OKLAHOMA GEOLOGICAL SURVEY

Carl C. Branson, *Director*

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Geology and Water Resources of Okmulgee County, Oklahoma

Part I.—Geology of Okmulgee County

by

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With a chapter on paleontology by

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Part II.—Water Resources of Okmulgee County

by

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GEOLOGY AND WATER RESOURCES OF OKMULGEE COUNTY, OKLAHOMA

ABSTRACT

Part I. Geology

Okmulgee County is an area of about 700 square miles in eastern Oklahoma. The county seat is Okmulgee, about 35 miles south of Tulsa, the county seat of Tulsa County. It is an area of low relief; the maximum is about 400 feet. Good roads make nearly every square mile accessible by automobile. The climate is mild; the average mean annual temperature is 57 degrees fahrenheit, and the average annual precipitation is 37 inches.

The county has produced a large quantity of oil and gas, and oil and gas production is still a major occupation of the people. Coal mining is limited only by demand. Farming and ranching are major occupations, but there is also considerable manufacturing.

Most of the consolidated rocks that crop out in Okmulgee County are sandstones and shales of Pennsylvanian age. Shale predominates in amount; it is mostly silty to sandy and dark gray to black, but weathers to various shades of brown and yellow. The sandstone is conspicuous because it caps escarpments, occupies dip slopes, and its debris covers much of the area of shale outcrops; it is mostly fine grained to silty and yellow brown to reddish brown. Many sandstone units extend into the county from the south and interfinger with similar sandstone units that extend into the county from the north. When these rocks were deposited the north part of the area of Okmulgee County was on the south side of a stable area now called the shelf, and the south part was on the north limb of a subsiding area now called the Arkoma basin. Basin sediments were of predominantly southern origin, whereas shelf sediments came, in part at least, from the north.

The consolidated rocks that crop out in Okmulgee County contain only one important unconformity, that between the Des Moines Series, below and the Missouri Group, above, at the base of the Seminole Formation. The dip of the rocks is north about 60 degrees west. Generally the rate of dip ranges from 30 to 100 feet per mile. The Schulter anticline extends from the surficial deposits south of Deep Fork at Schulter southward into Okfuskee County. It is asymmetrical; the west limb is gently dipping but the east limb is steeper and is faulted, at least locally. A few other faults of small throw are present.

The Quaternary System is represented by unconsolidated rocks, the terrace deposits associated with the major streams and the Recent alluvium.

No systematic paleontological collections have been made in the county. However, diverse flora and fauna have been reported by numerous authors. The Senora has yielded numerous brachiopods.

In addition, it has yielded 14 species of spores from the Croweburg coal and a number of plant compressions from the shales and ironstone concretions above the Croweburg. The Wewoka Formation has been reported to have yielded corals, gastropods, pelecypods, brachiopods, crinoids, foraminifers, shagreen granules, and 22 species of cephalopods. The type and only known locality of *Limipecten wewokanus* Newell is in the Wewoka Formation. Limestone and shale considered equivalent to the Lenapah Limestone yielded the type and only known specimens of *Septimyalina orbiculata* Newell. The Holdenville has yielded a crinoid fauna comprising 20 genera and 25 species of inadunate crinoids as well as brachiopods, corals, and mollusks. It has also yielded a fossil tree stump identified as *Cordaites michiganensis*. The scyphomedusan *Conostichus* occurs in the Senora, Seminole, and Holdenville Formations.

Other than oil and gas, coal has been the most important mineral resource. Mining conditions are good and remaining reserves are large. Output is entirely dependent upon demand, but in recent years demand has been almost nil. No quarry site in good limestone is known. One small quarry in impure limestone is operated occasionally for crushed limestone. Sandstone suitable for building is available in most communities. Good common bricks and paving bricks have been made at several places in the county, and shale suitable for such wares is probably available at many places.

Part II. Water Resources

Surface-water supplies are used to a greater extent than are ground-water supplies in Okmulgee County because of the low yield of ground water, the shallow depth to highly mineralized water, and the presence of impotable salt water at shallow depths in some areas. All the larger towns of Okmulgee County obtain their water from surface reservoirs; the major industries obtain their water from the municipal supplies of Okmulgee and Henryetta. An increasing number of people are using surface water rather than ground water for domestic and stock use.

Okmulgee County has two types of ground water, one occurring in the alluvium (alluvial water) and the other occurring in the bedrock (bedrock water). The alluvial water occurs in Recent alluvium of the valleys and in older terrace deposits on the valley margins. Although they are erratic in the amount and quality of water and although they cannot supply large amounts of water to wells, the alluvial aquifers yield more water than do the bedrock aquifers. Wells drilled in the alluvial aquifers will normally furnish all the water needed for domestic purposes and often enough for stock purposes.

The bedrock aquifers are sandstones with siltstones and shales as confining beds. Water in the sandstones is perched with respect to the lower zone of saturation. The quantity and quality of water in the sandstone beds are related to the size and sorting of the sand grains, the massiveness of the strata, and the topographic elevation of the beds. In places relatively large amounts of water occur in faults in the bedrock. Pockets of highly mineralized water, present in areas of otherwise potable water, are the result of contamination by oil-well brine and of contamination by natural causes. A common cause for natural contamination is solution of constituents from the poorly permeable bedrock by slowly moving ground water. Although individual values differ considerably, water from oil-well contamination shows high values of percent sodium and SAR and low values of the sodium-chloride ratio, whereas water from natural contamination shows low values of percent sodium and SAR and high values of the sodium-chloride ratio.

The shallow, potable ground-water resources can be classified into naturally occurring areal subdivisions, or provinces. The Alluvial ground-water province offers the best conditions for ground-water use. Of the bedrock provinces, the Calvin province, the Northern Upland province, and the Dissected Holdenville province offer the best possibilities for ground-water development. The Dissected Wewoka province and the Coffeyville province offer moderate possibilities for ground-water development; the Senora province, the Northern Lowland province, and the Southern Lowland province offer poor possibilities for ground-water development.

PART I.—GEOLOGY OF OKMULGEE COUNTY

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Assisted by Donald G. Leitner, Glen Charles Luff,
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David G. Campbell

INTRODUCTION

Purpose. The primary purpose of this investigation was to study the character, distribution, thickness, and paleontology of the rocks exposed in Okmulgee County, in order to apply to them the classification commonly used for stratigraphically equivalent rocks in this part of Oklahoma. Other purposes were to describe deposits of mineral materials of economic value and to make more precise correlations of the exposed rocks with rocks encountered in the subsurface in areas farther west.

Location. Okmulgee County is in the eastern part of Oklahoma. Okmulgee, the county seat, is centrally located in the county and is about 35 miles south of Tulsa, Tulsa County, Oklahoma. It is about 700 square miles in area.

Accessibility. Okmulgee is at the junction of the most traveled of the paved roads. State Highway 56 extends to the west line, passing around the north end of Lake Okmulgee. From Okmulgee, U. S. Highway 62 extends eastward through Morris to the east line and, with U. S. Highway 75, extends southward to Henryetta and

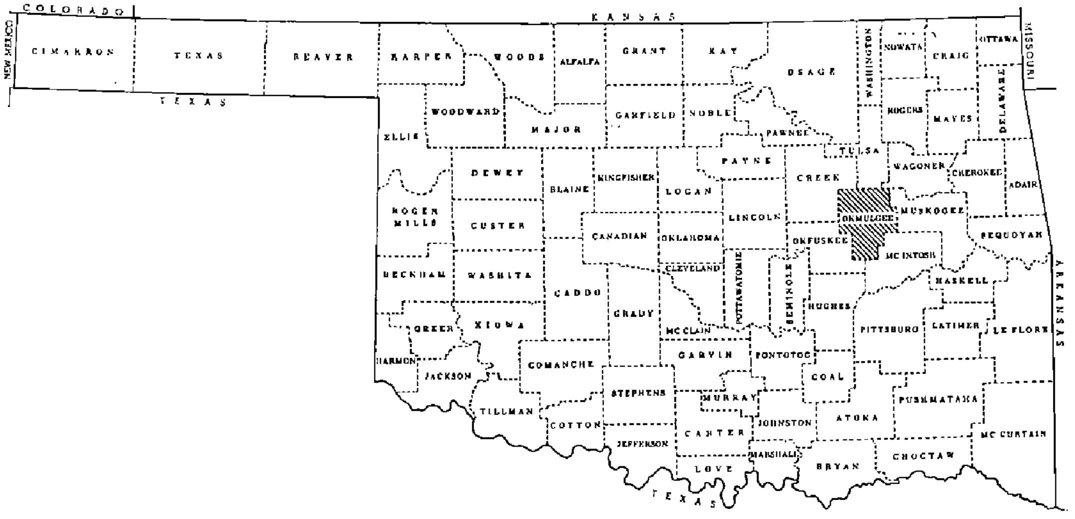

Figure 1. Index map of Oklahoma showing location of Okmulgee County.

thence westward to the west line. From Okmulgee, U. S. Highway 75 also extends northward through Preston and Beggs to the north line. State Highway 138 is a shorter route north from Preston to Tulsa. State Highway 16 crosses the northern part of the county through Beggs. From Henryetta, U. S. Highway 266 extends northeastward to the east line. State Highway 52 extends northward from Wildcat to Morris and connects U. S. Highways 266 and 62. Federal-aid secondary roads and improved roads along section lines, many paved or graveled, give ready access to all parts of the county, except to a few local areas of rough lands used mostly for grazing.

The Saint Louis and San Francisco Railway serves Okmulgee County with a main line through Henryetta, Schulter, Okmulgee, Preston, and Beggs, with a branch line east from Okmulgee through Cosden, Morris, and Eram. The Kansas, Oklahoma, and Gulf Railroad crosses the southeastern part of the county through Henryetta, Dewar, and Hoffman, with a short branch, which once served now defunct coal mines in the vicinity of Coalton, extending from the main line at Dewar north across Deep Fork to a junction with the Okmulgee Northern Railway, a short industrial line.

Previous investigations. The earliest investigation of coal beds in what is now Oklahoma was by H. M. Chance (1890) for the Choctaw Coal and Railway Company. Chance traced certain coal beds from the Arkansas-Oklahoma line to McAlester on the Missouri, Kansas, and Texas Railroad, but he did not encounter any of the coal beds that crop out in Okmulgee County.

Okmulgee County is part of the region examined by Drake (1897) in the course of his reconnaissance of the coal fields of the Indian Territory.

Taff (1901) named, defined, and described several formations in the Coalgate quadrangle; some of them have subsequently been traced into Okmulgee County. Also, Taff (1905) described the Henryetta coal bed and correlated it with the coal bed mined at Broken Arrow, in Tulsa County.

Siebenthal (1908) published a paper on the mineral resources of northeastern Oklahoma, including Okmulgee County.

Fath and Emery (1917) wrote part of the section on oil and gas in Okmulgee County which appeared in Oklahoma Geological Survey Bulletin 19, part 2.

Shannon and others (1917) discussed the oil and gas fields in

Okmulgee County; in the same year Fath and Emery (1917) made a structural reconnaissance in the vicinity of Beggs.

Frank C. Greene (1920) wrote on the possible correlations of the "Wilcox sand."

Aurin and others (1921) wrote on the subsurface pre-Pennsylvanian stratigraphy of the northern Midcontinent oil fields, including some fields in Okmulgee County.

Clark and Bauer (1921) contributed some notes on the geology of the Okmulgee district; Clark (1927) wrote on folding in Oklahoma and specifically included Okmulgee County; Clark (1926, 1930) wrote a report on oil and gas in Okmulgee County, which appeared in Bulletin 40 of the Oklahoma Geological Survey.

Bloesch (1926) correlated the Fort Scott Limestone with the upper part of the Wetumka Shale.

Shannon and others (1926) included the Henryetta mining district of Okmulgee County in a report on the coal resources of Oklahoma.

Davis and others (1944) investigated the carbonizing properties of coal from the Henryetta bed.

Lontos (1952) mapped an area of nine square miles in the northeastern part of the county; his map was used in compiling the geologic map that accompanies this report (pl. I).

Dunham and Trumbull (1955) made a geologic map of the Henryetta coal-mining district, described the coal beds, and estimated the coal reserves.

David M. Logan (1956), for many years a geologist and oil producer in the Okmulgee district, read a paper before the Tulsa Geological Society which embodies much of his accumulated knowledge; the reference is to an abstract in the society's *Digest.* Virtually the same material was published in full a year later by the Okmulgee Geological and Engineering Society (Logan, 1957).

Trumbull (1957) estimated the coal reserves of Oklahoma by county, by bed, and by rank.

From 1900 to 1920, many geologists made investigations in Okmulgee County for the purpose of finding oil and natural gas; but few results of that work were made available to the public, except in incidental references to it in discussions of problems common to that and other areas. Other more or less incidental references to field observations in Okmulgee County have appeared in various articles published by petroleum geologists, principally in the *Bulletin of the American Association of Petroleum Geologists,* the *Tulsa Geological Society Digest,* the *Oil and Gas Journal,* and the guide books of the various geological societies and of the Oklahoma Geological Survey.

During the field seasons from 1947 to 1950, inclusive, the author did reconnaissance mapping, some of it in Okmulgee County, incidental to the compilation of the *Geologic map of Oklahoma* (Miser, 1954).

Present investigation. The present investigation is part of a cooperative project of the Oklahoma Geological Survey and the School of Geology of The University of Oklahoma for surface mapping in Oklahoma. Florida State University also cooperated in mapping Okmulgee County.

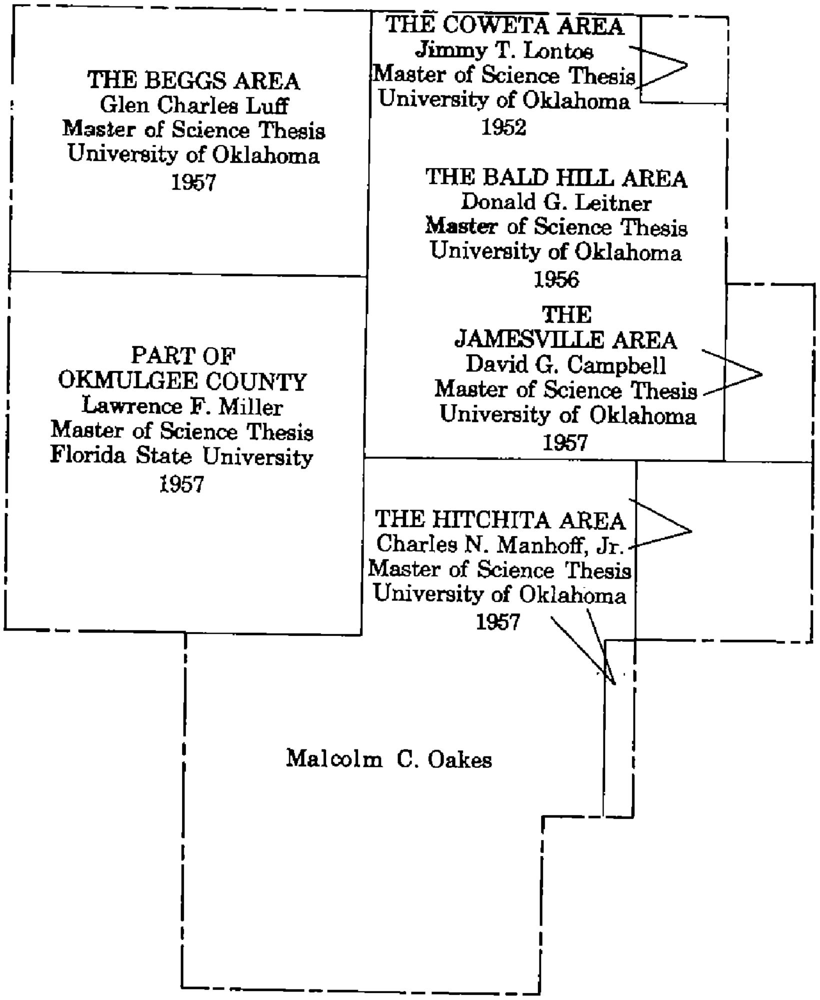

Figure 2. Showing parts of Okmulgee County mapped by graduate students and the author. Field work by Leitner, Luff, Manhoff, Miller, and Campbell was supervised by Oakes. Field work by Lontos was supervised by Carl C. Branson.

Donald G. Leitner, Charles N. Manhoff, Jr., Glen C. Luff, and David G. Campbell, of The University of Oklahoma, and Lawrence F. Miller, of Florida State University, mapped the areas shown in figure 2 under the supervision of the author in partial fulfilment of the requirements for the degree of Master of Science. J. T. Lontos likewise mapped nine square miles in the northeastern part of the county under the supervision of Carl C. Branson. The author mapped the remainder of the county, as shown in figure 2.

Field work was done by Lontos in the summer of 1952; by Miller, February to May 1956; by Leitner, March to May 1956; by Manhoff, March to July 1956; by Luff, May to August 1956; by Campbell, during the summer and fall of 1956; and by the author as opportunity afforded, the major part in 1958, but some as late as April 1960.

The Oklahoma Geological Survey uses aerial photographs in most of its geologic mapping. The photographs used for most of the work in Okmulgee County constitute a full stereoscopic coverage of prints from negatives made in 1949 for the Agricultural Adjustment Administraton of the United States Department of Agriculture. Their scale is about 1:20,000 or about 3 inches per mile. The photographs have little tip or tilt, and the relief in Okmulgee County is so small that tilt and tip distortions can be neglected. The result is a more accurate map than is attainable by any method of mapping that involves sketching from a limited number of accurately determined points, such as plane-table mapping, even with a telescopic alidade.

All indications of mappable geologic features that appeared on the stereoscopic image were marked on the photographs in the office and investigated later in the field; the same photographs served as a sterescopic base for the field work. All verifiable geologic data and other data, such as drainage and roads, were transferred to township plats of approximately the same scale as the photographs, principally by tracing, and the plats were used in compiling the maps which accompanied the theses. The geologic map (pl. I of this report) was compiled from the author's township plats of his own area and, with minor modifications, from the maps that appear in the several theses. The symbols used on plate I are not the same as those on the thesis maps, nor is the grouping of outcrops into map units the same in all instances.

The area mapped by the author includes the Henryetta mining district, previously mapped by Dunham and Trumbull (1955) whose report was most helpful. The mapping of most of the outcrops remains much the same, but the author has classified certain beds in the upper part of the Senora Formation, south of Deep Fork, as tongues of the Calvin Sandstone and believes that it is more in keeping with the evidence to draw an inferred fault along part of the east limb of the Schulter anticline. Also, certain ill-defined sandstone deposits associated with the Croweburg (Henryetta) and Morris coal beds, north of Deep Fork, have been treated in a different manner.

Stratigraphic sections were measured by hand level where there were nearly continuous exposures and most measurements were made on nearly vertical exposures. The thickness of any unit, the boundaries of which were a considerable distance apart areally, was computed from the difference in elevation of its boundaries, the distance between the points where the elevations were determined, and the component of dip along the line connecting these points. Differences in elevation were determined either by telescopic alidade or by barometry, using a single Paulin altimeter. Distances could be determined with sufficient accuracy from aerial photographs. Crude barometer readings were corrected for atmospheric pressure changes and for instrumental drift by prompt return to a previously occupied station; the distribution of elapsed time was considered. Dip was usually determined by suitable barometry in the vicinity; local dips that can be measured by a clinometer are generally unreliable in this region.

The dip of the strata in Okmulgee County is commonly low enough that the vertical distance between upper and lower limits of a stratigraphic unit can be regarded as its true thickness with an error normally less than that of determinations based on local dip and thickness measurements. This justifiable assumption leads to a great convenience, as the vertical distance can be computed quite as accurately in any other direction as in the direction of true or maximum dip, and one is thus free to work along established roads, so that the barometry can be done rapidly and serious errors caused by rapid or even by sudden, unsuspected changes in barometric pressure can be minimized.

Each of the sections of plate II was compiled from computed thicknesses and measured sections, for the most part, from a strip no more than three miles wide from south to north.

Acknowledgments. The author is grateful to Carl C. Branson, director of the Oklahoma Geological Survey and of the School of Geology of The University of Oklahoma, for the opportunity to participate in the field work leading to this report, and for his constructive criticism of the manuscript. Thanks are due William E. Ham, associate director of the Survey, for supervising the drafting and printing of the map and for help with the text.

Robert Smith, county agricultural agent of Okmulgee County, has been courteous and cooperative in supplying the data on agriculture and climate. The citizens of Okmulgee County have been cooperative throughout the field investigations, especially in supplying information and permitting ready access to their lands.

Roy Davis, our draftsman, and his two assistants, Mrs. Marion Clark and Miss Eileen Krall, have been helpful with constructive suggestions during the drafting of the map and the compiled outcrop sections and in the preparation of the illustrative diagrams.

The author takes this opportunity to express his appreciation to his assistants, Donald G. Leitner, Glen C. Luff, Charles N. Manhoff, Jr., Lawrence F. Miller, and David G. Campbell, for their excellent work and for their cheerful companionship in the field.

GEOGRAPHY

Topographic features. Parts of Okmulgee County appear on each of the following 30-minute topographic sheets of the United States Geological Survey: Okmulgee, Nuyaka, Wewoka, and Canadian. The northeast quarter of the Nuyaka quadrangle has also been mapped on the 15-minute Kiefer sheet. Together these sheets cover the county. The contour interval of the sheets is 50 feet, excepting that of Kiefer, which is 25 feet. The total relief is somewhat more than 400 feet, between the North Canadian River immediately north of the southeast corner of T. 11 N., R. 13 E., elevation below 600 feet, and the top of the hill near the middle of T. 16 N., R. 11 E., elevation a trifle more than 1,000 feet.

The North Canadian River cuts the southeast corner of the county. A tributary, Deep Fork, is the only major stream which flows across the county. It enters near the southeast corner of T. 14 N., R. 11 E., elevation about 650 feet, and flows in a general southeasterly direction to the northeast corner of sec. 33, T. 12 N., R. 14 E., elevation about 590 feet, a drop of 60 feet. The Arkansas River flows in a southeasterly direction about 3 miles north of the northeast corner of the county.

Local relief (differences in elevation within about one mile) varies greatly over the county; the maxima by townships generally ranges from 100 to 250 feet. Much of the county is rolling, and the land was probably mostly prairie in its natural state.

The present topography is the result of erosion in rocks of unequal resistance. Rocks at the surface are mostly shale, but at intervals of several tens of feet are more resistant rocks, generally sandstones 5 to 25 feet thick. All strata were deposited essentially horizontally; subsequently were uplifted and tilted so that they now dip a little north of west, commonly at rates of 30 to 100 feet per mile but most commonly at about 60 feet per mile. Erosion has resulted in the ridge-and-plain type of topography common on rocks of this character and structure; the drainage is dendritic, branching as does a tree.

The hills are generally capped by resistant sandstone that has protected the underlying shale from erosion. The height of a hill is dependent upon the thickness of the underlying shale and upon the depth of erosion. Some of the hills in Okmulgee County are round or oval, and shale is at or near the surface on all sides, below a sandstone cap. Most hills are elongate, with an alignment somewhat east of north, at right angles to the dip of the rocks. In profile the hills are asymmetrical, the more gentle slopes being in the direction of the dip of the rocks, but a little less steep. Commonly, the more gentle slopes, at least in their upper parts, are on sandstone that

TABLE I. AVERAGE MONTHLY PRECIPITATION, OKMULGEE COUNTY

Month	*Inches*
January	2.41
February	2.60
March	2.94
April	4.14
May	4.66
June	4.44
July	2.92
August	2.93
September	3.53
October	3.64
November	2.22
December	1.92

caps the ridges and litters the steeper slopes with debris ranging in size from large blocks to sand and silt.

Drainage. Okmulgee County is drained by tributaries of the Arkansas River. Bad Creek crosses the southwest corner of the county and flows into the North Canadian River, which, in turn, crosses the southeast corner. Deep Fork crosses the southwestern part of Okmulgee County and finally joins the North Canadian River in central McIntosh County, about eight miles northwest of the confluence of the North Canadian River and the Canadian River; the Canadian River flows thence northeastward into the Arkansas River. Tributaries of Deep Fork from the south are Salt, Honey, Montezuma, Coal, and Wolf Creeks; from the north they are Little Deep Fork, Flat Rock, Adams, Negro, Okmulgee, Osseetta, and Grove Creeks. Cane, Ash, and Concharty Creeks drain the east-central and northern parts of the county into the Arkansas River in Muskogee County. Snake Creek and its tributary from the west, Duck Creek, drain the northern part of Okmulgee County into the Arkansas River in Tulsa County.

Climate. The climate of Okmulgee County is mild; the average mean temperature is 57 degrees fahrenheit. Precipitation records supplied to Miller by Robert Smith, Okmulgee County agricultural agent, show that the average annual precipitation is 36.97 inches. Records compiled over a period of 35 years yield the averages shown in table I.

It may be noted that the months of heaviest precipitation are April, May, and June. The maximum temperature over the 35-year

TABLE II. MEAN MONTHLY TEMPERATURE, OKMULGEE COUNTY 1943-1945

Month	*Degrees F*
January	39.3
February	43.2
March	52.3
April	61.4
May	68.5
June	77.7
July	81.8
August	81.6
September	74.5
October	62.6
November	51.0
December	41.7

period was 114 degrees fahrenheit; the lowest, 20 degrees below zero. Only once in a lifetime does the temperature fall so low. The average growing season for the county is 116 days, from March 27, the average date of the last killing frost, to October 30, the average date of the earliest killing frost.

Economic development. Okmulgee County was originally a part of the Creek Indian Nation. It is supposedly named for the Okmulgee River in Georgia, the old homeland of the Creek Indians. The total area is 738 square miles, nearly three-fourths of which has been occupied by farms at one time or another. In the first decade of the present century the vogue was for small farms; cotton, corn, and the small grains were the principal crops. The productivity of the soil decreased under this regimen and so did the prosperity of the small farmer. The recent trend in Okmulgee County, as in most other places, has been away from many small farms toward fewer large farms. This trend has been accompanied by increasing mechanization and a decline in farm population.

Oil was discovered in paying quantities in Okmulgee County in 1907. The intense exploration that followed discovery reached a climax in the early twenties. Recently developed, more effective methods of petroleum recovery have stimulated renewed activity in many of the old fields of the county, and the increased interest has led to some new discoveries.

Coal mining has been important, especially in the Henryetta district, but, as in most of the country, competition from oil and natural gas has all but terminated it. The demand for coking coal during World Wars I and II and for export coal immediately following each war twice revived coal mining in Okmulgee County and in other coal-mining districts, but each revival was short; now the Ben Hur mine alone is worked and its output is greatly reduced. Zinc smelting was established at Henryetta during the flush production of natural gas and has continued, although intermittently in recent years, to the present. Plentiful natural gas also led to the manufacture of glass. There are three sheet-glass plants in the county: American Window Glass Company and Southwestern Sheet Glass Company, at Okmulgee, and Pittsburgh Plate Glass Company, at Henryetta.

Okmulgee has a plentiful supply of good water from Lake Okmulgee, an artificial lake that stores 13,200 acre-feet; smaller lakes supply Henryetta, Beggs, and Morris.

Soils. The soils of Okmulgee County are mainly residual from weathering of bedrock formations. The exceptions are soils developed on the Recent alluvium and the associated terrace deposits. Sandstone areas, mostly hilltops and upper parts of the dip slopes of ridges, are covered by sandy soil which traps and retains precipitation rather well. However, such soils are generally too infertile and commonly the topography on them is too rough to be fit for cultivation; they support a variety of forest cover, in which blackjack, post oak, and hickory are dominant. The shale areas, on the contrary, are rolling to nearly level and are consequently more suited to farming. Even these soils are none too productive, and long-continued clean cultivation has partially depleted them. They do not absorb water quickly from the short, heavy rains, a condition which leads to lack of moisture during the long, hot summer dry spells. Under clean cultivation, high winds blow away much of the fine soil and the rapid runoff results in gullies and sheet erosion. However, these soils will support a fairly rich grass cover which, in turn, decreases runoff, increases absorption and retention of rainwater, and effectually prevents wind damage. Much of the land has been put to grasses, mostly to native grasses; farms have given way to ranches where fine beef cattle are raised.

The recent alluvium and adjacent terrace deposits are dotted with small farms and pecan groves; uncultivated portions grow black willow, black walnut, and cottonwood trees.

SURFACE STRATIGRAPHY

Historical setting. It will be much easier to understand the stratigraphy, character, and interrelations of the rocks that crop out in Okmulgee County if we first review, even if briefly, the history of deposition and structural changes in a region that includes eastern Oklahoma, southeastern Kansas, southern Missouri, and northwestern Arkansas.

This region consists of two areas; the northern and western area, usually called the shelf, or platform, area, and the southeastern area, usually called the Ouachita geosynclinal area. The shelf area is commonly subdivided into two areas, based on the present attitude of the rocks. One subdivision includes the Ozark uplift, or Ozark dome, in northeastern Oklahoma, southern Missouri, and northern Arkansas; the other subdivision includes the Central Oklahoma arch, which rims the Ouachita geosynclinal area on the north and northwest and extends northward beyond the borders of Oklahoma and westward to the Anadarko basin, west of the longitude of Oklahoma City.

Sedimentary rocks present on the shelf and in the geosynclinal area range in age from Cambrian to Pennsylvanian, inclusive. Limestones are conspicuous among the rocks on the shelf; the clastics are shales, siltstones, and fine-grained sandstones. The many unconformities indicate repeated withdrawal of the sea, erosion, and repeated submergence. Many of the rocks particularly of the Pennsylvanian, are cyclic.

In contrast, the rocks of the geosynclinal area are mostly clastic; nearly all units thicken remarkably southeastward. The evidence indicates that the source of clastic sediments in the geosynclinal area and of much of the clastic sediments on the shelf was an ancient land mass somewhere to the southeast, now buried beneath Cretaceous and younger rocks. However, some of the clastics on the shelf seem to have come from the east, others from the north, and some even from the west. Many of the sandstones in the geosynclinal area thin out and disappear northward before they reach the shelf area, but some clastic units extend from the geosynclinal area northward over the shelf area with great thinning, convergence of beds, and gradual change of facies; they thus indicate that the shelf area was changing but little with respect to the level of the sea at the time when the geosynclinal area was sinking and being filled continuously or intermittently. It is probable that the geosyncline was so well filled with clastic sediments much of the time that water was shallower over the geosynclinal area than over the shelf area. Furthermore, coal beds of Pennsylvanian age that extend over part of the shelf area and are still preserved from erosion in the north end of the geosynclinal area indicate that at times swamps extended over parts of both areas.

At the present time, Mississippian rocks crop out around the Ozark dome except where they are covered by Quaternary sediments, and outliers of Mississippian rocks are so distributed over much of the Ozark dome as to indicate that much of the area of the dome was below sea level in at least part of Mississippian time. Also, outliers of probable Desmoinesian (Pennsylvanian) age are distributed over a considerable part of the Ozark dome, many being preserved in limestone sinkholes into which they have fallen; they indicate that probably as late as Desmoinesian time, and possibly later, the area of the Ozark dome was truly a part of the shelf area.

Rocks of the greater part of the Ouachita geosynclinal area have been much folded, and in Oklahoma they have been much faulted. These folded and faulted rocks now form the Ouachita Mountains, the northern limit of which in Oklahoma is the Choctaw fault. The forces that formed the Ouachita Mountains were compressive, from the south and southeast, and most of the large faults are reverse faults, upthrown on the south side. The rocks in that part of the geosynclinal area north of the Choctaw fault have been squeezed between the Ouachita Mountains rocks and rocks of the more stable shelf area, and now lie in an east-west syncline, formerly called the McAlester coal basin or the Arkansas-Oklahoma coal basin, but now called the Arkoma basin (Branson, 1956, p. 83-86).

It has been generally observed in drilling for oil and gas in Oklahoma that most of the structures persist to great depths. In general, they are most intensely folded and faulted in the oldest rocks penetrated by drilling, as if they were initiated at an early time and have been repeatedly rejuvenated. They may even extend into the basement rocks. By analogy, we may surmise, or perhaps even assume, that the present structure of the Ouachita Mountains had its beginnings as more or less gentle folds and perhaps even small faults long before the youngest of the rocks in the mountains were deposited.

Rocks younger than the Atoka Formation have been eroded from the Ouachita Mountains area, but some of their equivalents have been preserved in the Arkoma basin and in the shelf area. Hendricks (1939, p. 271) found that the thickest part of the McAlester Formation is in the deepest part of the Arkoma basin, and that it is thinner southward toward the Choctaw fault. On the other hand, the McAlester, in common with other units, thins northward out of the basin; many of the sandstones pinch out in that direction, others converge, and at least two merge. It appears that McAlester sediments came from the south, spilling northward into the Arkoma basin across an arch in the botton of the sea at about the position of the Choctaw fault, and that the squeeze which formed the Arkoma basin was already operating, making it at once a structural basin and a depositional basin; still it remained part of the Ouachita geosynclinal area.

The youngest rocks cut by the Choctaw fault are of Atokan age, but earlier uplift of considerable magnitude is indicated by chert pebbles near the base of the Atoka Formation on the southeast side of the Lehigh syncline in Atoka County, west of Stringtown (Taff, 1902, p. 5). It is not possible to date the end of major folding and faulting in the Ouachita Mountains more exactly than post-Atoka pre-Cretaceous. However, from a study of the structure of the rocks north of the mountains, in the Arkoma basin and on the shelf, the author suspects that much of the movement in the Ouachita Mountains and most of that on the Ozark dome were over before the Thurman Sandstone was deposited.

Rocks in the Arkoma basin and on the shelf west of the Ozark dome as young as the Boggy Formation are only less complexly folded and faulted than are rocks in the Ouachita Mountains. The character, distribution, and orientation of these folds and faults indicate that some are related to the compressive forces that made the Ouachita Mountains, and others to the more vertical forces that raised the eastern part of the shelf area to make the present Ozark dome. Some of these structures are discernible in the Thurman Sandstone and younger rocks but in these younger rocks the amplitude is smaller. One exception is the Ahloso fault in Pontotoc County, south of Ada. It cuts the Thurman Sandstone and has a throw of more than 2,000 feet, upthrown on the south side. It is probably associated with movement in the Arbuckle Mountains.

Chert pebbles in the Thurman Sandstone and younger formations seem to have come from the southeast and their presence indicates recurrent uplift in the Ouachita Mountains, but lack of evidence of pronounced movement in the Thurman and younger rocks indicates that these later stresses in the Ouachita Mountains were not transmitted northward across the Choctaw fault with any considerable strength. However, such things as pressure ridges in the soil, straight lines of leaning trees, offset sewers, and occasional weak tremors indicate that some faults in the Ouachita Mountains and in the Arkoma basin are still slightly active.

General character. The consolidated rocks that crop out in Okmulgee County are mostly shale, but sandstones are most conspicuous because they form the broad dip slopes and serve as cap rocks of the long northeastward-trending escarpments and the outlying hills. The Hogshooter Limestone is represented locally in the northwestern part of the county by extremely sandy limestone beds, at no place more than 15 feet thick. The Checkerboard Limestone, about 2.5 feet thick, crops out across the northwestern part. Limestone stringers a few inches thick represent the Fort Scott Limestone from place to place in the northeastern part. A few sandy limestone beds, normally less than one foot thick, are sparsely distributed in other parts of the county.

Origins. Aside from surficial deposits made by present and ancient streams and a few of possible eolian origin, rocks that crop out in Okmulgee County are younger than the Boggy Formation and show little effect from the forces that formed the Ouachita Mountains, the Arkoma basin, and the Ozark dome. They are dominantly clastic and the sediments that formed most of them came from the south or southeast. That they came from that direction is not so evident in Okmulgee County as it is farther south, in McIntosh County, northern Hughes County, and northern Seminole County, where some of the units are thicker, sandstones are more numerous and coarser grained, and conglomerates are present. However, the southward increase in thickness is not nearly so great as in the Boggy and pre-Boggy rocks. Each unit has its own area of maximum thickness and coarseness and is thinner and finer grained from there both northward and southward. It is inferred that the clastic sediments were brought into the sea by streams flowing from the southeast, probably from the area of the present Ouachita Mountains, and that they were worked over and spread both northward and southward by waves and currents, with considerable sorting.

Not all sandstones that crop out in Okmulgee County are of such apparent origin. The outcrops of some do not extend to the borders of the county and seem to grade into shale underground, down dip to the west. The sand grains that compose them are commonly as fine as the sand grains in most of the shales, and they may have come from the east where coarser and thicker parts have been removed by erosion. However, such sandstones may be accounted for by postulating special conditions of turbulence in which the agitation was just sufficient to keep most of the shale particles in suspension while the sand grains settled.

Other sandstones extend into the county from the shelf area to the north, split into tongues southward, and finally grade into shale, as if the sand composing them came from a northern source. Some of these are comparable in stratigraphic position to some of the sandstones of southern origin; others are not.

Nomenclature and correlation. The names Nellie Bly, Hogshooter, Coffeyville, and Checkerboard belong to the nomenclature of northern Oklahoma and southern Kansas; the corresponding formations have been traced by the author from the Kansas-Oklahoma line into Okmulgee County. Although each exhibits almost continuous facies change, from north to south, all have continuous natural boundaries. The names Seminole, Holdenville, Wetumka, Calvin, and Senora belong to the nomenclature established in the area north of the Arbuckle and Ouachita Mountains. Within the last few years the boundaries of the corresponding formations have been traced by the author and by graduate students under his supervision from their type localities to southern Okmulgee County, with difficulties no greater than the disappearance of sandstone tongues northward with the attendant necessity of shifting the boundary arbitrarily a negligible distance up or down to a mappable base or top of the sandstone formation. More serious difficulties were encountered in Okmulgee County because it was the meeting ground of sediments from the south and sediments from the north. Sandstones interfinger and coalesce in such a pattern that it is difficult to extend the boundaries of some named formations from the south northward across the county; it was found even more difficult to extend certain northern terms and boundaries southward into Okmulgee County. The final choice was to use the southern nomenclature for most of the rocks that crop out in Okmulgee County. As a result, some of the formation boundaries shown on the geologic map (pl. I) are choices made in the interest of simplicity and clarity, doing as little violence as possible, and following the rule that rocks mapped under a given name must include rocks that are, so far as is knowable, representatives of that formation as originally defined, but may also include other rocks, older or younger. Where no natural boundary could be mapped in the field, an artificial boundary is indicated by a zigzag line.

PENNSYLVANIAN SYSTEM

The Pennsylvanian rocks of northern Oklahoma are included in three main divisions. They are the Des Moines Series, the Missouri Series, and the Virgil Series, in ascending order. South of the latitude of central Mayes County are Pennsylvanian rocks older than Desmoinesian. Rocks that crop out in Okmulgee County are included in the Des Moines and Missouri Series of Middle and Upper Pennsylvanian age.

DES MOINES SERIES

In Iowa, Missouri, and Kansas the base of the Des Moines Series is placed, generally, at the unconformity between Pennsylvanian and pre-Pennsylvanian (Mississippian and older) rocks. This is satisfactory for northeastern Oklahoma, but south of central Mayes County are still older Pennsylvanian rocks. They are thousands of feet thick in the Arkoma basin, in contrast to the mere hundreds of feet of Desmoinesian rocks along the Kansas-Oklahoma line. Some writers have placed these older, much thicker Pennsylvanian rocks in the Des Moines Series, in accordance with the practice of placing the lower boundary of the Des Moines at the pre-Pennsylvanian unconformity; to others, such a drastic expansion of the Des Moines Series has seemed out of place, out of proportion, and incongruous with usual practice. However, attempts to reach other generally acceptable solutions foundered in perplexity.

By the time preparation of the *Geologic map of Oklahoma* (Miser, 1954) was nearing completion, it seemed fairly certain that future usage would arrange these older Pennsylvanian rocks in several series, and that the youngest would include the rocks of the Atoka Formation. Accordingly Oakes (1953) placed the base of the Des Moines Series in Oklahoma at the top of the Atoka Formation, or at the top of pre-Pennsylvanian rocks wherever the Atoka is absent, from the north flank of the Arbuckle Mountains northeastward to the Kansas-Oklahoma line, and eastward in the Arkoma basin. The top of the series is at the obscure but extensive and important pre-Missourian unconformity, at the base of the Seminole Formation.

