| Flint, blue | 25 | 375 |
| Flint, blue, and lime | 20 | 395 |
| Shale, white | 55 | 450 |
| Sandstone, brown | 4 | 454 |
| Lime, brown | 46 | 500 |
| Sand, gray | 8 | 508 |
| Lime, gray | 342 | 850 |
| Sand, gray | 30 | 880 |
| Lime, gray | 70 | 950 |
| Sand, white | 100 | 1,050 |

## 29N23E-29, Skelton No. 5 Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay and boulders | 16 | 16 |
| Lime and flint | 8 | 24 |
| Limestone, hard, white | 66 | 90 |
| Boulders and hogchaw | 105 | 195 |
| Flint, hard, white | 16 | 211 |
| Flint, blue | 27 | 238 |
| Limestone and flint | 45 | 283 |
| Limestone, white | 102 | 385 |
| Limestone, white, with some flint | 491 | 876 |
| Limestone, sandy | 16 | 892 |
| Sandstone, very hard, white | 12 | 904 |
| Limestone, blue | 15 | 919 |
| Limestone, hard, sandy | 51 | 970 |
| Sandstone, white, water-bearing | 20 | 990 |

## 29N23E-30, Blue Goose Mine Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 35 | 35 |
| Soapstone, sand, boulders and mundic | 110 | 145 |
| Sand, oil-bearing | 5 | 150 |
| Lime, mundic and few zinc shines | 35 | 185 |
| Flint, blue and gray, mixed with lime | 55 | 240 |
| Flint, brown and gray | 11 | 251 |
| Flint, light brown, 7% lead and zinc | 5 | 256 |
| Flint, light brown, about 10% zinc | 19 | 275 |
| Flint, brown, good jack shines | 10 | 285 |
| Flint, black and gray, lead and zinc shines | 5 | 290 |
| Flint, white, rotten | 5 | 295 |
| Flint, gray, thin zinc shines | 65 | 360 |
| Lime and flint | 80 | 440 |
| Lime, brown | 160 | 600 |
| Lime, gray | 350 | 950 |
| Selvage and lime | 10 | 960 |
| Lime, gray | 50 | 1,010 |
| Sand, brown | 15 | 1,025 |
| Sand, gray | 55 | 1,080 |
| Sand, gray, and blue lime | 68 | 1,148 |

## 29N23E-32, Consolidated No. 6 Well

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Soil and clay | 5 | 5 |
| Lime and flint | 107 | 112 |
| Soapstone and iron ore | 28 | 140 |
| Lime and shale | 21 | 161 |
| Flint, white | 156 | 317 |
| Flint, dark | 40 | 357 |
| Shale, green, and lime | 8 | 365 |
| Lime | 21 | 386 |
| Lime and flint | 423 | 809 |
| Lime, sandy | 51 | 860 |
| Sand, water-bearing | 12 | 872 |
| Sand, hard, water-bearing | 38 | 910 |
| Sand, white, water-bearing | 75 | 985 |

# APPENDIX C.

## RECORDS OF WELLS INVESTIGATED FOR THIS REPORT

Wells visited in the course of this investigation for which logs, analyses, or pumpage, or other data were obtained are listed in table 13 and are shown on figures 13 and 14. All the municipal and institutional wells, most of the industrial and many of the deep mine wells, are included. A special effort was made to verify the location of wells in the mining district for which logs are available, but with only moderate success. Many have been abandoned since central milling of the ores became common practice or since termination of operations in the mines they served, and they are not readily distinguished from the many cased air vents, old prospect holes, and foundations in the vicinity. Several that were pointed out by long-time residents proved to have been filled with debris.

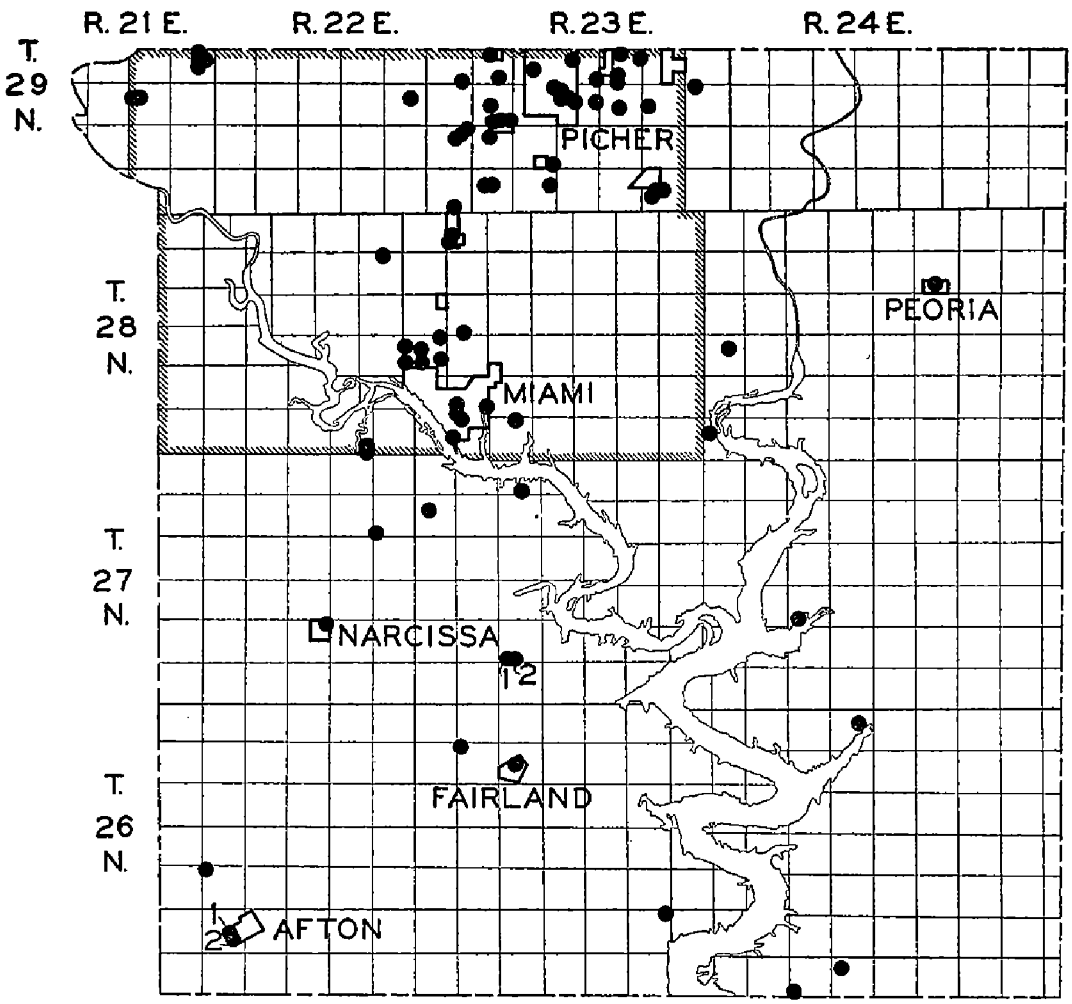


FIG. 13. Map of Ottawa County showing locations of water wells listed in table 13. See paragraph headed "Well-numbering system" for explanation of the relation of well numbers to land description. See also figure 14 for detail map of northwestern four townships (within the heavy boundary line).

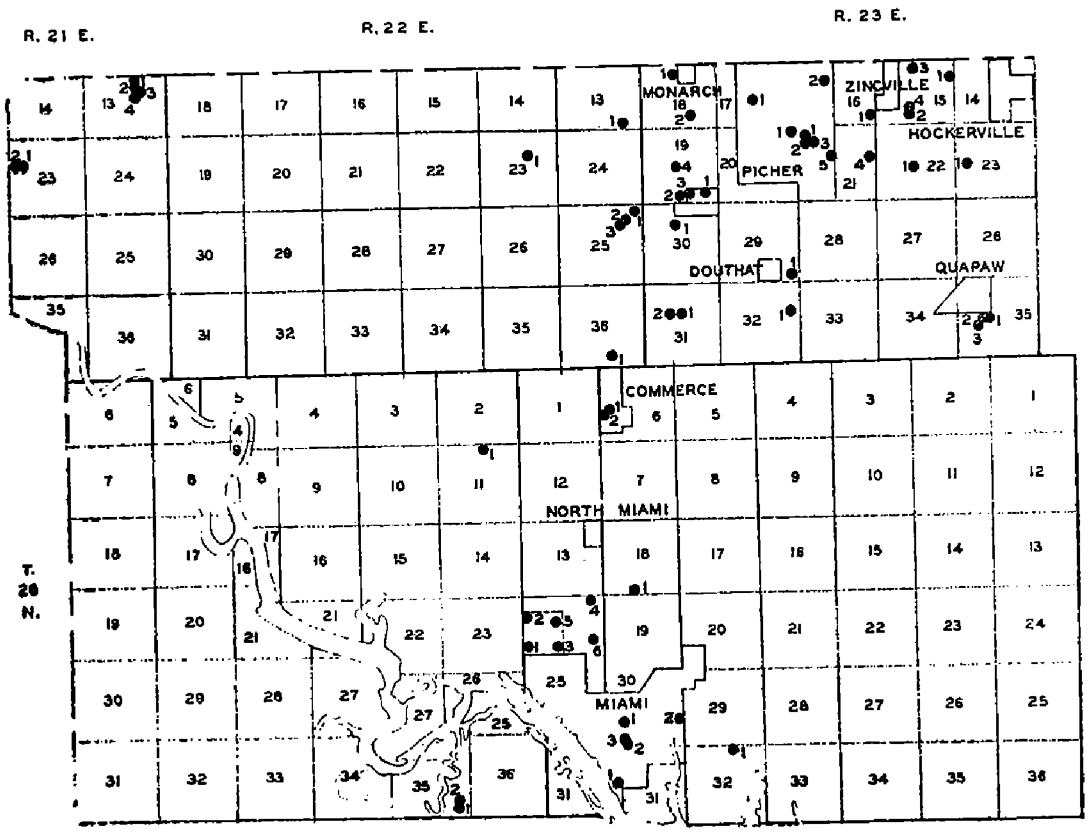


*Fig.* 14. Map of northwestern four townships of Ottawa County (within heavy boundary line of figure 13) giving identifying members of closely spaced wells.

TABLE 13.

RECORDS OF WELLS IN OTTAWA COUNTY, OKLAHOMA, INVESTIGATED FOR THIS REPORT.

