OKLAHOMA GEOLOGICAL SURVEY

CARL C. BRANSON, *Director*

Bulletin 83

GEOLOGY OF PAWNEE COUNTY, OKLAHOMA

By

PAUL B. GREIG

Norman, Oklahoma

November 1, 1959

1959

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

GEOLOGY OF PAWNEE COUNTY, OKLAHOMA

Paul B. Greig

ABSTRACT

This investigation is one of many similar investigations supervised by the University of Oklahoma School of Geology in cooperation with the Oklahoma Geological Survey in its program of mapping the surface geology of Oklahoma. Data were gathered in seven months' field work during which 27 key beds were mapped on aerial photographs, and the lithology, thickness, sequence, and faunal content of the section were studied.

Sedimentary rocks of the Upper Pennsylvanian, Lower Permian, and Quaternary systems are exposed in Pawnee County. Pennsylvanian beds range upward from the Wann formation of late Missourian age to the Brownville limestone of latest Virgilian age. They are overlain with apparent conformity by a Permian sequence containing Wolfcamp sediments up to and including the Winfield limestone formation of the Chase group. Quaternary deposits and alluvium lie unconformably on the truncated edges of the Paleozoic strata.

During Upper Pennsylvanian and Lower Permian time the Pawnee County area was situated between an eroding landmass to the south and a cyclicly subsiding marine basin to the north. The resultant sediments form a complex sequence transitional between the coarsely clastic continental deposits of the source area and the cyclic primarily marine deposits of the basin. Subdivision and classification of this transitional sequence requires the use of nomenclature from both the marine and continental sections.

In late Missourian and early Virgilian time deposition was controlled largely by conditions in the source area, and the rocks are mainly interbedded sandstones and shales of continental and deltaic origin. Southward encroachment of a marine environment and a concurrent decrease of source material are indicated in upper Virgil and lower Wolfcamp time by subcylic deposition of sandstones, shales, thin limestones, and coals. A thick red bed sequence of upper Wolfcamp age records rejuvenation of the source area and retreat of the sea, although a marine environment recurred periodically over much of the county during this time.

The subsurface strata are primarily of marine origin and include beds of Cambro-Ordovician, Ordovician, Mississipian, Pennsylvanian, and Permian age.

The sedimentary sequence contains four major angular unconformities and at least four minor unconformities. The westerly dip of the beds is interrupted locally by north-trending belts of en echelon faults and small dome-like folds. Faulting and folding are attributed to horizontal and vertical movements, respectively, along ancestral zones of weakness in the granite basement. Folding took place recurrently throughout Pennsylvanian and Lower Per-

mian time. The faulting probably occurred in late Permian or early post-Permian time, when the sediments were uplifted and tilted westward. The area was subsequently peneplaned and later rejuvenated. Dissection of the peneplane is currently in progress.

The county's chief mineral resources is oil. Potentially valuable deposits of clay and building stone and non-commercial deposits of coal, copper and radioactive minerals are known.

INTRODUCTION

Scope and Purpose of Report

The data acquired in a field and laboratory study of the surface rocks of Pawnee County and their westward continuation into the subsurface are presented in this report. Special attention is given to lithology, thickness, sequence, and faunal content of each formation. The distribution and structural features of key units mappable by reconnaissance methods are shown on the accompanying geologic map (Plate 1). Correlation of the surface and subsurface sections is shown on electric log cross sections A-B, B-C, and D-E (Plates 2, 3, and 4, respectively). The location and occurrence of mineral deposits of possible economic value, with particular emphasis on crude oil and natural gas, are briefly discussed.

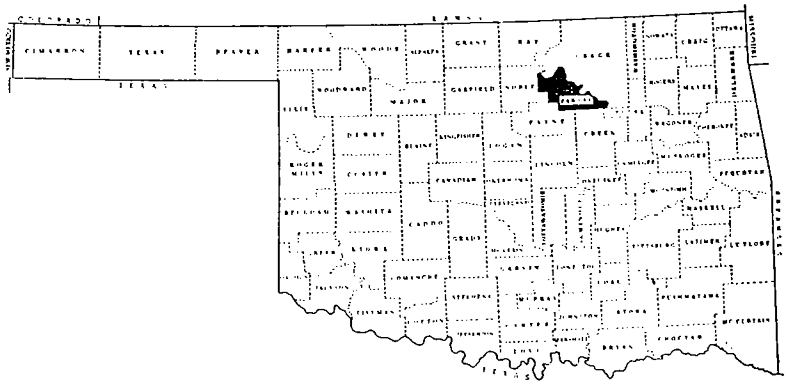

Figure 1. Index map of Oklahoma showing location of Pawnee County.

Location of the Area

Pawnee County includes about 584 square miles of north-central Oklahoma northwest of the city of Tulsa (Fig. 1). The county is roughly triangular with the sharpest apex of the triangle pointing eastward. The Arkansas River forms the county boundary on the north and east, separating Pawnee County from Osage County. Other adjacent counties are Noble on the west, Payne on the west and south, and Creek and Tulsa Counties on the south.

Previous Investigations

Published data on the surface geology of Pawnee County are limited almost exclusively to discussions of a regional nature. Subsurface data are more plentiful, however, and include several references on the geology of individual oil pools in the county.

The most comprehensive report yet published on the geology of Pawnee County was written by Frank C. Greene (1928). It consists of a brief discussion of the structure and stratigraphy of the surface and subsurface rocks together with a resumé of oil field development and future oil possibilities. A guide to the geology along Oklahoma's highways, issued by the Oklahoma City Geological Society (1932; revised, 1955) summarizes the geology of Pawnee County along U.S. Highway 64. The surface geology of the easternmost portion of the county was mapped by Oakes (1952) in conjunction with his work on Tulsa County. Included in Oakes' report are several measured sections from Pawnee County. A soils map of the county was published by Galloway and others (1952).

The earliest contribution to the regional geology of the area was made by Gould, Ohern, and Hutchison (1910), who proposed a new classification of the Pennsylvanian rocks of eastern Oklahoma. Heald (1916) first extended Kansas terminology into Oklahoma in his report on the Foraker quadrangle in northern Osage County. Beede (1914) described the areal extent and stratigraphic relations of the Neva limestone south of the Arkansas River with particular reference to exposures north of Pawnee. Fath (1920) described the anticlines and en echelon fault zones of central and north-central Oklahoma and presented a theory for their origin. The structure of the region has been discussed by several authors including Foley (1926), Sherrill (1929), Melton (1930), and Powers (1931).

Miser's "Geologic Map of Oklahoma", first published in 1926, shows the areal geology of Pawnee County on a scale of 1:500,000. A revised edition of this map was published in 1954.

Further regional background was supplied by Gould and Wilson (1927), who discussed the Upper Paleozoic rocks of Oklahoma in their "Paleogeography of Oklahoma". The stratigraphy of the Mid-Continent region, which includes Pawnee County, was the subject of papers by Levorsen (1927), Hiestand (1935), Green (1936, 1937), and Dott (1941). Anderson (1941) described the interfingering marine and red bed deposits of north-central Oklahoma. The upper Pennsylvanian and lower Permian stratigraphy of north-central Oklahoma was reviewed by Parker and others (1946) in a field trip guide book of the Oklahoma City Geological Society.

Brief reference to the economic geology of Pawnee County has been made in a number of articles. In surveys of Oklahoma's mineral resources Gould et al. (1908), Gould (1911), Snider (1911), Shannon (1914), and Cullen (1917) mentioned the possible economic value of the limestones, sandstones, and shales of Pawnee County. A review of the physical properties of the clay and the operation of the brick plant at Cleveland was given by Snider (1917) and later by Sheerar (1932.) Shannon et al. (1926 p. 57) mentioned a coal deposit in the town of Ralston, and small copper deposits in the western part of the county were described by Merritt (1940). The occurrence and value of radioactive minerals associated with the copper were discussed by Branson and others (1955).

The history and geography of Pawnee County were reviewed by Snider (1917) in a report on the geography of Oklahoma.

The discovery of oil near the town of Cleveland in 1904 resulted in an active program of investigation of the subsurface geology of the county. Unfortunately, most of this work has been done by private corporations, who have not published their findings.

One of the earliest published references to oil and gas in Pawnee County was in a review of the mineral resources of Oklahoma by Gould et al. (1908), who told of the discovery of the Cleveland pool. The Cleveland pool was also discussed by Hutchison (1911) in his summary of hydrocarbon production in Oklahoma. Wood (1911) reviewed the oil and gas development of north-central Oklahoma, including all of easternmost Pawnee County in his survey. In 1917 a brief summary of the structure, stratigraphy, and cumulative and prospective oil production of Pawnee County was given by Shannon and others in a report on oil and gas in Oklahoma. The Morrison (Watchorn) field was the subject of a detailed study by Carpenter in 1927, and a year later Bess M. Bullard (1928) published a compilation of data on each of Oklahoma's oil and gas fields.

The geology of the Red Fork shoestring sand production in the Keystone area of Pawnee, Creek, and Tulsa Counties was discussed in detail by Ralph White (1941), and in 1942 a bibliography of Oklahoma's oil and gas pools, including those in Pawnee County, was published by A. G. and M. B. Shelton. Three significant contributions to the knowledge of the county's subsurface geology have been made in regional studies published subsequent to the Shelton's bibliography. Lukert (1949), in a subsurface study of southern Kansas and northern Oklahoma, extended one of his east-west electric log cross sections across Pawnee County; Ireland (1955) discussed the configuration of the Precambrian surface in northeastern Oklahoma and parts of adjacent states; and Tarr (1955) described the pre-Woodford paleogeography and thickness of the Hunton formation in Oklahoma.

The present report on Pawnee County is one of many similar reports supervised by the University of Oklahoma School of Geology in cooperation with the Oklahoma Geological Survey in its program of mapping the surface geology of Oklahoma. Figure 2 shows the location of Pawnee County in relation to other areas on which reports of the surface geology are available. Frequent reference is made to several of these reports, especially those to the north, in the following chapter on surface stratigraphy. The reports on the areas immediately south of Pawnee County are in various stages of completion. Most of the field work is finished, however, and the results thereof have been drawn upon in writing this report.

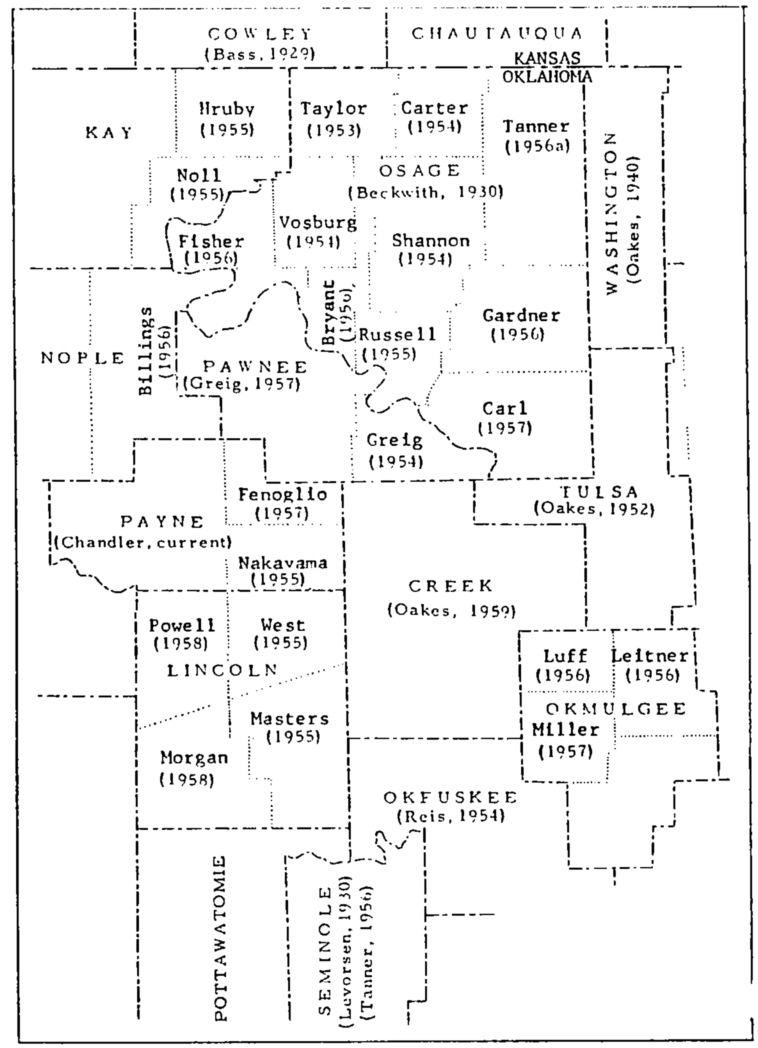

Figure 2. Index map of north-central Oklahoma showing areas of which surface geology has been mapped.

Preparation

Aerial photographs of the county taken for the Agriculture Adjustment Administration in July, 1938, were obtained from the Oklahoma Geological Survey. Alternate photographs in each flight line were covered with a cellulose acetate flap on which section corners, drainage, railroads, and irregular roads were traced from the photographs.

A grid map of the county was constructed on tracing paper, and using the section corners on the acetate overlay for orientation, the drainage and culture were traced onto the grid. Where differences occurred between the scale of the grid and the scale of the photographs, adjustments were made to the section corners.

Field Procedure

Field work on the eastern portion of the county was carried out in the summer of 1953 and the work was submitted to the University of Oklahoma faculty as partial fulfillment of the requirements for the degree of Master of Science. The remainder of the county was mapped during the winter of 1954-55. A total of about 7 months was spent in the field.

Mapping was carried out from east to west, one or two rock units at a time. Following careful stereoscopic examination of the aerial photographs, an escarpment-forming or otherwise recognizable unit was followed along its north-south belt of exposure by checking outcrops along roads and in creek beds. At many places it was necessary to walk the outcrop to establish the continuity of the bed. The trace of the outcrop and the traces of observed or inferred faults were indicated directly on the photographs in colored grease pencil. This information was later traced onto the grid map.

Lithology and faunal content of the beds were noted and sampled, and detailed sections were measured with a hand level and steel tape.

Laboratory Procedure

Fossil collections were cleaned, sorted, and identified, and insoluble residues and thin sections were made for key limestone beds. In cases where it had not been possible to determine accurate thickness and sequence of beds in the field, electric logs of wells drilled down dip from the outcrops were studied, the beds were identified on the logs, and true thickness was measured. Regional dips were established by the three-point method using both surface and subsurface elevations.

PHYSIOGRAPHY OF THE AREA

General Statement

According to the physiographic division of the United States by Fenneman (1938), Pawnee County is in the southwestern part of the Central Lowland province. Snider (1917), in describing the physiographic provinces of Oklahoma, placed the east portion of the county in the Sandstone Hills and the west portion in the Red Beds Plains. The division line runs approximately north-south through the town of Pawnee and in essence follows the outcrop of the Neva limestone. East of this line the surface rocks are predominantly gray shales interbedded with resistant escarpment-forming beds of sandstone and limestone. West of the line the rocks are predominantly red shale and weakly resistant sandstone.

Topography And Drainage

Differential erosion of the gently west-dipping beds of the Prairie Plains homocline has produced the main topographic features of Pawnee County. The Prairie Plains homocline is a regional structural feature involving the Pennsylvanian and Permian beds of the Mid-Continent region west of the Ozark dome. Truncation of these beds has formed a series of parallel east-facing ridges or cuestas which trend due north to just east of north, following the strike of the beds. The cuestas are capped by resistant sandstone or limestone and are separated by broad valleys underlain by less resistant sandstones and limestones and non-resistant shales. Locally this "ridge and valley" pattern is modified by changes in the regional dip of the beds induced by faulting or warping.

Pawnee County occupies the northern two-thirds of the east-pointing "V" formed by the confluence of the Arkansas and Cimarron Rivers. The lowest elevation in the county, about 650 feet above sea level, occurs at this junction. The highest point is in the north-central part of T. 20 N., R. 5 E., just east of Lone Chimney, where four hills rise to a height of slightly more than 1,120 feet. Local relief is generally less than 150 feet and decreases westward, whereas average elevation increases westward.

East of R. 7 E. cuestas capped by thick massive sandstones give rise to a rough, timber-covered topography typical of the Sandstone Hills. In Rs. 5, 6, and 7 E. limestone and sandstones crop out alternately. Here shale valleys are more common, the topography is less rugged, and timbered slopes are fewer than in the area farther east. West of Pawnee in Rs. 3 and 4 E. minor escarpments along the Arkansas River blend southward into the gently rolling grasslands of the Red Beds Plains. Much this area is almost flat, especially where covered by upland terrace deposits.

The county is drained by two major rivers, the Arkansas and the Cimarron, and by several secondary streams. The drainage is directed north and northwestward into the Arkansas and south-eastward into the Cimarron by an east-west divide which crosses the county in the north part of T. 20 N. All but a few of the secondary streams are intermittent in normal years, and even the largest, Black Bear Creek, is dry in periods of severe drought. Such a drought occurred in late 1954.

The drainage is in large part subsequent, although a dendritic pattern is developed in areas of uniformly resistant surface rock. Where faults occur in the surface beds, the drainage tends to follow the fault trace.

The topography and drainage of all of Pawnee County except a two-mile strip along the westernmost border are shown on seven quadrangle sheets of the "Topographic Atlas of the United States" (United States Geological Survey).

Climate

The climate of Pawnee County is characterized by long, hot summers and short, mild winters. Average annual rainfall is about 36 inches, most of which falls during the spring and summer months. Field work is best undertaken in the winter when vegetation, insects, snakes, and temperatures are at a minimum.

Accessibility of the Area

Access to Pawnee County is provided by four paved highways, a better-than-average system of secondary and section-line roads, and three railroads. Paved highways include U. S. Highway 64, which crosses the county in an east-west direction, linking the towns of Pawnee, Cleveland, and Keystone. Oklahoma Highways 18 and 99 cross the county in a north-south direction, serving Pawnee and Cleveland, respectively. Oklahoma Highway 51 enters the southeast corner of the county near Keystone, where it joins U.S. 64 en route to Tulsa, 24 miles distant. Several graveled, all-weather roads, including Oklahoma Highway 15, traverse the county, and graded roads follow most section lines except in areas of high topographic relief. Many of the graded roads become temporarily impassable after heavy rains, especially where the roads are built across outcropping shale.

The main line of the Missouri, Kansas, and Texas Railway between Kansas City and Dallas crosses the area in a southwest direction, serving Cleveland, Hallett, and Jennings en route; the St. Louis and San Francisco Railroad crosses the area in an east-west direction, serving Pawnee, Hallett, Terlton, and Keystone; and a spur of the Atchison, Topeka, and Sante Fe serves Ralston, Skedee, and Pawnee as it crosses the county from north to south.

ACKNOWLEDGMENTS

Dr. Carl C. Branson suggested and supervised this investigation, and the report was presented as a dissertation for the doctorate degree at the University of Oklahoma. Doctors William E. Ham, Frank A. Melton, George G. Huffman, Philip A. Chenoweth and Mr. Arthur W. McCray read and criticized the manuscript. Dr. Louise Jordan of the Oklahoma Geological Survey assisted in subsurface correlation and nomenclature.

The Oklahoma Geological Survey provided airplane photographs and financial assistance for the field work. The Standard Oil Company of Texas, through its Fellowship in Geology, supported academic and field work. The residents of Pawnee County were friendly and helpful. The author is especially indebted to his wife, Jean, without whose assistance, encouragement, and understanding this report would not have been completed.

STRATIGRAPHY

General Statement

The surface rocks of Pawnee County include approximately 2,500 feet of Upper Pennsylvanian and Lower Permian sediments, overlain locally by thin deposits of Quaternary age. The Pennsylvanian and Permian beds have been tilted gently westward, and subsequent erosion has beveled the section, exposing progressively older beds to the east.

Pennsylvanian beds with an aggregate thickness of about 1,500 feet are exposed in the eastern part of the county, ranging upward from the Wann formation of the Missouri series to the Brownville limestone, the top unit of both the Virgil series and the Pennsylvanian system. Permian beds occurring in the county include all of the Wolfcamp series except the uppermost part and have an aggregate thickness of about 1,000 feet.

Resting unconformably on the truncated edges of these late Paleozoic sediments are local deposits of unconsolidated Quaternary alluvium and terrace material.

PENNSYLVANIAN SYSTEM

MISSOURI SERIES

In north-central Oklahoma and adjacent areas the Missouri series lies with regional unconformity on the Des Moines series and is overlain unconformably by the Virgil series (Table 1).

Missouri exposures in Pawnee County occur in the narrow eastern portion of the county in Rs. 9 and 10 E. They range from the middle of the Wann formation to the top of the series and consist mainly of sandstones interbedded with red and gray shales. Exposures constitute a thickness of approximately 450 feet. Dip is to the west at less than one degree.

TABLE 1

KEY BEDS OF THE MISSOURI SERIES OF NORTH-CENTRAL OKLAHOMA

- Virgil series
- (U n c o n f o r m i t y)
- Missouri series
  - Tallant formation
    - Revard sandstone member
    - Bigheart sandstone member
  - Barnsdall formation
    - Unnamed shale
    - Okesa sandstone
  - (U n c o n f o r m i t y)
  - Wann formation
    - Clem Creek sandstone
    - Washington Irving sandstone
  - Iola formation
  - Chanute formation
  - (U n c o n f o r m i t y)
  - Dewey formation
  - Nellie Bly formation
  - Hogshooter formation
  - Coffeyville formation
  - Checkerboard limestone
  - Seminole formation
  - (U n c o n f o r m i t y)
- Des Moines series

A slight southward component to the dip is suggested by local outcrop patterns although because of the narrow exposure along strike and a dearth of good horizon markers, a quantitative estimate of degree and direction of dip was not attempted.

The Missouri rocks of Pawnee County yielded no faunal remains. One plant impression was found.

Study of the regional stratigraphy of north-central Oklahoma discloses unconformity and southward truncation of progressively older beds between the Wann and Barnsdall formations as well as between the Missouri and Virgil series. These relationships are not evident in the narrow belt of Missouri outcrop in eastern Pawnee County nor are they revealed by study of the subsurface section downdip from the outcrop belt (Plates 2-4). Subsurface data indicate the presence of an angular unconformity in the lower

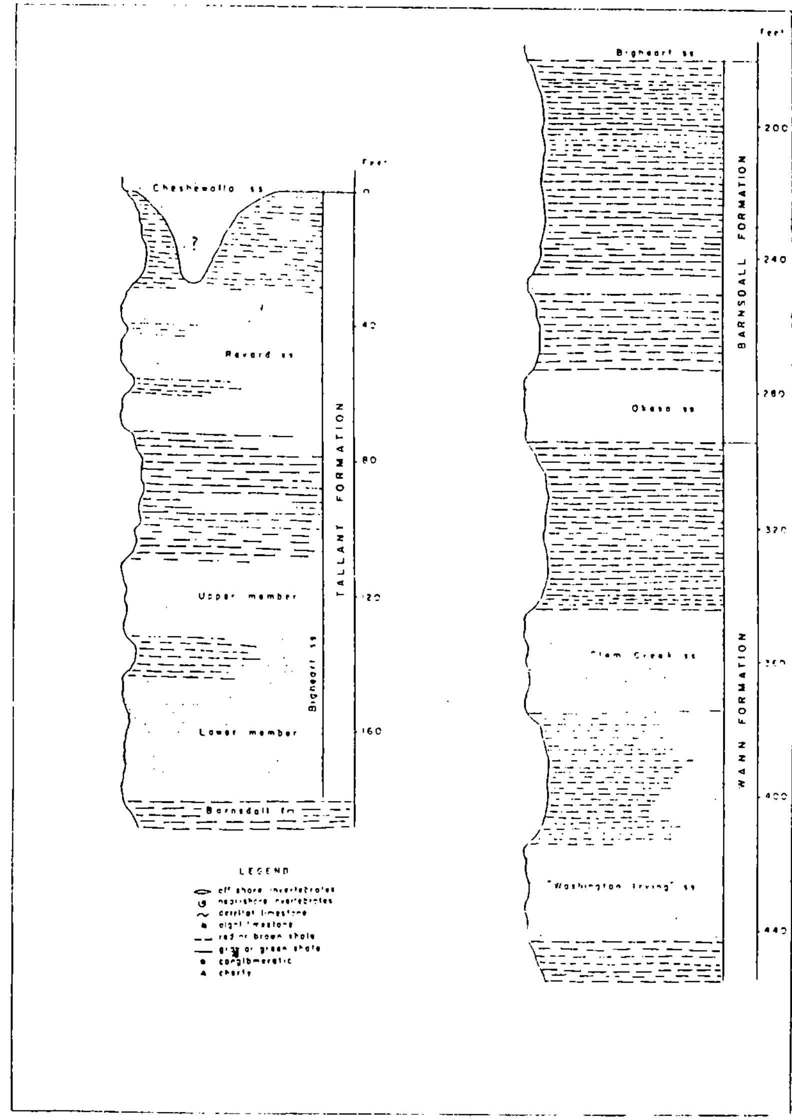

Figure 3. Generalized columnar section of the rocks of upper Missouri age in Pawnee County.

part of the Wann formation, but this indication is based on incomplete data and should be considered as only a possibility until confirmed or refuted by more detailed investigation.

Wann formation

Definition and distribution. The name Wann was first applied by Ohern (1910, p. 28) to a sedimentary sequence near the village of Wann in Nowata County, Oklahoma. The term fell into disuse until Oakes (1940, p. 72) redefined it to include all the upper Missouri rocks above the top of the Iola formation and below the base of the Torpedo sandstone. In areas where the Torpedo sandstone has been removed by pre-Barnsdall erosion, as in Pawnee County, the upper limit of the Wann is designated as the base of the Birch Creek limestone or its southern equivalent, the Okesa sandstone, basal member of the overlying Barnsdall formation.

The Wann formation is recognized from the Kansas-Oklahoma line southward into Creek County, where it is completely truncated by pre-Barnsdall erosion (Oakes, 1952, p. 87). It crops out in the easternmost portion of Pawnee County in T. 20 N., R. 10 E., and in adjacent portions of R. 9 E., where it was mapped by Oakes (1952) in conjunction with his work in Tulsa County.

Thickness and character. Oakes (1952, p. 84) describes the Wann formation in Tulsa County as being composed of heterogeneous rock types which intergrade both laterally and vertically. Thick sandstones split southward into thinner sandstones and intercalated maroon shales. According to Oakes the thickness of the Wann ranges from 225 feet in T. 22 N., R. 10 E., Osage County, to 265 feet in T. 19 N., R. 10 E., Tulsa County. Thickening of the formation to the south more than compensates for truncation by pre-Barnsdall erosion.

Only the upper part of the formation crops out in Pawnee County. The most complete section occurs in sec. 25, T. 20 N., R. 9 E., where the top 142 feet is exposed.

The thick sandstones referred to by Oakes include the "Washington Irving" and Clem Creek sandstones, both of which occur in Pawnee County. "Washington Irving" is a colloquial term applied to a local coalescence of several sandstone lenses which forms a prominent escarpment along the banks of the Cimarron

River just west of Keystone in secs. 35 and 36, T. 20 N., R. 9 E. The "Washington Irving" is the lowest recognizable member of the Wann formation exposed in the county although north and east of the "Washington Irving" exposures, unnamed sandstone lenses are exposed lower in the section.

Figure 4. Clem Creek - "Washington Irving" sandstone scarp along the Cimarron River is in SW ¼ sec. 21, T. 20 N., R. 9 E. Ninety feet of sandstone is exposed above the alluvium.

In the SE¼ sec. 25, T. 20 N., R. 9 E., the "Washington Irving" sandstone is overlain by 38 feet of silty maroon shale capped by an eroded remnant of the Clem Creek sandstone. One half mile northwest in the SW¼ sec. 24 of the same township the shale unit pinches out and the "Washington Irving"-Clem Creek section is represented by 90 feet of massive to cross-bedded sandstone, contorted toward the base, which forms the precipitous east bank of the Cimarron River at that point (Figs. 4 and 5). These relations exemplify the extremely lenticular character of most of the sandstone beds in the Wann formation.

Overlying the Clem Creek sandstone is the topmost unit of the Wann, an unnamed section of predominantly gray shale containing ironstone concretions. The bed is about 50 feet thick and persists across the county with little change in thickness or lithology.

A detailed measurement of that portion of the Wann formation exposed in Pawnee County may be found in Appendix D, section 41.

Correlations and stratigraphic relations. The Wann formation is equivalent to that portion of the Kansas section above the top of the Iola formation and below the base of the uppermost limestone member (probably the South Bend limestone) of the Stanton formation (Oakes, 1940, p. 80). It also corresponds to a part of the lower portion of the Hoxbar formation of the Ardmore Basin in southern Oklahoma (Moore and others, 1944, Pl. 1).

Figure 5. Contorted bedding in basal part of Clem Creek - "Washington Irving" sandstone scarp. This exposure is visible just above the alluvium in the center of Fig. 4.

The Wann formation lies conformably on the Iola formation and is overlain with slight angular unconformity by the Barnsdall formation. The Torpedo sandstone member is reportedly absent by erosion in Pawnee County, but no evidence of disconformity was seen at the top of the Wann. Evidence of unconformity in the lower part of the formation is presented on Plate 2 and discussed on page 126.

Paleontology. No evidence of either fauna or flora was found in the Pawnee County exposures of the Wann formation.

Barnsdall formation

Definition and distribution. The Barnsdall formation was named by Oakes (1951, p. 120) for exposures near the town of Barnsdall (formerly Bigheart) in east-central Osage County, Oklahoma. Oakes defined the formation as the rocks from the base of

the Birch Creek limestone upward through a section composed largely of shale to the base of the Bigheart sandstone, basal unit of the overlying Tallant formation. Southward from the type locality the Birch Creek limestone grades into the bottom of the Okesa sandstone, and much of the overlying shale changes facies to sandstone.

The Barnsdall formation is recognized from the Kansas-Oklahoma line southward into Okfuskee County. In Pawnee County the formation is exposed in T. 20 N., Rs. 9 and 10 E.

Thickness and character. In describing the Barnsdall formation Oakes (1952, p. 89) stated

> The Barnsdall formation is heterogeneous and contains shale, sandstone, dolomitic limestone and dolomite. It has several members, probably none of which is coextensive with the formation, unless it is the shale member at the top which apparently is present all along the outcrop. . . . The . . . formation is about 100 feet thick at the Kansas-Oklahoma line, 110 feet in T. 23 N., 145 feet in T. 22 N., 120 feet in T. 21 N. and 120 feet in T. 19 N.

Carl (1957, p. 39) reported a fairly constant thickness of 165 feet for the Barnsdall in southeastern Osage County. The formation is 80 feet thick in T. 12 N. in central Okfuskee County (Ries, 1954, p. 77).

No accurate measurement was obtained of the thickness of the Barnsdall formation in Pawnee County, but along the south line of sec. 19, T. 20 N., R. 10 E., the Okesa sandstone member attains a thickness of 16 feet. The overlying shale is as much as 78 feet thick in sec. 12, T. 20 N., R. 9 E., and the NE ¼ sec. 27, T. 20 N., R. 9 E.

No calcareous members were seen in the sections of Barnsdall in eastern Pawnee County. The Wildhorse dolomite member, which occurs near the top of the formation in southern Osage County (Carl, 1957, p. 42), is not found south of the Arkansas River.

Okesa sandstone member

The basal Okesa sandstone consists of one persistent bed in Pawnee County, contrasting with the several beds noted by Oakes (1952, p. 90) in adjacent Tulsa and Osage Counties. It is a fine- to medium-grained sandstone, massive to cross-bedded, with some contorted bedding. It caps the bluffs along the Cimarron and Arkansas Rivers in R. 10 E. and adjacent portions of R. 9 E., forming the easternmost continuous escarpment in the county.

Exposures of the Okesa sandstone are poor, however, largely because of the non-resistant character of the upper shale.

Above the Okesa is an unnamed sequence composed principally of shale and a few thin lenticular beds of fine-grained sandstone. Where exposed below the Bigheart member of the Tallant formation in secs. 28 and 29, T. 20 N., R. 9 E., the shale is maroon to red in the top part, but farther north in sec. 11 of the same township shale exposed immediately below the Bigheart is gray to gray-green. Measured sections of portions of the Barnsdall formation are listed in Appendix D, sections 39 and 40.

Correlation and Stratigraphic relations. According to Oakes (1952, p. 92) the basal Okesa-Birch Creek member of the Barnsdall formation is probably equivalent to the South Bend limestone of Kansas and eastern Nebraska and the overlying shale member to the lower part of the Weston shale of southern Kansas. To the south in Seminole County, Oklahoma, Tanner (1956, p. 86) correlated the Barnsdall with the upper part of the Hilltop formation.

The contact of the Barnsdall formation with the underlying Wann is one of slight angular unconformity. This relationship is not evident in Pawnee County but becomes apparent when observations are made on a regional basis. The unconformity truncates the Wann and Iola formations southward so that in south-central Creek County the Okesa sandstone lies on the Chanute formation (Oakes, 1952, p. 92). The contact of the Barnsdall formation with the overlying Tallant formation is conformable.

Paleontology. No evidence of either fauna or flora was observed in the exposures of the Barnsdall formation in Pawnee County. Carl (1957, p. 44) lists a small faunule collected from the unnamed shale member in the NW¼ sec. 21, T. 22 N, R. 10 E.

Tallant Formation

Definition and distribution. The Tallant formation was named by Oakes (1951, p. 121) from exposures near the town of Tallant in central Osage County, Oklahoma. Until the formation was named, the beds of which it is composed were considered to be of Virgil age and were included in the basal part of the Nelagoney formation, a term which has now been discarded. Work by Oakes has demonstrated that the basal Virgil unit of Kansas, the Tonganoxie channel sandstone, correlates with the Cheshewalla sandstone of northern Oklahoma, not with the Bigheart sandstone as previously supposed. As a result, the section from the base of the Bigheart to the base of the Cheshewalla was reclassified, the beds being assigned to the Missouri series and given the name Tallant formation.

The Tallant formation extends southward from the Kansas-Oklahoma line in a relatively narrow strip across Osage, Pawnee, and Creek Counties into Okfuskee County, where it is truncated by pre-Virgil erosion.

Exposures of the Tallant in Pawnee County extend eastward from about the center of R. 8 E., attaining a maximum width of outcrop of more than 8 miles in the "V" between the Arkansas and Cimarron Rivers.

Thickness and character. In his original definition Oakes (1951), p. 121) described the Tallant formation as follows:

> It consists of sandstone and shale. In Osage County . . . there are two principal, named, sandstone members, the Bigheart and the Revard in ascending order, but the several geologists who have written about them are not in accord as to their limits except, fortunately, that all agree on the base of the Bigheart, the basal member of the Tallant. In addition to the Bigheart and the Revard there are other sandstone units and some of these may be extensive enough to be mapped, eventually, as members.

This description is applicable to the formation in Pawnee County, where the Tallant consists of a sandstone-shale sequence, three of the sandstones being persistent enough to be mapped as members.

The thickness of the formation in northeastern Osage County ranges between 100 and 250 feet (Tanner, 1956a, p. 32). Southward from the type locality in T. 25 N. the formation becomes progressively thinner (Oakes, 1952, p. 94), presumably by truncation. In Pawnee County no exposure was found where the entire section is present and measurable, but a composite section indicates a thickness of about 230 feet.

Bigheart sandstone member

The basal unit of the Tallant is the Bigheart sandstone. The name Bigheart was first applied by Hutchison (1907, p. 89) to a sandstone-shale sequence exposed near the town of Bigheart (now Barnsdall) in central Osage County. Subsequent usage has restricted the name to the basal sandstone member of the sequence. Because of the lenticularity of the beds within this interval, there is no agreement as to the upper limit of the sandstone body, but the base is well defined (Oakes, 1952, p. 94).

In Pawnee County the Bigheart is a thick, resistant bed of fine- to coarse-grained sandstone. It is massive to well-bedded to cross-bedded and contains silty or shaly streaks. Small shale pebbles in the sandstone occur locally. A thickness of 72 feet was measured in the south-central portion of sec. 28, T. 20 N., R. 9 E., and at least 50 feet of Bigheart is present in the escarpment facing the Arkansas River in the east half of sec. 12 of the same township.

Wedges of red and gray shale interfinger into the massive Bigheart sandstone from the west, resulting in a complex sandstone-shale sequence typical of the Bigheart in the western part of its outcrop. Two persistent sandstones in this sequence were mapped and have been designated as upper and lower Bigheart (IPtb-u and IPtb-l, respectively, Plate 1). East of sec. 9, T. 20 N., R. 9 E., these sandstones coalesce, forming the thick, unbroken sandstone section typical of the Bigheart in the eastern portion of its outcrop.

Unnamed shale member

Resting on the Bigheart member is an unnamed shale section approximately 100 feet thick consisting of maroon and gray shales and thin lenticular beds of light-colored siltstone and fine-grained sandstone.

Revard sandstone member

Above the unnamed shale is the Revard sandstone member, which was named by Winchester, Heald, and others (1918, p. 61) from exposures on Revard Point in the Pawhuska quadrangle of central Osage County, Oklahoma. The limits of the Revard are obscure even at the type locality and consequently, the unit is of doubtful stratigraphic value. It is applied to the persistent sandstone normally present in the upper part of the Tallant formation. However, the lenticular nature of upper Missouri sandstones makes it doubtful that the "Revard" of one locality is the exact equivalent of the "Revard" of an adjacent locality unless the beds can be walked out or otherwise continuously traced.

The Revard of Pawnee County is a massive to cross-bedded sandstone containing thin lenses of red shale and white siltstone. It is 35 feet thick in the SE¼ sec. 12, T. 20 N., R. 8 E., the only locality at which the bed was found fully exposed.

Unnamed shale member

Above the Revard is another unnamed sequence of red shale containing thin lenticular beds of light-colored siltstone and fine-grained sandstone. This sequence has a maximum thickness of 35 feet and is the top unit of the Tallant formation.

Correlation and stratigraphic relations. The Tallant formation is equivalent to the upper part of the Weston shale of Kansas. It lies conformably on the Barnsdall formation. The top of the Tallant is the top of the Missouri series and was subjected to erosion prior to the deposition of the overlying Cheshewalla sandstone, the basal unit of the Virgil series in north-central Oklahoma. In Pawnee County the Missouri-Virgil unconformity is not evident from lithology or other outcrop features. A conglomeratic or coarse-grained sandstone which elsewhere marks the base of the Virgil was not found. The section appears to be conformable, and Missouri and Virgil sediments on either side of the contact are so similar in appearance that they can be distinguished only by careful tracing of beds on the ground or on the aerial photographs. The beds in question are lenticular and are traced with difficulty, a state augmented by characteristically poor exposures.

The base of the first mappable sandstone above the Revard was arbitrarily chosen as the top of the Tallant formation. Since it is not certain which of the lower Virgil sandstones is thus developed, it is uncertain that the contact shown on Plate I is the true base of the Virgil. In any case, the questionable stratigraphic interval is relatively short, and the contact on Plate 1 should be a close approximation of the actual contact.

It will be noted on Plate 1 that in sec. 36, T. 21 N., R. 8 E. and in sec. 25, T. 20 N., R. 8 E., the Revard sandstone terminates near the Missouri-Virgil unconformity. This may be the result of westward pinchout or of truncation of the Revard by pre-Virgil erosion. Outcrops at both of these localities are so poor that the true relationships could not be established.