In Kansas and northern Oklahoma, as far south as the Arkansas River, the Marmaton Group of the Des Moines Series extends from the base of the Fort Scott Limestone, below, to the top of the series. Farther south in Oklahoma, the upper limit is the same, but the Fort Scott Limestone is not identifiable much farther south than the Arkansas River. In the course of field work incident to preparation of the *Geologic map of Oklahoma* (Miser, 1954), Oakes (1953) found that the base of the Fort Scott Limestone occupies substantially the same stratigraphic position as does the base of the Calvin Sandstone and that there is an unconformity at the top of the Boggy Formation; accordingly he placed the base of the Marmaton Group at the base of the Calvin Sandstone south of the Arkansas River and subdivided Desmoinesian rocks older than Marmaton into two groups, the Krebs, below the unconformity, and the Cabaniss, above.

Cabaniss Group

The Cabaniss Group was named from Cabaniss in T. 6 N., R. 12 E., northwestern Pittsburg County, and includes, in ascending order, the Thurman Sandstone, the Stuart Shale, and the Senora Formation. It is conformable with the Marmaton Group, above, and unconformable with the Krebs Group, below. The base of the Marmaton Group is the base of the Fort Scott Limestone north of the Arkansas River and the stratigraphically equivalent base of the Calvin Sandstone south of the Arkansas. (See unit ℙsn-fs in the discussion of character under Senora Formation, also unit ℙcv-5 under Calvin Sandstone.) At many places along the unconformity between the Krebs and the Cabaniss, the shale below is succeeded by similar shale above, and the unconformable contact cannot be

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TABLE III. SUBDIVISIONS OF THE CABANISS GROUP IN OKLAHOMA

- Des Moines Series
    - Cabaniss Group
        - Senora Formation
        - Stuart Shale
        - Thurman Sandstone
    - *Unconformity*
    - Krebs Group

Of the Cabaniss Group, only about the upper three-fourths of the Senora Formation crops out in Okmulgee County.

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mapped exactly. The criteria for drawing the unconformity are: (1) the abrupt change in the character of the sediments in the Arkoma basin, where coarse chert pebbles mixed with coarse quartz sand in the base of the Thurman Sandstone abruptly succeed shale and fine-grained sandstone of the underlying Boggy Formation; (2) a distinct paleontological break, especially noticeable north of the Arkansas River; and (3) marked structural discordance.

Rocks of the Cabaniss Group crop out from the northeast flank of the Arkuckle Mountains northeastward to the Kansas-Oklahoma line. They are thickest and coarsest in the latitude of the type locality, T. 6 N., R. 12 E., where they range in character from chert conglomerate to clay shale. Both southwestward and northeastward they contain a greater proportion of finer grained material and are thinner, because of overlap of lower units by higher units and because of thinning within units. The gradation of sandstone units into shale makes it difficult to map the boundaries of the Cabaniss formations with exactness wherever wide stretches of surficial deposits must be crossed. The Thurman Sandstone is thought to be overlapped by the Stuart Shale beneath surficial deposits associated with the Canadian River. The Stuart Shale is thought to be overlapped in turn by the Senora Formation in T. 13 N., R. 13 E., southwestern Muskogee County. From that locality north to the Kansas-Oklahoma line, the Senora Formation rests unconformably upon the Boggy Formation of the Krebs Group.

Senora Formation

Nomenclator. J. A. Taff (1901).

Type locality. Taff did not mention a specific type locality, but the name is from the old postoffice of Senora, in southern Okmulgee County.

Original description.

> This formation is composed of interstratified sandstone and shaly beds having a thickness of nearly 500 feet in the northeastern corner of the quadrangle [Coalgate quadrangle, Oklahoma]. . . The outcrop of the formation in the northeastern part of the quadrangle averages about 10 miles in width. The lower 320 feet of the formation there is composed entirely of sandstone which forms a very rugged stony highland with sandstone bluffs, in places nearly 100 feet high, along the eastern side. This sandstone grades upward through thin

> sandy beds into shale strata which are approximately 160 feet in thickness. . .
>
> In texture the sandstones are generally fine grained and are gray or reddish brown in color. The shale, which occupies the more level land in the western and northern parts of the outcrop, are rarely well exposed and their original physical characteristics were not satisfactorily determined. Bluish clay shales and brownish sandy shales belonging in the upper part of the series, however, are exposed in the deeper cuttings of the streams which flow from the higher land of the succeeding Calvin sandstone (Taff, 1901, p. 4).

Histroy of usage. Taff's original use of the term "Senora Formation" has not been modified.

Distribution. The outcrop of the Senora Formation extends from the Ahloso fault in T. 3 N., R. 7 E., a few miles southeast of Ada, Pontotoc County, northeastward across Pontotoc, Hughes, Pittsburg, McIntosh, Okmulgee, Muskogee, Wagoner, Rogers, and Craig Counties to the Kansas-Oklahoma line. The maximum width of the outcrop, about 20 miles, is in northeastern Hughes County. The outcrop is about 12 miles wide in eastern Okmulgee County and extends another 3 miles into western Muskogee County.

Thickness. The total maximum thickness of the Senora Formation in the latitude of Okmulgee County is about 800 feet. Of this about 660 feet crops out in eastern Okmulgee County and the remainder, and older part, estimated to be about 140 feet thick, crops out farther east, in western Muskogee County. Lack of good exposures suitably distributed for measuring dips introduces considerable uncertainty into some of the computed thicknesses.

Character. The Senora Formation is divided naturally into two intergrading parts. The lower part, approximately that part older than the Croweburg (Henryetta) coal, consists of sandy to silty shale, fine-grained to silty sandstone, and a few limestone beds. The upper part consists of less silty shale, a minor amount of silty sandstone, and still less limestone.

The upper shaly part of the Senora Formation increases irregularly in thickness from about 100 feet in the southwestern part of Hughes County to about 250 feet in the northeastern part (Weaver, 1954, pl. III). Weaver stated (p. 74) that it is gray silty to sandy shale and contains numerous sandstone lenses. Ries (1954) mapped 90 feet of brown and greenish-brown shale in the upper part of the Senora Formation in T. 10 N., R. 12 E., southeastern Okfuskee County, but the base of the shale probably crops out farther east, in western McIntosh County. The upper shaly part of the Senora Formation in Okmulgee County is about 220 feet thick at the south line of the county and about 180 feet thick at the north line.

Weaver (p. 51, pl. III) found several places in northeastern Hughes County where sandstone tongues split off from the basal part of the overlying Calvin Sandstone, thin rapidly, intertongue with shale in the upper part of the Senora Formation, and finally grade into Senora Shale. Most of these tongues in Hughes County drop only slightly in the section as they split away from the massive Calvin Sandstone. However, several split off from the basal Calvin, drop rapidly in the section, approach the lower sandy part of the Senora, and finally lose their identity by grading into shale. Ries (1954) mapped no such tongues in Okfuskee County, but the writer found that along the south line of Okmulgee County such tongues do split off from the base of the Calvin Sandstone, descend in the section, and grade into shale. These tongues would not be noticed by one working only in McIntosh County. On the other hand Dunham and Trumbull (1955), who worked only in Okmul-

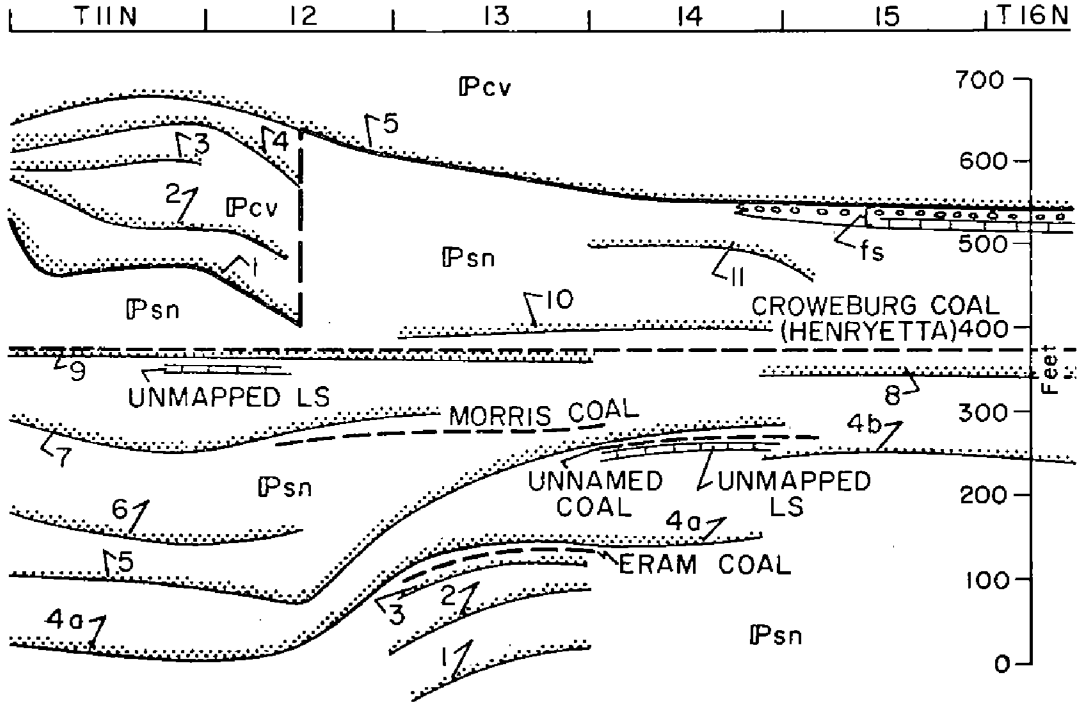

Figure 3. Diagram of the Senora Formation and part of the Calvin Sandstone in Okmulgee County, approximately to scale. The Senora Formation is divided into a lower markedly sandy part, and an upper markedly shaly part, approximately at the horizon of the Croweburg (Henryetta) coal. Symbols and unit numbers correspond to those used on plates I and II and in the text; not all units are shown. Owing to intertonguing of the Senora with the Calvin, the boundary between them is placed arbitrarily at the base of IPcv-1 south of Deep Fork and at the base of IPcv-5 north of Deep Fork.

gee County, did not recognize them as part of the Calvin Sandstone; as a consequence, they described the Senora of southern Okmulgee County as "a monotonous sequence of sandstone regularly alternated with thicker beds of shale and silty shale."

About 1925 to 1930 the tongues described by Weaver were the subject of considerable informal discussion among oil-company field parties working in the area. Some consideration was given to the notion that the base of the Calvin might mark an unconformity, the tongues being truncated sandstone beds in the upper part of the Senora Formation. However, structural studies seemed to favor the opinion that they are tongues of the Calvin Sandstone. Surface and subsurface studies by Weaver confirmed the latter opinion.

Most of the rock debris that was incorporated into the Senora Formation and the Calvin Sandstone in southern Okmulgee County and farther south probably came from the southeast and seems to have been spread northward and westward, partly by traction and partly in suspension.

We may account for the intertonguing of the Calvin Sandstone and the Senora Formation by assuming the following sequence of events. (1) In late Senora time, a mud delta was formed with a sloping front and a top which was, at any particular time, at the base level of deposition for mud, and in time the mud became shale. (2) Slight subsidence of the site of deposition with, perhaps, uplift of the source area loosed a flood of residual sand, which had been accumulating in the stream valleys and even on the uplands; this built the top of the delta up to the base level of deposition for sand, initiated the Calvin Sandstone, and spilled over onto the sloping front of the delta. (3) Another period of mud deposition; this time no mud would be deposited on the top of the delta because it was already at the base level of deposition, even for sand, but the sand on the sloping front of the delta would be covered by mud and, in time, would become a tongue of the Calvin Sandstone. (4) In the next period of sand deposition, the base-leveled part of the Calvin would be built thicker and probably would be extended over the base-leveled part of the mud deposit of step (3); if there were enough sand, it would spill over onto the sloping front of the delta as in step (2) and form another Calvin tongue. When so viewed, tonguing indicates a kind of cyclic sedimentation.

Such tonguing is present at the bases of many sandstones. Generally the tongues are not so noticeable or can be ignored in mapping, but some of the Calvin tongues cannot be so treated without doing intolerable violence to the facts. Weaver mapped the tongues in Hughes County as part of the Calvin Sandstone and the shale between them as tongues of the upper part of the Senora Formation, but such a procedure for Okmulgee County would result in an overcrowded map. Hence the awkward expedient was adopted of mapping both the sandstone tongues and the intervening shale as part of the Calvin. The Calvin Sandstone tongues cannot be separately identified farther north than the alluvium associated with Deep Fork. Therefore, the base of the lowest mappable Calvin Sandstone unit (IPcv-5) is taken as the base of the Calvin and the top of the Senora in northern Okmulgee County, thus restoring the upper shaly part of the Senora to near its thickness at the south line of the county.

Unit IPsn-1 crops out in the extreme eastern part of Okmulgee County and grades into shale just south of the middle of T. 13 N., R. 15 E. It extends northward out of Okmulgee County. The fact that it does grade into shale southward indicates that it probably belongs to the family of sandstones on the shelf whose materials came from the north or east. It is fine grained and silty, and its most common thickness is about 20 feet.

Unit IPsn-2 is silty, shaly, thin-bedded sandstone which extends into the area from the south. It is 40 to 20 feet thick across T. 13 N., is thinner farther north, and probably grades into shale in T. 14 N., R. 15 E.

Unit IPsn-3 is silty, shaly, fine-grained sandstone, 40 feet thick where it extends into the county from the south. It grades upward into sandy shale, thins northward, and may grade into shale in the southern part of T. 14 N., where its westward dip is greater than common; and it may be faulted.

Unit IPsn-4a is fine-grained, silty to shaly, generally thin-bedded sandstone which extends into Okmulgee County from Muskogee County across the north line of T. 14 N., R. 15 E., where it is about 85 feet thick. It is irregularly thinner southward to the south side of the county, the south side of T. 11 N., R. 13 E., where it is about 40 feet thick. It represents the lower part of the Chelsea Sandstone of Rogers County.

Unit IPsn-4b is fine-grained, silty to shaly, thin-bedded light-brown sandstone. It caps a low eastward-facing escarpment from the middle of the north line of sec. 1, T. 15 N., R. 14 E., where it is about 45 feet thick, to NE¼ sec. 3, T. 14 N., R. 14 E., where it grades into shale. It represents the upper part of the Chelsea Sandstone of Rogers County.

Unit IPsn-5 extends into Okmulgee County from the south and grades into shale in the northern part of T. 14 N. In Tps. 11, 12, 13 N., it is gray brown, massive to thin bedded, and fine grained to silty and shaly. It is probably less than 10 feet thick at the south side of the county but is thicker northward to as much as 70 feet in T. 12 N., where the upper 50 feet is markedly shaly. It is about 50 feet thick in T. 13 N. Dunham and Trumbull (1955) mapped it as grading into shale in sec. 5, T. 13 N., R. 14 E. True, the upper part is markedly shaly and the upper limit is difficult to pick, but approximately the lower 10 feet is resistant enough to show plainly in the topography and is continuous with a sandstone mapped by Leitner in his Bald Hill area; his description reads: "A northward-thinning sandstone, IPsn-5, extends from the southeast corner of sec. 32, T. 14 N., R. 14 E., to the SE¼ of sec. 4, T. 14 N., R. 14 E. This 10- to 15-feet-thick sandstone is thin bedded, gray brown and micaceous. Where it is more resistant, it caps a low eastward-facing escarpment, notably in secs. 10, 21, 29, and 33, T. 14 N., R. 14 E."

Unit IPsn-6 extends into the county from the south. It is gray to brown, generally fine grained, thin bedded, quite shaly, and nowhere more than 20 feet thick. Both upper and lower limits are hard to pick at many places. In T. 12 N., it is lenticular and discontinuous and seems, finally, to grade into shale.

Unit IPsn-7 extends into the county from the south, but its outcrop is covered for a mile and a half from the south line by the alluvium along Wolf Creek and by the water in Lake Henryetta. It is generally less than 10 feet thick, gray to brown, fine grained, and thin bedded. It finally grades into shale in T. 13 N.

Unit IPsn-8 extends into Okmulgee County from the north, near the northeast corner of sec. 24, T. 16 N., R. 14 E. It is either a tongue of the Chelsea Sandstone of Rogers County or is only slightly younger than the Chelsea. It caps a low eastward-facing escarpment. Leitner's description reads: "This unit is from 5 to 10 feet thick and consists of thin-bedded reddish-brown to gray-brown fine-grained sandstone, at places interbedded with gray-brown siltstone or silty shale. In the SW¼ sec. 14, T. 15 N., R. 14 E., a 3- to 5-foot-thick, dark-brown, loosely consolidated ironstained sandstone overlies a one-foot-thick, dark-gray, dense fossiliferous, silty, wavy-bedded limestone. This limestone thickens southward to a probable maximum of 15 feet in the SE¼ sec. 28, T. 15 N., R. 14 E., where it is dark gray, massive, dense, and contains few fossils. In this vicinity it has been quarried and crushed for use as road metal. Southeast of the quarry, the limestone is thinner, platy, fossiliferous, and contains solution cavities, geodes, and small veins of calcite. Farther south it grades rapidly into sandstone. The sandstone becomes silty and shaly and thins out in sec. 4, T. 14 N., R. 14 E."

Unit IPsn-9 extends into Okmulgee County from the south and is here considered to mark the top of the lower (sandstone) part of the Senora Formation. Like other Senora sandstones, it is gray to brown, fine grained, silty, and generally thin bedded. Its normal thickness is about 10 feet. It is present north of Deep Fork as silty, shaly sandstone and finally grades into shale.

Unit IPsn-10 is weakly resistant sandstone. It is gray to brown, extremely fine grained, silty, and shaly. It is about 25 feet thick in the southern part of T. 13 N., but thins northward to about 10 feet in the northern part of T. 14 N., where it finally grades into shale. Leitner described it in T. 14 N. as a "northward-tonguing, light-brown to gray-brown fine-grained sandstone. It is thin and silty at places and consequently does not hold up a continuous escarpment. The average thickness is about 10 feet." It may represent one or both of the Calvin sandstone tongues (IPcv-1, 2) but could not be firmly correlated with either. In T. 13 N., R. 13 E., Dunham and Trumbull (1955, p. 186) described the rocks included in the writer's Senora units 7, 9, and 10 and their intervening extremely sandy shales as "a mass of current-marked sandstone about 200 feet thick, through the middle of which passes a zone of highly carbonaceous shaly sandstone equivalent to the Henryetta coal." As a general description, this is pat and points up the difficulties encountered in mapping individual units across the area.

Unit IPsn-11 "is a sandstone lens which extends from the SE¼ of sec. 24, T. 14 N., R. 13 E., to the SW¼ of sec. 32, T. 15 N., R. 14 E. It is gray brown to light brown, silty at the base, coarser and more resistant at the top. Except at the northern and southern ends, it forms a noticeable east-facing scarp" (Leitner, 1956).

Unit IPsn-fs is composed of limestone, gray calcareous shale, and black fissile shale containing phosphatic nodules. It represents the Fort Scott Limestone and, possibly, the Breezy Hill Limestone.

In southern Kansas and northern Oklahoma, the Fort Scott Limestone consists of upper and lower limestone members and an intervening shale member, which is black and fissile at most places and generally contains phosphatic nodules. According to Wallace B. Howe and John H. Warren (oral statements, 1951) only the lower limestone member and the middle shale member are present in southern Tulsa County, where the Breezy Hill Limestone is only a few feet below the base of the Fort Scott and the shale between them is black and fissile, contains phosphatic nodules, and is indistinguishable, by appearance only, from the shale member of the Fort Scott (Oakes, 1952, p. 20-22). In that part of Tulsa County south of the Arkansas River, the Breezy Hill-Fort Scott representatives are probably less than 10 feet thick.

In the course of field work incident to the preparation of the *Geologic map of Oklahoma* (Miser, 1954) the writer traced representatives of the Breezy Hill-Fort Scott rocks into northeastern Okmulgee County. The limestones grade southward into gray calcareous shale and limestone stringers, not separable into Breezy Hill and Fort Scott. Limestone was not found south of the SE cor. sec. 17, T. 15 N., R. 14 E.; black fissile shale and phosphatic nodules were traced as far south as The Twins (Bald Hill) in sec. 29, T. 15 N., T. 14 E., which confirmed earlier work done by Dr. A. N. Murray and his students of the University of Tulsa. The shale and nodules were traced farther still, into sec. 1, T. 14 N., R. 13 E., where nodules were found in place only a few inches below the base of sandstone, here mapped as Calvin Sandstone unit IPcv-5. If we neglect or prune away the basal tongues of the Calvin, the base of IPcv-5 is continuous with the base of the Calvin Sandstone in the type locality.

In Tulsa County and northward, the base of the Fort Scott Limestone is the boundary between the Cabaniss Group, below, and the Marmaton Group, above. In northeastern Okmulgee County, the representatives of the Fort Scott are mapped as part of the Senora Formation and the base of the Calvin Sandstone is taken as the boundary between the Cabaniss and Marmaton Groups in Okmulgee County and southward.

Stratigraphic relations. So far as is known, the Senora Formation is conformable with the Stuart Shale below, in the area from the Canadian River southward to the Ahloso fault in Pontotoc County, where both are cut off. The base is not present in Okmulgee

County, but the Senora is thought to overlap the Stuart northward and to rest unconformably upon the Boggy Formation from southwestern Muskogee County northward into Kansas.

Correlation. The Senora Formation is represented in southeastern Kansas by the upper part of the Cherokee Shale of older usage, by the Cabaniss Formation of present usage.

Detailed sections. For measured outcrop sections of the Senora Formation see sections 5-7, 12, 57-60, 77-81.

Marmaton Group

In Kansas, "strata from the base of the Fort Scott limestone to the disconformity which marks the upper limit of the Desmoinesian series are designated the Marmaton group" (Moore, 1949, p. 47).

In Oklahoma, as far south as the north flank of the Arbuckle Mountains, the upper limit of the Marmaton Group is the unconformity at the base of the Seminole Formation. North of the Arkansas River, the base of the Marmaton is at the base of the Fort Scott Limestone, as in Kansas. From the Arkansas River to the north flank of the Arbuckle Mountains, the lower limit is placed at the base of the Calvin Sandstone. In the course of field work incident to the preparation of the *Geologic map of Oklahoma* (Miser, 1954), the author found that the base of the Calvin Sandstone is at virtually the same stratigraphic position as is the base of the Fort Scott Limestone. (See unit ℙsn-fs in the discussion of character under Senora Formation; see, likewise, unit ℙcv-5 under Calvin Sandstone, this report.)

Limestones are conspicuous among the shales and sandstones of the Marmaton Group in Kansas, and only less conspicuous in Oklahoma as far south as the Arkansas River. In contrast, lime-

TABLE IV. SUBDIVISIONS OF THE MARMATON GROUP IN OKLAHOMA

- *Unconformity*
- Des Moines Series
  - Marmaton Group
    - Holdenville Shale
    - Wewoka Formation
    - Wetumka Shale
    - Calvin Sandstone
  - Cabaniss Group

stones are sparse from the Arkansas River to the north flank of the Arbuckle Mountains and sandstones are conspicuous. The relatively thinner sandstone units crop out extensively on many westward-dipping slopes and cap high eastward-facing escarpments above steep, less extensive outcrops of the relatively thicker shale units. Also, most shale outcrops are covered by sandstone debris ranging in size from boulders to sand grains.

Most of the clastic debris incorporated into the rocks of the Marmaton Group south of the Arkansas River seems to have come from the southeast. Almost every mappable unit has a locality of maximum thickness away from which, southwestward and northeastward, it is thinner and splits into tongues. The sandstone units are coarsest and most massive where they are thickest.

Calvin Sandstone

Nomenclator. J. A. Taff (1901).

Type locality. The vicinity of Calvin, Hughes County, Oklahoma.

Original description.

> Above the Senora formation there is a deposit of massive and thin-bedded sandstone with some shaly beds in the upper part having a thickness of 140 to 240 feet. For nearly 140 feet upward from the base, the rock is massive but not very hard sandstone. In the northern part of its occurrence this lower and more massive member of the formation crops in the steep hillsides and bluffs overlooking the more level Senora formation toward the east. In the southern part of its outcrop the lower sandy member becomes shaly, and even the massive beds which occur are more friable than the same deposits in the northern part of the quadrangle. . . .
>
> The upper part of the Calvin sandstone is least shaly in the northern part of the area, and many of the beds are hard and weather into slabs and hard plates. The upper 90 to 100 feet of the formation here contains two, and in places more, shaly beds 10 to 20 feet in thickness. The sandstone beds of this upper portion decrease southward from 40 feet in thickness to thin layers interstratified with shales. (Taff, 1901, p. 4).

History of usage. Subsequent usage has followed Taff's original application of the term "Calvin sandstone."

Distribution. The outcrop of the Calvin Sandstone extends from the north branch of the Ahloso fault in T. 3 N., R. 7 E., a few miles southeast of Ada, Pontotoc County, northeastward across

Hughes, Okfuskee, and Okmulgee Counties, and across the southwestern part of Wagoner County to alluvium associated with the Arkansas River, at the north line of T. 16 N., R. 14 E. It is not recognized farther north. The maximum width of the outcrop is about eight miles, in eastern Hughes County, and again in southern Okmulgee County and eastern Okfuskee County.

Thickness. Weaver (1954, p. 51) stated that the Calvin Sandstone in Hughes County is consistently 320 to 350 feet thick in the area north of the Canadian River, but thinner to the southwest. Morgan (1924, p. 89) stated that the Calvin thins rapidly farther southwest, probably in part by gradation of the upper sandstone beds into shale, and that it is only 40 feet thick near the western end of its outcrop. Ries (1954, p. 29) stated that in oil wells west of the outcrop in Okfuskee County the Calvin Sandstone is rather uniformly about 245 feet thick. As mapped in Okmulgee County, the Calvin Sandstone reaches its maximum thickness, 440 feet, in T. 12 N., where the lowest deltaic tongue descends into shale that would otherwise be mapped as upper Senora Shale almost to the Croweburg (Henryetta) coal. Excluding the deltaic tongues, its maximum thickness is 225 feet, at the extreme south side of the county. Loss of recognizable sandstone units by gradation into shale reduces its thickness to a minimum of about 10 feet, in Tps. 14, 15 N.

Character. The Calvin Sandstone, as its name implies, contains a conspicuous amount of sandstone, but also contains much sandy to silty shale and, locally, a few discontinuous fossiliferous limestone beds. The Calvin Sandstone and the underlying Senora Formation are so laced together by intertonguing that a complete description of the one must, perforce, include a considerable amount of what must be said of the other. To avoid repetition, reference is here made to the section on character in the description of the Senora Formation.

The rock debris that was deposited to form the Calvin Sandstone probably came from the east or southeast and reached the sea in the latitude of Hughes County. From that area the debris seems to have been spread northeastward and southwestward. Weaver (1954) mapped the Calvin south of T. 8 N., Hughes County, as one sandstone unit which thins southwestward, and Morgan (1924) found that it continues to thin farther southwestward. In northern Hughes County, Weaver (1954) divided the Calvin into three map units, a lower sandstone unit, a middle shale unit, and an upper sandstone unit. Ries (1954) divided the Calvin into essentially the same three map units in Okfuskee County, and these units extend into Okmulgee County where the upper sandstone unit is mapped as ℙcv-6 and the upper part of the lower sandstone unit is mapped as ℙcv-5. The lower part of the lower unit of Weaver and of Ries splits off from ℙcv-5 and then further subdivides into four sandstone tongues along the south line of T. 11 N., R. 12 E., the south line of Okmulgee County; they are shown on plates I and II as ℙcv-1, 2, 3, 4.

The writer first noticed these tongues while engaged in field work incident to preparation of the *Geologic map of Oklahoma* (Miser, 1954). They would hardly be recognized as tongues of the Calvin by one whose work was confined to either Okfuskee County or Okmulgee County. Ries (1954) did not mention them in Okfuskee County, and Dunham and Trumbull (1955) mapped them as sandstone units of the Senora Formation in Okmulgee County. They are fine-grained silty thin-bedded to cross-bedded gray-brown to reddish-brown sandstone.

Unit ℙcv-1 has a maximum thickness of about 25 feet. Its base is continuous with the base of the Calvin Sandstone a short distance south of the south line of Okmulgee County. It descends markedly into shale that otherwise would be mapped with the Senora Formation to a position about 25 feet above the Croweburg

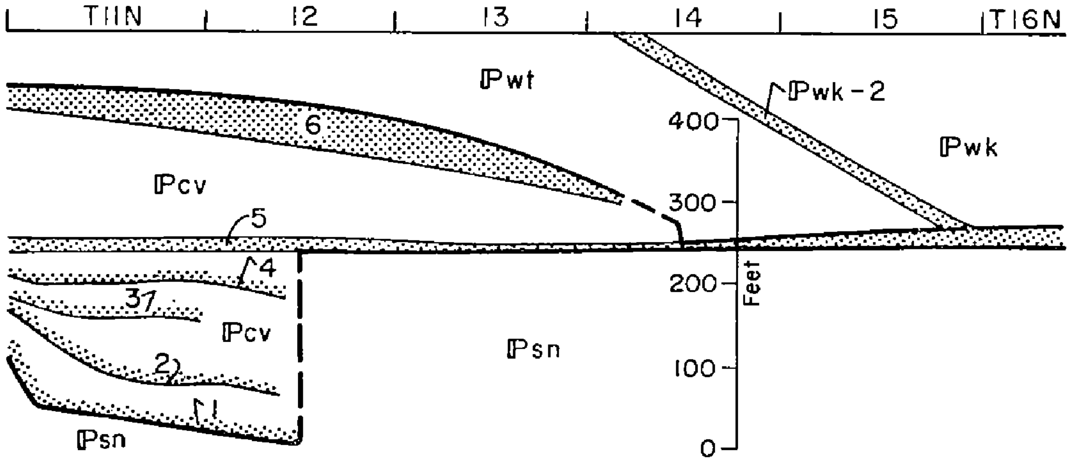

Figure 4. Diagram of the Calvin Sandstone, part of the underlying Senora Formation, and parts of the overlying Wetumka Shale and Wewoka Formation in Okmulgee County, approximately to scale. Symbols and unit numbers correspond to those used on plates I and II and in the text. Despite its name, the Calvin Sandstone in Okmulgee County is predominantly shale. It contains 6 sandstone units; nos. 1 to 4 are fingers, not identified north of Deep Fork; no. 6 pinches out in T. 14 N., no. 5 alone can be mapped to the north line of the county. Boundaries have been chosen accordingly. The Calvin is conformable with older and younger rocks.

(Henryetta) coal, in T. 12 N. It could not be separately identified north of Deep Fork; it may be equivalent to part of the sandstone mapped there as IPsn-10.

Unit IPcv-2 is irregular in thickness with a maximum of about 25 feet. Like IPcv-1, it descends markedly in the section and was not recognized north of Deep Fork where it may be equivalent to part of the sandstone mapped there as IPsn-10.

Plate II indicates that IPcv-1 and IPcv-2 descend northward irregularly in the section. The irregularity is probably apparent rather than real; the measurements were made on outlying hills, some farther east than others.

Unit IPcv-3 is less than 10 feet thick and seems to grade into shale in the northern part of T. 11 N.

Unit IPcv-4 has a maximum thickness of about 30 feet, near the south line of the county. Along the main part of its outcrop, mostly in R. 12 E., it alternates between vertically continuous sandstone and sandstone beds separated by shale. It descends only moderately in the section. In general, it thins northward and finally grades into shale in sec. 25, T. 12 N., R. 12 E. It is here correlated with the sandstone outliers on hilltops in Tps. 11, 12 N., R. 13 E., and with a sandstone outcrop in the north-central part of T. 12 N., R. 13 E. This outcrop extends considerably farther north than does the main outcrop, and this part of the unit probably grades into shale northwestward; it was not found north of Deep Fork.

Because none of the lower four tongues of the Calvin Sandstone could be mapped north of Deep Fork, the base of the formation is placed at the base of the unit IPcv-5 from Deep Fork to the north line of Okmulgee County.

Unit IPcv-5 is sandstone, fine to medium grained, thin bedded to massive, locally cross-bedded, gray brown to reddish brown, and 15 to 25 feet thick in the southern part of the county. In T. 13 N., north of Deep Fork, it is fine grained, thin bedded, silty to shaly, and grades upward into shale. It is finer grained and more silty farther north and almost grades into shale in the northern part of T. 14 N. Nevertheless, it is resistant enough, relative to the underlying shale, to cap an asymmetric eastward-facing ridge or escarpment.

A sandstone unit, here also designated IPcv-5, which probably represents lenticular sandstone in the lower part of the Labette Shale of northeastern Oklahoma and southeastern Kansas, extends into Okmulgee County from the north; materials that compose it probably came from the north or northeast. The sandstone is as much as 40 feet thick in southwestern Wagoner County, but is thinner and finer grained southward. It merges at the top with a northward-thinning sandstone unit of the Wewoka Formation in sec. 7, T. 15 N., R. 14 E., and thereby appears to bifurcate, probably a false impression. Farther south still, this probable Labette representative grades into extremely fine-grained silty sandstone which is, nevertheless, sufficiently resistant to cap an eastward-facing escarpment continuous with the escarpment capped by the Calvin Sandstone unit IPcv-5, which can thus be considered to extend across Okmulgee County; it is the only part of the Calvin that does.

The shale betweeen Calvin Sandstone units IPcv-5 and 6 is the thickest shale in the Calvin of Okmulgee County; it is 190 feet at the south line. It is progressively thinner northward to 40 feet in the southern part of T. 14 N. Predominantly sandy to silty shale, it contains a minor amount of weakly resistant extremely fine-grained silty sandstone, not mapped. It contains also sparsely distributed clay shale, calcareous shale, and a few thin fossiliferous limestone beds. A limestone exposure that has been visited by many geologists is in SE¼ SE¼ sec. 18, T. 13 N., R. 13 E., on the point of the hill, at the south line of the section, and just east of the railroad.

Unit IPcv-6 extends into Okmulgee County from the south; it is 30 feet thick in the southern part of the county. The lower part is generally massive, medium to fine grained, and gray brown to brown. The upper part is generally shaly and grades upward into shale. North of Deep Fork, the unit is only about 25 feet thick at most, is finer grained, and grades into shale in T. 14 N., R. 13 E. North from that locality the top of the sandstone unit IPcv-5 is mapped as the top of the Calvin Sandstone, and shale equivalent to part of the Calvin younger than IPcv-5 is mapped with the Wetumka Shale.

Stratigraphic relations. The Calvin Sandstone is underlain conformably by the Senora Formation; it is overlain conformably by the Wetumka Shale from the type locality to NE¼ sec. 7, T. 15 N., R. 14 E., where the Wetumka pinches out. Farther north in Okmulgee County, the Calvin is overlain conformably by the Wewoka Formation.

Correlation. North of the Arkansas River, the Calvin Sandstone is represented by sandstone in the lower part of the Labette Formation.

Detailed sections. For measured outcrop sections of the Calvin Sandstone see sections 1-12, 30, 57, 58, 77, 79.

Wetumka Shale

Nomenclator. J. A. Taff (1901).

Type locality. Taff gave no type locality, but the name is from the old village of Wetumka, which was about one mile east of the present town.

Original description.

> The shaly beds of the Calvin sandstone grade into the succeeding Wetumka shale, so that the division line between the formations can not be easily determined stratigraphically nor very accurately mapped.
>
> With the exception of thin shaly sandstone layers near the center, the Wetumka shale is composed of friable, laminated clay shales. It is estimated to be about 120 feet thick throughout its occurrence in the Coalgate quadrangle. From the head of Big Creek to the Canadian River Valley this shale crops in gently rolling prairie land and produces a soil more fertile than is usually found upon other formations of this region (Taff, 1901, p. 4).

History of usage. Subsequent usage has followed Taff's original application of the term "Wetumka shale."

Distribution. The outcrop of the Wetumka Shale extends from the Ahloso fault, T. 3 N., Rs. 6, 7 E., a few miles southeast of Ada, Pontotoc County, northeastward across Hughes and Okfuskee Counties to sec. 7, T. 15 N., R. 14 E., Okmulgee County.

Thickness. The Wetumka Shale is about 120 feet thick across Okfuskee and Hughes Counties (Ries, 1954; Weaver, 1954). It is thicker farther southwest where the upper part of the underlying Calvin Sandstone probably grades into shale (Morgan, 1924). It is about 100 feet thick at the south line of Okmulgee County, but only 60 feet thick where the oldest sandstone of the overlying Wewoka Formation grades into shale, in sec. 21, T. 12 N., R. 12 E. From there northward, the Wetumka, as mapped, probably contains shale not included in the Wetumka of the type locality. Its maximum thickness, 180 feet, is in the southern part of T. 14 N. It pinches out where sandstone unit IPwk-2 of the overlying Wewoka Formation merges with unit IPcv-5 of the underlying Calvin Sandstone, in sec. 7, T. 15 N., R. 14 E.

Character. The Wetumka Shale, as mapped in Okmulgee

County, generally crops out in escarpments capped by sandstone. It is covered, for the greater part, but seems to be, in general, greenish-gray to gray silty shale containing local lenses of weakly resistant, extremely fine-grained silty sandstone, not mapped. It grades into underlying and overlying sandstones. Miller stated that in the south part of the county the Wetumka contains, here and there, thin fossiliferous limestones. He found one such lens along the south bank of Deep Fork in sec. 26, T. 13 N., R. 12 E.

Stratigraphic relations. The Wetumka Shale is underlain conformably by the Calvin Sandstone and overlain conformably by the Wewoka Formation.

However, at most places in Okmulgee County the shale here mapped as Wetumka probably contains considerably more than the equivalent of the Wetumka Shale of the type locality. The youngest sandstone unit of the Calvin Sandstone (IPcv-6) has been mapped by tracing and correlation to the southern part of T. 14 N., R. 13 E., where it grades into shale. From that locality northward, the top of the Calvin Sandstone unit IPcv-5 is mapped as the top of the Calvin Sandstone and the base of the Wetumka Shale, and shale elsewhere mapped as part of the Calvin Sandstone is thereby mapped with the Wetumka Shale. Above the Wetumka Shale, the oldest sandstone unit of the Wewoka Formation (IPwk-1) extends into Okmulgee County only as far as sec. 21, T. 12 N., R. 12 E., where it

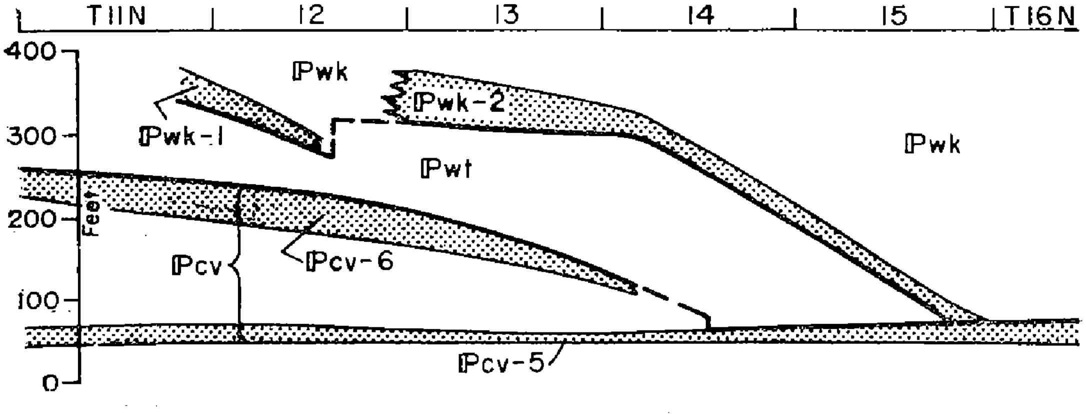

Figure 5. Diagram of the Wetumka Shale and parts of the Calvin Sandstone and the Wewoka Formation, as mapped, approximately to scale. Symbols and unit numbers correspond to those on plates I and II and in the text. The Wetumka is predominantly shale, much of it silty to sandy. Lower and upper boundaries of the Wetumka Shale in southern Okmulgee County are continuous with those of the type locality; in other parts of the county they are placed arbitrarily at the top of the youngest sandstone unit of the Calvin Sandstone and at the base of the oldest unit of the Wewoka Formation. The Wetumka terminates in sec. 7, T. 15 N., R. 14 E., where the unit IPwk-2 merges with unit IPcv-5; it is conformable with both the Calvin and the Wewoka.

grades into shale. From that locality the top of the Wetumka Shale is drawn arbitrarily northward across an area of shale outcrop to the base of sandstone unit IPwk-2 in sec. 10, T. 12 N., R. 12 E., which is mapped northward by tracing and correlation as the base of the Wewoka and the top of the Wetumka; shale elsewhere mapped as part of the Wewoka Formation is thereby mapped with the Wetumka Shale. The Wewoka Sandstone unit IPwk-2 merges with the Calvin Sandstone unit IPcv-5 in sec. 7, T. 15 N., R. 14 E.; this terminates the shale between them, here mapped as the Wetumka Shale.