Use: Ind., industrial; Dom., domestic; P. S., public supply.
Method of lift: Turb., turbine pump; Cyl., cylinder pump; Air, air lift.
Sample logs, Appendix A; Drillers' logs, Appendix B; Water Analyses, Table 12.

| Well No. | Location | Owner or name | Date completed | Altitude above sea level (feet) | Depth (feet) | Diameter (inches) | Probable aquifer | Use of water | Method of lift | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | TOWNSHIP 25 NORTH, RANGE 24 EAST | | | | | | | |
| 25N24E- | | | | | | | | | | |
| 3 | NW¼ | T. Tomlinson | 1945 | ........ | 1,010 | 8 | Boone and Canadian | Dom., Stock | Cyl. | Driller's log. Cased only 20 feet below land surface. |
| 4 | SW¼SW¼SW¼ | Gregory | ........ | ........ | 200 | 6 | Boone | Stock | None | Analysis. Flows about 2 gallons per hour. |
| | | | TOWNSHIP 26 NORTH, RANGE 22 EAST | | | | | | | |
| 26N22E- | | | | | | | | | | |
| 29 | NW¼NW¼NW¼ | James S. Chubb | before 1907 | ........ | 1,165 | ........ | Canadian | Stock | Cyl., H. | Analysis. (U.S.G.S. Bull. 340c) |
| 32-1 | NW¼SE¼ | Town of Afton | 1910 | 785 | 1,066 | 8 | ......do...... | P. S. | Cyl. | |
| 32-2 | ..........do.......... | ............do............ | ..do.. | 785 | 1,066 | 8 | ......do...... | P. S. | Turb. | Analysis |
| | | | TOWNSHIP 26 NORTH, RANGE 23 EAST | | | | | | | |
| 26N23E- | | | | | | | | | | |
| 8 | NW¼NW¼ | Shell Pipeline Co. | 1935? | ........ | 1,100 | ........ | Canadian | Ind. | Air | Analysis |
| 9 | NE¼SW¼ | Town of Fairland | 1924 | 835 | 1,244 | 8 | ......do...... | P. S. | Turb. | Analysis |
| 36 | NE¼NE¼ | E. H. Offield | 1927 | ........ | 410 | ........ | Boone | ............ | ............ | Driller's log. |
| | | | TOWNSHIP 26 NORTH, RANGE 24 EAST | | | | | | | |
| 26N24E- | | | | | | | | | | |
| 3 | NE¼ | Wm. Johnson | 1945 | ........ | 437 | 8 | Boone | Dom., Stock | Cyl. | Analysis. |

TABLE 13.—(Continued)

RECORDS OF WELLS IN OTTAWA COUNTY, OK LAHOMA, INVESTIGATED FOR THIS REPORT.

| ell No. | Location | Owner or name | Date completed | Altitude above sea level (feet) | Depth (feet) | Diameter (inches) | Probable aquifer | Use of water | Method of lift | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **TOWNSHIP 27 NORTH, RANGE 22 EAST** | | | | | | |
| N22E-12 | SW¼SW¼SW¼ | Ottawa County Welfare Home | 1927 | 850± | 1,055 | ........ | Canadian | P. S. | Cyl. | Sample log. Analysis. |
| 27 | NE¼NE¼NE¼ | Gaines Bros. | ........ | ........ | 1,000 | ........ | Boone and Canadian | P. S. Stock | Cyl. | Supplies town of Narcissa. |
| | | | | **TOWNSHIP 27 NORTH, RANGE 23 EAST** | | | | | | |
| N23E-4 | SW¼SW¼SE¼ | Fred DeMier | 1946 | 810± | 1,033 | 8¼ | Roubidoux | Dom., Ind. | Cyl. | Analysis. Cased to Roubidoux. Dairy use. |
| 7 | Center of SE¼NW¼ | Dave Wilson | 1932 | 850 | 1,055 | ........ | Canadian | Dom., Stock | Turb. | Sample log. Analysis. |
| 28-1 | SE¼SW¼ | Fred Newton | ........ | ........ | 245 | 6 | Boone | Dom., Stock | Cyl. | Analysis. |
| 28-2 | ..........do.......... | ............do............ | 1944 | 810± | 1,000 | 6¼ to 4 | Canadian | None | None | Water level 255.4 feet below land surface, 7/25/46 |
| | | | | **TOWNSHIP 27 NORTH, RANGE 24 EAST** | | | | | | |
| N24E-21 | SE¼SW¼ | Seneca Indian School | 1928 | ........ | 1,040 | 8 | Canadian | P. S., Stock | Cyl. | |
| | | | | **TOWNSHIP 28 NORTH, RANGE 22 EAST** | | | | | | |
| N22E-11 | NW¼NE¼ | J. A. Robinson | ........ | ........ | 1,150 | ........ | Canadian | Dom., Stock | Turb. | Analysis. |
| 24-1 | SW¼NW¼SW¼ | B. F. Goodrich Co. | 1944 | 785.7 | 1,200 | 10¾ | ......do...... | Ind. | Turb. | Sample log. |

TABLE 13.—(Continued)

RECORDS OF WELLS IN OTTAWA COUNTY, OK LAHOMA, INVESTIGATED FOR THIS REPORT.

| ell No. | Location | Owner or name | Date completed | Altitude above sea level (feet) | Depth (feet) | Diameter (inches) | Probable aquifer | Use of water | Method of lift | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **TOWNSHIP 28 NORTH, RANGE 22 EAST (Continued)** | | | | | | | |
| N22E- | | | | | | | | | | |
| 24-2 | NW¼SW¼NW¼ | B. F. Goodrich Co. | 1944 | 764.8 | 1,200 | 10¾ | Canadian | Ind. | Turb. | Sample log. |
| 24-3 | SE¼NE¼SW¼ | ............do............ | ..do.. | 798.2 | 1,055 | 10 | ......do...... | Ind. | Turb. | Sample log. |
| 24-4 | NW¼NE¼NE¼ | ............do............ | ..do.. | 788.4 | 1,235 | 10¾ | ......do...... | Ind. | Turb. | Sample log. Analysis. |
| 24-5 | NE¼SE¼NW¼ | ............do............ | ..do.. | 791.8 | 1,465 | 10¾ | ......do...... | Ind. | Turb. | Sample log. |
| 24-6 | NW¼NE¼SE¼ | McCoy Greenhouse | 1926 | 795 | 1,046 | 8? | ......do...... | None | None | Log. |
| 35-1 | SE¼ | J. A. Robinson | 1940? | ........ | 1,130 | ........ | ......do...... | Dom., Stock | Cyl. | Analysis. |
| 35-2 | ..........do.......... | Walter Tydings | ........ | ........ | 610 | ........ | Cotter | ............ | ............ | Driller's log. |
| | | | **TOWNSHIP 28 NORTH, RANGE 23 EAST** | | | | | | | |
| N23E- | | | | | | | | | | |
| 6-1 | NW¼SW¼ | City of Commerce | ........ | ........ | 1,050 | 6¼ | Canadian | P. S. | Turb. | South well. Analysis. |
| 6-2 | ..........do.......... | ............do............ | ........ | ........ | 1,110 | 6¼ | ......do...... | P. S. | Turb. | 100 feet NE of 6-1. |
| 18 | SW¼SE¼SW¼ | B. F. Goodrich Co. | 1944 | 776.9 | 1,145 | 10¾ | ......do...... | Ind. | Turb. | Sample log. |
| 30-1 | SE¼NW¼SW¼ | City of Miami | ........ | 792 | 1,250 | ........ | ......do...... | P. S. | Turb. | Abandoned well nearby flowed when drilled, before 1907. (U.S.G.S. Bull. 340c p. 225.) |
| 30-2 | SW¼NW¼SE¼ | Southwest Service Co. | Before 1907 | 765 | 1,680 | ........ | ......do...... | Ind. | Turb. | Flowed more than 100 g pm when drilled, (U.S. G.S. Bull. 340c, p. 225). Used in summer only for making ice. |

TABLE 13.—(Continued)

RECORDS OF WELLS IN OTTAWA COUNTY, OKLAHOMA, INVESTIGATED FOR THIS REPORT.

| ll No. | Location | Owner or name | Date completed | Altitude above sea level (feet) | Depth (feet) | Diameter (inches) | Probable aquifer | Use of water | Method of lift | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **TOWNSHIP 28 NORTH, RANGE 23 EAST (Continued)** | | | | | | |
| **N23E-** | | | | | | | | | | |
| 31-1 | .......................... | City of Miami | 1946 | 767 | 1,116 | ........ | Canadian | P. S. | Turb. | In City Park. |
| 31-2 | NW¼NW¼ | ............do............ | ........ | 780 | ........ | 10 | ......do...... | P. S. | Turb. | North well at power plant |
| 31-3 | NW¼NE¼ | ............do............ | 1919 | 776 | 1,247 | 10 | ......do...... | P. S. | Turb. | South well at power plant. Driller's log. Analysis. |
| 32 | NW¼NE¼NW¼ | ............do............ | 1948 | 790 | 1,345 | 11¾ | ......do...... | P. S. | Turb. | |
| | | | | **TOWNSHIP 28 NORTH, RANGE 24 EAST** | | | | | | |
| **N24E-** | | | | | | | | | | |
| 12 | SE¼SW¼ | P. R. Liederbrand | 1946 | ........ | 185 | 6 | Boone | Dom. | Cyl. | Water level measured 17.3 feet below land surface, 4-27-48. |
| 19 | SW¼NE¼ | J. A. Robinson | 1945 | ........ | ........ | 8 | Boone and Canadian | None | None | Prospect hole. Water level measured 318 feet below land surface, 4-26-46. |
| 31 | SW¼NW¼ | Boy Scout Camp | 1935 | ........ | 431 | 6½ | Cotter | P. S. | ............ | Driller's log. |
| | | | | **TOWNSHIP 29 NORTH, RANGE 21 EAST** | | | | | | |
| **N21E-** | | | | | | | | | | |
| 13-1 | NW¼NE¼ | United Zinc Smelting Corp. | 1942 | ........ | 375 | 12¼ | Boone | None | None | Analysis. North well. Water level reported 111 feet below land surface, 8-3-42, before pump was installed. |

TABLE 13.—(Continued)

RECORDS OF WELLS IN OTTAWA COUNTY, OKLAHOMA, INVESTIGATED FOR THIS REPORT.

| l No. | Location | Owner or name | Date completed | Altitude above sea level (feet) | Depth (feet) | Diameter (inches) | Probable aquifer | Use of water | Method of lift | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | TOWNSHIP 29 NORTH, RANGE 21 EAST (Continued) | | | | | | | |
| 21E- | | | | | | | | | | |
| 13-2 | NW¼NE¼ | United Zinc Smelting Corp. | 1942 | ........ | 375 | 12¼ | Boone | Ind. | Turb. | 125 feet south of 13-1. Discharge 480 gpm (est. 4-28-48). Mine dewatering; also used for drinking and sanitation. |
| 13-3 | ..........do.......... | ............do............ | ..do.. | 820 | 367 | 12¼ | ......do...... | Ind. | Turb. | 400 feet south of 13-2. Discharge 730 gpm (est. 4-28-48). Mine dewatering. |
| 13-4 | ..........do.......... | ............do............ | ........ | ........ | 350 | 8 | ......do...... | Ind. | Turb. | South of pond. Discharge 280 gpm (est. 4-28-48). Mine dewatering. |
| 23-1 | SE¼SW¼NW¼ | Claude Webb | ........ | ........ | 182 | 6 | Krebs group(?) | Dom. | Cyl. | Analysis. Water level measured 15.10 feet below land surface, 4-28-48. |
| 23-2 | ..........do.......... | ............do............ | ........ | ........ | 12 | 48 | Alluvium | None | Cyl. | Dug well. Analysis. Water level measured 8.9 feet below land surface, 4-28-48. |
| | | | TOWNSHIP 29 NORTH, RANGE 22 EAST | | | | | | | |
| 22E- | | | | | | | | | | |
| 13 | SW¼SE¼ | Bird Dog No. 1 Mine Eagle-Picher M. & S. Co. | 1930 | 822 | 1,267 | ........ | Canadian | None | None | Analysis. |
| 23 | SE¼NE¼ | Adams Mine | 1926 | ........ | 1,082 | ........ | ..do.. | ..do.. | ..do.. | Driller's log. |

TABLE 13.—(Continued)

RECORDS OF WELLS IN OTTAWA COUNTY, OK LAHOMA, INVESTIGATED FOR THIS REPORT.