Carl (1957, p. 46) stated that the Revard sandstone or its equivalent in southeastern Osage County was probably removed by pre-Virgil erosion, though no physical evidence of an unconformity was seen. He correlated the Osage County equivalent of the Revard sandstone as herein described with the Cheshewalla sandstone of northern Osage County. The Cheshewalla sandstone of this report corresponds to Carl's Kiheki sandstone. According to Carl's correlation the Missouri-Virgil boundary in Pawnee County would be at the base of the Revard sandstone of Plate 1, or approximately 70 feet lower stratigraphically than shown in Fig. 3. In making this correlation, Carl had the advantage of continuous surface mapping between his map area and the type sections of the lower Virgil sandstones involved. In Pawnee County exposures of these units are separated from their type sections by the flood plain of the Arkansas River, and correlation must be established solely on the basis of interval and lithologic sequence. Carl's correlation may therefore be the more reliable.

Paleontology. An impression of a pinnulate leaf, possibly a seed fern of the genus *Pecopteris,* was found in the sandstone float near the base of the formation in sec. 9, T. 20 N., R. 9 E. No other evidence of flora or fauna in the Tallant formation was seen. Carl (1957, p. 48) also reported a paucity of fossils from the Tallant.

VIRGIL SERIES

The Virgil sediments of Pawnee County are transitional between the cyclic deposits of Kansas and the predominantly nonmarine clastics characteristic of central Oklahoma; however, the Virgil series in Pawnee County bears a greater similarity to the Kansas section than it does to that of central Oklahoma in that unconformities and associated coarse clastic deposits are absent.

The Virgil deposits of Kansas have been divided into three groups: the Douglas, the Shawnee, and the Wabaunsee. This division is applicable to the Virgil beds of northern Oklahoma southward to and including those of Pawnee County (Table 2). The contact between the Douglas and the Shawnee is not evident in Pawnee County, however, so the groups will be combined in this report.

TABLE 2

KEY BEDS OF THE VIRGIL SERIES OF NORTH-CENTRAL OKLAHOMA

	Permian system
	(U n c o n f o r m i t y)
	Pennsylvanian system
	Virgil series
Wabaunsee group	Brownville limestone
	Grayhorse limestone
	Elmont limestone
	Reading limestone
	Wakarusa limestone
	Bird Creek limestone
	Pawhuska formation
Shawnee group	Turkey Run limestone
	Lecompton limestone
	Vamoosa formation
	Kanwaka shale
	Elgin sandstone
	Oread limestone
Douglas group	Wynona sandstone
	Cochahee sandstone
	Kiheki sandstone
	Cheshewalla sandstone
	(U n c o n f o r m i t y)
	Missouri series

Douglas—Shawnee Group

Haworth (1898, p. 93) first applied the names Douglas and Shawnee as formation names to lower Virgil beds exposed in Douglas and Shawnee Counties, Kansas. Both names have since been raised to group status. The presently accepted definition of these groups was made by Moore (1932, p. 93).

The Douglas group includes the beds between the Missouri-Virgil unconformity and the base of the Oread limestone; the Shawnee group extends upward from the base of the Oread limestone to the top of the Topeka limestone. The top member (Coal Creek) of the Topeka limestone of Kansas is equivalent to the Turkey Run limestone of Oklahoma (Moore and others, 1937, p. 14).

In Pawnee County neither the Oread limestone nor a recognizable correlative thereof is present; therefore the Douglas-Shawnee contact cannot be determined, and the two groups have been combined in classifying the Virgilian beds of the county. A marked change in the type of sedimentation within the upper part of the section provides a natural position for a group boundary, but unfortunately the group boundaries carried down from Kansas do not reflect the natural division of the Pawnee County section. The

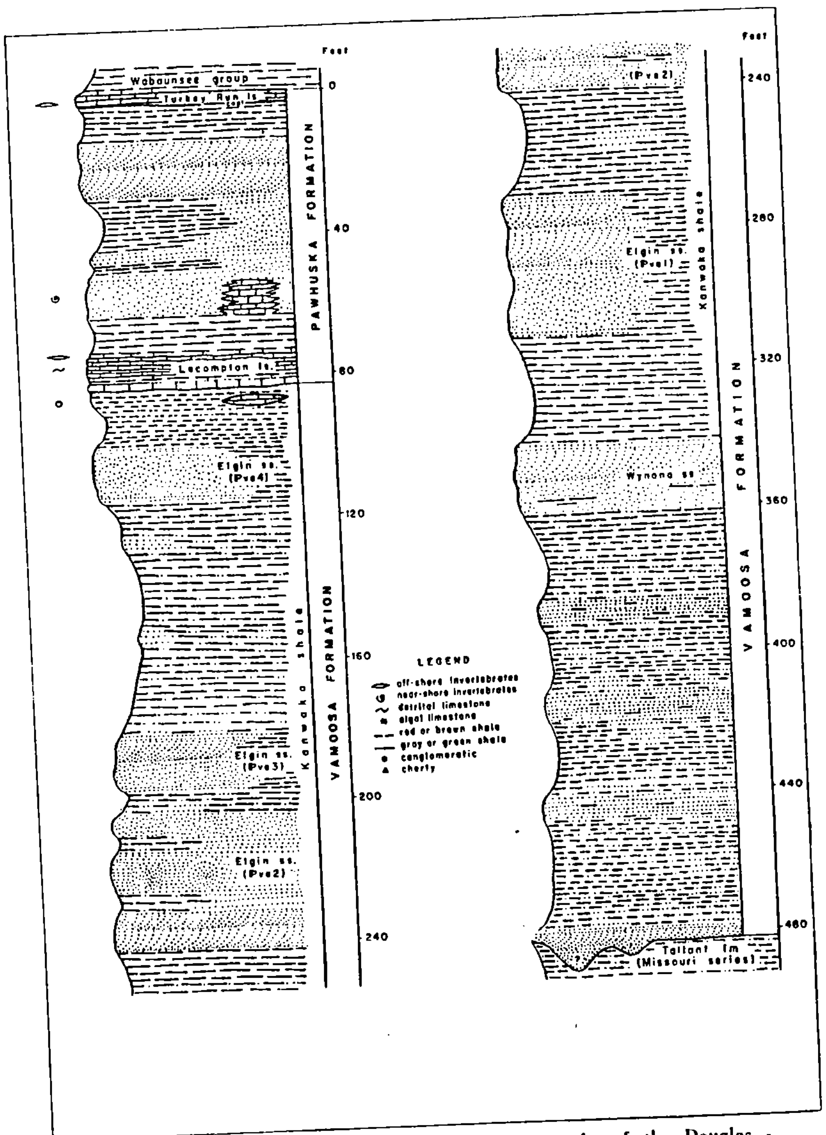

Figure 6. Generalized columnar section of the rocks of the Douglas - Shawnee group (lower Virgil) in Pawnee County.

change is one from continental, deltaic, and shallow marine clastics to a sub-cyclic marine and non-marine sequence and represents a change from an environment dominated by conditions and events in the source area to one dominated by conditions and events in the depositional basin. The upward migration of this change from the Oread limestone at the Kansas-Oklahoma line to the Lecompton limestone in Pawnee County reflects either progressive southward encroachment of the oscillating seas which produced the cyclothems of the Virgil series in Kansas(Moore, 1936, 1949) or progressive reduction in the supply of clastics from the south.

In Pawnee County the Douglas-Shawnee group is composed of two formations, the Vamoosa below and the Pawhuska above. The contact between the two is placed at the base of the Lecompton limestone, coinciding with the above-mentioned change in facies.

Vamoosa formation

Definition and distribution. The Vamoosa formation was named by Morgan (1924, p. 125) from exposures in T. 6 N. near the village of Vamoosa in south-central Seminole County, Oklahoma. Ries (1955, p. 81) raised the lower contact of the formation to the base of the lowermost conglomerate in the sequence, which presumably coincides with the Missouri-Virgil boundary. Work in Creek County shows the Vamoosa to be continuous into north-central Oklahoma, where it interfingers with the cyclic deposits of the Douglas and lower Shawnee groups of the Kansas classification (M. C. Oakes, personal communication, 1954).

In Pawnee County the Vamoosa extends upward from the Missouri-Virgil unconformity to the base of the Lecompton limestone. Vamoosa exposures occur mostly in R. 8 E.

Thickness and character. Southward from the type locality in T. 6 N. the Vamoosa formation is truncated by erosion, thinning from 230 feet to zero feet at a point in T. 4 N. three miles north of Ada. The formation thickens from the type locality northward to a maximum of 690 feet in Okfuskee County (Ries, 1955, p. 83).

In his original description of the Vamoosa Morgan (1924, p. 126) stated:

> At the base is about 30 feet of dark shale . . . . very probably fossiliferous. The main mass of the formation is above this shale and has a maximum thickness of about 230 feet. It consists in large part of chert

conglomerates . . . . of massive, coarse, red and brown sandstones, and red shales. The clastic material is finer near the top and the red coloration is there also less pronounced.

Ries (1955, p. 81) placed the basal dark shale in the Missouri series, restricting the Vamoosa to the overlying coarse clastics and red shales. The clastics become finer to the north, and the ratio of sand to shale decreases.

In Pawnee County the Vamoosa formation is about 400 feet thick. It contains no conglomerate or coarse clastic beds, and the northward decrease of the sand-shale ratio is readily apparent. Many thick sandstone members present in the southern part of the county wedge out northward in the width of one township. Others can be traced completely across Pawnee County and continue into Osage County and southern Kansas with little change in thickness. Still others thicken northward from little or no representation in Pawnee County to prominent sandstones in central and northern Osage County.

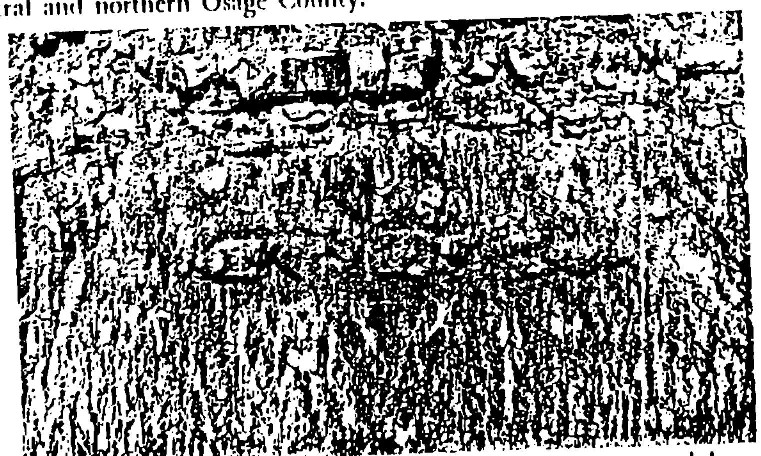

Figure 7. Lenticular siltstone bed in lower part of the Vamoosa shale exposed along north side of county road in NE ¼ sec. 33, T. 20 N., R. 8 E. This is a striking example of the discontinuity of beds typical of the upper Missouri and basal Virgil sedimentation.

Of the several members of the Vamoosa formation shown in Table 2 only the Kanwaka shale and Wynona sandstone can be positively identified. The Oread limestone is absent, and the sequence below the Wynona is a complex interfingering of red silty shales, thin light colored siltstones, and lenticular sandstones (Fig. 7). Within this interval are as many as four separate sand-

stone units with individual thicknesses of generally less than 3 feet, ranging locally to 8 feet. Among these sandstones may be equivalents of the Cheshewalla, Cochahee, and Kiheki, but the erratic development makes correlation doubtful.

Cheshewalla sandstone member

The only one of the lower Virgil sandstones that will be discussed is the Cheshewalla, which is important because it forms the base of the Virgil series. The Cheshewalla was named from exposures along Cheshewalla Creek in T. 25 N., R. 10 E., Osage County, by Winchester, Heald, and others (1918, p. 61), who defined the bed as

. . . the first heavy bed of massive sandstone below the Labadie limestone. . . . The lithology of the Cheshewalla sandstone is not distinctive enough to permit its identification by . . . lithologic means . . . . This sandstone is 20 to 50 feet thick and . . . appears as a single heavy bed. . .

According to Oakes (1952, p. 93) the Cheshewalla correlates with the Tonganoxie channel sandstone of the Kansas section. Like the Tonganoxie the Cheshewalla was laid down on the gentle topography produced by erosion during the Arbuckle disturbance at the end of the Missourian epoch.

Figure 8. Cross-bedding in Cheshewalla sandstone along north side of county road in NW ¼ sec. 31, T. 20 N., R. 8 E.

In Pawnee County the Labadie limestone is absent. The first sandstone above the Revard is probably the Cheshewalla. This sandstone is fine grained and cross-bedded, the same as adjacent sandstones (Fig. 8), and shows no evidence of disconformity nor any increase in grain size toward its base. Neither is the grain size of the Cheshewalla as a unit larger than the grain size of adjacent sandstones.

In mapping the Cheshewalla as the base of the Virgil series an attempt was made to follow what appears on the aerial photographs to be a single escarpment, but it is probable that the contact shown on Plate 1 "jumps up and down in the section" somewhat with the lateral variation of sandstone development. A vertical error of more than 50 feet is unlikely between any two points on the contact, however, because the total thickness ot the section between the Revard and Wynona sandstones is only about 150 feet.

Wynona sandstone member

The Wynona sandstone was named for exposures near the town of Wynona in T. 24 N., R. 9 E., Osage County, Oklahoma, by Heald and Bowen (1922, p. 195), who gave the following description:

> . . . a massive bed 15 to 125 feet thick, similar in characteristics to other sandstones in the Pawhuska quadrangle . . . Above the Wynona sandstone is a bed of red shale 2 to 10 feet thick which terminates abruptly below the Oread limestone and is succeeded by the dark fossiliferous shales that accompany that bed. Below the Wynona sandstone there is a thick series of alternating red shales and sandstones.

The Wynona is the lowest member of the Vamoosa formation that can be identified positively in Pawnee County. It is fine- to medium-grained massive to cross-bedded sandstone, commonly cut by northwest-striking vertical joints. Its maximum thickness is 15 feet.

The Wynona occurs at the top of the complex 100-foot shale-sandstone sequence which comprises the lower part of the Vamoosa formation. It underlies a thick sequence of dark fossiliferous shales. Outcrops occur mostly in the east part of R. 8 E., striking north-south in a belt up to 4 miles wide.

Kanwaka shale member

The name Kanwaka was proposed by Adams (Adams, Girty, and White, 1903, p. 45) for the 100-foot shale interval between the Oread and Lecompton formations. The shale takes its name from Kanwaka township, Douglas County, Kansas, where it underlies much of the surface. Southward toward the Kansas-Oklahoma line the Elgin sandstone wedges into the section as a member within the Kanwaka interval.

The beds limiting the Kanwaka formation of Kansas are not present in the Pawnee County section. The most southerly outcrops of the Oread limestone are in Osage County in T. 23 N. (Gardner, 1956, p. 59), and only the top limestone member of the Lecompton formation extends as far south as Pawnee County. Hence the true Kanwaka as defined in Kansas cannot be delimited. However, because the interval between the Wynona sandstone and the Lecompton limestone in Pawnee County contains a unit lithologically similar to the Kanwaka formation of southern Kansas and because it occupies essentially the same stratigraphic position, the name Kanwaka will be applied to rocks of that interval in this report.

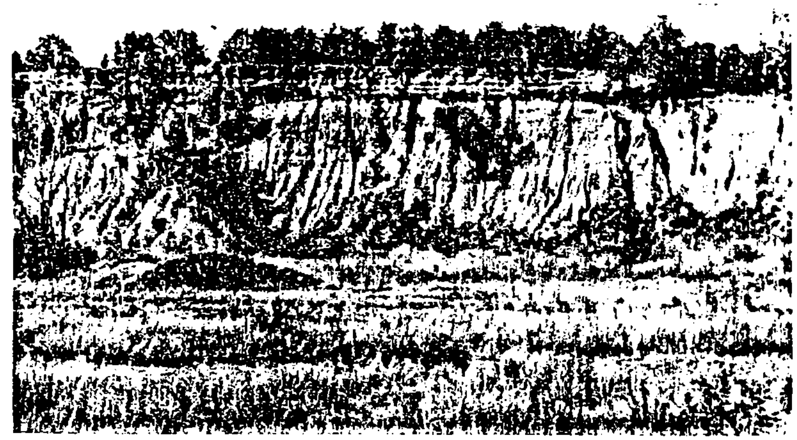

Figure 9. Kanwaka shale capped by Elgin sandstone in west wall of shale quarry in SE ¼ sec. 18, T. 21 N., R. 8 E., southwest of Cleveland. Eighty feet of blue-gray shale is exposed beneath the Elgin.

The aggregate thickness of the Kanwaka in Pawnee County is about 265 feet. It consists of dark marine shale and thick deltaic sandstones, which wedge out northward and are stratigraphically equivalent to the Elgin sandstone of southern Kansas. The shale is best developed in the vicinity of Cleveland, where it contains numerous small ironstone concretions and locally an abundant molluscan fauna (Figs. 9, 10, 13). The shale is typically gray, gray-green, or blue-gray, weathering to buff, and contains a few thin silty beds. In the SW ¼ sec. 24, T. 20 N., R. 8 E., 96 feet of shale was measured between the Wynona and the basal bed of

Elgin sandstone. To the south the shale interval is broken by Elgin sandstone wedges lower in the section.

Elgin Sandstone Member

The name Elgin was suggested by Adams and applied by Haworth (1898, p. 64) to sandstone beds occurring within the Kanwaka shale near the town of Elgin in southern Kansas. In the type area the Elgin is 140 feet thick and consists of two sandstone members separated by shaly sandstone. In Pawnee County the Elgin consists of four sandstone beds and numerous sandstone lenses within the Kanwaka. These sandstones have been desig-

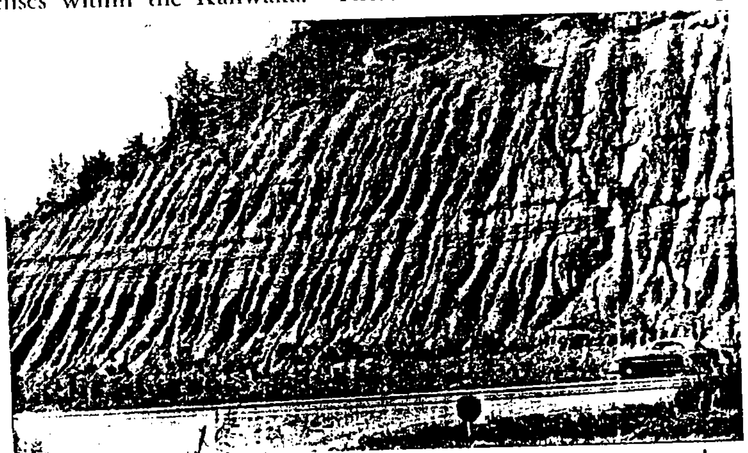

Figure 10. Kanwaka shale exposed along Oklahoma Hwy. 99 on north side of Arkansas River, sec. 4, T. 21 N., R. 8 E., Osage County. Vertical displacement of resistant beds on right is probably a small fault.

nated on Plate 1 by number, IPve1 being the lowest and IPve4 highest. Only IPve2 is continuous across the county. The other three are well developed along the Pawnee-Creek county line but wedge out northward. Lithologically the beds and lenses are indistinguishable from each other or from the other Vamoosa sandstones. They are medium- to fine-grained, massive to cross-bedded, and in some exposures jointed and ripple-marked. Contorted bedding occurs locally in IPve2 (Figs. 11, 12).

Exposures of IPve1, the lowermost Elgin sandstone, are restricted to the central and southern portions of T. 20 N., R. 8 E. It is the least extensive but the thickest of the Elgin sandstones. An unbroken section 35 feet thick was measured in the NE ¼ sec. 17, where the base of the sandstone is not exposed. The unit thins eastward to 20 feet in sec. 22. Rapid pinchout northward, apparently combined with faulting, results in the disappearance of IPve1 in the NE ¼ sec. 15. North of this point the lower 100 feet of the Kanwaka consists entirely of shale.

Figure 11. Contorted bedding in Elgin sandstone (IPve 2) capping shale in quarry shown in Fig. 9.

The second Elgin sandstone, IPve2, occurs 15 to 45 feet above IPve1, separated from it by gray shale. IPve2 is the most extensive Elgin unit, extending northward from Creek County across Pawnee and Osage Counties to the type locality of the Elgin in southern Kansas (Beckwith, 1928, p. 21). In Pawnee County the thickness ranges from 35 feet in sec. 22, T. 20 N., R. 8 E., to 12 feet in sec. 17, T. 21 N., R. 8 E. In the northern part of the outcrop IPve2 consists of several distinct sandstones interbedded with shale. The sandstones are lenticular, and it is doubtful that any one of them is continuous over a wide area. IPve2 should probably be considered as a zone of lenticular sand bodies, therefore, rather than as a single continuous bed.

Although IPve3 appears on the aerial photographs as a separate and distinct unit, it is probably no more than the top member of this zone of lenticular sandstones. Locally IPve3 is separated from the main bed of IPve2 by as much as 20 feet of shale, but generally the interval between the two beds contains one or more sandstone lenses several feet in thickness. IPve3 can be traced northward from Creek County to sec. 19, T. 20 N., R. 8 E., where it becomes indistinct and disappears. A mile farther north, where the Elgin forms the precipitous south bank of the Arkansas River, only one thick massive bed of sandstone is present.

Figure 12. Contorted bedding in boulder of Elgin sandstone on floor of shale quarry shown in Fig. 9.

Overlying IPve3 is a sequence approximately 100 feet thick composed predominantly of gray shale. In the southern part of the outcrop several sandstone lenses occur within this shale interval. One of these, IPve4, attains a thickness of more than 15 feet and is resistant and continuous enough to be mapped. Outcrops of this bed extend northward from Creek County, forming a prominent east-facing escarpment in the northeast part of T. 20 N., R. 7 E. IPve4 is separated from the overlying Lecompton member of the Pawhuska formation by 15 to 20 feet of shale, generally red.

In secs. 1 and 2 of T. 20 N., R. 7 E., IPve4 thins and disappears. North of this point the interval between IPve3 and the base of the Pawhuska formation is about 100 feet and the rocks consist entirely of shale and thin lenses of siltstone.

Detailed measurements of representative stratigraphic sequences in the Vamoosa formation may be found in Appendix D, sections 32 to 37, inclusive.

Correlation and stratigraphic relations. The predominantly arenaceous beds of the Vamoosa formation of Pawnee County and central Oklahoma grade northward into the cyclic deposits of the Douglas and lower Shawnee groups of the Kansas section. The Vamoosa lies with slight angularity on the Tallant formation of Missouri age, though no evidence of unconformity was seen at this contact in Pawnee County. The Vamoosa is overlain conformably by the sub-cyclic beds of the Pawhuska formation.

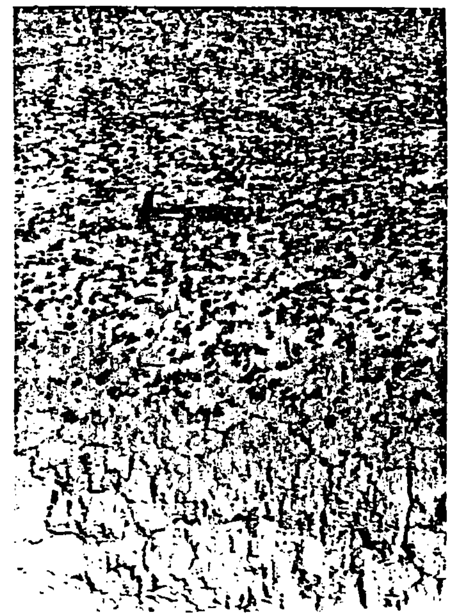

Figure 13. Ironstone concretions concentrated on floor of quarry in Kanwaka shale shown in Fig. 9. An abundant molluscan fauna occurs with this concentrated material.

Paleontology. The Vamoosa formation is the oldest formation in the area in which a faunule was found. An abundant molluscan faunule was collected in an abandoned quarry in the Kanwaka shale in the SE ¼ sec. 17, T. 21 N., R. 8 E., southwest of Cleveland. The fossils occur as ironstone casts and molds and in ironstone concretions, which have been concentrated on the floor of the quarry by weathering and erosion of the thick section of gray shale between the Wynona sandstone and IPve2 (Fig. 13). Although this shale probably contains a marine fauna throughout the area, fossils are apparently sparse except for occasional pockets, so that some means of secondary concentration is necessary before they become evident. Other Kanwaka exposures were examined for fossils without success, but Russell (1955, p. 15) and Shannon (1954, p. 19) reported rich molluscan faunas from Kanwaka exposures in Osage County.

The following fossils were collected from the Kanwaka shale member of the Vamoosa formation, SE ¼ sec. 17, T. 21 N., R. 8 E.:

Anthozoa
- Lophophyllidium sp.

Crinoidea
- unidentifiable fragments

Brachiopoda
- Crurithyris planoconvexa (Shumard)
- Juresania sp.
- Lingula carbonaria Swallow
- Linoproductus sp.
- "Marginifera" sp.
- Neospirifer sp.
- Orbiculoidea missouriensis (Shumard)

Bryozoa
- encrusting forms
- fenestrate forms

Pelecypoda
- Acanthopecten sp.
- Wilkingia sp.
- Astartella concentrica McChesney
- Aviculopinna americana Meek
- Edmondia ovata Meek and Worthen
- Myalina sp.
- Nucula sp.
- Yoldia glabra Beede and Rogers

Gastropoda
- Amphiscapha catilloide (Conrad)
- Cymatospira montfortiana (Norwood and Pratten)
- Euphemites carbonarius (Cox)
- Glabrocingulum grayvillense (Norwood and Pratten)
- Pharkidonotus percarinatus Conrad
- Phymatopleura brazoensis (Shumard)
- Trepospira depressa (Cox)
- Worthenia sp.

Cephalopoda
- Dimorphoceras texanum (Smith)
- Gastrioceras excelsum (Meek)
- Mooreoceras tuba (Girty)
- Pseudorthoceras knoxense (McChesney)

Conularidae
- Paraconularia crustula (White)

Chondrichthyes
- Deltodus sp.

Pawhuska formation

Definition and distribution. The Pawhuska[1] limestone was named in 1892 for exposures in a limestone quarry 3 miles northwest of the town of Pawhuska in Osage County, Oklahoma, by H. C. Hoover in an unpublished report of the Arkansas Geological Survey (Smith, 1894, p. 199). Heald (1918, p. 66) raised the term to formation rank. It has been variously defined since then, but recent usage has placed the bottom and top of the formation at the base of the Lecompton limestone and the top of the Turkey Run limestone, respectively (C. C. Branson, 1954, personal communication).

The Pawhuska formation can presumably be traced from the Kansas-Oklahoma line southward into Creek County, where one or both of the bounding limestones pinches out. As will be pointed out, however, the extent, correlation, and even the status of the Pawhuska formation is open to question.

In Pawnee County, except for three outliers in R. 8 E., exposures of the Pawhuska formation occur in a north-south belt which crosses the county in R. 7 E.

Thickness and character. In Kansas and northern Osage County, Oklahoma, the interval occupied by the Pawhuska formation contains as many as 12 limestones separated by shale and a few thin coals and sandstones. The limestones and coals thin and pinch out southward, and the percentage of sandstone in the section increases. Only the Turkey Run and Lecompton limestones, which delimit the formation, extend as far south as Pawnee County.

The Pawhuska thickens southward from about 150 feet in northern Osage County and Kansas (Carter, 1954, Plate 2, and Moore, 1949, fig. 29) to 210 feet in central Osage County (Shan-

[1] Hoover and Smith spelled the name "Pawhuski" after the former spelling of the name of the town.

non, 1954, p. 24). Farther south in Osage County Russell (1955, p. 21) reported only 100 feet of Pawhuska.

In Pawnee County the Pawhuska formation ranges from 96 feet thick in the north to about 56 feet in the south. The loss of section across the county seems to be mainly the result of thinning in the upper part of the sandstone-shale interval between the Lecompton and Turkey Run limestones. No evidence of unconformity was found within the formation.

Lecompton limestone member

In Pawnee County the Lecompton is the lowest limestone bed in the stratigraphic section. The Lecompton limestone takes its name from the Lecompton formation of Kansas, which was originally described by Haworth (1895, p. 278) at Lecompton, Douglas County, Kansas. As presently defined, the Lecompton formation of Kansas

. . . includes four closely associated limestones, which with the included shales have a total thickness . . . of 35 to 40 feet. The formation is underlain by the Kanwaka shale and overlain by the Tecumseh shale. (Moore, 1949, p. 152).

According to Moore (idem, p. 126) the Lecompton limestone of northern Oklahoma is equivalent to the top two limestone beds of the Lecompton formation in Kansas.

In Pawnee County the Lecompton is generally about 10 feet thick but ranges from 7.5 to a doubtful 18 feet. It consists of several thin beds of fossiliferous limestone, flaggy in the upper part, and interbedded shale. In the well-exposed section along U. S. Highway 64 in the NW 1/4 sec. 23, T. 21 N., R. 7 E., the Lecompton is 10 feet thick, 3.5 feet of which is shale (Fig. 14). The limestone is dark-gray to gray-brown, dense, cryptocrystalline to finely crystalline, and more than 90 percent soluble in hydrochloric acid, the residue being mostly clay (Appendix A). Fossils are locally abundant, both in the shale and in the limestone, on which they stand out in relief on weathered surfaces. About 1.5 feet above the main body of limestone is a thin fusulinid coquinite which occurs at the top of the Lecompton section all across the county.

Algal limestone lenses having a conglomeratic appearance and composed largely of pellets up to 0.25 inches in diameter are associated with the Lecompton at two localities. Remnants of a small algal limestone lens cap an outlier in the NE 1/4 sec. 14, T. 20 N., R. 7 E. This lens is apparently stratigraphically lower than the main body of Lecompton exposed in the larger outlier immediately to the southwest. A similar algal bed occurs within the main body of the Lecompton where it is exposed along the road on the north border of sec. 36, T. 20 N., R. 7 E.

Figure 14. Lecompton limestone exposed on north side of U. S. Hwy. 64 about 6 miles west of Cleveland in NW 1/4 sec. 23, T. 21 N., R. 7 E. Thin resistant bed at top of section is a coquinite composed of *Triticites*.

Twelve feet above the Lecompton on the south slope of the outlier in sec. 6, T. 20 N., R. 8 E., is a small reef-like mass of white coarsely crystalline porous limestone containing an abundance of gastropod remains. The carbonate body attains a maximum thickness of 12 feet. It pinches out about 50 feet east of its thickest point and is truncated on the west by the small fault which borders the outlier. Leaching along fractures near the fault reveals a high percentage of fine-grained quartz sand in the limestone.

Fossils collected from the Lecompton limestone and interbedded shales in the NW ¼ sec. 23, T. 21 N., R. 7 E., include:

Protozoa
  Triticites sp.
Anthozoa
  Lophophyllidium sp.
Crinoidea
  unidentifiable fragments
Brachiopoda
  Chonetes granulifer Owen
  Chonetinella (?) sp.
  Composita subtilita (Hall)
  Condrathyris perplexa (McChesney)
  Crurithyris planoconvexa (Shumard)
  Derbyia sp.
  Hustedia mormoni (Marcou)
  Linoproductus sp.
  "Marginifera" sp.
  Neospirifer sp.
Bryozoa
  Rhombopora lepidodendroides Meek
  Tabulipora sp.
  encrusting forms
  tabular ramose forms
  ramose forms
Pelecypoda
  Astartella sp.
Cephalopoda
  Pseudorthoceras knoxense (McChesney)
Trilobita
  Ameura (?) sp.

In the NE corner sec. 26, T. 21 N., R. 7 E., the corals *Caninia torquia* (Owen) and *Syringopora* sp. occur in profusion.

Lying between the Lecompton and Turkey Run limestones is a non-fossiliferous shale-sandstone sequence ranging in thickness from 77 feet in the northern part of the county to 44 feet in the southern part. This sequence is as much as 147 feet thick in northern Osage County (Carter, 1954, Pl. 2), where it contains the Plummer, Deer Creek, Little Hominy, and Pearsonia limestone members. None of these limestones extends southward as far as Pawnee County.

Immediately above the Lecompton is 10 to 15 feet of gray silty shale which is overlain by a massive fine-grained sandstone, locally jointed, about 25 feet thick. The sandstone is a prominent scarp-former and caps the hill or forms a ridge above almost every exposure of Lecompton. Immediately above the massive sandstone is a sequence of thick cross-bedded sandstones and interbedded red and gray shales. The thickness and composition of this sequence varies considerably from place to place throughout the area. It is overlain by the Turkey Run limestone.

Turkey Run limestone member

The Turkey Run limestone was named from exposures at the head of Turkey Run in T. 24 N., R. 8 E., Osage County, Oklahoma, by Heald and Mather (1919, p. 153), who describe the bed as

> . . . a dark-gray limestone, 1 to 3 feet thick. . . . . This limestone is fine grained, thin bedded, hard, and brittle and weathers into smoothly rounded slabs. . . . The weathered surface is generally light gray . . . . On fresh fracture the color is a much darker bluish gray, at some localities almost black.

According to Moore (1949, p. 126), the Turkey Run is equivalent to the Coal Creek limestone, which in Kansas constitutes the uppermost unit of both the Topeka formation and the Shawnee group.

In Pawnee County the Turkey Run limestone is a single bed of dense gray fossiliferous limestone with subconchoidal fracture and locally well-developed vertical joints striking northwest (Figs. 15, 16). It weathers rapidly to light brown. The bed is a calcilutite and contains abundant crinoid debris, several species of brachiopods, and in the middle part, a zone of *Triticites*. In several exposures the Turkey Run has been altered to a hard crystalline light-gray dolomite containing a few small solution channels. Where the rock has been thus dolomitized, it weathers to a rusty brown and few fossils occur.

Figure 15. Vertical jointing in Turkey Run limestone exposed in NW ¼ sec. 35, T. 21 N., R. 7 E. Joints strike northwest.

The Turkey Run is a relatively pure carbonate, being approximately 95 percent soluble in hydrochloric acid. The insoluble components consist mostly of clay (Appendix A).

Figure 16. Solution along joints in the Turkey Run limestone exposed in the bed of Hellroaring Creek just east of the fault in SE ¼ sec. 6, T. 21 N., R. 7 E., looking southeast.

The thickness of the Turkey Run ranges from 3 feet in the NW ¼ sec. 23, T. 21 N., R. 7 E., (Fig. 17) to 1.5 feet elsewhere in the county.

A thin bed of lignitic coal is exposed just below the Turkey Run limestone at two localities (Appendix D, sections 30 and 31). In the NW ¼ sec. 23, T. 21 N., R. 7 E., immediately underlying the limestone, are 6 inches of laminated shaly lignite underlain by a gray clayey shale which may be an underclay (Fig. 17). In the east bank of the creek in the SE ¼ sec. 29, T. 21 N., R. 7 E., a seam of lignite one inch thick is exposed one foot below the base of the Turkey Run limestone. This lignite lies on gray shale and is separated from the Turkey Run by one foot of dark gray carbonaceous shale. Russell (1955, p. 37) reported two occurrences of coal just below the Turkey Run in southern Osage County, indicating that the bed has more than local distribution.

Although the Turkey Run contains an abundant fauna, it is generally so well embedded in the limestone that collection and identification is not possible. In addition to *Triticites,* which

abounds in the lower part of the limestone, a few specimens of *Chonetes* and *Neospirifer* may be seen in most exposures. A rich fauna occurs locally immediately above the Turkey Run limestone in the lower part of the Severy shale. This fauna is listed on page 48.

Detailed measurements of representative stratigraphic sequences in the Pawhuska formation are tabulated in Appendix D, Sections 30 to 33, inclusive.

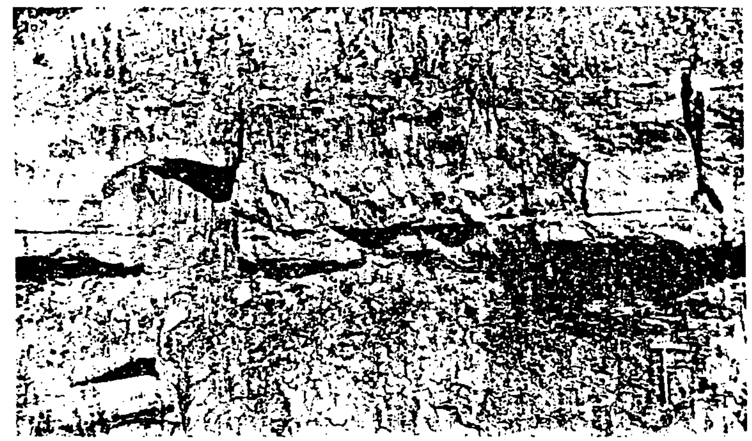

Figure 17. Turkey Run limestone, with underlying lignite (above and to left of hammer), exposed in NW ¼ sec. 23, T. 21 N., R. 7 E. This is the maximum development of Turkey Run in the area. An abundant fauna was collected from the Severy shale immediately above the limestone at this locality.

Correlation and stratigraphic relations. The Pawhuska formation is generally thought to be equivalent to the section in Kansas from the middle of the Lecompton formation to the top of the Topeka formation. No question has arisen on the correlation of the lower limit, but recent work in Osage County has cast doubt on the validity of the upper correlation. According to Shannon (1954, p. 48) and Carter (1954, p. 43), the Turkey Run limestone in northern Osage County is so poorly developed that it cannot be mapped; therefore, Moore's correlation of the Turkey Run with the Coal Creek limestone (1949, p. 126) may be erroneous.

South of Pawnee County the Lecompton limestone member of the formation is thought to be equivalent to the "Pawhuska" formation of Okfuskee County (Ries, 1955, p. 84) which grades into the basal part of the Ada formation of central Oklahoma (Greene, 1936, p. 1459). An alternate theory put forth by Tanner (1956) postulates that the "Pawhuska" is overlapped southward by the Ada formation in western Okfuskee County.

Recent work in Creek and Lincoln Counties has cast doubt on all these correlations. K. E. Masters (1955, personal communication) is of the opinion that the "Pawhuska" formation of Okfuskee County is actually the southward extension of the Bird Creek limestone of the Wabaunsee group. The base of the "Pawhuska" formation defines the top of the Vamoosa formation (Ries, 1954, p. 80). If the "Pawhuska" formation of Okfuskee County is in reality Bird Creek, the Vamoosa formation extends upward into the Wabaunsee group to the base of the Bird Creek limestone and contains the Pawhuska formation of Pawnee County. If such be the case, it is evident that a difficult problem of subdivision and classification is posed. The solution to the correlation should be provided by M. C. Oakes in conjunction with his current work on the geology of Creek County.

The Pawhuska limestone rests conformably on the Kanwaka shale of the Vamoosa formation and is overlain conformably by the Severy shale of the Wabaunsee group.

WABAUNSEE GROUP

The Wabaunsee group is the uppermost group of the Virgilian series. Its top boundary coincides with the boundary between the Pennsylvanian and Permian beds in the Mid-Continent region.