Correlation. The Wetumka Shale, as well as the upper part of the Calvin Sandstone and the lower part of the Wewoka Formation, which are mapped with the Wetumka in a large part of Okmulgee County, is represented by shale and sandstone in the lower part of the Labette Formation of northeastern Oklahoma and southeastern Kansas.

Detailed sections. For measured outcrop sections of the Wetumka Shale see sections 1, 8, 11, 30, 54.

Wewoka Formation

Nomenclator. J. A. Taff (1901).

Type locality. Taff mentioned no specific type locality, but the name is from Wewoka in east-central Seminole County, a few miles west of the outcrop.

Original description.

> Above the Wetumka shale there is a succession of massive, and for the most part, friable sandstones and shales, seven in number in alternate beds 40 to 130 feet thick. These beds together are about 700 feet thick and are named the Wewoka formation, from the town of the same name in the Wewoka quadrangle to the north. The separate massive beds composing the formation are of sufficient thickness to be mapped, but on account of the obscurity of the contact lines, due to the friable nature of the beds, it is not possible to accurately distinguish them (Taff, 1901, p. 4).

History of usage. The term "Wewoka formation" appears to have been used consistently in the original sense of Taff.

Distribution. According to Morgan (1924) the lower part of the formation ends southward at the Ahloso fault, in T. 3 N., R. 6 E., southeast of Ada, Pontotoc County. The upper part extends southwestward across the fault, where the beds are sharply folded but not broken, to the vicinity of SE cor. sec. 19, T. 3 N., R. 6 E., where it is overlapped by the Holdenville Shale. Morgan thought that he recognized the upper part of the Wewoka in the Franks graben, on the north flank of the Arbuckle Mountains, in an outcrop which extends from north to south in the east-central part of T. 2 N., R. 6 E.

From the Ahloso fault, the outcrop of the Wewoka Formation extends northeastward across the southern tip of Seminole County, western Hughes County, southeastern Okfuskee County, Okmulgee County, southern Tulsa County, and the tip of southwestern Wagoner County to alluvium associated with the Arkansas River. The outcrop is commonly 6 to 9 miles wide, but it is 13 miles wide along the north line of Okmulgee County.

Thickness. Southward from Okmulgee County, the Wewoka Formation is about 750 feet thick in most of Okfuskee County (Ries, 1954), about 680 feet in Hughes County (Weaver, 1954), and thinner southwestward to a featheredge in Pontotoc County, where it is overlapped by the Holdenville Shale (Morgan, 1924).

The Wewoka Formation, as mapped in Okmulgee County, is about 650 feet thick in the southern part, 600 to 530 feet in T. 13 N., 600 feet in T. 15 N., but only 400 feet along the north side of the county. However, the Wewoka Formation of Okmulgee County does not correspond exactly to the Wewoka of the type locality. The upper limit is the same, but in most of the county, the lower limit is not. The oldest sandstone unit of the Wewoka, which marks the base elsewhere, extends into Okmulgee County only as far as sec. 21, T. 12 N., R. 12 E., where it grades into shale. From that locality northeastward to sec. 7, T. 15 N., R. 14 E., shale that is equivalent to part of the Wewoka elsewhere is mapped with the underlying Wetumka Shale.

Character. The rocks of the Wewoka Formation south of Okmulgee County are predominantly shale but include also a considerable amount of sandstone. Both shale and sandstone are locally calcareous and fossiliferous. Northward-tonguing is common. The shale ranges from sandy through silty to clay shale; much is calcareous. The sandstone outcrops fall naturally into mappable units, which range widely in thickness; many individual beds have no great lateral extent. They crop out in four generally recognizable escarpments, some of which contain more than one mappable sandstone unit. More or less local lenses ranging in character from calcareous sandstone to sandy limestone are common, especially in the upper part of the youngest sandstone unit (Taff, 1901; Morgan, 1924; Weaver, 1954; Ries, 1954).

Morgan mentioned limestone conglomerate in the Wewoka Formation near the Arbuckle Mountains and thought that the fragments composing them came from limestones now exposed in the mountains. Morgan also found that several sandstones of the Wewoka Formation in Pontotoc County contain chert conglomerate. Weaver found chert conglomerate locally in sandstones of the first, second, and third escarpments, in ascending order, in the southern part of Hughes County. Ries did not mention conglomerate in the Wewoka Formation of Okfuskee County.

It seems that most of the rock debris in the Wewoka Formation came from the south and southeast and was spread northward and southward, with a considerable degree of sorting by waves and currents. The fourfold arrangement of sandstone units can be

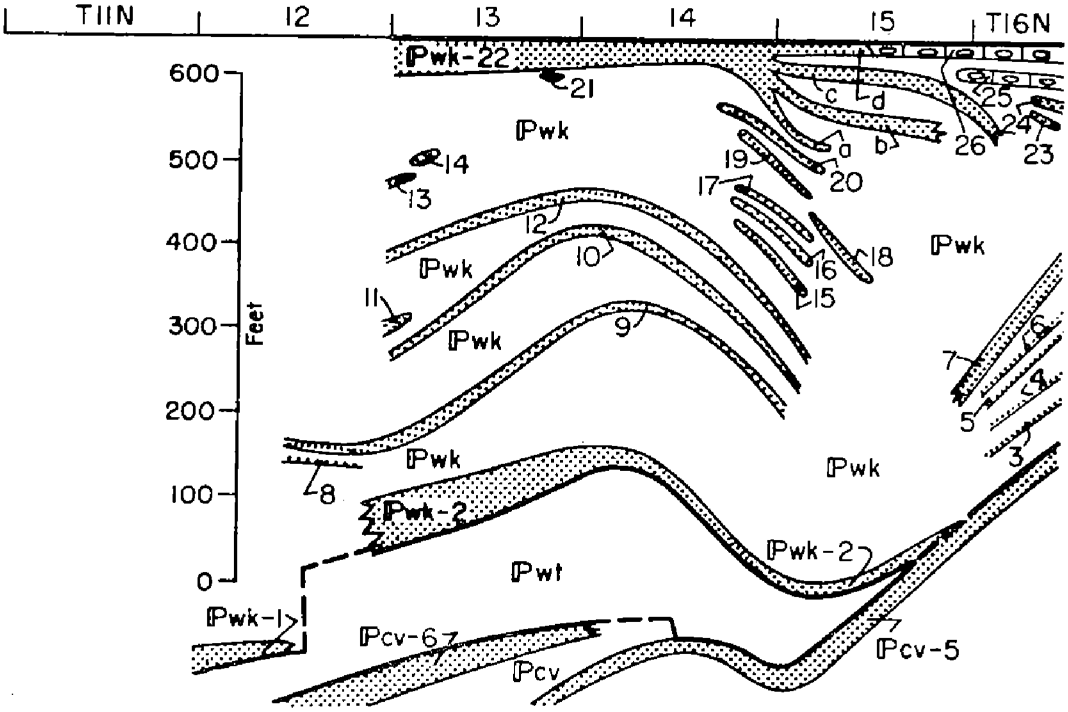

Figure 6. Diagram of the Wewoka Formation, the Wetumka Shale, and part of the Calvin Sandstone, as mapped in Okmulgee County, approximately to scale. Symbols and unit numbers correspond to those used on plates I and II and in the text. The Wewoka is predominantly shale, calcareous at many places, and varies from clay shale to sandy shale. It contains 24 mapped sandstone units and 2 calcareous flagstone units, 25 and 26. The upper boundary is continuous with that of the type locality; the lower boundary, in southern Okmulgee County, is likewise continuous with that of the type locality, but farther north it is arbitrarily placed (1) at the base of unit IPwk-2 and (2) at the top of unit IPcv-5 The Wewoka is conformable with both older and younger rocks.

traced northward with little difficulty almost to the southern boundary of Okmulgee County. It is less clear in Okmulgee County for three reasons: (1) some of the sandstones of southern origin grade into shale; (2) other sandstone units of northern origin extend into the county from the north, interfinger with those from the south, and finally grade into shale; (3) the pattern is further complicated by outcrops of sandstone units that do not extend to the borders of the county; the latter may have originated from the east.

Unit IPwk-1 is buff to yellow-brown fine-grained silty to shaly sandstone with a maximum thickness of about 30 feet. Its base marks the base of the Wewoka Formation southward to the type locality, but it extends into Okmulgee County only as far as sec. 21, T. 12 N., R. 12 E., where it grades into shale. From that locality northeastward to sec. 10, T. 12 N., R. 12 E., the boundary between the Wewoka Formation and the underlying Wetumka Shale is drawn arbitrarily across an area of shale outcrop to the base of the sandstone unit IPwk-2, which is younger than unit IPwk-1.

Unit IPwk-2 is a sandstone lens, possibly of eastern origin. Its greatest thickness, about 60 feet, is in the southern part of T. 13 N., R. 12 E., where it is buff to yellow brown; the lower and upper few feet are medium- to fine-grained massive sandstone, and the middle part is fine grained, silty, thin bedded, and shaly. It grades abruptly into shale between the sandstone units IPwk-1 and IPwk-8, in the northern part of T. 12 N., R. 12 E. It is thinner northward. It has been mapped by tracing and correlation to sec. 7, T. 15 N., R. 14 E., where it is an extremely fine-grained light-brown to yellow-brown thick-bedded sandstone about 8 feet thick and rests upon and merges with the Calvin Sandstone unit IPcv-5, the top of which is here chosen to mark the base of the Wewoka Formation from that locality to the north line of Okmulgee County.

Units IPwk-3, 4, 5, 6, 7 are fine-grained thin-bedded yellow-brown to brown sandstone units that extend into Okmulgee County from the north. They represent lenticular sandstones in the lower part of the Labette Formation of northeastern Oklahoma and southeastern Kansas. The shales between them and immediately above and below the group are so sandy and silty that at many places it is difficult to pick boundaries or to make more than approximate measurements of thickness.

Unit IPwk-8 extends into Okmulgee County from the southwest. It is a monotonously common fine-grained buff to yellow-brown sandstone, is less than 10 feet thick, and grades into shale within about three miles.

Unit IPwk-9 is a fine-grained buff to yellow-brown sandstone. At most places it is less than 10 feet thick but is locally 25 feet or more thick in the south-central part of T. 14 N., R. 12 E., where it is quite shaly and where its upper and lower boundaries are uncommonly gradational and indistinct. It grades into shale in sec. 29, T. 15 N., R. 13 E. It was not mapped from sec. 6, T. 12 N., R. 12 E., to the alluvium associated with Salt Creek in the northern part of T. 13 N., R. 12 E., because the outcrop was so shaly and indistinct.

Unit IPwk-10 is fine-grained brown sandstone. It is 5 to 15 feet thick and more commonly massive than are most Wewoka Sandstones. It splits into two parts in the southern part of T. 15 N., R. 13 E., and the upper part finally grades into shale in sec. 21.

Unit IPwk-11 is sandstone, only about 5 feet thick. It enters the county in sec. 7, T. 12 N., R. 12 E., and grades into shale in sec. 20, T. 13 N., R. 12 E.

Unit IPwk-12 is the usual fine-grained brownish sandstone; it grades into shale, both above and below. It extends into Okmulgee County from the south, is about 10 feet thick in T. 13 N., thins rapidly northward, and grades into shale in sec. 31, T. 15 N., R. 13 E.

Unit IPwk-13 is fine-grained buff to yellow-brown sandstone. It enters Okmulgee County from the south, in secs. 35, 36, T. 13 N., R. 11 E., and grades into shale in sec. 30, T. 13 N., R. 12 E., less than 2 miles farther north. Probably it is nowhere more than 10 feet thick.

Unit IPwk-14 is fine-grained buff to yellow-brown sandstone which crops out only on hilltops east of Lake Okmulgee, in T. 13 N., Rs. 11, 12 E.

Units IPwk-15, 16, 17, 18, 19, 20 are sandstone units the outcrops of which do not extend to the borders of Okmulgee County. They crop out almost entirely in T. 15 N., Rs. 12, 13 E., in an area where the dip is northwest instead of a few degrees north of west as in most other parts of the county. The dip is uncommonly steep; Luff measured 1.5 to 5 degrees which contrasts with the common maxima of 1 to 2 degrees elsewhere in the county. The uncommon dips seem best explained by assuming that the sands were deposited on the sloping front of a delta. They crop out along the south and east front of the high escarpment west of Snake Creek, and each outcrop is high above the stream at the south end but is progressively lower northward and finally grades into shale.

Because these sandstone units grade into shale both northward and southward, and presumably underground westward, the debris composing them was conceivably brought to the area from the east. If so, their thicker, coarser, more shoreward parts have been eroded away.

Unit IPwk-15 is alternately thin- and thick-bedded tan to light-brown fine-grained sandstone, commonly 3 to 5 feet thick; the maximum thickness is 25 feet near the south end of the outcrop.

Unit IPwk-16 is fine-grained brown sandstone about 10 feet thick; the maximum is 17 feet.

Unit IPwk-18 is light-brown fine-grained massive to irregularly bedded sandstone, 5 to 20 feet thick.

Unit IPwk-19 is fine-grained brown sandstone about 10 feet thick.

Unit IPwk-20 is sandstone, commonly less than 10 feet thick, but in T. 15 N., R. 12 E., it grades upward into shaly siltstone as much as 60 feet thick, which is overlain by 10 feet of sandstone; the entire 70 feet of siltstone plus sandstone is here considered part of the overlying shale. As exposed in fresh road cuts near C sec. 35, T. 15 N., R. 12 E., IPwk-20 is cream colored, weathers red brown, is medium grained, and contains fossil brachiopods and plants. It is 24 feet thick at the northeast corner of sec. 25. In T. 15 N., R. 13 E., it is gray-brown to light-brown sandstone with partings of sandy to silty shale; cross-bedding, solution pits, and iron staining are also present. Its maximum thickness is 37 feet, in the east half of sec. 19. It is thinner farther north, along the east face of the escarpment, and disappears in sec. 10, but is 22 feet thick in a deep erosion window in sec. 6 .

The overlying 60-foot siltstone of the preceding paragraph deserves further mention. In fresh road cuts near C sec. 35, T. 15 N., R. 12 E., it is gray tan, locally shaly, and contains a few poorly preserved fossils; it is more shaly in the road cut on Oklahoma Highway 16, at the northeast corner of sec. 35.

Unit IPwk-21 is a lens of fine-grained brown sandstone, probably less than 10 feet thick and is mapped only in sec. 6, T. 13 N., R. 12 E.

Unit IPwk-22 is the youngest map unit of the Wewoka Formation. It extends into Okmulgee County from the south in T. 13 N., R. 11 E., as buff, yellow-brown, or brown fine-grained massive to thin-bedded sandstone, 25 to 40 feet thick, which contains sandy to silty shale partings from less than one inch to several feet thick. In general, it is more resistant than most Wewoka Sandstone units, and its outcrop is prominent as the cap rock of a high eastward-facing escarpment, above a shale interval more than 150 feet thick. It extends northward with much the same characteristics to the northern part of T. 14 N., R. 12 E.

As mapped farther north, it consists of four more or less resistant subunits (IPwk-22a, b, c, d) mapped as sandstones, with intervening weakly resistant rocks ranging from shaly, silty sandstone through siltstone to sandy, silty shale, lumped together as shale on plates I and II. The total maximum thickness of the four subunits and the intervening rocks is about 120 feet. The outcrop area is wooded, the strata are complex, and exposures are poor; it is doubtful that the subdivisions could have been made with a reasonable amount of effort in the field, except with the aid of aerial photographs.

The outcrops are in that rather restricted part of the county where the strike swings eastward from a few degrees east of north to nearly northeast; as the dip swings around to northwest it increases from the 1 to 2 degrees common farther south to as much as 6 degrees. This uncommon dip is best explained by assuming that the beds were deposited on the sloping front of a delta.

The writer has an intuitive impression, which he cannot verify, that the rock debris composing subunits a and b and their associated shales came from the east, and that after they were deposited the debris composing subunits c and d advanced over them from the south. However diverse in origin, the four subunits, as now exposed, constitute a convenient cartographic family.

The four subdivisions (a, b, c, and d), mapped as sandstones, are monotonously alike. They are from cream to brown, depending on the content of iron and the state of weathering, fine to medium grained, massive to thin bedded, and grade into siltstone locally.

Subunit IPwk-22a is an extensive ridge-former in the south half of T. 15 N., R. 12 E. It ranges in thickness from 10 to 35 feet, and grades into shale in sec. 19, T. 15 N., R. 13 E.

Subunit IPwk-22b is an extensive ridge-former in the north half of T. 15 N., R. 12 E. It is from 20 to 30 feet thick. In the south, it contains 8 feet of interbedded blue-gray shale, which pinches out to the north. It grades into shale in sec. 33, T. 16 N., R. 13 E.

Subunit IPwk-22c is 20 feet thick in sec. 33, T. 15 N., R. 12 E., contains interbedded shale locally, and is separated from IPwk-22d by only 4 feet of silty shale; north of Oklahoma Highway 16, it is a more distinctly separate unit. There is some indication that it grades into shale down dip in secs. 10, 11, T. 15 N., R. 12 E. An outcrop of tan calcareous sandstone 2 feet thick, in Eagle Creek at C sec. 2, T. 15 N., R. 12 E., led Luff to think that this bed grades into calcareous mudstone flags in that vicinity; that conclusion may be correct, but after considerable field work in that and a much larger area, the writer prefers to draw the base of the flags somewhat higher.

Subunit IPwk-22d is probably nowhere more than 10 feet thick. It extends only to the vicinity of C NW¼ sec. 15, T. 15 N., R. 12 E., where the upper part interfingers with unit IPwk-26.

Units IPwk-23 and 24 are sandstone lenses probably younger than subunit IPwk-22c. They crop out in the southern part of T. 16 N., R. 13 E., and are light brown, massive, cross-bedded, and iron stained. Each is about 10 feet thick, maximum, and the shale between them is also about 10 feet thick. They seem to grade into shale southward, westward, and northward.

Unit IPwk-25 is a fairly continuous band of calcareous mudtone flags only a few feet thick.

Unit IPwk-26 is a band of calcareous mudstone flags only a few feet thick, sparsely interspersed with fossiliferous limestone flags. It interfingers with the upper part of subunit IPwk-22d in the vicinity of C NW¼ sec. 15, T. 15 N., R. 12 E. From that locality to the north line of Okmulgee County, it is mapped as the uppermost unit of the Wewoka Formation.

The shale between units IPwk-25 and 26 is calcareous at many places and contains numerous calcareous mudstone flags. The flags do not crop out in extensive bands.

Correlation. The Wewoka Formation is represented north of the Arkansas River, from the base upward, by the greater part of the Labette Formation; by the Oologah Limestone (Pawnee Limestone, Bandera Shale, and Altamont Limestone); by the Nowata Shale; and by the Lenapah Limestone.

In the latitude of Talala, T. 24 N., R. 15 E., Rogers County, a band of calcareous mudstone flags and interbedded marly shale crops out as part of the Nowata Shale, probably not more than 20 feet below the horizon of the Lenapah Limestone, which was removed in that locality by post-Des Moines pre-Missouri erosion. Farther south in Rogers County and in northern Tulsa County, these flagstones were removed along with the Lenapah. But the Lenapah Limestone crops out from Bird Creek south to the Tulsa-Okmulgee County line. In many localities it consists of interbedded limestone and calcareous shale; in other localities it consists of sandy limestone or even calcareous sandstone. Below the Lenapah Limestone in this area is a band of calcareous flagstones similar to the flagstones in the latitude of Talala, but the band is thicker and contains thin fossiliferous limestone lenses which extend up to and at some places may include the Lenapah. At many places in Tulsa County, south of the Arkansas River, the Lenapah Limestone is not well exposed; between good exposures the upper few feet of the flags was mapped as its representative (Oakes, 1952, p. 35, 51, pl. I).

The calcareous flags continue southward into northern Okmulgee County, where the lower few feet constitutes the fairly continuous band mapped as unit IPwk-25; the upper few feet, which is considered to represent the Lenapah Limestone, also crops out in a fairly continuous band, mapped as unit IPwk-26, the youngest Wewoka unit in northern Okmulgee County. More or less local lenses, ranging in character from sandy limestone to calcareous sandstone, are common in the Wewoka Formation, especially in the upper part of the youngest sandstone unit (Taff, 1901; Morgan, 1924; Weaver, 1954; Ries, 1954).

Stratigraphic relations. The Wewoka Formation is conformable with the Wetumka Shale, below, wherever the Wetumka is present. From C NW¼ sec. 15, T. 15 N., R. 14 E., to the north line of the county it is conformable with the Calvin Sandstone, below, which represents sandstone in the lower part of the Labette Formation north of the Arkansas River. The Wewoka is conformable with the Holdenville Shale, above, in Okmulgee County and southward. Along much of the outcrop from Okmulgee County to the Kansas-Oklahoma line, the Holdenville was removed along with some older rocks and the Nowata Shale, which represents the upper part of the Wewoka, is overlain unconformably by the Seminole Formation.

Detailed sections. For measured outcrop sections of the Wewoka Formaton see sections 1, 8, 9, 13-16, 18-30, 36, 38-43, 45-56, 69-76, 87, 90-92.

Holdenville Shale

Nomenclator. J. A. Taff (1901).

Type locality. Taff did not mention a specific type locality, but probably had in mind the area between Holdenville, Hughes County, and the base of the Seminole Formation which caps the prominent escarpment to the west.

Original description.

> This shale, 250 feet in thickness, rest upon the Wewoka formation . . . .
>
> The formation is composed of friable, blue clay shale, with local thin beds of shelly limestone and shaly calcareous sandstone in the upper part. . . .The shales are rarely exposed. The smooth grass-covered prairie soil, however, even in the steep slopes, bears evidence of the friable shale beneath. (Taff, 1901, p. 4).

History of usage. The term "Holdenville shale" has always been used in the original sense of Taff. However, in Tulsa County and farther north, even beyond the borders of Oklahoma, other names and classifications have been applied to rocks now known to belong to the Holdenville Shale (Oakes, 1952, p. 43-45).

Distribution. The outcrop of the Holdenville Shale extends southward from its type locality west of Holdenville, Hughes County, to a point midway between Ada and Fitzhugh, Pontotoc County, where it is overlapped by the Seminole Formation. The outcrop extends northward in an unbroken band, except where covered by alluvial deposits, to the alluvium associated with Bird Creek in northern Tulsa County. Farther north, patches left by pre-Seminole erosion crop out from place to place. The most northern Holdenville outcrop known in Oklahoma is along the south line of SW¼ sec. 33, T. 24 N., R. 15 E., in Rogers County. Other outcrops are known in Kansas. The outcrop in Oklahoma is commonly about 3 miles wide.

Thickness. The Holdenville is irregular in thickness, due, in part at least, to pre-Seminole erosion. Along most of the outcrop the range is from 200 to 300 feet; in Okmulgee County it is from 180 to 280 feet.

Character. The Holdenville Shale is composed mostly of shale, much of it silty to sandy; it is fossiliferous at many places; it also contains sandstone which is erratic in distribution both laterally and vertically, and sparse limestone beds from less than one inch to a few feet in thickness. Only one such limestone bed was mapped in Okmulgee County.

Unit IPhd-1 is a lens of fine-grained brown sandstone, with a maximum thickness of about 20 feet, which crops out about 10 feet above the base of the Holdenville, in the northern part of T. 13 N., Rs. 11, 12 E. It seems to grade into shale westward.

Unit IPhd-2 is a fine-grained buff sandstone. It extends northeastward from SE cor. sec. 4, T. 15 N., R. 12 E., to the north line of the county. It is 2 or 3 feet thick at its southern extremity, where it is almost in contact with the unit IPhd-3, above; but it is thicker northward to a maximum of about 12 feet at the north side of the county, where it caps an escarpment nearly 70 feet high and where the overlying shale is more than 50 feet thick. An unmapped red-brown fossiliferous limestone, about 4 inches thick and with an insoluble-residue content of about 40 percent, crops out from place to place about 30 feet below this bed.

Unit IPhd-3 is a fine-grained buff sandstone, 2 to 10 feet thick. It extends from C sec. 16, T. 15 N., R. 12 E., northeastward into Tulsa County. The overlying shale increases in thickness from a few feet at the southern extremity to about 60 feet at the Tulsa-Okmulgee county line.

Unit IPhd-4 extends from C NW¼ sec. 29, T. 15 N., R. 12 E., northeastward to the north line of the county. Along the southern part of its outcrop it is fine-grained buff to brown sandstone, 3 to 5 feet thick, which grades northeastward through calcareous sand-

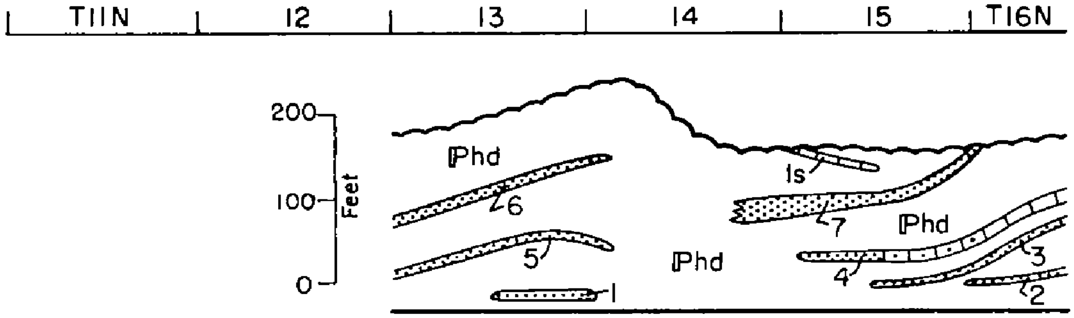

Figure 7. Diagram of the Holdenville Shale in Okmulgee County, approximately to scale. Symbol and unit numbers correspond to those used on plates I and II and in the text. Like the underlying Wewoka, the Holdenville consists predominantly of shale which is calcareous at many places, and it ranges from clay shale to sandy shale. It contains both sandstone and limestone units; none extends across the county. The Holdenville is conformable with the Wewoka, below, but unconformable with the Seminole Formation, above.

stone into a 3-foot bed of gray-blue dense limestone flags. This unit forms a dip slope as much as a mile wide.

Unit IPhd-5 and IPhd-6 crop out in the southern part of the county, south of Deep Fork. They consist of fine-grained yellow-brown generally thick-bedded sandstone which caps hilltops. Their outcrops are not found along the hillsides where they would be expected. Each hilltop seems to be at a slightly different stratigraphic position. The writer thinks that they are remnants of the more resistant parts of the sandy Holdenville Shale and that before they were brought into prominent view by differential erosion they were probably connected, both laterally and vertically, by less resistant shaly sandstone. They are here bracketed loosely into two stratigraphic groups or units, designated Holdenville units 5 and 6.

Unit IPhd-7 crops out in Tps. 14, 15 N., Rs. 11, 12 E., mostly north of Deep Fork, where Luff mapped it as several sandstone units which are here combined. It is composed of intergrading lenses of buff to brown medium- to fine-grained sandstone and sandy to extremely sandy shale; total thickness is from 5 to 25 feet. It was truncated at the north end of the outcrop by pre-Seminole erosion.

Unit IPhd-1s is the only limestone that was mapped in the Holdenville Shale of Okmulgee County. It was truncated by pre-Seminole erosion a short distance south of C sec. 25, T. 15 N., R. 11 E. It is easy to trace northward across sec. 25; less easy in sec. 24. It could not be found north of NW¼ sec. 19, T. 15 N., R. 12 E., and may well have been removed by pre-Seminole erosion, or at least so profoundly weathered at that time as to be unrecognizable now. The unit consists of two beds. The lower one is about 3 feet thick, dense, blue gray at the base, and light chocolate brown at the top. The upper one is 3 to 5 inches thick, tan gray, and fossiliferous. Both beds weather yellow.

Luff found a remarkable deposit of reworked fossiliferous limestone nodules along the small stream which flows eastward across NE¼ sec. 24, T. 15 N., R. 11 E., from which a great number of nearly perfect crinoid crowns have been taken, including many new genera and species. The character of the material and its position, only slightly below the outcrop of Unit IPhd-1s, as mapped, indicates that it is probably from that limestone. Indeed, in view of the uncertainty as to the exact position of the outcrop of the limestone in this vicinity, the material may have merely settled slightly, due to leaching in the underlying shale. Pre-Seminole, as well as

Quaternary and Recent weathering, may have contributed to its present condition and position.

Stratigraphic relations. The Holdenville Shale is underlain conformably by the Wewoka Formation and overlain unconformably by the Seminole Formation.

Detailed sections. For measured outcrop sections of the Holdenville Shale see sections 13, 14, 16, 17, 19, 22, 31-33, 35-37, 39, 40, 42, 44, 51, 66, 67, 69, 87, 88.

MISSOURI SERIES

The Missouri Series is set off from the underlying Des Moines Series by an unconformity and by a faunal change that has been observed from the Kansas-Oklahoma line to the area of the Arbuckle Mountains; it is separated from the overlying Virgil Series by an unconformity which is marked by a faunal change and by truncation of beds. Moore and others (1937) suggested a division of the Missourian rocks of Oklahoma and southern Kansas into two groups, Skiatook and Ochelata, using the unconformity at the base of the Chanute Formation as the boundary between them.

Skiatook Group

Ohern (1910) was the first to use the term "Skiatook.". He intended to apply the name to the beds between the base of the Lenapah Limestone and the base of the Dewey Limestone, but his Lenapah later proved to be the Checkerboard Limestone, and the term "Skiatook" fell into disuse. Moore and others (1937) revived and redefined it, so that it now applies to the strata between the

TABLE V. SUBDIVISIONS OF THE SKIATOOK GROUP IN OKMULGEE COUNTY, OKLAHOMA

- Missouri Series
    - Skiatook Group
        - Nellie Bly Formation (lower part)
        - Hogshooter Formation
        - Coffeyville Formation
        - Checkerboard Limestone
        - Seminole Formation
    - *Unconformity*
- Des Moines Series

base of the Missouri Series and the top of the Dewey Limestone, or, where the Dewey is absent, to the "base of sandstone in the lowermost Chanute Shale." Inasmuch as the Dewey and Chanute Formations crop out in Creek County, west of Okmulgee County (Oakes, 1959), the upper boundary of the Skiatook will not be discussed further here.

Seminole Formation

Nomenclator. J. A. Taff (1901).

Type locality. Taff's text and map imply that the southeastern part of the Seminole Nation (now Seminole County, probably T. 6 N., Rs. 7, 8 E.) is the type locality.

Original description.

> About 50 feet of the lower part of the Seminole conglomerate is exposed in a small area in the northwestern corner of the Coalgate quadrangle. This part of the formation is composed of laminated or stratified subangular chert, with a sprinkling of quartz pebbles from 3 inches in diameter to small grains in a cement of fine brown and usually ferruginous sand. The coarser conglomerate in the beds at the base is loosely cemented and on weathered surfaces it breaks down into rounded boulders and loose gravel. Forty to 50 feet from the base the conglomerate grades into brown sandstone which continues upward about 100 feet to the top of the formation. The Seminole formation crops in rugged hilly country northwestward in the Seminole Nation, making rough timbered lands (Taff, 1901, p. 4).

History of usage. Taff defined the lower limit of the Seminole Formation in the Coalgate quadrangle as the base of the conglomerate that, by implication of text and map, lies next above the Holdenville Shale; he left the upper limit undefined, except to imply that it is about 150 feet above the base of the conglomerate that constitutes the lower part. Morgan (1924) fixed the upper limit definitely at the base of the DeNay Limestone, which he stated is about 150 feet above the base of the conglomerate in the northeastern part of the Stonewall quadrangle.

Oakes (1940, 1952, 1959) has written the story of the extension of application of the term "Seminole formation" into northern Oklahoma, and Oakes and Jewett (1943) correlated the upper part of the Seminole with the Hepler Sandstone of southeastern Kansas.

The upper limit of the Seminole in northern Oklahoma is taken as the base of the Checkerboard Limestone. Though not continuous in outcrop and probably not continuous underground, the DeNay and Checkerboard Limestones do occupy substantially the same stratigraphic position.

Distribution. The Seminole Formation crops out from the vicinity of Fitzhugh, in the northern part of T. 2 N., R. 5 E., southwest of Ada, Pontotoc County, northeastward to the Kansas-Oklahoma line, in the vicinity of South Coffeyville, Nowata County. Sandstone that represents the upper part of the formation continues into Kansas. The outcrop crosses southeastern Seminole County, western Hughes County, Okfuskee County, northwestern Okmulgee County, the southeast corner of Washington County, and Nowata County. The outcrop is about six miles wide in the latitude of Collinsville, Tulsa County, where the lower part of the formation lies in a pre-Seminole erosion valley, which was cut down almost to the Oologah Limestone. Elsewhere the outcrop is generally less than three miles wide, as in Okmulgee County.

Thickness. The Seminole Formation is irregular in thickness, partly because it rests upon an uneven pre-Seminole erosion surface. Morgan (1924, p. 12) stated that it is 90 feet thick in the area north of Fitzhugh, Pontotoc County. Tanner (1956, p. 55) stated that it is about 120 feet thick west of Sasakwa and 375 feet thick southeast of Wewoka, in Seminole County. Weaver (1954, p. 76) stated that it averages 300 feet thick across Hughes County. Ries (1954, p. 51) found it to be 270 feet thick in a well in sec. 12, T. 11 N., R. 9 E., and he stated that composite surface measurements indicate a thickness of 250 to 330 feet in other parts of Okfuskee County. In Okmulgee County, it is from 100 to 200 feet thick. Oakes (1952, pl. II) found that it ranges in thickness from 100 to 320 feet in Tulsa County. It is thinner farther north, owing to progressive overlap of older parts by younger parts, and only a few feet of the youngest Seminole is present in T. 28 N., Oklahoma, and 5 to 20 feet in Tps. 35, 34 S., southern Kansas (Oakes and Jewett, 1943 fig. 1).

Character. The Seminole Formation consists of sandy shale, with a minor amount of clay shale; coarse- to fine-grained sandstone, with a minor amount of chert conglomerate; coal, some of which is of economic importance; and sparse sandy limestone beds, generally less than one foot thick. The lower part of the Seminole Formation is sandstone and extremely sandy shale; it rests upon a pre-Seminole erosion surface and fills channels and valleys cut into older formations. Some of the channels contain sandy limestone beds of no great thickness or lateral extent, and coal beds ranging from less than one inch to 2.5 feet in thickness. These limestones and coals probably represent local ponds and swamps in depressions on the pre-Seminole erosion surface. Chert conglomerate occurs at or near the base from the south end of the Seminole outcrop to the north side of Okmulgee County; at many places in Tulsa County and even farther north are small angular noncalcareous white fragments of chalky texture, which are presumed to be profoundly weathered chert.

Morgan (1924) did not describe the Seminole Formation in detail but mentioned several sandstones and chert conglomerate in Pontotoc County. Tanner (1956) and Weaver (1954) in Seminole and Hughes Counties, respectively, mapped three sandstone units, separated by shale units, and above these, at the top of the formation, shale commonly less than 50 feet thick. Ries (1954) mapped the same three sandstone units and the upper shale unit in southern Okfuskee County but found that the three sandstone units converge northward and finally merge to form a single sandstone unit in northern Okfuskee County. As the sandstones converge and merge, the shale at the top of the formation increases in thickness to about 160 feet; it corresponds to the shale unit IPsl and the sandstone unit IPsl-2 combined.

Unit IPsl-1 of Okmulgee County corresponds to the greater part of the Seminole Formation of the type locality. It is predom-

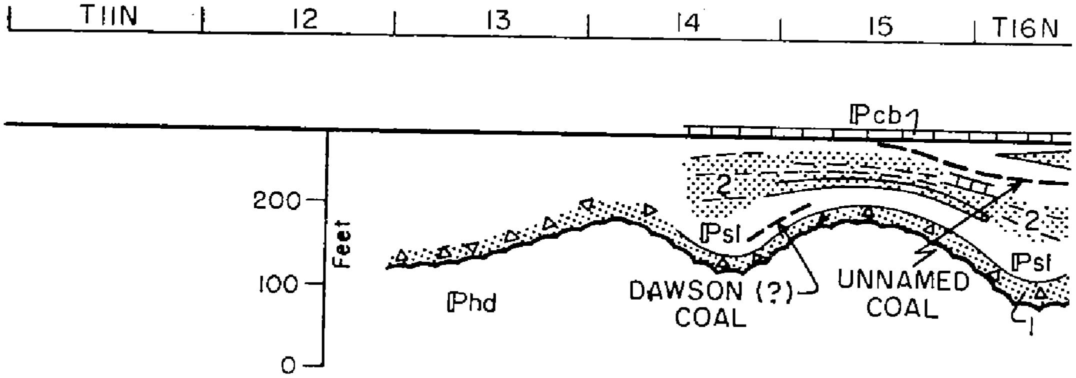

Figure 8. Diagram of the Seminole Formation, the Checkerboard Limestone, and part of the Holdenville Shale in Okmulgee County, approximatly to scale. Symbols and unit numbers correspond to those used on plates I and II and in the text. Unit IPsl-1 is predominantly sandstone and contains chert conglomerate. Unit IPsl is predominantly shale. Unit IPsl-2 is sandstone and sandy to extremely sandy shale; it grades into shale southward, in Okfuskee County. The Seminole rests unconformably upon the Holdenville Shale, and is overlain conformably by the Checkerboard Limestone.

inantly sandstone, from 10 to 60 feet thick. The lower 10 to 35 feet is, at most places, resistant to moderately resistant sandstone. An outlier of this sandstone in secs. 25, 26, 35, 36, T. 15 N., R. 11 E., contains resistant chert conglomerate near the base. The unit is thinner and finer grained farther north and is difficult to trace in some localities. The unit grades upward through interfingering lenses of less resistant sandstone and sandy shale into overlying shale unit IPsl.

Coal beds from one to about 3 inches thick, associated with carbonaceous shale, occur a few feet below the base of unit IPsl-1. They are probably Seminole in age and probably represent swamps in low places on the pre-Seminole erosion surface. Luff found two such deposits, one north of the creek and a short distance east of the center of the west line of the SW¼ sec. 25, T. 15 N., R. 11 E., and another in and south of Duck Creek, sec. 29, T. 16 N., R. 12 E.

Unit IPsl is predominantly shale but contains weakly resistant sandstone lenses. Both its upper and lower boundaries are gradational and indistinct, a fact which probably accounts for most of its great range in thickness, from 10 to 70 feet. This unit contains the Dawson coal in Tulsa County, but the only evidence of the possible presence of the Dawson found by Luff is a few grains of coal in ant hills around the southeast corner of sec. 12, T. 15 N., R. 11 E., where, according to local residents, coal was once taken from pits. The stratigraphic position corresponds closely to that of the Dawson coal.

Unit IPsl-2 contains, at the base, more or less resistant sandstone, from 10 to 25 feet thick, overlain by interfingering and intergrading weakly resistant sandstone and sandy to extremely sandy shale. The unit is from 60 to 90 feet thick. It contains progressively less sandstone upward and also southward, and is represented in Okfuskee County by shale in the upper part of the unit IPsl-3 of Ries (1954).

An unnamed coal bed, from less than 1 foot to 2 feet thick, mentioned by Oakes (1952, p. 43), was mapped by Luff from the north side of Okmulgee County to NW¼ sec. 13, T. 15 N., R. 11 E., where it apparently pinches out. This coal bed is 45 feet below the top of the Seminole Formation in sec. 20, T. 15 N., R. 12 E., and is only 13 feet below the top at a good exposure in a stream bank near SW cor. sec. 12, T. 15 N., R. 11 E.

The lower and upper sandstone units and the intervening shale unit of the Seminole in Okmulgee County extend northward into Tulsa County where they are much more distinct (Oakes, 1952). The three parts extend still farther north beyond Tulsa County, but the lower sandstone is overlapped by the middle shale, and probably the middle shale is overlapped in turn by the upper sandstone, which extends into southeastern Kansas (Oakes and Jewett, 1943).

In general, the sandstone and chert conglomerate of the southern Seminole are finer grained northward and this fact, taken with the northward convergence of the sandstones into the lower sandstone of the northern Seminole, is here considered to indicate that the rock debris that formed the southern Seminole and also much of the northern Seminole came from the south or southeast. On the other hand, the similar southward gradation of the upper sandstone of the northern Seminole into the upper shale of the southern Seminole is taken to indicate a northern or northeastern origin for the clastics of at least the upper part of the northern Seminole. This is only one of many reminders that Okmulgee County lies astride the boundary between the stable northern shelf and the subsiding Arkoma basin.