| ll No. | Location | Owner or name | Date completed | Altitude above sea level (feet) | Depth (feet) | Diameter (inches) | Probable aquifer | Use of water | Method of lift | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | TOWNSHIP 29 NORTH, RANGE 22 EAST (Continued) | | | | | | |
| N22E- | | | | | | | | | | |
| 25-1 | NE¼NE¼NE¼ | Powerhouse, Eagle-Picher M. & S. Co. | 1929 | 835 | 1,229 | ........ | Canadian | Ind. | Turb. | Sample log. Analysis. Used for cooling, drinking and sanitation. Water level reported 235 feet below land surface, 10-22-45. |
| 25-2 | NW¼SW¼NE¼ | Goodeagle Mine | ........ | ........ | 1,025 | ........ | ......do...... | None | None | Driller's log. |
| 25-3 | NE¼NE¼ | B. & R. Mining Co. | 1917 | ........ | 1,057 | ........ | ......do...... | ..do.. | ..do.. | Driller's log. |
| 36 | SW¼SE¼ | Scammon Hill Mine | 1923 | 825 | 510 | ........ | Boone and Canadian | ..do.. | ..do.. | Driller's log. |
| | | | | TOWNSHIP 29 NORTH, RANGE 23 EAST | | | | | | |
| N23E- | | | | | | | | | | |
| 15-1 | SE¼NE¼ | Brewster Lease | ........ | 840 | ........ | ........ | ................ | None | None | Water level measured 294.54 feet below land surface, 4-11-47; 296.09 feet, 11-20-47; 297.42 feet, 4-29-48. |
| 15-2 | Center of SE¼SW¼ | Beck Mining Co. | ........ | 828 | 475 | ........ | Boone(?) | ..do.. | ..do.. | Driller's log. |
| 15-3 | NE¼SE¼NW¼ | Huttig | ........ | 828 | 401 | ........ | ......do...... | ............ | ............ | Driller's log. |
| 15-4 | SE¼SW¼ | Beck Mining Co. | ........ | 828 | 675 | 6 | Canadian | Ind. | Air | Analysis. Used for cooling. |
| 16-1 | SE¼SE¼ | Consolidated No. 2 | ........ | 820 | 1,060 | ........ | ......do...... | None | None | Driller's log. |
| 16-2 | SE¼NW¼ | Victory Metals No. 2 | 1919 | 835 | 1,025 | 6¼ | ......do...... | ..do.. | ..do.. | Driller's log. Cased to 450 feet. |

TABLE 13.—(Continued)

RECORDS OF WELLS IN OTTAWA COUNTY, OK LAHOMA, INVESTIGATED FOR THIS REPORT.

| 'ell No. | Location | Owner or name | Date completed | Altitude above sea level (feet) | Depth (feet) | Diameter (inches) | Probable aquifer | Use of water | Method of lift | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | TOWNSHIP 29 NORTH, RANGE 23 EAST (Continued) | | | | | | | |
| 9N23E- | | | | | | | | | | |
| 17 | NE¼SW¼ | Lucky Syndicate | ........ | 840 | 1,525 | ........ | Canadian | None | None | Driller's log. |
| 18-1 | NE¼NW¼ | Pelican Mine | 1916 | 840 | 1,080 | ........ | ......do...... | Dom. | Cyl. | Driller's log. Analysis. Supplies several homes. Pump 255 feet below surface. Water level reported 265 feet below land surface, 4-27-48. |
| 18-2 | SW¼SE¼ | Gordon Mine | ........ | 840 | 1,176.5 | ........ | ......do...... | ............ | ............ | Analysis. |
| 19-1 | SW¼SE¼SE¼ | Masters | ........ | 825 | 1,100+ | ........ | ......do...... | P. S. | Turb. | Analysis. Supplies town of Cardin. |
| 19-2 | SW¼SW¼SE¼ | Eagle-Picher M. & S. Co. (John Beaver) | 1938 | 833.3 | 1,772 | 12½ to 6⅝ | ......do...... | None | None | Sample log. Low yield. Near Miami syncline. |
| 19-3 | SW¼SE¼ | Beaver Mine | ........ | 830 | 1,113 | ........ | ......do...... | None | None | Driller's log. Low yield. Near Miami syncline. |
| 19-4 | NE¼NE¼SW¼ | Eagle-Picher M. & S. Co. (Lion Mine) | ........ | 830 | 1,138 | 10½ | ......do...... | Ind. | Air | Driller's log. Water level measured 255.73 feet below land surface, 4-29-48. Standby use only. |
| 20 | NE¼NE¼ | Netta Mine | 1915 | 830 | 1,049 | ........ | ......do...... | None | None | Driller's log. |
| 21-1 | SW¼NW¼NW¼ | City of Picher | 1920 | 822 | 1,077 | 8 to 6 | ......do...... | P. S. | Turb. | Driller's log. Analysis. Water level reported 380 feet below land surface, 8-8-42. |

TABLE 13.—(Continued)

RECORDS OF WELLS IN OTTAWA COUNTY, OK LAHOMA, INVESTIGATED FOR THIS REPORT.

| ll No. | Location | Owner or name | Date completed | Altitude above sea level (feet) | Depth (feet) | Diameter (inches) | Probable aquifer | Use of water | Method of lift | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | TOWNSHIP 29 NORTH, RANGE 23 EAST (Continued) | | | | | | |
| N23E- | | | | | | | | | | |
| 21-2 | SW¼NW¼NW¼ | City of Picher | 1924 | 822 | 1,125 | 8 to 6 | Canadian | P. S. | Turb. | Driller's log. Deepened from 1,006 to 1,125 in 1946. |
| 21-3 | ..........do.......... | .........do............ | ..do.. | 822 | 1,125 | 8 to 6 | ......do...... | P. S. | Turb. | Driller's log. Deepened from 1,068½ to 1,125 in 1946. |
| 21-4 | SE¼NE¼ | Cosmos Mine | 1919 | 830 | 1,100 | ........ | ......do...... | None | None | Driller's log. |
| 21-5 | SE¼NW¼ | Mahutska Mining Co. | ........ | 820 | 968 | ........ | ......do...... | ....do.... | ....do.... | Driller's log. |
| 22 | NE¼NE¼SW¼ | Tulsa L. & Z. Co. | ........ | 845 | 1,005 | ........ | ......do...... | ............ | ............ | Driller's log. |
| 23 | NW¼SW¼ | Bob Cropp | 1933 | 855 | 915 | ........ | ......do...... | ............ | ............ | Driller's log. |
| 24 | NW¼NW¼ | Ontario Smelter | 1918 | 850 | 1,050 | ........ | ......do...... | None | None | Driller's log. Water level reported 104 feet below land surface when drilled. |
| 29 | SE¼SE¼ | Skelton No. 5 | 1924 | 822 | 990 | ........ | ......do...... | ............ | ............ | Driller's log. |
| 30 | SE¼NW¼ | Eagle-Picher M. & S. Co. (Blue Goose Mine) | 1927 | 832 | 1,130 | ........ | ......do...... | Ind. | Air & cyl. | Driller's log. Pumped by air to mine level, from mine level to surface by cylinder. Used for drinking and sanitation. |
| 31-1 | SE¼NW¼ | Eagle-Picher M. & S. Co. (Central Mill) | 1932 | 834.5 | 1,175 | 8¼ to 6¼ | .........do........... | Ind. | Turb. | Sample log. For water levels, see figure 5. |

TABLE 13.—(Continued)

RECORDS OF WELLS IN OTTAWA COUNTY, OKLAHOMA, INVESTIGATED FOR THIS REPORT.

| ell No. | Location | Owner or name | Date completed | Altitude above sea level (feet) | Depth (feet) | Diameter (inches) | Probable aquifer | Use of water | Method of lift | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **TOWNSHIP 29 NORTH, RANGE 23 EAST (Continued)** | | | | | | |
| **N23E-** | | | | | | | | | | |
| 31-2 | SE¼NW¼ | Eagle-Picher M. & S. Co. (Central Mill) | ........ | 830 | 1,505 | ........ | Canadian | ............ | ............ | Sample log. |
| 32 | SE¼NE¼ | Consolidated No. 6 | 1924 | ........ | 985 | ........ | ......do...... | None | None | Driller's log. Contaminated by mine waters and abandoned. |
| 35-1 | SE¼SE¼NW¼ | Town of Quapaw | ........ | ........ | 400 | ........ | Boone | ..do.. | ..do.. | Water level reported 160 feet below land surface, 1932. |
| 35-2 | ..........do.......... | ............do............ | ........ | 845 | 1,200 | ........ | Canadian | ..do.. | ..do.. | Casing deteriorated, admitting water from Boone. Well, abandoned. |
| 35-3 | NE¼NE¼SW¼ | ............do............ | 1942 | 845 | 1,325 | 8 to 6½ | ......do...... | P. S. | Turb. | Sample log. Analysis. Drilled to Roubidoux, deepened to Gunter; acidized Gunter, then Roubidoux; later shot Roubidoux. Water level after acidizing and shooting, reported 258 feet below land surface, 7-23-42. |

# APPENDIX D.

## RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA

(from State Mineral Survey)

An inventory of rural water wells in the county was carried out in 1937 by the State Mineral Survey, which was Works Progress Administration Project 65-65-538 and was sponored and directed by the Oklahoma Geological Survey. The records of this survey are published here in table 14, except that wells appearing in table 13 are not repeated. Obviously, many water wells have been drilled since the inventory was made, and some have been abandoned. Obviously, too, the records lack something in precision, for they are based on the well-user's report, which often may have been an estimate rather than a measurement. Nevertheless, they are helpful in appraising the general ground-water conditions of localities, such as townships.

The figures for capacity generally represent the greatest amount normally withdrawn rather than the maximum yield of which a well may be capable. The quality is based on the user's opinion, not on chemical analyses. The hardness, for example, is generally estimated from the relative amount of soap used for laundry purposes. A small amount of hydrogen sulfide in the water gives an unmistakable odor of rotten eggs and usually gives rise to the report of "sulfur water." Waters from which black sulfides—probably the sulfides of zinc or iron—will precipitate after standing a while are described as "black-sulfur" water. As the locations of the wells in table 14 are not shown on a map and reference is not made in the text to any of these wells individually, well numbers are not given to them. Locations in the table are given to 40 acres.