The name Wabaunsee was introduced by Prosser (1895, p. 686) for a formation of sedimentary rocks in Wabaunsee County, Kansas. Moore (1932, p. 94) raised the Wabaunsee formation to group rank, limiting the group to those beds between the Topeka and Americus limestones. Following the proposal by Moore and Moss (1933, p. 100) to lower the Pennsylvanian-Permian contact to the top of the Brownville limestone, Condra (1935, p. 9) restricted the top of the Brownville limestone, Condra (1935, p. 9) restricted the Wabaunsee group accordingly. Currently the group includes those beds upward from the top of the Topeka (Turkey Run) limestone to the top of the Brownville limestone (Fig. 18).

In Kansas the Wabaunsee deposits are cyclic and similar to those of the underlying Shawnee group. Southward these deposits

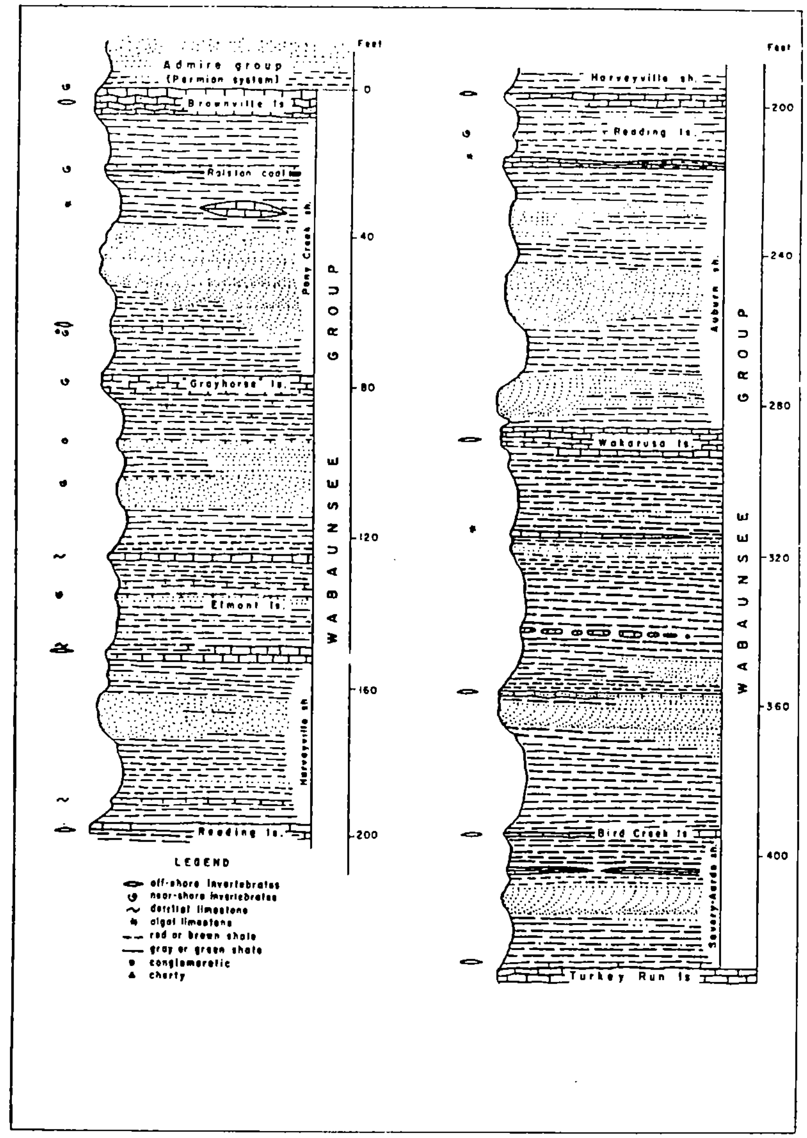

Figure 18. Generalized columnar section of the rocks of the Wabaunsee group (upper Virgil) in Pawnee County.

lose much of their cyclic character, and although alternating marine and non-marine beds are present in the Pawnee County section the rhythmic pattern of cyclic deposition is obscure.

The key beds of the Wabaunsee group in Pawnee County (Table 2, p. 25) are traceable northward into Kansas, and the names of these beds are generally taken from the Kansas section. When it comes to naming the shale-sandstone sequences between the key limestones of Pawnee County, however, modification of the Kansas nomenclature is necessary. Most of the limestones on which subdivision of the Kansas section is based pinch out southward; hence the beds between any two key units of Pawnee County may represent several formations in the Kansas section. Moore (1936, p. 206) suggested that this situation be dealt with by applying hyphenated names in areas where missing key units make the standard Kansas section inapplicable. Thus a section representative of the A, B, C, D, & E formations in which the key beds B and D are absent would be referred to as A-E shale or the A-E shale formation.

Branson (1956) provided an alternate solution to the problem by giving names to each of the shale-sandstone units between the most extensive limestones of the upper Pennsylvanian and lower Permian section in north-central Oklahoma. The stratigraphic sequence to which each name applies becomes progressively greater southward as recognizable Kansas units disappear from the section. Branson's revised nomenclature has been used in the classification of the upper Pennsylvanian and lower Permian rock units of this report.

Wabaunsee outcrops cover most of the central portion of Pawnee County, forming a belt up to 8 miles wide that strikes north-south across the county in Rs. 6 and 7 E.

Except for minor indistinguishable periods of emergence between depositional cycles, sedimentation was continuous in the Pawnee County area during Wabaunsee time and the rock units which constitute the group form an essentially conformable sequence. Southward from Pawnee County the sub-cyclic Wabaunsee beds grade into the clastic deposits of the Vanoss formation of central and south-central Oklahoma (Dott, 1941, p. 1671).

Severy shale

Definition and distribution. The name Severy was proposed in field notes by G. I. Adams for the shale below the Howard limestone near Severy, Greenwood County, Kansas (Haworth, 1898, p. 67). Moore (1936, p. 203) redefined the Severy as the basal formation of the Wabaunsee group, including the section between the top limestone of the Topeka formation and the bottom limestone of the Howard formation. Moore (1932, p. 94) also introduced the name Aarde for the shale section between the lower and middle limestone members (Bachelor Creek and Church limestones respectively) of the Howard formation and suggested (1936, p. 206) that where the basal limestone is missing, the resulting shale section should be called the Severy-Aarde shale.

The lowermost stratigraphic unit of the Wabaunsee group in Pawnee County is the shale-sandstone section between the Turkey Run and Bird Creek limestones. Branson (1956, p. 122) applied the name Severy shale to this unit in north-central Oklahoma. Inasmuch as the Bird Creek is equivalent to the Church limestone member of the Howard formation (Moore, 1949, p. 166), it is evident that the Severy shale of Pawnee County is equivalent to the Severy-Aarde shale of Kansas. The Severy can be traced southward from Kansas into southern Creek and Lincoln Counties, Oklahoma, where one or both of the limiting limestones pinch out (see discussion on p. 47).

Thickness and character. In Kansas the Severy shale ranges from 70 to 80 feet and consists of sandy shale and even-bedded sandstone. The Aarde is also a sandy shale, ranging from 3 to 10 feet thick, and contains the persistent Nodaway coal (Moore, 1949, p. 171-172). The Severy-Aarde section thins southward across Osage County, Oklahoma.

In Pawnee County the section thins from about 40 feet in the northern part of the county to 27 feet near the south county line. At the base is a gray marine shale, the bottom 2 feet of which is marly and locally fossiliferous. Overlying the shale is a cross-bedded sandstone, probably deltaic, interbedded with thin gray shales. The sandstone grades upward into red silty shale and finally, immediately underlying the Bird Creek, into light-gray shale, locally carbonaceous and clayey. The Nodaway coal is absent.

Under the Bird Creek outlier in the SE¼ sec. 28, T. 20 N., R. 7 E., remnants of a thin lens of algal limestone were noted along the west side of the section-line road about 0.1 mile north of the section corner. This lens is local and occurs approximately 10 feet stratigraphically below a Bird Creek exposure about 100 yards to the west. A similar lens was found in a salt wash in the SE corner sec. 16, T. 20 N., R. 7 E., just below the postulated position of the Bird Creek outcrop. These lenses have the same conglomeratic appearance as the algal limestones found in and below the Lecompton limestone farther east (p. 38).

Paleontology. A rich faunule occurs in the marly gray portion of the Severy shale immediately above the Turkey Run limestone in the NW¼ sec. 23, T. 21 N., R. 7 E. The following fossils were collected and identified from this locality:

- Protozoa
  - Triticites sp.
- Anthozoa
  - Lophophyllidium sp.
- Crinoidea
  - unidentifiable fragments
- Echinoidea
  - plates and spines
- Brachiopoda
  - Antiquatonia sp.
  - Chonetes granulifer Owen
  - Cleiothyridina perplexa (McChesney)
  - Crurithyris planoconvexa (Shumard)
  - Derbyia sp.
  - Hustedia mormoni (Marcou)
  - Juresania nebrascensis (Owen)
  - "Marginifera" sp.
  - Neospirifer dunbari King
  - Punctospirifer kentuckyensis (Shumard)
- Bryozoa
  - Rhombopora lepidodendroides Meek
  - Tabulipora sp.
  - fenestrate forms
- Gastropoda
  - Platyceras sp.
- Cephalopoda
  - Pseudorthoceras knoxense (McChesney)
- Chondrichthyes
  - Petalodus destructor (Newberry and Worthen)

Bird Creek limestone

Definition and distribution. The Bird Creek limestone was named by Heald (1919, p. 216) from exposures along Bird Creek in T. 27 N., R. 8 E., Osage County, Oklahoma, where it consists

of about 2 feet of dark-gray to black dense shaly limestone. At a few localities there are two limestones separated by about 6 feet of shale. According to Moore (1949, p. 166), the Bird Creek limestone of Oklahoma is the southward continuation of the Church limestone member of the Howard formation of Kansas.

The Bird Creek of Pawnee County consists of a single thin bed of limestone resting on the Severy shale. It extends into Creek County on the south, where its southern extent is not known (see discussion on p. 47).

Thickness and character. The Bird Creek limestone covers a wide area with remarkably little change in lithologic character and only a gradual thinning southward. Its Kansas correlative, the Church limestone member of the Howard formation, ranges from 1.5 to 6 feet in thickness, averaging 2 feet (Moore, 1949, p. 174). In Oklahoma the Bird Creek is about 2 feet thick in the type area and to the south in Pawnee County ranges in thickness from 1.5 feet in the NW ¼ sec. 25, T. 21 N., R. 7 E., to less than one foot in the southern part of the county.

Heald (1919, p. 216) described the Bird Creek at the type locality in Osage County as

> . . . hard and extremely brittle, so that when struck with a hammer . . . it shatters like glass. . . . Both weathered and fresh surfaces are of a dark bluish-gray color—so dark, in fact, that many samples might justly be called black. Fossil remains may rarely be seen on its weathered surface, but it is nevertheless characterized by a distinct brachiopod fauna, and in practically every locality where it was carefully examined the round, nutlike brachiopod *Enteletes hemiplicata* (sic) was discovered embedded in the interior of the limestone.

In Pawnee County the Bird Creek limestone consists of a single bed of dense gray to dark-gray limestone. Weathered exposures are light-brown to gray and have smooth, rounded surfaces. Freshly broken surfaces show a subconchoidal fracture, and in the northern part of the county the limestone is much like that described by Heald in Osage County. In the vicinity of Blackburn the Bird Creek is known as the "bell lime" because of the characteristic ring produced by the rock when struck a sharp blow with a hammer or other hard object. The Bird Creek generally is non-resistant and is at many places traced with difficulty, occurring only as float on the shale slope between the underlying and overlying sandstones. In the northern part of the county the limestone is fairly pure, but the percentage of impurities—both sand and clay—increases markedly southward (Appendix A).

Paleontology. The faunal content of the Bird Creek is apparently sparse, and the adjacent shales are non-fossiliferous. The bed itself contains a few brachiopods, crinoid fragments, and many small *Triticites*. The fossils do not weather out of the limestone and stand out in only slight relief on the weathered surface. The few specimens that were collected had to be broken out of the rock with a hammer.

The following fauna was noted in scattered localities throughout the area:

Protozoa
- Triticites sp.

Crinoidea
- columnals

Brachiopoda
- Chonetes granulifer Owen
- Crurithyris planoconvexa (Shumard)
- "Dictyoclostus" sp.

Bryozoa
- Rhombopora lepidodendroides Meek
- fenestrate forms

Enteletes hemiplicatus, said to be characteristic of the Bird Creek by Heald (see above), was not found in the Bird Creek of Pawnee County.

Hallett shale

Definition and distribution. The Hallett shale formation was named by Branson (1956, p. 122), who defined the formation as

> . . . the predominantly shale sequence from the top of the Bird Creek limestone to the base of the Wakarusa limestone. The name is derived from the village of Hallett in Pawnee County [Oklahoma] and the type section is that exposed in and south of the village.

It is a poorly exposed sequence consisting of shale, lenticular sandstone, and several thin lenses of sandy limestone. The equivalent section in Kansas contains nine subdivisions, none of which can be identified in Pawnee County.

Thickness and character. The beds of the Hallett formation total approximately 110 feet in thickness, showing a tendency to thin slightly toward the south. The following composite section of the formation was compiled by Branson (1956, p. 123) from several measured sections from the report on the eastern portion of Pawnee County submitted by the author in partial fulfillment of the degree of Master of Science (Greig, 1954, Appendix).

Composite section of Hallett formation, based upon measured section . . . taken in NE ¼ sec. 31, T. 20 N., R. 7 E. . . . [Appendix D, section 29].

	Feet
Wakarusa limestone	
Limestone, light-gray, fossiliferous, with *Triticites*	2
Hallett formation	
Shale, gray, weathers buff, calcareous near top, thin siltstone beds near base, *Tritiicites* in upper calcareous zone	7
Sandstone, buff, fine- to medium-grained, cross-bedded	11
Shale, gray to red, with siltstone beds, contains thin limestone with *Cryptozoon*	26
Sandstone, buff, cross-bedded	4
Shale, gray, with local siltstone and sandstone beds	20
Sandstone, white with spots of brown	3
Shale, gray	2.5
Sandstone, buff, massive	3
Shale, gray, with thin siltstone layers which are fucoidal on the basal bedding plane, local sandstone beds, red shale near top	29
Thickness of Hallett fm.	105.5
Bird Creek limestone	
Limestone, darkgray, shaly, fossiliferous, contains *Triticites*	0.5

Immediately overlying the Bird Creek limestone is from 20 to 30 feet of gray shale, apparently unfossiliferous, which grades upward to silty shale containing thin beds of red shale and siltstone. The shale interval is overlain by a well-bedded but lenticular sandstone. Certain beds of this sandstone are well cemented with a bluish gray calcareous cement. Fossiliferous sandy limestones found in the same interval exhibit many features similar to the calcareous sandstones and may grade laterally into them. One such limestone, 1.5 feet thick, is exposed in the SE corner sec. 20, T. 20 N., R. 7 E., along the railroad. The bed contains a faunule which includes *Chonetes*, *Cryptozoon*, and crinoid debris.

In the northern part of the county along the Arkansas River in T. 22 N., R. 7 E., this sandy-calcareous zone is represented by a unit up to 5 feet thick which grades from calcareous sandstone at the base to sandy limestone at the top. The upper 6 inches to one foot of the limestone contains abundant fusulinids which weather brown and stand out in a striking fashion against the light-gray to white limestone matrix. Because of the resemblance of the fusulinids to grains of wheat, this limestone is known locally as the "wheat lime".

Above the calcareous sandstone the sediments are predominantly shales, grading from red at the base to gray at the top. Thin lenticular beds of sandstone and a few lenses of limestone are interbedded with the shales (Fig. 19).

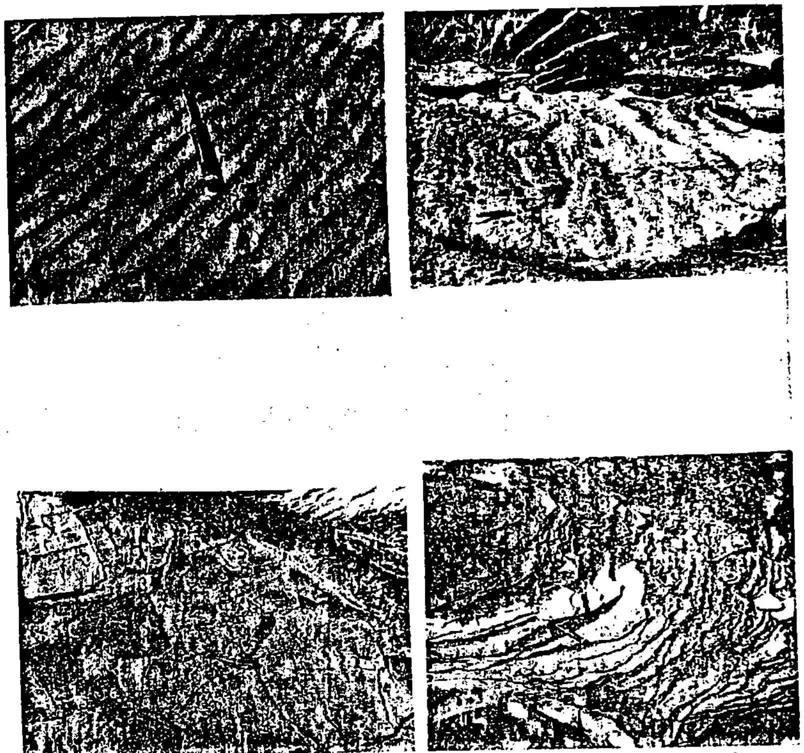

Figure 19. Sedimentary structures in a sandstone in the Hallett shale exposed in the bed of Hellroaring Creek in the NE 1/4 sec. 12, T. 21 N., R. 6 E.:
A) oscillation ripple marks;
B) large ripple marks, probably of current origin.
C) desiccation cracks;
D) depositional depression in thin-bedded sandstone. Note pool of water in upper left, joints in upper right and center.

Measured sections of the Hallett formation are listed in Appendix D, sections 28 to 30, inclusive.

Paleontology. A sparse fauna occurs in the limestones of the Hallett formation. The following faunule was collected in the SE corner sec. 17, T. 20 N., R. 7 E.:

Porifera
  unidentifiable specimen
Crinoidea
  columnals
Brachiopoda
  Chonetes granulifer Owen
Pelecypoda
  Myalina sp.

Gastropoda
  Meekospira sp.
  Naticopsis sp.
  Worthenia sp.
Cephalopoda
  Pseudorthoceras sp.

Wakarusa limestone

Definition and distribution. The term Wakarusa was first applied by Beede (1898, p. 30) to a limestone exposed along Wakarusa Creek southwest of Topeka, Kansas. Subsequent usage by Condra (1927, p. 66) and others has changed the original definition of the term, and as now defined the name Wakarusa is applied to the first resistant limestone unit above the Burlingame limestone of the Kansas section. The fusulinid-bearing phase of the Wakarusa extends southward into Oklahoma, where in earlier reports it was referred to as the *Cryptozoon* limestone (Moore, 1937, p. 12). Recent workers in north-central Oklahoma have referred to the unit as the Wakarusa limestone, however, and this report conforms to the recent usage.

The Wakarusa is traceable in surface outcrop from Nebraska southward into northern Oklahoma (Moore, 1949, p. 183), where it has been traced as far south as T. 13 N., in the southern part of Lincoln County (K. E. Masters, 1954, personal communication). Wakarusa exposures in Pawnee County form an escarpment which is readily followed across the county in Rs. 6 and 7 E.

Thickness and character. In Kansas the Wakarusa is a shale-limestone sequence ranging in thickness from 2 to 18 feet.[2] The fusulinid phase of the limestone has been traced southward from Kansas across Osage County, Oklahoma, where the name *Cryptozoon* limestone was applied for the numerous specimens of *Cryptozoon* that occur on the bedding surfaces. Thickness of the Osage County section ranges from 1.5 to 5 feet.

In Pawnee County the thickness of the Wakarusa ranges from 2 to 9.5 feet, being greatest in the central part of the county. It is a dense greenish-gray fossiliferous limestone interbedded with gray to green fossiliferous shales (Appendix D, sections 27, 28, and 29). Shale generally comprises less than 50 percent of the

[2]According to Moore (1949, p. 183), the greater thickness includes more shale than limestone.

section. No cryptozoans were seen. The percentage of insoluble material in the limestone, consisting mostly of clay, appears to decrease southward (Appendix A).

In the southern part of the county the Wakarusa thins to 2.5 feet and is commonly concealed beneath a thick massive sandstone which occurs in the overlying Auburn shale a few feet above the limestone.

Paleontology. A prolific fauna occurs in the Wakarusa limestone and associated shale. The fossils weather out of the shale readily and are well preserved.

The following forms were collected:

- Protozoa
  - Triticites sp.
- Anthozoa
  - Lophophyllidium sp.
- Crinoidea
  - columnals, radials, and basals
- Echinoidea
  - plates and spines
- Brachiopoda
  - Antiquatonia sp.
  - Chonetes granulifer Owen
  - Chonetinella (?) sp.
  - Composita subtilita (Hall)
  - Crurithyris planoconvexa (Shumard)
  - Derbyia sp.
  - "Dictyoclostus" sp.
  - Dielasma bovidens (Morton)
  - Enteletes hemiplicatus (Hall)
  - Juresania nebrascensis (Owen)
  - Neospirifer sp.
  - Neospirifer dunbari King
  - Punctospirifer kentuckyensis (Shumard)
  - Rhipidomella sp.
- Bryozoa
  - Rhombopora lepidodendroides Meek
  - Tabulipora sp.
  - fenestrate forms
  - ramose forms
- Pelecypoda
  - Wilkingia sp.

Auburn shale

Definition and distribution. The Auburn shale was named by Beede (1898, p. 30) from exposures in southern Shawnee County, Kansas. As modified by Condra (1927, p. 78) the term is applied to the sandstone-shale sequence between the Wakarusa and the Reading limestones.

The Auburn is continuous from southeastern Nebraska across Kansas into northern Oklahoma, where it has been traced as far south as southern Lincoln County (K. E. Masters, 1955, personal communication). South of Lincoln County the limiting limestones pinch out and the Auburn cannot be distinguished from adjacent shales.

Character and thickness. In Kansas the Auburn is a complex sequence of shale, sandstone, and some limestone ranging from 20 to 70 feet in thickness (Moore, 1949, p. 184). A complex section of erratic thickness characterized by lenticular sandstones and disconformities is recorded for the Auburn in Osage County, Oklahoma, by Carter (1954, p. 54).

No disconformities were recognized in the Auburn shale in Pawnee County, where the section maintains a rather constant thickness, ranging from 65 to 70 feet. It consists principally of red and gray shale and generally contains one or more lenticular sandstones and thin nodular limestones (Appendix D, sections 27 to 29 inclusive). A thick massive to cross-bedded sandstone near the base of the section conceals the outcrop of the underlying Wakarusa limestone in the southern part of T. 20 N.

Paleontology. No fossils were found in the Auburn shale section.

Emporia limestone

The Emporia limestone was named by Kirk (1896, p. 72-85), who did not clearly define a type section or locality but who applied the name to a shale-limestone sequence between two thick shales in the vicinity of Emporia, Kansas. After a long period of disuse the name Emporia was recently revived by Moore and Mudge (1956, p. 2276) and applied in the identical sense as originally proposed by Kirk. The underlying and overlying shales have since come to be known as the Auburn and Willard shales, respectively. The Emporia limestone of Kansas contains three members. In ascending order they are the Reading limestone member, the Harveyville shale member, and the Elmont limestone member.

Moore (1949, p. 166) correlated the Reading limestone, Harveyville shale, and Elmont limestone of Kansas with the lower, middle and upper units of the Stonebreaker formation in Osage County, Oklahoma. The Stonebreaker was named by Heald (1918a, p. 131) for exposures on the Stonebreaker ranch in the northern part of the Pawhuska quadrangle in Osage County. The name Stonebreaker has subsequently been discarded as a formation name in north-central Oklahoma in favor of the name Emporia (Branson, 1956, p. 122). The Kansas subdivisions of the Emporia limestone were traced southward into Osage County by Taylor (1953) and Carter (1954) and are recognizable across most of Pawnee County. The southern extent is not known.

Thickness and character. In Kansas the Emporia limestone ranges from 7 to nearly 40 feet in thickness (Moore and Mudge, p. 2276). The aggregate thickness of the three member units in Pawnee County averages 90 feet.

Reading limestone member

Definition and distribution. The Reading limestone overlies the Auburn shale and underlies the Harveyville shale (Condra, 1935, p. 10). It was named by Smith (1905, p. 150) for exposures near the town of Reading in eastern Lyon County, Kansas, and is continuous from southern Nebraska to northern Oklahoma.

Outcrops of Reading limestone in Pawnee County occur in Rs. 6 and 7 E. The unit is not easily traced, and both its northern and southern extremities in the county are indistinct. The Reading occurs south of Pawnee County, but its southern extent is not yet known.

Thickness and character. According to Moore (1949, p. 184), the Reading limestone of Kansas consists of one to three beds of limestone separated by shale. Thickness ranges from 1.5 to 15 feet. The most persistent limestone contains abundant fusulinids. In northern Osage County, Taylor (1953, p. 13) described the Reading as three limestone units separated by gray shale, averaging about 20 feet in total thickness. The middle limestone unit is thickest and contains abundant fusulinids in its middle bed. Russell (1955, p. 51) described the lower member of the Stonebreaker as one foot of mottled limestone containing many large *Triticites*.

The Reading limestone of Pawnee County thickens southward from 15 feet in T. 22 N. to 26 feet in T. 20 N. Its base is marked by a massive bed of mottled red to gray-green sandy limestone ranging from less than one foot to three feet thick. This bed is commonly crinoidal and partly algal and is overlain by red shale. It becomes markedly more sandy to the south (Appendix A).

The top of the Reading is a gray fusulinid limestone one to 5 feet thick, containing interbedded gray shale in its thicker portion. Between the two limestones is a complex sequence of red and gray shale, thin limestones and, in the southern part of the county, thin sandstones (Appendix D, sections 24, 26, and 27).

Paleontology. The Reading limestone section is moderately fossiliferous, but generally the fossils are poorly preserved and difficult to collect and identify. Locally, however, the gray shale and limestone at the top of the section contain a rich fauna.

A collection from one such locality in the NW ¼ sec. 17, T. 20 N., R. 7 E., yielded the following faunule:

- Protozoa
  - Triticites sp.
- Anthozoa
  - Lophophyllidium sp.
- Crinoidea
  - columnals, radials, basals, and spines
- Brachiopoda
  - Antiquatonia sp.
  - Chonetes granulifer Owen
  - Composita subtilita (Hall)
  - Crurithyris planoconvexa (Shumard)
  - Enteletes hemiplicatus (Hall)
  - Linoproductus sp.
  - "Marginifera" sp.
  - Neospirifer dunbari King
- Bryozoa
  - Rhombopora lepidodendroides Meek
  - Tabulipora sp.
  - fenestrate forms
  - ramose forms
- Pelecypoda
  - Acanthopecten sp.
- Gastropoda
  - Amphiscapha catilloide (Conrad)
  - Platyceras sp.
  - steinkerns

Phosphate nodules up to 4 mm in diameter occur with the faunule listed above.

Harveyville shale member

Definition and distribution. The Harveyville shale overlies the Reading limestone and underlies the Elmont limestone. It was named and defined by Moore (1936, p. 226) for exposures in southeastern Wabaunsee County, Kansas. It is continuous from southeastern Nebraska to north-central Oklahoma, where it was identified in northern Osage County by Taylor (1953) and Carter (1954).

The Harveyville extends southward across Pawnee County into northern Payne County. The southern extent of the unit is not known.

Thickness and character. In Kansas the Harveyville is predominantly shale but locally includes a zone of thin-bedded sandstone overlain by a coal bed. Thickness of the Kansas section ranges from less than one foot to about 25 feet (Moore, 1949, p. 185). In northern Osage County, Oklahoma, the Harveyville consists of 6 to 8 feet of gray shale, which contains a thin bed of smutty coal in the middle part (Carter, 1954, p. 58).

The thickness of the Harveyville in Pawnee County ranges from 35 to 53 feet. The section consists of red and gray shales, thin limestones, and lenticular sandstones (Appendix, measured sections 24, 26, and 27). At many places a thin bed of gray-green limestone composed largely of fossil detritus occur 5 to 7 feet above the base. Locally this limestone contains a few fusulinids. Sandstones occur mainly in the upper part of the section. They are massive to cross-bedded and locally contorted, ranging up to 12 feet thick. Color ranges from orange to white.

Paleontology. No fossil collections were made from the Harveyville. The section is sparsely fossiliterous except for the thin limestones, many of which are composed largely of fossil fragments. Identifiable fossils are few, consisting mostly of small *Triticites* from a thin limestone near the base of the section.

Elmont limestone member

Definition and distribution. The Elmont limestone was named by Beede (1898, p. 30) for exposures near the town of Elmont in Shawnee County, Kansas. It comprises the upper part of the Emporia limestone of some early reports. As currently defined (Moore, 1949, p. 185), the Elmont overlies the Harveyville shale and underlies the Willard shale. In Pawnee County the overlying shale section is called the Gano shale.

The Elmont is continuous from southeastern Nebraska into north-central Oklahoma, where it was identified in northern Osage County by Taylor (1953) and Carter (1954). It can be traced southward across Pawnee County into Payne County, but the southern extent of the Elmont is not known.

Thickness and character. In describing the Elmont of southern Kansas, Moore (1949, p. 185) stated that it is a dense, hard, dark-blue rock, typically a single massive bed, in which fusulinids are prominent. According to Carter (1954, p. 58) and Taylor (1953, p. 18), the Elmont consists of upper and lower limestone members separated by 6 or 7 feet of gray to dark-gray shale. The lower limestone is fusulinid-bearing. Total thickness of the section is about 9 feet.

Total thickness of the Pawnee County section averages about 25 feet, ranging from 20 to 34 feet. Otherwise the Elmont in Pawnee County is similar to that in northern Osage County. It consists of two limestones separated by red and gray shale (Appendix D, section 24, 25 and 26). The lower limestone is gray-brown, dense, and finely crystalline, averaging 1.5 feet thick. It contains an abundance of large fusulinids which stand out in relief on the weathered surface. This limestone becomes thinner and more shaly southward (Appendix A), and on the south county line just east of the underpass under the Missouri, Kansas, and Texas Railway tracks in the SE ¼ sec. 33, T. 20 N., R. 6 E., it is represented by a poorly resistant 6-inch bed of highly argillaceous fusulinid coquinite.

In the northern part of the county the fusulinid limestone is overlain by a dense massive bed of mottled detrital limestone, which lies upon or a few feet above the basal fusulinid limestone. The detrital limestone is the only unit between the top and bottom limestones of the Elmont that could be recognized in more than one exposure. It, together with the underlying fusulinid limestone, is probably equivalent to Russell's middle Stonebreaker limestone (Russell, 1955, p. 51).

The middle Elmont section contains a predominance of gray and red shales. Thin fossiliferous limestones and lenticular sandstones, partly calcareous, are developed locally.

The upper Elmont limestone is generally one foot or less in thickness. In the northern part of the county it is a dense fossiliferous partly shaly gray-green limestone locally mottled with red. A few small fusulinids occur in some exposures. Southward this unit grades into a single massive bed composed largely of fossil detritus. The detrital phase is dark gray, dense, and finely crystalline. It is well exposed in the S/2 secs. 33 and 34, T. 20 N., R. 6 E., along the road on the south county line.

Paleontology. The lower limestone member of the Elmont limestone and the associated shale contain *Triticites* in profusion and locally contain an abundant brachiopod fauna. The upper limestone is moderately fossiliferous, but collections are difficult to obtain because the fossils do not weather out of the rock. The middle Elmont shale sequence contains a few fossils, mainly mollusks, particularly in the thin limestones.

The following fauna was identified from collections made from the Elmont sequence:

- **Protozoa**
  - **Triticites sp.**
- **Anthozoa**
  - **Lophophyllidium sp.**
- **Crinoidea**
  - **columnals, radials, and spines**
- **Brachiopoda**
  - **Antiquatonia sp.**
  - **Chonetes granulifer Owen**
  - **Chonetinella (?) sp.**
  - **Composita subtilita (Hall)**
  - **Crurithyris planoconvexa (Shumard)**
  - **Derbyia sp.**
  - **"Dictyoclostus" sp.**
  - **Enteletes hemiplicatus (Hall)**
  - **Hustedia mormoni (Marcou)**
  - **Juresania nebrascensis (Owen)**
  - **Linoproductus sp.**
  - **"Marginifera" sp.**
  - **Meekella striatocostata (Cox)**
  - **Neospirifer sp.**
  - **Neospirifer dunbari King**
  - **Punctospirifer kentuckyensis (Shumard)**
  - **Wellerella sp.**
- **Bryozoa**
  - **encrusting forms**
  - **fenestrate forms**
  - **ramose forms**
- **Pelecypoda**
  - **Wilkingia sp.**
  - **Aviculopecten sp.**
  - **Myalina sp.**
- **Gastropoda**
  - **Euphemites carbonarius (Cox)**

Gano shale

Definition and distribution. The first recognizable key bed above the Elmont limestone in Pawnee County is the "Grayhorse" limestone. Between the Elmont and "Grayhorse" is a shale-sandstone sequence which in Kansas is subdivided into more than a dozen stratigraphic units on the basis of several persistent limestones which occur in the section there (Moore, 1949, p. 186 ff.). All of these limestones pinch out north of Pawnee County, Oklahoma, however; consequently there is no basis for subdivision of the Pawnee County section. Branson (1956, p. 123) applied the name Gano shale to this shale-sandstone sequence which he named from exposures northeast of the village of Gano in southeastern Payne County, Oklahoma. As defined by Branson, the upper limit of the Gano formation is formed by the base of the lowermost recognizable key bed in the Wood Siding formation. As a result of the southward pinchout of progressively higher key beds in the lower part of the Wood Siding formation, the Gano-Wood Siding boundary migrates upward in the section toward the south. In Pawnee County this boundary is formed by the base of the "Grayhorse" limestone.

The Gano is traceable from Pawnee County northward into the highly subdivided Kansas sequence. The southern extent of the unit is not known although it is probably recognizable for a considerable distance south of Pawnee County.

Thickness and character. In Pawnee County the Gano formation consists of 35 to 50 feet of red and gray shale and lenticular sandstones. A few thin impure limestones occur locally (Appendix D, sections 24, 25).

Moore (1949, Fig. 35 and p. 190) indicated a thickness of less than 100 feet for the Gano equivalent in southern Kansas (Chautauqua County), which compares favorably with the thickness of the Gano shale in Pawnee County, Oklahoma. Taylor, on the other hand, (1953, p. 22 ff.) assigned a thickness of about 200 feet to the Gano equivalent in northern Osage County, Oklahoma. The implication of Taylor's abnormally thick Gano section is nullified by an overlying section of Admire shale which is abnormally thin when compared to the Admire sections of southern

Kansas and Pawnee County· Oklahoma (p. 97), and it is likely that Taylor's correlation of beds between the Emporia limestone and the top of the Admire shale is in error.

Paleontology. A thin unnamed limestone in the Gano shale exposed along the north side of U. S. Highway 64 in the S W corner sec. 15, T. 21 N., R. 6 E., yielded several specimens of *Euphemites carbonarius.* No other fossils were seen in the formation.

Wood Siding formation

Definition and distribution. The Wood Siding formation is the uppermost formation of the Pennsylvanian system in the Mid-Continent area. The name Wood Siding was first applied by Condra and Reed (1943, p. 43) to a section in southeastern Nebraska extending upward from the base of the Nebraska City limestone to the base of the Brownville limestone. Moore and Mudge (1956, p. 2273) redefined the formation and extended the use of the name into Kansas. As redefined by Moore and Mudge, the Wood Siding formation includes five member units, which are, in ascending order, the Nebraska City limestone, the Plumb shale, the Grayhorse limestone, the Pony Creek shale and the Brownville limestone.

The name Wood Siding was introduced into Oklahoma nomenclature by Branson (1956, p. 122), who modified the Kansas definition to suit the transitional sediments of the Oklahoma section. As defined by Branson, the Wood Siding formation extends downward from the top of the Brownville limestone to the base of the lowest recognizable member unit. As a result of the southward pinchout of the Nebraska City limestone member somewhere in Osage County, Oklahoma, the base of the formation in Pawnee County is defined by the base of the "Grayhorse" limestone. South of Pawnee County where the "Grayhorse" limestone can no longer be recognized the Brownville limestone member constitutes the entire Wood Siding formation.

Thickness and character. Moore and Mudge (1956, p. 2275) give the average aggregate thickness of the five members of the Wood Siding formation in Kansas as 36 feet, ranging between 12 and 50 feet. The restricted Wood Siding formation of Pawnee County has an average thickness of 75 feet.

"Grayhorse" limestone member

Definition and distribution. The Grayhorse limestone was named by Bowen (1918, p. 138) for an exposure on the crest of Little Grayhorse anticline in the NW ¼ sec. 11, T. 24 N., R. 6 E., Osage County, Oklahoma. The type section is about 6 miles northeast of the Pawnee County village of Ralston. On Plate XXI in Bowen's report, the Grayhorse is shown to be about 125 feet above the Stonebreaker (Elmont) and about 75 feet below the Americus limestone. If these measurements are correct, it is doubtful that the Grayhorse extends southward into Pawnee County (Fig. 20).

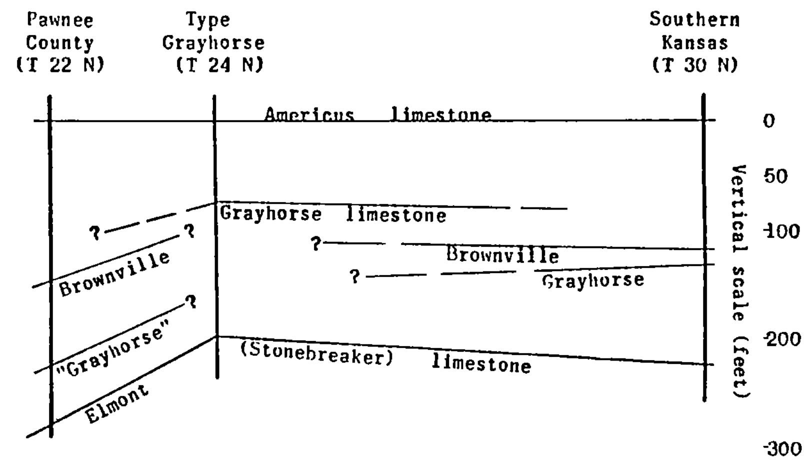

Figure 20. Sketch showing relationship of Pawnee County "Grayhorse" to type Grayhorse (Bowen, 1918, Pl. XXI) and Grayhorse of southern Kansas (Moore, 1949, p. 186, Fig. 35; 1951, p. 49).

Moore (1936, p. 241) correlated the Grayhorse with the molluscan phase of the Caneyville cyclothem in the Kansas section, giving the name Grayhorse a place in Kansas nomenclature. This correlation was based on somewhat meager information, however, and is open to question.