Stratigraphic relations. The Seminole Formation rests unconformably upon the Holdenville Shale and older formations. It is overlain conformably by younger rocks: by the Francis Formation in the area between the Arbuckle Mountains and the North Canadian River; by the Checkerboard Limestone from the Kansas-Oklahoma line southward to sec. 23, T. 11 N., R. 9 E., southwest of Okemah, Okfuskee County, where the Checkerboard terminates; and by shale mapped as lowermost Coffeyville from that point to the North Canadian River.

Correlation. The Hepler Sandstone represents the upper part of the Seminole Formation in southeastern Kansas.

Detailed sections. For detailed outcrop sections of the Seminole Formation see sections 17, 19, 31-33, 37, 40, 63, 65, 67, 69, 87-89.

Checkerboard Limestone

Nomenclator. The name "Checkerboard" seems to have crept into general usage without formal definition. Hutchison (1911) made reference to the limestone by name; Carl D. Smith (1914) used the name in describing it; Fath and Emery (1917) mentioned it by name.

Type locality. Gould (1925) designated the vicinity of Checkerboard Crossing of Flat Rock Creek, sec. 22, T. 15 N., R. 11 E., Okmulgee County, as the type locality of the Checkerboard Limestone.

Original description. No description can be quoted as the original description. Gould (1925) gave the following:

> The Checkerboard limestone member of the Coffeyville formation lies near the base of the formation. It is 2.5 to 3 feet thick, fine-grained and fossiliferous; bluish-white on fresh surfaces but becomes yellowish-white on weathered surfaces. In bare areas the limestone presents a checkerboard appearance, due to solution channels along the joints, which occur in two sets, the one crossing the other. From this characteristic feature the limestone was for years known as the Checkerboard lime.'' but the geographic locality which is here designated as its type locality is the exposure on Checkerboard (Salt) Creek in T. 15 N., R. 11 E.

History of usage. Nothing in the literature indicates that the term "Checkerboard" has ever been applied in any but its present sense. The earliest published reference to the bed now known as the Checkerboard Limestone is by Gould, Ohern, and Hutchison (Gould and others, 1910). They showed its outcrop on a sketch map of a part of eastern Oklahoma as extending as far south as the North Canadian River, in Okfuskee County, but erroneously called it the Lenapah Limestone. Moore and others (1937) included the sandy basal beds of the Coffeyville in the Seminole Formation, restricted the term "Coffeyville" to apply only to the strata between the Checkerboard Limestone and the Hogshooter Formation, and raised the Checkerboard to formation rank.

Distribution. The outcrop of the Checkerboard Limestone extends northeastward from NW¼ sec. 23, T. 11 N., R. 9 E., across Okfuskee, Okmulgee, Tulsa, Rogers, Washington, and Nowata Counties to the Kansas-Oklahoma line at South Coffeyville. The Checkerboard crops out also east of Coffeyville in southeastern Kansas, a short distance above the Hepler Sandstone (Oakes and Jewett, 1943).

Thickness and character. The Checkerboard Limestone, at most localities in Washington and Nowata Counties, is composed of three limestone beds separated by gray calcareous shale. The total thickness is generally less than 10 feet. In Tulsa County it is a single massive bed of dark-blue fossiliferous limestone about 2.5 feet thick.

We are indebted to Luff and to Miller for most of our information about the Checkerboard Limestone in northwestern Okmulgee County. At most places it strikes about north 30 degrees east and the dip is about one degree, north 60 degrees west. The outcrop extends from the Tulsa-Okmulgee county line, sec. 20, T. 16 N., R. 12 E., to the alluvium associated with Deep Fork, sec. 8, T. 14 N., R. 11 E. It is a single bed of limestone about 2 feet thick. On fresh surfaces it ranges from bluish white to dark blue, but it weathers yellow; it is massive and fossiliferous. It is cut into large blocks by two sets of joints; one trends north, the other 70 degrees west. The resulting checkerboard pattern is striking everywhere but particularly so at the type locality, the vicinity of Checkerboard Crossing of Salt Creek, sec. 22, T. 15 N., R. 11 E., where the exposure is about 20 feet wide and about 200 feet long. People living nearby have advertised and exhibited this exposure as a "highway of ancient civilization." A sample of the Checkerboard Limestone from sec. 20, T. 16 N., R. 12 E., contained 13.54 percent insoluble residue; one from sec. 22, T. 15 N., R. 11 E., contained 19.64 percent. Impurities increase southward, and the abundance of fossils increases in the same direction; few fossils were found north of sec. 31, T. 16 N., R. 12 E.

The Checkerboard Limestone is by no means continuously exposed in Okmulgee County, but the outcrop is commonly indicated by changes in slope or by low escarpments with westerly dip slopes, just above the weakly resistant upper part of the Seminole Formation. The outcrop is also indicated by a change from the sandy soil derived from the underlying Seminole to the dark-gray soil with residual gray to black phosphatic nodules derived from black shale in the lower part of the overlying Coffeyville Formation.

Several thin sandy limestone lenses in the lower part of the Coffeyville Formation and similar lenses in the upper part of the Seminole Formation could be mistaken easily for the Checkerboard Limestone; they even display similar but less striking joint patterns. The extremely sandy thin limestone exposed beneath and in the vicinity of the bridge over Deep Fork at E¼ cor. sec. 31, T. 14 N., R. 11 E., has long been accepted by many geologists as Checkerboard Limestone; it is so mapped on plate I, but it seems to the writer that, barring unknown structural anomalies, it is well below the stratigraphic position of the Checkerboard Limestone. Further, it is much more sandy than the Checkerboard of the continuous outcrop in that latitude. It may well be one of many local lenses of such rock in the Seminole.

The Checkerboard Limestone is covered by the alluvium associated with Deep Fork for a distance of about 5.5 miles. Limestone at the stratigraphic position of the Checkerboard appears in the northern part of sec. 2, T. 13 N., R. 10 E., in Okfuskee County. It is from 8 inches to 4 feet thick and caps the first prominent escarpment above the sandstone of the Seminole Formation, equivalent to unit IPsl-1 of Okmulgee County. Ries (1954) mapped this limestone southwestward as the Checkerboard to NW¼ sec. 23, T. 11 N., R. 9 E.; he was unable to find exposures farther south.

Stratigraphic relations. The Checkerboard Limestone is conformable with the Seminole Formation, below, and with the Coffeyville Formation above.

Correlation. The Checkerboard Limestone occupies substantially the same stratigraphic position as does the DeNay Limestone, the basal member of the Francis Formation in Seminole and Hughes Counties. However, they are not continuous in outcrop and probably not even underground to the west.

Detailed sections. For detailed measured sections showing the Checkerboard Limestone see sections 33, 63, 65, 69, 87, 89.

Coffeyville Formation

Nomenclators. Schrader and Haworth (1906).

Type locality. The vicinity of Coffeyville, southeastern Kansas.

Original description.

> The name Coffeyville formation, after the town of Coffeyville, is here adopted for the portion of the geologic section included between the base of the Drum and the top of the Parsons* (Schrader and Haworth, 1906, p. 14).

History of usage. The term "Coffeyville" as a formation name has had a long and checkered history which was reviewed by Oakes (1940, 1959). As now used in Oklahoma, it applies to strata between the Checkerboard Limestone, below, and the Hogshooter Formation, above; it is not in current use in Kansas.

Distribution. The outcrop of the Coffeyville Formation extends from the vicinity of South Coffeyville, T. 29 N., Rs. 15, 16 E.,

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* The Parsons Limestone included the Altamont Limestone, at the base, and the Lenapah Limestone, at the top. The name was discarded by Moore (1935, p. 64).

Nowata County, southward across northwestern Nowata County, southeastern Washington County, northwestern Rogers County, southeastern Osage County, eastern Creek County, and northwestern Okmulgee County to alluvium associated with the North Canadian River, southwest of Okemah in Okfuskee County. The maximum width of the outcrop is about six miles. Equivalent rocks make up the lower part of the Francis Formation, south of the North Canadian River.

Thickness. The Coffeyville Formation has a considerable and irregular range in thickness. It ranges from 175 to 235 feet across Washington and Nowata Counties; increases southward across Tulsa County from 240 feet to 440 feet; ranges across eastern Creek County from 375 to 500 feet; decreases southward across northwestern Omulgee County from 470 to 450 feet; and is 250 feet thick in Okfuskee County.

Character. The Coffeyville Formation consists predominantly of sandy shale, but contains a minor amount of clay shale, a few thin coal seams, sporadic thin sandy limestone, and sandstone; the sandstone is conspicuous out of all proportion to its amount because it caps escarpments, occupies dip slopes, and, as debris, is scattered over much of the shale outcrops.

At the base of the Coffeyville Formation, from the Kansas-

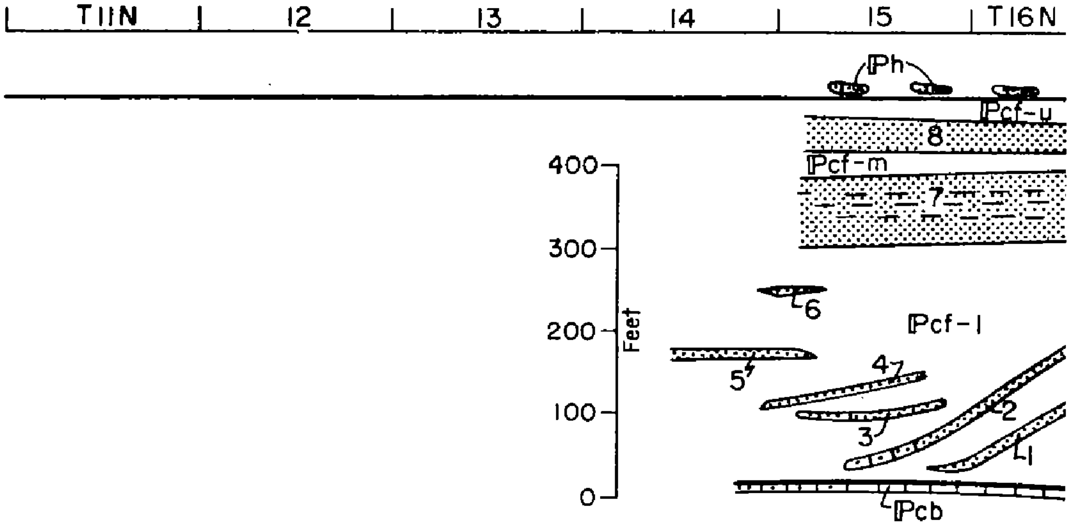

Figure 9. Diagram of the Coffeyville Formation, the Hogshooter Formation, and the Checkerboard Limestone in Okmulgee County, approximately to scale. Symbols and unit numbers correspond to those used on plates I and II and in the text. The Coffeyville is predominantly shale, divided into lower, middle, and upper units by the dominantly sandstone units 7 and 8. None of the thin dominantly sandstone units 1 to 6 in the lower shale extends across the county. The Coffeyville is conformable with the Checkerboard Limestone, below, and with the Hogshooter Formation, above.

Oklahoma line southward to the alluvium associated with Deep Fork, in Okmulgee County, the lower few feet of the Coffeyville Formation is black shale, generally fissile, which contains small black phosphatic nodules. The nodules are so resistant to weathering that they remain long after all else has been reduced to soil. They are a great aid to tracing the base of the formation. Ries (1954) did not mention their presence in Okfuskee County, and stated that shale at the base of the formation is yellowish brown and fossiliferous.

In Okmulgee County, the Coffeyville Formation contains eight mappable sandstone units; two units are continuous and serve to divide the shale of the formation into three parts of unequal thickness, lower, middle, and upper, IPcf-l, m, u. The lower shale unit is nearly 300 feet thick and contains six mapped sandstone units, none of which is continuous across the county.

Unit IPcf-1 is sandstone, probably not more than 3 feet thick. It does not crop out well but is sufficiently resistant to form a dip slope from the east-central part of sec. 11, T. 15 N., R. 11 E., where it is about 10 feet above the base of the formation, to the west-central part of sec. 19, T. 16 N., R. 12 E., where it is more than 50 feet above the base.

Unit IPcf-2 extends from the south line of sec. 22, T. 15 N., R. 11 E., to the southwestern part of sec. 24, T. 16 N., R. 11 E. At the south end of the outcrop, it is gray-tan calcareous sandstone a few inches thick, but it grades northward into noncalcareous sandstone about 4 feet thick.

Unit IPcf-3 is about 4 feet thick and extends from the alluvium in sec. 28, T. 15 N., R. 11 E., northward to the center of sec. 3, T. 15 N., R. 11 E. Its joint pattern resembles that of the Checkerboard Limestone and a sample from near the south end of its outcrop contained 42.35 percent soluble material. However, it grades northward into noncalcareous sandstone.

The shale overlying unit IPcf-3 contains a coal seam which crops out in the east bank of the creek, on the north line of sec. 21, T. 15 N., R. 11 E., where it is only a few inches thick. The coal was traced a quarter of a mile southward to an exposure where it is about 4 feet thick; it was not found farther south.

Unit IPcf-5 was mapped by Oakes (1959) in Creek County, where it is a sandstone, 10 to 20 feet thick, about 200 feet below the top of the shale here designated IPcf-l. The outcrop extends into

Okmulgee County at the southwest corner of sec. 6, T. 14 N., R. 11 E. It is 20 feet thick at the north line of T. 14 N., but pinches out in the eastern part of sec. 20, T. 15 N., R. 11 E., where it is about 100 feet below the top of the shale.

Unit IPcf-6 is indistinctly exposed but does form a dip slope in secs. 30, 31, T. 15 N., R. 11 E. It is probably an extremely shaly sandstone about 4 feet thick.

Unit IPcf-7 was mapped by Oakes, (1959) in Creek County as unit IPcf-2. It is about 80 feet thick in Okmulgee County and is composed of resistant to weakly resistant sandstone and sandy to extremely sandy shale. Bases of resistant ledges are shown on plate I as black lines. At the base of the unit is resistant medium- to fine-grained, silty sandstone, which weathers brown and is about 35 feet thick. It caps a high eastward-facing escarpment above the thick lower shale of the Coffeyville. Similar resistant sandstone about 10 feet thick crops out in the middle of the unit across secs. 8, 17, T. 15 N., T. 11 E. At the top of the unit is another similar resistant sandstone about 25 feet thick.

The middle shale of the Coffeyville, IPcf-m, lies between sandstone units IPcf-7 and 8. It is 25 to 35 feet thick, is extremely silty, and contains a considerable amount of siltstone.

Unit IPcf-8 was mapped by Oakes (1959) in Creek County as units IPcf-4 and 5 and an intervening sandy shale of variable thickness. In Okmulgee County, this body of rocks generally ranges in thickness from 30 to 50 feet and includes, in the lower part, medium- to fine-grained silty sandstone which weathers brown and is from 10 to 20 feet thick; the upper part is less resistant fine-grained to silty brown sandstone with a smaller amount of sandy shale.

The upper shale of the Coffeyville Formation, IPcf-u, is gray to blue, 30 to 50 feet or more thick, and is covered at most places; a complete section was not seen.

Stratigraphic relations. The Coffeyville Formation lies conformably between the Checkerboard Limestone, below, and the Hogshooter Limestone, above; for a short distance in southern Okfuskee County, where neither limestone is present, the base is mapped at the base of the lowest sandstone unit of the Coffeyville and the top is mapped at the base of the lowest sandstone unit of the Nellie Bly Formation.

Correlation. The Coffeyville Formation is equivalent to the lower part of the Francis Formation, in the area between the North

Canadian River and the Arbuckle Mountains. It is equivalent to strata in Kansas between the Checkerboard Limestone, below, and the Dennis (Hogshooter) Formation above.

Detailed sections. For measured outcrop sections of the Coffeyville Formation see sections 33, 34, 61, 64, 65, 68, 69, 83-87.

Hogshooter Formation

Nomenclator. D. W. Ohern (Gould and others, 1910, p. 12).

Type locality. Along Hogshooter Creek in T. 26 N., R. 14 E., eastern Washington County.

Original description.

> This name is proposed for the limestone which lies immediately above the Curl formation in the Nowata quadrangle. The name is from Hogshooter Creek along whose west bank the limestone is well exposed (Ohern, 1910, p. 28).

History of usage. The history of application of the term "Hogshooter" was reviewed by Oakes (1940, 1959). Suffice it to say here that in present usage the Hogshooter Formation is equivalent to the Dennis Formation of Kansas and, like the Dennis, consists of three members at some places in northern Oklahoma. In descending order they are the Winterset Limestone Member, the Stark Shale Member, and the Canville Limestone Member.

In the vicinity of Sand Springs, western Tulsa County, the Hogshooter consists of two members, the Winterset Limestone Member, above, and the Lost City Limestone Member, below. The Lost City seems to represent the combined Stark Shale and Canville Members. At most places north of the Arkansas River only the Winterset Limestone Member, the original Hogshooter of Ohern, is present.

It is not possible to divide the Hogshooter Formation into members in Creek County and in northwestern Okmulgee County. South of Sapulpa in Creek County, and in northwestern Okmulgee County, sandy calcareous fossiliferous rock generally one to 5 feet thick is exposed from place to place at the approximate stratigraphic position of the Hogshooter, in shale that lies between sandstone known to be in the upper part of the Coffeyville Formation and sandstone known to be in the lower part of the Nellie Bly Formation. This rock is mapped as the Hogshooter Formation, following a precedent set by earlier geologists, mostly petroleum geologists, who supplied maps used in compiling the *Geologic map of Oklahoma* (Miser, 1926, 1954).

Distribution. The Hogshooter Formation crops out from a point about three miles north of Okemah, Okfuskee County, northward across eastern Creek County, northwestern Okmulgee County, western Tulsa County, southeastern Osage County, Washington County, and northwestern Nowata County to the Kansas-Oklahoma line, one mile west of South Coffeyville.

Thickness. The Hogshooter Formation is from 5 to 25 feet thick in Nowata and Washington Counties, as little as one foot thick in southeastern Osage County, as much as 50 feet in the vicinity of Sand Springs, western Tulsa County, and from less than one foot to about 15 feet in Creek County and in northwestern Okmulgee County.

Character. Luff described two exposures of rock assigned to the Hogshooter Formation in northwestern Okmulgee County. One is in a gully in the southeast face of the escarpment, in NW¼ sec. 32, T. 16 N., R. 11 E.; it is chalky white silty limestone about 8 inches thick. The other is around the top of the hill on the south line of sec. 21, T. 16 N., R. 11 E.; it consists of 10.5 feet of off-white shaly fucoidal limestone, capped by 0.5 foot of blue-gray sandy fossiliferous limestone, which weathers red brown. Other exposures used to control the outcrop line on the map are so profoundly weathered that only extremely porous fossiliferous sandstone is left.

Stratigraphic relations. The Hogshooter Formation is underlain conformably by the Coffeyville Formation and overlain conformably by the Nellie Bly Formation.

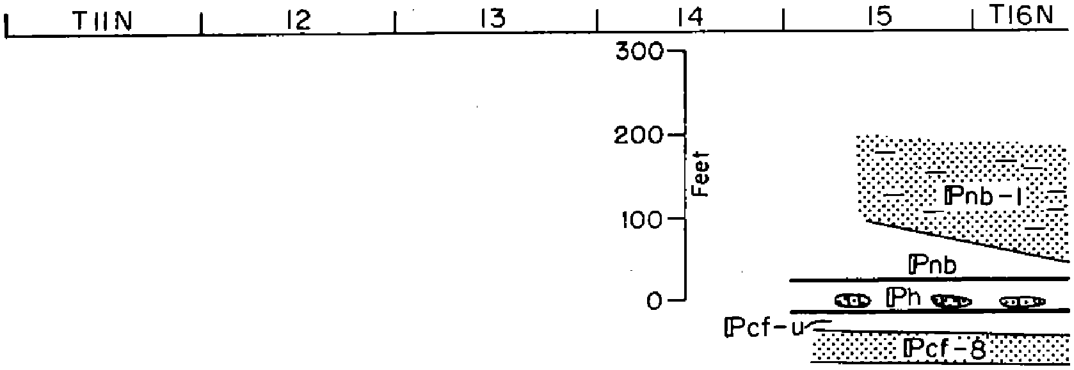

Figure 10. Diagram, approximately to scale, showing the calcareous sandstone lenses that represent the Hogshooter Formation in northwestern Okmulgee County; they lie in shale between the Coffeyville Sandstone unit IPcf-8 and the Nellie Bly Sandstone unit IPnb-1. Symbols and unit numbers correspond to those used on plates I and II and in the text. The Hogshooter is conformable with the Coffeyville, below, and with the Nellie Bly, above.

Correlation. The Hogshooter Formation is the southward continuation of the Dennis Formation of Kansas.

Detailed sections. For detailed sections of Hogshooter rocks in Okmulgee County see sections 84, 85.

Nellie Bly Formation

Nomenclator. D. W. Ohern*.

Type locality. On Nellie Bly Creek in secs. 31, 32, 28, 29, T. 24 N., R. 13 E., Washington County, Oklahoma.

Original description†

> "Alternating shales and hard gray sandstones, the latter ranging in thickness from a few inches to several feet" from 15 feet on the Kansas line to 200 feet in southeastern Osage County. . . rests on the Hogshooter limestone and is overlain by the Dewey limestone.

History of usage. The name has always been used in its original sense.

Distribution. The Nellie Bly Formation crops out from the North Canadian River, southwest of Okemah, Okfuskee County, northeastward to the Kansas-Oklahoma line, one to four miles west of South Coffeyville, Nowata County.

Thickness. The Nellie Bly Formation is nearly 400 feet thick in the latitude of northwestern Okmulgee County, but most of the outcrop lies in Creek County, to the west. Only about 200 feet of the lower part crops out along the steep eastward-facing escarpment in the extreme northwestern part of Okmulgee County, where it occupies about four square miles.

Character. In Okmulgee County shale (IPnb), 50 to 80 feet thick, crops out immediately above the Hogshooter Formation. It is generally sandy and contains a few local lenses of fine-grained to silty sandstone (fig. 10).

Unit IPnb-1 is about 120 feet thick and is composed of resistant to weakly resistant sandstone and sandy to extremely sandy shale. Bases of resistant ledges within the unit are indicated on plate I by black lines. The upper part of this unit crops out farther west, in Creek County.

Stratigraphic relations. The Nellie Bly Formation is conform-

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* In an unpublished manuscript, Geology of the Nowata and Vinita quadrangles: U. S. Geological Survey, 1914.

† Quoted and paraphrased by Gould and Decker (1925, p. 74) from Ohern's unpublished manuscript.

able with the Hogshooter Formation, below, and with the Dewey Formation, above.

Correlations. The Nellie Bly Formation is represented in Kansas by strata from the top of the Winterset Limestone Member of the Dennis Formation to the base of the Drum Limestone; that is, by the Cherryvale Shale of older Kansas usage. South of the North Canadian River, it is represented by approximately the upper half of the Francis Formation.

Detailed sections. For measured outcrop sections of the Nellie Bly Formation see sections 62, 82, 85.

QUATERNARY? SYSTEM

Deposits of sand, silt, and clay (Qt, pl. I) mantle the older rocks in limited areas along Deep Fork, mostly along its north side. In some localities it seems that more than one terrace is present, notably in the area west of Okmulgee; all are mapped together on the geologic map (pl. I) even including one unusually high deposit of similar appearance, perched on a hilltop in sec. 15 and adjoining sections in T. 14 N., R. 12 E. The maximum thickness of these terrace deposits is not known, but it is probably not more than 100 feet. At most places they carry a light, generally infertile, sandy soil, suitable for growing such crops as peanuts, fruits, berries, and yams. In some localities they supply moderate amounts of ground water.

QUATERNARY SYSTEM

Flood plains (Qal, pl. I) composed of sand, silt, and clay cover areas of considerable size along Deep Fork and smaller areas along several other streams. The maximum thickness along Deep Fork is probably between 50 and 100 feet; it may be no more than 30 feet along other streams. The streams still overflow from time to time and build the alluvium higher. Some of the most fertile land in Okmulgee County is on this recent alluvium. Water supplies of several hundred gallons per minute can be developed at some places from sand near the base.

PALEONTOLOGY

Carl C. Branson

No systematic collections have been made from the strata of Okmulgee County. A number of the fine fossil-collecting localities are known, however. The lowest of these stratigraphically is in the Senora Formation in a railroad cut at Dewar. Chonetids and abundant specimens of *Desmoinesia muricatina* (Dunbar and Condra), 1932, Hoare, 1960, occur there, and specimens of the latter are figured by Muir-Wood and Cooper (1960, pl. 64, figs. 17, 19-25).

The shales and clay-ironstone concretions above the Henryetta (Croweburg) coal in the Senora Formation contain plant compressions, and these are currently under study by Professor Wood of the Botany Department, University of Missouri. The Croweburg coal from the Sam Crabtree mine, sec. 26, T. 16 N., R. 14 E., has yielded 13 spore species:

Calamospora hartungiana Schopf, 1944
Cirratriradites intermedius Wilson and Hoffmeister, 1956
Endosporites ornatus Wilson and Coe, 1940
Florinites antiquus Schopf, 1944
Granulatisporites granularis Kosanke, 1950
G. verrucosus (Wilson and Coe, 1940), Schopf, Wilson, and Bentall, 1944
Laevigatosporites globosus Schemel, 1951
L. minutus (Ibrahim, 1933), Schopf, Wilson, and Bentall, 1944
Lycospora punctata Kosanke, 1950
Punctatisporites dentatus Wilson and Hoffmeister, 1956
Triquitrites bransonii Wilson and Hoffmeister, 1956
T. crassus Kosanke, 1950
T. dividuus Wilson and Hoffmeister, 1956
Raistrickia crinita Kosanke, 1950

Exposures below the dam at Lake Okmulgee and on the shores of the lake have yielded hundreds of specimens of the porpitid coral *Gymnophyllum wardi* Howell, 1945, a species figured by Jeffords (1955, pl. 2, figs. 1-14, pl. 3, fig. 7). The shales are in the Wewoka Formation below Unit 12 of Oakes (1961). The type and only known locality of *Limipecten wewokanus* Newell, 1937, is from the locality. Moore (1940, pl. 2, figs. 7 a-c) figured a specimen of *Allagecrinus* cf. *A. bassleri* Strimple from there. *Neochonetes granulifer* is abundant east of the dam at Lake Okmulgee. Warthin (1930) listed the foraminifers. *Hyperamminoides glabra* (Cushman and Waters), 1927; *Ammovertella inversa* (Schellwein), 1898, Cushman, 1928; *Rectocornuspira calcarina* (Waters), 1928; and *Deckerella laheei* Cushman and Waters, 1928, from the Wewoka in sec. 25, T. 15 N., R. 12 E., in addition to the gastropod *Meekospira paracuta choctawensis* Girty, 1911.

The cephalopods of the Wewoka Formation of the county have been described by Unklesbay (1962). *Poterioceras* sp., *Mooreoceras normale, Pseudorthoceras knoxense, Brachycycloceras longulum, B. normale, Solenochilus missouriensis, Liroceras liratum, Metacoceras sinuosum, Bisatoceras primum, Gonioglyphioceras gracile, Neodimorphoceras lenticulare, N. oklahomae, Eoasianites hyattianus, E. kansasensis, E. welleri, Wewokites newelli,* and *W. venatus* have been identified from sec. 10, T. 13 N., R. 12 E. Other fossils from the locality are the corals *Stereostylus* sp., and *Lophophyllidium wewokanum,* the brachiopod *Crurithyris planoconvexa,* the snails *Euphemites vittatus, Bellerophon crassus wewokanus, Amphiscapha catilloide, Meekospira peracuta choctawensis, Trepospira depressa,* and *Glabrocingulum grayvillense,* the clams *Culunana bellistriata, Nuculopsis girtyi, Palaeonucula? anodontoides,* and *Anthraconeilo taffiana,* and the shark shagreen granule *Petrodus.*

A locality at the same horizon in SE¼ sec. 12, T. 14 N., R. 12 E., yielded *Eoasianites angulatus* and *Liroceras* sp. A Wewoka faunule from sec. 8, T. 13 N., T. 12 E., contains *Bisatoceras greenei, Maximites cherokeensis, Gonioglyphioceras gracile, Neochenetes granulifer, Composita subtilita, Anthraconeilo taffiana, Nuculopis girtyi, Trepospira depressa,* and *Worthenia tabulata. Brachycycloceras crebricinctum* occurs in the Wewoka in sec. 2, T. 14 N., R. 12 E.

Limestone and shale considered to be equivalent to the Lenapah Limestone yielded the type and only known specimen of *Septimyalina orbiculata* Newell, 1942, in NW¼ sec. 19, T. 15 N., R. 12 E. (Newell, 1942, p. 68, pl. 11, figs. 1-3).

Holdenville shales along the county line in secs. 14 and 23, T. 16 N., R. 12 E., yielded the type specimens of the scyphomedusans *Conostichus hoodi* Branson, 1961, and *C. pulcher* Branson, 1961 (Branson, 1960, 1961). The genus also occurs in the Seminole and Senora Formations of Okmulgee County.

The cobble bed at the top of the Holdenville Formation in sec. 24, T. 15 N., R. 11 E., has yielded a fauna of 436 crinoid crowns and hundreds of partial crowns. The faunule of 20 genera and 25 species of inadunates was described by Strimple (1961). An associated slabby, ferruginous limestone contains the brachiopods *Derbyia* sp., *Juresania nebrascensis, Linoproductus prattenianus, Neospirifer dunbari,* the clams *Aviculopecten* sp., *Myalina* sp., *Schizodus?* sp., *Wilkingia* sp. The fauna contains two species of the coral *Stereostylus,* one of *Michelinia,* an undetermined nautiloid, *Metacoceras perelegans, M. cornutum?* and *Eoasianites excelsus.*

From a coal bed in the Seminole Formation a fossil tree stump was collected which was identified by Tynan (1959) as *Cordaites michiganensis* Arnold, 1931.

The meager fauna and flora described from the county is not a true representation. No systematic collecting has been done and many species which occur in the county have not been recorded.

SURFACE STRUCTURE

It was not the purpose of this investigation to make a detailed study of the structure of the surface rocks of Okmulgee County, such as would be made in virgin territory thought to contain important accumulations of oil and gas.

The surface rocks in Okmulgee County strike about north 30 degrees east and dip about north 60 degrees west. The rate generally ranges from 30 to 100 feet per mile, tending to be steeper in the western part of the county than in the eastern part; in a few places the dip is greater or less than the limits given; in one area the dip is reversed, toward the east. The Schulter anticline is apparent in the surface rocks from the alluvial deposits along the south side of Deep Fork southward through Schulter and Henryetta to the south side of the county. Its west limb is relatively gentle, but on the east limb dips of 10 degrees are common and dips of 25 degrees have been reported. Several years ago the writer talked with many of the older coal miners in the district, and they stated that underground some of the sandstone beds are nearly vertical, and that at some places the coal "ends against a solid sandrock." The east limb is undoubtedly faulted, at least locally; but it is not possible to say how much the throw of any particular fault may be, or how much of the total difference in elevation of the coal, from the crest of the anticline to the bottom of the syncline, is due to faults. The

Schulter anticline is best described as an asymmetrical anticline with a gentle west limb and a steep, faulted east limb.

Clark (1930) mentioned another anticline, also faulted on the east limb, extending from sec. 20, T. 13 N., R. 14 E., northeastward into T. 14 N., R. 15 E. Manhoff found small faults along that trend, with downthrow to the east, but did not recognize an anticline in the surface rocks. The fault in sec. 2, T. 13 N., R. 14 E., and in secs. 25, 36, T. 14 N., R. 15 E., is rather evident in the surface rocks, but both Manhoff and Leitner thought that the throw was not more than a few feet. Manhoff was told by the operators that it does not interfere with water flooding in the shallow oil-producing sands.

It is inferred that there is a fault along Deep Fork in the northeastern part of T. 14 N., R. 11 E., which is largely concealed by the alluvium. The sandstone unit IPwk-22 (pl. I) passes under the alluvium in NW¼ sec. 25, and emerges in SW¼ sec. 11, much farther west than would be expected in the absence of some structural anomaly. Miller thought that a large block or small outlier of sandstone unit IPhd-7 south of the inferred fault in sec. 10, not shown on plate I, owes its abnormally low position to faulting rather than to slumping.

Two small faults shown in secs. 7, 18, T. 11 N., R. 12 E., were inferred from an inspection of the aerial photographs.

ECONOMIC GEOLOGY

The consolidated surface rocks of Okmulgee County are mostly shales and sandstones, deposited in relatively shallow water and probably in a nearshore environment. Only one local impure limestone has ever been worked commercially for crushed limestone. Sandstone outcrops have yielded stone suitable for building; and sandstone will no doubt be used again whenever economic conditions warrant the hand labor involved. Coal has been an important mineral product of Okmulgee County; mining conditions are good and remaining reserves are large. Output depends almost entirely on demand, not on available mineable coal. Demand is now low, and output in the fiscal year ending June 30, 1960, was 42,087 short tons, the lowest since 1908, when production for Oklahoma was first reported on a county basis. The maximum for a calendar year was 1,477,677 short tons in 1920; it reached a slightly lower high, 1,164,622 short tons, in 1947. Both highs reflect unusual world-wide demands for coal, following World War I and World War II.

COAL

Dunham and Trumbull (1955) mapped the Henryetta mining district of Okmulgee, Okmulgee County, and Trumbull (1957) wrote on the coal resources of Oklahoma. Their reports contain far more detailed information about the coal resources of Okmulgee County than the writer and his assistants gathered in the course of their studies of the stratigraphy of the county; they should be studied by anyone considering mining coal in Okmulgee County. The following discussion contains much information quoted and paraphrased from these two publications, supplemented by information from our own observations and from other sources.

Coal in the Midcontinent region is limited almost entirely to rocks of the Des Moines and Missouri Series. Such of these coal-bearing rocks as may have been deposited in the areas now included in the Ozark dome or uplift in southwestern Missouri and northwestern Arkansas, in the Arbuckle Mountains areas of south-central Oklahoma, and in the Ouachita Mountains area of southeastern Oklahoma and southwestern Arkansas have been removed by erosion.

A folded and faulted remnant is preserved in the Arkoma basin of west-central Arkansas and east-central Oklahoma; it merges through less disturbed rocks with rocks of gentle westerly dip in the shelf area, on the Central Oklahoma arch and the west flank of the Ozark dome. In Oklahoma, the principal coal beds are, in ascending order: the Lower and Upper Hartshorne, which merge northward (Oakes and Knechtel, 1948, p. 23); the McAlester, including the loosely correlated Stigler and Lehigh; the Secor; the Croweburg also known as the Henryetta and as the Broken Arrow; and the Dawson. Of these, only the Croweburg (Henryetta) and possibly the Dawson, crop out in Okmulgee County; and only the Croweburg, in the upper part of the Des Moines Series, is mined commercially. Two local coal beds, the Morris, about 100 feet below the Croweburg, and the Eram, about 270 feet below the Croweburg, have contributed a small amount of the total production.

Croweburg (Henryetta) coal. The Croweburg coal was named from a locality in Kansas. Oakes (1944, p. 12, pl. I) mapped the

Broken Arrow coal from the Arkansas River to the north side of T. 22 N., R. 16 E., and correlated it with the Croweburg. Its maximum reported thickness north of the Arkansas River is 37 inches, in the vicinity of Broken Arrow, Tulsa County, a locality in which it is commonly 18 to 24 inches thick. It is thinner farther north, being only 14 inches thick at some places between Sequoyah and Bushyhead, Rogers County. The Croweburg, in most localities north of the Arkansas River, is hard black bituminous coal; it is reported to have good keeping qualities, which adapt it to stockpiling for seasonal or emergency use.

According to Lontos (1952) the Croweburg coal is about 11 inches thick in a strip pit in SE¼ sec. 6, T. 16 N., R. 12 E., Wagoner County. The Croweburg has been strip mined in NE¼ sec. 26, T. 16 N., R. 14 E., Okmulgee County, where Lontos found it to be 15 inches thick at one place and 19 inches at another. So far as the writer is aware, the Croweburg has not been mined between this strip pit and an extremely small strip pit (not shown on pl. I) on the north bank of the creek just west of the road, between 0.3 and 0.5 mile south of NE cor. sec. 19, T. 14 N., R. 14 E. The position of the inferred outcrop is well indicated by sandstone outcrops and is shown on plate I by a queried dashed line. Leitner found one exposure of the coal, in NW¼ sec. 4, T. 14 N., R. 14 E., where it is 6 inches thick and of poor quality. Careful prospecting would probably disclose the coal at other places along the inferred outcrop, but it may not be of suitable thickness and quality for profitable mining.

Strip mines are almost continuous along the outcrop from sec. 31, T. 14 N., R. 14 E., to sec. 14, T. 13 N., R. 13 E., and Dunham and Trumbull (1955, pl. XXIV) indicated that the content of clean coal generally ranges from 21 to 29 inches.

From these strip pits south to the alluvium associated with the Arkansas River, the Croweburg has not been mined. Dunham and Trumbull (1955, p. 196, pl. XXIV) indicated that the coal is progressively more shaly southward across sec. 23, T. 13 N., R. 13 E., and stated that from there to the river it is represented by highly carbonaceous sandstone at many places. The writer, with much difficulty, divided the sandstone in this area into units representative of sandstone units south of the river and then hesitantly mapped the inferred outcrop of the coal in more detail than did Dunham and Trumbull.

From Deep Fork south to the latitude of Henryetta, the outcrop of the Croweburg coal is well marked by numerous strip mines and drift mines. Two other reliable guides to the outcrop of the Croweburg south of the Arkansas River are (1) the outcrop of the sandstone unit IPsn-9, which extends to the south side of the county and is 1 to 15 feet below the coal, and (2) a bed of shaly fossiliferous limestone, not shown on plate I, which is 2 to 4 feet thick and 15 to 30 feet below the coal. At many places the outcrop of the limestone is difficult to find, but in some localities its fossiliferous rubble makes a white band on the ground; a convenient and accessible exposure is in the railroad cut south of U. S. Highway 260 at Dewar. According to Dunham and Trumbull (1955), the thickness of clean coal in this area generally ranges from 28 to 41.5 inches, and averages depart but little from just under 36 inches.

Dunham and Trumbull stated (1955, p. 196):

> West of the Henryetta mining area, 6 diamond drill holes, located 5 to 8 miles from the outcrop and 1.5 to 4 miles ahead of mining, found the coal to be 35 to 39 inches thick. The holes are spaced 1 to 3.5 miles from each other, and form a rough line nearly 9 miles long trending about N. 30 degrees E. There is thus no indication of thinning as the coal becomes deeper toward the west: and though the many wells drilled in the area for oil and gas can be expected to interfere to some extent with mining and to reduce the over-all recoverability, the almost certain presence of many square miles of coal of a thickness probably equal to that now being profitably mined is established.

The following quotation, including the table, is from Trumbull (1957, p. 353).

> Except for the area disturbed by the Henryetta-Schulter anticline, . . . mining conditions in this field are good: the roof and floor are excellent, the dip is low and uniform, and little gas is present. . .
>
> The Henryetta coal is of high-volatile A and B rank. The maximum, minimum, and average composition of the bed as shown by analyses of 46 samples from this mining area are shown as follows (U. S. Bureau of Mines, 1928, p. 20-21; Moose and Searle, 1929, p. 26-30; Dunham and Trumbull, 1955, table 1).

	Minimum (percent)	Average (percent)	Maximum (percent)
Moisture	4.9	7.2	8.9
Volatile matter	31.9	34.4	36.8
Fixed carbon	49.4	52.8	55.4
Ash	3.9	5.5	9.5
Sulfur	.7	1.8	3.7
Btu.	12,350	12,860	13,450

> Twenty determinations made by the U. S. Bureau of Mines of the ash-softening temperature of this coal averaged 2,120 degrees F. to 2,420 degrees F. Estimated remaining reserves in the Henryetta bed in this mining area total about 243 million tons.

Ries (1954, p. 99) stated, "No coal deposits of any size were found cropping out in Okfuskee County. Wells in the eastern part of the county show the presence of the Henryetta coal." Weaver (1954, p. 46, 105) reported a coal about 12 inches thick in a mine N½ SW¼ sec. 21, T. 9 N., R. 12 E., Hughes County, which L. R. Wilson (oral communication, 1961) called Croweburg, on the basis of its spore content. Weaver also found coal at about the same horizon in wells drilled farther west. Shannon and others (1926, p. 38) stated that the Croweburg (Henryetta) had been traced as far south as the town of Calvin, and that it is thinner there than in the vicinity of Henryetta.