## TABLE 14.

## RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA.

(From State Mineral Survey, 1937)

Dr., drilled; spr., spring.
gpm, gallons per minute; gph, gallons per hour; gpd, gallons per day.
Med., medium; $H_2S$ is shown when "sulfur water" was reported; white S and black S when "white" or "black sulfur water" was reported.
Ls., limestone; ss., sandstone; sh., shale; gr., gravel; ch., chert; cl., clay; alluv., alluvium.
Dep., (dependable): Drought had no effect on yield of well.
Good: Drought had noticeable effect but well yielded enough water for normal use.
Poor: Well yielded insufficient water, or failed completely.

| Section | Location in section | Type | Depth (feet) | Capacity | Quality of water | Water-bearing material | Performance during drought |
|---|---|---|---|---|---|---|---|
| | | | T. 25 N., R. 22 E. | | | | |
| 5 | NW¼SW¼ | Dr. | 95 | ........ | Hard | Ls. | Dep. |
| | | | T. 25 N., R. 23 E. | | | | |
| 1 | NE¼NE¼ | Dr. | 165 | 80 gpd | Soft | Ls. | Good |
| 3 | SE¼NE¼ | Dr. | 100 | 800 gpd | Hard | Ls. | Dep. |
| 4 | SW¼SW¼ | Dug | 17 | 200 gpd | Soft | Ls. | Dep. |
| 5 | SE¼SE¼ | Dr. | 40 | 200 gpd | Soft | Ls. | Poor |
| 6 | NE¼NW¼ | Dug | 25 | 200 gph | Soft | Ls. | Good |
| 6 | SW¼SW¼ | Dug | 35 | ........ | Soft | Ls. | Dep. |
| | | | T. 25 N., R. 24 E. | | | | |
| 2 | SW¼NE¼ | Spr. | ........ | 3,000 gpm | Soft | Ls. | Dep. |
| 2 | NE¼SE¼ | Dr. | 80 | 400 gpd | Soft | Ls. | Dep. |
| 6 | NW¼NW¼ | Dug | 20 | 500 gpd | Soft | Gr. | Dep. |
| | | | T. 25 N., R. 25 E. | | | | |
| 4 | SE¼SW¼ | Spr. | ........ | 75 gpm | Soft | Gr. | Dep. |
| 5 | NW¼SW¼ | Spr. | ........ | 25 gpm | Soft | Alluv. | Dep. |
| 6 | SW¼SE¼ | Spr. | ........ | 75 gpm | Soft | Gr. | Dep. |
| | | | T. 26 N., R. 22 E. | | | | |
| 1 | SW¼SW¼ | Dr. | 80 | ........ | Hard | ........ | ........ |
| 2 | SE¼SE¼ | Dr. | 179 | ........ | Black S. | Ss. | ........ |
| 3 | NE¼SE¼ | Dr. | 180 | ........ | Black S. | ........ | Good |
| 4 | NE¼NE¼ | Dr. | 200 | ........ | Soft | ........ | Good |
| 5 | NW¼NE¼ | Dr. | 300 | ........ | Black S. | ........ | Dep. |
| 6 | NW¼NW¼ | Dug | 26 | 50 gph | Med. soft | Sh. | Poor |
| 7 | SW¼NW¼ | Dug | 30 | 150 gph | Soft | Sh. | Poor |
| 7 | NE¼NE¼ | Dr. | 303 | ........ | Black S. | ........ | Dep. |
| 10 | SE¼SE¼ | Dr. | 150 | ........ | Hard | ........ | Good |
| 11 | SW¼NW¼ | Dr. | 240 | ........ | $H_2S$ | ........ | Dep. |
| 12 | SW¼SW¼ | Dug | 20 | ........ | Hard | ........ | Dep. |
| 14 | SE¼NE¼ | Dr. | 175 | ........ | $H_2S$ | Ls. | Dep. |
| 15 | SW¼SW¼ | Dr. | 190 | ........ | Black S. | ........ | Dep. |
| 20 | NE¼NE¼ | Dr. | 300 | ........ | Soft $H_2S$ | ........ | Dep. |
| 21 | SW¼SW¼ | Dr. | 100 | 250 gph | Hard | ........ | Dep. |
| 23 | NW¼SW¼ | Dug | 20 | 200 gph | Hard | Ls. | Good |
| 24 | NE¼NE¼ | Dr. | 225 | ........ | Hard | Ls. | Dep. |
| 34 | SE¼SE¼ | Dr. | 20 | ........ | Med. soft | Gr. | Dep. |
| 35 | SE¼SW¼ | Dr. | 30 | ........ | Soft | Ls. | Dep. |

TABLE 14.—(Continued)

RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA.
(From State Mineral Survey, 1937)

| Section | Location in section | Type | Depth (feet) | Capacity | Quality of water | Water-bearing material | Performance during drought |
|---|---|---|---|---|---|---|---|
| | | | T. 26 N., R. 23 E. | | | | |
| 2 | SW¼SW¼ | Dr. | 50 | 200 gpd | Hard | Ls. | Poor |
| 2 | NE¼NW¼ | Dr. | 300 | 40 gph | Soft | Ls. | Dep. |
| 3 | NW¼NW¼ | Dr. | 285 | .............. | Soft $H_2S$ | .......... | Dep. |
| 3 | SW¼SE¼ | Dr. | 40 | .............. | $H_2S$ | Ls. | Dep. |
| 4 | SE¼SE¼ | Dr. | 245 | 1,000 gpd | Soft | Ls. | Dep. |
| 5 | SE¼SW¼ | Dr. | 200 | 3,000 gpd | Soft $H_2S$ | .......... | Dep. |
| 7 | SW¼SW¼ | Dr. | 172 | 400 gpd | $H_2S$ | Ls. | Good |
| 10 | NE¼NE¼ | Dr. | 30 | .............. | Hard | Ls. | Good |
| 11 | NE¼NE¼ | Dr. | 240 | 250 gph | Soft | Ls. | Good |
| 12 | SW¼SW¼ | Dr. | 35 | 400 gpd | Med. soft | Ls. | Good |
| 12 | SE¼NW¼ | Spr. | ....... | 20 gpm | Soft | Alluv. | Good |
| 13 | SE¼SE¼ | Dug | 28 | 1,000 gpd | Med. soft | Ls. | Good |
| 13 | NW¼SW¼ | Spr. | ....... | 150 gpm | Soft | Ls. | Dep. |
| 13 | SE¼NW¼ | Dr. | 106 | 1,000 gpd | Soft | Ls. | Poor |
| 14 | NW¼NW¼ | Dr. | 490 | 1,000 gpd | Soft | Ls. | Dep. |
| 15 | NW¼SW¼ | Dr. | 300 | 2,000 gpd | Black S. | Ls. and ch. | Dep. |
| 16 | NE¼SE¼ | Dr. | 300 | .............. | Soft | Ls. | Dep. |
| 18 | SW¼NW¼ | Dr. | 50 | 200 gpd | Soft | Ls. | Poor |
| 21 | NE¼NE¼ | Dr. | 40 | 160 gpd | Hard | Ls. | Dep. |
| 22 | NW¼SW¼ | Dr. | 215 | 2,000 gpd | Med. soft | Ls. | Good |
| 23 | SE¼SE¼ | Spr. | ....... | .............. | Soft | Ch. | Dep. |
| 24 | NE¼NE¼ | Dug | 16 | 500 gpd | Med. hard | Ls. | Poor |
| 25 | SW¼SW¼ | Dr. | 139 | 1,200 gpd | Med. hard | .......... | Dep. |
| 27 | NE¼NW¼ | Dr. | 190 | .............. | Soft | Ls. and ch. | Dep. |
| 28 | SW¼SW¼ | Dr. | 16 | .............. | Soft | Ls. and ch. | Poor |
| 29 | SW¼NW¼ | Dr. | 98 | .............. | Med. hard | .......... | Poor |
| 31 | SW¼SW¼ | Dug | 16 | .............. | Med. hard | .......... | Good |
| 33 | SW¼SW¼ | Dug | 18 | .............. | Soft | .......... | Poor |
| 34 | SE¼SE¼ | Dr. | 100 | .............. | Hard | Ch. and ls. | Dep. |
| 35 | NW¼NW¼ | Dr. | 110 | 1,000 gpd | Med. soft | Ch. | Dep. |
| 36 | NE¼SE¼ | Spr. | ....... | 10 gpm | Soft | Gr. | Good |
| | | | T. 26 N., R. 24 E. | | | | |
| 2 | SW¼SW¼ | Dug | 40 | 2,000 gpd | Med. soft | Ls. | Dep. |
| 2 | NW¼NE¼ | Dug | 14 | 170 gph | Hard | Ls. | Good |
| 2 | SW¼NE¼ | Dug | 25 | 25 gpm | Hard | Ls. | Dep. |
| 2 | SE¼SE¼ | Dug | 6 | 5 gpm | Hard | Ls. | Poor |
| 2 | SW¼SW¼ | Spr. | ....... | 100 gpm | Soft | Gr. | Dep. |
| 2 | SE¼SE¼ | Spr. | ....... | 10 gpm | Soft | Ls. | Good |
| 2 | SW¼NW¼ | Dug | 25 | 1,000 gpd | Hard | Ls. | Good |
| 3 | NW¼SE¼ | Dug | 15 | 3,000 gpd | Soft | Ls. | Dep. |
| 6 | SW¼SW¼ | Dr. | 75 | 600 gpd | Hard | Ls. | Dep. |
| 6 | NE¼SE¼ | Spr. | ....... | 10 gpm | Soft | Ls. | Dep. |
| 7 | SE¼NE¼ | Spr. | ....... | 100 gph | Soft | .......... | Dep. |
| 7 | SW¼SW¼ | Dr. | 260 | 500 gpd | Med. soft | Ls. | Good |
| 8 | SW¼SE¼ | Dr. | 115 | 80 gpd | Soft | Ls. | Dep. |
| 9 | SW¼SW¼ | Dr. | 128 | 500 gpd | Med. Soft | Ls. | Dep. |
| 9 | NE¼NE¼ | Dug | 20 | 800 gpd | Soft | Ls. | Dep. |
| 10 | SW¼NW¼ | Dug | 22 | 400 gpd | Soft | Ls. | Poor |
| 16 | NE¼NW¼ | Dr. | 150 | 1,200 gpd | Med. hard | Ls. | Dep. |

TABLE 14.—(Continued)

RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA.
(From State Mineral Survey, 1937)