Lithologically the "Grayhorse" in Pawnee County resembles neither that described by Bowen nor that described by Moore. Each of the three sections contains abundant specimens of a large *Myalina,* but this alone is not significant. Correlation of the

Pawnee County "Grayhorse" with the true Grayhorse of Bowen is doubtful because the Pawnee County "Grayhorse" occurs too low in the section. Pawnee County intervals correlate more closely with those in Kansas, however, and on this basis the name "Grayhorse" has been retained for the unit in Pawnee County, although to indicate doubtful correlation the name will be enclosed in quotation marks.

The "Grayhorse" can be traced entirely across Pawnee County except for the southernmost mile and one half, where it is not exposed. In all probability the unit extends southward into Payne County.

Thickness and character. Bowen (1918, p. 138) described the Grayhorse at the type locality as

> . . . one of the most distinctive key rocks in the area. . . . It is a dark brownish-gray crystalline conglomeratic limestone, commonly about 2 feet thick. . . . It contains numerous small pebbles ranging in size from mere grains to pebbles as large as a large pea, which weather to a dirty-white color and give the weathered surface of the rock a mottled appearance. In most places it also contains numerous large fossils of the species **Myalina subquadrata**, some of which are 3 or 4 inches in their longest dimension. . . . The bed is so distinctive that after having once been identified it is generally recognized without difficulty. . .

According to Moore (1951, p. 58), the Grayhorse in Kansas is a ferruginous gray crystalline limestone characterized by organic debris and large specimens of *Myalina* of the *Myalina subquadrata* type. The limestone ranges in thickness from 0.5 feet to 6 feet and occurs 5 to 50 feet or more below the Brownville limestone.

The "Grayhorse" limestone of Pawnee County consists of calcareous shale ranging in thickness from 2 to 6 feet. The shale is gray-green on fresh exposure and weathers to a characteristic shade of buff. It is highly fossiliferous and easily recognized by the abundance of large myalinids of the *Myalina subquadrata* type, ranging up to 5 inches in length. These shells occur in such profusion that they commonly form thin limestone beds in the shale. The omnipresence of *Myalina* permits this thin non-resistant bed to be traced entirely across the county. Even in the poorest exposures, fragments of *Myalina* may be found as float. Other fossils occur but are in the minority.

In the NE corner sec. 14, T. 20 N., R. 6 E., the "Grayhorse" is represented by a massive bed of gray-green shaly limestone containing *Myalina* and shell fragments. The limestone is about 1.5 feet thick and forms a prominent escarpment, unlike the "Grayhorse" in other parts of the county.

Paleontology. Fossils in the "Grayhorse" are abundant but poorly preserved. Molluscan forms predominate.

The following fauna was identified from the several collections made:

Brachiopoda
- Chonetes granulifer Owen
- Derbyia wabaunseensis Dunbar and Condra
- Juresania sp.
- Juresania nebrascensis (Owen)
- Linoproductus sp.
- Punctospirifer kentuckyensis (Shumard)

Bryozoa
- Bascomella fusiformis Condra and Elias
- Rhombopora lepidodendroides Meek
- encrusting forms
- fenestrate forms

Pelecypoda
- Wilkingia sp.
- Aviculopinna sp.
- Myalina sp.
- Myalina (Orthomyalina) subquadrata Shumard

Gastropoda
- Euphemites sp.
- Pharkidonotus sp.
- Pharkidonotus percarinatus (Conrad)
- Pharkidonotus tricarinatus (Shumard)

Trilobita
- Ditomopyge sp.

Chondrichthyes
- Petalodus destructor (Newberry and Worthen)

Pony Creek shale member

Definition and distribution. The Pony Creek shale includes the beds between the "Grayhorse" and Brownville limestones. It was first described by Condra (1927, p. 74) from exposures near Pony Creek south of Falls City, Nebraska. The presently accepted definition of the unit was written by Moore (1936, p. 49, 243) and modified by Moore and Mudge (1956, p. 2273).

The Pony Creek is recognized from southeastern Nebraska to northern Oklahoma, where it has been identified as far south as T. 20 N. in southern Pawnee County. Farther southward continuation of the unit appears likely, but its extent is not known.

Depending on the accuracy of correlation with the Kansas section, the lower limit of the Pony Creek of Pawnee County may differ slightly from that of its Kansas correlative. For the purposes of this report, however, any such difference is of minor importance.

Thickness and character. Moore (1951, p. 58) describes the Pony Creek of Kansas as

> Bluish-gray shale chiefly, some red clay shale or sandy shale locally. Commonly sandstone or siltstone occurs near the middle part, locally this type of deposit fills channels. . . . A thin coal bed occurs in the upper middle part in southern Kansas. Brachiopods and bryozoans are more or less common in upper layers. Thickness ranges from about 5 to 50 feet or more.

In Pawnee County the thickness of the Pony Creek ranges from 65 to 70 feet. The section consists principally of red and gray shale but contains a thin impure limestone in the lower part and a thick massive to highly cross-bedded sandstone in the middle. A thin persistent coal occurs about 15 feet below the top of the section (Appendix D, measured sections 23-25).

Interbedded gray shale and sandstone, generally overlain by a thin impure red and gray-green mottled limestone, constitute the basal 10 to 20 feet of the Pony Creek. At places the limestone is conglomeratic and contains abundant organic detritus.

The sandstone in the middle part of the Pony Creek section is persistent across the county. It ranges up to 30 feet thick, grading from highly cross-bedded at the base to massive in the upper part. The base is generally covered, but at two places where exposures reveal the relationship of the sandstone to underlying beds it is evident that the sandstone has channelled into the sediments below it. The magnitude of the truncation could not be determined, but indications are that it is not large. Channelling can be seen in an exposure along the road on the west line of the SW ¼ sec. 11, T. 20 N., R. 6 E., where the sandstone occurs about 10 feet above the "Grayhorse", evidently truncating much of the basal part of the Pony Creek section. Farther north the sandstone occurs slightly higher in the section. In an exposure along the road on the west line of sec. 22, T. 22 N., R. 6 E., it occurs about 4 feet above the limestone in the lower part of the Pony Creek section. Here again the contact with the underlying shale is irregular.

Between the sandstone and the top of the Pony Creek is a 20- to 30-foot section consisting mostly of gray shale. In the lower

part of this section about 5 feet above the sandstone is a thin persistent coal bed, generally 1 to 2 inches thick, that can be traced entirely across the county. This coal was once mined in the NE ¼ sec. 2, T. 23 N., R. 5 E., in the town of Ralston, where it attains its maximum development; and the name Ralston coal is here proposed for the bed. An exposure 18 inches thick was reported in the bed of Eagle Creek just west of the bridge to the Santa Fe station in Ralston. This exposure was below water and could not be checked, but a 6-inch seam was seen downstream high in the precipitous south bank of the creek.

Beneath this coal and commonly separated from it by a thin lenticular sandstone is about 2 feet of underclay. Immediately overlying the coal is a 2-foot section of highly fossiliferous gray shale containing an abundance of *Myalina* and other molluscan forms. The same sequence of underclay-coal-fossiliferous shale is exposed a few feet below the Brownville limestone along the road on the east side of sec. 30, T. 24 N., R. 6 E., in Osage County and probably extends northward into the thin coal in the upper part of the Pony Creek shale in Kansas. The Ralston coal has been reported as far south as sec. 25, T. 15 N., R. 5 E., along the Turner Turnpike in Lincoln County (A. West, 1955, personal communication).

A lens of algal limestone 5 feet thick occurs near the base of the upper shale about 25 feet below the Brownville in the NE ¼ sec. 7, T. 21 N., R. 6 E. No other limestone was noted in the upper part of the Pony Creek section.

Paleontology. Parts of the Pony Creek are highly fossiliferous, but the fossils are poorly preserved. In addition to a great deal of unrecognizable shell detritus, the limestone in the lower part of the section contains crinoid debris and fragments of trilobites. The fossiliferous shale above the coal contains a profusion of *Myalina* sp. as well as a few other mollusks (*Pseudorthoceras, Pharkidonotus*) and crinoid debris.

Brownville limestone member

Definition and distribution. The Brownville limestone is the top unit of the Pennsylvanian system in the Mid-Continent region. It lies with apparent conformity on the Pony Creek shale but is disconformable, at least locally, with the overlying Admire shale of the Permian system. This disconformity is not apparent in Pawnee County.

The Brownville was named by Condra and Bengston (1915, pp. 17, 19) for exposures south of the town of Brownville in Nemaha County, Nebraska. In 1933 Moore and Moss (p. 100) proposed lowering the Pennsylvanian-Permian boundary to the top of the Brownville, a proposal which was accepted by Condra (1935, p. 9) when he restricted the top of the Wabaunsee group to coincide with the top of the Brownville limestone.

The Brownville is continuous from southeastern Nebraska to north-central Oklahoma, where it has been traced as far south as the North Canadian River (K. E. Masters, 1955, personal communication). South of the North Canadian River the "Prague" limestone of Seminole County is probably the continuation of the Brownville.

The Brownville crops out across Pawnee County in Rs. 5 and 6 E. and generally forms a prominent escarpment. North and south of Ralston and northeast of Skedee, however, long stretches of the limestone are covered by terrace deposits and its trace is concealed (see Plate 1).

Thickness and character. Moore (1951, p. 58) described the Brownville limestone of Kansas as one or two beds of bluish-gray limestone, locally sandy, containing large fusulinids and ranging in thickness from about 2 to 8 feet.

In Pawnee County the Brownville is a single limestone unit characterized by wavy bedding (Fig. 21) and a light grayish-brown color. It weathers into irregular slabs, commonly almost white. Thickness ranges from less than a foot in the southern part of the county (Fig. 22) to about 10 feet in the central part and 4 to 5 feet in the northern part. In the SW ¼ sec. 35, T. 22 N., R. 5 E., along Black Bear Creek a 7-foot lens of algal limestone immediately above the Brownville results in a total limestone thickness of over 15 feet. No other such occurrence was seen.

The Brownville limestone is best developed east and southeast of Pawnee. Here it is more than 95 percent carbonate (Appendix A), forming a dense sublithographic rock exhibiting subconchoidal fracture. Stylolites are developed locally in the upper part. The rock is moderately fossiliferous, but except for crinoid fragments, the fossils do not weather out in relief on the surface and are seen only in cross-section. Small cigar-shaped fusulinids constitute a major portion of the lower 2 or 3 feet of limestone, giving to the rock a characteristic texture which is readily identifiable even in isolated slabs or fragments. A few large *Triticites* are scattered throughout the rock.

Figure 21. Brownville limestone exposed on west bank of Camp Creek in SW ¼ sec. 13, T. 21 N., R. 5 E. Note wavy bedding.

In the northern part of the county the Brownville is sandy and sparsely fossiliferous. The characteristic fusulinid hash at the base of the unit was not seen.

In T. 20 N. the Brownville forms a prominent escarpment to within 2 miles of the south county line. In the 2 miles north of the county line the Brownville escarpment is almost obscured by thick bracketing sandstones together with an abrupt decrease in thickness and resistance of the limestone. A sample of the Brownville taken along the creek in the E. ½ sec. 30, T. 20 N., R. 6 E. (Fig. 22) yielded an insoluble residue of almost 72 percent, principally quartz sand (Appendix A).

Figure 22. Brownville limestone exposed along drainage gully in the east-central part of sec. 30, T. 20 N., R. 6 E. The Ralston coal crops out in the floor of this gully to the east and across the road in sec. 29.

Paleontology. Although the Brownville is moderately to highly fossiliferous, conditions of preservation are such that only meager collections can be made. Aside from the fusulinid hash in the bottom part of the limestone, the most typical fossils are fragments of large crinoid columnals, commonly pink, which stand out in relief on the weathered surface of the limestone.

The largest collections were obtained from the abandoned quarries in the NE ¼ sec. 13, T. 21 N., R. 5 E. A thin molluscan zone containing *Myalina* and algal pellets occurs at the top of the limestone in these quarries.

The following fauna was identified from several collections made in the central part of the county:

Protozoa
- Triticites sp.

Crinoidea
- columnals, radials, spines

Brachiopoda
- Chonetes granulifer Owen
- Chonetinella (?) sp.
- Composita subtilita (Hall)
- Enteletes hemiplicatus (Hall)
- Juresania nebrascensis (Owen)

- Linoproductus sp.
- "Marginifera" sp.
- Neospirifer sp.

Bryozoa
- Rhombopora lepidodendroides Meek
- fenestrate forms
- ramose forms

Pelecypoda
- Wilkingia sp.
- Aviculopecten sp.
- Myalina sp.

Chondrichthyes
- Petalodus destructor (Newberry and Worthen)

PERMIAN SYSTEM

Rocks of Permian age cover the western half of Pawnee County. The series divisions of the Permian system now standard for North America were originally proposed by J. E. Adams (1939, p. 1673). These divisions are based on unconformity and lithology of beds in the Permian basin of West Texas and southeastern New Mexico. The four series currently recognized are, in ascending order, Wolfcamp, Leonard, Guadalupe, and Ochoa.

Unlike the Permian basin section, however, the Permian beds of Kansas and northern Oklahoma show little or no evidence of major unconformity on which series breaks can be based. Major divisions in this area are based largely on lithology. Even the postulated major unconformity at the base of the system is open to doubt. Nowhere in northern Oklahoma and only locally in Kansas is there evidence of such unconformity. In discussing the problem Moore (1940) noted that the postulated position of the boundary has ranged from the top of the Brownville limestone, its presently accepted position, all the way up to the top of the Carlton limestone member of the Wellington formation, currently classified as lower Leonard.

Placement of the boundary at the top of the Brownville limestone by Moore and Moss (1933, p. 100) conforms to the later recommendation of the American Association of Petroleum Geologists Committee on the Permian. That committee recommended that in the absence of a diagnostic unconformity the base of the system be drawn at the first important hiatus below strata characterized by the fusulinid genera *Schwagerina, Pseudoschwagerina,* or *Paraschwagerina* (Tomlinson et al., 1940, p. 341).

At places in Kansas and southeastern Nebraska channel sandstones occur at the base of the Admire shale, truncating as much as 100 feet of underlying strata. Lithologies above and below the break are "strikingly different", and *Pseudoschwagerina* and *Schwagerina* occur 100 to 200 feet above it (Moore and Moss, 1933, p. 100). In northern Oklahoma *Schwagerina* is common in the Long Creek limestone of Pawnee County and *Pseudoschwagerina* is known from the Neva limestone of Osage County (Taylor, 1953, p. 61). No evidence of truncation at the base of the Admire shale has been reported, however, and the lithology of the sediments above and below the postulated break is strikingly similar. Thus a sedimentary break of major proportions at this point in the northern Oklahoma section is refuted, but because there is no evidence for placing the contact elsewhere in the northern Oklahoma section, the Pennsylvanian-Permian contact of the Kansas section is also considered to be the contact in Oklahoma.

WOLFCAMP SERIES

Lower Permian rocks including all but the uppermost part of the Wolfcamp series occur in Pawnee County. The section is composed of gray and red shales, lenticular sandstones, and thin fossiliferous limestones. The limestones in the eastern part of the belt of Permian outcrop are persistent and can be traced entirely across the county. West of Pawnee, however, the limestones thin and die out southward into the red shales and sandstones that characterize the rocks exposed over most of the western part of the county.

The subdivisions of the Wolfcamp series of Kansas have been tabulated by Moore (1951, pp. 42, 43). As in the case of the underlying Wabaunsee section, the key beds of the Wolfcamp in Pawnee County are continuous from the Kansas section although many of the Kansas units pinch out north of Pawnee County. This sequence of marine and non-marine beds grades southward into the coarsely clastic continental deposits of the Konawa and Asher formations of central Oklahoma.

Subdivisions of the series used in Pawnee County are shown in Table 3. All units shown crop out in the county except the Herington limestone and Odell shale which crop out to the west in Noble County.

TABLE 3

Divisions of the Wolfcamp series in Pawnee County

Permian system

Leonard series

Wolfcamp series

Chase group	Herington limestone
	Odell shale
	Winfield limestone
	Doyle shale
	Fort Riley limestone
	Ma field shale
	Wreford limestone
Council Grove group	Garrison shale
	Cottonwood limestone
	Eskridge shale
	Neva limestone
	Roca shale
	Red Eagle limestone
	Johnson shale
	Long Creek limestone
	Hughes Creek shale
	Americus limestone
Admire group	Admire shale

(-?- U n c o n f o r m i t y -?-)

Pennsylvanian system

None of the Kansas units of the Admire group can be recognized in Pawnee County so the group has not been subdivided. The Council Grove and Chase groups have been subdivided into limestone and shale-sandstone units of equal rank. Where applicable, names from the Kansas section have been used, but the rank of these names in the Kansas classification has been disregarded.

ADMIRE GROUP

As currently defined, the Admire group is the basal Permian (Wolfcampian) unit of the Mid-Continent area and includes those beds overlying the Brownville limestone and underlying the Americus limestone. The name Admire was first applied by Adams (1903, p. 53) to a sequence of fossiliferous shales overlying the Emporia (Reading) limestone and underlying the Americus limestone near the town of Admire in Lyon County, Kansas. Condra (1927) restricted the Admire shale to that interval from the base of the Brownville limestone upward to the base of the Americus limestone. Subsequent redefinition by Moore (1932) raised the base of the Admire to the top of the Brownville limestone. Condra (1935, pp. 8-9) raised the name to group status.

Admire formation

Definition and distribution. In Nebraska and Kansas the Admire group has been subdivided into seven limestone and shale units with the Indian Cave channel sandstone occurring locally at the base (Moore, 1951, p. 49). In Osage County, Oklahoma, Taylor (1953), Vosburg (1954), and Fisher (1956) made tentative correlations with some of the Kansas units, but in Pawnee County exposures of the Admire group are poor and no attempt at subdivisions was made. Branson (1956, p. 123) proposed that where subdivision of the Admire group is not possible the name Admire formation be applied to the sedimentary sequence separating the Brownville and Americus limestones.

The Admire group is recognized from Nebraska southward across Kansas into north-central Oklahoma. Its southern extent has not yet been determined, although recent field work indicates that it probably cannot be mapped farther south than T. 17 N. in southern Payne County (E. Nakayama, 1955, personal communication).

In Pawnee County the Admire formation forms a broad valley averaging three miles in width which trends generally north-south across the county, lying just west of Ralston and east of Pawnee.

Thickness and character. According to Moore (1951, p. 49) the Admire group of Kansas consists of thin limestones and some coals and sandstones in a section composed predominantly of shale. Except at places where the Indian Cave sandstone is developed, the group has a thickness of about 130 feet. Maximum reported thickness of the Indian Cave sandstone is 250 feet in Pottawatomie County, Kansas.

In Oklahoma, Taylor, Vosburg, and Fisher each reported a thickness of about 50 feet for the Admire group in Osage County. These authors subdivided the upper part of the Admire sequence on the basis of thin limestones thought to be continuous from the Kansas section. The basal channel sandstone is absent in Osage County but otherwise the lithology of the group is much as it is in Kansas, consisting principally of shale and a few thin limestones and lenticular sandstones.

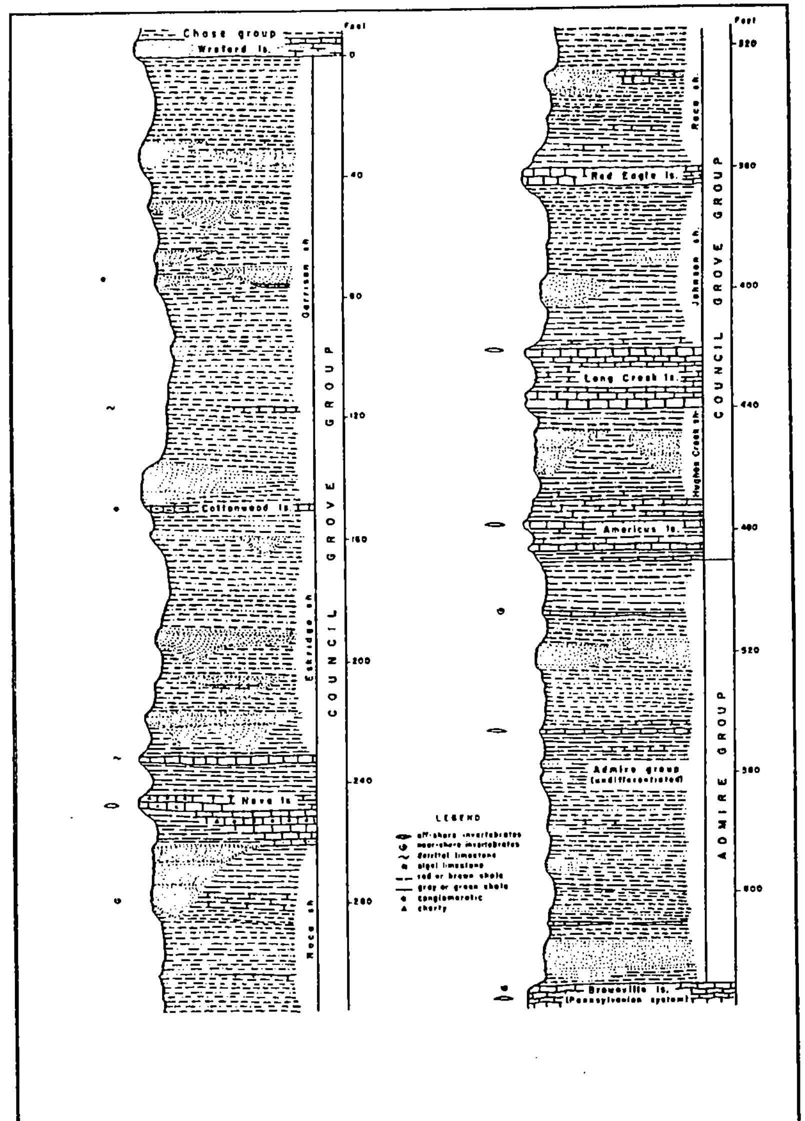

Figure 23. Generalized columnar section of the rocks of the Admire and Council Grove groups (lower and middle Wolfcamp in Pawnee County.

In Pawnee County the Admire group is about 140 feet thick, representing an abrupt increase in thickness southward from Osage County. Only two complete surface measurements were made of the formation, and in both of these rocks are largely covered and the horizontal distance is great. The thickness of the formation may readily be checked in the subsurface, however, on electric logs of bore holes drilled for oil (Plates 3 and 4). Comparison of several electric log intervals confirmed the surface measurements and indicated a surprising constancy in thickness across the county in a north-south direction.

It will be noted that the thicknesses of the Admire sections in Pawnee County and in Kansas are approximately the same, compared to which the Osage County section is thinner by almost two-thirds. Such an abrupt thinning is geologically possible but in this case it seems more likely that the disagreement is the result of a difference in correlation of the Osage County section (see Fig. 20 and discussion on p. 61 and 62).

Exposures of the Admire group in Pawnee County are poor, especially near the base of the group. The sequence consists predominantly of red shale (Appendix D, Sections 19 to 22, inclusive). Thin limestones, generally highly fossiliferous, occur in most exposures, but these beds are shaly, non-resistant, and probably lenticular. Thin beds of fossiliferous gray shale are associated with the limestones. No coal was seen.

One or more lenticular beds of massive to cross-bedded sandstone generally occur in the upper half of the Admire section. Locally these sandstones attain a thickness of more than 20 feet, forming an escarpment which at many places is the only portion of the section exposed.

At the few places in the county where the contact of the Admire beds with the underlying Brownville limestone can be examined, there is no evidence of a major unconformity. The Brownville is overlain by shale, generally red, which contains a few feet from its base a fine-grained massive to well-bedded iron-stained sandstone up to 11 feet thick. The upper limit of the Admire formation is the base of the lowermost limestone (Americus) of the overlying Council Grove group. Where exposed, this

contact is a simple shale-limestone contact showing no evidence of unconformity.

Paleontology. The thin beds of limestone and associated gray shales exposed locally in the upper part of the Admire section are generally highly fossiliferous. Molluscan, brachiopod, and mixed assemblages occur. A calcareous zone which commonly occurs about 50 feet below the top of the formation contains a small species of *Triticites*. Although it is likely that the lower part of the Admire group contains fossiliferous beds similar to those in the upper part, the lower beds and their fauna are covered by slump.

The following faunule was collected from the NW 1/4 of sec. 2, T. 23 N., R. 5 E. (Appendix D, bed 4 of section 21).

Protozoa
- Triticites sp.

Crinoidea
- columnals and spines

Echinoidea
- plates and spines

Brachiopoda
- Chonetes granulifer Owen
- Chonetes granulifer meekanus (Girty)
- Chonetinella (?) sp.
- Crurithyris planoconvexa (Shumard)
- Derbyia sp.
- Enteletes hemiplicatus (Hall)
- Hustedia mormoni (Marcou)
- Juresania sp.
- Linoproductus sp.
- Neospirifer sp.

Bryozoa
- Bascomella fusiformis Condra and Elias
- Rhombopora lepidodendroides Meek
- encrusting forms
- fenestrate forms
- ramose forms
- tabular ramose forms

Gastropoda
- Amphiscapha catilloide (Conrad)

COUNCIL GROVE GROUP

Council Grove was first applied as a stage name by Prosser (1902, p. 709) to the Cottonwood limestone—Garrison shale interval exposed in Morris County, Kansas, near the town of Council Grove. Moore (1932, p. 95) changed the name to Council Grove group and lowered the base of the unit to include the Americus limestone. As presently applied, Council Grove group includes the beds from the base of the Americus limestone upward to the base of the Wreford limestone. It lies with apparent conformity between the underlying Admire group and the overlying Chase group.

The Council Grove group consists principally of shale with several persistent escarpment-forming limestones and, in Pawnee County, a few thick lenticular sandstones. Thickness of the group increases southward from an average of 321 feet in Kansas (Moore, 1951, p. 45) to about 480 feet in northwestern Pawnee County.

The Council Grove group can be traced from southeastern Nebraska across eastern Kansas into Pawnee County, Oklahoma. There in the southwest part of T. 22 N., R. 4 E., the Wreford limestone, the base of which defines the upper limit of the group, loses its identity. Farther south, therefore, the Council Grove and overlying Chase groups cannot be differentiated. They grade laterally into the Konawa-Asher sequence of central Oklahoma.

Foraker limestone

Definition and description. The basal formation of the Council Grove group is the Foraker limestone, which was named by Heald (1916, p. 21) for limestone exposures near the town of Foraker in northwestern Osage County, Oklahoma. Bass (1929, p. 45) introduced the name into Kansas terminology when he identified the Americus limestone of Cowley County, Kansas, as the basal member of the Foraker limestone.

The name Foraker was introduced into the stratigraphic classification of northwestern Missouri and southeastern Nebraska by Condra (1935, p. 8). Condra applied the name to a sequence containing the Americus limestone, Hughes Creek shale, and Long Creek limestone, which he designated as lower, middle, and upper members, respectively, of the Foraker limestone formation.

The three members of the Foraker formation are traceable southward from Nebraska across Kansas and into Lincoln County, Oklahoma. They are well exposed in Pawnee County where they form abrupt escarpments west of the wide erosional valley in the Admire shale.

Thickness and character. Moore (1951, p. 48) assigned an average aggregate thickness of 50 feet to the members of the Foraker formation in Kansas. Heald (1916) reported a Foraker thickness of approximately 74 feet in the type area in Osage County, Oklahoma,

but more recent workers report only about 50 feet of Foraker in Osage County (Taylor, 1953; Vosburg, 1954; Fisher, 1956). The thickness of the Foraker formation in Pawnee County ranges between 60 and 70 feet, showing a tendency to thicken slightly toward the south.

It will be noted in the descriptions that follow that the thickness of the individual members of the Foraker formation has a wide range. Accurate measurement of the total thickness of the formation at the surface is not possible owing to the scattered nature of exposures, but it is felt that an increase in thickness of one member is accompanied by a corresponding decrease in thickness of one or both of the other members and that the aggregate thickness of the member beds is fairly constant. This conclusion is supported by Foraker sections penetrated in bore holes west of the outcrop. Although it is not possible to identify the individual members on the electric logs of these bore holes, the formation as a unit can be recognized and is about the same thickness in all wells examined (Plates 3 and 4).

Americus limestone member

Definition and distribution. The name Americus was first applied by Kirk (1896, p. 80) to a six-foot limestone-shale section near the town of Americus, Lyon County, Kansas. Bass (1929, p. 45) correlated the Americus with the lower part of the Foraker limestone of Osage County, Oklahoma, and current usage in Nebraska, Kansas, and northern Oklahoma places the Americus as the basal member of the Foraker formation.

The Americus limestone has been traced from southeastern Nebraska across eastern Kansas into north-central Oklahoma. Recent field work indicates that the unit continues as far south as T. 16 N. in central Lincoln County (A. West, 1955, personal communication). In Pawnee County outcrops of Americus limestone are restricted almost completely to R. 5 E., where the Americus escarpment forms the western limit of the broad valley in the Admire shale.

Thickness and character. In Kansas the Americus consists of two beds of bluish-grey limestone separated by 3 to 13 feet of gray to black shale (Moore, 1951, p. 49). The upper limestone bed is commonly cherty. Overall thickness of the unit averages about 18 feet. The Americus can be traced southward into Oklahoma with only minor change in lithology, but the thickness decreases to 12 feet in northwestern Osage County (Taylor, 1953, p. 45).

The thickness of the Americus in northern Pawnee County averages 16 feet and reaches a maximum of 32 feet (Appendix D, section 21). Well-exposed sections of the unit are few, however, and its average thickness may be greater than is apparent. It thins gradually southward and along the Pawnee-Payne county line is only about 8 feet thick.

Figure 24. Americus limestone exposed on the west bank of Black Bear Creek just north of the car bridge in the SW ¼ sec. 33. T. 22 N., R. 3 E. Here the Americus consists of a thin-bedded lower limestone (seen in the lower right) separated from the massive middle member by 5 feet of fossiliferous shale. Upper beds of the Americus are not exposed. A rich molluscan faunule was collected from the shaly upper portion of the massive bed at this exposure.

The Americus is composed of dense gray limestone interbedded with marly gray shale. In the northern and central parts of the county the limestone and shale beds are more or less evenly distributed from top to bottom. Shales generally predominate. Near the middle of the section there is a persistent bed of greenish-gray limestone about 1.5 feet thick. In a typical outcrop it is the bed best exposed and is chiefly responsible for the Americus escarpment (Fig. 24). The upper portion of this bed is shaly and contains a rich brachiopod fauna. Myalinids and pectenoids are common in some of the thin limestones above and below the massive bed.

Exposures of Americus in the southern part of the county consist of a basal limestone less than one foot thick overlain by 4 to 5

feet of shale and 3 feet of well-bedded limestone with thin intercalations of marly gray shale. *Triticites* occur in profusion in the middle of the upper limestone, which is otherwise sparsely fossiliferous.

The insoluble component of the Americus increases toward the south, but in no case was the residue found to be over 10 percent. It consists mostly of dark-gray clay with a small amount of quartz silt. A trace of white chert was noted in the residue of a sample collected in the northern part of the county (Appendix A).

Paleontology. In the northern and central parts of the county large and varied fossil collections are readily obtained from most exposures of the Americus limestone, principally from the shaly zone at the top of the massive member. The Americus thins and becomes less fossiliferous southward except for fusulinids, which are rare in the northern and central parts of the county but are abundant in the southern part.

Specimens were collected from several localities across the county, and the following forms were identified:

Protozoa
- **Triticites sp.**

Anthozoa
- **Lophophyllidium sp.**

Crinoidea
- **columnals, radials, basals, infrabasals, and spines**

Echinoidea
- **plates and spines**

Brachiopoda
- **Antiquatonia sp.**
- **Chonetes granulifer Owen**
- **Chonetes granulifer meekana (Girty)**
- **Chonetinella (?) sp.**
- **Composita subtilita (Hall)**
- **Crurithyris planoconvexa (Shumard)**
- **Derbyia sp.**
- **Hustedia mormoni (Marcou)**
- **Juresania sp.**
- **Juresania nebrascensis (Owen)**
- **Linoproductus sp.**
- **"Marginifera" sp.**
- **Meekella striatocostata (Cox)**
- **Neospirifer sp.**
- **Neospirifer dunbari King**
- **Punctospirifer kentuckyensis (Shumard)**
- **Rhipidomella sp.**
- **Teguliferina (?) sp.**
- **Wellerella sp.**
- **Wellerella delicatula Dunbar and Condra**
- **Wellerella truncata Dunbar and Condra**

Bryozoa
 Bascomella fusiformis Condra and Elias
 Rhombopora lepidodendroides Meek
 fenestrate forms
 ramose forms
 tabular forms
Pelecypoda
 Wilkingia sp.
 Aviculopecten sp.
 Myalina sp.
 Myalina (Orthomyalina) slocomi Sayre
Gastropoda
 Amphiscapha catilloide (Conrad)
Trilobita
 Ditomopyge decurtata (Gheyselinck)

Hughes Creek shale member

Definition and distribution. As presently defined, the Hughes Creek shale includes the rocks between the Long Creek and the Americus limestones. The type section is along Hughes Creek in Nemaha County, Nebraska, where the unit was orignally described by Condra (1927, p. 84). The original boundaries given by Condra were subsequently revised by Moore and Condra (1932) to those now recognized. The Hughes Creek has since been designated as the middle member of the Foraker formation (Condra, 1935, p. 8).

The Hughes Creek is recognized from southeastern Nebraska across eastern Kansas into north-central Oklahoma, where it can be traced as far south as northern Lincoln County. Exposures of Hughes Creek in Pawnee County occur almost entirely within R. 5 E.

Thickness and character. The Hughes Creek shale in Nebraska consists of 36 to 38 feet of bluish-gray to black fossiliferous shales with a zone of thin gray limestones in the central part (Condra, 1935, p. 8). The unit grades into an almost continuous section of cherty fossiliferous limestone in southern Kansas, the thickness ranging from 20 to 40 feet (Moore, 1951, p. 49). Taylor (1953) and Vosburg (1954) traced the Hughes Creek southward into Osage County, Oklahoma, and reported 25 feet of limestone similar to the section in southern Kansas. Fisher (1956, p. 24) reported a Hughes Creek thickness of 22 feet in southern Osage County, where the section consists predominantly of shale and sandstone.

Thickness of the Hughes Creek shale in Pawnee County ranges from 30 feet in the northern part of the county to 43 feet along the south county line. Thicker sections occur where sandstone lenses are developed. The section consists predominantly of gray shale and lenticular sandstones. Thin red shales occur locally, especially in the southern part of the county. Where present, limestones are thin and nodular and constitute a minor part of the unit.

In the southern part of Pawnee County thick sandstone lenses are present locally. The thickest lens observed is in sec. 26, T. 20 N., R. 5 E., where more than 40 feet of massive to contorted sandstone occurs (Appendix D, section 17). The same interval less than two miles east in sec. 25 contains almost no sandstone. Sandstone lenses are also present farther north, but they are thinner and less extensive than those to the south.

Representative measured sections of the Hughes Creek shale are listed in Appendix D, sections 17, 18, and 19.

Paleontology. No fossils were collected from the Hughes Creek shale. The unit is essentially non-fossiliferous except locally adjacent to the underlying and overlying limestones. Sparse assemblages are present at places where the unit contains thin limestones.

Long Creek limestone member

Definiton and distribution. As defined by Condra (1957, p. 84) the Long Creek limestone consists of 3 to 5 feet of limestone underlying the Johnson shale and overlying the Hughes Creek shale. It was named for exposures along Long Creek near Auburn in Nebraska County, Nebraska. Condra's original definition is still valid, though now the Long Creek is also recognized as the top unit of the Foraker limestone formation (Condra, 1935, p. 8). It has been traced across Kansas from southwestern Nebraska into north-central Oklahoma. Recent work indicates that it persists as far south as T. 16 N. in southern Lincoln County, Oklahoma (A. West, 1955, personal communication).

Thickness and character. According to Moore (1951, p. 48) the Long Creek limestone in southern Kansas consists of sparsely fossiliferous light-gray limestone ranging in thickness from 4.5 to possibly 17 feet. In northern Osage County, Oklahoma, the Long Creek is described as interbedded shaly limestone and shale, containing minor amounts of chert and ranging in thickness from 9.8

to 12 feet. The sequence is fossiliferous and contains a profusion of large fusulinids (Taylor, 1953).

In Pawnee County the Long Creek consists of interbedded dense gray limestone and gray marly shale. No chert was observed, but fusulinids are abundant. Large specimens of *Schwagerina* occur in exposures in the northern part of the county, and *Triticites*, large and small, are characteristic of the section entirely across the county. Except for fusulinids, however, the fauna is sparse when compared to the rich assemblages of the Americus and Red Eagle limestones.

The Long Creek is not as effective a scarp-former as are the thinner limestones stratigraphically above and below it. The alternating arrangement of limestone and shale lends itself to the formation, not of one big escarpment, but of several small ones. Accordingly, it is uncommon for the entire Long Creek sequence to be exposed at one place, and the outcrop of the base of the unit is traced with difficulty. A thick well-exposed Long Creek section occurs along the road at the NE corner sec. 9, T. 23 N., R. 5 E. (Appendix D, section 18). This exposure has an aggregate thickness of 25.3 feet, consisting of 11.3 feet of limestone in beds up to 1.3 feet thick separated by marly gray shale.

The essentially uniform distribution of limestone and shale in the Long Creek section of northern Pawnee County gives way southward to upper and lower limestones separated by a 10-to-12-foot bed of gray fossiliferous marly shale. Thickness of the complete sequence ranges up to 19 feet (Appendix D, section 17). The lower limestone is from 4 to 7 feet thick. It is gray to gray-brown and contains interbedded shale, partly red. Algal and molluscan remains are common. The middle shale contains a fauna which grades from a molluscan assemblage in the lower part to a brachiopod assemblage in the upper part. The upper limestone is about 3 feet thick, consisting of 3 to 5 beds of sparsely fossiliferous dense gray limestone separated by thin beds of gray shale. *Triticites* is abundant in the middle beds of the upper limestone in southern Pawnee County.

The limestones of the Long Creek are relatively pure all across the county. Average insoluble clastic content is less than 10 percent, consisting mostly of gray to gray-brown clay. Comparison of weight percentages and compositions of insoluble material from several exposures established no significant trends (Appendix A).

Paleontology. Because of the sparse faunal content only a few collections were made from the Long Creek. Where present, fossils are generally in the limestones and do not weather out readily. Fossils occurring in the shale are limited mostly to bryozoans and crinoid debris.

The thick middle shale in the southern part of the county contains poorly preserved mollusks and brachiopods in addition to bryozoan and crinoid fragments.

Fossils identified from the formation include the following:

Protozoa
- Schwagerina sp.
- Triticites sp.

Crinoidea
- columnals, radials, basals, and spines

Brachiopoda
- Antiquatonia sp.
- Chonetes granulifer Owen
- Composita subtilita (Hall)
- Crurithyris planoconvexa (Shumard)
- Hustedia mormoni (Marcou)
- Linoproductus sp.
- "Marginifera" sp.
- Neospirifer sp.
- Wellerella delicatula Dunbar and Condra

Bryozoa
- Rhombopora lepidodendroides Meek
- encrusting forms
- fenestrate forms
- ramose forms
- tabular ramose forms

Johnson shale

Definition and distribution. In Kansas and southeastern Nebraska rocks of the interval above the Long Creek limestone and below the Glenrock limestone member of the Red Eagle limestone are known as the Johnson shale. The name was first applied by Condra (1927, p. 84) to exposures north of the town of Johnson, Johnson County Nebraska.