Morris coal. Dunham and Trumbull (1955, p. 197) used the name "Morris" for the local coal bed which has been strip mined at the town of Morris and stated (p. 197):

> In the area around Morris in the north half of T. 13 N., the thickness of the Morris coal bed ranges from 12 to 22 inches and averages 16 inches, all of which is clean coal. Southward its thickness becomes very erratic. This is best illustrated by the excellent esposures in the N½ NW¼ sec. 6, T. 12 N., R. 14 E.; there the coal thins southwestward in less than 2,000 feet from 36 to 2 inches.
>
> Mining has been restricted to the area of fairly uniform thickness around Morris, where large scale power stripping has been successful; to small team pits in the NW¼ SE¼ NW¼ sec. 6, T. 12 N., R. 14 E., where the coal reaches its maximum thickness of 36 inches in an extremely small area; and to the south quarter-section corner of sec. 2, T. 12 N., R. 13 E., near Wildcat, where the thickness is 15 inches. Mineable coal in the Morris zone is unknown south of Wildcat.

Eram coal. Another local coal, known as the Eram, has been strip mined in secs. 25, 36, T. 14 N., R. 14 E., and in sec. 30, T. 14 N., R. 15 E., in an area that probably contains several small faults. The coal was covered by water and caved earth and no description can be given. Trumbull (1957, p. 352) stated:

> Drilling records show bed thickness ranging from 15 to 29 inches in 19 drill holes, but it is very probable that large amounts of parting and impure coal are included in these figures, and in the calculation leading to the estimate of 2.45 million tons of reserve of all categories in this bed, generally much smaller bed thickness figures were used. . .

No analyses of this coal were available.

Unnamed coal beds. Leitner mapped a coal bed across T. 14 N., R. 14 E., below the Senora Sandstone unit IPsn-5, and correlated it with the Morris coal. At the time the correlation seemed sound, but subsequent field work by the writer, farther south, indicated that the Morris coal bed is above the unit IPsn-5. The coal bed mapped by Leitner is shown on plates I and II as an unnamed coal. It has been strip mined in secs. 3, 19, T. 14 N., R. 14 E., but neither description nor estimate of reserves is available.

Luff mapped an unnamed coal bed in the upper part of the Seminole Formation. Its maximum thickness is about 2 feet, but generally, it is probably less than one foot thick. It is exposed in the bank of the small stream 200 feet northeast of SW cor. sec 12, T. 15 N., R. 11 E., where it is only 0.8 foot thick. Coal has been taken from

TABLE VI. REPORTED COAL PRODUCTION (SHORT TONS), OKMULGEE COUNTY, 1908-1960*

1908	127,934	1935	223,999
1909	262,310	1936	311,036
1910	227,107	1937	314,649
1911	408,202	1938	224,315
1912	629,989	1939	231,575
1913	820,659	1940	351,859
1914	905,128	1941	368,089
1915	869,244	1942	533,212
1916	852,206	1943	639,630
1917	1,051,748	1944	623,211
1918	1,282,139	1945	699,262
1919	965,497	1946	848,746
1920	1,477,677	1947	1,164,622
1921	974,457	1948	1,110,630
1922	829,554	1949	767,650
1923	818,050	1950	690,724
1924	818,683	1951	457,596
1925	541,069	1952	394,094
1926	584,607	1953	366,718
1927	869,227	1954	352,581
1928	735,322	1955	283,780
1929	772,819	1956	123,928
1930	541,284	1957	72,624
1931	259,931	1958	65,710
1932	254,733	1959	48,524
1933	227,629	1960	42,087
1934	185,846		

*Sources: 1908-1931, Mineral Resources of the United States: U. S. Geol. Survey.
1932-1957, Minerals Yearbook: U. S. Bur. Mines.
1958-1960 (fiscal years ending June 30), Annual Reports of Mines and Mining in Oklahoma: [Okla.] Dept. Chief Mine Inspector.

this and several other exposures and from extremely small pits for local use, but the bed will, in all probability, never yield coal commercially. Luff also found grains of coal in ant hills around the SE cor. sec. 12, T. 15 N., R. 11 E., where, according to local residents, coal was found in prospect pits. It is in the stratigraphic position of the Dawson coal of Tulsa County, but there is no other evidence that the Dawson is present in Okmulgee County.

Coal a few inches to one foot thick is rather common immediately below the lower sandstone of the Seminole Formation (IPsl-1). It is generally much less than one foot thick, is probably Seminole in age, and probably accumulated in small swamps on the pre-Seminole erosion surface. It is not of commercial importance.

Production. Coal has been mined commercially in what is now eastern Oklahoma since about 1872, and in what is now Okmulgee County since about 1902. Annual reported production in the entire area for the years 1873-1907 was compiled by Trumbull (1957, p. 364). Annual reported production for Okmulgee County for the years 1908-1960 is given in table VI.

Reserves. The U. S. Geological Survey now follows a much more conservative plan than any formerly used in estimating reserves of mineable coal; the results of the plan are much lower estimates than any heretofore published. To comprehend fully the meaning of these estimates for Oklahoma, one should consult Bulletin 1040-J of the U. S. Geological Survey. In table 8 (p. 377) of that bulletin, Trumbull gave the estimated remaining reserves of coal in all categories in Okmulgee County as 254 million short tons, round figures.

LIMESTONE

One small quarry in Okmulgee County produces impure crushed limestone, from Senora unit IPsn-8. Similar quarries might possibly be opened along the outcrop of the same bed. The following description of the limestone part of the unit is adapted from Leitner: In SW¼ sec. 14, T. 15 N., R. 14 E., is a limestone, one foot thick, dark gray, dense, fossiliferous, silty and wavy bedded. It is overlain by 3 to 5 feet of sandstone, dark brown, loosely consolidated, and iron stained. This limestone thickens southward to a possible maximum of 15 feet in SE¼ sec. 28, T. 15 N., R. 14 E., where it is dark gray, massive, and dense and contains few fossils. It has been quarried for road metal in this locality. Southeast from the quarry, the limestone is thinner, platy, and fossiliferous and contains solution cavities, geodes, and small veins of calcite. Still farther south it grades rapidly into sandstone.

BUILDING STONE

The sandstone outcrops of Okmulgee County supply the only locally available building stone. Commonly, the exposed sandstone is too much weathered or too thin bedded and shaly to be useful for any kind of building. However, at many places the beds are thick enough and erosion has been active enough to remove the weathered portions as fast as formed, or at most, the weathered overburden is not so thick as to make its removal prohibitive. The prevalence of sandstone in the older business and public buildings of the towns and in the older culverts and bridge abutments demonstrates that sandstone serviceable for building does exist; the prevalence of small quarries and pits from which stone has been taken and the sparsity of larger quarries indicate that such stone can be found in proximity to most building projects. Building with sandstone will again be common if economic conditions justify the hand labor involved.

CLAY AND SHALE

Formerly, there were several brick and tile plants in Okmulgee County, but the writer does not know of a single plant that is still in operation.

Snider (1911, p. 243-245) described the plant and shale pit of the Okmulgee Coal and Brick Company at Gaither, four miles east of Okmulgee. The soil was used with the shale and the total face was about 15 feet high. Three feet of Croweburg (Henryetta) coal lies a few feet below the bottom of the shale pit, but the shale immediately above the coal was not used. No trouble was experienced at any stage of the manufacturing process; the product was free from "whitewash," and the color was a "rich, rather dark red." Paving blocks from this plant were used at Guthrie; they were completely vitrified and the loss on the rattler test was 9 percent.

Snider described another plant only 300 yards to the southeast. The shale was taken down to the coal, and there was a great deal of trouble with "whitewash" and "black coring"; also, the overburned bricks puffed. However, when careful burned, the shale made "good firm common bricks."

Sheerar and Redfield (1932, p. 189-192) described the plant and shale pit of the Kusa Brick and Tile Company in sec. 3, T. 11 N., R. 13 E. At that time the pit was about 40 feet deep and the plant, "which was originally one of the best-equipped plants in the state," was operating part time and employing 25 to 30 men.

Sheerar and Redfield also reported tests of shales with possibilities for making common and face brick, sewer pipe, and hollow tile from the following localities: sec. 11, T. 11 N., R. 12 E.; sec. 3, T. 12 N., R. 13 E.; and sec. 11, T. 13 N., R. 13 E.

An abundance of shale crops out in all parts of the county, but no special attention was paid to its quality in the course of the field work on which this report is based. However, there is little doubt that detailed, diligent, and intelligent prospecting and testing would disclose shale and probably clay suitable, at the least, for common brick and tile in most parts of the county. Shale from some localities might produce higher grade products, such as face brick, paving brick, and, possibly, pottery. So far as the writer knows, the clays of the recent alluvium and terrace deposits have received no attention.

PART II.—WATER RESOURCES OF OKMULGEE COUNTY

WARD S. MOTTS

GROUND WATER

The purposes of this ground-water investigation were (1) to determine the potential of ground-water supplies for municipal, industrial, irrigation, and domestic purposes in Okmulgee County and (2) to determine the relation of geology to the general occurrence of ground water in the county. In the field, ground-water conditions were studied, wells were scheduled, depth to water in wells was measured, and quality of water expressed in micromhos was measured with a solu-bridge conductance meter. The U. S. Geological Survey supplied information about conditions of quality of water and surface water in the county; and water samples were chemically analyzed by the Quality of Water Branch of the U. S. Geological Survey. For this reconnaissance investigation, elevations of wells were not obtained because of lack of adequate topographic maps.

With the exception of an unpublished report, completed by the Ground Water Branch of the U. S. Geological Survey on ground-water conditions near the town of Beggs, no detailed investigation has previously been made of ground-water conditions in Okmulgee County.

GENERAL OCCURRENCE OF WATER IN OKMULGEE COUNTY

Okmulgee County has two types of ground water, one occurring in the alluvium (alluvial water) and the other occurring in the bedrock (bedrock water). The pronounced hydrologic differences between the alluvial water and the bedrock water result from the contrasting sedimentary and structural characteristics of the alluvium and bedrock. The bedrock aquifers underlie the larger part of Okmulgee County and are important for local sources of domestic and stock water (fig. 11). The alluvial aquifers underlie a much smaller area but are important because they produce water in more abundance and of better quality than do the bedrock aquifers. Both the alluvium and bedrock have well-defined zones of better quality

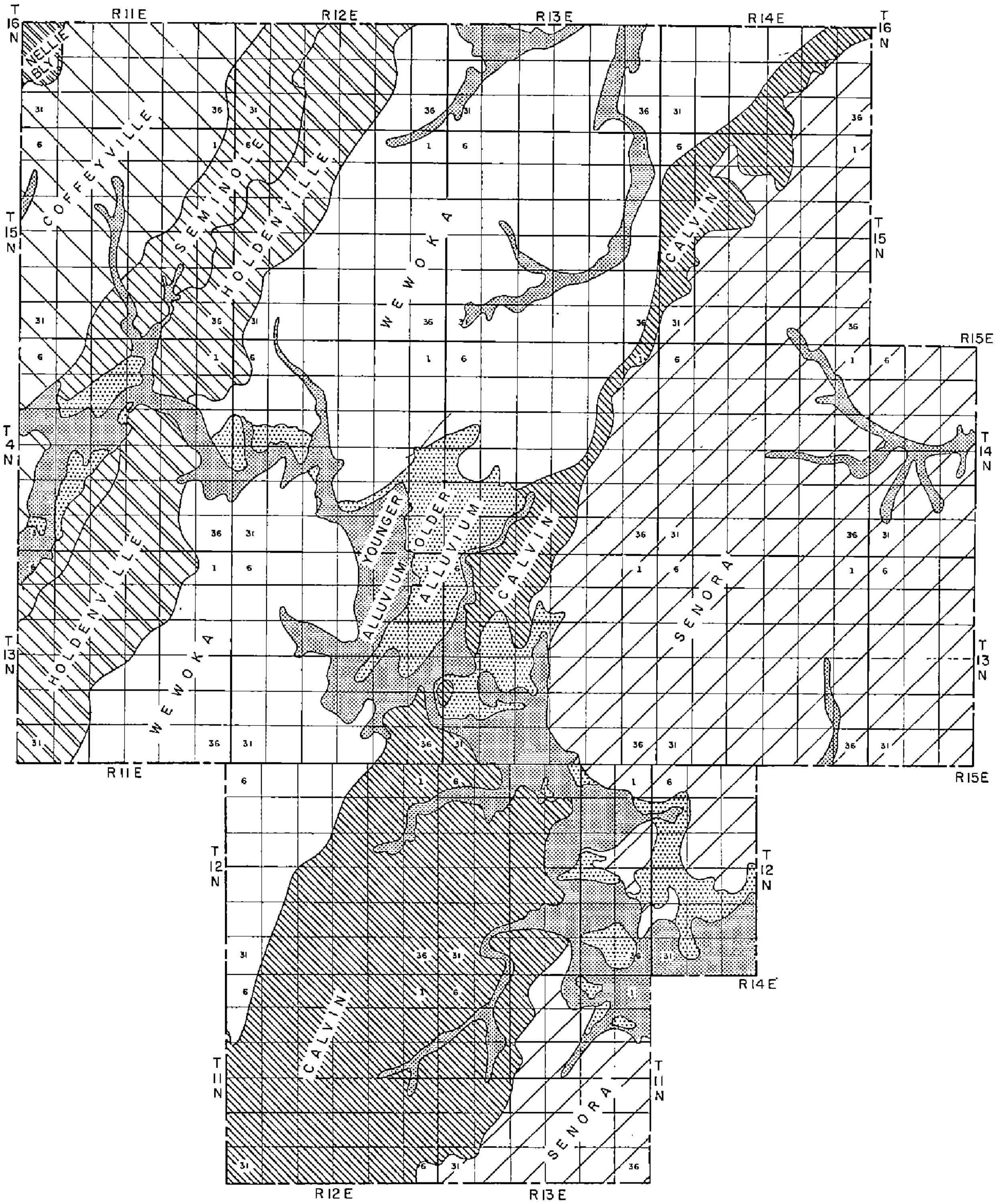

Figure 11. Major aquifers of Okmulgee County. Aquifer boundaries do not necessarily conform to formation boundaries.

potable water grading downward into zones of poorer quality impotable water. Figure 12 shows quality of water zones in the bedrock and table VII gives chemical analyses of water from wells in Okmulgee County.

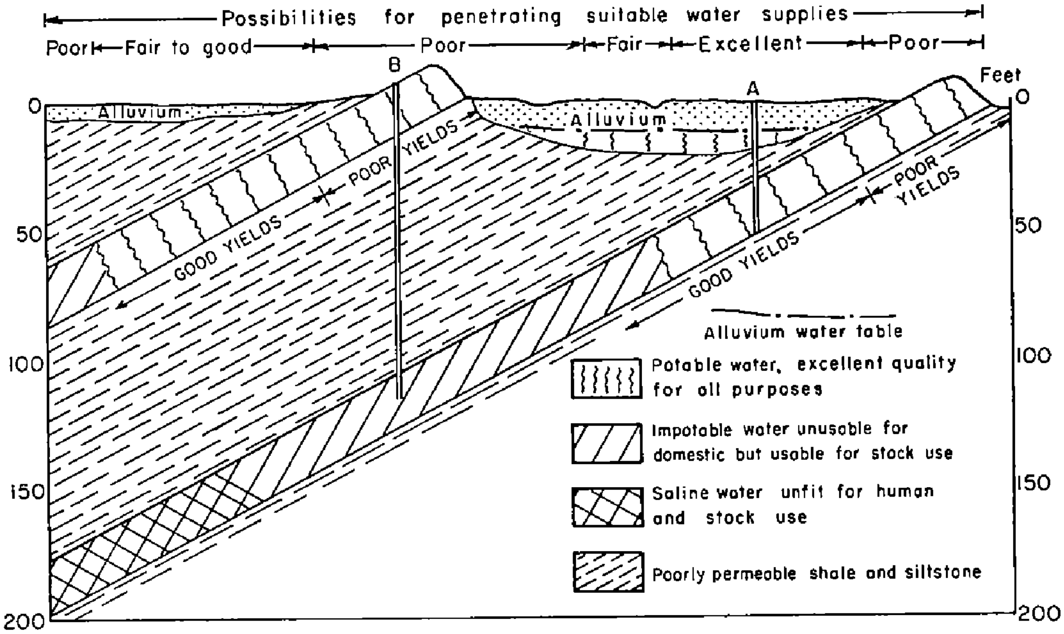

Figure 12. Idealized cross section showing quality-of-water relationships in the alluvium and bedrock sandstones of strike valleys.

Despite the large use of ground water in many local areas of the county, it is less used than is surface water. The usefulness and development of ground water in the alluvium and bedrock of Okmulgee County are restricted by three conditions. The first condition is the low yield of ground water both in the alluvium and in the bedrock. With a relatively large average annual rainfall of 39 inches, one might expect that more water would percolate into the subsurface. However, the alluvium and bedrock are composed of fine-grained material that is capable of transmitting only small amounts of ground water. The bedrock, of Pennsylvanian age, consists of shales and siltstones interbedded with very fine-, fine-, and medium-grained sandstones. The alluvium which is derived from the Pennsylvanian bedrock has the same average grain size as the bedrock sandstones; however, the alluvial materials are better sorted. None of the aquifers of Okmulgee County is capable of yielding the amounts of water necessary for extensive irrigation or for municipal use. In almost all parts of the county the major problem is to find enough ground water for domestic and stock use.

The thinness of the potable-water zone is the second condition that restricts the development of ground water in Okmulgee County. Potable water grades at depth into highly mineralized impotable water of high salt content in both the alluvium and bedrock. In the bedrock of the county, fresh water has not been found at depths greater than 300 feet. At most places the limit is 150 feet, and in a large part of the eastern side of the county it is 75 feet. The depth to salt water in Okmulgee County is unusually shallow even for the Paleozoic bedrock ground-water province, which was characterized by Meinzer (1923, p. 201-205) as having shallow depth to salt water.

The third condition restricting ground-water development in some areas of the county is the presence at shallow depth of salt water alone. These areas of impotable water result from natural causes and from contamination by oil-well brine. Oil wells pump large amounts of highly mineralized water that must be disposed of. If such water is disposed of properly by injecting it into deeper bedrock aquifers, no contamination will result. However, the fresh, potable water in the shallow aquifers will be contaminated if brine, ejected on the surface, seeps underground or if brine leaks through improperly constructed casing into the potable-water zone. The contamination of potable ground water has occurred in both the shallow and deeper aquifers. In some areas of the county, residents have had to discontinue using their water wells because of the increase in the amount of mineral constituents in their water.

Because of unfavorable conditions for ground-water development, all of the large users of water in Okmulgee County use surface water rather than ground water. When their populations are small, many municipalities use ground water supplies; however, as the population increases, they turn to surface water. Numerous users of large and small quantities of water utilize surface water, as indicated by the numerous stock ponds and cisterns in Okmulgee County. Dale Earnest, county agent, reported that at present 1,050 stock ponds are in the county. The same geologic and hydrologic conditions that limit the development of ground water are the ones that promote the use of surface water. The low porosity and permeability of Pennsylvanian bedrock effect greater surface runoff, which favors construction of surface reservoirs.

OCCURRENCE OF GROUND WATER IN THE ALLUVIAL DEPOSITS

The alluvial deposits in Okmulgee County are mapped as older terrace deposits (Qt) and as Recent channel and flood-plain deposits (Qal) (pl. I). In this discussion the terrace deposits are called older alluvium and the lower, Recent deposits are called younger alluvium. The areas underlain by the older alluvial aquifer and the younger alluvial aquifer are shown on figure 11.

The alluvial deposits form a band that ranges in width from about one mile to six miles. The band of alluvium extends from the southeastern part of the county to the central-western part of the county. The two largest areas of alluvium are in the southeastern part (Tps. 11, 12 N., Rs. 13, 14 E.) and in the central part (Tps. 13, 14 N., Rs. 12, 13 E). The greatest promise for ground-water development lies in these two areas. Smaller areas of alluvium project into Okmulgee County from the east and north.

Generally water in the older and younger alluvia along Deep Fork is of better quality for human use than is water in the bedrock. Because of the higher permeability of the alluvium and the shorter distance from the recharge area to the discharge area, the constituents causing contamination are flushed out in a relatively short time. On the other hand, because of the lower permeability of the bedrock aquifers and the greater distance from the recharge area to discharge area, the bedrock aquifers remain contaminated for relatively long periods.

The older and younger alluvia consist primarily of sand, silt, and clay but contain no appreciable amounts of gravel. The alluvial deposits derived from the Pennsylvanian bedrock contain sandy, silty, and clayey facies that interfinger in an abrupt manner. Much of the material is well sorted. The sand of the alluvial deposits is in channel deposits; the silt and clay in flood-plain deposits. Grains of much of the channel sand are well rounded, well sorted, and medium to fine grained, with small amounts of interstitial silt. Much of the silt is in the medium to coarse size of the Wentworth scale. The fine-grained silt and clay are formed in part in flood-plain lakes. Wells penetrating the sands obtain the larger yields of ground water, whereas wells penetrating the silt and clay obtain the smaller yields of ground water. In places the silt and clay form semiconfining beds for water in the more permeable channel sands.

The abrupt interfingering of the sand, silt, and clay is one cause for the erratic occurrence of water in the alluvial deposits. The medium-grained, well-sorted channel sands have permeabilities that probably range from about 50 to 100 gpd/ft, and the more abundant medium- to coarse-grained silts have permeabilities that probably range from about 25 to 75 gpd/ft (Wenzel, 1942, p. 13). Only a few specific-capacity tests were made on wells in alluvial materials and all the tests indicated low specific capacities. A test was made on a well in the alluvium of Coal Creek in NW¼ SW¼ sec. 35, T. 12 N., R. 13 E. This well had a specific capacity of 3.6 gpm per foot of drawdown. The well penetrated flood-plain silts which are interbedded with channel sandstones.

Davis and others (1959, p. 206-211) stated that the coarser, better sorted sandstones in the San Joaquin Valley of California, which are similar to sandstones in the younger alluvium of Okmulgee County, have specific yields of from 15 percent to 20 percent. The study by Davis also indicated that the silt and clay of Okmulgee County may have specific yields of from 5 percent to 15 percent. The foregoing information indicates that the alluvial materials have relatively low permeabilities and small specific yields because of insufficient amounts of coarse sands and the absence of gravel. These factors, combined with the small saturated thickness (20 to 50 feet) and the limited areal extent of the alluvium, indicate strongly that the alluvial deposits cannot be extensively developed for ground water. No high-yield water wells have been developed in the alluvium, although wells have been drilled for that purpose. People using large amounts of water have been forced to turn from ground-water to surface-water supplies as the demand for water increases. It is reported that in 1915 a well, 24 feet wide, was drilled in alluvium in SW¼ sec. 11, T. 13 N., R. 13 E., for the town of Morris but although it had three laterals, the well did not yield enough water. In 1925 Morris turned from ground water to surface water and built a dam, forming a lake east of town.

Despite their incapacity to yield large amounts of water to wells, the alluvial aquifers yield more water than does any other aquifer in Okmulgee County. Wells drilled in the alluvial aquifers will in most instances furnish all the water needed for domestic purposes and often enough for stock purposes. The yield from wells in the alluvial aquifers ranges from 25 to 500 gph (gallons per hour). The low yields of wells that have been drilled in the alluvium result in part from improper development and in part from penetration of silty and clayey alluvial facies. Some of these wells are called wet-weather wells because they yield water only during long-range humid climatic cycles or during rainy seasons. The wet-weather wells are common in the older alluvium.

The wet-weather springs also yield water only in times of higher precipitation. Many of the wet-weather springs have small recharge areas and emerge where shallow, semiconfining silt beds have been truncated. The yields of the wet-weather springs are small and most are seeps. Large-yielding springs are present in the alluvium where the water table intersects the surface. This generally occurs where streams have cut below the water table. Figure 13A shows where the irregular surface of the bedrock has forced water to the surface. The springs occur over the areas where the water-bearing alluvium is thin. An example of this type of spring in older alluvium is in NW¼ sec. 9, T. 19 N., R. 11 E. Another type of alluvial spring, shown on figure 13B, is near the boundary between the older and younger alluvia. This type of spring can result where permeable materials of the older alluvium are in contact with younger alluvium of low permeability. A spring in NE¼ SW¼ sec. 35, T. 12 N., R. 13 E., is near the boundary between the older and younger alluvia. A dam has been built downstream from the spring, forming a perennial pond. Springs emerging from alluvium in subsequent valleys along sandstone beds are discussed in the section on younger alluvium. One of the larger yielding springs in the alluvium

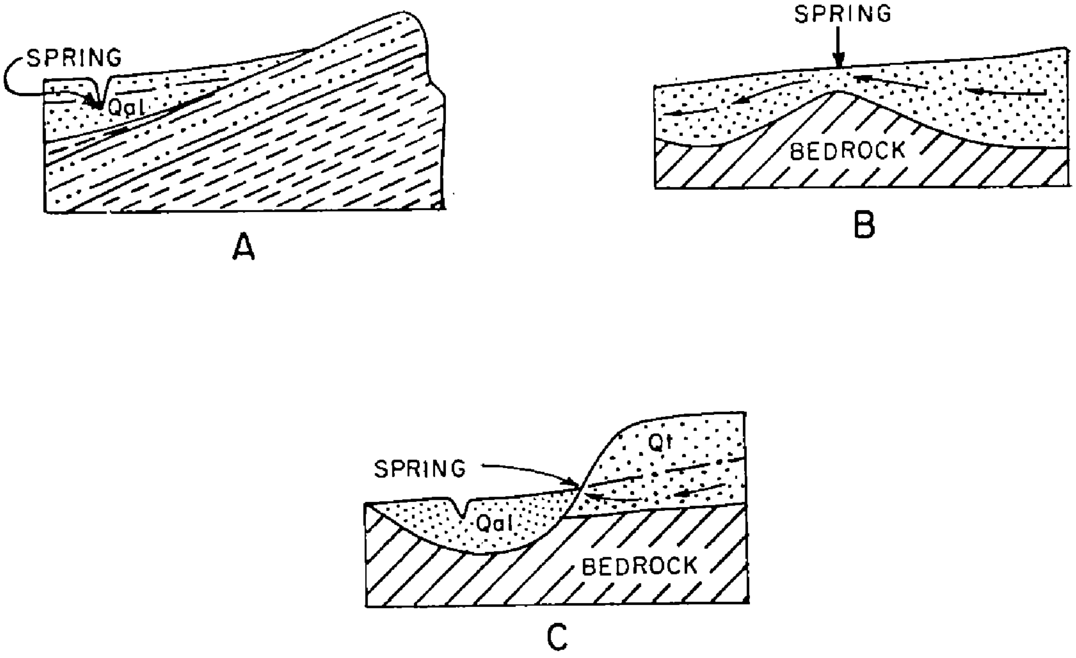

Figure 13. Typical alluvial springs in Okmulgee County.
A. Stream valley cut below water table in alluvium of strike valley
B. Irregular bedrock floor
C. Contact of older alluvium (Qt) and younger alluvium (Qal)

emerges from younger alluvium of Wolf Creek in SW¼ sec. 11, T. 11 N., R. 13 E. This spring, which once furnished the former town of Kusa with water, has been enclosed by a rock wall and has a considerable yield. The spring is reported to have been pumped at rates of 100 to 750 gph without appreciably lowering the water level.

The fine-grained materials in the alluvium cause major problems in construction and development of wells. In the fine-grained sand and silt, it is necessary to case the wells and resort to gravel packing or to slotted screens. To achieve maximum efficiency, the well should be drilled to penetrate a maximum thickness of alluvium and should be carefully developed by proper methods of surging. Caved wells have been reported where no casing, or where improper casing, has been used, and in some places "sand flows" have resulted.

Many of the low-yielding wells in the alluvium could have been developed into good producers if the wells had been properly finished and developed.

Older Alluvium

The older alluvium (Qt) underlies a terrace that is 10 to 30 feet above the younger alluvium. Recharge to the older alluvium is principally from direct recharge on the terrace surfaces and to a minor extent from subsurface inflow from the bedrock formations. Generally the surface of the older alluvium does not have the thick underbrush that characterizes many areas underlain by younger alluvium along the Deep Fork. In a few places, however, the older alluvium is covered with a thick undergrowth of vegetation such as that in parts of secs. 8, 9, T. 14 N., R. 11 E.

In the present cycle of cut-and-fill, Deep Fork has eroded away a considerable part of the permeable sands of the older alluvium, leaving along the margins of the valley the remnants of older alluvium. The remnants consist of the less-permeable finer grained materials of the flood plain, interbedded with small amounts of channel sandstones.

These materials consist primarily of silt in the medium- to coarse-size range and of sand from very fine through medium size. The sand and silt interfinger in an abrupt and somewhat erratic manner, and in many cases it is difficult to determine whether a well will penetrate predominantly relatively high-yielding sand or low-yielding silt. Generally it is advantageous to drill near the axes of the valleys for two reasons: (1) near the axis the channel sands are more likely to be present, whereas near the margin of the alluvium the silt is more likely to be present, and (2) the older alluvium is thickest near the axis and thins toward the margin. The yields of wells in the older alluvium range from a few gallons a minute where wells are drilled predominantly in the silt to as high as 15 to 25 gpm where the wells are drilled predominantly in the sand. The low permeability of large parts of the alluvium is indicated by the numerous wet-weather wells described in the section on occurrence of water in bedrock. Some of the wells in the alluvium went dry during the latter years of the drought that lasted from 1951 to 1957. The wells that went dry probably penetrated small amounts of perched water or penetrated water in the thin alluvium along the margins of the valley alluvium. The close relationship between climate and water yield in wells is characteristic of aquifers of small yield and areal extent, of limited recharge area, and of a short distance between recharge area and aquifers. In summary, to be assured of a sustained yield in the older alluvium one should drill into the thicker parts of the alluvium away from surface trace of the bedrock-alluvium contact.

The quality of water in the older alluvium ranges widely. In most places water is potable and satisfactory for domestic and stock use. However, in some places water is highly mineralized and unusable. The depth required to penetrate water in the older alluvium ranges from about 15 to 50 feet. In many places the flood-plain silts form confining beds over the water-yielding channel sands and water occurs under semiconfined conditions. The pumping lift in the older alluvium ranges from about 10 to 30 feet.

Younger Alluvium

The younger alluvium underlies the channels and flood-plains of the streams and rivers in Okmulgee County (pl. I). Along Deep Fork the yields of wells are greater in the younger alluvium than in the older alluvium. The permeability of the younger alluvium may be greater because of the presence of permeable channel facies, whereas parts of the channel facies of the older alluvium have been eroded away.

Some parts of the alluvium along Deep Fork contain relatively highly mineralized water with total-dissolved-solids concentrations ranging from 1,000 to 2,000 ppm. These concentrations result from seepage of poorer quality river water into the alluvium and from inflow of highly mineralized water from the bedrock. Water in most of the alluvium along Deep Fork and in the tributaries of the smaller streams is abundant and generally has a low mineral content. However, not all the younger alluvium along the smaller tributaries is thick enough for high yields or adequate storage. In addition, the alluvium contains many isolated areas of highly mineralized water.

Alluvium underlying the following streams provides usable water: areas of Deep Fork that are not highly mineralized; the larger tributaries to the Arkansas River in the northern part of Okmulgee County, such as Duck Creek with its tributary, Snake Creek, and as Cane Creek; and the larger tributaries to Deep Fork

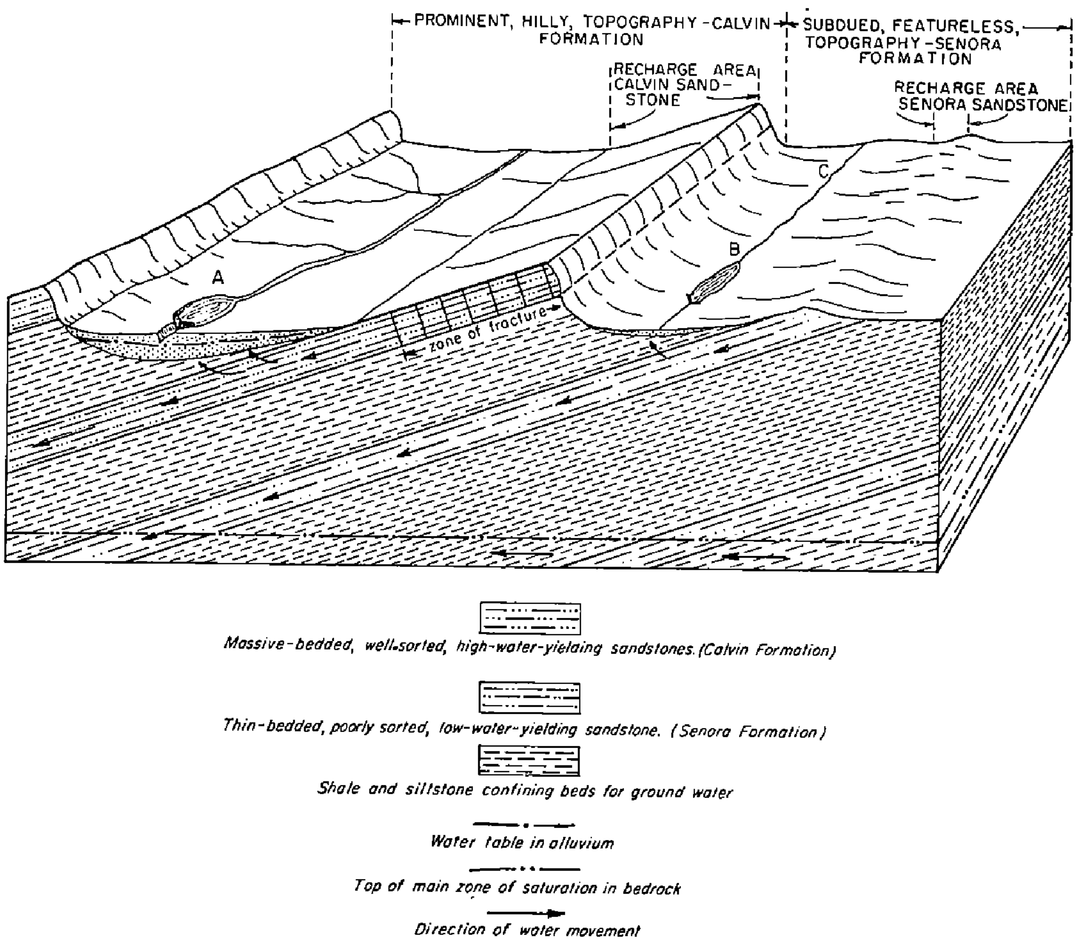

Figure 14. Block diagram showing relationships of high-yielding and low-yielding aquifers in Okmulgee County. Stock tank A is fed by ground water from alluvial spring. Stock tank B is fed by surface from subsequent stream C.

in the southern part of the county, such as Coal Creek, Wolf Creek, Grove Creek, and Okmulgee Creek. The alluvium of Eagle Creek, tributary to Duck Creek, is a typical example of high-yielding younger alluvium. One well, bottomed in alluvium of Eagle Creek in SW¼ SE¼ sec. 20, T. 16 S., R. 13 E., has a minimum yield from 750 to 1,000 gph; and it is reported that pumping rates in this range have never lowered the water level. However, no tests of long duration were made. Water from this well contains 250 to 300 ppm total dissolved solids, and hence is considerably less highly mineralized than water in the adjoining bedrock aquifers.

The many pockets of highly mineralized water, which occur in an erratic manner in the younger alluvium, result from (1) seeping of highly mineralized brine from oil wells into the alluvium and (2) natural discharge of highly mineralized water from deeper aquifers. The former of these processes is the principal cause of contamination of water in the younger alluvium. Before the adoption of regulations concerning the disposal of oil-well brines, it had been common practice to dump brines into the streams of the county.

Subsequent streams have formed along most of the larger strike valleys in Okmulgee County. In many places the thin alluvium along the strike valleys may be saturated with water. This is true if the sandstone to the east of the valley is a high water-yielding type. If considerable recharge occurs on the sandstone slope, part of the water moves into the shallow alluvium. Springs may occur where the recharge is excessive. Springs may also occur in the highly faulted and jointed structural zone adjacent to the more massive part of the sandstone, or they can result from erratic cementation of the sandstones. An example of this latter type of spring is on the dip slope of sandstone 4 of the Calvin Formation in SW¼ SW¼ sec. 22, T. 11 N., R. 12 E. In places in the alluvium of some of the strike valleys it is possible to dig stock ponds into the water table and thus have a perennial source of water (fig. 14).

The thicker alluvium that contains substantial amounts of water is in valleys adjacent to the well-sorted, massive sandstones that erode to form prominent topographic ridges. Although figure 14 applies specifically to the Calvin Formation, the general relationships also apply to other strike valleys adjacent to massive, well-sorted sandstones. Wells penetrating alluvium of the strike valleys have been reported to have yields ranging from 10 to 2,000 gpd. The higher yields are from the thicker alluvium. Higher mineral content in ground water in the strike valleys may be due in part to evapotranspiration.

Soils on the younger alluvium of Deep Fork and its larger tributaries are of two types—Roebuck soils and a soil as yet unnamed by the Soil Conservation Service (W. A. Sparwasher, personal communication). Each is a young soil without well-developed horizons. The Roebuck soils are silt and clay deposited in temporary lakes formed by overflow of Deep Fork. They have low permeability and support ponds and lakes for many months of the year. Areas underlain by Roebuck soils are therefore suitable sites for stock ponds. The unnamed soil has more sand than the Roebuck soil and, consequently, has greater permeability. Some of the soils along the smaller streams of Okmulgee County are the Verdigris-Mason-Lightning soil association, the Parsons soil, and the Dwight soil. The Dwight and Parsons soils have low permeabilities and are therefore excellent foundations for ponds. The generally low permeability of soils along the younger alluvium retards the seepage of ground water into the alluvium and favors the escape and discharge of surface water. The Parsons soil, which is a high-sodium soil, is perhaps the most impermeable of the soils in Okmulgee County. Its low permeability may have been caused by precipitation of mineral matter from highly mineralized water coming up from below.

A description of the soils of Okmulgee County is being prepared for publication by the Soil Conservation Service of the U. S. Department of Agriculture. Some of the soils of Okmulgee County have been described by Helmer (1959).

OCCURRENCE OF WATER IN THE BEDROCK

The bedrock of Okmulgee County comprises rocks of Pennsylvanian age containing low-yield aquifers which occupy a much larger area than do the alluvial aquifers (fig. 12). Aquifer boundaries follow the formation boundaries only in a general way; at many places the aquifer boundaries are to the west of the formation boundaries. The aquifers are sandstone, with shales and siltstones being the confining layers. Almost every major sandstone bed is an aquifer over part of its areal extent. The best quality water is found in perched aquifers above the zone of saturation. Consequently, most water wells are bottomed in these perched aquifers, whereas, because of the generally high mineral content of the water in the zone of saturation, few wells yield water from this zone and little is known about its hydrology.

Water in the bedrock consists of an upper zone of better quality water and a lower zone of highly mineralized water (fig. 12). A zone of mixing is present between the zones of better and poorer quality water. Water that has infiltrated into the bedrock takes three divergent paths: (1) some of it migrates upward into the shallow alluvium and is lost by evapotranspiration, (2) some mixes with the deeper, poorer quality water that forms most water in the zone of saturation (this water discharges mainly into the Arkansas River, the North Canadian River, the Canadian River, and Deep Fork), and (3) a small part may continue on through the bedrock and discharge beyond the limits of Okmulgee County.

Generally ground water is under artesian head. Wells may penetrate water at depths from 200 to about 300 feet, but water commonly will rise to within 40 feet of the surface. Most wells in the bedrock yield enough water only for domestic use, and numerous dry wells have been drilled. The few localities where water is present in large amounts in the bedrock are fault controlled and are restricted areally.

The low permeability of the bedrock is indicated by the small amount of leakage from the surface-water reservoirs. Lake Henryetta on the dip slope of sandstone 6 of the Senora Formation, SW¼ sec. 19, T. 11 N., R. 13 E., a small reservoir on the dip slope of sandstone 3 of the Calvin Formation, and Lake Okmulgee on the dip slope of sandstone 12 of the Wewoka Formation do not leak appreciably despite the fact that at places the sandstones of the Calvin and Wewoka Formations are relatively permeable. Silt and clay brought into the reservoirs have settled to form a clastic blanket, which further reduces infiltration into the bedrock formations. The small amount of ground-water leakage into coal mines is another indication of the low permeability of the confining beds in the bedrock.