| Section | Location in section | Type | Depth (feet) | Capacity | Quality of water | Water-bearing material | Performance during drought |
|---|---|---|---|---|---|---|---|
| | | | T. 26 N., R. 24 E. (Continued) | | | | |
| 21 | SE¼SE¼ | Dug | 30 | 1,200 gpd | Soft | Alluv. | Dep. |
| 28 | SE¼SW¼ | Spr. | ........ | 20 gpm | Soft | Ls. | Dep. |
| 29 | NE¼SE¼ | Dug | 23 | 400 gpd | Soft | Ls. | Good |
| 31 | SE¼SE¼ | Dr. | 110 | 2,000 gpd | Hard | Ls. | Dep. |
| 32 | SW¼SW¼ | Dr. | 136 | 800 gpd | $H_2S$, soft | Ch. and sh. | Dep. |
| 35 | SW¼SE¼ | Spr. | ........ | 50 gpm | Soft | Gr. | Dep. |
| 35 | SW¼NE¼ | Spr. | ........ | 25 gpm | Soft | Gr. | Dep. |
| | | | T. 26 N., R. 25 E. | | | | |
| 5 | NE¼SW¼ | Dug | 25 | 250 gpm | Soft | Ls. | Good |
| 6 | NE¼SW¼ | Dug | 17 | ................ | Soft | Ls. | Dep. |
| 6 | NW¼NE¼ | Dr. | 45 | 200 gph | Soft | Ls. | Dep. |
| 6 | NW¼NW¼ | Spr. | ........ | 50 gph | Soft | ............ | Dep. |
| 6 | NE¼SW¼ | Spr. | ........ | 80 gph | Soft | ............ | Poor |
| 7 | SE¼SE¼ | Spr. | ........ | 8 gpm | Soft | Ls. | Dep. |
| 7 | NE¼SE¼ | Spr. | ........ | 30 gpm | Soft | Ls. | Dep. |
| 7 | SE¼SW¼ | Dr. | 90 | 120 gph | Soft | Ls. | Dep. |
| 7 | SW¼NW¼ | Dug | 30 | 170 gph | Soft | Ls. | Dep. |
| 8 | SW¼SW¼ | Spr. | ........ | 10 gpm | Soft | ............ | ............ |
| 9 | NW¼NW¼ | Dug | 26 | 400 gph | Soft | Ls. | Good |
| 9 | NW¼NW¼ | Spr. | ........ | 1,600 gph | Soft | Ls. | Good |
| 17 | NE¼NW¼ | Dug | 20 | ................ | Soft | Ch. | Dep. |
| 17 | NE¼NE¼ | Spr. | ........ | 200 gph | Soft | ............ | Dep. |
| 31 | NE¼SW¼ | Spr. | ........ | 50 gpm | Med. soft | Ls. | Dep. |
| 32 | SW¼NW¼ | Dr. | 83 | 1,400 gpd | Hard | Ch. | Dep. |
| | | | T. 27 N., R. 22 E. | | | | |
| 2 | SE¼SW¼ | Dug | 18 | ................ | Hard | Ss. | Dep. |
| 3 | NE¼NW¼ | Dug | 20 | 150 gph | Med. soft | Alluv. | Good |
| 4 | NW¼NW¼ | Dug | 32 | ................ | Med. hard | ............ | Poor |
| 5 | SW¼NW¼ | Dug | 11 | ................ | Hard | ............ | Dep. |
| 5 | SE¼SE¼ | Dr. | 200 | 1,000 gpd | Hard | ............ | Dep. |
| 7 | NW¼NE¼ | Dr. | 300 | ................ | ............ | ............ | Dep. |
| 8 | SE¼SE¼ | Dr. | 565 | ................ | Soft, salty | ............ | Dep. |
| 10 | NW¼NE¼ | Dug | 35 | ................ | Hard | ............ | Dep. |
| 11 | NW¼NW¼ | Dug | 14 | ................ | Hard | Ss. | Poor |
| 14 | SW¼NW¼ | Dr. | 102 | ................ | Hard | Ls. | Dep. |
| 17 | SW¼NW¼ | Dug | 30 | ................ | Hard | Ss. | Poor |
| 18 | SW¼SE¼ | Dug | 14 | ................ | Soft | Sh. | Poor |
| 19 | NW¼NW¼ | Dug | 17 | ................ | Soft | Ss. | Poor |
| 23 | SW¼NW¼ | Dug | 40 | ................ | Hard | Ls. | Dep. |
| 26 | NE¼NE¼ | Dr. | 301 | ................ | Soft $H_2S$ | ............ | Dep. |
| 26 | NE¼NE¼ | Dr. | 340 | 2,000 gpd | $H_2S$ | Ls. | Dep. |
| 27 | NE¼NW¼ | Dr. | 800 | 5,000 gpd | Soft | Ls. | Dep. |
| 28 | NW¼NW¼ | Dr. | 400 | 1,000 gpd | Soft | Ls. | Dep. |
| 29 | NW¼NW¼ | Dug | 20 | ................ | Soft | ............ | Poor |
| 30 | SE¼SE¼ | Dug | 13 | ................ | Soft | Alluv. | Poor |
| 32 | NW¼NW¼ | Dug | 18 | ................ | Hard | Sh. | Dep. |
| 33 | NW¼NW¼ | Dug | 38 | ................ | Hard | Sh. | Dep. |
| 35 | NW¼NW¼ | Dug | 17 | 80 gph | Hard | Ss. | Dep. |

TABLE 14.—(Continued)

RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA.
(From State Mineral Survey, 1937)

| Section | Location in section | Type | Depth (feet) | Capacity | Quality of water | Water-bearing material | Performance during drought |
|---|---|---|---|---|---|---|---|
| | | | T. 27 N., R. 22 E. (Continued) | | | | |
| 35 | SE¼SE¼ | Dug | 14 | 150 gph | Hard | Ls. | Dep. |
| 35 | SE¼SE¼ | Dr. | 190 | 600 gpd | Soft | ............ | Dep. |
| 36 | SE¼SE¼ | Dug | 30 | ................ | Hard | Ls. | Poor |
| | | | T. 27 N., R. 23 E. | | | | |
| 3 | SW¼SW¼ | Dug | 20 | 200 gpd | Hard | Ls. | Poor |
| 3 | SW¼NW¼ | Dr. | 205 | ................ | Soft | ............ | Dep. |
| 4 | SE¼NE¼ | Dr. | 96 | ................ | Soft | ............ | Dep. |
| 4 | SE¼SE¼ | Dr. | 702 | 300 gph | Soft, $H_2S$ | Ls. | Dep. |
| 5 | SE¼SE¼ | Dr. | 200 | 250 gph | Soft | Ls. | Dep. |
| 6 | SW¼SW¼ | Dr. | 83 | 1,000 gpd | Black S. | Ss. | Dep. |
| 6 | NW¼SE¼ | Dr. | 65 | 150 gph | Hard | Ls. | Good |
| 7 | NE¼SE¼ | Dr. | 280 | 3,000 gpd | Soft, $H_2S$ | Ss. and ls. | Dep. |
| 8 | NE¼NE¼ | Dr. | 182 | 1,500 gpd | Soft, $H_2S$ | Ss. | Dep. |
| 9 | NE¼NE¼ | Dug | 30 | 800 gpd | Soft | Ss. | Good |
| 10 | NW¼SW¼ | Dr. | 55 | 400 gpd | Hard | Ch. | Poor |
| 10 | SE¼NE¼ | Spr. | ........ | 10 gpm | Soft | Ls. | Poor |
| 11 | SW¼SW¼ | Dr. | 91 | 1,200 gpd | Med. soft | Ls. | Dep. |
| 11 | NE¼NE¼ | Dug | 235 | 1,500 gpd | Soft | ............ | Dep. |
| 11 | SW¼SE¼ | Dr. | 100 | ................ | Soft | ............ | Dep. |
| 12 | SW¼SE¼ | Dr. | 150 | ................ | Hard | ............ | Dep. |
| 13 | SE¼SE¼ | Dr. | 206 | 1,000 gpd | Med. soft | Ls. | Dep. |
| 13 | SE¼SW¼ | Spr. | ........ | 10 gpm | Soft | ............ | Poor |
| 14 | SE¼SE¼ | Dr. | 100 | 1,500 gpd | Soft | ............ | Dep. |
| 14 | NW¼NE¼ | Dr. | 105 | 200 gph | Soft | Ls. | Dep. |
| 15 | SW¼SW¼ | Spr. | ........ | 400 gpd | Soft | Ch. | Dep. |
| 16 | SW¼SW¼ | Dr. | 60 | 600 gpd | Soft | Ls. | Good |
| 17 | NE¼NW¼ | Dr. | 64 | 2,000 gpd | $H_2S$ | ............ | Dep. |
| 17 | NW¼SW¼ | Dug | 16 | 200 gpd | Hard | Ls. | Dep. |
| 18 | SE¼NE¼ | Dr. | 110 | 400 gpd | Soft, $H_2S$ | Ls. | Good |
| 19 | NE¼NW¼ | Dr. | 95 | 300 gpd | Hard | Ls. | Dep. |
| 21 | NW¼NW¼ | Dr. | 50 | 400 gpd | Soft | Ls. and ss. | Good |
| 21 | SW¼SE¼ | Dr. | 100 | 400 gpd | Hard | Ls. | Dep. |
| 22 | SE¼SW¼ | Dr. | 98 | 120 gph | Hard | Ls. | Dep. |
| 22 | NE¼SE¼ | Dr. | 100 | 800 gpd | Med. hard | Ls. | Dep. |
| 22 | SW¼NW¼ | Dr. | 65 | 140 gph | $H_2S$ | Ch. | Dep. |
| 22 | NW¼NE¼ | Dug | 30 | 400 gpd | Med. soft | ............ | Poor |
| 23 | NE¼NW¼ | Dr. | 115 | 2,500 gpd | $H_2S$ | ............ | Dep. |
| 23 | NW¼NW¼ | Dr. | 175 | 800 gpd | Med. soft | Ls. | Good |
| 25 | NE¼NW¼ | Dug | 35 | 250 gpd | Soft | Gr. | Dep. |
| 25 | NW¼SW¼ | Dug | 35 | 125 gpd | Hard | Ls. | Poor |
| 26 | SW¼NW¼ | Dr. | 50 | 1,500 gpd | Hard | Ls. | Dep. |
| 28 | NW¼NW¼ | Dr. | 50 | 80 gpd | Soft | Ls. | Poor |
| 28 | SW¼NW¼ | Spr. | ........ | 400 gpd | Soft | Ls. and ss. | Dep. |
| 28 | NE¼NE¼ | Dr. | 187 | 2,000 gpd | Soft | Ls. | Dep. |
| 28 | NE¼NE¼ | Dr. | 500 | 3,300 gpd | Soft | Ls. and sh. | Dep. |
| 29 | SE¼SW¼ | Dr. | 100 | 120 gph | Soft, $H_2S$ | ............ | Good |
| 30 | NE¼SE¼ | Dug | 12 | 400 gpd | Soft | Ls. and ss. | Good |
| 31 | NE¼SW¼ | Dr. | 130 | 1,400 gpd | Hard | Ls. | Dep. |
| 32 | NW¼NE¼ | Dr. | 180 | 1,000 gpd | Black S. | ............ | Poor |

TABLE 14.—(Continued)

RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA.
(From State Mineral Survey, 1937)