In Pawnee County the Red Eagle limestone has not been subdivided, and it is not certain that the Glenrock member is present. The name Johnson shale has been retained, however, and is here applied to the beds between the Red Eagle and Long Creek limestones.

The Johnson shale is recognized from southeastern Nebraska across Kansas into northern Oklahoma. Mapping of the formation in Oklahoma is almost continuous from the Kansas line southward to central Lincoln County, beyond which the Johnson cannot be distinguished from underlying shales.

Thickness and character. The Johnson shale of the type area in Nebraska consists of 18 to 20 feet of gray to buff shale (Condra, 1935, p. 8). In Kansas the unit consists of 14 to 25 feet of gray and green shale, locally sandy in the lower and middle portion, containing thin beds of shaly limestone. Dark carbonaceous material occurs in the upper part (Moore, 1951, p. 48).

Taylor (1953) reported about 35 feet of Johnson in T. 29 N., where the unit consists of gray shale and a few thin limestones. Vosburg (1954, p. 48) reported southward thinning from 33.4 feet in T. 26 N. to 16 feet in the southern part of T. 25 N. Fisher (1956, Plate II) shows a thickness of 46 feet for the Johnson of southwestern Osage County.

The Johnson shale in Pawnee County thickens southward from about 35 feet in T. 24 N. to about 60 feet in T. 20 N. In the northern half of the county the section consists mainly of gray shale. Thin lenses of fine-grained light-colored sandstone are developed locally. As far north as Pawnee, however, red shale appears in the section about 6 feet below the Red Eagle, and the percentage of red shale increases steadily southward until along the south border the section is mainly red except for a few feet of gray marly shale immediately above the Long Creek and below the Red Eagle limestones. The number and thickness of sandstones also increase southward. They are generally red and their structure suggests deposition in a deltaic environment.

Exposures of the Johnson shale are generally badly slumped and grass covered, preventing detailed stratigraphic description. Outcrops are restricted to benches formed by resistant sandstone lenses. The shale generally forms a valley about one mile wide, and as a result even the thickness is not readily determined.

Paleontology. No fossils were observed in the Johnson shale of Pawnee County.

Red Eagle limestone

Definition and distribution. The Red Eagle limestone was named by Heald (1916, p. 24), who applied the name to a limestone exposed near the since-destroyed Red Eagle school in T. 26 N., R. 6 E., southwest of Foraker in Osage County, Oklahoma. At the type section the Red Eagle lies 17 feet above the Long Creek and 71 feet below the Neva limestone. Bass (1929, p. 54) identified the Red Eagle in southern Kansas and was instrumental in tracing the unit northward across the state. Condra (1935, p. 8) extended the name into northwestern Missouri and southeastern Nebraska as the Red Eagle limestone formation, subdivided into three members: the Glenrock limestone, Bennett shale, and Howe limestone. These subdivisions have been recognized across Kansas (Moore, 1951, p. 48) and have been tentatively identified in Osage County, Oklahoma, by Taylor (1953) and Vosburg (1954).

The Red Eagle of Pawnee County crops out along the western half of R. 5 E. It is well exposed on the courthouse lawn and elsewhere in the town of Pawnee, where it was named the Pawnee limestone by Drake (1897, p. 386). The name Pawnee had already been applied to a limestone in the Des Moines series, however, and was therefore displaced by Red Eagle in the classification of the Wolfcamp beds of Pawnee County. In the north and central part of the outcrop belt a threefold subdivision of the Red Eagle sequence is possible, but there is no sound basis for correlation with the subdivisions of Kansas and Nebraska and such correlation will not be attempted here. For the purpose of this report the Red Eagle limestone is considered as a single unit and is defined as the first persistent limestone zone above the Long Creek limestone. This unit can be traced entirely across Pawnee County as far south as T. 13 N. in Lincoln County (K. E. Masters, 1955, personal communication).

Thickness and character. In Kansas and Nebraska the thickness of the Red Eagle ranges from 6 to 20 feet. It consists of two limestone members separated by gray to black shale. In southern Kansas and northern Oklahoma, the Red Eagle consists mainly of limestone. In Osage County a thickness of about 20 feet was reported by both Taylor (1953) and Vosburg (1954).

The Red Eagle section in Pawnee County consists of interbedded limestone and shale, thickening from less than 3 feet in the north to more than 6 feet in the south. Concurrent with the southward thickening is an increase in topographic expression. The escarpment formed by the limestone between Pawnee Lake and the Arkansas River is generally low and inconspicuous, and where resistant sandstones occur in the overlying shale, there is no escarpment whatsoever; the limestone is covered by slumped rock or is exposed only in gullies or in larger drainage channels. In the town of Pawnee and to the south, however, the Red Eagle escarpment is readily traceable, and together with the escarpments of the Long Creek and Americus limestones produces a north-south belt of considerable relief.

Throughout the north and central part of its outcrop the Red Eagle consists of two limestones separated by shale. Southward the shale grades into limestone, and in T. 20 N. the Red Eagle can be described as 6 feet of well-bedded limestone with thin shale partings. The limestone is dark-gray to gray, dense, locally shaly, and highly fossiliferous. Numerous specimens of the brachiopod "*Marginifera*" characterize the limestone in and north of the town of Pawnee. Fusulinids occur abundantly in the middle beds of the section in southern Pawnee County, but in the northern part of the county they are comparatively rare.

The insoluble constituents of the Red Eagle limestone are minor (Appendix A), consisting mostly of dark-gray clay. A few small fragments of chert occur in the limestone in the southern part of the county. Microscopic examination of a thin-section of the rock exposed in the quarry in sec. 28, T. 20 N., R. 5 E. showed it to be a microcoquina or spergenite.

A detailed study of the Red Eagle limestone formation in Kansas was made by O'Conner and Jewett (1952). These authors were able to subdivide the formation in southern Kansas, where it is predominantly limestone, on the basis of faunal horizons and microscopic rock characteristics which persist southward from the area where threefold subdivision of the formation is apparent. A zone of *Orbiculoidea* occurs at the base of the Bennett shale member, and the Howe limestone member is identified by its micro-

coquinoid character. According to the authors, these diagnostic features extend into northern Oklahoma. No *Orbiculoidea* were seen in the Pawnee County section, however, and although some of the beds could be called spergenite, subdivision of the section on this basis alone is not justified.

Paleontology. Both the shale and limestone phases of the Red Eagle contain a rich marine fauna. Fusulinids are an important constituent of the fauna in the central and northern parts of the area.

The following fossils were identified from several collections made along the outcrop belt:

Protozoa
- Schwagerina sp.
- Triticites sp.

Anthozoa
- Lophophyllidium sp.

Crinoidea
- columnals, basals, and spines

Echinoidea
- plates and spines

Brachiopoda
- Antiquatonia sp.
- Chonetes granulifer Owen
- Chonetinella (?) sp.
- Composita subtilita (Hall)
- Crurithyris planoconvexa (Shumard)
- Derbyia sp.
- Dielasma bovidens (Morton)
- Hustedia mormoni (Marcou)
- Juresania nebrascensis (Owen)
- Linoproductus sp.
- "Marginifera" sp.
- Meekella striatocostata (Cox)
- Neospirifer sp.
- Neospirifer dunbari King
- Punctospirifer kentuckyensis (Shumard)
- Rhipidomella sp.
- Wellerella sp.
- Wellerella delicatula Dunbar and Condra
- Wellerella truncata Dunbar and Condra

Bryozoa
- Bascomella fusiformis Condra and Elias
- Caulostrepsis dunbari Condra and Elias
- Rhombopora lepidodendroides Meek
- encrusting forms
- fenestrate forms
- ramose forms
- tabular ramose forms

Gastropoda
- Amphiscapha catilloide (Conrad)

Chondrichthyes
- Deltodus sp.

Roca shale

Definition and distribution. As used in this report, the Roca shale includes the rocks between the Red Eagle and Neva limestones. In essence this is the original definition of the unit proposed by Condra (1927, p. 86) for a section near Roca, Lancaster County, Nebraska. Condra's definition has been modified by the establishment of the Grenola formation (Condra and Busby, 1933), which, except for the Neva limestone, consists of beds formerly included in the upper part of the Roca. Subdivisions of the Grenola are, in descending order, the Neva limestone, Salem Point shale, Burr limestone, Legion shale, and Sallyards limestone. The definition of the Roca as thus restricted by Condra and Busby is the one currently used in Kansas and Nebraska.

Taylor (1953) and Vosburg (1954) identified all the Kansas subdivisions of the Grenola in northwestern Osage County, Oklahoma, but Fisher (1956, p. 32) reported that the lower three members of the formation grade southward into sandstone just north of Pawnee County. In Pawnee County the top of the Kansas Roca is indeterminate and only the Neva limestone member of the Grenola formation can be recognized with assurance. Accordingly, the Roca shale of this report includes in its upper part a section representative of all but the Neva limestone member of the Grenola formation of Kansas. This section can be identified southward as far as T. 17 N. in southern Payne County (E. M. Nakayama, 1955, personal communication). Northward the Roca of Pawnee County grades into the Roca and basal Grenola beds of northern Oklahoma, Kansas, and Nebraska.

Roca exposures are generally poor in Pawnee County although along Oklahoma Highway 18 between Pawnee and Ralston there are several road cuts in which the Roca is well exposed and may be studied in detail (Appendix D, sections 14, 15, and 16).

Thickness and character. In Nebraska and Kansas the Roca is 15 to 20 feet thick and is composed predominantly of gray, red, and green shale; thin impure limestones occur in the Kansas section. In northern Oklahoma also the Roca consists predominantly of red and gray shale. Taylor (1953, p. 57) reported a thickness in northern Osage County of 17.5 feet. Farther south Vosburg (1954, p. 56) reported a southward thickening of the formation

from 13.8 feet in T. 26 N. to 34.5 feet in T. 24 N. Vosburg attributed the thickening to sandstones wedging into the section from the south. In southern Osage County Fisher (1956, Pl. II) showed a thickness of 80 feet for the section between the Red Eagle and Neva limestones. This thickness includes the lower part of the Grenola formation and is therefore not directly comparable with Roca sections farther north.

Figure 25. Channel sandstone in the upper part of the Roca shale exposed along the road on the west line of the SW ¼ sec. 30, T. 20 N., R. 5 E.

The thickness of the sequence between the Red Eagle and Neva in Pawnee County ranges from 80 feet along the Arkansas River in T. 24 N. to about 120 feet in the central part of the county, from whence it decreases southward to about 105 feet in T. 20 N. Nakayama (1955, personal communication) reported only about 90 feet of Roca in southern Payne County.

The rocks composing the Roca section in Pawnee County are principally red and gray shales, lenticular sandstones, and thin impure limestones. The basal 20 to 25 feet consists of gray shale which, except in the central part of the county, contains one or more thin beds of fossiliferous generally impure gray to gray-green limestone. The gray shale grades upward into 50 to 70 feet of red and reddish-brown silty shale. Lenticular sandstones with a maximum thickness of over 30 feet occur in the red shale section. The sandstones are red to light tan and generally grade from cross-bedded in the lower part to massive or well-bedded in the upper part. Contorted bedding is common. The sandstones are generally thicker in the southern part of the county.

One of these sandstones, the base of which is exposed along the road on the west side of sec. 30, T. 20 N., R. 5 E., is a channel sandstone resting disconformably on the underlying red shale (Fig. 25). Similar disconformities probably occur at the base of many or most of the sandstones in this sequence, but the contact relationships are concealed by slumped rock at all but a few places.

Overlying the red shale-lenticular sandstone sequence is a 20-foot section of dark-gray to black shale, which forms the upper part of the Roca. The black shale contains thin beds of impure highly fossiliferous limestone and calcareous siltstone, especially in the lower part (Appendix D, sections 11, 13, and 14). Several thin beds of siltstone are intercalated in the shale just below the Neva, and excepting in the central and southern parts of the county, where a thick sandstone occurs immediately below the Neva.

Two persistent limestones occur in the Roca. Near the base of the red shale section there is a gray to brown sandy limestone which grades laterally into sandstone. The thickness of this unit averages 5 feet (Appendix D, sections 15 and 16). On the outcrop the rocks appear decomposed, and consist of irregular dark-brown masses of leached sandstone surrounded by lighter-colored unleached sandy limestone. The basal bed is crinoidal; the overlying beds contain a molluscan fauna including *Myalina* sp. and *Euphemites* sp. Small lenses of dense limestone composed largely of molluscan remains occur in the top part. The limestone is especially well developed in and just north of Pawnee, where it is exposed on the playground of the grade school in town and along Oklahoma Highway 18 just east of Pawnee Lake (Fig. 26). It forms an escarpment that can be traced across the central part of the county from the northwestern part of T. 21 N., R. 5 E., to sec. 19, T. 23 N., R 5 E., where it crops out on the south bank of Coal Creek just east of the bridge on Oklahoma Highway 18. North of this point the unit was not seen although similar beds occur higher in the Roca section. South of Pawnee a thin-bedded to massive sandstone occurs 30 to 40 feet above the Red Eagle. This sandstone is probably correlative with the sandy limestone unit to the north.

A second persistent limestone occurs higher in the red shale section 40 to 50 feet below the base of the Neva limestone. It is a non-resistant argillaceous mottled gray-green and maroon limestone about 0.5 feet thick. It contains a few mollusks and lenses of algal pellets. This limestone occurs as far south as Pawnee Lake and may be the Sallyards or the Burr limestone member of the Grenola formation. Along the Arkansas River in sec. 17, T. 24 N., R. 5 E., where the Roca is only 80 feet thick, a limestone 25 feet below the Neva may be the northward continuation of the mottled limestone.

Figure 26. Thin unnamed limestone in the Roca shale exposed along Oklahoma Highway 18 in SW 1/4 sec. 20, T. 22 N., R. 5 E. The leached, rotten appearance of the central portion is typical. The bottom bed is dense and crinoidal; the upper bed contains a profusion of *Myalina*.

Paleontology. The limestones and adjacent shales of the Roca section are commonly fossiliferous. The limestones of the basal gray shale contain a brachiopod fauna with a few fusulinid specimens, but the fossiliferous zones in the upper part of the unit are all molluscan and algal.

The following forms were identified from collections made from the molluscan zones, mainly from the exposures of the upper gray shale along the east side of Oklahoma Highway 18 in sec. 29, T. 23 N., R. 5 E. (Appendix D, section 14).

Crinoidea
- columnals

Brachiopoda
- Composita subtilita (Hall)
- Hustedia mormoni (Marcou)
- Juresania nebrascensis (Owen)
- Linoproductus sp.
- Orbiculoidea missouriensis (Shumard)

Bryozoa
- fenestrate forms

Pelecypoda
- Wilkingia sp.
- Astartella sp.
- Aviculopecten sp.
- Aviculopinna sp.
- Leda sp.
- Myalina sp.
- Myalina (Myalina) copei Whitfield
- Myalina (Orthomyalina) slocomi Sayre
- Myalina (Orthomyalina) subquadrata Shumard
- Nucula sp.
- Pseudomonotis (?) sp.
- Septimyalina sp.

Gastropoda
- Amphiscapha Catilloide (Conrad)

Chondrichthyes
- Petalodus destructor (Newberry and Worthen)

Neva limestone

Definition and distribution. The type locality of the Neva limestone is near Neva station, Chase County, Kansas. The name was proposed in an unpublished manuscript by Prosser and Beede (Beede, 1902, p. 180) for 6 to 8 feet of gray limestone in two beds separated by shale. Following discussion and reclassification of this part of the Permian section by Condra and Busby (1933), Moore (1936), and Bass (1936), the Neva is now defined as the top member of the Grenola formation and is underlain in turn by the Salem Point shale, Burr limestone, Legion shale, and Sallyards limestone members. Only the Neva member of the Grenola can be identified with assurance in Pawnee County. At least one thin limestone occurs a short distance below the Neva in the northern part of the county, however, and may represent the southernmost extension of one of the lower Grenola limestones. The Neva is overlain by the Eskridge shale formation.

The Neva can be traced continuously southward from southeastern Nebraska across Kansas into north-central Oklahoma. In Pawnee County the escarpment of the Neva limestone cuts back and forth across Oklahoma Highway 18, swinging sharply to the west of Pawnee along Black Bear Creek. Recent work by Nakayama (1955, personal communication) indicates that the Neva pinches out in southern Payne County.

Thickness and character. The Neva limestone of Kansas was described by Moore (1951, p. 47) as a series of four or five limestone beds separated by shale. In southern Kansas the lower limestones are locally chert-bearing. Total thickness ranges from 16 to 24 feet. According to Taylor (1953, p. 61) and Vosburg (1954, p. 60) the Neva of Osage County, Oklahoma, consists of 20 to 30 feet of limestone and thin interbedded gray shales. A zone of cherty limestone 2.5 feet thick occurs about 6 feet below the top. Taylor (p. 61) reported *Pseudoschwagerina* from a shale zone near the middle of the section. According to Fisher (1956, p. 33) the Neva of southwestern Osage County has a fairly constant thickness ranging between 10 and 13 feet.

In Pawnee County the Neva consists of upper and lower limestone members separated by 13 to 22 feet of blue-gray shale. Overall thickness of the formation ranges from 40 feet in T. 22 N. to 17 feet in T. 20 N. (Appendix D, sections 10 to 14 inclusive). In the northern part of the county the thick lower limestone member of the sequence forms an abrupt escarpment which bounds the Roca shale valley on the west. The thin upper limestone generally crops out somewhat west of the main escarpment and is difficult to trace. Massive sandstones are commonly developed above and/or below the upper limestone, effectively concealing its outcrop. In southern Pawnee County, however, where the upper and lower limestones are more equally resistant and are both bounded by shale, the Neva forms two escarpments. When tracing the Neva outcrop in this area, either on the aerial photographs or in the field, caution is necessary to prevent jumping from bed to bed.

In the northern part of the county good exposures of the scarp-forming lower limestone occur in several abandoned quarries and at almost all places where roads cross the outcrop, but a complete section of Neva is rarely exposed. In T. 23 N., where the lower member is best developed, it is 21 feet thick. It is silty at the base and grades upward into cherty limestone with intercalations of gray silty shale up to 0.5 feet thick. Irregular masses of chertified limestone, probably representing post-depositional replacement, occur throughout the limestone. In the upper part there are horizontal zones of chert nodules and lenticular beds of

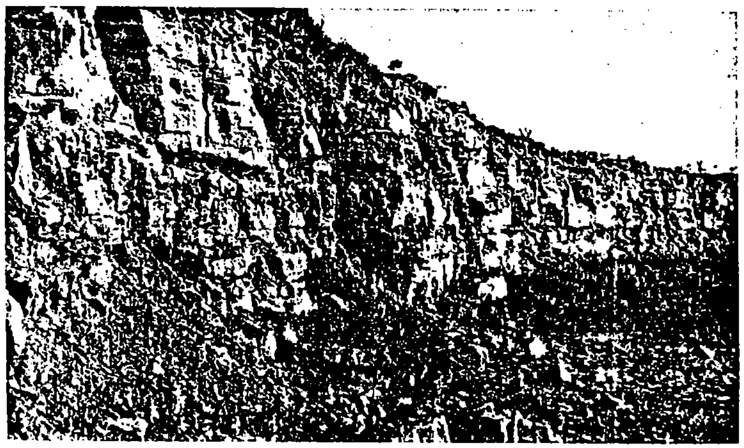

Figure 27. Neva limestone in quarry east of Oklahoma Highway 18 in sec. 20, T. 23 N., R. 5 E. The Neva is 16 feet thick in this quarry.

chert, apparently primary, which stand out in relief on the weathered surface of the limestone (Figs. 27 and 28). The chert nodules and lentils are dark-gray to dark-brown; the limestone is dense and ranges from buff to blue-gray to gray-brown. Where chertification is greatest, the color of the chert prevails. Fossils are abundant, especially in some of the shale beds, and a zone of fusulinids, mostly *Triticites,* occurs in the lower part. A sample of the limestone which appeared to be relatively pure yielded an insoluble residue of 20.7 percent, most of which consisted of chert fragments and silt (Appendix A).

The upper limestone is dense, greenish-gray, and locally shaly and is composed largely of broken shell fragments. It is about one foot thick and is separated from the lower limestone by 15 to 20 feet of shale, which contains lenticular sandstones in the upper part.

Southward the chert disappears from the section and is absent in the Neva exposures near Pawnee, where the entire Neva section is only 20 feet thick. Here the lower member consists of fossiliferous sandy limestone or calcareous sandstone. Upon leaching these beds appear to be a dark-brown sandstone. They contain casts of several large brachiopods, notably *Neospirifer.*

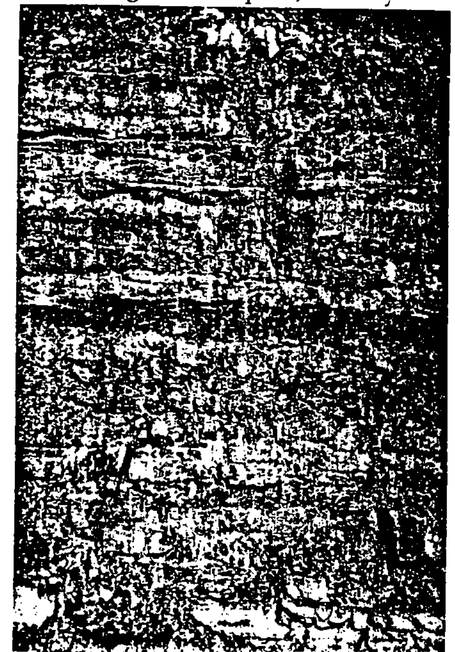

Figure 28. Neva limestone. Close-up of left part of Figure 27. Note resistant well-bedded chert in the upper part and irregular nodular chert in the center. Pick head rests in fossiliferous shale bed 5.5 feet above the base of the Neva.

Farther south the Neva section is composed of an upper and lower limestone, each about 2.5 feet thick, separated by 13 feet of blue-gray shale (Appendix D, section 11). The limestones are similar in appearance, the principal difference being the occurrence of red shale in and immediately below the upper limestone. Both weather dark brown. Freshly fractured surfaces have a characteristic dull brownish-gray color and a rough granular texture. Small cavities lined with crystalline calcite are common. Fossils are rare except for the local occurrence of *Myalina* and crinoid fragments which stand out in relief on the weathered surface (Fig.

29). A sample of the lower member contained about 13 percent insoluble material, mostly silt (Appendix A).

Paleontology. The upper limestone member of the Neva contains a sparse molluscan fauna and is locally crinoidal. The lower member contains a rich brachiopod fauna in the northern part of the county. This fauna diminishes southward and grades into a molluscan facies south of Pawnee. The fusulinid zone in the lower part of the cherty bed is most prominent in outcrops along the Arkansas River and dies out north of Pawnee Lake. Neva exposures in the southern part of the county are essentially nonfossiliferous except for crinoid fragments and a few *Myalina*.

Figure 29. Basal crinoidal limestone member of the Neva limestone in southern Pawnee County, SW ¼ sec. 6, T. 20 N., R. 5 E.

The following forms were collected, mostly from exposures of the lower limestone in the northern part of the county:

Protozoa
- Schwagerina sp.
- Triticites sp.

Anthozoa
- Lophophyllidium sp.

Crinoidea
- columnals, basals, and spines

Echinodea
- plates and spines

Brachiopoda
- Antiquatonia sp.
- Chonetes granulifer Owen
- Chonetinella (?) sp.

- Composita subtilita (Hall)
- Crurithyris planoconvexa (Shumard)
- Derbyia sp.
- Hustedia mormoni (Marcou)
- Juresania sp.
- Juresania nebrascensis (Owen)
- Linoproductus sp.
- "Marginifera" sp.
- Meekella striatocostata (Cox)
- Neospirifer sp.
- Neospirifer dunbari King
- Orbiculoidea missouriensis (Shumard)
- Rhipidomella sp.
- Wellerella delicatula Dunbar and Condra
- Wellerella truncata Dunbar and Condra

Bryozoa
- encrusting forms
- fenestrate forms
- ramose forms
- tabular ramose forms

Pelecypoda
- Wilkingia sp.

Chondrichthyes
- Petalodus destructor (Newberry and Worthen)

This faunal assemblage is noteworthy because it is the youngest occurrence of fusulinids and a normal brachiopod fauna in the Pawnee County section. In the younger beds west of the Neva outcrop, the fauna is restricted to mollusks, phosphatic brachiopods, and algae, indicating a marked change in sedimentary environment in post-Neva time.

Eskridge shale

Definition and distribution. C. S. Prosser in an unpublished manuscript suggested the name Eskridge for about 30 feet of shale overlying the Neva limestone and underlying the Cottonwood limestone near the town of Eskridge, Wabaunsee County, Kansas (Beede, 1902, p. 181). Prosser's original definition is still valid.

The Eskridge shale was formerly considered to be the top unit of the Wabaunsee group in Kansas, but reclassification of the section by Moore (1936) and others has since placed the Eskridge in its present position in the Council Grove group. The formation can be traced continuously across Kansas from southwestern Nebraska into north-central Oklahoma, where it can readily be mapped as far south as central Pawnee County. In southern Pawnee County identification of the Cottonwood limestone is uncertain, and recognition of the upper limit of the Eskridge is accordingly doubtful.

Character and thickness. The Eskridge shale of Kansas is described by Moore (1951, p. 47) as principally red and green shale, 20 to 40 feet thick, with minor amounts of limestone and thin coals locally. According to Taylor (1953, p. 63), Vosburg (1954, p. 62), and Fisher (1956, Pl. II), the Eskridge shale of Osage County, Oklahoma, consists of about 65 feet of yellowish-gray and maroon shales containing thin sandstones and, in the upper part, thin fossiliferous limestones.

The Eskridge shale of Pawnee County is a non-fossiliferous sequence of maroon to red shales and thick lenticular generally cross-bedded sandstones. Small lentils of conglomeratic limestone occur locally in the sandstones. The thickness of the Eskridge ranges from about 80 to 90 feet, increasing southward. This thickness may be open to question, however, owing to the uncertainties inherent in measuring a thick weakly-resistant section of poorly exposed lenticular beds.

Lying immediately above the Neva is 10 to 15 feet of gray shale. Locally (e.g., along the road on the east side of sec. 12, T. 22 N., R. 4 E.) this gray shale is thinner and is overlain with apparent disconformity by a cross-bedded channel sandstone up to 25 feet thick. This contact is generally covered, but the occurrence of a highly cross-bedded sandstone a short distance above the Neva at many places in the county suggests the existence of a local disconformity.

The section above the cross-bedded sandstone is generally covered. It consists of a complex sequence of red shales and red to tan lenticular sandstones (Appendix D, section 8).

Paleontology. The rocks of the Eskridge shale section are apparently non-fossiliferous.

Cottonwood limestone

Definition and distribution. In the stratigraphic subdivision used in Pawnee County the Cottonwood limestone lies above the Eskridge shale and below the Garrison shale. Cottonwood limestone is an established abbreviation for the Cottonwood Falls limestone, named by Haworth and Kirk (1894, p. 112) for exposures near Cottonwood Falls, Chase County, Kansas. Condra and Busby (1933, p. 13), in setting up the Beattie formation, included the Cottonwood as the basal member, overlain in turn by the Florena shale and the Morrill limestone. This classification is currently used in Kansas, southeastern Nebraska, and north-central Oklahoma. Taylor (1953), Vosburg (1954), and Fisher (1956) each identified the three units of the Beattie formation in Osage County.

The members of the Beattie formation can be identified in Pawnee County just south of the Arkansas River in the two northernmost outliers of Cottonwood limestone. These outliers are shown on Plate 1 in the northwest part of T. 23 N., R. 4 E. They are capped by a thin limestone about 30 feet above the Cottonwood (Appendix D, section 9). This limestone is undoubtedly the Morrill and the underlying shale the Florena. A few scattered limestone exposures of indeterminate stratigraphic position occur immediately to the southwest of the outliers and may be erosional remnants of the Morrill, but the extent of discernible Morrill limestone in Pawnee County is very small. Only the Cottonwood limestone member of the Beattie formation is traceable for any distance across the county. Accordingly, the Beattie formation has been ignored in subdividing the rocks of the Council Grove group for this report. The Cottonwood limestone was mapped as a key bed, and the trace of its outcrop is shown on Plate 1. The upper members of the Beattie formation are not mappable and are here included in the basal portion of the Garrison shale.

The Cottonwood limestone can be traced with fair assurance as far south as Black Bear Creek in T. 22 N. and tentatively as far as the south county line.

Thickness and character. Moore (1951, p. 47) described the Cottonwood limestone of Kansas as light-buff massive limestone, about 6 feet thick, containing abundant fusulinids in the upper part. In Osage County, Oklahoma, the Cottonwood is a light-gray partly shaly limestone containing fusulinids. It thins southward from 2.5 feet in the Foraker area to 1.3 feet in the Burbank-Shidler area, though Fisher (1956, Pl. II) assigned an average thickness of 6.5 feet to the Cottonwood in the Belford area. The maximum development in Pawnee County occurs along the Arkansas River, where the Cottonwood occurs as a single resistant bed of light greenish-gray limestone 2.2 feet thick (Fig. 30). Careful examination of the limestone reveals a sparse macrofauna, probably molluscan, but no fusulinids. Examination of thin-sections showed the rock to be spergenite or microcoquina composed of minute shell fragments and calcareous pellets, probably algal. A sample of the Cottonwood collected just south of the Arkansas River had an insoluble residue of 10.7 percent, the arenaceous component consisting largely of the silicified tests of micro-organisms (Appendix A).

Figure 30. Cottonwood limestone exposure in field north of road along south line of SE ¼ sec. 2, T. 22 N., R. 4 E.

The Cottonwood thins southward in Pawnee County. In the SW ¼ sec. 22, T. 22 N., R. 4 E., the southernmost outcrop in which Cottonwood can definitely be recognized, 1.2 feet of limestone is exposed. It is light gray, dense, finely crystalline, and slightly silty. Here again cilicified microfossils occur in the insoluble component (Appendix A). Southward from this point the Cottonwood is concealed beneath colluvium, alluvium, and terrace deposits. There are no recognizable exposures of Cottonwood south of Black Bear Creek. The outcrop pattern shown on Plate 1 is the trace of a sandstone escarpment beneath which occurs a thin calcareous mudstone conglomerate. The conglomerate occurs in the approximate stratigraphic position of the Cottonwood farther north. On the strength of its stratigraphic position and calcareous nature the conglomerate has been tentatively equated to the Cottonwood; but owing to the uncertainty of this correlation, the trace of the Cottonwood shown south of Black Bear Creek may be only a rough approximation.

Representative sections of the Cottonwood limestone may be found in Appendix D, sections 8, 9, and 10.

Paleontology. No identifiable fossils were seen in the Cottonwood limestone although a few macro-organisms are visible on the weathered surface of the limestone. Microscopic examination of the rock reveals that the matrix is composed largely of minute shell fragments and small rounded calcareous pellets, which may be of algal origin.

Garrison shale

Definition and distribution. As used in this report the Garrison shale is the top unit of the Council Grove group. It includes the beds upward from the top of the Cottonwood limestone to the base of the Wreford limestone. This definition was originally proposed by Prosser (1902, p. 712), who applied the name to exposures at the town of Garrison, Pottawatomie County, Kansas. The name was discarded by Moore (1936, p. 251), who raised the various members of the Garrison to formation rank within the Council Grove group.

The formations constituting the Garrison section in Kansas, Nebraska, and northern Oklahoma cannot be identified in Pawnee County, and in this report the general term Garrison shale has been retained. South of T. 22 N. the disappearance of the Wreford limestone from the section precludes accurate separation of the Garrison sandstones and shales from those of the overlying Matfield. The Council Grove-Chase contact shown in T. 21 N. on Plate 1 is based principally on topography and is only an estimate of the true position of the contact.

Thickness and character. In Kansas and Nebraska the rocks equivalent to the Garrison consist of gray and olive shales and gray locally cherty limestones. Thickness of the sequence is about 135 feet (Moore, 1951, fig. 16). In northern Oklahoma Hruby (1955, p. 17) and Taylor (1953, Pl. III) reported about 130 feet of red and gray shales, fossiliferous gray limestones, and lenticular sandstones between the Cottonwood and Wreford. Most of the Kansas units can be identified in northern Oklahoma, but only the Crouse limestone, which occurs about midway in the sequence, has any persistent topographic expression. Fisher (1956, p. 42) tentatively identified the Crouse in southwestern Osage County.

The rocks of the Garrison interval in Pawnee County consist of a poorly exposed heterogeneous sequence of red shales and red to tan lenticular sandstones. The poor exposures and the lack of recognizable beds within the sequence prevent complete and detailed measurement of the section on the surface, but the corresponding interval in the subsurface, measured on electric logs of holes slightly to the west of the outcrop, is about 140 feet thick (Plate 4). This compares to 125 feet measured by Fisher (1956, p. 46) just across the Arkansas River in southern Osage County.

Two or more limestone zones are present in the lower part of the Garrison just south of the Arkansas River. One of these, previously discussed on page 101, occurs about 30 feet above the Cottonwood limestone (Appendix D, section 9) and is probably the southern extremity of the Morrill limestone member of the Beattie limestone formation. It is the only unit within the Garrison section that can be correlated, even on a tentative basis, with the Kansas section. It is light gray and finely crystalline and contains an abundance of small round algal pellets, which together with the indistinct outlines of small shells, stand out in relief on the weathered surface. Lentils of conglomeratic limestone containing rounded pebbles up to 2 inches in length occur in the basal cross-bedded portion of a thick sandstone about 70 feet above the Cottonwood in sec. 15, T. 23 N., R. 4 E. (Appendix D, section 8). Other limestones of uncertain position in the Garrison section occur in the northern part of the outcrop belt. These limestones all pinch out southward, and none is present in the Garrison section south of T. 23 N.

The amount and average grain size of sandstone in the Garrison increase southward. In T. 21 N. many of the sandstones in the Garrison-Matfield sequence are medium- to coarse-grained arkoses or subgraywackes. Most are friable and generally nonresistant, forming a gently rolling surface covered in the most part by sandy soils.

Paleontology. A fossiliferous algal limestone occurs 30 feet above the base of the Garrison section in the northern part of the county, but no identifiable fossils were seen in this bed. Other portions of the Garrison section are apparently non-fossiliferous.

Chase Group

The Chase group is the upper division of the Wolfcamp series in the western Mid-Continent area. As presently defined, the group includes those beds from the base of the Wreford limestone upward to the top of the Nolans (Herington) limestone. In southern Kansas and northern Oklahoma the Chase group consists of over 340 feet of red and green shales and persistent chert-bearing limestones, erosion of which has formed the major portion of the Flint Hills. Southward the limestones thin and their chert content diminishes abruptly.

In T. 23 N. the Chase group is composed primarily of sandstones and red shales. Only thin remnants of four of the ten limestones in the Kansas section are present—the Wreford, Fort Riley, Winfield, and Herington. These limestones have a high sand content but contain no chert (Appendix A). The Winfield limestone is the youngest member of the Chase group in Pawnee County, where about 300 feet of the section is exposed (Fig. 31). The subdivisions of the group used in this report are shown in Table 3, Page 73. South of Pawnee County the rocks of the Chase group grade laterally into the Asher formation of central Oklahoma.

Wreford limestone

Definition and distribution. Hay (1893, p. 104) applied the name Wreford to a cherty limestone 25 feet thick at the town of Wreford, Geary County, Kansas. Prosser (1902, p. 713) defined the limestone as the basal formation of the Chase stage, underlying the Matfield shales and overlying the Garrison formation. Prosser's original definition is still valid and is the one used in this report. In Kansas the Wreford has been divided into three members (Moore, 1951, p. 45), but these divisions have not been identified in Oklahoma.

The Wreford is recognized from southeastern Nebraska across Kansas into north-central Oklahoma, where it can be traced as far south as T. 20 N. In and south of T. 20 N. the Wreford disappears and there is no detectable horizon on which the Garrison and Matfield shales—or the Council Grove and Chase groups—may be separated.

Thickness and character. Moore (1951, p. 45) described the Wreford limestone of Kansas as two partly cherty limestone members separated by gray shale. Thickness of the sequence ranges from 30 to 40 feet. In northern Oklahoma the Wreford is essentially all limestone. The limestone is partly cherty and thins southward from 31 feet in T. 29 N., R. 5 E. (Taylor, 1953, p. 74) to 12 feet in T. 26 N., R. 4 E. (Noll, 1955, p. 39). Noll described the Wreford in southern Kay County as a maroon to tan sandy algal limestone.

Billings (1956, p. 13) described the Wreford in northeastern Noble County as " . . . two algal limestone ledges separated by shale . . . the silt content increases southward . . . . the lower ledge is only a few inches thick." Billings also noted that algal bodies, probably of the genus *Osagia,* replaced by limonite, are common in the limestone.

In northwestern Pawnee County about midway between the Cottonwood and Fort Riley limestones there is a limestone zone that can be traced as far south as sec. 1, T. 21 N., R. 3 E. On the strength of its stratigraphic position and algal content this zone has been correlated with the Wreford limestone of northern Oklahoma and Kansas. Abrupt facies changes appear to be characteristic of the zone, although owing to poor exposures in this part of the section, some of the facies variation may be more apparent than real, and the possibility exists that two or more beds have been mapped as one.