A pumping test that indicates the sustained yield of one of the higher yielding sandstones of the bedrock was made in NE¼ sec. 30, T. 15 N., R. 12 E., by the town of Beggs.* The well was drilled to a depth of about 240 feet and cased to approximately 160 feet.

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* Test data from unpublished note by S. L. Schoff, U. S. Geological Survey, and from R. W. Steinman, superintendent of water department, Beggs.

This should place the open hole in sandstone 22 of the Wewoka Formation, one of the more highly productive sandstones in Okmulgee County. The well was pumped continuously for periods of 8 to 10 days at an average rate of about 22 gpm. The static water level of the well was 14 feet below the surface. Pumping induced a drawdown of 201 feet, indicating a specific capacity of 0.11 gpm per foot of drawdown, an extremely low value. The pumping caused water-level declines in wells as much as a mile away and the water levels of nearby wells were greatly lowered. A well of Purl Rohl, half a mile to the west of the pumping well, has a total depth of 216 feet with the pump set at 205 feet. Rohl reported that his well had never been pumped dry with his pump; however, during the testing, water could be pumped only for periods of 15 to 30 minutes.

The Wewoka Formation, despite the fact that it is a relatively prolific aquifer, is not usable as a source of municipal water, as indicated by the excessive drawdown in the test well and in nearby observation wells. This test helps verify the conclusions reached from other evidence in this investigation that the water yields from sandstones of the bedrock are adequate only for domestic and stock uses.

Within the water-yielding sandstone beds, a relationship exists between the massiveness, grain size, sorting, and topographic elevation of the beds and the quantity and quality of water available. Small differences in the size, sorting, and massiveness of the sandstones result in considerable differences in the nature of weathering of the beds. The massive beds that are coarser grained and better sorted erode to form long strike ridges with steep scarp slopes and gentle dip slopes. In places the beds most resistant to weathering form rugged dissected upland areas covered with post oak and blackjack. The most striking examples of these ridge formers are sandstones of the Wewoka Formation, which strikes across the central part of the county (pl. I). On the other hand, the thinner bedded, silty sandstones that are poorly sorted and fine grained form relatively flat featureless plains. The gentle dip and scarp slopes of the plains are hardly recognizable in the field. The better sorted, massive, ridge-forming sandstones contain greater amounts of better quality water than do the poorly sorted, thin-bedded sandstones of the plains for five reasons. First, better sorting results in greater porosity and permeability. Second, the better sorted sandstones weather into a young sandy soil with ill-defined horizons in contrast to the poorly sorted sandstones which form a silty clayey soil with a moderately well-developed B horizon; the sandy soils permit infiltration, whereas the silty clayey soils retard it. Third, because of their topographic prominence, the better sorted sandstone beds have greater hydrostatic heads between recharge and discharge areas than do the topographically subdued poorly sorted sandstone beds; this results in more rapid ground-water movement and greater depth of flushing so that the water in the better sorted sandstones is generally much less mineralized. Fourth, the better sorted sandstones are generally more extensively fractured and jointed at the surface, resulting in greater recharge and storage (fig. 14). Fifth, the dip slopes of the ridge formed by the better sorted sandstones expose larger areas of rock for recharge than do the dip slopes of the lower topography formed by the poorly sorted sandstones (fig. 14). Although figure 14 refers specifically to the Calvin and Senora Formations, the relationships shown apply to most of the massive well-sorted sandstones rather than to the thin-bedded poorly sorted sandstones in the county.

The differences in water-bearing characteristics of the two sandstone types discussed above are economically important. Most wells penetrating the better sorted sandstones yield enough water of good quality for domestic use; whereas most wells penetrating poorer sorted sandstones, such as the Senora Formation, do not.

Although wells bottomed in bedrock aquifers obtain small amounts of water, the wells generally have sustained seasonal and long-term yields that are not affected by climatic changes. On the other hand, some wells of the bedrock and many wells in the older alluvium and shallow younger alluvium are the so-called wet-weather type. The wet-weather wells yield water satisfactorily during the normal, humid climatic cycle, but the wells go dry during a dry climatic cycle, such as the one during the years 1951-1957. The wet-weather wells are shallow and their aquifers generally have a small recharge area. Wells drilled into the deeper bedrock normally are not affected by changes in the climatic cycles and therefore have sustained yields. Bedrock wells should not be drilled near the limiting rechrage areas that are near the scarp slopes of the bedrock sandstones nor into aquifers of upland sandstones that have been extensively dissected.

The previously mentioned relationships of ground water to lithology and topography are generalized, and great differences occur in amount and quality locally. Even in sandstones of fairly high yield, such as those in the Calvin Formation, the yields of water vary considerably. Numerous dry holes have been drilled in the Calvin Formation, some close to high-yielding wells. One example is in NW¼ sec. 19, T. 12 N., R. 13 E., where coal has been mined in the subsurface. Mr. Morgan, a local resident, reports a dry hole drilled about 100 feet from a relatively large-yielding well. The latter well penetrated a coal drift, and the hole had to be cased and cemented to prevent flooding of the mine. Conversely, in a relatively low-yielding formation, such as the Senora, areas of high yield are present.

The large differences in water yields of the bedrock formations are reflections of differences in permeability. Such differences appear to result from two major causes: (1) erratic conditions of cementation in the sandstones and (2) the influence of fractured

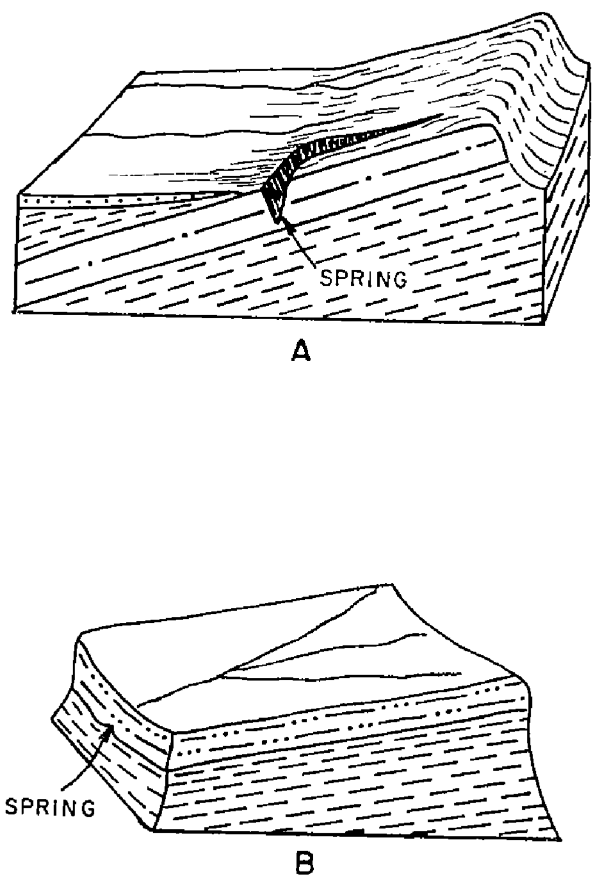


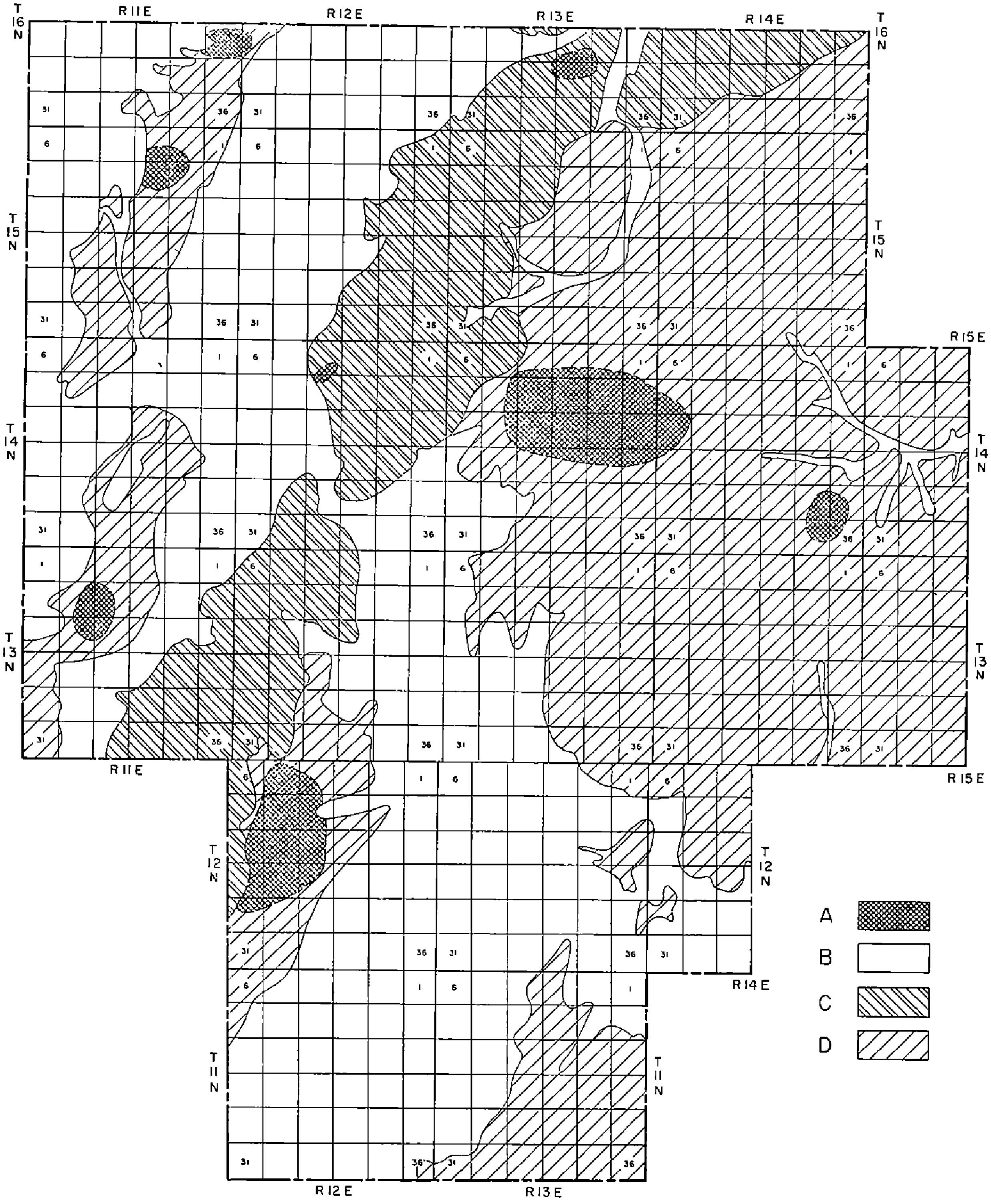
Figure 15. Typical bedrock springs in Okmulgee County.
A. Stream trenching perched water table in sandstone
B. Mesa spring at structural and topographic axis

zones on the occurrence of water. Calcium carbonate is the cementing agent in the sandstones of Okmulgee County. Where the carbonate cement has been removed and the permeability is high, the sandstones can yield considerable amounts of water. In other places the carbonate cement fills the pore spaces and forms an impermeable coherent zone in which little ground water is present. The unusually high yields of ground water occur in the fractured zones of the bedrock. Faulting appears to be the major factor causing high water yields from the Senora Formation in parts of T. 13 N., R. 14 E. The fault zone passes diagonally through sec. 2, T. 13 N., R. 14 E., and northward through sec. 36, T. 14 N., R. 14 E. The water yields in the southern part of the fault zone are greater than 500 gph, whereas elsewhere the Senora Formation normally yields 10 to 150 gph. High yields in the Senora Formation that may be the result of faulting have been reported in NW¼ sec. 33, T. 14 N., R. 14 E. Unusually high yields in the Calvin Formation occur in parts of secs. 5, 6, T. 11 N., R. 12 E. In this area wells have been reported with yields of 1,500 to 3,000 gph in an area where yields are normally 10 to 300 gph.

Numerous springs occur on the dip slopes of the sandstone strata. Figure 15A shows a spring debouching in a stream valley which has been cut below the water table of a perched water body on the dip slope of a sandstone bed. The springs are generally some distance down the dip slope, the recharge area being the upper part of the slope. Springs are more common upon the dip slopes of well-sorted sandstones than upon dip slopes underlain by poorly sorted sandstones. Some springs are caused by changes in permeability arising from erratic distribution of cement or from transition from fractured and faulted rock to relatively undisrupted rock. The springs generally yield only a few gallons a minute and some have been impounded for local use.

An example of a spring flowing from the dip slope of a permeable sandstone is in S½ NW¼ sec. 3, T. 11 N., R. 12 E., where it emerges from sandstone 6 of the Calvin Formation. At this place the Calvin is a fine- to medium-grained well-sorted quartz sandstone; the grains are well rounded and are dominantly medium-sized. The spring is impounded and is reported to take six hours to replenish withdrawals of 700 to 1,000 gallons.

Mesa springs, or butte springs, are also found at a number of places in the county where resistant permeable sandstones cap isolated buttes. The total recharge of the buttes is commonly discharged from a single spring (fig. 16) such as the spring issuing from a butte northwest of Dewar in SE¼ sec. 33, T. 12 N., R. 13 E.



Contamination of Bedrock Aquifers

Most of the naturally occurring highly mineralized water is in the bedrock rather than in the alluvium. Meteoric water readily flushes contaminated water from the alluvium. Contaminated water is flushed more slowly from the bedrock or even may be trapped there.

Part of the highly mineralized water present in otherwise potable-water zones is the result of contamination by oil-well brines. This type of contamination can occur in the areas adjacent to oil wells, as in E½ T. 12 N., R. 12 E., or it can occur at considerable distances from the oil wells causing the contamination. In the areas adjacent to oil wells contamination is caused principally in three ways. (1) If the brine is discharged into shallow pits or ponds, the highly mineralized water may seep into the aquifers. (2) If the brine is discharged into deeper aquifers, leakage may occur through defective casing. (3) Contamination may result from water-flooding operations. Many unplugged open holes are present in Okmulgee County, wells which were drilled in the early days of oil exploration. Many of these abandoned holes have not been recorded. Water-flooding operations may force highly mineralized water up the abandoned holes into the potable-water zone. Water also can be forced up holes that are improperly plugged and cause contamination of the potable-water zones.

If oil-well brine is discharged into streams, it may flow down the stream and into the water-bearing horizons at a considerable distance from the oil wells that cause the contamination. This type of contamination is in part the cause of pockets of highly mineralized water in the otherwise potable-water zones.

Figure 16. Map of Okmulgee County showing distribution of quality of water.

A. Area of highly mineralized water

B. Area of generally potable water; better than average chance of obtaining water containing less than 1,000 ppm total dissolved solids

C. Area of erratic distribution of water quality; average chance of obtaining water containing less than 750 ppm total dissolved solids

D. An area of relatively highly mineralized water; better than average chance of obtaining water containing more than 1,000 ppm total dissolved solids

Some contamination is apparently due to natural causes because no oil wells are known to have been drilled nearby and because older residents report that the water has always had a high mineral content. One such area apparently is the northern part of the county in S½ T. 16 N., R. 13 E. (fig. 16). The major cause of natural contamination is probably the slow movement of ground water. Another cause may be the upward movement of highly saline water along fault zones. Some of the salt water in the deeper horizons is under high hydrostatic pressure. Bottom-hole-pressure tests indicate that the saline water in the Arbuckle Group could rise to an absolute elevation of 300 to 450 feet. Little information could be obtained on hydrostatic levels of water in other deeper formations. If water from the Arbuckle Group or water from other formations that is subjected to high hydrostatic pressure could percolate upward through fault zones, the water could contaminate some of the shallow aquifers or the basal parts of some of the shallow aquifers.

One purpose of the quality-of-water study in Okmulgee County was to determine if areas of oil-well-brine contamination could be differentiated from areas of natural contamination. A well in which water has been definitely contaminated by oil-well brine is in SE¼ SE¼ sec. 19, T. 12 N., R. 12 E. Water from this well can be compared with water from a well penetrating an aquifer that is contaminated from natural causes, such as one in NW¼ NE¼ sec. 28, T. 16 N., R. 13 E. Both wells have waters of high mineral content but the waters differ in their percent sodium, sodium absorption ratio, and sodium-chloride ratio. Percent sodium is calculated as the percentage of sodium in the sum of the cations of sodium, potassium, calcium, and magnesium, expressed in equivalents per million (epm). The sodium absorption ratio (SAR) is a number derived by dividing the square root of one-half the sum of calcium and magnesium into the amount of sodium, all expressed in equivalents per million. The sodium-chloride ratio is the ratio between the sodium ions and chloride ions expressed in parts per million (ppm). Ground water contaminated by oil-well brine has higher values of percent sodium and SAR, and lower values of sodium-chloride ratio than has water from the well contaminated by natural causes. Brine-contaminated water has a percent sodium of 95, a SAR of 44, and a sodium-chloride ratio of 8. The water from naturally

TABLE VII. CHEMICAL ANALYSES OF WATER FROM WELLS IN OKMULGEE COUNTY

(All analyses except 15.12.30.230 made by Quality of Water Branch, U. S. Geological Survey. Except as otherwise indicated all values are parts per million).

Location number	Date of collection	Stratigraphic unit	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25° C)	pH
																	Calcium magnesium	Noncarbonate				
11.12. 7.220	1-21-61	ℙcv	13	.00	11	6.9	166	2.0	284	8	54	75	.5	1.4	.34	483	56	0	86	9.6	792	8.4
12.12.19.440	1-21-61	ℙwk			26	16	1170		606	0		1440					132	0	95	44	5270	8.1
12.12.21.120	1-21-61	ℙcv			4.0	.5	494		464	16		385					12	0	99	62	1900	8.6
13.11. 8.100	1-19-61	ℙsi			18	4.6	10		80	0		12					64	0	26	.6	162	7.1
13.11.11.120	1-19-61	ℙhd	17	.00	144	48	75	1.9	378	0	356	38	.4	1.2	.15	917	555	245	23	1.4	1210	8.2
13.15. 3.313	1- 4-61	ℙsn			19	11	504		286	0		660					92	0	92	23	2500	8.2
13.15. 4.444	1- 4-61	ℙsn			31	7.4	10		62	0		52					108	57	17	.4	286	7.3
14.11. 6.111	1-12-61	ℙcf			380	341	1200		240	0		820					2350	2150	53	11	7630	8.1
14.11.10.112	1-13-61	Qts			59	15	30		48	0		72					210	170	24	.9	612	7.2
14.13.31.220	1-19-61	Qt	21	.00	78	40	73	1.0	270	0	266	20	.5	.0	.30	663	360	138	31	1.7	921	8.1
14.13.36.133	1- 3-61	ℙcv			42	20	94		126	0		47					186	82	52	3.0	837	7.6
14.14.19.110	1-19-61	ℙsn			472	171	277		176	0		13					1880	1740	24	2.8	3370	7.8
14.14.33.130	1-19-61	ℙsn	17	.00	192	68	370	2.5	436	12	758	230	.3	28	.23	1930	760	382	51	5.8	2600	8.3
14.15. 5.444	1- 6-61	ℙsn			2.4	1.0	32		56	0		5.5					10	0	87	4.4	194	7.6
15.11.23.440	1-11-61	ℙsi			24	15	54		200	8		39					120	0	49	2.1	492	8.5
15.11.27.110	1-11-61	ℙsi	11	.01	38	56	290	1.8	678	30	104	148	.6	60	1.9	1100	324	0	66	7.0	1750	8.6
15.12. 6.440	1-18-61	ℙsi			260	275	282		516	0		30					1780	1360	26	2.9	3490	8.0
15.12.30.230	7- -48	ℙwk	12		6.8	4.7	Na + K = 575		528	8	12	585	.7	.2		1460					2580	
15.14.34.220	1- 8-61	ℙsn			70	25	47		232	0		78					276	86	27	1.2	715	7.5
15.14.34.220	1- 6-61	ℙsn			22	48			550	16		240					252	0	68	6.9	1560	8.6
16.13.28.210	1-18-61	ℙwk			380	188	97		178	0		62					1720	1570	11	1.0	2780	7.8
16.14.32.444	1- 7-61	ℙcv			26	44	196		272	0		63					244	21	64	5.4	1250	8.2

occurring contamination has a precent sodium of 11, a SAR of 1, and a sodium-chloride ratio of 1.56. The sodium-chloride ratios ranged considerably in value for the samples collected; therefore, the ratio should be used in conjunction with the percent sodium and SAR for determination of source of contamination.

With the above criteria, the following conclusions can be reached. Probably the entire area of high mineralization in E½ T. 12 N., R. 12 E. (fig. 16) has been contaminated by brine from oil wells. A spot check on another well in the area (Mr. Henry's well in NE¼ NW¼ sec. 21, T. 12 N., R. 12 E.) shows evidence of contamination (table VII). Many of the smaller areas of high mineralization in the Senora Formation are the result of contamination from oil-well brines. For example, two isolated areas, one in SW¼ NW¼ SW¼ sec. 3, T. 13 N., R. 15 E., and the other in NE¼ NE¼ sec. 34, T. 15 N., R. 14 E., show evidence of oil-well contamination (table VII).

The conditions of contamination in the well-sorted, massive sandstones are different from those in the poorly sorted, thin-bedded sandstones. In the more permeable massive sandstones contamination of the brine diffuses rapidly and infiltrates relatively large areas; whereas in the poorly sorted, thin-bedded sandstones the areas of contamination appear to be more restricted and erratic. For example, the sandstones of the Wewoka, which are perhaps the most permeable of the Pennsylvanian sandstones, are characterized by large areas of contamination. The area of mineralized water in E½ T. 12 N., R. 12 E., covers a relatively large area, and apparently most of the deeper water zones in the Wewoka have been contaminated. On the other hand contaminated water in the Senora Formation occurs as isolated pockets, most of which are not shown on figure 16. Because of low permeability, thin bedding, and low hydrologic gradient, the contaminated water in the Senora Formation has not had time to diffuse over large areas. The low permeability of the Senora also causes highly mineralized water to be adjacent to weakly mineralized water. For example, a well which produces contaminated water from the Senora in NE¼ NE¼ sec. 34, T. 15 N., R. 14 E. (Clarkson's well) is only about two hundred feet from a well producing relatively fresh water (Cullen's well) (table VII). Both Clarkson's and Cullen's wells were drilled to depths of about 30 feet. Another area of the Senora in which highly mineralized water is adjacent to weakly mineralized water is in secs. 3, 4, T. 13 N., R. 15 E., as shown on table VII.

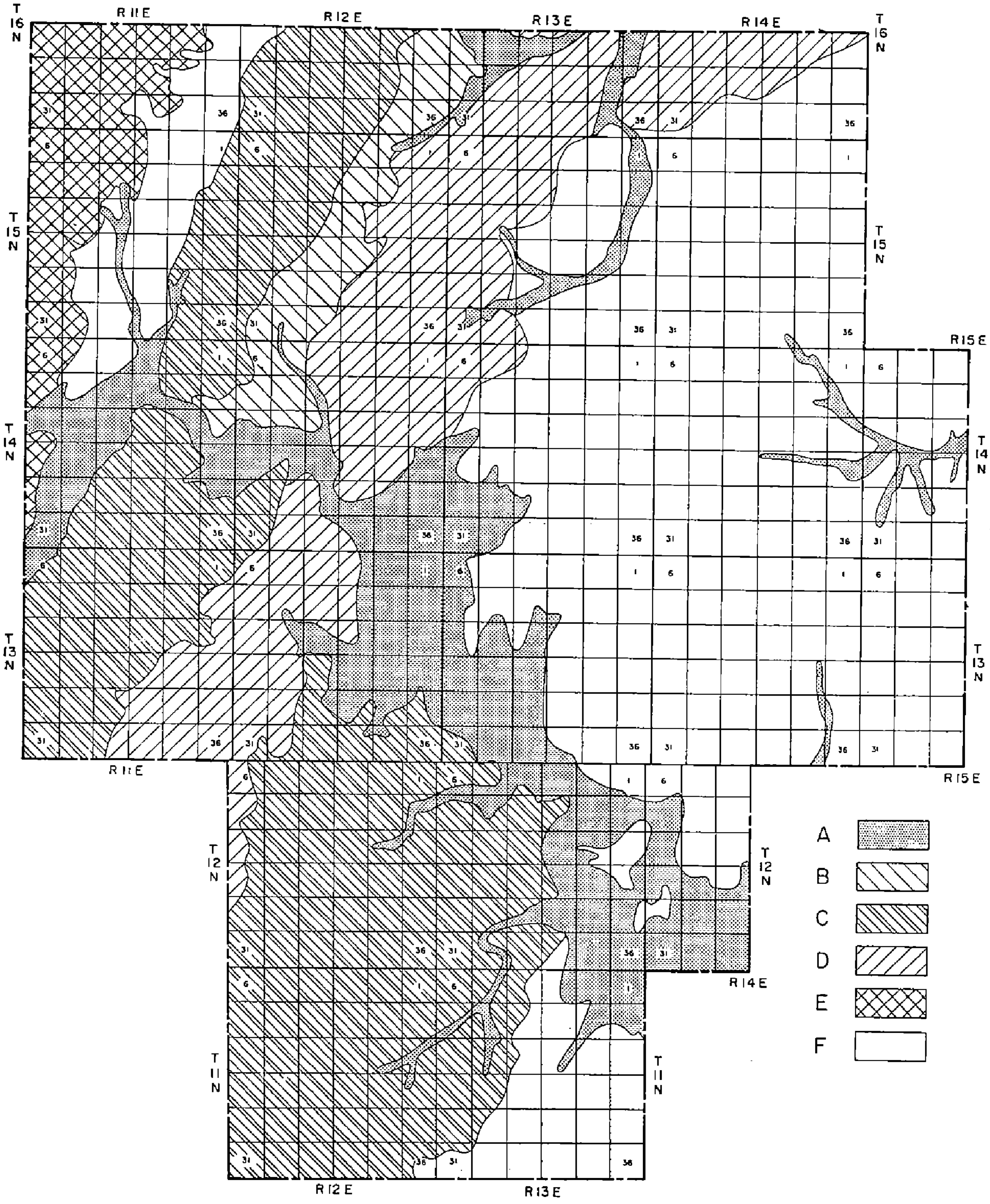
Water-bearing Characteristics of the Bedrock Formations

In this discussion of the water-bearing characteristics of the bedrock formations, the values given for water quality are those obtained from the usable potable-water zones. All formations have more highly mineralized water at depth. The yields given are the average yields of wells penetrating the formations and were obtained from short periods of pumping; they are not the yields from sustained pumping.

Senora Formation

Although water in the Senora Formation is of poor quality and the yields are small, the Senora must be classified as one of the important water-bearing formations in Okmulgee County because of its extensive areal exposure and because of the large areas underlain by its aquifers. The Senora Formation is predominantly shale and siltstone interbedded with thin- to medium-bedded sandstone. The sandstone is poorly sorted, containing predominantly very fine- through medium-sized grains and an abundance of silt and mica. The Senora has a greater permeability parallel to the bedding than across it. Because of its thinly bedded silty nature, it erodes to form flat featureless plains with low relief. The yield of water in the Senora ranges from almost zero to about 1,000 gph; however, the average yield of producing wells is from about 5 to 150 gph (fig. 17). Numerous dry wells have been drilled in the Senora, and there is less than average chance of obtaining satisfactory yields of water for domestic and stock uses. Yields of 1,000 gph and greater are probably the result of fracturing in bedrock, and can be maintained only for short periods of time. The depth of water-bearing beds in the Senora ranges from 20 to 150 feet, the average being between 30 and 100 feet.

Most ground water in the Senora Formation is under artesian conditions and will rise in the drill hole to within 10 to 50 feet of the surface. The depth to salt water ranges from 75 to 125 feet although a few wells will yield potable water from depths greater than 125 feet. One such well in NW¼ sec. 22, T. 15 N., R. 14 E., is reported to produce potable water from a depth of 150 feet. The shallow depth to salt water is in part related to small topographic relief and small differences in elevation of the recharge area, the zone of saturation, and the discharge area. Because of the lower hydraulic



gradient and the slow movement of water, parts of the Senora Formation have not been completely flushed by ground water and the water is therefore generally more highly mineralized than is that in most other bedrock formations. Incomplete flushing is also a consequence of the small size of the grains in the silty sandstone, which retards ground-water movement allowing the water to pick up the mineral constituents and keep them in solution. The incomplete flushing also has resulted in some isolated areas of high mineralization. Other areas of highly mineralized, impotable water in the Senora are probably the result of contamination by oil-well water and by movement of highly mineralized water upward along faults as discussed in the section on occurrence of water in the bedrock. In a few places the mineral content of water in the Senora is as low as 150 ppm; however the average mineralization ranges from about 500 to 1,500 ppm. Water containing between 1,500 and 2,000 ppm total dissolved solids is used from numerous wells. If adequate amounts of water of satisfactory quality are not found in the first water-yielding zone, it is fruitless in most cases to drill farther because the deeper water is almost everywhere of poor quality (fig. 12). Because of the low yields and the poor quality of water in the Senora Formation, surface-water supplies, rather than ground-water supplies, are commonly used in the areas underlain by Senora aquifers.

Calvin Formation

The aquifers of the Calvin Formation, one of the important water-bearing formations in Okmulgee County, underlie a large area of southern Okmulgee County (fig. 11) and water from the Calvin is generally of good quality and of sufficient amount for domestic and stock purposes. Whereas the Senora Formation is

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Figure 17. Ground-water yields in Okmulgee County. Maximum yields are adequate for stock and domestic uses only.

A. Better than average chance of producing adequate amounts of water; yields average between 25 and 500 gph
B. Good chance of producing adequate amounts of water; yields average between 25 and 400 gph
C. Better than average chance of producing adequate amounts of water; yields average between 10 and 300 gph in the southwestern part; slightly less in central and northwestern parts
D. Erratic yields ranging from adequate to inadequate
E. Average chance of producing adequate amounts of water; yields between 15 and 200 gph
F. Less than average chance of producing adequate amounts of water; yields average between 5 and 150 gph

typical of the low water-yielding formations, the Calvin Formation is typical of the high water-yielding formations. The water-bearing, lithologic, and geomorphic relationships of the Calvin and Senora Formations are shown on figure 14. Generally, the sandstones of the Calvin Formation are better sorted and contain less silt than do the sandstones of the Senora Formation. The well-sorted sandstones range from a fine- to medium-grain size. Sandstones of the Calvin Formation have considerable permeability normal to the bedding planes in contrast to the sandstones of the Senora Formation, whose dominant permeability is parallel to the bedding planes. Water is absorbed readily by a typical hand sample of the massive Calvin Sandstone. Because of its better sorting, larger grains, and massive character, the Calvin is exposed as a series of prominent topographic ridges, whereas the major part of the Senora underlies a plain of low relief. The higher elevations of the sandstone ridges produce a greater hydraulic head of the water in the Calvin aquifers, which results in deeper and more extensive flushing of the aquifer. For these and other reasons discussed in the section on occurrence of water in the bedrock, water in the Calvin is present in larger amounts and is of better quality than is water in the Senora.

The water yields in the Calvin range from zero to about 4,000 gph; however, the average is between 10 and 300 gph. The higher yields of water can be sustained for only a short time. Generally wells of satisfactory yield may be obtained in the Calvin downdip from the crest of the topographic ridges. The depth to water in the Calvin Formation ranges from about 20 to 350 feet; however, the average is between 25 and 200 feet. Salt water is encountered at greater depth in the Calvin than in the Senora, generally between 175 and 225 feet, and as much as 350 feet in some places. The water is under artesian conditions and rises in the hole to within 10 to 50 feet of the surface. Although the quality of its water ranges widely, the Calvin yields some of the most potable water from the bedrock. The water has an apparent range from about 275 to 1,500 ppm total dissolved solids. Areas of more highly mineralized water occur in scattered places, one being along the Schulter anticline. Because of the better water quality and greater yields of wells, ground-water development is greater in the Calvin than in the Senora. However, not all beds or all parts of the same bed of the Calvin are equally permeable. For example, in some areas of sandstone 4 of the Calvin Formation the bed is relatively impermeable, whereas in other areas it is permeable. Sandstone 4 of the Calvin Formation in SW¼ sec. 22, T. 11 N., R. 12 E., appears to be fairly permeable. A spring is present in the alluvium of the strike valley along sandstone 4 and some stock ponds in the alluvium have been dug into the water table.

The abundance of water in the shallow alluvium indicates considerable recharge from the underlying sandstone 4 of the Calvin Formation. On the other hand, in NE¼ sec. 1, T. 11 N., R. 12 E., sandstone 4 appears to be considerably less permeable. The Calvin changes in lithologic and water-yielding characteristics northward along the strike of the beds. To the north, the Calvin thins as a unit and the sandstones become finer grained and more silty. In this region, the water-bearing qualities of the Calvin Formation more closely resemble those of the Senora and therefore the Calvin is here included in the Senora ground-water province. The water is more highly mineralized than it is to the south; the yield of water is less; and the fresh-water zone is thinner. Under a large area of the northwestern part of T. 15 N., R. 14 E., the depth to salt water has been reported to be less than 50 feet.

Wewoka Formation

Despite a wide range and erratic distribution of quality of water, the Wewoka is one of the important water-bearing formations of Okmulgee County. The Wewoka aquifers underlie much of the county, and in many places they yield abundant supplies of water for domestic and stock uses. In this discussion the Wetumka and Wewoka Formations and their aquifers are treated as a single hydrologic unit, the Wewoka aquifer (fig. 11). In places the Wewoka contains potable drinking water; however in other places it contains highly mineralized water. Wells in the Wewoka have greater yields of water than do those in any other formation in Okmulgee County. Many of the sandstones in the Wewoka are well sorted, well rounded, and predominantly fine to medium grained. Hand specimens of the Wewoka absorb fluids quickly, indicating high permeability. The Wewoka Formation erodes to form prominent ridges in central Okmulgee County (pl. I). In the north-central part of the county the Wewoka underlies a well-dissected highland in contrast to the long gentle dip slopes and abrupt scarp slopes of the southwestern part of the county. The fragmented, dissected upland area does not appear to be so good a source for ground water as does the area to the east where the Wewoka gently plunges into the subsurface. Water occurs in a somewhat erratic manner in the fragmented, dissected upland area, where some wet-weather wells are bottomed in the perched aquifers in the Wewoka Formation.

In the subsurface in the east-central and north-central part of Okmulgee County, the Wewoka is the highest yielder of water (fig. 17). In this area the water yield appears to range from 25 to 400 gph. In some respects the water yield of the Wewoka is similar to that of the Calvin but it has more high-yielding wells, many yielding more than 300 gph. Most wells penetrating the Wewoka Formation yield adequate amounts for domestic and stock uses.

The depth to water ranges from about 25 to 250 feet, generally between 25 and 125 feet. At most places, water in the formation is under artesian pressure. The water in the Wewoka that is used for domestic and stock purposes ranges from about 150 to 2,000 ppm total dissolved solids, many wells yielding water having between 1,000 and 2,000 ppm total dissolved solids. Local residents report that, before the development of oil fields, potable water was obtained in places from the Wewoka at depths from 300 to 400 feet. Oil-well brine has contaminated water in the deeper aquifers, and today few wells yield potable water from depths greater than 200 feet. The contamination of the Wewoka has greatly reduced its usefulness as a ground-water aquifer. One of the areas most severely affected by brine contamination is in T. 12 N., R. 12 E. (fig. 16). The ground water in this area, reportedly potable in the past, now has a mineral content (mostly sodium chloride) as high as 3,700 ppm.

In this report the Wetumka Shale is considered to be poorly permeable and not a water yielder in Okmulgee County. The Wetumka forms a confining bed for sandstones 5 and 6 of the Calvin Formation under large areas of the county. The formation reaches a thickness of 225 feet in the southern part of T. 15 N. and of 100 feet in T. 12 N. Because of the thickness of the shale, the Wetumka forms an effective confining bed that retards upward percolation of water and, consequently, few springs are in the areas covered by the shale.

Holdenville Shale

Because of the excellent quality of the water it contains, the

Holdenville Shale must be considered one of the important aquifers of Okmulgee County, despite its limited areal extent. The water is less highly mineralized than is water in either the underlying Wewoka Formation or in the overlying Seminole Formation.

Most of the sandstone beds in the Holdenville have moderately well-sorted and well-rounded sand grains. Sandstone 7 of the Holdenville, which is an excellent aquifer in the northwestern part of the county, has the following characteristics in the Beggs area. The quartzose sandstone is about 5 feet thick, well sorted, well-rounded, and very fine to fine grained. The field samples show high permeability. Topographically the Holdenville does not form the prominent uplands of the Wewoka; however, the Holdenville forms more pronounced ridges and scarps than does the Seminole Formation. The Holdenville erodes to moderate relief, forming long gentle dip slopes and somewhat abrupt scarp slopes. Sandstones of the Holdenville, such as sandstone 7, have fair yields where they are extensively exposed and also have fairly large recharge areas. Parts of the formation have been considerably dissected, forming numerous buttes in the east-central part of the county (Tps. 13, 14 N., R. 11 E.). Despite its dissection in this part of the county, the formation yields fair amounts of potable water that are adequate in many places for domestic use. Water yields range widely in the Holdenville. The yields range from small to more than 1,000 gph, with the average between 10 and 250 gph. Some of the larger yields are obtained from sandstone 7, which is a large, continuous, widely exposed sandstone unit. In most places water in the Holdenville is under artesian pressure and rises in the hole to within 10 to 50 feet of the surface. It is generally of suitable quality for domestic purposes, although locally the water may have a high mineral content. The total-dissolved-solids content ranges from about 300 to 1,000 ppm. Highly mineralized water is present in the Holdenville in the central part of T. 16 N., R. 12 E.

Seminole Formation

The Seminole Formation is not an important aquifer in Okmulgee County because it yields small amounts of water of poor quality. The Seminole aquifer is somewhat restricted areally (fig. 11). Generally, sandstones of the Seminole Formation contain much silt, which greatly reduces their permeability. In large areas of the northern parts of the county the formation erodes to a relatively flat, almost featureless plain, where the dip slopes on the plain have gentle relief. In some parts of the county the Seminole has greater relief. For example, in Tps. 13, 14 N., sandstone 1 of the Seminole Formation has eroded to a prominent dip slope, forming a heavily wooded upland area. However, even where the Seminole has greater relief, the water yield is erratic and low. Generally, the yield of a single well in the Seminole is not sufficient for domestic purposes. The depth to potable water in the formation ranges from about 15 to 150 feet. Most wells penetrate potable water at depths less than 100 feet. Water in the Seminole is generally under artesian pressure and rises to within 5 to 50 feet of the surface. The mineral content of water ranges widely in the Seminole; however, it is considerably higher than that of water in the underlying Holdenville. Water from few wells in the Seminole contains less than 700 ppm total dissolved solids; however, most water used for domestic and stock purposes ranges from about 700 to 2,100 ppm. Water is reported to be deteriorating in quality in a deeper aquifer of the Seminole in the northeastern part of T. 15 N., R. 11 E. It is reported that twenty-five years ago fresh, potable water was obtainable in this area from the Seminole at depths between 250 and 300 feet. Today potable water is present only at depths less than 100 feet. The water has probably become more highly mineralized from contamination by oil-well brines. A few springs are present in the Seminole in the sandstones forming the dip slopes. Many of the springs in the Seminole Formation are utilized locally. Such a spring is on the dip slope of sandstone 1 of the Seminole Formation in SE¼ SW¼ sec. 7, T. 15 N., R. 12 E. It yields about 50 gph; the water has a mineral content of about 325 ppm total dissolved solids, which is low for the Seminole.

Coffeyville Formation

Because of limited areal extent, low water yield, and high mineral content of its water, the Coffeyville Formation is not an important water producer in Oklahoma County. Coffeyville sandstones 1, 2, 3, and 4, and parts of sandstone 5 have low permeabilities because they are thin bedded, contain considerable amounts of silt, and erode to form relatively flat, featureless plains. The plains are a part of the Northern Lowland ground-water province (fig. 18).