| Section | Location in section | Type | Depth (feet) | Capacity | Quality of water | Water-bearing material | Performance during drought |
|---|---|---|---|---|---|---|---|
| | | | T. 27 N., R. 23 E. (Continued) | | | | |
| 33 | NE¼SE¼ | Dr. | 196 | 500 gpd | Soft | Ls. | Dep. |
| 35 | NE¼SE¼ | Spr. | ........ | 20 gpm | Soft | Gr. | Good |
| 36 | SW¼NE¼ | Dr. | 150 | 200 gph | Soft | Ls. | Dep. |
| 36 | NE¼NW¼ | Spr. | ........ | 15 gpm | Soft | Gr. | Dep. |
| | | | T. 27 N., R. 24 E. | | | | |
| 3 | SE¼SE¼ | Spr. | ........ | 100 gpm | Soft | ............ | Dep. |
| 3 | SW¼SE¼ | Dr. | 81 | 1,200 gpd | Soft | Ls. | Dep. |
| 4 | NW¼SE¼ | Dug | 35 | 1,000 gpd | Hard | Gr. | Dep. |
| 5 | SE¼NW¼ | Spr. | ........ | 80 gph | Med. hard | Ls. | Dep. |
| 5 | NW¼NW¼ | Spr. | ........ | 75 gpm | Med. hard | Ls. | Good |
| 5 | NW¼NW¼ | Dug | 25 | 150 gph | Soft | Ch. | Dep. |
| 6 | SW¼SE¼ | Dr. | 180 | 200 gph | Soft | Ls. | Dep. |
| 7 | SW¼NW¼ | Dr. | 262 | 2,000 gpd | Hard | Ls. | Dep. |
| 7 | SW¼SE¼ | Spr. | ........ | 5 gpm | Med. soft | ............ | Dep. |
| 7 | SE¼SW¼ | Spr. | ........ | 25 gph | Soft | Gr. | Dep. |
| 7 | NE¼SW¼ | Spr. | ........ | 40 gph | Soft | ............ | Dep. |
| 8 | NW¼NE¼ | Dug | 5 | 500 gpd | Soft | Ls. | Dep. |
| 8 | SE¼NW¼ | Dr. | 150 | 500 gpd | Hard | Ls. | Good |
| 9 | NW¼SE¼ | Dr. | 135 | ................ | Soft | Ch. and ls. | Dep. |
| 9 | SE¼SW¼ | ........ | 40 | 600 gpd | Hard | Ch. and ls. | Poor |
| 9 | SE¼SW¼ | Spr. | ........ | 400 gpd | Soft | ............ | Poor |
| 15 | SE¼SE¼ | Dug | 20 | 2,000 gpd | Soft | Ch. | Dep. |
| 17 | SE¼SW¼ | Spr. | ........ | 30 gpm | Soft | Ls. | Dep. |
| 18 | SW¼SW¼ | Spr. | ........ | 40 gph | Soft | Ls. | Dep. |
| 18 | NE¼NW¼ | Dug | 30 | 150 gph | Hard | Ls. | Dep. |
| 18 | SE¼SE¼ | Dug | 18 | 5 gph | Hard | Ls. | Dep. |
| 18 | SE¼NW¼ | Spr. | ........ | 20 gpm | Soft | Ls. | Good |
| 19 | SE¼SE¼ | Dr. | 194 | 400 gph | Soft | Ls. | Dep. |
| 19 | NW¼SE¼ | Spr. | ........ | 15 gpm | Soft | Ls. | Dep. |
| 24 | NW¼NW¼ | Dug | 25 | 400 gpd | Soft | Ch. | Dep. |
| 24 | NW¼NE¼ | Spr. | ........ | 50 gph | Hard | Ch. | Good |
| 24 | SE¼NW¼ | Dug | 65 | 3,000 gpd | Soft | Ch. and ls. | Good |
| 24 | NE¼SW¼ | Spr. | ........ | 50 gpm | Soft | Gr. | Good |
| 25 | NW¼SE¼ | Dug | 18 | 1,600 gph | Soft | Ls. | Dep. |
| 25 | SW¼SE¼ | Dug | 10 | 1,600 gph | Soft | Ls. | Dep. |
| 25 | SE¼NE¼ | Spr. | ........ | 5 gpm | Soft | Ls. | Poor |
| 26 | NE¼NW¼ | Dr. | 62 | 4,000 gpd | Hard | Ls. | Dep. |
| 29 | NE¼SW¼ | Dug | 35 | 25 gpm | Soft | Ls. | Dep. |
| 29 | NW¼SE¼ | Spr. | ........ | 75 gpm | Soft | Ls. | Good |
| 30 | SE¼NW¼ | Dr. | 160 | 300 gph | Soft | Ls. | Dep. |
| 35 | SE¼NE¼ | Dr. | 50 | 1,000 gpd | Med. soft | ............ | Dep. |
| 35 | SE¼SE¼ | Dr. | 65 | 2,000 gpd | Soft | Ls. | Dep. |
| 36 | SE¼SE¼ | Dug | 36 | 200 gph | Soft | Ch. and ls. | Dep. |
| | | | T. 27 N., R. 25 E. | | | | |
| 4 | SW¼SW¼ | Dr. | 221 | 400 gph | Med. hard | ............ | Dep. |
| 6 | SE¼NE¼ | Dr. | 49 | 200 gph | Soft | Ch. and ls. | Dep. |
| 6 | NE¼NE¼ | Dr. | 175 | 1,000 gpd | ............ | Ls. | Good |
| 7 | SE¼NW¼ | Dug | 30 | 4,000 gpd | Soft | Ls. | Dep. |

TABLE 14.—(Continued)

RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA.
(From State Mineral Survey, 1937)

| Section | Location in section | Type | Depth (feet) | Capacity | Quality of water | Water-bearing material | Performance during drought |
|---|---|---|---|---|---|---|---|
| | | | T. 27 N., R. 25 E. (Continued) | | | | |
| 7 | SW¼SE¼ | Spr. | ........ | 200 gpm | Soft | Alluv. | Dep. |
| 7 | SE¼NE¼ | Spr. | ........ | 200 gpm | Soft | Alluv. | Dep. |
| 7 | NE¼NW¼ | Spr. | ........ | 300 gpm | Soft | Ls. and ch. | Dep. |
| 8 | NE¼SE¼ | Dr. | 96 | 5,000 gpd | Soft | Gr. | Good |
| 8 | SE¼SE¼ | Spr. | ........ | 10 gpm | Soft | Ls. | Good |
| 8 | SE¼SE¼ | Dug | 10 | 200 gph | Soft | Ls. | Good |
| 9 | SW¼NW¼ | Dug | 15 | 25 gph | Soft | Ls. | Good |
| 9 | SW¼SW¼ | Dr. | 60 | 400 gph | Soft | Ls. | Dep. |
| 16 | SW¼NE¼ | Dug | 18 | 50 gpm | Soft | Ch. | Dep. |
| 16 | SW¼NE¼ | Spr. | ........ | 40 gpm | Soft | Alluv. | Good |
| 18 | NE¼NE¼ | Spr. | ........ | 50 gpm | Hard | Ls. | Dep. |
| 18 | NE¼SW¼ | Dug | ........ | 200 gpd | Med. hard | ............ | Poor |
| 19 | SE¼NE¼ | Spr. | ........ | 50 gpm | Soft | Gr. | Dep. |
| 19 | SE¼NE¼ | Spr. | ........ | 25 gpm | Soft | Gr. | Dep. |
| 20 | NW¼SW¼ | Spr. | ........ | 10 gpm | Soft | Alluv. | ............ |
| 21 | NW¼SW¼ | Spr. | ........ | 600 gph | Soft | ............ | Dep. |
| 21 | SE¼SW¼ | Spr. | ........ | 1,200 gph | Soft | ............ | Dep. |
| 21 | SW¼SW¼ | Spr. | ........ | 200 gph | Med. soft | ............ | Dep. |
| 29 | NE¼SW¼ | Dug | 28 | 120 gph | Soft | Ch. | Good |
| 29 | SW¼SW¼ | Dr. | 60 | 160 gph | Soft | Ch. and ls. | Good |
| 29 | SW¼SE¼ | Spr. | ........ | 50 gpm | Soft | Ls. | Good |
| 29 | SE¼SW¼ | Spr. | ........ | 100 gpm | Soft | Ls. | Good |
| 30 | NE¼NW¼ | Dug | 22 | 40 gpm | Soft | Ch. and ls. | Good |
| 31 | SW¼SW¼ | Dug | 29 | 50 gph | Soft | Ch. and ls. | Good |
| 31 | NE¼NW¼ | Dug | 19 | 400 gph | Soft | Ls. | Dep. |
| 31 | NE¼NE¼ | Spr. | ........ | 200 gpm | Soft | Ls. | Dep. |
| 31 | NW¼NE¼ | Spr. | ........ | 150 gpm | Soft | Ls. | ............ |
| 31 | NW¼SW¼ | Spr. | ........ | 800 gpm | Soft | Alluv. | Good |
| 32 | NE¼SW¼ | Spr. | ........ | 20 gpm | Soft | Ls. | ............ |
| | | | T. 28 N., R. 22 E. | | | | |
| 2 | NW¼NW¼ | Dug | 27 | ................ | Soft | S. | Good |
| 3 | SE¼NE¼ | Dug | 27 | ................ | Soft | Alluv. | Dep. |
| 4 | NW¼NW¼ | Dr. | 125 | ................ | Hard | Ls. | Dep. |
| 5 | NE¼NW¼ | Dr. | 238 | 1,500 gpd | Hard | Ls. | Dep. |
| 5 | SE¼SE¼ | Dr. | 350 | 2,000 gpd | Hard | ............ | Dep. |
| 6 | NE¼SW¼ | Dug | 15 | 400 gpd | Hard | Gr. | Dep. |
| 6 | NW¼SW¼ | Dug | 16 | 1,000 gpd | Soft | Gr. | Dep. |
| 8 | SW¼SW¼ | Dug | 10 | ................ | Soft | Gr. | Dep. |
| 8 | NE¼SE¼ | Dr. | 200 | 2,500 gpd | Hard | Ss. and ls. | Dep. |
| 9 | NE¼SW¼ | Dug | 19 | ................ | Hard | Ss. | Dep. |
| 11 | NE¼NE¼ | Dr. | 1,100 | ................ | White S. | Ch. | Good |
| 11 | NW¼SW¼ | Dug | 20 | ................ | Soft | Alluv. | ............ |
| 12 | NE¼SW¼ | Dug | 35 | ................ | Hard | Alluv. | Dep. |
| 13 | NW¼NW¼ | Dug | 20 | ................ | Hard | Alluv. | ............ |
| 14 | SW¼NW¼ | Dug | 18 | ................ | Hard | Alluv. | ............ |
| 14 | NW¼SE¼ | Dr. | 80 | ................ | Black S. | Ls. | ............ |
| 15 | SE¼NE¼ | Dug | 45 | ................ | Hard | Alluv. | Good |
| 16 | NE¼NE¼ | Dr. | 40 | ................ | Soft | Ls. | Dep. |
| 17 | SW¼NW¼ | Dug | 35 | 1,000 gpd | Soft | Ls. | Dep. |

TABLE 14.—(Continued)

RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA.
(From State Mineral Survey, 1937)

| Section | Location in section | Type | Depth (feet) | Capacity | Quality of water | Water-bearing material | Performance during drought |
|---|---|---|---|---|---|---|---|
| | | | T. 28 N., R. 22 E. (Continued) | | | | |
| 19 | SE¼SE¼ | Dug | 35 | ............ | Soft | ............ | Dep. |
| 20 | NE¼NW¼ | Dug | 18 | ............ | Soft | Gr. | Dep. |
| 22 | NW¼SE¼ | Dug | 18 | ............ | Hard | Gr. | Dep. |
| 25 | SW¼SE¼ | Dug | 18 | 150 gph | Med. soft | Ls. | Dep. |
| 27 | SW¼SW¼ | Dug | 18 | ............ | Soft | Ls. | Dep. |
| 27 | ............ | Dug | 18 | ............ | Med. soft | Ls. | Dep. |
| 28 | ............ | Dug | 38 | ............ | Hard | ............ | Dep. |
| 28 | SW¼SE¼ | Dug | 38 | ............ | Hard | ............ | Dep. |
| 29 | ............ | Dug | 16 | 100 gph | Soft | Ss. | Poor |
| 30 | ............ | Dug | 20 | ............ | Soft | Ss. | Dep. |
| 31 | ............ | Dug | 25 | ............ | Hard | Sh. | Poor |
| 32 | ............ | Dug | 24 | 200 gph | Med. soft | ............ | Good |
| 33 | ............ | Dug | 20 | 300 gph | Soft | Gr. | Dep. |
| 33 | NW¼NE¼ | Dug | 20 | 300 gph | Soft | Gr. | Dep. |
| 34 | SE¼SE¼ | Dug | 18 | 100 gph | Soft | Alluv. | Poor |
| 36 | NW¼NW¼ | Dug | 24 | ............ | Hard | ............ | Dep. |
| | | | T. 28 N., R. 23 E. | | | | |
| 1 | SE¼SE¼ | Dr. | 180 | 200 gph | Soft | Ls. | Dep. |
| 3 | SW¼NE¼ | Dr. | 200 | 2,000 gpd | Hard | Ls. | Dep. |
| 5 | NE¼SE¼ | Dr. | 300 | 400 gpd | Hard | Ls. | Dep. |
| 9 | NE¼SE¼ | Dr. | 300 | 250 gph | $H_2S$ | Ls. and ch. | Poor |
| 10 | SW¼SE¼ | Dr. | 150 | 1,000 gpd | Hard | Ls. | Good |
| 13 | NW¼NE¼ | Dr. | 150 | 1,000 gpd | Med. soft | ............ | Dep. |
| 14 | NE¼SE¼ | Dr. | 1,500 | 400 gpd | Soft | Ls. | Dep. |
| 15 | SW¼SW¼ | Dug | 50 | 160 gph | Soft | Ls. | Dep. |
| 16 | SE¼SE¼ | Dr. | 300 | 300 gph | Soft $H_2S$ | Ls. | Dep. |
| 16 | SW¼SW¼ | Dug | 20 | 125 gph | Hard | Ss. | Dep. |
| 17 | SW¼NW¼ | Dr. | 400 | 350 gph | Hard | Ls. | Dep. |
| 18 | NW¼SE¼ | Dr. | 250 | 1,500 gpd | $H_2S$ | Ls. | Dep. |
| 19 | NW¼NE¼ | Dug | 14 | 500 gpd | Hard | ............ | Poor |
| 19 | NW¼NW¼ | Dr. | 200 | 1,500 gpd | Black S. | Ls. | Dep. |
| 20 | SE¼SW¼ | Dr. | 48 | 400 gpd | Hard | ............ | Poor |
| 21 | NE¼NE¼ | Dr. | 200 | 2,000 gpd | $H_2S$ | Ls. | Dep. |
| 21 | NE¼NE¼ | Dr. | 100 | 250 gph | Soft | Ls. | Dep. |
| 22 | SW¼SE¼ | Dug | 25 | 800 gpd | Hard | Ls. | Poor |
| 22 | SE¼SE¼ | Dr. | 30 | 125 gph | Soft | Ls. | Dep. |
| 23 | NW¼NW¼ | Dr. | 175 | 1,300 gpd | Black S. | Ls. | Dep. |
| 24 | NW¼NW¼ | Dr. | 180 | 800 gph | Soft | ............ | Dep. |
| 29 | SW¼SW¼ | Dr. | 100 | 800 gpd | Med. hard | ............ | Good |
| 31 | SE¼NW¼ | Dug | 30 | 125 gph | Hard | Gr. | Dep. |
| 32 | SE¼SE¼ | Dug | 20 | 800 gpd | Hard | Ls. | Dep. |
| 34 | NE¼NE¼ | Dug | 130 | 300 gpd | Hard | ............ | Poor |
| | | | T. 28 N., R. 24 E. | | | | |
| 5 | SE¼NW¼ | Dr. | 150 | 25 gpm | Med. soft | Ls. | Dep. |
| 5 | SE¼NW¼ | Spr. | ....... | 30 gpm | Soft | Ch. | Dep. |
| 6 | SE¼SW¼ | Dr. | 96 | 1,500 gpd | Soft | ............ | Dep. |
| 8 | SW¼SE¼ | Dr. | 75 | 1,000 gpd | Med. soft | Ls. | Dep. |
| 8 | SE¼NE¼ | Dr. | 90 | 150 gph | Soft | Ls. | Dep. |