The Wreford is best developed in the northern part of T. 22 N. and the southern part of T. 23 N., R. 4 E., where it forms a prominent escarpment both north and south of Oklahoma Highway 15. A maximum of 7 feet has been assigned to the Wreford

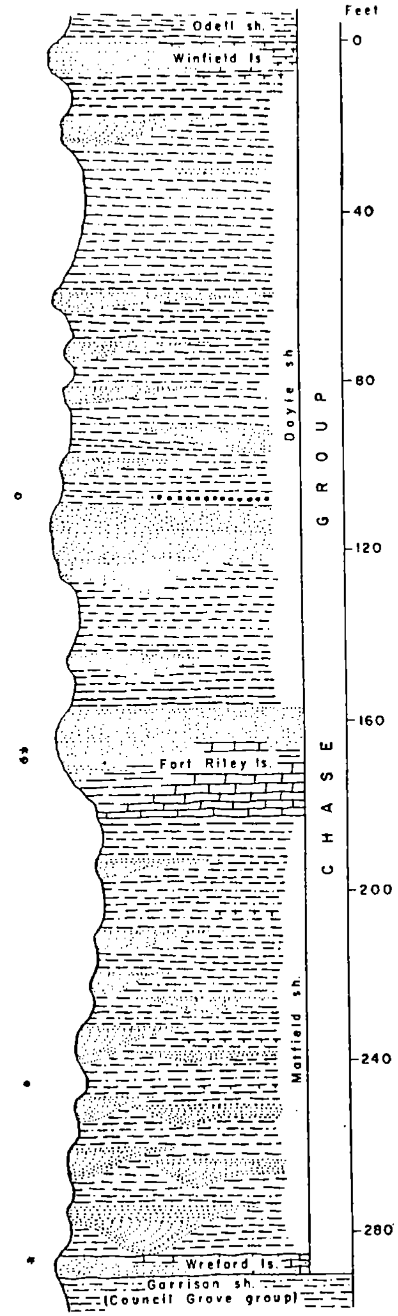

Figure 31. Generalized columnar section of the rocks of the Chase group (upper Wolfcamp) in Pawnee County.

in this area (Appendix D, section 6). The lower 2 feet consists of thinly interbedded fossiliferous limestone and red shale. The limestone beds are a coquinite composed of myalinid, pectenoid, and productid (*Linoproductus*) shells. The upper 5 feet consists principally of highly leached calcareous sandstone and sandy limestone. Old exposures are completely leached and appear to be sandstone. They are stained dark red by ferric oxide from adjacent shales and have a pitted surface and well-displayed bedding (Fig. 32). Fisher (1956, Fig. 11) depicts a similarly pitted surface

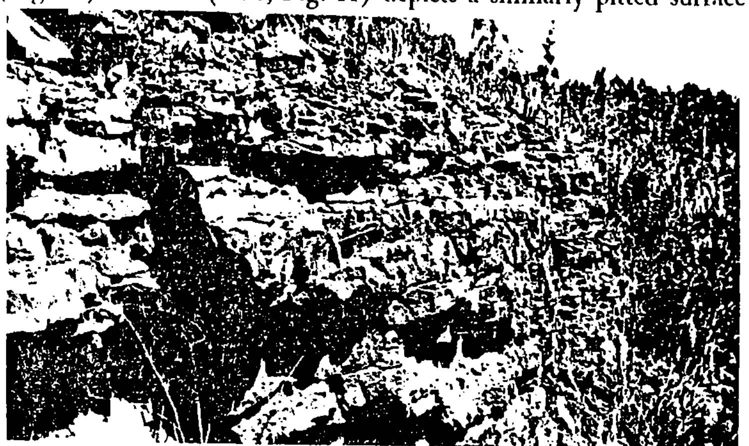

Figure 32. Scarp-forming sandy phase of the Wreford limestone exposed along the north side of Oklahoma Highway 15 in SW ¼ sec. 3, T. 22 N., R. 4 E. The pitted surface, leached appearance, and distinct bedding of this exposure are typical of the easternmost outcrops of Wreford in Pawnee County. (Sun glassses for scale.)

in the Wreford exposures of southern Osage County. Close examination discloses that each pit contains a sandstone core, possibly the internal mold of a bivalve. These "steinkerns" and the highly porous nature of the sandstone suggest that prior to leaching the rock may have been a fossiliferous calcareous sandstone. Fresh exposures exhibit less leaching and are white to gray. Lenticular masses of fossiliferous sandy gray limestone, locally vuggy and highly recrystallized, occur at places in the top part of the sandstone.

Where the Wreford is exposed along the Arkansas River in the east part of R. 3 E., it is a red shaly limestone about 0.5 feet thick, containing a sparse molluscan fauna and small limonitic pellets which are probably altered algal material. Generally the

limestone is bounded above and below by red shale, but locally a lenticular bed of red deltaic sandstone up to 20 feet thick occurs immediately above the limestone. The Wreford is composed of similar red limestone in exposures along the road on the north line of secs. 31 and 32, T. 23 N., R. 4 E., but between these two exposures, in the SE ¼ sec. 25, T. 23 N., R. 3 E., the Wreford is represented by about one foot of dense light-gray spergenite completely different from the nearby red algal limestone. A similar change from the gray to the red facies occurs within one mile along the road on the west line of sec. 18, T. 22 N., R. 4 E. Here there is evidence of southward gradation from gray to red, possibly as the result of weathering together with southward thinning or pinchout. Two insoluble residues obtained from the non-red facies of the Wreford indicate a marked southward increase of sand and silt (Appendix A).

The Wreford exposure along the road in the SW corner sec. 18 is the southernmost exposure of the limestone in Pawnee County. It consists of a few inches of nodular dark-red limestone encased in red shale. A few crinoid fragments occur in the limestone, marking it as marine. South of this point the Wreford was mapped as far as Black Bear Creek on the basis of the escarpment of an overlying sandstone. A limestone thought to be Wreford is exposed beneath this sandstone in a small outlier north of Black Bear Creek in sec. 1, T. 21 N., R. 3 E., Noble County. This outcrop in Noble County is the southernmost exposure of Wreford known (Billings, 1956, p. 15).

An attempt was made to trace the sandstone overlying the Wreford southward across T. 21 N., R. 4 E., but it was not possible to distinguish this sandstone from adjacent sandstones; hence the Council Grove-Chase contact shown on Plate 1 is an approximation drawn primarily on the basis of topography.

Paleontology. Few identifiable fossils were seen in the Wreford section. The gray facies contains local concentrations of myalinids and pectinoids, and the red facies is characterized by limonitic algal pellets, (*Osagia?*), crinoid debris, and sundry small mollusk shells. *Linoproductus* sp. was collected from both facies.

Matfield shale

Definition and distribution. The Matfield shale of this report extends upward from the top of the Wreford limestone to the base of the Fort Riley limestone. The Matfield was originally defined by Prosser (1902, p. 714) as 60 to 70 feet of shale and thin limestones overlying the Wreford limestone and underlying the Florence flint. This section has subsequently been divided into the Blue Springs and Wymore shale members separated by the Kinney limestone member (Condra and Upp, 1931, p. 37, and Moore, 1936, p. 12). These members were identified as far south as T. 27 N. in Kay County, Oklahoma (Noll, 1955, p. 43). South of this point the Kinney limestone is absent and the shale members cannot be differentiated. The Florence flint member of the Barneston formation, which defines the top of the Matfield shale farther north, does not occur in Pawnee County. As used in this report the Matfield is an undifferentiated section of red sandstones and shales and probably includes a thin section in the upper part that is equivalent to the lower part of the Barneston formation of Kansas.

The Matfield shale occurs in southeastern Nebraska, Kansas, and northern Oklahoma. In Pawnee County the Matfield cannot be distinguished from the underlying Garrison shale south of T. 22 N.

Thickness and character. The Matfield shale of Kansas consists of two varicolored shale units separated by a limestone; total thickness ranges from 50 to 80 feet (Moore, 1951, p. 45). A thickness of 96 feet was reported in northern Kay County, Oklahoma, (Hruby, 1955, p. 26) and about 62 feet in southern Kay County (Noll, 1955, p. 42-45), where the sequence includes 23 feet of dark-red shales below and 35 feet of tan clay shale above separated by 4 feet of sandy algal limestone.

In Pawnee County the best exposures of the Matfield section are in the bluffs along the Arkansas River (Appendix D, section 4). Here the unit consists of about 100 feet of red shales, thick lenticular red sandstones, and a few thin nodular and conglomeratic limestones. The limestones pinch out abruptly southward and the percentage of sandstone in the section increases.

The red shale in the upper part of the Matfield grades upward to gray shale about 8 feet below the Fort Riley limestone. This gray shale may be equivalent to the Florence flint of the section to the north, but for convenience in mapping and because it is not readily separable from the underlying red shales, it has been included in the Matfield shale section.

The lenticularity of the sandstones in the Matfield is well illustrated in the SW ¼ sec. 24, T. 23 N., R. 3 E., where at one place the Wreford is overlain by a resistant massive to cross-bedded sandstone more than 20 feet thick. Less than 50 feet to the west the Wreford forms a small bench on the slope and there is no evidence whatsoever of the overlying sandstone.

Paleontology. No fossils were seen in the Matfield shale of Pawnee County.

Fort Riley limestone

Definition and distribution. The name Fort Riley was given by Swallow (1866, p. 14) to a prominent limestone exposed near Fort Riley in Geary County, Kansas. Subsequent to several redefinitions, the Fort Riley limetsone is currently considered to be the top member of the Barneston formation (Condra and Upp, 1931, p. 41). It is underlain in turn by the Oketo shale member, which is commonly absent, and the Florence limestone (Florence flint) member. These subdivisions of the Barneston formation are recognized in Kansas and southeastern Nebraska and have been traced southward across Kay County, Oklahoma, by Hruby (1955) and Noll (1955). Between Kay and Pawnee Counties the cherty Florence limestone member of the formation disappears and only a non-cherty limestone, here considered to be the Fort Riley member, extends southward as far as Pawnee County. In southwestern Osage County Fisher (1956, p. 51) correlated this non-cherty limestone with the entire Barneston formation.

Exposures of Fort Riley limestone in Pawnee County occur only in R. 3 E. The limestone can be traced southward across the county to a point about 1.5 miles north of the Noble County line. From this point to the county line no exposure of the limestone was found. The trace of the Fort Riley outcrop shown on Plate I follows the sandstone escarpment under which most Fort

Riley limestone exposures in the northern part of the county occur.

The Geologic Map of Oklahoma (Miser, 1926, 1954) shows a large outlier of Fort Riley extending into the southwest corner of T. 21 N., R. 4 E. The existence of this outlier was not confirmed by the field work for this report, although more refined mapping may prove it to be present. Miser (1954) shows the Fort Riley continuing southward to the Cimarron River in T. 17 N., but Billings (1956, p. 19) reported only one isolated exposure of Fort Riley in southern Noble County (T. 20 N.). It seems unlikely that the Fort Riley limestone extends much farther south than this exposure.

Thickness and character. Moore (1951, p. 44) described the Fort Riley limestone of Kansas as 35 to 40 feet of light-gray and tan limestone and thin interbedded gray shales. Near the base is a massive bed of resistant algal limestone. In northern Kay County, Oklahoma, the Fort Riley consists of approximately 31 feet of soft light-gray to buff limestone with a massive algal bed more than 10 feet thick occurring locally in the lower part (Hruby, 1955, p. 35). According to Noll (1955, p. 48) the Fort Riley in southern Kay County is typically massive light- to dark-tan fossiliferous limestone containing many algal beds in which the algal pellets have been replaced by limonite. Billings described the Fort Riley limestone of Noble County as a fossiliferous algal limestone, commonly jointed, averaging 3 feet in thickness (Billings, 1956, p. 19).

In Pawnee County abrupt changes in facies, thickness, and/or resistance of the Fort Riley beds effectively prevent compilation of a complete Fort Riley section. Maximum development of the limestone facies occurs around the Watchorn oil field in the southern part of T. 23 N., R. 3 E. In describing these exposures, Carpenter (1927, p. 1091) said, ". . . This formation has lost the calcareous nature it possesses in Kansas and northern Oklahoma, and consists mostly of sand, with a limestone bed about 10 feet thick at its base. . ." Carpenter assigned 25 feet of sandstone above the limestone to the Fort Riley section.

An 18.5-foot section of Fort Riley composed of interbedded limestone and gray shale is exposed at the NE corner of sec. 5, T. 22 N., R. 3 E. (Appendix D, section 5). The lower 15 feet

consists of well-bedded gray-brown dense silty limestone in beds up to one foot thick separated by gray shale. The limestone beds increase in thickness and number in the upper part of the section. They contain a sparse molluscan fauna. Above the bedded limestone is a 3.5-foot calcarenite composed principally of small algal pellets, most of which have altered to limonite. This material is partly disintegrated, forming a yellow-brown algal-pellet sand in which occurs a sparse molluscan fauna. Red shale and sandstone, probably the lower part of the Doyle shale, occurs above the algal zone.

Figure 33. Fort Riley limestone, massive algal member, looking west from the SE corner sec. 20, T. 23 N., R. 3 E. Limestone blocks are about 4 feet thick.

In the NE ¼ sec. 29, T. 23 N., R. 3 E., the algal bed is a dense massive unit about 3 feet thick which weathers dark brown. It is vertically fractured and weathers into large blocks which litter the slope below the outcrop and conceal the well-bedded portion of the limestone (Fig. 33). Immediately above the algal bed at this location is a 2-foot section of thin-bedded limestone containing an abundant myalinid fauna.

In its easternmost exposures along Oklahoma Highway 15 the Fort Riley is represented by two 6-inch beds of limestone, both of which weather black, separated by a thin bed of gray shale. The lower limestone is dense, finely crystalline, and light gray on fresh break. The upper bed is gray-brown on fresh break and is composed largely of molluscan shells and fragments.

These limestones and a thin overlying sandstone do not appear to be sufficiently resistant to account for the abrupt topographic break characteristic of the Fort Riley escarpment at this locality, and it is not impossible that a lower limestone section is concealed by soil and slope wash.

Except for these three exposures in which limestone predominates, the Fort Riley escarpment is formed by a sandstone. Fragments of algal or molluscan limestone can generally be found in the float below the sandstone escarpment, and although the sandstone and limestone were not seen in place together, indications are that the Fort Riley consists of limestone overlain by a resistant sandstone.

The sandstone thickens to 14 feet along the south bank of Greasy Creek in secs. 21 and 22, T. 32 N., R. 3 E., where it forms a steep north-facing bluff. The upper part of the sandstone is highly calcareous and secondary deposits of crystalline calcite up to one inch thick occur in vertical fractures. Impressions of pectinoids are common. Algal limestone float was found beneath the escarpment at this location.

It is possible that the algal limestone in the Pawnee County section correlates with the algal limestone near the base of the Fort Riley in northern Osage County and southern Kansas and that the overlying sandstone in Pawnee County grades into the limestones which constitute the upper part of the Fort Riley section farther north.

The limestones of the Fort Riley contain between 15 and 20 percent insoluble material, which consists largely of fine-grained quartz sand (Appendix A). The sand content shows no notable increase either northward or southward. Detailed measurements of the Fort Riley are listed in Appendix D, sections 3, 4, and 5.

Paleontology. Although the Fort Riley is locally fossiliferous, fossils are difficult to collect or identify. Molluscan and algal forms predominate.

The following faunule was identified from the weathered algal limestone which caps the Fort Riley section in the SE corner sec. 33, T. 23 N., R. 3 E., and the NW corner sec. 28, T. 23 N., R. 3 E:

Brachiopoda
- Derbyia sp.
- Orbiculoidea missouriensis (Shumard)

Bryozoa
- Bascomella fusiformis Condra and Elias

Pelecypoda
- Aviculopecten sp.
- Myalina sp.

Doyle shale

Definition and distribution. The Doyle shale overlies the Fort Riley limestone and underlies the Winfield limestone. The name Doyle was first applied by Prosser (1902, p. 715) to exposures along Doyle Creek in Marion County, Kansas. Condra and Upp (1931, p. 43) divided the Doyle into three members, the Gage shale above, underlain in turn by the Towanda limestone and the Holmesville shale. The members of the Doyle formation are recognized in Kansas, southeastern Nebraska, and northern Oklahoma, where Hruby (1955) and Noll (1955) mapped them across Kay County. Fisher (1956, p. 55) also identified these subdivisions in southwestern Osage County, but the members of the Doyle cannot be differentiated in Pawnee County.

Doyle exposures occur in westernmost Pawnee County and extend southward into Noble County. The southern extent of the Doyle has not been determined.

Thickness and character. In Kansas the Doyle shale consists of two shale members separated by a limestone and has an aggregate thickness of about 70 feet (Moore, 1951, p. 44). Hruby (1955) and Noll (1955) reported 103 and 118 feet of Doyle in northern and southern Kay County, respectively. The Kay County section consists primarily of red shale and thin beds of limestone. Fisher (1956, p. 55) assigned a thickness of 125 to 135 feet to the Doyle in southwestern Osage County.

In Pawnee County the Doyle is represented by thick red interbedded sandstones and shales. The section is poorly exposed so that a complete measurement of the surface section was not obtained. Measurements from electric logs of bore holes just west of the outcrop show a thickness of about 150 feet. Carpenter (1927, p. 1091) described the Doyle section west of the Watchorn (Morrison) oil field as 160 feet of red sand and shale.

The top and bottom of the Doyle are characterized by beds of green shale ranging from a few inches to 5 feet thick. The green color is probably secondary, resulting from reduction of the ferric iron of the red sediments. The Doyle sandstones are highly cross bedded to massive and at places appear to be deposited on a channelled surface (Appendix D, section 3, bed 6). The sandstones are generally coarser in the southern part of the county.

In the NW ¼ sec. 28 and the SE ¼ sec. 17, T. 23 N., R. 3 E., a porous red conglomerate composed of rounded limestone and sandstone pebbles up to 2 inches in length occurs about 50 feet above the Fort Riley.

Scattered exposures of a dark-brown fossiliferous limestone occur 20 to 30 feet below the Winfield in the northwest part of T. 22 N., R. 3 E. This limestone is best exposed along the south side of Oklahoma Highway 15 in the NW ¼ sec. 8. It generally occurs as float in pieces ranging up to 0.7 feet thick, capping slopes and small hills east of the Winfield escarpment. The limestone contains abundant mollusks which are seen only in cross section on the weathered surface.

Paleontology. Fossils were seen only in the upper part of the Doyle section in two thin limestones. These fossils are poorly preserved, permitting only general identification. The brown limestone 20 to 30 feet below the Winfield contains an abundant molluscan fauna including myalinids. Small high-spired gastropods and a few bellerophontids occur in a one-inch bed of nodular limestone 2 feet below the Winfield (Appendix D, section 1, bed 3). The nodular limestone is enclosed by variegated shales, suggesting a fresh or brackish water environment.

Winfield limestone

Definition and distribution. The Winfield limestone is the uppermost Permian unit exposed in Pawnee County. The name Winfield was first applied by Prosser (1897, pp. 64-66) to 13 feet of concretionary limestone exposed near the town of Winfield, Cowley County, Kansas. Condra and Upp (1931, p. 49) divided the Winfield of southeastern Nebraska into three members, which Moore (1936a, p. 12) extended into northern Kansas. In southern Kansas and northern Oklahoma these members have not been identified and the Winfield is there considered to be a single unit.

The southern extent of the Winfield is not known. Exposures of the limestone extend across Kay County as far south as T. 26 N. From this point southward to the Kay-Noble County line the trace of the Winfield outcrop is based on topography (Noll, 1955, p. 55). The Winfield limestone was mapped across northern Noble and southwestern Osage Counties by Billings (1956) and Fisher (1956), respectively. The Winfield extends from Noble County eastward into Pawnee County in T. 22 N., R. 3 E. It appears to grade into sandstone southward, but Billings (idem, p. 27) reported 6 inches of dolomite 7 feet below the lower sandstone in the Enterprise (Odell) shale of southern Noble County. Billings identified this dolomite as Winfield. It disappears south of Black Bear Creek in sec. 1, T. 21 N., R. 2 E.

Figure 34. Well-bedded scarp-forming calcareous sandstone exposed along the south of Oklahoma Highway 18 in the NW ¼ sec. 7 T. 22 N., R. 3 E.: thought to be the Pawnee County correlative of the Winfield limestone of northern Oklahoma and Kansas.

Thickness and character. In western Pawnee County the red sandstones and shales of the Doyle are capped by about 7 feet of thin-bedded sandstone, which contains thin lenticular beds of light-colored non-fossiliferous calcareous sandstone and sandy limestone (Appendix D, sections 1 and 2). This section has been correlated with and mapped as the Winfield limestone (Plate 1). It is best exposed along Oklahoma Highway 15 in secs. 6 and 7, T. 22 N., R. 3 E., where it forms an abrupt escarpment and several steep flat-topped outliers (Figs. 34 and 35).

The Winfield limestone of southern Kansas and northern Oklahoma consists of 8 to 11 feet of massive organic limestone. Noll (1955, p. 55) noted that the limestone grades into shale southward across T. 26 N. and shows signs of dying out. Fisher (1956, p. 58) described the Winfield of southwestern Osage County as three algal limestones containing crinoid, brachiopod, and bryozoan fragments. Red shale and siltstone separate the limestones, forming an aggregate section 15 feet thick.

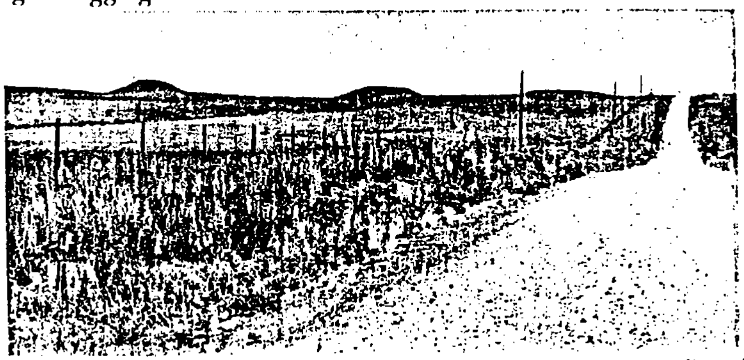

Figure 35. Outliers of Winfield limestone, looking north along east line of sec. 7, T. 22 N., R. 3 E.

Just west of Pawnee County in the SE ¼ sec. 1, T. 22 N., R. 2 E., Billings (1956, p. 27) described the Winfield as 7.5 feet of limestone directly beneath a 5-foot sandstone. The limestone is highly fossiliferous, containing gastropods and small algal pellets replaced by limonite. The escarpment formed by this sequence is a continuation of the one in T. 22 N., R. 3 E., along Oklahoma Highway 15. The 7.5-foot limestone in Noble County probably thins and grades into the lower part of the 7-foot calcareous sandstone in Pawnee County, though it may pinch out almost completely into the one-inch fossiliferous nodular limestone just below the sandstone (Appendix D, section 1, portion of bed 3).

A sample taken from one of the more calcareous beds of the Winfield in the exposures along Oklahoma Highway 15 yielded an insoluble residue of 24.1 percent, of which 19.1 percent consisted of fine-grained quartz sand and silicified microfossils.

Southward from Oklahoma Highway 15 the Winfield escarpment diminishes abruptly and blends into the gently rolling topography of the Red Beds Plains. Two miles south of Highway 15 the escarpment is almost imperceptible, and the Winfield appears to have graded into a thick non-calcareous massive to cross-

bedded sandstone. The exposures of this sandstone across the southern part of the township are so indistinct that the trace of the outcrop shown on Plate I can be considered only an approximation.

The lithology of the Winfield of Pawnee County is nothing like that of the Winfield to the north, but the stratigraphic interval between the Fort Riley and Winfield is comparable to that farther north and the physical character of the Pawnee County Winfield is about what might be expected of the extremity of a limestone which is dying out laterally. The possibility exists, however, that the Pawnee County correlative of the Winfield is the brown fossiliferous limestone in the upper part of the Doyle section (discussed on p. 116), arther than the scarp-forming sandy limestone above it. The crystalline fossiliferous nature of the lower limestone is perhaps more suggestive of the widespread carbonate environment that characterized Winfield deposition to the north than is the non-fossiliferous highly sandy nature of the overlying zone. Exposures of the fossiliferous limestone are so scattered that the bed cannot be mapped, but its position in the stratigraphic sequence does not preclude its correlation with the Winfield.

Paleontology. No fossils were seen in the Winfield section of Pawnee County.

QUATERNARY SYSTEM

The Pleistocene and Recent deposits of Pawnee County are composed of modern flood plain and older terrace materials. Flood plain deposits consisting of gravel, sand, silt and clay occur along the Arkansas and Cimarron Rivers, and coarse sand is characteristic of the alluvium of Black Bear Creek. In both cases the coarse material has probably been derived from sources upstream from Pawnee County. Fine material is typical of the alluvium of the smaller streams, forming small patches of arable bottom-land. This material is primarily of local provenance.

Two distinct types of terrace material are present in Pawnee County—the red draped deposits associated with the Arkansas and Cimarron River drainage systems and the gray upland deposits of the Red Beds Plains in the western part of the county.

A broken strip of red terrace deposits, at places more than a mile wide, occurs along the Arkansas River from north of Ralston to Keystone. Red terrace deposits also occur in the drainage basins of some of the larger tributaries and are especially extensive near the confluence of the Arkansas and Cimarron Rivers. Much of the area around Skedee is covered by terrace material, which conceals the elsewhere prominent Brownville limestone for a distance of more than three miles (Plate 1). Locally a thick bed of fluvial gravel lies at the base of the terrace in this area, providing a shallow source of fresh water.

TABLE 4

GRAIN SIZE DISTRIBUTION OF QUATERNARY TERRACE MATERIAL*

Mesh (ASTM)	Size Range (mm)	Wentworth Size Class	Weight %	Cumulative Weight %
50	0.35 —0.30	m.g. sand	0.14	0.14
60	0.30 —0.25	m.g. sand	0.10	0.24
70	0.25 —0.21	f.g. sand	0.06	0.30
80	0.21 —0.177	f.g. sand	0.10	0.40
100	0.177—0.149	f.g. sand	0.30	0.70
120	0.149—0.125	f.g. sand	2.32	3.02
140	0.125—0.105	v.f.g. sand	4.28	7.30
170	0.105—0.088	v.f.g. sand	6.00	13.30
200	0.088—0.074	v.f.g. sand	7.00	20.30
230	0.074—0.062	v.f.g. sand	9.00	29.30
pan	<0.062	silt and clay	70.80	100.10

* Sieve analysis of sample collected along road on south line sec. 26, T. 20 N., R. 9 E.

The red terrace material consists of unstratified red silty clay, probably of eolian origin, with few if any coarse components (Table 4). Where cut by streams or roads, the outcrop is almost vertical and looks much like loess (Fig. 36). The deposits occur on the high bluffs along the Arkansas River as well as in the drainage channels south of these bluffs and appear to have been draped over a surface of considerable topographic relief. Apparent thicknesses of over 30 feet were noted at several places; but due to the effects of draping, these measurements may be excessive.

The occurrence of upland terrace deposits is restricted to three remnants, which cap divides in the gently rolling Red Beds Plains region west of Pawnee (Plate 1). Projection of the areal extent of these deposits onto the Pawnee topographic quadrangle sheet reveals that the surface of the remnant in R. 4 E. is 80 to 100

feet lower than that of the two remnants in R. 3 E. and suggests the former existence of one continuous surface, now sloping to the east. Rounded fluvial gravel was noted at the base of the upland terrace material at two places in R. 4 E.

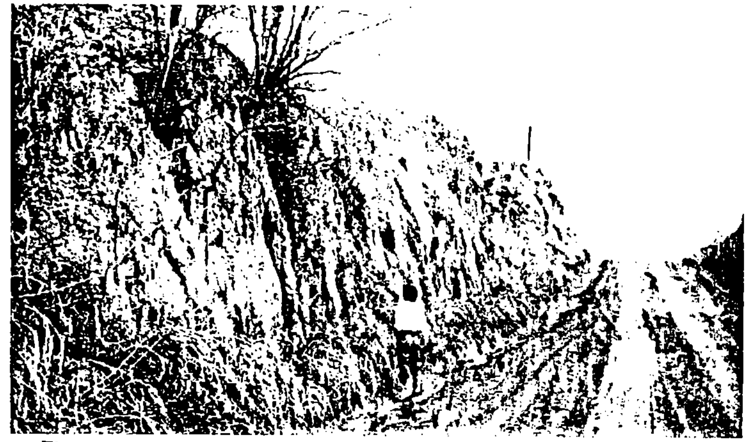

Figure 36. Exposure of Quaternary terrace material along road on south line sec. 26, T. 20 N., R. 9 E. Loess-like appearance of the outcrop is typical.

The upland deposits differ from the draped deposits in many respects. The upland deposits are buff to gray, do not form vertical exposures, and do not occur in lowland channels. Generally they are thinner and contain a higher percentage of sand than the draped deposits. These differences suggest separate origins for the two types of deposit, but since they nowhere occur in juxtaposition, it is difficult to ascertain their age relationship. The wider areal extent of the draped terrace and its occurrence in actively eroding drainage channels indicate a later origin than that of the upland terrace.

It is conceivable that the upland terrace deposits once occurred over a much wider area, forming the surface of a post-Permian peneplane. Rejuvenation and tilting of this surface, perhaps combined with an increase in precipitation, resulted in the dissection of the peneplane, destroying it completely in its eastern portion and establishing present topographic trends. The resulting topography was later modified by local deposits of wind-borne red silts and clays. Erosion of these younger deposits of eolian terrace material is currently in progress.

SUBSURFACE STRATIGRAPHY

General Statement

It is not the purpose of this report to describe in detail the stratigraphy of the subsurface rocks of Pawnee County, and the following account should be considered as a brief summary only. For those whose interest is more than general, references are cited from which more detailed knowledge may be acquired.

The sedimentary sequence in Pawnee County rests unconformably on an irregularly eroded west-sloping surface of Precambrian plutonic rocks, probably the Spavinaw granite or its equivalent. The sequence overlying the granite comprises rocks of Upper Cambrian, Lower and Middle Ordovician, Lower Mississippian, Middle and Upper Pennsylvanian, Lower Permian, and (locally) Quaternary age. Except for the Quaternary, the sequence is characterized by stable shelf deposits which were laid down in the tectonic province known as the Central Oklahoma platform. Thickness of the sequence ranges from about 3,000 feet in the eastern part of the county to about 5,000 feet in the western part. The degree and direction of dip of the beds is different for each system but is generally westward. The principal subdivisions and relative thicknesses of the rocks of each system are illustrated on the accompanying electric log cross-sections (Plates 3, 4, and 5).

Cambro-Ordovician

The oldest sediments in the Pawnee County section are those of the Arbuckle group. They are predominantly dolomites and are underlain locally by a thin basal sandstone. These beds were deposited in an encroaching late Cambrian-early Ordovician sea in which the highlands of the Precambrian surface became islands, some of which (in Osage County) persisted throughout Arbuckle time (Ireland, 1955, p. 496). Accordingly, the older members of the Arbuckle sequence occur only in the troughs between Precambrian highs, and the thickness of the Arbuckle is notably thinner over Precambrian highs than in Precambrian lows. Ireland (idem, Table II) reported a range of thickness from 63 feet to 785 feet for the Arbuckle in five Pawnee County basement tests. These relatively thin Arbuckle sections indicate that the Cambrian portion of the Arbuckle is probably absent in the county.

A complete section of Arbuckle is divisible into 10 members.

It is probable that only the three uppermost of these (the Jefferson City, Cotter, and Powell dolomites), all of Ordovician age, occur in Pawnee County. The Arbuckle section can also be zoned on the basis of insoluble residues (op. cit., p. 472), but generally the rocks of the group are treated as a single unit referred to simply as the Arbuckle group.

In Pawnee County the Arbuckle is oil productive only at Lauderdale (Table 6, p. 147), where production is from a leached zone at the erosional surface of the dolomite. This zone is known as the Turkey Mountain sand.

Ordovician

Lying unconformably on the rocks of the Arbuckle group is the shale-sandstone sequence which forms the Simpson group. In north-central Oklahoma the rocks of this group are divided, in ascending order, into the Burgen sandstone, Tyner shale, and "Wilcox" sand. Aggregate thickness of the group in Pawnee County is as much as 250 feet.

The "Wilcox" sand (the name of which is pre-empted by a lower Eocene sand in the Gulf Coast area) is one of the principal oil-producing reservoirs of Pawnee County as well as of the state as a whole. According to published data, the Simpson and Tucker sands as well as the "Wilcox" are productive in Pawnee County (see Table 6). It should be noted that the names Simpson and Tucker are thought to be synonymous with "Wilcox" (Branson, 1954). Because of doubtful correlation with the type "Wilcox", all production in the county from reservoirs in the Simpson group should properly be assigned to the Simpson undifferentiated.

Above the Simpson group in the west and southwest part of the county is the Viola limestone, which is nowhere more than 50 feet thick. This limestone produces oil from one well at Watchorn West (reported as Simpson in Table 6).

A few operators have reported thin remnants of Sylvan shale above the Viola in wells in the southwestern part of the county, but according to Tarr (1955, Fig. 1) the Sylvan in Pawnee County has been completely removed by erosion.

The Ordovician rocks discussed above are progressively truncated to the northeast by pre-Mississippian uplift and erosion; hence Sylvan and Viola beds are missing over all or most of

Pawnee County and the "Wilcox" is absent in a narrow strip along the northeast border of the county (Ireland, 1955, Fig. 1B). Tyner and Burgen beds are truncated in turn farther toward the northeast and are absent in northeastern Osage County, where rocks of Mississippian age lie directly on the truncated edges of the beds in the Arbuckle group.

Mississippian System

The lowermost Mississippian unit in Pawnee County is the widespread black shale deposit of Kinderhook age known in Oklahoma as the Woodford (Chattanooga) shale. The Woodford is commonly less than 30 feet thick and is present over the entire county. A basal sand, the Misener, occurs locally beneath the Woodford. This sand is equivalent to the Sylamore sandstone of the surface section to the east.

Above the Woodford is a thick limestone section known by subsurface geologists as the Mississippi lime. Pre-Desmoinesian erosion has removed all but the Osage portion of the limestone in Pawnee County, although farther to the south in Creek County the upper part of the limestone is of Meramec age (L. Jordan, 1955, personal communication). The Mississippi lime of Pawnee County is thought to correlate with the cherty limestones of the Keokuk and Reeds Spring formations of the surface section in northeastern Oklahoma. Its thickness generally ranges between 200 and 300 feet, though locally it thins to about 100 feet.

A detrital section consisting primarily of weathered chert occurs at places on the eroded surface of the limestone. This deposit is known as the Mississippi chat.

The Misener sand and the Mississippi lime are both oil productive in Pawnee County. Although no production has been reported from the chat, it is productive elsewhere in Oklahoma and should not be overlooked as a possible oil reservoir.

Pennsylvanian System

Rocks of the Des Moines, Missouri, and Virgil series are represented in the subsurface section of Pawnee County. Their aggregate thickness ranges from 2,200 feet in R. 10 E., where the top of the section has been truncated by post-Permian erosion, to 3,400 feet in R. 5 E., where the section is thickest and most complete. Subdivision and key beds of this section are shown on

Plates 2, 3, and 4. Principal producing zones are listed on Table 6 (p. 147).

Des Moines Series

The eroded surface of the Mississippi lime is onlapped from the southeast by sedimentary deposits of Des Moines or Middle Pennsylvanian age. A basal Pennsylvanian sand, the Burgess, is developed locally immediately above the pre-Desmoinesian unconformity. The lowermost Des Moines unit in Pawnee County is the Savanna formation, which is overlapped to the northwest by the Boggy formation, the oldest Desmoinesian unit that extends completely across the county. The Bartlesville sand, which occurs at the base of the Boggy, is well developed in the southeast part of the county, pinches out to the northwest concurrent with the onlap in the same direction, and is developed only locally in the northwest part of the county.

The Des Moines section consists predominantly of marine shale interbedded with thin limestones and lenticular sandstones. Its thickness decreases abruptly westward from approximately 1,050 feet in R. 10 E. to between 550 and 600 feet in and west of R. 5 E. More than 300 feet of this thinning can be attributed to the loss of section by onlap, as discussed above, and the remainder is accounted for by pre-Missouri truncation of the Des Moines section in the west and central part of the county. The pre-Missouri unconformity is evident on Plate 2, where 180 feet of section is truncated westward across the southern part of the county. Plate 3 suggests northward onlap of this erosional surface by Missouri sediments, but Plate 4 shows no evidence of either truncation or onlap at the Des Moines-Missouri contact.

From the standpoint of oil production, the Des Moines series is the most prolific stratigraphic unit in Pawnee County. Oil is produced from 11 separate zones (Table 6). Of these, the Bartlesville and Skinner sands, together with the "Wilcox" (Simpson) zone of the Ordovician system, account for a majority of the oil produced in the county.

Missouri Series

Missourian beds in Pawnee County range upward from the basal Seminole sandstone to the deltaic sands and non-marine shales of the Tallant formation. The thickness of a complete Missourian section is about 1,700 feet. The section is sandier and contains more non-marine beds, particularly in the upper part, than the underlying Des Moines section.

The base of the Missourian series is unconformable. Basal Missouri beds apparently onlap the truncated Des Moines section toward the north (see discussion above). An unconformity within the Missouri series is suggested by the marked thinning of the section between the Coffeyville and Chanute formations toward the north and west. The thinning is evident on Plates 2, 3, and 4. Electric log correlation in this section is uncertain in Pawnee County and does not permit accurate determination of the stratigraphic position of the unconformtiy, but it may correspond to the one reported by Lukert (1949, p. 149) separating the Skiatook and Ochelata groups. A second unconformity within the Missouri section is indicated in the lower part of the Wann formation, particularly on Plate 2, which shows almost complete truncation of the lower part of the Wann in easternmost Pawnee County. This unconformity appears to die out westward, and in the central and western portions of the county the Wann section appears to be complete. Because of the narrow north-south dimension of eastern Pawnee County, where the effect of the unconformity is the greatest, further study of the lateral extent of this truncation in Creek and Osage Counties will be necessary before the stratigraphic importance of the hiatus becomes evident. If such a study substantiates the presence of the unconformity, the subdivision of this portion of the Missouri series should be revised.

The lower Wann unconformity is the highest, stratigraphically, for which substantiating evidence was noted in either the surface or subsurface sections. Neither the erosional break reported by Lukert (1949, p. 145) at the base of the Tonkawa (Bigheart) sand nor the break reported by Oakes (1952, p. 93) at the Missouri-Virgil boundary is evident in Pawnee County.

Missouri units which are productive of oil or gas in Pawnee County include the Cleveland, Layton, and Tonkawa sands (Table 6). The names Cleveland and Layton were first applied to sands in the Cleveland field. These sands are productive at places all across Pawnee County. The Tonkawa (Bigheart) sand crops out in the eastern part of the county and is productive only in western Pawnee County, where it produces gas in the Watchorn North field.

Virgil Series

The stratigraphy of the Virgil series in Pawnee County is discussed in the chapter on surface stratigraphy. The electric log cross-sections show no evidence of unconformity at the base, at the top, or within the Virgil section.

Several sands in the Virgil section are oil productive in Noble County, downdip and to the west of Pawnee County (Page , 1955, p. 7), but only one Virgil sand has been reported productive in Pawnee County. This sand, the Hoover, is equivalent to one or both of the middle Elgin sandstones of the surface section. It produces gas in the Watchorn East field in T. 23 N., R. 3 E.

Permian

Wolfcamp Series

Study of the electric log cross-sections confirmed the conclusion drawn from field work that the Wolfcamp beds are an essentially uninterrupted continuation of Pennsylvanian sedimentation. Unconformities, if present, are not recognizable.

Page (1955, p. 5) reported oil production from several Wolfcamp sands to the west in Noble County, but no Wolfcamp production is known in Pawnee County. The same reservoir beds occur in both counties, but they are probably too close to the outcrop to be productive in Pawnee County.

STRUCTURE

Surface Structure

The principal structural feature of the surface rocks of Pawnee County is their gentle homoclinal dip toward the west. The county forms a part of the Prairie Plains homocline, a regional post-Permian structure in the Pennsylvanian and Permian beds west of the Ozark dome. Truncated edges of sedimentary units are exposed in long parallel belts extending northward without interruption from south-central Oklahoma into southeastern Nebraska. The dip of the homocline in north-central Oklahoma is approximately due west and ranges between 30 and 65 feet per mile. It is interrupted locally by north-trending belts of en echelon faults and by gentle "Plains-type" folds.