Low yields ranging form 5 to 150 gph are produced from wells drilled in the lowland area of the Coffeyville. In a few places, the yield may be as high as 500 gph; however this is exceptional and in places the yield is too small even for domestic purposes. An area

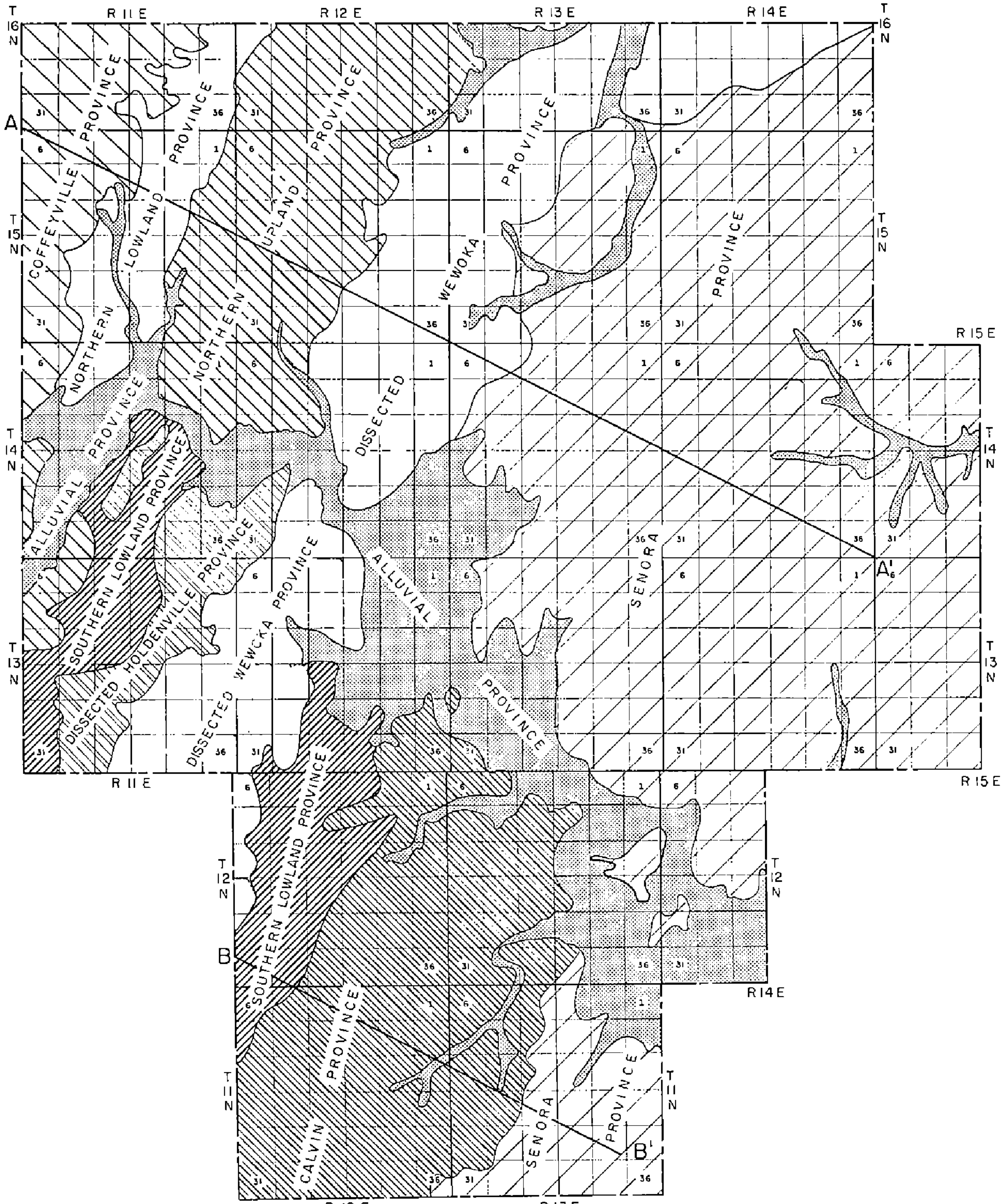

Figure 18. Major ground-water provinces of Okmulgee County.

of low yield to which water must be hauled is in parts of sec. 16, T. 15 N., R. 11 E. The quality of water of the Coffeyville in the area of the flat, featureless plains is poor. The water used for domestic and stock purposes ranges from about 1,000 to 2,000 ppm total dissolved solids. An area of impotable water is present in secs. 2, 3, 10, 11, T. 15 N., R. 11 E. The depth to the aquifer was less than 100 feet in all the wells examined. Water generally occurs under artesian conditions and rises in the hole to within 25 feet of the surface. Parts of sandstone 5 and sandstones 6, 7, and 8 of the Coffeyville form prominent ridges rather than the relatively featureless plains of the basal units. These upper sandstones have greater permeability and greater yields of water than have the poorly permeable lower units of the Coffeyville; however the yields of the upper sandstones are not so great as those of the Holdenville Shale. The depth to water is probably less and the water is less highly mineralized in the upper sandstones than in the lower sandstones. In the upper sandstones the depth required to penetrate water probably ranges from about 15 to 200 feet, and the quality of water is generally less than 1,000 ppm total dissolved solids.

Checkerboard Limestone, Hogshooter Formation, and Nellie Bly Formation

In Okmulgee County, no water wells are known from the Checkerboard Limestone, Hogshooter Formation, or Nellie Bly Formation. The Hogshooter and Nellie Bly Formations are present in the northwestern part of the county in a wooded upland area that is poorly accessible. The Checkerboard Limestone and Hogshooter Formation are silty and sandy calcareous units that are less than 10 feet thick and probably contain little water. The ground-water characteristics of the Nellie Bly Formation appear similar to the upper part of the Coffeyville Formation (parts of sandstone 5 and sandstones 6, 7, and 8).

GROUND-WATER PROVINCES OF OKMULGEE COUNTY

Okmulgee County may be subdivided into nine ground-water provinces, delineated on the basis of differences in yield of water, quality of water, and depth to water. Yield and quality are the more important criteria as they determine the usability of ground water. Because all potable water occurs at relatively shallow depths, depth to water is not an important criterion. The boundaries of the ground-water provinces cut across those of ground-water aquifers and of geologic formations in many places. The relationships of gross lithology and topography to ground-water provinces is shown in figure 19, in which it can be seen that in many places the province boundaries are west of the topographic boundaries.

Alluvial Province

The Alluvial ground-water province derives its name from the fact that the province is underlain by younger and older alluvia. It is the most promising of the ground-water provinces for potential ground-water use. Sufficient water may be produced from the alluvia to supply some villages or smaller industries if the isolated higher water-yielding zones are penetrated. However, long-term pumping tests are necessary to determine if the required yield of water can be sustained.

Although numerous isolated pockets of impotable water are present, large areas of the province can yield sufficient water of suitable quality for domestic and stock uses. The more suitable well sites are away from the surface trace of the alluvium-bedrock contact. Generally, the yields of wells range from 25 to 500 gph, although some exceed this range. The total-dissolved-solids content of the water ranges from 400 to 1,000 ppm, and the depth to water ranges from 15 to 100 feet.

Calvin Province

The Calvin ground-water province is so named because it includes the major part of the Calvin Formation in the southern part of the county; the Calvin in the northeastern part of the county is included in the Senora province. Although insufficient for municipal or industrial uses, yields in this area are generally adequate for stock and domestic wells. The water yields range from zero to about 3,000 gph, with the average between 10 and 300 gph. The larger yields can be sustained only for short periods of time. The water appears to have an average total-dissolved-solids content between 275 and 1,500 ppm. The depth to water ranges from about 20 to 350 feet, the average being between 25 and 200 feet.

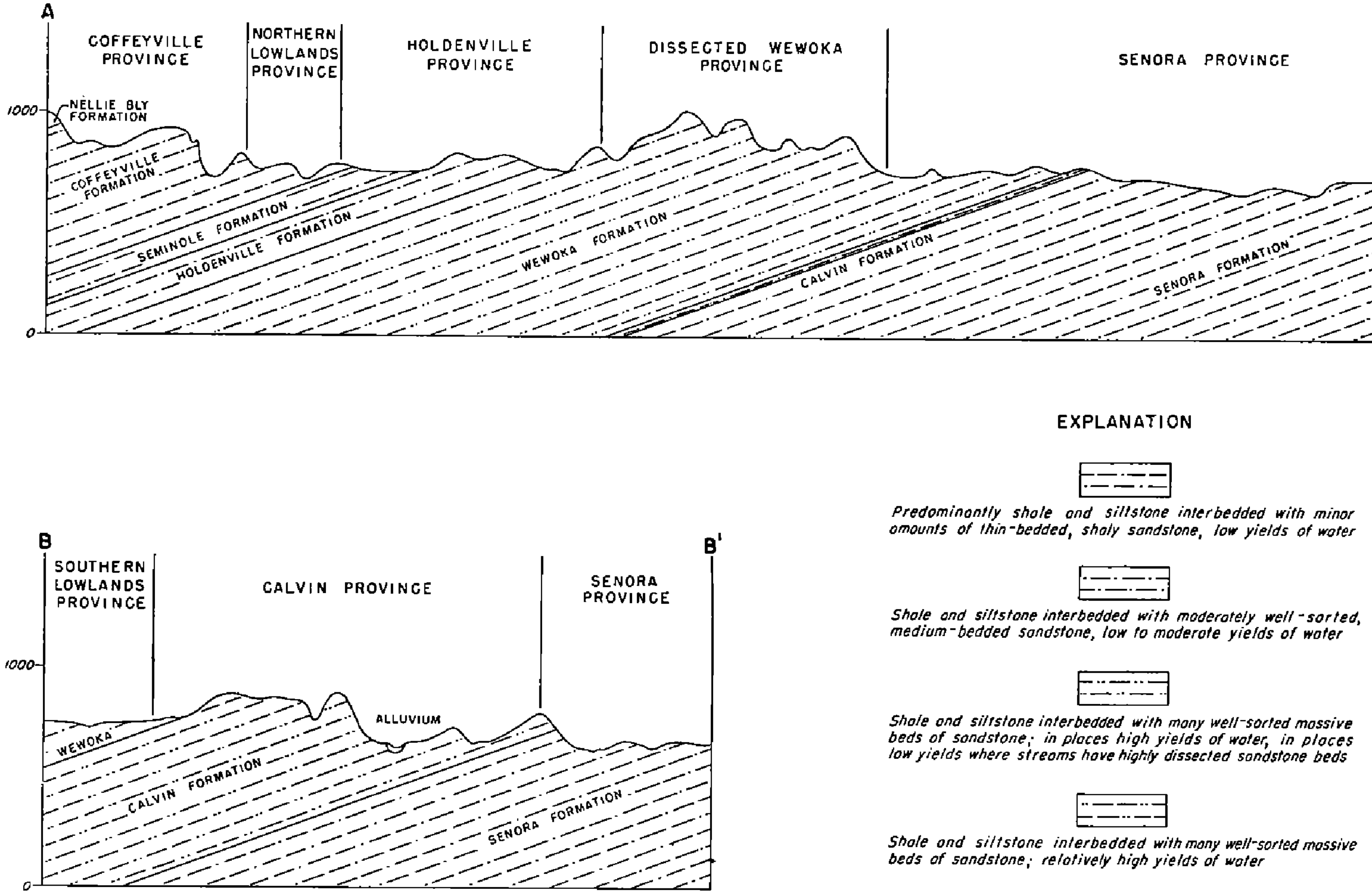

Figure 19. Schematic cross sections along lines A-A′ and B-B′ (fig. 18) showing relationship of gross lithology and topography to ground-water provinces.

Northern Upland Province

The Northern Upland province includes part of the Holdenville and Seminole Formations and the less highly dissected parts of the Wewoka Formation. Generally, the province is characterized by adequate yields of good-quality water suitable for stock and domestic purposes. Some small areas have highly mineralized water (fig. 16) or low yields or both. Yields are greater from the Wewoka aquifers on the eastern side of the province and decrease progressively toward the west where the province is underlain by the Seminole Formation. The yields generally range from 10 to 300 gph, but on the eastern side of the province the average is between 25 and 400 gph. Total-dissolved-solids content of the ground water ranges from 300 to 1,000 ppm, and the depth to water from 15 to 150 feet.

Dissected Holdenville Province

The Dissected Holdenville province is in the west-central part of the county and is named from the dissected outliers of the Holdenville Formation. The isolated exposures form low hills, which rise in places as much as 75 feet above the surrounding plain. Wells drilled in the Dissected Holdenville province generally yield small amounts of good-quality water. However, the yields and quality of water range widely and suitable well sites are not easily chosen. Yields of potable water range from 15 to 250 gph at dephts ranging from 15 to 150 feet. The total-dissolved-solids content of the water ranges from 300 to 1,000 ppm. Generally the better water-well sites are in the lowlands, as the depth to water is greater in the higher areas.

Dissected Wewoka Province

The Dissected Wewoka province is named from the highly dissected nature of the Wewoka Formation, which underlies the province (fig. 18). The Wewoka has been incised and eroded so that the bedrock outliers form heavily wooded high rugged topographic areas. The Wewoka sandstones are fairly massive, and the sand grains, generally well rounded and well sorted, range from very fine through medium size. None of the Wewoka sandstone beds has a large recharge area because they have been eroded into isolated fragments. Consequently little water is obtained from the shallower sandstones in the Wewoka, and one must drill deeper for adequate supplies of water. Little ground-water information is available from this province because few wells have been drilled. From the available information, wells must be drilled from 100 to 300 feet for potable water. In some areas of the province the yields are inadequate for domestic and stock purposes, but other areas have high yields. The northern part of the province seems to be an area of high yield. At no place does there appear to be sufficient water for industrial or municipal purposes. The quality of the shallow water in the Wewoka appears to be excellent with total dissolved solids ranging from about 200 to 1,000 ppm. Water from the deeper units is probably highly mineralized.

Coffeyville Province

The Coffeyville province is so named because parts of sandstones 5, 6, and 7 of the Coffeyville Formation underlie the greater part of the province. A small area in the northwestern part of the province is underlain by the Nellie Bly Formation. Topographically the Coffeyville province is characterized by relatively high upland areas, which are heavily wooded. The area is unfavorable for human habitation; therefore few water wells have been drilled. Generally, although the water is of excellent quality and depth to water not too great (25 to 150 feet), the probability of obtaining adequate supplies for stock or domestic uses is less than average.

Senora Province

The Senora province, the largest of the ground-water provinces, underlies an area in the eastern part of the county (fig. 18). It derives its name from the fact that all of the Senora Formation is included in the province. Also included in the province are parts of the Calvin, Wetumka, and Wewoka Formations in the northern part of the county. The yield of water in the province is too small for municipal or industrial use. Because of low yields and poor quality of ground water, most supplies are from surface sources. Yields of ground water range from zero to about 1,000 gph, but the average yield is between 5 and 150 gph. Large ground-water yields are encountered only in a few faulted areas. Water used for domestic and stock purposes ranges from about 150 to 2,000 ppm in total dissolved solids. As shown on figure 16, areas of highly mineralized impotable water occur within the province. The depth to water ranges from about 20 to 150 feet, with the average between 30 and 100 feet.

Northern Lowland Province

The Northern Lowland province derives its name from the fact that the province occupies a lowland area in the northwestern part of the county. The province is underlain by the weakly resistant beds of the Seminole and Coffeyville Formations. The province is unsuitable for ground-water development because the yields of water are too small and the quality of water is too poor for industrial and municipal purposes and in most places for domestic and stock needs. Water from a few wells has less than 700 ppm total dissolved solids; however the average is between 700 and 2,100 ppm. As shown on figure 16, two areas of impotable, highly mineralized water are present in the province. The depth to water in the province ranges from about 15 to 150 feet but most wells penetrate water at depths of less than 100 feet.

Southern Lowland Provinces

The Southern Lowland provinces consist of two areas, one of which is in the west-central part of the county and the other in the southwestern part (fig. 18). The Southern Lowland provinces are so named because they occupy lowland areas between areas of higher topography in the southern part of the county. The lowland area in the southwestern part of the county is underlain by weakly resistant sandstones and shales of the Wetumka and Wewoka Formations; the lowland area of the west-central part of the county is underlain by weakly resistant sandstones and shales of the Holdenville Formation. The Southern Lowland provinces are considered to have poor potentialities of ground-water use because of low water yield and because of the presence of highly mineralized water. In places relatively large yields of water are obtained from the Southern Lowland provinces which probably would have good potentialities of water use if the quality of water were better. Two areas of impotable, highly mineralized water occur in the southwestern part of the province, and one occurs in the west-central part (fig. 16). The water may have been contaminated by oil-well brines.

RECOMMENDATIONS FOR GROUND-WATER DEVELOPMENT

Large users of water in Okmulgee County must rely on surface-water rather than ground-water supplies because of low yields of ground water. In many parts of the county small users of water find it preferable to develop supplies of surface water rather than supplies of ground water or cistern water for two reasons: (1) in most places there is considerable uncertainty in obtaining adequate supplies of ground water of good quality and (2) there is a greater probability of pollution of water from wells and cisterns. If proper steps are not taken to prevent surface seepage into wells and cisterns, serious pollution may result. The better types of sand-filter systems that have been developed for surface-water supplies are generally safe and reliable.

Advantages of ground-water supplies over surface-water supplies in Okmulgee County are the following: (1) the lower cost of drilling for ground water and of setting up water systems from wells, (2) the feasibility of drilling a well near the location of ground-water use, and (3) availability of continuous supplies of ground water if the amounts of water penetrated are substantial. If it is fed by runoff, a surface tank or pond may dry up during dry periods. Surface tanks dried up during the drought of 1951-1956. In recent years, better constructed and deeper tanks have been built and water can be held for longer periods of time. It should be kept in mind that many of the shallower wells also had decreased yields during the drought years; however the wells penetrating the deeper aquifers in the bedrock and alluvium had sustained yields during the periods of low rainfall.

Despite the advantages of ground water, surface water appears to be a more feasible source of water than erratic-occurring ground water in most parts of the county. Many people, in seeking the cheaper source of ground water, have drilled numerous holes and have spent more money than it would have cost initially to develop a surface-water supply. Those seeking ground-water supplies should refer to the ground-water maps of this report to ascertain if they are drilling in favorable areas.

Localities Favorable for Water Development

Of the nine ground-water provinces of Okmulgee County (fig. 18), the Alluvial ground-water province offers the best conditions for ground-water use. Of the bedrock provinces, the Calvin, the Northern Upland, and the Dissected Holdenville provinces offer the best possibilities for ground-water development. The Dissected Wewoka and the Coffeyville provinces offer moderate possibilities for ground-water development.

The better well sites for the bedrock aquifers are not near the crests of the dip slopes of the sandstone beds but toward the axes of the valleys for the following reasons: (1) nearer the axes of the valleys, the sandstones contain more water because of the greater recharge area on the sandstone slope; (2) in some places it is possible to drill into a lower sandstone of high ground-water yield; (3) in many places the shallow alluvium of the subsequent valleys contains ground water (fig. 12).

It is best to locate the stock ponds in the valleys between the sandstone dip slopes of the bedrock because then the ponds may be supplied with water from the subsequent streams of the strike valleys which are underlain in many areas by poorly permeable soils such as the Parsons and Dwight soils. If feasible, the ponds should be constructed on these poorly permeable soils. If relatively thick alluvium is present in the strike valley, the alluvium may have a fairly large saturated thickness of ground water. If this is true, it may be possible to dig the pond below the water table and have a perennial supply (fig. 14). If the ponds are constructed on the alluvial deposits, they should be placed on the silty flood-plain facies and not the channel facies. The ponds should be constructed, if possible, on the Roebuck soils of the younger alluvium and on the Vanoss soils and the Chouteau soils of the older alluvium.

Well Drilling and Construction

As a general rule, one should stop drilling at the first water zone penetrated in bedrock or alluvium if sufficient quantities of water are available. In many cases the deeper zones contain impotable water. On the other hand, if sufficient water is not obtained in the first water zone, it is probably advisable to drill deeper and hope to intersect a more abundant water-yielding zone. The possibilities of penetrating deeper potable water zones are better in the more massive and better sorted sandstones than in the thin-bedded, poorly sorted sandstones.

The type of well finishing and well development is important because of the fine-grained nature and the low permeability of water-yielding materials in Okmulgee County. Medium-sized sand grains are the coarsest materials in the aquifers of the county; therefore the formational permeability and flow of water can be greatly reduced by small amounts of silt and clay which coat the hole or which are lodged between the grains. The water yields of the wells can be increased considerably by dislodging much of the silt and clay by proper methods of surging and development. The yield and life of the wells, especially those in alluvium, can be increased by gravel-pack or slotted screens.

Various combinations of cisterns and wells have been used in Okmulgee County where small amounts of potable water are present in the bedrock sandstones. One type of cistern-well combination utilizes the potable water in the uppermost sandstone by allowing the water from the sandstone to percolate into the lower part of the well. The lower part, which is finished in the impermeable shales of the bedrock, is cemented or cased so that it forms a collecting gallery for water percolating from the sandstone. If more water is needed than the sandstone can produce, a cistern can be added to the structure. The cistern-well structure must be carefully constructed to prevent contamination by surface water. Many of the cisterns and wells in Okmulgee County have been polluted by surface drainage.

SURFACE WATER

Surface-water supplies are considerably more important than ground-water supplies in Okmulgee County. All the larger towns of the county obtain water from surface-water reservoirs and the larger industries obtain their water from the water reservoirs of the towns. In 1959 the total amount of water for municipal use was 805,670,000 gallons and the total amount for industrial use was 340,810,000 gallons. This amount for industrial use does not include the use of recirculated water.

Lake Okmulgee, supplying the city of Okmulgee, is the largest lake in the county. Its surface area is about 13,200 acres. The amount of water taken from the lake in 1959 for municipal and industrial purposes amounted to 840,430,000 gallons. Other large lakes in the county are Lake Henryetta, which supplies Henryetta; old Lake Henryetta, which formerly supplied the town; and the lakes supplying Morris and Beggs. When Eufaula Dam is completed, a tongue of Eufaula Lake will cover part of the flood plain of Deep Fork and extend to within a few miles of Okmulgee. The lake will cover areas of the flood plain that are not economically important because of dense undergrowth and frequent flooding of the river. Users of smaller quantities of water are turning more and more to surface supplies. Most of the surface-water supply systems have been built during the last 15 years. Generally the surface reservoirs contain water of excellent quality that has a low mineral content, but occasionally ponds and lakes are contaminated by oil-well brines. At one time the lake supplying Beggs was thus contaminated.

Deep Fork, the master stream, is the only perennial stream in the county. The discharge of the stream ranges from almost zero to about 25,000 cfs (cubic feet per second). The higher seasonal discharges are commonly from 1,000 to 10,000 cfs. The normal variations of the stream flow of Deep Fork are very high; a range of from 100 cfs to 5,000 cfs is not unusual during the seasonal variations. Such variation indicates that the flow of Deep Fork is almost all surface-water discharge and very little ground-water discharge. It reflects the poor permeability of the Pennsylvanian and Permian formations that underlie the drainage area for Deep Fork. Another reason for the low base flow of Deep Fork is that most ground water in its drainage basin discharges into the more deeply entrenched North Canadian and Arkansas Rivers.

The low flow of Deep Fork is generally less than 100 cfs and may represent ground-water discharge upstream from Okmulgee County. The Surface Water Branch of the U. S. Geological Survey maintains two measuring stations on Deep Fork in Okmulgee County. The Beggs station is in the northwestern part of the county on a line between secs. 19, 20, T. 14 N., R. 12 E. The Dewar station is near the locality where Deep Fork leaves the county in SW¼ sec. 25, T. 12 N., R. 13 E. At times of low flow the increase in discharge between the two stations ranges from 10 to 20 cfs, this quantity probably representing ground-water discharge from the Pennsylvanian bedrock of Okmulgee County.

The highly variable flow of Deep Fork has had devastating effects on the farming and ranching along the flood plain of the river. Frequent flooding has prevented much farming and ranching along the flood plain. To control flooding and to promote watershed protection, the Soil Conservation District is sponsoring the building of small upstream dams on the tributaries of Deep Fork. About 30 upstream dams have been completed (August 1961) of a planned total of 50, and these should help reduce the hazards of flooding on Deep Fork. The upstream dams probably have helped indirectly to intensify downcutting on the Deep Fork and its tributaries. Deep Fork has entrenched into its flood plain, and its larger tributaries have lowered their channels 5 to 15 feet. The cycle of downcutting may have been intensified by the reduction of the amount of silt inflow to Deep Fork, thereby reducing the load of the river and causing downcutting. The deeper channel of Deep Fork may help retain the flood flows of the river. A deeper channel would also help drain the perched water from the shallow alluvium. The establishment of a local base level by the creation of Eufaula Lake a few miles south of Okmulgee will complicate matters and may cause sedimentation upstream.

Data from the Quality of Water Branch, U. S. Geological Survey, indicate a wide range of mineral concentration of the water in Deep Fork near the Beggs station. The water contains from about 250 to 16,000 ppm total dissolved solids. The low mineral content of the river water probably occurs during times of high flow, and the high mineral content probably results from discharge of oil-well brine into the river at times of low flow. The average specific conductance at low flow indicates a range of from 850 to 1,000 ppm total dissolved solids.

Some tributaries of Deep Fork in the southern part of the county and some tributaries of the Arkansas River in the eastern part of the county flow during most months of the year. The tributaries in the southern part of the county are Honey Creek, Montezuma Creek, and Salt Creek; the tributaries in the eastern part of the county are Cain Creek and its larger tributaries. The streams usually flow during all months except in the dry seasons; in years of high percipitation the streams may flow all year. Many of the farmers and ranchers utilize the water along these tributaries. Flooding is common during the rainy season; and, as these streams recede, many ponds of water are left standing upon the more impermeable soils. These temporary ponds are used for stock ponds.

The large tributaries of the Arkansas River in the northern part of the county, Snake Creek, Duck Creek, and Eagle Creek, do not flow so frequently as do the larger tributaries in the eastern and southern parts of the county. The tributaries in the northern part of the county are generally considered to be unreliable as sources of water.

Flooding by the tributaries of Deep Fork frequently causes flood damage. Because of severe flooding of Cain Creek, many farmers have had to convert from high-hazard crops of cotton and wheat to low-hazard crops of alfalfa, soya beans, and bermuda grass. At present the Soil Conservation Service has completed a study of watershed protection and flood prevention for Cain Creek and its tributaries in Okmulgee and Muskogee Counties (Soil Conservation Service, 1961). Plans are also being made for a similar study on Okmulgee Creek. Earth dams will provide flood control, prevent silt damage, and provide additional water for stock.

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APPENDIX TO PART I

MEASURED SECTIONS

1

Secs. 7, 8, 9, T. 11 N., R. 12 E. From the record of a barometer traverse, from the vicinity of SE cor. sec. 9 to the top of the hill west of SE cor. sec. 7, by M. C. Oakes.

	WEWOKA FORMATION	
1	Sandstone: weathers brown; fine-grained; top eroded	10.0
	WETUMKA SHALE	
	Covered: probably shale; about	60.0
	CALVIN SANDSTONE	
6	Sandstone: weathers brown; fine- to medium-grained, thin-bedded to massive; about	30.0
	Covered: probably shale; not measured	

2

Sec. 10, T. 11 N., R. 12 E. Measured at turn of road up escarpment near north quarter corner, by M. C. Oakes.

	CALVIN SANDSTONE	
6	Sandstone: light-buff; weathers brown; fine-grained; beds one inch to three feet thick; top eroded	28.0
	Shale: poorly exposed; at least	30.0

3

Sec. 11, T. 11 N., R. 12 E. Measured from bed of stream, just west of the east quarter corner, west along road to the top of the hill by the cemetery, by M. C. Oakes.

	CALVIN SANDSTONE	
5c	Sandstone: weathers buff; fine-grained; interbedded with sandy shale	12.0
b	Covered: probably interbedded shale and sandstone	6.0
a	Sandstone: weathers brown; fine-grained, thin-bedded, and cross-laminated	5.0
	Shale: weathers buff; sandy to silty	4.0
	Sandstone: weathers buff to brown; fine-grained, thin-bedded	2.0

	Shale: weathers buff; sandy to silty	4.0
4c	Sandstone: gray; weathers buff to brown; fine-grained; massive but laminated	2.0
b	Shale: dark, sandy to silty	5.0
a	Sandstone: gray; weathers buff to brown; fine-grained, massive	2.0
	Covered: probably shale	70.0

4

Sec. 33, T. 11 N., R. 12 E. Measured from recent alluvium on the south line west to the southwest corner, by M. C. Oakes.

CALVIN SANDSTONE

4c	Sandstone: weathers brown; fine-grained, massive; top eroded	20.0
b	Shale: weathers reddish-brown; sandy	3.0
a	Sandstone: weathers brown; fine-grained, massive	10.0
	Shale: weathers buff	27.0
3	Sandstone: gray; weathers brown; fine-grained, massive	12.0
	Covered: shale; not measured	

5

Sec. 7, T. 11 N., R. 13 E. Measured in the east-central part, from a point north of the road to the top of the high hill south of the road, by M. C. Oakes.

CALVIN SANDSTONE

4	Sandstone: weathers brown; fine-grained; contorted laminations make up beds as much as two feet thick; top eroded; about	10.0
	Covered: probably dark shale	40.0
2	Sandstone: not well exposed; about	5.0
	Covered: probably dark shale	85.0
1	Sandstone: weathers brown; fine-grained; not well exposed but makes a prominent bench about	3.0

SENORA FORMATION

Covered: probably dark shale; not measured

6

Secs. 28 and 29, T. 11 N., R. 13 E. From the record of a barometer traverse; from the edge of Lake Henryetta, about the center of sec. 28, to the base of the sandstone that caps the escarpment about the center of sec. 29, by M. C. Oakes.

CALVIN SANDSTONE

2	Sandstone: top eroded; about	10.0

	Covered: probably sandy shale; about	65.0
1	Sandstone: indicated by a change in slope and by sandstone rubble; about	5.0
	Covered: probably sandy shale; about	100.0
	SENORA FORMATION	
9	Sandstone: weathers brown; medium- to fine-grained; not well exposed; about	10.0
	Covered: probably sandy shale; not measured	

7

Sec. 31, T. 11 N., R. 13 E. Measured northward along road from culvert, center of the SW¼, to the top of the hill, on north line of NW¼, by M. C. Oakes.

	CALVIN SANDSTONE	
4	Sandstone: weathers reddish-brown; fine-grained; not well exposed; top eroded	6.0
	Covered: probably sandy shale and thin sandstone beds	6.0
3	Sandstone: gray to tan; weathers reddish brown; fine-grained, massive	12.0
	Shale: gray to buff; weathers red; sandy	9.0
2	Sandstone: weathers buff to reddish-brown; fine-grained; beds one foot or less thick interbedded with sandy shale	6.0
	Shale: dark, sandy	6.0
1	Sandstone: gray; weathers buff; fine-grained, massive	20.0
	SENORA FORMATION	
	Covered: probably shale	150.0

8

Sec. 1, T. 12 N., R. 12 E. From the record of a barometer traverse; along the east side of the NE¼, by M. C. Oakes.

	WEWOKA FORMATION	
2	Sandstone: weathers brown; fine-grained, partly covered; top eroded	25.0
	WETUMKA SHALE	
	Covered: probably sandy shale; about	120.0
	Sandstone: weathers brown; fine-grained; about	10.0
	Covered: probably sandy shale; about	30.0
	CALVIN SANDSTONE	
6c	Sandstone: not well exposed; about	5.0
b	Covered: probably weakly resistant sandstone and sandy shale; about	30.0
a	Sandstone: not well exposed; about	5.0
	Covered down to turn in road at the E¼ corner: probably shale	30.0

9

Secs. 19, 20, and 21, T. 12 N., R. 12 E. From the record of a barometer traverse; from the top of the Calvin Sandstone on the south line of sec. 21 to the top of the escarpment in NE¼ sec. 19, by M. C. Oakes.

Wewoka Formation		
9	Sandstone: weathers brown; medium- to fine-grained, massive; top eroded	10.0
	Covered: probably sandy shale; about	25.0
	Sandstone: indicated by a change in slope and by sandstone rubble; about	3.0
	Covered: probably sandy shale; about	60.0
8	Sandstone: indicated by a change in slope and by sandstone rubble; about	5.0
	Covered: probably sandy shale; estimated	250.0
Calvin Sandstone		
6	Sandstone: not measured	

10

Sec. 31, T. 12 N., R. 12 E. From the record of a barometer traverse; from the vicinity of the southeast corner west to the top of the escarpment, just east of the southwest corner, by M. C. Oakes.

Calvin Sandstone		
6	Sandstone: gray; weathers brown; massive to thin-bedded, medium- to fine-grained; top may be eroded; at least	25.0
	Covered: probably sandy shale; about	85.0
5	Sandstone: weathers brown; fine-grained; not well exposed; about	5.0
	Covered: probably shale; not measured	

11

Secs. 35 and 36, T. 12 N., R. 12 E. From the record of a barometer traverse; from the vicinity of the S¼ corner sec. 36 to the top of the escarpment in the vicinity of the S¼ cor. sec. 35, by M. C. Oakes.

Wetumka Shale		
	Shale: not measured	
Calvin Sandstone		
6	Sandstone: weathers brown; medium- to fine-grained, thick- to thin-bedded; about	40.0
	Covered: probably sandy shale; about	85.0
5	Sandstone: weathers brown; medium- to fine-grained; about	20.0
	Covered: probably sandy shale; about	45.0

4	Sandstone: weathers brown; about	15.0
	Covered: probably sandy shale; not measured	

12

Sec. 29, T. 12 N., R. 13 E. From the record of a barometer traverse; from the abandoned coal mine by the railroad track, near the E¼ corner to the top of the hill near the northeast corner, by M. C. Oakes.

CALVIN SANDSTONE		
2	Sandstone: top eroded; about	15.0
	Covered: probably sandy shale; about	120.0
3c	Sandstone: weathers brown; medium- to fine-grained; about	5.0
b	Covered: probably sandy shale and weakly resistant sandstone; about	25.0
a	Sandstone: weathers brown; medium- to fine-grained; about	15.0
	Covered: probably sandy shale and sandstone; about	45.0
1	Sandstone: light-gray; weathers brown; fine-grained; about	15.0
SENORA FORMATION		
	Covered: probably sandy shale; not measured	

13

Sec. 11, T. 13 N., R. 11 E. Measured northeastward from base of thick ledge in creek bottom to very top of outlying hill in the NE¼ SE¼, by L. F. Miller.

HOLDENVILLE SHALE		
5b	Covered to top of hill	12.0
a	Sandstone: buff to brown, medium- to fine-grained, silty	1.0
	Covered: probably shale	50.0
1	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, massive, friable	8.0
	Covered: probably shale	34.0
WEWOKA FORMATION		
22	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, massive, friable; base not exposed	17.0

14

Sec. 13, T. 13 N., R. 11 E. Measured northwestward from the edge of Lake Okmulgee, at the southeast corner, to the top *of the escarpment in the NW¼ SE¼, by L. F. Miller.*

HOLDENVILLE SHALE		
1	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin- to thick-bedded, friable; top eroded	3.0
	Covered	17.0
WEWOKA FORMATION		
22	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded to massive; about	5.0
	Covered: probably shale; about	230.0
12	Sandstone: buff to yellow-brown, fine-grained, silty, thick-bedded; base not exposed	3.0

15

Sec. 14, T. 13 N., R. 11 E. Measured west from the southeast corner to the top of the escarpment, by L. F. Miller.

WEWOKA FORMATION		
22c	Sandstone: buff to yellow-brown, fine-grained, silty, massive, friable; contorted bedding; top eroded	13.6
b	Shale: greenish-gray, silty; limonite concretions common	10.0
a	Sandstone: buff to yellow-brown, fine-grained, silty, thin-bedded	1.0
	Covered: probably shale more than	32.0

16

Sec. 15, T. 13 N., R. 11 E. Measured northward in road along the east side of the SE¼, by L. F. Miller.

HOLDENVILLE SHALE		
5	Sandstone: buff to brown, medium- to fine-grained, silty, thin-bedded, fossiliferous; top eroded	2.0
	Covered: probably shale	45.0
WEWOKA FORMATION		
22	Sandstone: (just above creek) not measured	

17

Secs. 15, 16, and 17, T. 13 N., R. 11 E. Measured from the top of the outlier in the SW¼ SW¼ sec. 15 to the top of the escarpment in the NW¼ NW¼ sec. 17, by L. F. Miller.

SEMINOLE FORMATION		
1	Sandstone: buff to yellow-brown, coarse- to fine-grained, massive, conglomeratic; contains weathered chert particles; top eroded	10.0

HOLDENVILLE SHALE		
	Shale: tan to greenish-gray; base not exposed	100.0
2	Sandstone: not measured	

18

Sec. 26, T. 13 N., R. 11 E. Measured from base to top of escarpment in the NE¼ NE¼, by L. F. Miller.

WEWOKA FORMATION		
22c	Sandstone	1.0
b	Covered	20.0
a	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, massive	11.0
	Covered: probably shale; more than	125.0

19

Secs. 31, 32, and 33, T. 13 N., R. 11 E. Measured from the top of the Wewoka Formation, near end of the road on the south side of sec. 33, westward along road to the vicinity of the southwest corner of sec. 32, thence northward to the top of the escarpment capped by sandstone in the Seminole Formation in the SE¼ NW¼ sec. 31, by L. F. Miller.

SEMINOLE FORMATION		
1	Sandstone: buff to yellow-brown, fine- to coarse-grained, massive, conglomeratic; weathered chert particles; top eroded	12.0
HOLDENVILLE SHALE		
	Covered: probably shale	95.0
6c	Sandstone: yellow-brown to brown, speckled, fine- to medium-grained, thin-bedded	2.0
b	Covered	28.0
a	Yellow-brown to brown, speckled, medium- to fine-grained, thin-bedded	3.0
	Shale: tan to dark-brown, silty; mostly covered	31.0
WEWOKA FORMATION		
22	Sandstone: not measured	

20

Sec. 34, T. 13 N., R. 11 E. Measured from the bottom of Salt Creek northward to the top of the hill, all in the SW¼ SW¼, by L. F. Miller.

WEWOKA FORMATION		
22c	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin- to thick-bedded; top eroded	4.0

b	Covered	17.0
a	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin- to thick-bedded	4.0
	Covered	25.0
	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded to massive	5.0
	Covered: probably shale; more than	34.0

21

Secs. 34, 35, and 36, T. 13 N., R. 11 E., and sec. 31, T. 13 N., R. 12 E. The base of the section is at a bridge over a small stream near the center of the SE¼ sec. 31. It follows a road northwestward to the top of the hill and thence westward to the west side of sec. 36; extends thence north of west to the northwest corner of sec. 35; thence follows the road west along the north side of sec. 34 to the first farm house, at the top of the hill. Compiled from three sections measured separately by L. F. Miller.

WEWOKA FORMATION

22d	Covered: extends to top of hill	17.0
c	Sandstone: buff to yellow-brown, medium- to fine-grained, massive, friable	5.0
b	Covered	17.0
a	Sandstone: buff to yellow-brown, medium- to fine-grained, thin-bedded to massive, friable	12.0
	Covered: probably shale	90.0
13	Sandstone: buff to yellow-brown, medium- to fine-grained, thin-bedded	1.0
	Covered: probably shale	28.0
12	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded to massive, friable	5.0
	Shale: greenish-gray; mostly covered	14.0
	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded, friable	1.0
	Shale: greenish-gray; mostly covered	57.0
11	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded, friable	2.0
	Shale: greenish-gray, silty; mostly covered	55.0
	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded, friable	2.0
	Shale: greenish-gray, silty; mostly covered	23.0
10	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, massive, friable; base not exposed	10.0

22

Sec. 1, T. 13 N., R. 12 E. Measured northward along the east side of the SE¼ from a small bridge over a creek to the top of the escarpment, by L. F. Miller.

	HOLDENVILLE SHALE	
	Shale: greenish-gray, silty; top eroded	23.0
1	Sandstone: yellow-brown to tan, fine-grained to silty, thin-bedded to massive	4.0
	Shale: buff to yellow-brown	6.0
	WEWOKA FORMATION	
22	Sandstone: buff to yellow-brown, fine-grained, silty, thin-bedded; includes thin silty shales	16.0
	Shale: yellow-brown to greenish-brown, silty, nonfossiliferous; base not exposed	57.0

23

Sec. 3, T. 13 N., R. 12 E. Measured from recent alluvium westward to top of hill, along south side, by L. F. Miller.

	WEWOKA FORMATION	
12	Sandstone: buff to tan, massive; some scattered limonite concretions	11.0
	Covered	51.0
11	Sandstone: buff to tan, medium-bedded	4.0
	Covered	23.0
10	Sandstone: buff to yellowish-tan, medium-grained, massive, friable; scattered limonite concretions	11.4
	Shale: greenish-gray; limonite concretions in large amounts; more than	222.0

24

Sec. 6, T. 13 N., R. 12 E. Measured north from Lake Okmulgee along the east side to top of escarpment, by L. F. Miller.