TABLE 14.—(Continued)

RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA.
(From State Mineral Survey, 1937)

| Section | Location in section | Type | Depth (feet) | Capacity | Quality of water | Water-bearing material | Performance during drought |
|---|---|---|---|---|---|---|---|
| | | | T. 28 N., R. 24 E. (Continued) | | | | |
| 15 | SW¼SE¼ | Spr. | ........ | 2,000 gpm | Soft | Ch. | Good |
| 16 | NW¼NW¼ | Spr. | ........ | 25 gpm | Soft | Ls. | Dep. |
| 17 | NE¼SW¼ | Dr. | 150 | 400 gpd | Med. hard | Ch. | Dep. |
| 18 | SE¼SE¼ | Dr. | 109 | 600 gpd | Med. soft | Ch. | Dep. |
| 19 | NW¼NE¼ | Dr. | 120 | 125 gph | Hard | Ch. and ls. | Dep. |
| 20 | SE¼SE¼ | Dr. | 300 | 800 gpd | Med. hard | Ls. | Dep. |
| 21 | NW¼NW¼ | Dug | 20 | 1,500 gpd | Soft | Gr. | Dep. |
| 22 | NW¼NW¼ | Spr. | ........ | 100 gpm | Soft | Alluv. | Poor |
| 26 | SE¼SW¼ | Spr. | ........ | 1,000 gpd | Soft | Ch. | Good |
| 26 | SW¼SE¼ | Spr. | ........ | 1 gpm | Soft | Ch. | Poor |
| 26 | SW¼SE¼ | Spr. | ........ | 30 gpm | Soft | Ch. | Dep. |
| 28 | NE¼SW¼ | Spr. | ........ | 100 gpm | Soft | Alluv. | Good |
| 28 | SW¼SW¼ | Spr. | ........ | 100 gpm | Soft | ............ | Good |
| 29 | SE¼SW¼ | Dr. | 62 | 2,500 gpd | Med. soft | Ls. | Dep. |
| 30 | NW¼SW¼ | Dr. | 120 | 125 gph | Hard | Ls. and ch. | Dep. |
| 30 | NW¼SW¼ | Spr. | ........ | 10 gpm | Soft | Ch. | Dep. |
| 31 | SE¼NE¼ | Dr. | 100 | 3,000 gpd | Soft | Ls. | Dep. |
| 31 | NE¼SW¼ | Dr. | 200 | 800 gpd | Hard | Ls. | Poor |
| | | | T. 28 N., R. 25 E. | | | | |
| 5 | SE¼SE¼ | Dug | 12 | 2,600 gpd | Soft | Gr. | Dep. |
| 5 | SW¼SE¼ | Dug | 15 | 800 gpd | Soft | Ls. | Dep. |
| 6 | SW¼NE¼ | Dug | 30 | 600 gpd | Soft | Ch. | Poor |
| 6 | NW¼SE¼ | Dug | 20 | 1,000 gpd | Soft | Gr. | Dep. |
| 7 | NE¼NW¼ | Dug | 25 | 400 gpd | Soft | Ls. | Good |
| 16 | SW¼NW¼ | Dug | 80 | 250 gpd | Soft | Ch. | Dep. |
| 16 | SW¼SW¼ | Dug | 30 | 400 gpd | Soft | Ls. | Dep. |
| 17 | SE¼NE¼ | Dr. | 250 | 2,000 gpd | Hard | ............ | Dep. |
| 18 | SW¼NE¼ | Dug | 22 | 400 gpd | Soft | Ls. and ch. | Dep. |
| 19 | NE¼SE¼ | Dug | 35 | 3,000 gpd | Hard | Ch. | Dep. |
| 20 | SE¼NW¼ | Dr. | 350 | 500 gpd | Hard | Ls. and ch. | ............ |
| 20 | SE¼NW¼ | Dug | 35 | 250 gpd | Med. soft | ............ | Good |
| 21 | NW¼SW¼ | Dr. | 80 | ................ | Hard | ............ | Dep. |
| 29 | NE¼NE¼ | Dr. | 285 | 400 gpd | Hard | ............ | Dep. |
| 29 | NE¼NE¼ | Dug | 16 | 600 gpd | Hard | Ch. | Dep. |
| 29 | NW¼NW¼ | Dr. | 96 | 500 gpd | Hard | Ch. | Good |
| 29 | SE¼SW¼ | Dr. | 87 | 500 gph | Hard | Ls. | Dep. |
| 29 | NE¼NE¼ | Dr. | 145 | 200 gpd | Hard | ............ | Dep. |
| 32 | SE¼NE¼ | Dug | 25 | 300 gpd | Hard | Ls. | Dep. |
| 32 | SE¼NE¼ | Dr. | 125 | 600 gpd | Hard | Ls. | Dep. |
| 32 | NW¼SE¼ | Dug | 24 | ................ | Hard | Ls. | Dep. |
| | | | T. 29 N., R. 21 E. | | | | |
| 13 | NW¼NW¼ | Dug | 14 | 400 gpd | Soft | Gr. | Poor |
| 14 | NE¼SE¼ | Dr. | 300 | 400 gph | Soft | Ls. | Dep. |
| 15 | SE¼NE¼ | Dr. | 475 | 1,600 gpd | $H_2S$ | ............ | Dep. |
| 22 | SE¼SE¼ | Dr. | 28 | 1,000 gpd | Soft | Gr. | Dep. |
| 23 | NE¼NE¼ | Dug | 14 | 400 gpd | Hard | Gr. | Good |
| 24 | NW¼NW¼ | Dr. | 275 | 1,000 gpd | Soft | Ls. | Dep. |
| 25 | SW¼NE¼ | Dr. | 12 | 125 gpd | Soft | Gr. | Dep. |

TABLE 14.—(Continued)

RECORDS OF WELLS AND SPRINGS IN OTTAWA COUNTY, OKLAHOMA.
(From State Mineral Survey, 1937)

| Section | Location in section | Type | Depth (feet) | Capacity | Quality of water | Water-bearing material | Performance during drought |
|---|---|---|---|---|---|---|---|
| | | | T. 29 N., R. 21 E. (Continued) | | | | |
| 26 | NE¼NW¼ | Dug | 15 | 125 gph | Soft | Gr. | Dep. |
| 27 | NE¼NE¼ | Dug | 18 | 600 gpd | Hard | ............ | Poor |
| | | | T. 29 N., R. 22 E. | | | | |
| 14 | NE¼SE¼ | Dug | 25 | 800 gpd | Hard | Sh. | Dep. |
| 16 | NW¼SW¼ | Dr. | 300 | 20 gpm | Soft | ............ | Dep. |
| 16 | SW¼SW¼ | Dr. | 395 | 2,000 gpd | Soft | Ch. | Dep. |
| 16 | NE¼SE¼ | Dr. | 340 | 2,000 gpd | $H_2S$ | Ch. | Dep. |
| 17 | SE¼SW¼ | Dr. | 350 | 2,500 gpd | $H_2S$ | ............ | Dep. |
| 18 | SW¼SW¼ | Dug | 30 | 175 gph | Hard | Gr. | Dep. |
| 19 | NW¼NW¼ | Dug | 32 | 200 gph | Hard | Gr. | Dep. |
| 20 | SW¼SW¼ | Dug | 30 | 125 gph | Hard | Ls. | Good |
| 27 | NW¼SW¼ | Dr. | 180 | 600 gph | Soft | Ls. | Dep. |
| 29 | SE¼SE¼ | Dr. | 166 | 1,000 gpd | Hard | Ls. | Dep. |
| 30 | SE¼SW¼ | Dr. | 300 | 300 gph | Soft | Ls. | Dep. |
| 31 | NW¼NE¼ | Dr. | 500 | 600 gph | Soft | Ls. | Dep. |
| 32 | SE¼SE¼ | Dr. | 395 | 2,000 gpd | Soft | Ch. | Poor |
| 33 | NE¼NW¼ | Dr. | 90 | 600 gpd | Black S. | Ls. | Dep. |
| 34 | SW¼SE¼ | Dr. | 180 | 400 gph | Soft | Ls. | Poor |
| | | | T. 29 N., R. 24 E. | | | | |
| 14 | SW¼SE¼ | Dr. | 60 | 100 gpm | Soft | Ls. | Dep. |
| 14 | NE¼SE¼ | Spr. | ........ | 50 gpm | Soft | Ch. | Dep. |
| 18 | SE¼NE¼ | Dr. | 250 | 1,000 gpd | Soft | ............ | Dep. |
| 18 | SE¼NE¼ | Dr. | 150 | 600 gpd | Hard | Ls. | Dep. |
| 18 | SE¼SE¼ | Dr. | 105 | 700 gpd | Hard | ............ | Dep. |
| 19 | NE¼NW¼ | Dr. | 30 | 400 gpd | Soft | Ls. | Dep. |
| 19 | NE¼NE¼ | Dug | 20 | 200 gpd | Hard | Ls. | Poor |
| 20 | SE¼SE¼ | Dr. | 300 | 2,500 gpd | Hard | Ls. | Dep. |
| 22 | NE¼NW¼ | Spr. | ........ | 100 gpm | Soft | ............ | Poor |
| 22 | SW¼NE¼ | Dr. | 60 | 200 gpm | Soft | Ls. | Dep. |
| 22 | NE¼NW¼ | Dr. | 132 | ................ | Soft | Ls. | Dep. |
| 22 | SW¼NE¼ | Dr. | 60 | 100 gpm | Soft | Ls. | Dep. |
| 23 | NE¼SW¼ | Spr. | ........ | 20 gph | Soft | Ch. | Good |
| 25 | SW¼NW¼ | Spr. | ........ | 250 gpm | Soft | Ls. | Dep. |
| 28 | SE¼SW¼ | Dr. | 60 | 200 gpm | Soft | Ls. | Dep. |
| 31 | NE¼NW¼ | Dug | 28 | 400 gpd | Soft | Ch. | Poor |
| 32 | SW¼SW¼ | Dr. | 165 | 1,000 gpd | Hard | Ls. | Good |
| 34 | NW¼SE¼ | Dr. | 200 | 150 gph | Soft | Ls. | Dep. |
| | | | T. 29 N., R. 25 E. | | | | |
| 13 | SE¼SE¼ | Spr. | ........ | 2,000 gpd | Soft | Alluv. | Dep. |
| 17 | SW¼SW¼ | Dr. | 87 | 200 gpm | Soft | Ls. | Dep. |
| 18 | SE¼SW¼ | Spr. | ........ | 30 gpm | Soft | Alluv. | Dep. |
| 18 | SE¼SE¼ | Dug | 24 | 200 gph | Soft | Ls. | Dep. |
| 26 | NE¼SE¼ | Dug | 30 | 150 gph | Soft | Ls. | Dep. |
| 26 | SE¼SE¼ | Spr. | ........ | 2,000 gpm | Soft | Alluv. | Dep. |