Faulting

A broad belt of en echelon faulting extends northward from southern Seminole and Hughes Counties across Okfuskee, Creek, and eastern Pawnee Counties into northern Osage County (Miser, 1954). According to Moore and Landes (1936), this faulting does not extend into Kansas. As described by Fath (1920, p. 78)

> These faults . . . . are of the normal type and are noteworthy not only because of their approximate parallelism but also because of their grouping into belts or series which also have a parallel trend, although in a different direction. Most of the individual faults trend about N. 20°-45° W. and lie en echelon to one another in such a manner that the linear belts or series into which they are grouped trend from north to N. 25° E., or roughly at an angle of 45° with the trend of the foults. The faults are of minor magnitude both in vertical displacement and areal extent, the largest stratigraphic throw observed . . . . amounting to about 130 feet and the greatest length to about 3¼ miles. As a general rule they are straight, but some have slightly curved traces.

The en echelon faults have been discussed by many authorities, who have offered almost as many different explanations of their origin. The most probable explanations were first proposed by Fath (1920) and Sherril (1929). Fath recognized a close relationship betweeen the faulting and folding of the region. He attributed both to horizontal movement in the basement along pre-existing planes of weakness, suggesting that the overlying sediments reacted passively to the movement and, being less competent that the basement, absorbed much of the stress by folding. En echelon breaks were produced where tensional stresses within the sediments above the plane of movement exceeded the rupture point of the sediments.

Sherrill pointed out that the degree of west dip of the homocline increases southward and attributed the faulting to the torsion thus produced.

The youngest beds known to be affected by the faulting are of late Wolfcamp age, indicating that the faults were formed in post-Wolfcamp time, but the available data do not permit precise determination of the age of faulting. Melton (1930) related the faulting to stresses produced in a Permian spasm of Ouachita thrusting; Tanner (1956, p. 128), using Sherill's theory, postulated that the faulting took place during the Permian as a result of tor-

sion caused by Permian downwarp of the Anadarko basin in the southwest portion of the homocline; and Levorsen (1930, p. 313) correlated the faulting with post-Permian tilting of the Prairie Plains homocline. Subsurface data on the faults are generally lacking, but it is thought that they die out downward at a relatively shallow depth, probably above the Mississippian (Levorsen, 1930, p. 313).

In Pawnee County 17 probable faults were mapped, mostly on the basis of lineations visible on the aerial photographs. Many of the faults occur in a shale-sandstone sequence containing no distinguishable marker beds, and in these cases it is generally impossible to substantiate the presence of faulting by field relationships or to differentiate between the disappearance of a bed by faulting or by pinchout.

Substantiating field evidence is available at some places, however. The fault in sec. 6, T. 20 N., R. 8 E., cuts the Lecompton limestone, and an overlying limestone lense appears to be brecciated adjacent to the fault. In sec. 31, T. 20 N., R. 8 E., a fault was substantiated mainly on the basis of a gas seep along its trace. A second gas seep was observed in House Creek in sec. 32, T. 20 N., R. 8 E., where the course of the creek is diverted southward by a fault. In the NE corner T. 21 N., R. 7 E., and in the NW corner T. 20 N., R. 6 E., key limestone beds are measurably displaced by faulting.

In eastern Pawnee County a well defined belt of en echelon faulting extends northward across the county along the west border of R. 8 E. The six faults in the Pawnee County portion of this belt range in strike from N. 10° W. to N. 65° W. and in length from 1 to 2 miles. The faults are downthrown either to the northeast or to the southwest. At no place was the throw measured, but judging from stratigraphic displacements, all movements were less than 100 feet.

A branch of this north-trending fault belt extends northeastward across the central part of the county. The faults of this belt are from 1 to 3 miles in length and with one exception they strike north-northwest. A throw of 90 feet was measured on the fault in sec. 4, T. 20 N., R. 6 E., along the road on the north line of the township. The throw of the other faults was not established.

Evidence of faulting in the north and west parts of the county is generally lacking. Only one small fault was mapped, that being in the southeast part of T. 23 N., R. 3 E. The proximity of this fault to two of the copper deposits discussed in above suggests a genetic relationship between faulting and copper deposition, and it is possible that in Pawnee County the occurrence of copper is an indication of faulting.

Faults in addition to those shown on Plate 1 may well be present. At several places hand leveling indicates vertical displacement of beds on opposite sides of a valley; at other places faulting is suggested by lineation of outcrop pattern; but actual displacement of beds cannot be established by reconnaissance mapping alone. En echelon northeast-striking lineations of considerable length are evident on Plate 1 both to the north and to the south of the town of Pawnee. The bed of Camp Creek follows one such lineation for about 4 miles in the southwest part of T. 21 N., R. 5 E. Parallel northeast-striking lineations are evident in the outcrop pattern of the Red Eagle and Long Creek limestones immediately northeast of Pawnee Lake. A secondary northwest-striking system of faults or joints south of Pawnee is suggested by the small fault along the east line of T. 21 N., R. 4 E., by the possible continuation of this fault toward the northwest, and by parallel lineations in the SW corner T. 21 N., R. 5 E., and NE corner T. 20 N., R. 4 E.

Folding

Plains-type folds are well known in Osage County, Oklahoma, where they occur as small domes, anticlines, and noses in the surface rocks. Most of these structures become more pronounced at depth. According to Powers (1931), plains-type folds occur where lateral compressive forces in the basement rocks were resolved into vertical movement by pre-existing zones of weakness, forming highs in the granite basement. Recurrent movement during Pennsylvanian time produced structures which have the greatest flexure in pre-Pennsylvanian beds. Folding decreases upward within the Pennsylvanian section and becomes barely discernible in the surface beds, which experienced the least number of uplifts. Later work has shown that the major uplift occurred in early Pennsylvanian time, although recurrent movement did take place throughout the Pennsylvanian (e.g. Page, 1955, p. 16, Fig. 3).

Reconnaissance mapping of Pawnee County revealed only three anticlinal structures in surface beds; but several subsurface structures were shown, particularly in the eastern part of the county, on maps published by Greene (1930, Pl. III) and Ireland (1955, Fig. 1). These structures are in all probability "Plains-type" folds like those in adjacent Osage County. Those evident at the surface are expressed as inliers or other deviations from a normal pattern of outcrop but are not readily apparent to the casual observer.

The Watchorn pool in the south-central part of T. 25 N., R. 3 E., produces from a structure formerly known as the Otoe anticline. This structure is expressed at the surface as a breached inlier in the Fort Riley limestone (Plate I). According to Carpenter (1927, p. 1091), closure on this structure increases from approximately 50 feet in the surface beds to about 150 feet on the "Wilcox" sand, some 4000 feet deep. Other structures evident at the surface are the small inlier in the Red Eagle limestone in the SE ¼ sec. 33, T. 21 N., R. 5 E., and the larger one in the Long Creek limestone in sec. 21, T. 22 N., R. 5 E. The former structure was drilled in 1953, resulting in a small oil producer from the Prue sand (Bryan NW). The latter was to have been drilled in 1955, but to date no well has been reported. The Ralston anticline in the northern part of T. 23 N., R. 5 E., was originally mapped by surface geologists, but the structure is too subtle to be detected by reconnaissance methods.

SUBSURFACE STRUCTURE

Whereas the regional dip of the Upper Pennsylvanian and Lower Permian beds is approximately due west, the dip of pre-Missouri beds in Pawnee County is generally southwest and ranges from 45 to 75 feet per mile. This dip is the resultant of a south and southwest dip imparted to the beds by three stages of pre-Pennsylvanian tilting combined with the west dip imparted by post-Wolfcamp tilting. The structural deformation and erosion which produced this dip and other structural features evident in the subsurface can be summarized as follows:

1) Post-Arbuckle: gentle warping and southwest tilt; moderate regional truncation toward the northeast;
2) Pre-Mississippian: gentle warping and southwest tilt; regional truncation toward the northeast;

3) Pre-Des Moines (probably Wichita orogeny): local faulting and folding; south tilt; regional truncation toward the north;
4) Post-Des Moines: gentle warping; minor regional truncation;
5) Late Missouri (Arbuckle orogeny): periodic gentle warping and north tilt; moderate regional truncation toward the south;
6) Pennsylvanian-Permian: recurrent uplift of local structure;
7) Post-Wolfcamp: west tilt; en echelon faulting (?); peneplanation;
8) Pleistocene (?): rejuvenation; renewed west tilt and erosion.

Some pre-Mississippian uplift is recognized in most of the structural highs of north-central Oklahoma but the most profound structural deformation occurred in late Mississippian or early Pennsylvanian time. This deformation was probably induced by the Wichita orogeny, which centered in southwestern Oklahoma. Since that time tectonic movement has been limited largely to gentle warping, tilting, and recurrent uplift of pre-Pennsylvanian highs. Accordingly, most of the significant structural highs in pre-Pennsylvanian strata are reflected in the overlying Pennsylvanian beds but less sharply. It is generally true that pre-Pennsylvanian structures of relatively great amplitude occur as closed highs in the surface beds, those of medium amplitude occur as noses, and those of small amplitude are largely or completely masked. The Otoe anticline (Watchorn pool) in western Pawnee County is an example of a pre-Pennsylvanian structure of relatively great amplitude. This structure has abount 100 feet more vertical closure on pre-Pennsylvanian horizons than it has on the Permian Fort Riley limestone (Carpenter, 1927, p. 1091).

A majority of the oil and gas accumulation in Pawnee County can be attributed to structure. Keystone, Cleveland, Lauderdale, East Watchorn, Watchorn, Masham, Terlton, and several of the smaller pools are primarily anticlinal accumulations; faulting plays an important part in controlling accumulation at Masham, East Watchorn, and Maramec; stratigraphic entrapment is the cause of accumulation in the Red Fork shoestring sand in the Keystone area (White, 1941), in the Tucker sand at Maramec East, and in many of the recently discovered reservoirs. The importance of the stratigraphic trap is expected to increase as exploration and development continue.

GEOLOGIC HISTORY

Interpretation of the foregoing stratigraphic and structural data and integration of the interpreted data with the established sequence of geologic events in the southern Mid-Continent area permit us to reconstruct in a general way the geologic history of Pawnee County.

The Precambrian history of the area is almost completely unknown, owing mostly to the thick cover of Paleozoic sediments and the lack of economic incentive to explore Precambrian igneous rocks in the subsurface. Paleozoic history dates from the Upper Cambrian, the age of the oldest sedimentary deposits in the area.

Eastward encroachment of the Cambrian sea gradually inundated all but the highest points of the irregular surface developed by pre-Paleozoic erosion of the Precambrian igneous complex of the Mid-Continent area. The sea first covered Pawnee County in late Cambrian (Croixian) and/or early Ordovician (Canadian) time, when the rocks of the Arbuckle group were laid down. Arbuckle deposition was followed by general emergence accompanied by gentle warping and slight tilting toward the southwest. The tilting and subsequent erosion resulted in the removal of uppermost Arbuckle beds in part of Pawnee County and gentle truncation of progressively older beds northeastward from Pawnee County (Ireland, 1955, Fig. 2A). Sediments of the Simpson group (Chazy) were deposited on the eroded Arbuckle surface and were followed more or less conformably by the Viola, Sylvan, and Hunton formations.

As reported by Tarr (1955, p. 185), "Following the deposition of the Hunton formation, the region of Oklahoma was subjected to a period of uplift, folding, and erosion which stripped off all rocks down to the Arbuckle formation in several of the northeastern counties of Oklahoma, even cutting nearly to granite in several structures." This erosion completely removed the Hunton and Sylvan formations in Pawnee County and left only remnants of Viola limestone in the southwestern part. Progressively older beds were truncated toward the north in Osage County, Oklahoma, and in southeastern Kansas.

The area remained positive and subject to erosion until early Mississippian time, when the Woodford shale was laid down on the truncated edges of the Ordovician beds. Mississippian sedimentation continued essentially uninterrupted into Meramec time and perhaps later. The duration of Mississippian sedimentation is obscured by the northward truncation of the Mississippian section in pre-Des Moines time.

The effects of the early Pennsylvanian Wichita orogeny are recorded in the structure and erosion now evident in the pre-Pennsylvanian sediments throughout the region. The principal deformation of most of the major structural features occurred at this time. The Middle Pennsylvanian sea advanced over the region from the south and east and in middle Des Moines time covered the Pawnee County area. Des Moines sedimentation was predominantly marine and was essentially continuous until the end of the epoch, when the sea withdrew temporarily and minor erosion occurred locally (Plate 2).

Missouri sediments onlapped the locally eroded Des Moines beds and initiated another long period of uninterrupted, predominantly marine sedimentation. Toward the end of Missouri time, however, the environment changed from stable marine to deltaic, characterized by lenticular sandstones interbedded with finer clastic deposits of both marine and continental environment. Several unconformities, all of which truncate progressively older beds toward the south, occur in the upper Missouri section of north-central Oklahoma, attesting to the uplift and erosion to the south. The deltaic sequence is exemplified by the upper Missouri and lower Virgil rocks that crop out in eastern Pawnee County. It records the effects of the Arbuckle orogeny, during which the rocks of the Arbuckle region were uplifted and intensely folded and eroded.

Mid-Virgil time saw a return to the Pawnee County area of a marine environment in which was deposited the thick dark-gray Kanwaka shale. Periods of renewed uplift in the source area are recorded by the Elgin sandstone tongues, which wedge into the Kanwaka section from the south.

During late Virgil and early Wolfcamp time the area was dominated by a marine environment, although deltaic and continental conditions occurred periodically. During this time Pawnee County occupied a transitional position between a cyclicly subsiding relatively shallow marine basin to the north in Kansas and an actively uplifting and eroding hinterland to the south in the Arbuckle and Wichita Mountain regions of Oklahoma. The sediments deposited during this time are subcyclic and reflect the combined effects of recurrent uplift of the source area and eustatic oscillation of the Kansas basin. Extensive marine transgressions are recorded by the fossiliferous limestones and dark-gray shales of the upper Virgil and lower Wolfcamp sequences. The limestones can be traced northward into Kansas, where they are recognized as marine members of a cyclic sedimentary sequence. Cyclic sedimentation in Pawnee County is suggested by coals and non-marine clastics interbedded in the marine sequence, but the typical cyclic character of the Upper Pennsylvanian and Lower Permian deposits of the Kansas, Illinois, Michigan, and Appalachian basins are not readily recognizable in the Pawnee County section.

No major sedimentary break occurred during the deposition of this transitional sequence. Interruptions of short duration probably marked the close of each sedimentary cycle, but evidence of disconformity is commonly lacking. Channel deposits occur in Kansas both below and above the recognized Pennsylvanian-Permian boundary, and they are particularly abundant and deeply incised in the section just below this boundary (Mudge, 1956, p. 677). Such sandstones were probably deposited in channels eroded in the depositional surface during the emergent stage of a cycle. Channel sandstones were recognized in the Pony Creek, Roca, and Eskridge sections in Pawnee County.

A subcyclic marine environment persisted through the time of deposition of the Neva limestone, following which a marked environmental change occurred in the Pawnee County area. The post-Neva portion of the Wolfcampian epoch was characterized by a continental to deltaic environment in which were deposited thick sequences of poorly sorted red clastic material containing lenticular sandstones. Many and possibly all of the sandstones were deposited in stream channels which meandered northward across the depositional surface of the red beds. According to Miller and Folk (1955, p. 344) the formation of red beds requires a source rich in magnetite and/or ilmenite. The most likely such source for the north-central Oklahoma red-bed sequence was the igneous core of the Wichita Mountains of southwestern Oklahoma.

Periodic marine transgression of the late Wolfcamp continental facies is recorded in the deposition of the Cottonwood, Wreford, Fort Riley, and Winfield limestones and associated gray shales. These marine units extend northward into the cyclic sequence of the Kansas basin. Their occurrence in Pawnee County attests to the continuing influence of cyclic conditions on sedimentation in the area.

The eroded surface of this red-bed sequence now forms the Red Beds Plains physiographic province of Oklahoma.

An environment similar to that of the late Wolfcamp persisted in northern Oklahoma until late in the Guadalupian epoch, but eastward truncation of the Permian section by post-Guadalupe erosion does not permit an accurate determination of the duration of sedimentation in Pawnee County. In late or post-Permian time the entire Mid-Continent was tilted westward to form the Prairie Plains homocline. Peneplanation of that portion of the homocline in which Pawnee County occurs is today evident in the accordant summits of the Pawhuska Rock Plain described by Ham (1939). According to Ham, the peneplanation probably occurred in late Tertiary or early Pleistocene time. The present dissection and lack of eastward gradient of the peneplaned surface indicate later rejuvenation and renewed westward tilt of the region.

Deposits of upland terrace (Qtu of Plate I) were probably laid down on the peneplane prior to its dissection, whereas deposition of the draped terrace (Qt of Plate 1) may have occurred as recently as post-glacial time. The eolian nature and red color of the draped terrace suggests deposition under conditions of extreme aridity.

ECONOMIC GEOLOGY

Water Resources

A systematic study of the water resources of Pawnee County is not within the scope of this paper. Generally, a supply ample for domestic and ranch purposes is readily obtainable from either surface or shallow underground sources. Larger supplies are available locally.

A summary of the source, depth, capacity, and chemical constituents of surface and subsurface water supplies in the county may be found in Gould (1905, p. 112) and Smith (1944, p. 202, 354).

Surface Water

Surface impoundment reservoirs provide much of the water used in the county. The towns of Pawnee, Cleveland, and Maramec have municipally owned reservoirs to supply their needs, and almost every farm has one or more small ponds which are used to water stock.

The Arkansas and Cimarron Rivers are dependable sources of surface water, and except in periods of severe drought, Black Bear Creek and other major tributary streams provide a year round supply of water to the farms and ranches along their banks. Currently there are plans to construct a dam on the Arkansas River below Keystone. If built, this dam will provide a reserve of several billion gallons, backing up water as far as Blackburn. In so doing, however, it will inundate much of the county's tillable acreage.

Subsurface Water

The most abundant supply of subsurface water is from alluvial and terrace sand and gravel deposits. A lesser supply is afforded downdip from the outcrop of most of the Permian and Pennsylvanian sandstones. If penetrated too far from the outcrop, however, many of these sands produce salt water.

Several small springs were noted in the county during the course of the field work. These springs generally occur where the contact of a massive sandstone on a shale is exposed some distance downdip from the main sandstone outcrop. Such a condition exists in R. 4 E. along the south bank of the Arkansas River, where several springs occur.

Sand and Gravel

The alluvial deposits of the Arkansas River provide the county with an abundant supply of sand and gravel. At present dredging, washing, and screening operations are underway at three places along the river. There are two separate operations at Ralston, one above and one below the highway bridge, and the third is below Cleveland at the Riversand siding of the Missouri, Kansas, and Texas Railroad. Gravel from these operations is used mostly for construction and is marketed via truck and railway over most of north-central Oklahoma.

The alluvium of Black Bear Creek is another possible source of sand. Except where bedrock is exposed in the floor of the creek, deposits of clean sand and fine gravel are common in the creek bed throughout its length in Pawnee County.

Shale and Clay

The abandoned pit in the Kanwaka shale southwest of Cleveland was formerly the site of a sizable brick plant owned by, among others, the Acme Brick Company. Operations of this plant covered a period of 15 to 20 years in the early part of the century. Early production was principally common building brick, most of which was sold in Oklahoma City (Snider, 1911, p. 251). Tile later became the chief product (Sheerar, 1932, p. 199). Operations were discontinued prior to 1920, since which time the plant has been almost completely dismantled.

A summary of plant operations and analyses of the shale were given by both Snider and Sheerar. Outcrops of this shale are plentiful near Cleveland and offer a potential source of income if a market becomes available. Other shales and clay suitable for brick and tile manufacture are no doubt present in the county, but it is doubtful if they can compete with the Kanwaka deposits near Cleveland.

Analyses of clay from the Pony Creek and Admire shales just north of Quay may be found in Snider (1917), pages 144 and 145, respectively.

Limestone

Pawnee County has an unlimited supply of limestone for use as crushed rock. A more restricted supply suitable for building stone is also available, but little if any has been quarried.

Although several of the limestones in the county have at one time been quarried commercially (see Plate 1), only one quarry is currently in operation. Abandoned quarries are present in the Turkey Run, Brownville, Red Eagle, and Neva limestones. The rock was used mainly in the construction and surfacing of roads. The active quarry is in the Brownville limestone in the NE ¼ sec. 13, T. 21 N., R. 5 E. The rock is crushed and used by the county for road maintenance. Rock from the abandoned Brownville quarries immediately to the south was used as ballast by the Atchison, Topeka, and Santa Fe Railway.

Shannon (1914, p. 155) refers to a lime kiln near Pawnee but does not mention the source of the raw material. It is probable, however, that the old Brownville quarries supplied the limestone for this kiln. Laboratory tests on samples of Brownville limestone collected near these quarries showed the limestone to be from 96 to 99 percent soluble in hydrochloric acid. Cullen (1917, p. 54) rejected the Neva and Red Eagle limestones as possible sources of lime because of their high chert and silica content. A study of insoluble residues confirms this opinion.

Brownville limestone from the quarry north of the St. Louis and San Francisco Railroad in sec. 18, T. 21 N., R. 6 E., was crushed and used as a base for a United States Army airstrip constructed in the early 1940's near Perry, Oklahoma. The large quarries in the Red Eagle limestone in sec. 28, T. 20 N., R. 5 E., and in the Neva in sec. 20, T. 23 N., R. 5 E., and sec. 30, T. 24 N., R. 5 E., were opened when the portion of Oklahoma Highway 18 through Pawnee County was paved but were abandoned at the completion of the paving operation. Large slabs of limestone from the Neva quarry in T. 23 N., R. 5 E., can be seen in Pawnee where they are used as rip-rap under the new bridge over Black Bear Creek.

Favorable thickness and exposure provide prospective quarry sites at many places along the outcrop of the Neva limestone in Tps. 23 and 24 N., where the section consists of up to 16 feet of almost solid limestone. Many prospective sites in the Brownville limestone in addition to these already worked occur along its outcrop in Tps. 21 and 22 N. east of Pawnee. The thickness of the Brownville in this area ranges from 6 to 10 feet. The Red Eagle presents the best prospects for quarrying in the southern part of the county. The Red Eagle thickness averages 6 feet in exposures in T. 20 N.

Prospective quarry sites also exist in the Wakarusa limestone in Tps. 21 and 22 N. and in the Long Creek limestone in Tps. 23 and 24 N. Up to 9.5 feet of Wakarusa and 25 feet of Long Creek were observed in the areas mentioned. but the limestones may contain too much interbedded shale to be of commercial importance.

With the exception of the quarries and locations here mentioned, the limestones of Pawnee County are too thin to permit large scale quarrying operations.

Building Stone

Although Pawnee County abounds in exposures of sandstones suitable for building purposes, production in the county is small. More than 35 quarries and a host of old sandstone buildings attest to the popularity of sandstone as a building stone in Oklahoma's early days. Today, however, sandstone has been largely replaced as a building material by brick and concrete, and most of the quarries have been abandoned. The quantity of stone removed from most of them was small except for a few that were propitiously located near the centers of population. In the town of Pawnee more than 62 buildings are constructed of sandstone[3], most of which came from nearby quarries in the sandstone immediately beneath the Neva limestone.

Sandstone from most of the other geological formations exposed in the county has also been quarried, but records of the location and production of quarries are unavailable.

In 1936 and 1937 a mineral survey of Oklahoma was conducted by the Works Progress Administration under the direction of the Oklahoma Geological Survey. The sandstones and limestones of Pawnee County were included in the study and a partial list of possible and existing quarry sites in the county may be found by referring to this data in the Geological Survey files in Norman.

[3] Unpublished data from Oklahoma Geological Survey files.

Coal

No commercial coal deposits are known in the county. The Ralston coal below the Brownville limestone can be traced entirely across the county, but it is generally only about one inch thick. At places it ranges from 6 to 10 inches and in Ralston an 18-inch seam is said to be exposed in times of low water in the north bank of Eagle Creek about 100 yards southeast of the bridge to the Santa Fe railroad station. Shannon (1926, p. 57) stated that about 200 tons had been mined from a 5- to 15-inch seam in Ralston. At least part of this production was mined through a shaft located west of the Santa Fe railroad tracks. The shaft has since been deepened and converted to a water well. Present residents of the town regard the 200-ton figure as excessive.

Two exposures of coal were noted immediately below the Turkey Run limestone (see p. 42). Although this bed in all probability extends over a wide area, it is doubtful that it attains commercial thickness.

Copper

Several small deposits of copper minerals occur in the Permian rocks of the western part of the county. Such deposits are known in the NE ¼ sec. 23 and the NW ¼ sec. 24, T. 22 N., R. 3 E., and in the NW ¼ sec. 19, T. 22 N., R. 4 E. (see Plate 1). They occur in sandstone and conglomeratic lenses in the lower part of the Matfield shale and consist chiefly of replacement of carbonized wood by chalcocite which has subsequently been altered to malachite and azurite. Traces of silver and gold are associated with the copper.[4]

At the prospects visited replacement of the carbonized wood is virtually complete and the copper minerals also occur as nodules and disseminated material in the clastic host rock. A similar deposit is reported in the NW ¼ sec. 28, T. 22 N., R. 3 E., in the Doyle shale, but this prospect could not be located.

A few attempts have been made to develop these copper deposits, but none of them has demonstrated the presence of a commercial deposit. One or more shafts are reported to have been dug at each prospect, and a crude mill was set up in the NW ¼

[4] Op. cit.

sec. 24, T. 21 N., R. 3 E., to process ore. In 1946 seven shallow core holes were drilled on the same property under the supervision of the Oklahoma Geological Survey.

These and similar "red bed" copper deposits in other parts of Oklahoma are described by Merritt (1940), together with a review of the several theories of origin and a bibliography. Fischer (1937, p. 915) described a Pawnee County deposit, which is probably the one in secs. 23 and 24, T. 22 N., R. 3 E.

Radioactive Minerals

Several prospects containing radioactive minerals are known in the county. Uranium minerals occur in the carbonized wood associated with the copper deposits described above, but like the copper, the uranium-bearing material is too disperse to be of value.

Geologists of the United States Geological Survey and of the Atomic Energy Commission have investigated a prospect in the NE ¼ sec. 8, T. 22 N., R. 4 E., known as the Lee D. Uto prospect. Hill (1953, p. 203) reported, "It is a bedded deposit of secondary uranium minerals associated with thin lignitic lenses in cupriferous sandstone of basal Permian age. Selected samples contained 16.3 percent uranium." This deposit occurs in the upper part of the Garrison shale, somewhat lower stratigraphically than the nearby copper deposits and with a much smaller copper content. It contains an appreciable amount of carbonized wood. According to Beroni (1954, p. 171), samples from the Uto prospect contain uranium minerals ranging from 0.002 to 0.068 percent of the sample. The radioactivity is concentrated in the sulphate-bearing carbonaceous material. To date this prospect is considered non-commercial.

Many black shales are known to have an abnormally high content of radioactive minerals. The owner of the Neva limestone quarry in sec. 20, T. 22 N., R. 5 E., reported that random samples of the black shale underlying the Neva had been shown by chemical analysis to contain as high as 1.08 percent uranium. To date uranium cannot be extracted from such shale commercially although the Atomic Energy Commission is currently conducting a survey of radioactive materials in the Chattanooga black shales of Tennessee. If a process is developed whereby this material can be worked economically, the shales such as the one under the Neva may provide an important source of uranium and other radioactive minerals.

Oil and Gas

Oil was discovered in Pawnee County on the Bill Lowrey farm near the town of Cleveland in September, 1904. This discovery established the county as one of the earliest oil-producing regions in Oklahoma. Accurate records of early drilling and production are not available, but in the many years following the completion of the initial well literally thousands of wells have been drilled and millions of barrels of oil produced. It is estimated that cumulative production from Pawnee County fields to the end of 1955 (the latest date for which figures are available) was approximately 100 million barrels. Oil production is second only to agriculture as the county's chief source of income. During 1955 a total of approximately 1,050 producing wells in 46 separate producing areas contributed to that income (Fig. 37, Table 5). Production is predominantly oil. Gas is produced in small quantities for local consumption, but no major gas reservoir has yet been discovered.

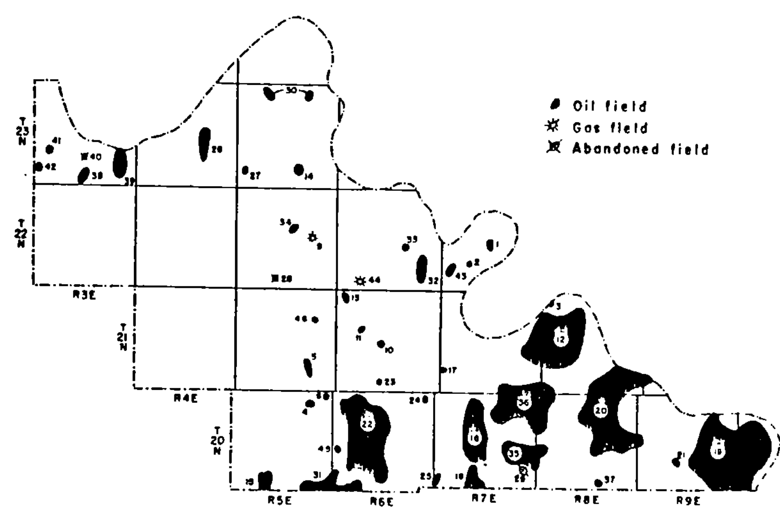

Figure 37. Principal oil and gas producing areas of Pawnee County. Numbers refer to field areas listed in Table 5.

TABLE 5
PRODUCTION STATISTICS FOR PRINCIPAL OIL AND GAS POOLS[a]
PAWNEE COUNTY, OKLAHOMA

No. [b]	Field	Location	Disc. Date	Producing Wells	1955 Prod. (bbls.)	Cumulative Prod. to 1/1/56 (bbls.)	Av. Grav. (° API)
1	Blackburn E	sec. 21-22N-7E	'20	12	33,865	157,224	
2	Blackburn SE	sec. 29-22N-7E	'54	1	2,797	3,962	51
3	*Boston	sec. 6-21N-8E	'54	1/28	?	?	37
4	Bryan	secs. 1 & 2 20N-5E	'54	2	183	978	38
5	Bryan N	secs. 26 & 35 21N-5E	'51	5	37,171	154,728	41
6	Bryan NE	sec. 1-20N-5E	'54	2	3,800	8,300	
7	Bryan NW	sec. 33-21N-5E	'53	1	2,160	8,946	38
8	Bryan SE	sec. 12-20N-5E	'53	2	2,814	5,711	
9	Buena Vista NE	sec. 14-22N-5E	'54	1	gas	......	....
10	Casey	sec. 21-21N-6E	'17	2	1,666	119,898	
11	Casey N	sec. 17-21N-6E	'51	3	8,166	20,915	36
12	Cleveland	21N-8E	'04	139	133,225	41,690,972	36
13	Cody	sec. 6-21N-6E	'54	8	42,262	61,612	37
14	Crescent Star S	secs. 27 & 34 23N-5E	'54	5	30,125	71,161	38
15	*Garr	secs. 32 & 33 20N-5E	'20	30/73	220,825	4,549,552	38
16	Hallett	20N-7E	'22	67	271,195	776,940	38
17	Hallett NW	sec. 30-21N-7E	'49	2	0	2,429	
18	*Jennings	secs. 28 & 33 20N-7E	'10	11/93	194,910	4,944,874	37
19	*Keystone	20N-9 & 10E	'19	104/178	241,265	5,694,133	
20	Lauderdale	20 & 21N-8E	'15	193	436,025	17,136,437	37
21	Mannford N	sec. 28-20N-9E	'40	?	?	25,718	
22	Maramec	20N-6E	'20	162	421,940	5,758,283	37

a Principal source: **National Oil Scouts and Landmen's Assoc. Yearbook**, 1956
b Field number refers to Fig. 37, which shows the oil and gas producing areas in Pawnee County.
* These fields extend into adjacent counties. Production figures are for the entire field. Under Producing Wells, figure above bar is number of producing wells in Pawnee County; figure below bar is total producing wells in the field.

TABLE 5 (Continued)
PRODUCTION STATISTICS FOR PRINCIPAL OIL AND GAS POOLS[a]
PAWNEE COUNTY, OKLAHOMA

No. [b]	Field	Location	Disc. Date	Producing Wells	1955 Prod. (bbls.)	Cumulative Prod. to 1/1/56 (bbls.)	Av. Grav. (° API)
23	Maramec N	sec. 33-21N-6E	'45	1	2,848	60,098	
24	Maramec E	sec. 1-20N-6E	'48	0	......	18,612	39
25	*Maramec SE	sec. 31-20N-7E	'48	1/3	2,555	16,582	
26	Masham	C 23N-4E	'24	25	76,285	?	39
27	Masham E	sec. 30-23N-5E	'50	1	0	2,183	
28	Pawnee E	21N-5E	'41	0	Abd. 1944	8,731	
29	Price	secs. 25 & 36 20N-7E	(?) '4?	0	Abd. 1948	12,000	
30	Ralston	secs. 2 & 4 23N-5E	'09	11	60,049	289,346	39
31	*Quay	20N-5 & 6E	'14	57/307	1,343,930	37,029,647	36
32	Skedee	SE 22N-6E	'42	17	20,110	399,614	40
33	Skedee N	secs. 22 & 23 22N-6E	'53	2	5,236	18,126	35
34	Skedee W	sec. 15-22N-5E	'50	2	3,385	73,287	42
35	Terlton	20N-7 & 8E	'12	24/35	74,095	1,264,469	38
36	Terlton N	20 & 21N-7 & 8E	'17	93	166,075	4,140,813	38
37	Terlton SE	secs. 33 & 34 20N-8E	'51	3	7,574	34,602	38
38	Watchorn	secs. 3 & 4 22N-3E	'15	12	33,723	8,182,909	41
39	*Watchorn E	SE 23N-3E	'42	33	297,226	8,627,010	43
40	Watchorn N	C 23N-3E	'45	0	Abd.	4,017	37
41	Watchorn NW	secs. 19 & 20 23N-3E	'45	3	8,639	31,354	43
42	Watchorn W	secs. 30 & 31 23N-3E	'53	2	5,072	28,119	
43	Blackburn S	sec. 30-22N-7E	'55	8	34,233	34,233	42
44	Sunny Slope SW	sec. 5-22N-6E	'55	1	gas	....	....
45	Quay N	sec. 19-20N-6E	'55	2	5,623	5,623	42
46	Cody SW	sec. 11-21N-5E	'55	1	1,896	1,896	37

Productive zones range in age from Cambro-Ordovician (Turkey Mountain zone) to Upper Pennsylvanian (Hoover sand); and most productive areas produce from more than one zone (Table 6). The most prolific zones are the Skinner and Bartlesville sands of Middle Pennsylvanian age and the Wilcox sand of Lower Ordovician age. Although some production is obtained from limestone reservoirs (e.g., Oswego, Inola), most comes from thin somewhat lenticular sandstones in a section composed predominantly of shale. The reservoir beds are part of a westward-dipping sedimentary sequence, the thickness of which increases from about 3,000 feet in the east to about 5,000 feet in the west. This sequence lies on a Precambrian surface of considerable relief which also dips to the west. Productive zones range in depth from 1,100 to 4,300 feet. Because of the westward dip of the beds, wells in the western part of the county are generally deeper than those in the eastern part.

TABLE 7

PIPELINE RUNS AND EXPLORATION STATISTICS

PAWNEE COUNTY, OKLAHOMA [a]

Year	Pipeline Runs (bbls)	Wildcat Wells No.	Wildcat Wells Footage	Disc.	Undev. acreage under lease to major companies	Geo-physical crew weeks
1955	b	32	103,561	7	14,862	13
1954	b	35	121,251	6	9,614(?)	17
1953	2,086,840	43	149,763	6	10,116	0
1952	2,012,612	21	72,731	1	9,851	0
1951	1,882,478	31	102,563	5	9,514	1
1950	1,506,083	21	69,609	4	4,983	13
1949	1,506,888	9	30,908	0	3,087	0
1948	b	8	26,625	1	11,872	3

a Compiled from Nat. Oil Scouts and Landmen's Assoc. Yearbook, 1949 to 1956, inclusive.
b Data not available.

Oil entrapment is primarily structural, occurring in small anticlines and domes and, in a few cases, against faults. Most of the obvious structural features have already been tested, however, and most recent discoveries and extensions have been from stratigraphic traps. These traps commonly occur on the flanks of known structures. The proportion of oil produced from stratigraphic reservoirs is expected to grow as exploration and development in the county continue.

TABLE 6

PRINCIPAL OIL AND GAS PRODUCING RESERVOIRSa

PAWNEE COUNTY, OKLAHOMA

FIELD	PENNSYLVANIAN															MISS		CAMBRO-ORDOVICIAN				
	Virgil		Missouri		Des Moines																	Arb.
	Hoover	Tonkawa	Layton	Cleveland	Wayside	Peru	Wheeler	Oswego	Prue	Skinner	Red Fork	Inola	Bartlesville	Taneha	Burgess	Mississippi	Misener	Simpson	Wilcox	Hominy	Tucker	Turkey Mountain
Blackburn E													•									
Blackburn SE																	•	•				
*Boston									•													
Bryan											•											
Bryan N													•									
Bryan NE											•											
Bryan NW									•													
Bryan SE										•												
Bueno Vista NE										-o-												
Casey									•													
Casey N									•													
Cleveland			•	•				•		•			•						•			
Cody				•																		
Crescent Star S																			•			
*Garr				•	•						•						•		•			
Hallett				•		•				•			•						•			
Hallett NW										•			•									
*Jennings										•			•	•	•	•			•			
*Keystone				•						•			•				•		•			
Lauderdale			•	•						•			•						•			•
Mannford N																						
Maramec			•	•				•	•	•	•		•		•				•			
Maramec N									•													
Maramec E																					•	
*Maramec SE										•												
Masham				☼				•										•				
Masham E								•														
Pawnee E																	•		•			
Price										•												
Ralston										•			•		•			•	•			
*Quay								•	•	•			•						•			
Skedee									•	•									•			
Skedee N																			•			
Skedee W																	•		•			
Terlton			•	•			•			•			•						•		•	
Terlton N									•			•										
Terlton SE													•									
Watchorn		☼	•																•			
*Watchorn E	☼																		•			
Watchorn N													•									
Watchorn NW			•																			
Watchorn W																		•				
Blackburn S																			•			
Sunny Slope SW										☼												
Quay N										•												
Cody SW											•											

a, *See Table 5 for explanation.

Most of the established oil and gas producing areas in Pawnee County are in the eastern part (Fig. 37), though many significant discoveries have been made in the central and western parts during the last 15 years. Since 1948 both yearly oil production and the tempo of exploration activity have shown a general increase (Table 7); and as long as the demand for petroleum products is maintained at the present high level, this increase should continue. Large areas in the western part of the county are virtually untested for oil or gas, and the discovery potential of these areas, together with that of the more thoroughly tested eastern portion of the county, should assure continuing growth of the oil industry in Pawnee County for many years to come.

SUMMARY

The principal conclusions which can be drawn from the data presented in this report are summarized as follows:

1) The surface rocks of Pawnee County range upward from the Wann formation of middle Missouri age through the Winfield limestone of late Wolfcamp age. The oldest beds crop out in the easternmost part of the county. The dip of the beds is approximately due west and ranges between 30 and 65 feet per mile. The sediments of the Permian system lie on those of the Pennsylvanian with apparent conformity.