	WEWOKA FORMATION	
22	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, massive, friable; contorted bedding; top eroded	12.0
	Covered: probably shale	52.0
	Sandstone: indicated only by a break in the slope	5.0
	Covered: probably shale	97.0
12	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, massive	6.0
	Covered: probably shale; more than	40.0

25

Sec. 8, T. 13 N., R. 12 E. Measured westward from the base to the top of the escarpment in the SW¼ SW¼, by L. F. Miller.

WEWOKA FORMATION

12	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin- to thick-bedded, friable; top eroded	4.0
	Covered: probably shale	62.0
10	Sandstone: buff to yellow-brown, medium- to fine-grained, silty; massive beds with shale partings	13.0
	Shale: greenish-gray where exposed, but mostly covered; at least	85.0

26

Sec. 20, T. 13 N., R. 12 E. Measured eastward from creek bottom to top of escarpment in the SW¼ NE¼, by L. F. Miller.

WEWOKA FORMATION

12	Sandstone: buff to yellow-brown, fine- to medium-grained, silty, thin-bedded to massive, friable; top eroded	7.0
	Covered: probably shale	103.0
10	Sandstone; buff to yellow-brown, medium- to fine-grained, massive, friable, ripple marked	12.0
	Covered: probably shale	51.0

27

Sec. 27, T. 13 N., R. 12 E. Measured in south bank of Deep Fork, about 150 feet west of bridge, NE¼ NE¼, by L. F. Miller.

WEWOKA FORMATION

12b	Siltstone or fine-grained sandstone: varicolored; mostly greenish-brown, thin- to medium-bedded; more indurated than underlying beds and overhangs them; top eroded	18.0
a	Siltstone: light- to dark-gray, thin-bedded, nonfossiliferous; weathers rapidly; base not exposed	13.0

28

Secs. 29, T. 13 N., R. 12 E. Measured from base to top of the escarpment in the SE¼, by L. F. Miller.

WEWOKA FORMATION

12	Sandstone: yellow-brown, fine- to medium-grained, silty, thin- to thick-bedded; top eroded	5.0
	Covered: probably shale	46.0
11	Sandstone: indicated only by a break in the slope; about	5.0

	Covered: probably shale	68.0
10	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded to massive, friable; scattered limonite concretions	12.0
	Shale: greenish-gray; limonite concretions common; base not exposed	134.0

29

Sec. 32, T. 13 N., R. 12 E. Measured northwest from base to top of escarpment in the NE¼ SW¼, by L. F. Miller.

WEWOKA FORMATION

11	Sandstone: buff to yellow-brown, fine- to medium-grained, massive, friable; a ledge which thins rapidly northeastward; top eroded	12.0
	Covered: probably shale	65.0
10	Sandstone: buff to yellow-brown, fine- to medium-grained, silty, massive to thin-bedded, friable; scattered limonite concretions	12.0
	Covered: probably shale; more than	75.0

30

Sec. 36, T. 13 N., R. 12 E. Measured from a short distance east to a short distance west of the southeast corner, by L. F. Miller.

WEWOKA FORMATION

2c	Sandstone: buff to tan, massive; top eroded	14.0
b	Covered: probably shale	28.0
a	Sandstone: yellow-brown to reddish	23.0

WETUMKA SHALE

	Shale: greenish-brown; mostly covered	46.0
	Sandstone: indicated only by a break in slope	6.0
	Shale: greenish-brown; mostly covered	68.0

CALVIN SANDSTONE

6c	Sandstone: buff to tan, medium-grained, massive; contains a few scattered limonite concretions	10.0
b	Covered: probably shale	20.0
a	Sandstone: buff to yellowish-brown, medium-grained, massive; contains scattered limonite concretions	20.0
	Shale: greenish-brown, blocky; slightly silty with streaks of dark-gray clay shale; more than	125.0

31

Sec. 1, T. 14 N., R. 11 E. Measured northwest from creek bottom in the NW¼ NW¼ to the base of the Seminole Formation on the west line, by L. F. Miller.

SEMINOLE FORMATION

1 Sandstone: buff to yellow-brown, medium- to fine-grained, thin-bedded to massive, friable, nonfossiliferous, conglomeratic; contains weathered chert particles; top eroded 7.0

HOLDENVILLE SHALE

Covered: probably shale 57.0

7 Sandstone: buff to yellow-brown, medium- to fine-grained, thin-bedded to massive; ripple marks common 6.0

Covered: probably shale; at least 10.0

32

Sec. 2, T. 14 N., R. 11 E. Measured southwest from the creek bottom to top of hill NE¼ SE¼, by L. F. Miller.

SEMINOLE FORMATION

1 Sandstone: buff to yellow-brown, fine- to coarse-grained, massive, fossiliferous, conglomeratic; contains weathered chert particles; top eroded 6.0

HOLDENVILLE SHALE

Covered 62.0

7 Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thick-bedded, friable 3.0

Covered: more than 35.0

33

Secs. 3, 4, and 5, T. 14 N., R. 11 E. Measured westward from the bridge over Salt Creek, near the northeast corner of sec. 3, to the top of the escarpment, near the south quarter corner of sec. 5, by L. F. Miller.

COFFEYVILLE FORMATION

5 Sandstone: buff to brown, medium-to fine-grained, silty, thin-bedded to massive, contorted; top eroded 32.0

Shale: greenish-gray to tan, silty 130.0

CHECKERBOARD LIMESTONE

Limestone: blue-gray; weathers light-brown; fine- to coarse-crystalline, thick-bedded, hard, dense, fossiliferous 4.0

SEMINOLE FORMATION

Covered by colluvium: probably sandstone and sandy shale; includes virtually all the Seminole Formation 160.0

HOLDENVILLE SHALE

Covered by recent alluvium and terrace deposits: probably part of map unit IPhd-7 and the overlying shale 35.0

34

Sec. 7, T. 14 N., R. 11 E. Measured northward from abandoned railroad to top of hill, SW¼ SW¼, L. F. Miller.

COFFEYVILLE FORMATION

5e	Sandstone: buff to dark-brown, medium- to fine-grained, silty, thin-bedded, friable; top eroded	2.0
d	Shale: light-gray to gray, silty	7.0
c	Sandstone: buff to yellow-brown, medium- to fine-grained, thin-bedded, fossiliferous	2.0
b	Shale: light-gray to gray, silty; partly covered	5.0
a	Sandstone: buff to brown, medium- to fine-grained, silty, thin-bedded to massive, friable, contorted, speckled	5.0
	Shale: cream to tan, silty, blocky, partly covered	17.0
	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thick-bedded, contorted	4.0
	Covered: probably shale; at least	50.0

35

Sec. 11, T. 14 N., R. 11 E. Measured northward from Recent alluvium to the top of the escarpment in NW¼ SW¼, by L. F. Miller.

HOLDENVILLE SHALE

7	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, massive, friable; top eroded	22.0
	Shale: greenish-gray, silty; base not exposed	123.0

36

Sec. 12, T. 14 N., R. 11 E. Measured from creek bottom northwest to top of ridge in the SW¼, by L. F. Miller.

HOLDENVILLE SHALE		
7	Sandstone: buff to yellow-brown, fine- to medium-grained, massive to thin-bedded, friable; top eroded	20.0
	Covered: probably shale	103.0
WEWOKA FORMATION		
22	Sandstone: buff to yellow-brown, fine- to medium-grained, silty; shale partings; ripple marks; base covered	25.0

37

Sec. 15, T. 14 N., R. 11 E. Measured eastward from base to top of outlying hill in the SE¼ NE¼, by L. F. Miller.

SEMINOLE FORMATION

1	Sandstone: buff to yellow-brown, fine- to coarse-grained, massive, friable, conglomeratic, fossiliferous; contains weathered chert particles; top eroded	6.0

HOLDENVILLE SHALE

	Covered: probably shale	40.0
7	Sandstone: buff to yellow-brown, fine- to coarse-grained, silty, massive, friable	11.0
	Covered: probably shale; more than	80.0

38

Sec. 25, T. 14 N., R. 11 E. Measured northwestward from Recent alluvium to top of escarpment in the SE¼ NE¼, by L. F. Miller.

WEWOKA FORMATION

22	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, massive, friable; top eroded	5.0
	Covered: probably shale	120.0

39

Sec. 25, T. 14 N., R. 11 E. Measured westward from creek bottom to top of hill in the SW¼, by L. F. Miller.

HOLDENVILLE SHALE

5	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded to massive; top eroded	4.0
	Covered	35.0

WEWOKA FORMATION

22c	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded, friable	5.0
b	Covered	17.0
a	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded to massive, friable	4.0
	Covered	34.0

40

Secs. 33, 34, 35, T. 14 N., R. 11 E. Measured from a small concrete bridge near the northeast corner sec. 35 south to the southeast corner, thence west to the top of the hill capped by sandstone in the Seminole Formation, near the south quarter corner sec. 33. Composed of three sections measured separately by L. F. Miller.

SEMINOLE FORMATION

1 Sandstone: buff to yellow-brown, coarse- to

	fine-grained, massive, conglomeratic; contains weathered chert particles; top eroded	11.0
	Holdenville Shale	
	Shale: tan to greenish-gray; scattered limonite concretions; mostly covered	90.0
6	Sandstone: buff to brown, fine-grained, silty, thin-bedded, speckled, exposed	2.0
	Shale: greenish-gray to gray; mostly covered	114.0
5c	Sandstone: yellow-brown to brown, medium- to fine-grained, silty, thin-bedded, friable	2.0
b	Covered	11.0
a	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded to massive, friable	11.0
	Covered: probably shale	57.0
	Wewoka Formation	
22	Sandstone: not measured	

41

Sec. 36, T. 14 N., R. 11 E. Measured northwestward from small bridge over creek to top of escarpment in the NE¼, by L. F. Miller.

	Wewoka Formation	
22	Sandstone: buff to brown, medium- to fine-grained, silty, thin- to medium-bedded, friable; top eroded	2.0
	Shale: greenish-gray; limonite concretions abundant; partly covered	102.0
12?	Siltstone: buff to yellow-brown	3.0
	Covered: not measured	

42

Sec. 36, T. 14 N., R. 11 E. Measured southwestward from road to top of escarpment in the NE¼ SW¼, by L. F. Miller.

	Holdenville Shale	
5	Sandstone: yellow-brown, fine-grained, silty, thin-bedded; top eroded	1.0
	Covered: probably shale	40.0
	Wewoka Formation	
22	Sandstone: buff to yellow-brown, fine- to medium-grained, thin-bedded to massive, friable; scattered ripple marks	5.0
	Covered: probably shale; more than	85.0

43

Sec. 1, T. 14 N., R. 12 E., and sec. 36, T. 15 N., R. 12 E. Measured northward from the creek bottom in the NE¼ SW¼ sec. 1 to the hilltop in the NW¼ SE¼ sec. 36, by L. F. Miller.

Wewoka Formation

19	Sandstone: buff to yellow-brown, medium- to fine-grained, thin-bedded	1.0
	Covered	36.0
17	Sandstone: buff to tan, medium- to fine-grained, thick- to thin-bedded, friable	4.0
	Covered	28.0
16	Sandstone: buff to yellow-brown, medium- to fine-grained, massive; a few scattered fossils	8.0
	Covered: probably shale	35.0
15	Sandstone: yellow-brown to tan, medium- to fine-grained, massive; a few scattered fossils	5.0
	Covered: probably shale	58.0
12	Sandstone: buff to tan, medium- to fine-grained, thick- to thin-bedded, friable	3.0
	Covered	30.0
10	Sandstone: buff to yellow-brown, medium- to fine-grained, massive, friable; a few fossil plants	6.0
	Covered: more than	13.0

44

Secs. 5, and 6, T. 14 N., R. 12 E. Measured westward from road, SW¼ SW¼ sec. 5, to top of escarpment, SE¼ SE¼ sec. 6, by L. F. Miller.

Holdenville Shale

7c	Sandstone: buff to yellow-brown, fine- to medium-grained, thin-bedded, friable; top eroded	2.0
b	Covered	26.0
a	Sandstone: buff to yellow-brown, fine- to medium-grained, thin- to medium-bedded, friable	3.0
	Shale: greenish-gray; mostly covered; at least	100.0

45

Sec. 13, T. 14 N., R. 12 E. Measured south to north along east side from base of hill to top, by L. F. Miller.

Wewoka Formation

10	Sandstone: buff to yellow-brown, medium-grained, massive, friable, nonfossiliferous	11.0
	Shale: greenish-gray, fossiliferous; conchoidal fracture; limonite concretions common; (includes unit ℙwk-9) more than	140.0

46

Secs. 16 and 17, T. 14 N., R. 12 E. Measured westward from edge of road, NW¼ NW¼, sec. 16, to top of escarpment, NE¼ NE¼ sec. 17, by L. F. Miller.

WEWOKA FORMATION

22c	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded, friable; top eroded	3.0
b	Covered	12.0
a	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded to massive, friable	6.0
	Shale: greenish-gray; abundant limonite concretions; partly covered; at least	100.0

47

Sec. 21, T. 14 N., R. 12 E. Measured southwest from edge of terrace to top of escarpment in the SW¼ SW¼, by L. F. Miller.

WEWOKA FORMATION

	Covered: probably shale; top eroded	40.0
12	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin- to thick-bedded, friable	8.0
	Covered: probably shale; more than	100.0

48

Sec. 23, T. 14 N., R. 12 E. Measured from north to south along the west side, from base of hill to top, by L. F. Miller.

WEWOKA FORMATION

	Covered to top of hill	28.0
10	Sandstone: buff to yellow-brown, medium-grained, massive, friable, nonfossiliferous	25.0
	Shale: greenish-gray; more than	40.0

49

Sec. 27, T. 14 N., R. 12 E. Measured from south to north along east side from vicinity of farm house at base of escarpment to top, by L. F. Miller.

WEWOKA FORMATION

12	Sandstone: buff to yellow-brown, medium-grained, thick-bedded, nonfossiliferous; top eroded	3.0
	Covered: probably shale	11.0
10	Sandstone: buff to yellow-brown, medium-grained,	

	thick-bedded, nonfossiliferous; two ledges mapped as one unit	23.0
	Covered: probably shale	114.0
9	Sandstone: indicated only by break in slope	17.0
	Covered: probably shale; some limonite concretions; more than	34.0

50

Sec. 30, T. 14 N., R. 12 E. Measured northeastward from Recent alluvium to top of outlying hill in the NW¼, by L. F. Miller.

WEWOKA FORMATION		
22	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, massive, friable; fossil plant imprints on weathered surfaces; top eroded	20.0
	Covered: probably shale; more than	110.0

51

Sec. 31, T. 14 N., R. 12 E. Measured southward from base to top of escarpment in the SE¼ SW¼, by L. F. Miller.

HOLDENVILLE SHALE		
5	Sandstone: buff to yellow-brown, medium- to fine-grained, silty, thin-bedded, friable; top eroded	1.0
	Covered: probably shale	37.0
WEWOKA FORMATION		
22	Sandstone: buff to yellow-brown, fine-grained, silty, thin-bedded; some ripple marks	0.5
	Shale: greenish-gray; mostly covered	97.0

52

Sec. 33, T. 14 N., R. 12 E. Measured from Recent alluvium to top of escarpment in the NE¼, by L. F. Miller.

WEWOKA FORMATION		
12	Sandstone: light-brown to buff, fine-grained, silty, massive; scattered limonite concretions	12.0
	Covered: probably shale	23.0
10	Sandstone: light-brown to buff, fine-grained, silty, massive, nonfossiliferous, scattered limonite concretions	14.0
	Shale: mostly covered (includes unit ℙwk-9); more than	135.0

53

Sec. 34, T. 14 N., R. 12 E. Measured southwestward from Recent alluvium in the NW¼ SW¼, by L. F. Miller.

WEWOKA FORMATION

12	Sandstone: buff to yellow-brown, fine- to medium-grained, silty; alternating massive beds and thin shale partings; top eroded	10.0
	Shale: greenish-gray, mostly covered; more than	190.0

54

Sec. 1, T. 14 N., R. 13 E. Measured up escarpment in NE¼, by D. G. Leitner.

WEWOKA FORMATION

2	Sandstone: light-brown; weathers dark gray with orange and black stains; partly covered	11.0

WETUMKA SHALE

	Covered: probably shale	38.5

55

Sec. 5, T. 14 N., R. 13 E. Measured in road cut at SW corner, by D. G. Leitner.

WEWOKA FORMATION

10e	Sandstone: light-brown, thin-bedded	6.5
10d	Sandstone: massive; cross-bedded at top	9.5
10c	Sandstone: thin-bedded; cross-bedded at base	4.1
10b	Sandstone: light-brown, fine-grained, massive	4.9
10a	Sandstone: thin-bedded, partly covered; grades downward into shale; about	2.0
	Covered: shale; about	55.0
9	Sandstone: blue-gray to brown, fine-grained to silty, thin-bedded, even-bedded	26.0
	Covered to bottom of scarp; shale; about	75.0

56

Sec. 6, T. 14 N., R. 13 E. Measured along road in NW¼, by D. G. Leitner.

WEWOKA FORMATION

15b	Sandstone: interbedded with sandy shale	1.0
15a	Sandstone: light-brown, fine-grained, massive	2.9
	Covered: shale; about	78.0

57

Sec. 27, T. 14 N., R. 13 E. Measured up the outlying hill in the SW¼, by D. G. Leitner.

CALVIN SANDSTONE		
6	Sandstone: thick-bedded; light brown with orange iron stains; weathers dark gray	3.5
SENORA FORMATION		
	Covered: shale	38.5

58

Sec. 34, T. 14 N., R. 13 E. Measured in road up low escarpment in NE¼, by D. G. Leitner.

CALVIN SANDSTONE		
	Covered: about	12.0
5	Sandstone: light-brown, thin-bedded, silty; contains small tabular limonitic concretions	11.0
SENORA FORMATION		
	Covered	5.5

59

Sec. 4, T. 14 N., R. 14 E. Measured in stream bank in NW¼, by D. G. Leitner.

SENORA FORMATION	
Shale: gray; contains clay-ironstone concretions	1.0
Coal: Croweburg (Henryetta); poor quality; shaly	0.5
Shale: gray	1.0
Shale: black	0.7
Shale: gray; contains clay-ironstone concretions	1.1
Shale: gray, silty; contains plant fossils	0.9

60

Sec. 10, T. 14 N., R. 14 E. Measured in stream-bank, north end of strip pit in NW¼, by D. G. Leitner.

SENORA FORMATION	
Covered	15.0
Shale: gray	0.1
Coal: unnamed	1.0
Shale: black	0.8
Limestone: gray, fossiliferous	1.5
Shale: gray	7.5
Shale: silty	2.0

61

Sec. 5, T. 15 N., R. 11 E. Measured from the base of the sandstone outcrop at the southeast corner northwest to top of ridge, by G. C. Luff.

COFFEYVILLE FORMATION

8	Sandstone: buff; weathers brown; fine- to medium-grained	16.0
7d	Covered: probably shaly siltstone	33.0
c	Sandstone: buff; weathers brown; medium-grained	22.0
b	Covered: probably shaly siltstone	55.0
a	Sandstone: buff; weathers brown; fine-grained	28.0

62

Sec. 6, T. 15 N., R. 11 E. Measured from trail east of hill in NW¼ west to top of hill, by G. C. Luff.

NELLIE BLY FORMATION

1h	Covered: probably silty shale; not measured	
g	Sandstone: buff to rust, medium-grained, friable	6.0
f	Covered: probably silty shale	43.0
e	Sandstone: buff; weathers brown; fine-grained	1.0
d	Covered: probably silty shale	18.0
c	Sandstone: buff; weathers brown; fine-grained	3.0
b	Covered: probably silty shale	19.0
a	Sandstone: buff, fine-grained, friable	12.0
	Covered: probably shale	11.0
	Sandstone: buff, fine-grained, friable	3.0
	Covered: probably shale	16.5

63

Sec. 12, T. 15 N., R. 11 E. Measured from base of exposure 200 feet northeast of the southwest corner southwest to that corner, by G. C. Luff.

CHECKERBOARD LIMESTONE

	Limestone: gray-blue; weathers yellow; fossiliferous; "checkerboard" jointing	2.0

SEMINOLE FORMATION

2i	Shale: gray-tan, sandy, fissile	0.4
h	Sandstone: buff, fine-grained, even-bedded	0.5
g	Shale: gray-tan, silty, even-bedded	4.0
f	Shale: gray-green; weathers tan; silty, micaceous	4.5
e	Sandstone: gray-tan, silty; pinches out southward	2.5
d	Coal: unnamed; NOT Dawson coal; associated with plant roots and trunks	0.8
c	Underclay: gray-green, waxy; conains a few plant remains	1.2

b	Underlime: white nodules in a red matrix; fossiliferous	0.3
a	Shale: gray-green, even-bedded; not measured	

64

Sec. 17, T. 15 N., R. 11 E. Measured from Recent alluvium in NW¼ sec. 20 north to top of ridge in SW¼ sec. 17, by G. C. Luff.

COFFEYVILLE FORMATION		
8	Sandstone: buff; weathers brown; fine- to medium-grained	17.5
7d	Covered: probably shaly siltstone	30.0
c	Sandstone: buff; weathers brown; medium-grained	20.0
b	Covered: probably shaly siltstone	33.0
a	Sandstone: buff; weathers brown; fine- to medium-grained	33.0
	Covered: probably shale; not measured	

65

Sec. 22, T. 15 N., R. 11 E. Measured at the type locality of the Checkerboard Limestone, NW¼ of the SE¼, by G. C. Luff.

COFFEYVILLE FORMATION	
Covered: probably shale; not measured	
CHECKERBOARD LIMESTONE	
Limestone: gray-blue; weathers yellow; shaly, fossiliferous	0.8
Limestone: gray-blue; weathers yellow; fossiliferous	1.5
SEMINOLE FORMATION	
Shale: dark-gray; poorly exposed; not measured	

66

Sec. 24, T. 15 N., R. 11 E. Measured from base of outcrop in cut on east road, NE¼ south of creek, to top of hill, by G. C. Luff.

HOLDENVILLE SHALE		
lsb	Limestone: gray-blue; weathers yellow; shaly, fossiliferous	0.5
a	Limestone: gray blue at base; chocolate brown at top; dense	3.1
	Shale: gray-blue, calcareous, thin-bedded; not measured	

67

Sec. 25, T. 15 N., R. 11 E. Measured from Recent alluvium in SW¼, northward up gulley on north side of creek, to top of chert-conglomerate sandstone, by G. C. Luff.

SEMINOLE FORMATION

1g	Sandstone: fine- to medium-grained; with interbedded chert conglomerate; not measured	
f	Shale: gray-green, massive	6.0
e	Limestone: gray-white, fossiliferous	0.2
d	Shale: gray, platy	0.3
c	Limestone: buff, crystalline, fossiliferous	0.4
b	Limestone: gray-blue, carbonaceous; plant fossils	0.1
a	Coal: shaly	0.7

HOLDENVILLE SHALE

Shale: gray-blue to black, fissile, poorly exposed; not measured

68

Sec. 28, T. 15 N., R. 11 E. Measured in west bank of Tiger Creek, one-eighth mile south from north line, from creek bed upward to Recent alluvium, by G. C. Luff.

COFFEYVILLE FORMATION

4	Sandstone: tan, medium-grained, even-bedded	2.0
3	Limestone: tan, sandy to silty, fucoidal; few fossils; "checkerboard" jointing	1.5
	Shale: black, fissile; interbedded *Myalina* fossil zone	4.5
	Shale: black to blue, even-bedded, calcareous; few fossils	1.2

69

T. 15 N., Rs. 11 and 12 E.

Geologic section along an alidade traverse from the top of the hill in the south-central part of sec. 20, T. 15 N., 11 E., southeastward to the section-line road, thence east to the center of the south line of sec. 21, T. 15 N., R. 12 E. Many thicknesses computed from distance, average dip, and differences in elevation. Measured by G. C. Luff.

COFFEYVILLE FORMATION

7	Sandstone: buff; weathers brown; fine-grained	35.0
	Covered: probably shale	136.0
5	Topographic bench: probably sandstone; about	2.0
	Covered: probably shale	60.0
4	Topographic bench: probably sandstone; about	3.0
	Covered: probably shale	2.0

3	Topographic bench: probably sandy limestone	2.0
	Covered: probably shale	79.0
CHECKERBOARD LIMESTONE		
	Topographic bench: limestone boulders beside the road; gray-blue; weathers yellow; fossiliferous	2.0
SEMINOLE FORMATION		
2b	Covered: probably sandy shale; about	85.0
a	Topographic bench: probably sandstone	8.0
	Covered: probably shale; about	10.0
1	Topographic bench: probably sandstone; about	9.0
HOLDENVILLE SHALE		
ls	Limestone: gray-blue; weathers yellow; dense; upper part fossiliferous	4.0
	Covered: probably shale	49.0
7	Sandstone: tan, fine-grained, poorly exposed	5.0
	Covered: probably shale	72.0
4c	Topographic bench: probably sandstone	3.0
b	Covered: probably siltstone	1.0
a	Topographic bench: probably sandstone	4.0
	Covered: probably shale	62.0
WEWOKA FORMATION		
22d	Covered: a dip slope; probably sandstone; not measured	

70

Sec. 25, T. 15 N., R. 12 E. Measured along east line, from base of hill in NE¼ to top near northeast corner, by G. C. Luff.

WEWOKA FORMATION		
20	Sandstone: buff; weathers brown; fine-grained	24.0
	Covered: probably shale	75.0
19	Sandstone: buff; weathers dark brown; fine-grained	12.0
	Covered: probably shale; not measured	

71

Secs. 26, 27, and 28 T. 15 N., R. 12 E.
Geologic section along an alidade traverse, along Oklahoma Highway 16, from its intersection with the west line of sec. 26 to the center of the west line of sec. 28. Thickness computed from distance, average dip, and difference in elevation. Measured by G. C. Luff.

WEWOKA FORMATION		
22d	Topographic bench: sandstone; about	4.0
	Shale: gray-tan, thin-bedded, silty	4.0
22c	Siltstone: gray-tan, sandy, massive; represents unit ℙwk-22c and underlying shale; undifferentiated	60.0
22b	Sandstone: gray-tan, massive	12.0

22a	Topographic bench: sandstone; measured with overlying shale; total thickness	34.0
20	Topographic bench: sandstone; measured with overlying shale; total thickness	44.0
	Covered: probably shale	16.0
19	Topographic bench: sandstone	21.0
	Covered: probably shale; not measured	

72

Sec. 32, T. 15 N., R. 12 E. Measured below dam of Beggs lake, from base of exposure vertically to top, by G. C. Luff.

WEWOKA FORMATION

		Covered: probably shale; not measured	
22a	f	Sandstone: buff; weathers brown; fine-grained	16.0
	e	Sandstone: buff; weathers brown; fine-grained, ripple-marked	2.5
	d	Siltstone: gray-tan, even-bedded, shaly	2.0
	c	Sandstone: buff, fine- to medium-grained, thin-bedded	1.3
	b	Siltstone: gray-tan, shaly; ungraded bedding	3.0
	a	Sandstone: buff; weathers dark brown; fine-grained, thin-bedded; contains minor interbedded siltstone and shale zones	9.0

73

Sec. 33, T. 15 N., R. 12 E. Measured from the low point on the south line just west of the southeast corner west one-eighth mile to top of hill, by G. C. Luff.

WEWOKA FORMATION

22c	c	Sandstone: buff, weathers brown; fine-grained	6.0
	b	Covered: probably shale	9.0
	a	Sandstone: buff; weathers brown; fine-grained	7.0
		Covered: probably shale	20.0
22b	c	Sandstone: buff; weathers brown; fine-grained	5.0
	b	Covered: probably shale	8.0
	a	Sandstone: buff; weathers brown; fine-grained	7.0
		Covered: probably shale and sandstone	22.0

74

Sec. 35, T. 15 N., R. 12 E. Measured along proposed highway from southeast corner northward to top of highest hill, center of section, by G. C. Luff.

WEWOKA FORMATION

22a	b	Siltstone: gray-tan, cross-bedded, ripple-marked; not measured	
	a	Sandstone: tan to cream; weathers brown; fine-grained,	

	massive, fossiliferous	10.0
	Shale: gray blue at base; tan at top; fissile	27.0
20c	Sandstone: dark-red-brown to cream, fine- to medium-grained, massive; poorly preserved fossils	10.0
b	Siltstone: gray-tan; massive, but contains interbedded thin gray-blue shales	60.0
a	Sandstone: tan; weathers red brown; slightly calcareous; fossil flora and fauna	12.0
	Shale: gray-blue to tan, silty, carbonaceous; fossil flora	8.0
	Shale: gray-blue, fissile	13.0
19	Sandstone: gray-tan; weathers brown; fine-grained	8.0
	Shale: gray-blue, fissile	22.0
17	Sandstone: gray-tan; weathers brown; fine-grained	8.0
	Covered: shale	11.0
16	Sandstone: gray-tan; weathers brown; fine-grained	17.0
	Shale: gray-blue, fissile	20.0
15	Sandstone: tan with patchy iron stains; fine-grained	14.0
	Shale: dark-gray-blue; massive, but contains concretions and thin calcareous zones; few fossils	16.0
	Sandstone: tan with patchy iron stains; fine-grained	5.0
	Shale: blue-gray, fissile; not measured	

75

Sec. 10, T. 15 N., R. 13 E. Measured up the east face of the escarpment in the west side. Compiled from two sections measured separately by D. G. Leitner.

WEWOKA FORMATION

22c	Sandstone: large angular blocks at the top of the escarpment	10.0
	Covered: probably shale	35.0
22b	Sandstone: light-brown, massive, thin-bedded, cross-bedded, fine-grained	29.9
	Covered: probably shale	16.5
20	Sandstone: light-brown, massive, thin-bedded	17.3
	Covered: probably shale	165.0
18	Sandstone: light-brown; large slump blocks down slope	19.4
	Covered: probably shale	110.0

76

Sec. 19, T. 15 N., R. 13 E. Measured up escarpment west of trail, by D. G. Leitner.

WEWOKA FORMATION

20	Sandstone: gray-brown, silty; massive, thin-bedded, cross-bedded	36.7
	Covered: probably shale	137.0

77

Sec. 2, T. 15 N., R. 14 E. Measured along road up escarpment in NW¼, by D. G. Leitner.

CALVIN SANDSTONE		
5	Sandstone:	
h.	red-brown, fine-grained, thin-bedded	2.2
g.	red-brown, brown-flecked, fine-grained, massive	2.8
f.	light-brown, fine-grained to silty, thin-bedded; poorly consolidated	0.9
e.	light-brown, fine-grained, massive	5.3
d.	light-tan, silty, thin-bedded	0.8
c.	light-brown, fine-grained, massive, well-consolidated	1.6
b.	gray, silty	1.0
a.	dark- to light-brown; orange and black stains; fine-grained, thin-bedded	3.1
SENORA FORMATION		
	Covered: shale; upper part dark	95.2

78

Sec. 14, T. 15 N., R. 14 E. Measured north of road in SW¼, by D. G. Leitner.

SENORA FORMATION		
8f	Sandstone: dark-brown, loosely consolidated	2.0
e	Covered: sandy red soil	1.0
d	Limestone: dark-gray, dense, silty, wavy-bedded, fossiliferous	1.0
c	Shale: gray	3.0
b	Shale: gray-brown, silty	6.0
a	Siltstone: brown	0.5
	Shale: dark-gray	2.0
	Shale: light-gray	5.5
	Covered: not measured	

79

Sec. 20, T. 15 N., R. 14 E. Measured up escarpment at NE corner, by D. G. Leitner.

CALVIN SANDSTONE		
5	Sandstone: light-brown with iron stains; thin-bedded at base and top; thick-bedded in middle	24.7
SENORA FORMATION		
	Shale: dark-gray; silty at top; phosphatic nodules in middle	7.0
	Covered: probably shale	58.0

80

Sec. 24, T. 15 N., R. 14 E. Measured in road up escarpment in SW¼, by D. G. Leitner.

SENORA FORMATION

4b	Sandstone: brown, fine-grained to silty, thin-bedded	13.7
	Covered: probably shale	55.0

81

Sec. 34, T. 15 N., R. 14 E. Measured south of road in NW¼, by D. G. Leitner.

SENORA FORMATION

8d	Limestone: gray; weathers brown; dense, fossiliferous, impure	1.9
c	Shale: gray, calcareous	4.1
b	Covered: probably shale	7.5
a	Limestone: dark-gray, thin-bedded, nonfossiliferous	2.0
	Shale: black; grading up into gray	6.0
	Covered: probably shale; not measured	

82

Sec. 19, T. 16 N., R. 11 E. Measured from Recent alluvium near northeast corner NW¼ SW¼ to southwest corner NW¼ SW¼, by G. C. Luff.

NELLIE BLY FORMATION

1n	Covered: probably silty shale; not measured	
m	Sandstone: buff, fine- to medium-grained	5.0
l	Covered: probably silty shale	3.5
k	Sandstone: buff, fine-grained	1.0
j	Covered: probably silty shale	11.0
i	Sandstone: buff, fine-grained	1.0
h	Covered: probably silty shale	16.5
g	Sandstone: buff, fine-grained	1.0
f	Covered: probably silty shale	16.5
e	Sandstone: tan with red iron stains	3.0
d	Covered: probably silty shale	16.0
c	Sandstone: red-tan with iron stains; weathers brown; friable	5.5
b	Covered: probably silty shale	22.0
a	Sandstone: tan to rust; weathers dark-brown; fine-grained, friable	14.0
	Covered: probably silty shale	44.0

83

Sec. 21, T. 16 N., R. 11 E. Measured from creek bottom near center of W½ northeast to top of hill in NE¼, by G. C. Luff.

COFFEYVILLE FORMATION		
8b	Covered: probably shaly siltstone; not measured	
a	Sandstone: buff; weathers brown; medium-grained, massive, friable	23.0
	Covered: probably shaly siltstone	39.0

84

Sec. 28, T. 16 N., R. 11 E. Measured from creek bottom one-fourth mile east of northwest corner eastward to the top of the hill, by G. C. Luff.

HOGSHOOTER FORMATION		
c	Sandsone: buff, fine-grained, friable, slightly calcareous	1.5
b	Limestone: blue-gray; weathers red-brown to buff; sandy, fossiliferous	0.8
a	Limestone: tan; weathers off-white; sandy with interbedded thin sandstone stringers; platy, fucoidal	10.5
COFFEYVILLE FORMATION		
	Shale: light-gray-green, partly covered	31.0
8b	Covered: probably shaly siltstone	16.0
a	Sandstone: buff; weathers brown; fine-grained	
	Covered: probably silty shale; not measured	

85

Sec. 32, T. 16 N., R. 11 E. Measured in the NW¼, from the bottom of the gully on the southeast side of the hill northwest to top of hill, by G. C. Luff.

NELLIE BLY FORMATION		
1	Sandstone: buff, fine-grained, friable, ripple-marked	12.0
	Covered: probably silty shale	55.0
HOGSHOOTER FORMATION		
	Sandstone: buff, fine- to medium-grained, friable, slightly calcareous	3.0
	Limestone: gray-tan; weathers off-white; sandy	0.7
COFFEYVILLE FORMATION		
	Shale: gray, fissile	2.5

86

Sec. 34, T. 16 N., R. 11 E. Measured along south line from *base of hill one-fourth mile east of southwest corner west to top of hill at that corner, by G. C. Luff.*

COFFEYVILLE FORMATION		
8	Sandstone: buff; weathers brown; fine- to medium-grained	19.0
7d	Siltstone: tan, shaly, poorly exposed	25.0
c	Sandstone: buff; weathers brown; fine- to medium-grained	16.0
b	Siltstone: tan, poorly exposed	37.0
a	Sandstone: buff; weathers brown; medium-grained	31.0
	Shale: gray-tan, thin-bedded, slightly silty	27.5
	Shale: tan; contains interbedded off-white limestone stringers 0.2 feet thick	2.5
	Shale: gray-tan, thin-bedded, platy	6.0
	Shale: tan; contains interbedded off-white limestone stringers 0.2 feet thick	3.0
	Shale: tan to gray-blue, thin-bedded; not measured	

87

T. 16 N., Rs. 11 and 12 E.

Geologic section along an alidade traverse from the top of the hill in the south-central part of sec. 34, T. 16 N., R. 11 E., southeast to junction of trail and road on south line, thence east along road to the southeast corner of sec. 36, T. 16 N., R. 12 E. Measured by G. C. Luff.

COFFEYVILLE FORMATION		
7	Sandstone: buff, fine-grained	39.0
	Covered: probably shale	152.0
2	Topographic bench: probably sandy limestone; about	4.0
	Covered: probably shale	75.0
1	Topographic bench: probably sandstone; about	3.0
	Covered: probably shale	60.0
CHECKERBOARD LIMESTONE		
	Topographic bench: limestone	2.0
SEMINOLE FORMATION		
2b	Covered: probably shale	37.0
a	Topographic bench: probably sandstone	22.0
	Covered: probably shale	69.0
1c	Topographic bench: probably sandstone	11.0
b	Covered: probably shale	24.0
a	Topographic bench: probably sandstone	26.0
HOLDENVILLE SHALE		
	Covered: probably shale	18.0
7	Sandstone: poorly exposed	12.0
	Covered: probably shale	48.0
4	Topographic bench: limestone flags	3.0
	Covered: probably shale	18.0
3	Topographic bench: probably sandstone	3.0

	Covered: probably shale	54.0
2	Topographic bench: sandstone	12.0
	HOLDENVILLE SHALE AND WEWOKA FORMATION	
	Covered: probably shale (includes unit ℙwk-26)	92.0
	WEWOKA FORMATION	
	Topographic bench: calcareous mudstone flags; about	2.0

88

Sec. 29, T. 16 N., R. 12 E. Measured in road cut on east line, just south of Duck Creek, from lowest shale outcrop south 100 feet to top of hill, by G. C. Luff.

	SEMINOLE FORMATION	
1c	Sandstone: gray-tan; massive in upper part; thin-bedded in lower part; grades into siltstone near base; friable; contains chert conglomerate	19.2
b	Shale: gray-tan, thin-bedded, silty; contains a few concretions	5.5
a	Coal: varies in occurrence from stringers one inch thick, in shale, to an unbroken coal bed	0.6
	HOLDENVILLE SHALE	
	Shale: blue-gray, platy; not measured	

89

Sec. 30, T. 16 N., R. 12 E. Measured on South Duck Creek from below unnamed coal, SW¼ NE¼, up the creek west to outcrop of Checkerboard Limestone, center W½, by G. C. Luff.

	CHECKERBOARD LIMESTONE	
	Limestone: gray-blue; weathers yellow; fossiliferous; "checkerboard" jointing	2.2
	SEMINOLE FORMATION	
2i	Shale: tan; contains thin sandy limestone stringers; silty at base; poorly exposed; about	10.0
h	Sandstone: tan, iron stained, fine-grained	4.0
g	Siltstone: gray-green, thin-bedded, sandy, micaceous; top not exposed; about	22.0
f	Sandstone: gray-tan, fine-grained, calcareous; "checkerboard" jointing	0.3
e	Shale: tan, thin-bedded	2.0
d	Sandstone: gray-tan, fine-grained, calcareous; "checkerboard" jointing	0.5
c	Shale: gray to black, thin-bedded, poorly exposed; about	6.0
b	Coal: unnamed, shaly; platy at top; contains plant fossils	1.3
a	Shale: gray-black, silty, poorly exposed; not measured	

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Sec. 32, T. 16 N., R. 13 E. Measured in west bank of creek in NE¼, by D. G. Leitner.

Wewoka Formation

24	Sandstone: light-brown, iron-stained, silty, massive to thin-bedded	15.0
	Covered: probably shale	11.0
23	Sandstone: light-brown, silty, massive to thin-bedded	13.5
	Covered: probably shale; not measured	

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Sec. 36, T. 16 N., R. 13 E. Measured up escarpment in SE¼, by D. G. Leitner.

Wewoka Formation

	Covered: gentle slope; probably shale	11.0
6	Sandstone: light-brown, silty; boulders mark outcrop; about	10.0
	Covered: gentle slope; probably shale	17.5
5	Covered: sandstone; about	10.0
	Covered: gentle slope; probably shale	17.5
4	Covered: steeper slope; probably sandstone	10.0
	Covered: probably shale	28.0

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Sec. 36, T. 16 N., R. 13 E. Measured along road up escarpment in SW¼, by D. G. Leitner.

Wewoka Formation

5	Sandstone: gray-brown, fine-grained to silty, thick-bedded and thin-bedded	11.0
	Covered: probably shale	33.0

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(**Boldface** indicates main references)