## REFERENCES CITED

Abernathy, G. E., 1941. Ground-water resources of Mississippian and older rocks in Bourbon, Crawford, Cherokee, and Labette Counties, southeastern Kansas: Kansas Geol. Survey, Bull. 38, pt. 8, p. 221-236.

————————, 1943. Deep water well at the Jayhawk Ordnance Works in Cherokee County, Kansas: Kansas Geol. Survey, Bull. 47, pt. 3, p. 77-112.

Bastin, E. S., 1939. Contributions to a knowledge of the lead and zinc deposits of the Mississippi Valley region: Geol. Soc. America, Special Paper 24.

Böse, E., 1918. Geological conditions near Bridgeport and Chico, Wise County, Texas: Texas Univ., Bull. 1758, p. 18.

Branson, C. C., 1954. Marker beds in the Lower Desmoinesian of northeastern Oklahoma. Oklahoma Acad. Sci., Proc., vol. 33, p. 190-193.

Cady, R. C., 1938. Ground water for domestic use in northeastern Oklahoma: U. S. Geol. Survey typewritten rept., in files of Ground Water Branch.

Chance, H. M., 1890. Geology of the Choctaw coal field. Amer. Inst. Min. Met. Eng., Trans., vol. 18, p. 653-661.

Cooper, C. L., 1928. The correlation of coals in Oklahoma and Kansas: Oklahoma Acad. Sci., Proc. vol. 7, p. 160-164. (Oklahoma Univ., Bull., new ser., no. 409).

Dale, Phyllis, and Beach, J. O., 1951. Mineral production of Oklahoma, 1885-1949: Oklahoma Geol. Survey, Circ. 29, 38 p., 4 figs.

Dean, H. T., 1936. Chronic endemic dental fluorosis: Amer. Med. Assoc., Jour., vol. 107, p. 1269-1272.

————————, Arnold, F. A., Jr., and Elvove, Elias, 1942. Domestic water and dental caries: Public Health Repts., vol. 57, p. 1155-1179.

Drake, N. F., 1893. Report on the Colorado coal field of Texas: Texas Geol. Survey, Ann. Rept. 4, pt. 1, p. 355-446.

Fenneman, N. M., 1938. Physiography of eastern United States: McGraw-Hill Book Co., N. Y.

Fowler, G. M., and Lyden, J. P., 1932. The ore deposits of the Tri-State District (Missouri-Kansas-Oklahoma): Amer. Inst. Min. Met. Engs., Trans., vol. 102, p. 206-239.

Gittinger, Roy, 1917. The formation of the State of Oklahoma (1803-1906): Univ. California, Pub. in History, vol. 6, Univ. California Press, Berkeley, map 1.

Ham, W. E., and Dott, R. H., 1943. New evidence concerning age of Spavinaw granite, Oklahoma. Amer. Assoc. Petroleum Geologists, Bull., vol. 27, no. 12, p. 1626-1631, 5 figs.

Hass, W. H., 1951. Age of Arkansas novaculite: Amer. Assoc. Petroleum Geologists, Bull., vol. 35, no. 12, p. 2526-2541.

Hays, C. W., 1891. The overthrust faults of the southern Appalachians: Geol. Soc. America, Bull., vol. 2, p. 141-154.

Hopkins, T. C., 1893. Marbles and other limestones: Arkansas Geol. Survey, Ann. Rept. for 1890, vol. 4, p. 253-349.

Ireland, H. A., 1930. Oil and gas in Oklahoma—Mayes, Ottawa and Delaware Counties: Oklahoma Geol. Survey, Bull. 40-NN.

————————, 1930a. Oil and gas in Oklahoma—Mayes, Ottawa and Delaware Counties: Oklahoma Geol. Survey, Bull. 40, vol. 3, p. 471-503.

————————, 1944. Correlation and subdivision of subsurface Lower Ordovician and Upper Cambrian rocks in northeastern Oklahoma: U. S. Geol. Survey, Oil and Gas Inv., Prelim. Chart 5.

————————, and Warren, J. H., 1946. Maps of northeastern Oklahoma and parts of adjacent states showing the thickness and subsurface distribution of Lower Ordovician and Upper Cambrian rocks below the Simpson group: U. S. Geol. Survey, Oil and Gas Inv., Prelim. Map 52.

Jacobsen, C. L., 1944. Ground water in the Mississippian rocks in the vicinity of Miami, Oklahoma: U. S. Geol. Survey typewritten rept., in files of Ground Water Branch.

Laine, L. L., Schoff, S. L., and Dover, T. B., 1951. Public water supplies in Oklahoma: Oklahoma Planning and Resources Board, 112 p.

McCutchin, J. A., 1930. Determination of geothermal gradients in oil fields located in anticlinal structures in Oklahoma: Amer. Petroleum Inst., Production Bull. 205, pt. 3, p. 19-61.

Meinzer, O. E., 1923. The occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey, Water Supply Paper 489.

———————— (editor), and others, 1942. Physics of the Earth, vol. 9, Hydrology: McGraw-Hill Book Co., Inc., N. Y. (Reprint, Dover Publications, Inc., N. Y., 1949.)

————————, and Wenzel, L. K., 1942. See Meinzer and others, 1942.

Miser, H. D., 1926. Geologic map of Oklahoma: U. S. Geol. Survey.

Moore, R. C., 1928. Early Mississippian formations in Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 21.

——————, and others, 1939. See Bastin, 1939.

Netzeband, F. F., 1953. Gold, silver, copper, lead, and zinc mining in Missouri, Oklahoma, Kansas, Arkansas, and Texas in 1952—final annual figures: U. S. Bur. of Mines, Region 7, Annual Area Rept. F-7 (advance summary—mimeographed), table 2.

Newell, N. D., 1937. See Wilson and Newell, 1937.

Oakes, M. C., 1953. Krebs and Cabaniss groups, of Pennsylvanian age, in Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 37, p. 1523-1526.

Purdue, A. H., and Miser, H. D., 1916. Description of the Eureka Springs and Harrison quadrangles, Arkansas-Missouri: U. S. Geol. Survey, Geol. Atlas 202.

Reed, E. W., and Jacobsen, C. L., 1944. Results of pumping tests at Goodrich plant site, Miami, Oklahoma: U. S. Geol. Survey typewritten rept., in files of Ground Water Branch.

Siebenthal, C. E., 1908. Mineral resources of northeastern Oklahoma: U. S. Geol. Survey, Bull. 340-C.

——————, 1915. Origin of the zinc and lead deposits of the Joplin Region, Missouri, Kansas, and Oklahoma: U. S. Geol. Survey, Bull. 606.

Simonds, F. W., 1891. The geology of Washington County, Arkansas: Arkansas Geol. Survey, Ann. Rept. for 1888, vol. 4, p. 1-148.

Smith, W. S. T., 1903. Lead and zinc deposits of the Joplin district, Missouri-Kansas: U. S. Geol. Survey, Bull. 213, p. 197-204.

——————, and Siebenthal, C. E., 1907. Description of the Joplin district: U. S. Geol. Survey, Geol. Atlas 148.

Snider, L. C., 1912. Preliminary report on the lead and zinc of Oklahoma: Oklahoma Geol. Survey, Bull. 9.

——————, 1914. The Mississippian rocks of northeastern Oklahoma: Jour. Geology, vol. 22, no. 6, p. 613-624.

——————, 1915. Geology of a portion of northeastern Oklahoma: Oklahoma Geol. Survey, Bull. 24, pt. 1.

Speer, J. H., 1951. Short Creek oolite horizon in Ottawa County, Oklahoma: Oklahoma Acad. Sci., Proc., vol. 31, p. 82.

——————, 1951a. A study of the Short Creek oolite, Ottawa County, Oklahoma: Univ. Oklahoma, M. S. thesis (typewritten), 50 p.

Theis, C. V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Amer. Geophys. Union, Trans., p. 519-524.

——————, 1939. Chart for the computation of drawdown in wells in vicinity of a discharging well: U. S. Geol. Survey duplicated rept.

Thornethwaite, C. W., 1941. Atlas of climatic types in the United States, 1900-39: U. S. Dept. Agr., Misc. Pub. 421, pl. 3.

Tolman, Carl, and Landes, K. K., 1939. See Bastin, 1939.

Van Orstrand, C. E., 1935. Normal geothermal gradient in United States: Amer. Assoc. Petroleum Geologists, Bull., vol. 19, no. 1, p. 78-115.

Waring, F. H., 1949. Significance of nitrates in water supplies: Amer. Water Works Assoc., Jour., vol. 41, no. 2.

Weather Bureau, 1930. Climatic summary of the United States, section 43, Eastern Oklahoma.

——————, 1931-53. Climatological data, Oklahoma section (annual summaries).

Weidman, Samuel, 1932. Miami-Picher zinc-lead district: Univ. Oklahoma Press, Norman, Oklahoma.

——————, 1939. See Bastin, 1939.

Weller, Stuart, 1901. Correlation of the Kinderhook formations of southwestern Missouri: Jour. Geology, vol. 9, p. 130-148.

Wenzel, L. K., 1942. Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods: U. S. Geol. Survey, Water-Supply Paper 887.

Williams, C. C., 1944. Ground-water conditions in the Neosho River valley in the vicinity of Parsons, Kansas: Kansas Geol. Survey, Bull. 52, pt. 2, p. 29-80, figs. 1-9, pl. 1-3.

Williams, C. F., 1932. See Weidman, 1932.

Wilson, C. W., Jr., and Newell, N. D., 1937. Geology of the Muskogee-Porum district, Muskogee and McIntosh Counties, Oklahoma: Oklahoma Geol. Survey, Bull. 57, 184 p., 7 pl., 5 figs., 10 tables.

Wood, F. C., 1939. Rock wool possibilities in Oklahoma: Oklahoma Geol. Survey, Bull. 60, 125 p., 19 figs.

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