2) During Upper Pennsylvanian and Lower Permian time the Pawnee County area was situated between an eroding landmass to the south and a shallow cyclicly subsiding marine basin to the north. The resultant sediments form a complex sequence transitional between the coarsely clastic continental deposits of the source area and the cyclic primarily marine deposits of the basin.

3) The stratigraphy of the surface section reveals three major stages of deposition: a) a deltaic stage from middle Missouri (Wann) through lower Virgil (Vamoosa) time, b) a subcyclic stage straddling the Pennsylvanian-Permian boundary from middle Virgil (Pawhuska) through middle Wolfcamp (Neva) time, and c) a continental stage from middle Wolfcamp (Eskridge) through late Wolfcamp (Winfield) time. Periodic interruption of the principal environment of each stage suggests that the entire surface sequence may have been affected by the pulsating environment which produced the correlative cyclic sequence in Kansas.

4) The sediments of the deltaic and continental stages are sparsely fossiliferous to non-fossiliferous, whereas many of the beds of the subcyclic stage are abundantly fossiliferous. No species or assemblage is peculiar to any one stratigraphic unit except for the fusuline *Schwagerina,* which is an index to beds of Permian age. Accordingly, correlation or identification of beds is impossible on the basis of fauna alone.

5) The correlation of the sandstones in the upper Missouri and lower Virgil sections is doubtful. On the basis of recent work in Osage County, the Revard and Cheshewalla sandstones of Plate 1 may actually be the Cheshewalla and Kiheki sandstones, respectively (see discussion on p. 24).

6) The Lecompton limestone, basal member of the Pawhuska formation, is the lowermost limestone in the surface section of Pawnee County.

7) The "Grayhorse" limestone of Pawnee County probably correlates with the Grayhorse limestone of Kansas, but both are probably older than the type Grayhorse limestone of Osage County (Fig. 20).

8) Channel sandstones occur in the Roca and Eskridge shale sections. Many or all of the other lenticular sandstones in the Upper Pennsylvanian and Lower Permian sequence might also prove to be channel deposits if their contacts with underlying beds could be observed.

9) The Cottonwood, Wreford, Fort Riley, and Winfield limestones all die out southward in or immediately south of Pawnee County. Correlation of the Wreford and Winfield limestones is somewhat doubtful. The true correlatives of these units may not extend southward as far as Pawnee County.

10) The fauna of the post-Neva limestones is typically molluscan and/or algal. Deep water assemblages, in particular fusulinids, are conspicuous by their absence.

11) The upland terrace (Qtu of Plate 1) was deposited and dissected prior to the deposition of the draped terrace (Qt of Plate 1).

12) The subsurface section contains beds of Upper Cambrian (?), Lower Ordovician, early Mississippian, Middle and Upper Pennsylvanian, and Lower Permian age. The thickness of this

sequence ranges from 3000 to 5000 feet. It contains the following major angular unconformities:

a) Precambrian granite overlain by Cambro-Ordovician (Arbuckle group);

b) Ordovician (Simpson group) overlain by Mississippian (Woodford shale);

c) Mississipppian (Osage limestone) overlain by Pennsylvanian (middle Des Moines). Minor unconformities occur between a) the Arbuckle and Simpson groups, b) the Des Moines and Missouri series, and c) the Missouri and Virgil series. Plate 2 suggests the presence of a minor unconformity in the lower Wann section. This possibility needs further checking in adjacent areas.

13) The westerly dip of the sediments is interrupted locally by north-trending belts of en echelon faults and small dome-like folds. The faults probably die out downward, but the folding is more pronounced at depth. Faulting and folding are thought to have been caused by horizontal and vertical movements, respectively, along ancestral zones of weakness in the granite basement.

14) Pawnee County has been above sea level and subject to erosion since sometime late in the Permian period. Uplift, westward tilt, and en echelon faulting probably occurred in late Permian or early post-Permian time. The area was subsequently peneplaned and later, probably in Quaternary time, rejuvenated. Erosion of the rejuvenated peneplane is currently in progress.

15) Petroleum is the county's chief mineral resource. Production is on the order of 6,000 barrels daily. Potentially valuable deposits of clay and building stone may be developed in the future if a local market develops. Non-commercial deposits of coal, copper, and radioactive minerals are known.

REFERENCES

Adams, G. I., Girty, G. H., and White, David, 1903, Stratigraphy and paleontology of the Upper Carboniferous rocks of the Kansas section: U. S. Geol. Survey, Bull. 211.

Anderson, G. E., 1941, Origin of line of color change in red bed deposition, Geol. Soc. America, Bull., vol. 52, p. 211-218.

Aurin, F. L., 1917, Geology of the redbeds of Oklahoma: Okla. Geol. Survey, Bull. 30.

Aurin, F. L., Officer, H. G., and Gould, C. N., 1926, The subdivision of the Enid formation: Amer. Assoc. Petroleum Geologists, Bull., vol. 10, p. 786-799.

Bass, N. W., 1929, Geology of Cowley County, Kansas: Kansas, State Geol. Survey, Bull. 12.

Bass, N.W., 1936, Origin of the shoestring sands of Greenwood and Butler Counties, Kansas: Kansas, State Geol. Survey, Bull. 23.

Beckwith, H. T., 1930, Geology of Osage County: Okla. Geol. Survey, Bull. 40 (T), vol. III, p. 211-267.

Beede, J. W., 1898, The stratigraphy of Shawnee County: Kansas Acad. Science, Trans., vol. 15, p. 27-34.

Beede, J. W., 1914, The Neva limestone in northern Oklahoma with remarks upon the correlation of the vertebrate fossil beds of the state: Okla. Geol. Survey, Bull. 21.

Beroni, E. P., 1954, South-central district, Oklahoma: U. S. Atomic Energy Commission, Trace Elements Inv. Rept. 440, p. 170-171.

Billings, R. L., 1956, Geology of eastern Noble County, Oklahoma: University of Okla., unpublished Master of Science thesis.

Bowen, C. F., 1918, Tps. 24, 25, and 26 N., Rs. 6 and 7 E.; Tps. 25 and 26 N., R. 5 E.; T. 26 N., R. 4 E.; U.S. Geol. Survey, Bull. 686 (L) p. 137-138.

Branson, C. C., 1954, Preliminary list of subsurface stratigraphic names in Oklahoma: Okla. Geol. Survey, The Hopper, vol. 14, no. 12.

Branson, C. C., 1956, Cyclic formations or mappable units: Okla. Geol. Survey, Oklahoma Geology Notes, vol. 16, p. 122-126.

Branson, C. C., Burwell, A. L., and Chase, G. C., 1955, Uranium in Oklahoma, 1955: Okla. Geol. Survey, Mineral Rept. 27.

Bryant, D. G., 1957, Geology of the Grayhorse area, Osage County, Oklahoma: Univ. of Okla., unpublished M. S. thesis.

Carl, J. B., 1957, Geology of the Black Dog area, Osage County, Oklahoma: Univ. of Okla., unpublished M. S. thesis.

Carpenter, E., 1927, The Morrison field, Pawnee County, Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 11, p. 1087-1096.

Carter, J. A. Jr., 1954, Geology of the Pearsonia area, Osage County, Oklahoma: Univ. of Oklahoma., unpublished M. S. thesis.

Clark, S. K., 1932, The mechanics of Plains-type folds of the Mid-continent area: Jour. Geology, vol. 40, p. 46-61.

Condra, G. E., 1903, The Coal Measure Bryozoa of Nebraska: Nebraska Geol. Survey, vol. II, pt. 1, p. 1-163.

Condra, G. E., 1927, The stratigraphy of the Pennsylvanian system in Nebraska: Nebraska Geol. Survey, Bull. 1, 2d ser.

Condra, G. E., 1935, Geologic cross section, Forest City, Missouri, to Du Bois, Nebraska: Nebraska Geol. Survey, Paper 8.

Condra, G. E., and Bengston, N. A., 1915, The Pennsylvanian formations of southeastern Nebraska: Nebraska Acad. Sci., Pub., vol. 9, no. 2.

Condra, G. E. and Upp, J. E., 1931, Correlation of the Big Blue series in Nebraska: Nebraska Geol. Survey, Bull. 6 2d ser.

Condra, G. E., and Busby, C. E., 1933, The Grenola formation: Nebraska Geol. Survey, Paper 1.

Condra, G. E., and Reed, E. C., 1943, The geological section of Nebraska: Nebraska Geol. Survey, Bull. 14, p. 1-82.

Cullen, John, 1917, Lime resources and industry in Oklahoma: Okla. Geol. Survey, Bull. 26.

Dott, R. H., 1941, Regional stratigraphy of the Mid-Continent: Amer. Assoc. Petroleum Geologists, Bull. vol. 25, p. 1619-1705.

Drake, N. F., 1897, A geological reconnassance of the coal fields of the Indian Territory: Amer. Philos. Soc., Proc., vol. 36, p. 326-419.

Dunbar, C. O., and Condra, G. E., 1932, Brachiopoda of the Pennsylvanian system in Nebraska: Nebraska Geol. Survey, Bull., 5, 2d ser.

Fath, A. E., 1920, The origin of the faults, anticlines, and buried granite ridge of the northern part of the Mid-Continent oil and gas fields: U. S. Geol. Survey, Prof. Paper 128, p. 75-84.

Fenneman, N. M., 1938, Physiography of Eastern United States, McGraw-Hill Book Co., New York City.

Fischer, R. P., 1937, Sedimentary deposits of copper, vanadium, uranium, and silver in southwestern United States: Econ. Geology, vol. 32, p. 906-951.

Fisher, H. C., Jr., 1956, Surface geology of the Belford area, Osage County, Oklahoma: Univ. of Oklahoma., unpublished M. S. thesis.

Foley, L. L., 1926, Origin of the faults in Creek and Osage Counties, Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 10, p. 293-303.

Galloway, H. M., Murphy, H. F., and Gray, Fenton, 1952, Soil Associations of Pawnee County, Oklahoma: Okla. Agr. Exper. Sta., Misc. Pub. 28.

Gardner, W. E., 1956, Geology of the Barnsdall area, Osage County, Oklahoma: Univ. of Okla., unpublished M. S. thesis.

Girty, G. H., 1915, Fauna of the Wewoka formation of Oklahoma: U. S. Geol. Survey, Bull. 544.

Gould, C. N., 1905, Geology and water resources of Oklahoma: U.S. Geol. Survey, Water-Supply Paper 148.

Gould, C. N., 1911, Structural materials of Oklahoma: Okla. Geol. Survey, Bull. 5.

Gould C. N., and Decker, C. E., 1925, Index to the stratigraphy of Oklahoma: Okla. Geol. Survey, Bull. 35.

Gould C. N., Hutchison, L. L., and Nelson, G., 1908, Preliminary report on the mineral resources of Oklahoma: Okla. Geol. Survey, Bull. 1.

Gould, C. N., Ohern, D. W., and Hutchison, L. L., 1910, Proposed groups of Pennsylvanian rocks of eastern Oklahoma: Univ. of Okla., Research Bull. 3.

Gould, C. N., and Wilson, R. A., 1927, The Upper Paleozoic rocks of Oklahoma: Okla. Geol. Survey, Bull. 41.

Green, D. A., 1936, Permian and Pennsylvanian sediments exposed in central and west central Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 20, p. 1454-1475.

Green, D. A., 1937, Major divisions of Permian in Oklahoma and southern Kansas: Amer. Assoc. Petroleum Geologists, Bull., vol. 21, p. 1515-1533.

Greene, F. C., 1930, Geology of Pawnee County, Oklahoma: Okla. Geol. Survey, Bull. 40 (CC), vol. III, p. 169-190.

Greig, P. B., Jr., 1954, Geology of the Hallett area, Pawnee County, Oklahoma: Univ. of Okla., unpublished M. S. thesis.

Ham, W. E., 1939, Origin and age of the Pawhuska rock plain of Oklahoma and Kansas: Univ. of Okla. unpublished M. S. thesis.

Haworth, Erasmus, 1895, The stratigraphy of the Kansas coal measures: Kansas Univ. Quart., vol. 3, p. 271-290.

Haworth, Erasmus, 1898, Special report on coal: Kansas Univ. Geol. Survey, vol. 3.

Hay, R., 1893, Kansas State Board of Agri., 8th Bienn. Rept., Pt. 2, p. 104.

Heald, K. C., 1916, The oil and gas geology of the Foraker quadrangle, Osage County, Oklahoma: U. S. Geol. Survey, Bull 641b, p. 17-47.

Heald, K. C., 1918, Geological structure of the northwest part of the Pawhuska qradrangle, Oklahoma: U. S. Geol. Survey, Bull. 691 (C).

Heald, K. C., 1918a, Structure and oil and gas resources of the Osage reservation, Oklahoma, T. 27 N., R. 7 E.: U.S. Geol. Survey, Bull. 686 (K), p. 130-131.

Heald, K. C., 1919, Structure and oil and gas resources of the Osage reservation, Oklahoma, T. 27 N., R. 8 E.: U.S. Geol. Survey, Bull. 686 (Q), p. 213-222.

Heald, K. C., Bowen, C. F., and others, 1922, Structure and oil and gas resources of the Osage Reservation, Oklahoma, T. 24 N., R. 9 E.: U. S. Geol. Survey, Bull. 686 (P), p. 193-196.

Heald, K. C., and Mather, K. F., 1919, Structure and oil and gas resources of the Osage reservation, Oklahoma, Tps 24 and 25 N., R. 8 E: U. S. Geol. Survey, Bull. 686 (M), p. 149-170.

Hiestand, T. C., 1935, Regional investigations, Oklahoma and Kansas: Amer. Assoc. Petroleum Geologists, Bull., vol. 19, p. 948-970.

Hill, J. W., 1953, South-central district, Oklahoma: U. S. Atomic Energy Commission, Trace Elements Inv. Rept. 330, p. 200-204.

Hruby, A. J., 1955, Geology of northeastern Kay County, Oklahoma: Univ. of Oklahoma., unpublished M. S. thesis.

Hutchison, L. L., 1907, The stratigraphy of Oklahoma north of the parallel of thirty-five degrees and thirty minutes: Univ. of Okla., unpublished Bachelor of Arts thesis.

Hutchison, L. L., 1911, Preliminary report on the rock asphalt, asphaltite, petroleum and natural gas in Oklahoma: Okla. Geol. Survey, Bull. 2.

Ireland, H. A., 1955, Pre-Cambrian surface in northeastern Oklahoma and parts of adjacent states: Amer. Assoc. Petroleum Geologists, Bull., vol. 39, p. 468-483.

Johnson, J. H., 1946, Lime-secreting algae from the Pennsylvanian and Permian of Kansas: Geol. Soc. America, Bull., vol. 57, p. 1087-1119.

Kirk, M. Z., 1896, A geologic section along the Neosho and Cottonwood Rivers, Kansas: Kansas Univ. Geol. Survey, vol. 1, p. 72-85.

Koschman, A. H., 1930, Payne County: Okla. Geol Survey, Bull. 40 (X), vol. III, p. 159-167.

Leitner, D. G. 1956, Geology of the Bald Hill area, Okmulgee County, Oklahoma: Univ. of Oklahoma., unpublished M. S. thesis.

Levorsen, A. I., 1927, Convergence studies in the Mid-Continent region: Amer. Assoc. Petroleum Geologists, Bull., vol. 11, p. 657-682.

Lavorsen, A. I., 1930 Geology of Seminole County: Okla. Geol. Survey, Bull. 40 (BB), vol. III, p. 289-352.

Luff, G., 1956, Geology of the Beggs area, Okmulgee County, Oklahoma: Univ. of Okla. unpublished Master of Science thesis.

Lukert, L. H., 1949, Subsurface cross sections from Marion County, Kansas, to Osage County, Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 33, p. 131-151.

Masters, K. E., 1955, Geology of Prague area, Lincoln and Pottawatomie Counties, Oklahoma: Univ. of Okla., unpublished Master of Science thesis.

Melton, F A., 1930, Age of the Ouachita orogeny and its tectonic effects: Amer. Assoc. Petroleum Geologists, Bull., vol. 14, p. 57-72.

Merritt, C. A., 1940, Copper in the 'red beds' of Oklahoma: Okla. Geol. Survey, Min. Rept. 8.

Miller, D. N., Jr. and Folk, R. L., 1955, Occurrence of detrital magnetite and ilmenite in red sediments: new approach to significance of red beds: Amer. Assoc. Petroleum Geologists, Bull., vol. 39, p. 338-345.

Miser, Hugh D., 1926, 1954, Geologic Map of Oklahoma: U. S. Geol. Survey and Okla. Geol. Survey.

Moore, R. C., 1932, A reclassification of the Pennsylvanian system in the northern Mid-Continent region: Kansas Geol. Soc. Guidebook, 6th Ann. Field Conference, p. 79-98.

Moore, R. C., 1936, Stratigraphic classification of the Pennsylvanian rocks of Kansas: Kansas, State Geol. Survey, Bull. 22.

Moore, R. C., 1936a, Pennsylvanian and lower Permian rocks of the Kansas Missouri region: Kansas Geol. Soc., Guidebook, 10th Ann. Field Conference, p. 7-16.

Moore, R. C., 1940, Carboniferous-Permian boundary: Amer. Assoc. Petroleum Geologists, Bull., vol. 24, p. 282-336.

Moore, R. C., 1949, Divisions of the Pennsylvanian system in Kansas: Kansas, State Geol. Survey, Bull. 83.

Moore, R. C., and Landes, K. K., 1937, Geologic Map of Kansas: Kansas, Geol. Survey.

Moore, R. C., and Moss, R. C., 1933, Permian-Pennsylvanian boundary in the northern Mid-Continent area: (Abstract) Geol. Soc. America, Proc., p. 100.

Moore, R. C., and Mudge, M. R., 1956, Reclassification of some lower Permian and upper Pennsylvanian strata in northern Mid-Continent: Amer. Assoc. Petroleum Geologists, Bull., vol. 40, p. 2271-2278.

Moore, R. C., Newell, N. D., Dott. R. H., and Borden, J. L., 1937, Definition and classification of the Missouri sub-series of the Pennsylvanian series of northeastern Oklahoma: Kansas Geol. Soc. Guidebook, 11th Ann. Field Conference, p. 43.

Moore, R. C. and others, 1944, Correlation of Pennsylvanian formations of North America: Geol. Soc. America, Bull., vol. 55, p. 657-706.

Moore, R. C., 1951, The Kansas rock column: Kansas, State Geol. Survey Bull. 89.

Morgan, George D., 1924, Geology of the Stonewall quadrangle, Oklahoma: (Okla.) Bureau of Geology, Bull. 2.

Mudge, R. M., 1956, Sandstones and channels in upper Pennsylvanian and lower Permian in Kansas: Amer. Assoc. Petroleum Geologists, Bull., vol. 40, p. 654-678.

Nakayama, Eugene, 1955, Geology of southeastern Payne County, Oklahoma: Univ. of Okla., unpublished Master of Science thesis.

Newell, N. D., 1942, Late Paleozoic pelecypods: Pectinacea and Mytilacea: Kansas State Geol. Survey, vol. 10.

Noe, A. C., 1925, Pennsylvanian flora of northern Illinois: Illinois Geol. Survey, Bull. 52.

Noll, C. R., Jr., 1955, Geology of southeastern Kay County, Oklahoma: Univ. of Okla., unpublished M. S. thesis.
Oakes, M. C., 1940, Geology and mineral resources of Washington County, Oklahoma: Okla. Geol. Survey, Bull. 62.
Oakes, M. C., 1940a, Results of recent field studies in Osage, Washington, and Nowata Counties, Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 24, p. 726-727.
Oakes, M. C., 1946, The lower Permian and upper Pennsylvanian of north; central Oklahoma: Okla. City Geol. Soc., Field Trip Guidebook, Nov.
Oakes, M. C., 1950, Mapping the Missouri-Virgil boundary in northeastern Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 34, p. 620.
Oakes, M. C., 1951, The proposed Barnsdall and Tallant formations in Oklahoma: Tulsa Geol. Soc., Digest, vol. 19, p. 119-122.
Oakes, M. C., 1952, The geology of Tulsa County, Oklahoma: Okla. Geol. Survey, Bull. 69.
O'Connor, H. G., and Jewett, J. M., 1952, The Red Eagle formation in Kansas: Kansas, State Geol. Survey, Bull. 96, p. 329-362.
Ohern, D. W., 1910, The stratigraphy of the older Pennsylvanian rocks of northeastern Oklahoma: Univ. of Okla., Research Bull. 4.
Okla. City Geol. Soc., 1932, 1955, Highway geology of Oklahoma: Okla. City Geol. Soc.
Page, K. G., 1955, The subsurface geology of southern Noble County, Oklahoma: Okla. City Geol. Soc., Shale Shaker, vol. 5, no. 10.
Parker, E. C., Murray, A. N., and Oakes, M. C., 1946, The lower Permian and upper Pennsylvanian north central Oklahoma: Okla. City Geol. Soc. Field Trip Guidebook.
Plummer, F. B., and Moore, R. C., 1932, Stratigraphy of the Pennsylvanian formations of north central Texas: Texas Univ., Bull. 2132.
Powers, Sidney, 1931, Structural geology of northeastern Oklahoma: Jour. Geology, vol. 39, p. 117-132.
Prosser, C. S., 1895, The classification of the upper Paleozoic rocks of central Kansas: Jour. Geology, vol. 3, p. 682-705; 764-800.
Prosser, C. S., 1902, Revised classification of the upper Paleozoic formations of Kansas: Jour. Geology, vol. 10 p. 703-737.
Ries, Edward R., 1955, Geology and mineral resources of Okfuskee County, Oklahoma: Okla. Geol. Survey, Bull. 71.
Russell, O. R., 1955, Geology of the Hominy area, Osage County, Oklahoma: Univ. of Okla., unpublished M. S. thesis.
Shannon, C. W., 1914, Mineral resources of Oklahoma and statistics of production from 1901 to 1914: Okla. Geol. Survey, Bull. 22, part 2.
Shannon, C. W., and others, 1917, Petroleum and natural gas in Oklahoma: Okla. Geol. Survey, Bull. 19, pt. 2.

Shannon, C. W., and others (revised by C. L. Cooper), 1926, Coal in Oklahoma: Okla. Geol. Survey, Bull. 4.
Shannon, P. J., 1954, The geology of the Pawhuska area, Osage County, Oklahoma: Univ. of Okla., unpublished M. S. thesis.
Shawnee Oil Scouts Assoc. and others, 1949-1956, Oklahoma oil and gas field development: Nat. Oil Scouts and Landmen's Assoc., Yearbook.
Sheerar, L. F., 1932, The clays and shales of Oklahoma. Okla. Agri., and Mech. College, Div. of Engineering, Publ., vol. 3, no. 5.
Sherrill, R. E., 1929, Origin of the en echelon faults in north-central Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 13, p. 31-37.
Skelton, A. G., 1944, Bibliography of oil pools in Oklahoma for 1942: Okla. Geol. Survey, Mineral Rept. 17.
Skelton, A. G., and Skelton, M. B., 1942, A bibliography of Oklahoma oil and gas pools: Okla. Geol. Survey, Bull. 63.
Smith, A. J., 1905, Reading blue limestone: Kansas Acad. Science, Trans., vol. 19, p. 150-153.
Smith, J. P., 1894, The Arkansas coal measures in their relation to the Pacific Carboniferous province: Jour. Geology, vol. 2, p. 187-203.
Snider, L. C., 1911, Preliminary report on the clays and clay industries of Oklahoma: Okla. Geol. Survey, Bull. 7.
Snider, L. C., 1911a, Preliminary report on the road materials and road conditions of Oklahoma: Okla. Geol. Survey, Bull. 8.
Snider, L. C., 1917, Geography of Oklahoma: Okla. Geol. Survey, Bull. 27.
Stehli, F. G., 1954, Lower Leonardian Brachiopoda of the Sierra Diablo: Amer. Museum Nat. History, Bull., vol. 105, art. 3.
Swallow, G. C., 1866, Preliminary report of the Geological Survey of Kansas: Kansas Geol. Survey.
Tanner, W. F., 1956, Geology of Seminole County, Oklahoma: Okla. Geol. Survey, Bull. 74.
Tanner, W. F., 1956a, Geology of northeastern Osage County, Oklahoma: Oklahoma Geol. Survey, Circ. 40.
Tarr, R. S., 1955, Paleogeologic map at base of Woodford, and Hunton isopachous map of Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 39, p. 1851-1858.
Taylor, R. C., 1953, Geology of the Foraker area, Osage County, Oklahoma: Univ. of Okla., unpublished M. S. thesis.
Tomlinson, C. W., and others, 1940, Classification of Permian rocks: Amer. Assoc. Petroleum Geologists, Bull., vol. 24, p. 337-358.
Trout, L. E., and Myers, G. W., 1915, Bibliography of Oklahoma geology with subject index: Okla. Geol. Survey, Bull. 25.
Tulsa Geol. Soc., 1941, Pennsylvanian stratigraphy of Tulsa County: Tulsa Geol. Soc., Field Trip Guidebook, Nov.
Vosburg, D. L., 1954, Geology of the Burbank-Shidler area, Osage County, Oklahoma: Univ. of Okla., unpublished Master of Science thesis.

Weller, J. M., 1956, Argument for diastrophic control of late Paleozoic cyclothems: Amer. Assoc. Petroleum Geologists, Bull., vol. 40, p. 17-50.

West, A. E., 1955, Geology of northeastern Lincoln County, Oklahoma: Univ. of Okla., unpublished Master of Science thesis.

White, David, and others, 1922, Structure and oil and gas resources of the Osage reservation, Oklahoma: U.S. Geol. Survey, Bull. 686.

White, Randall, 1941, Red Fork shoestring sand pool, Pawnee, Creek and Tulsa Counties, northeastern Oklahoma: Amer. Assoc. Petroleum Geologists, Stratigraphic Type Oil Fields, p. 473-491.

Winchester, D. E., Heald, K. C., and others, 1918, Structure and oil and gas resources of the Osage Reservation, T. 25 N., R. 10 E.: U. S. Geol. Survey, Bull. 686 (G), p 57-73.

Woods, R. H., 1911, Oil and gas development in north-central Oklahoma: U S. Geol. Survey, Bull. 531b, p. 27-53.

APPENDIX A

INSOLUBLE RESIDUE ANALYSES OF KEY LIMESTONES PAWNEE COUNTY, OKLAHOMA

Location	Total Insolubles (weight %)**	Clay Fraction %	Clay Fraction Color	Silt Fraction %	Silt Fraction Composition
Lecompton limestone					
NE ¼ 23-21N-7E	9.4 N	7.6	gray	1.8	gray quartz silt
NE ¼ 27-20N-7E	4.2 S	4.1	gy bwn	0.1	quartz sand and silt
SE ¼ 22-20N-7E	11.2* S				
Turkey Run limestone					
SW ¼ 22-22N-7E	5.3 N	4.8	gray	0.5	quartz silt and carbonaceous matter
NW ¼ 27-20N-7E	5.1 S	4.8	gray	0.3	quartz silt and limonite
NW ¼ 23-21N-7E	6.1* C				
SE ¼ 6-21N-7E	3.0* C				
Bird Creek limestone					
NW ¼ 19-22N-7E	5.5 N	4.2	dk gy	0.3	dark gray silt, pyrite, and a few sand grains
32-20N-7E	32.4 S	8.6	dk gy	23.8	unsorted quartz sand and silt, trace of pyrite and microfauna
E ½ 11-23N-6E	8.6 N	8.2	gray	0.4	quartz silt and pyrite
Wakarusa limestone					
NE ¼ 35-20N-6E	4.4 S	4.2	gy bwn	0.2	quartz silt and small pellets of red clay
NW ¼ 18-21N-7E	8.2* C				
Reading limestone					
NE ¼ 15-21N-6E	16.7 N	5.3	rd bwn	11.4	f.g. quartz sand, silt and mica
SW ¼ 23-20N-6E	67.1 S	11.8	buff	55.3	f.g. quartz sand
NE ¼ 14-21N-6E	39.6* C				
Elmont limestone					
SW ¼ 10-22N-6E	6.1 N	5.3	lt gy	0.8	quartz silt and f.g. sand
NE ¼ 3-19N-6E	20.6 S	16.1	lt gy	4.5	quartz silt and trace of sand
SW ¼ 14-21N-6E	3.2* C				

* Analyses from unpublished data in the files of the Oklahoma Geological Survey

** The letters N, S, and C which follow the total insoluble percentage figure designate the relative part of the county, north, south, or central, respectively, from which the sample analyzed was collected.

INSOLUBLE RESIDUE ANALYSES OF KEY LIMESTONES
PAWNEE COUNTY, OKLAHOMA (Continued)

Location	Total Insolubles (weight %)**	Clay Fraction %	Clay Fraction Color	Silt Fraction %	Silt Fraction Composition
Brownville limestone					
SE ¼ 23-23N-5E	15.6 N	4.8	lt gy	10.8	f.g. sand and mica
SW ¼ 13-21N-5E	0.9 C	0.9	bwn	trace	quartz silt
NE ¼ 30-20N-6E	71.6 S	13.6	gray	58.0	f.g. quartz sand, pyrite, and mica
SE ¼ 30-22N-6E	2.0* C				
SW ¼ 18-21N-6E	2.0* C				
Americus limestone					
SE ¼ 34-24N-5E	4.8 N	3.0	dk gy	1.8	quartz and trace of white chert
SW ¼ 34-20N-5E	9.8 S	6.5	dk gy	3.3	gray quartz silt
NE ¼ 15-22N-5E	3.4* C				
NW ¼ 26-22N-5E	5.7* C				
Long Creek limestone					
SE ¼ 4-23N-5E	6.5 N	4.2	gy bwn	2.3	quartz silt and a few shell fragments
SW ¼ 34-20N-5E	4.3 S	3.7	dk gy	0.6	quartz silt and glauconite
NW ¼ 34-23N-5E	11.9* C				
NE ¼ 15-22N-5E	14.9* C				
SE ¼ 16-24N-5E	4.9* N				
NW ¼ 4-21N-5E	8.4* C				
Red Eagle limestone					
SW ¼ 33-24N-5E	8.5 N	6.2	dk gy	2.3	dark gray silt and trace of quartz sand
NW ¼ 28-20N-5E	4.8 S	3.9	dk gy	0.9	gray quartz silt and chert fragments
NE ¼ 28-21N-5E	6.5* C				
Neva limestone					
NE ¼ 31-23N-5E	20.7 N	2.9	gray	17.8	chert, quartz silt, and silicified microfauna
SE ¼ 25-21N-4E	13.1 S	0.7	buff	12.4	unsorted quartz sand and silicified microfauna
NE ¼ 31-23N-5E	20.7 N	2.9	gray	17.8	chert, quartz silt, and silicified microfauna
SE ¼ 25-21N-4E	13.1 S	0.7	buff	12.4	unsorted quartz sand and silicified microfauna
SW ¼ 7-22N-5E	4.8* C				
NW ¼ 21-24N-5E	12.4* N				

INSOLUBLE RESIDUE ANALYSES OF KEY LIMESTONES
PAWNEE COUNTY, OKLAHOMA (Continued)

Location	Total Insolubles (weight %)**	Clay Fraction %	Clay Fraction Color	Silt Fraction %	Silt Fraction Composition
SE ¼ 2-21N-4E	4.6* C				
SE ¼ 2-21N-4E	4.0* C				
Cottonwood limestone					
SE ¼ 2-23N-4E	10.7 N	6.2	gray	4.5	quartz silt and sand and silicified microfauna
SW ¼ 22-22N-4E	7.4 C	5.1	buff	2.3	quartz sand and silicified microfauna
SE ¼ 2-23N-4E	10.9* N				
Wreford limestone					
SW ¼ 24-23N-4E	8.1 N	5.7	buff	2.4	quartz silt, limonite, red clay pellets, microfauna, and shell fragments
SE ¼ 4-22N-4E	23.8 C	3.0	bwn	20.8	m.g. euhedral quartz sand
Fort Riley limestone					
SE ¼ 18-23N-3E	18.8 N	8.0	gray	10.8	gray silty quartz sand
NE ¼ 15-22N-3E	16.4 S	4.9	gray	11.5	f.g. quartz sand
SE ¼ 32-23N-3E	32.4* C				
Winfield limestone					
N ½ 7-22N-3E	24.1 C	5.0	buff	19.1	f.g. quartz sand and microfauna

Appendix B

Register of Fossil Collecting Sites

Tallant formation
1. Sandstone exposure along abandoned road leading to Arkansas River bottomland in SE ¼ sec. 9, T. 20 N., R. 9 E.

Kanwaka shale
**2. Floor of abandoned shale pit in SE ¼ sec. 17, T. 21 N., R. 8 E.

Lecompton limestone
*3. Limestone exposure in road cut along both sides of U.S. Highway 64 in NW ¼ sec. 23, T. 21 N., R. 7 E. (about half way down hill).
4. Limestone exposure in borrow ditch along road on the east line of NE ¼ sec. 26, T. 21 N., R. 7 E.

Turkey Run limestone
5. Limestone outcrop at top of hill along north side of U.S. Highway 64 in NW ¼ sec. 23, T. 21 N., R. 7 E. (at top of hill near west section line).

Severy shale
*6. Shale exposed immediately above Turkey Run limestone along the east side of the road on the west line of NW ¼ sec. 23, T. 21 N., R. 7 E. (about 100 yards south of U.S. Highway 64).

Hallett shale
7. Limestone outcrop in borrow ditch on the north side of the road along the south line of the SE ¼ sec. 17, T. 20 N., R. 7 E. (about 50 yards east of Oklahoma Highway 99).
8. Limestone outcrop along north side of Missouri, Kansas, and Texas Railroad west of overpass on Oklahoma Highway 99 in the SE ¼ sec. 20, T. 20 N., R. 7 E.
9. Limestone outcrop in field in NE ¼ sec. 4, T. 20 N., R. 7 E., immediately across fence to the north of the Missouri, Kansas, and Texas Railroad.

Wakarusa limestone
10. Limestone outcrop in borrow ditches along road on the north line of NE ¼ sec. 31, T. 21 N., R. 7 E.
11. Limestone outcrop on both sides of road on south line of SW ¼ sec. 32, T. 21 N., R. 7 E.
*12. Limestone outcrop on east bank of creek immediately north of road along south line of SE ¼ sec. 35, T. 21 N., R. 6 E.

Reading limestone
*13. Limestone exposures in borrow ditch on east side of road along west line of the NW ¼ sec. 17, T. 20 N., R. 7 E.

Elmont limestone
**14. Upper limestone exposed on south slope of small outlier along Black Bear Creek in the NE ¼ sec. 3, T. 22 N., R. 6 E.
15. Limestone outcrop along abandoned road on the south line of the SW ¼ sec. 34, T. 21 N., R. 6 E. about ¼ mile east of section corner (upper Elmont limestone).
16. Shale exposure along abandoned road on the south line of the SW ¼ sec. 34, T. 21 N., R. 6 E., about 100 yards east of section corner (middle Elmont shale).

Gano shale
17. Stray limestone exposed along north side of U.S. Highway 64 in the SW ¼ sec. 15, T. 21 N., R. 6 E., immediately east of section corner.

"Grayhorse" limestone
18. Outcrop of limy shale on the east bank of creek immediately north of road along south line of the SE ¼ sec. 5, T. 21 N., R. 6 E.
19. Outcrop of limy shale along bluff overlooking Arkansas River in the NE ¼ sec. 4, T. 22 N., R. 6 E.
20. Outcrop of limy shale along north side of road along south line of the SE ¼ sec. 3, T. 20 N., R. 6 E.

Pony Creek shale
21. Thin limestone 10 feet above "Grayhorse" in the borrow ditch along the road on the south line of the SW ¼ sec. 27, T. 21 N., R. 6 E.
22. Thin limestone in borrow ditch along north side of the road on the south line of the SE ¼ sec. 5, T. 21 N., R. 6 E. (10 feet above Grayhorse (?) in the site 18).

Brownville limestone
23. Abandoned quarries in Brownville limestone in the NE ¼ sec. 13, T 21 N., R. 5 E.
24. Limestone ledge capping bluff west of Black Bear Creek in the NE ¼ sec. 29, T. 22 N., R. 6 E.

Admire shale
25. Thin fusulinid limestone exposed in borrow ditch on east side of curving north-south road about 100 yards south of the Spring Creek schoolhouse, SE ¼ sec. 35, T. 23 N., R. 5 E. (25 feet below Americus limestone in site 27).
26. Thin fusulinid limestone exposed in borrow ditch on east side of road on the west line of the SW ¼ sec. 19, T. 22 N., R. 6 E. (about 60 feet below the Americus limestone).

Americus limestone
27. Limestone outcrop on east side of curving north-south road about ¼ mile south of Spring Creek schoolhouse, SE ¼ sec. 35, T. 23 N., R. 5 E.
**28. Limestone ledge in west bank of Black Bear Creek immediately north of automobile bridge in the SW ¼ sec. 33, T. 22 N., R. 5 E.
29. Limestone ledge on east side of road along the west line of the SW ¼ sec. 23, T. 22 N., R. 5 E.
30. Limestone exposures in borrow ditch and in field north of road along south line of the SW ¼ sec. 1, T. 20 N., R. 5 E.
**31. Limestone exposures in field about ¼ mile east of the road along the west line of the NW ¼ sec. 31, T. 21 N., R. 6 E.
32. Limestone outcrop along the road on north and west lines of the NW ¼ sec. 6, T. 20 N., R. 6 E., near section corner.

Long Creek limestone
33. Limestone exposures along the north and east lines of the NE ¼ sec. 4, T. 23 N., R. 5 E., near the section corner
34. Limestone exposures in the field along the east side of the road in the NW ¼ sec. 4, T. 21 N., R. 5 E.
35. Limestone outcrop on the south side of Oklahoma Highway 18 along the north line of the NW ¼ sec. 3, T. 23 N., 5 E.

Red Eagle limestone
36. Limestone quarry in the NW ¼ sec. 28, T. 20 N., R. 5 E.
37. Limestone exposures in and along both sides of the road on the south line of the SW ¼ sec. 23, T. 20 N., R. 5 E.
38. Limestone exposures in small shale pit in the NW ¼ sec. 20, T. 21 N., R. 5 E., along the west side of Oklahoma Highway 18.
**39. Limestone exposure along the east side of Oklahoma Highway 18 south of creek in the SW ¼ sec. 19, T. 22 N., R. 5 E.
40. Limestone exposures in Lions Club picnic grounds in the SE ¼ sec. 18, T. 22 N., R. 5 E.
41. Limestone exposures on the west slope of the outlier immediately east of SW corner sec. 28, T. 22 N., R. 5 E.
**42. Limestone outcrop on the south side of the road along the north line of the NW ¼ sec. 20, T. 22 N., R. 5 E.
43. Limestone exposures along the automobile trail on the east line of the SE ¼ sec. 17, T. 24 N., R. 5. E.
*44. Limestone outcrop in the SE ¼ sec. 31, T. 22 N., R. 5 E., across U.S. Highway 64 from Hill's store in the southeastern part of the town of Pawnee.

Roca shale

*45. Shale bank along the east side of Oklahoma Highway 18 in the SW ¼ sec. 29,T. 23 N., R. 5 E.

46. Limestone outcrop on the east side of Oklahoma Highway 18 in NW ¼ sec. 29, T. 22 N., R. 5 E.

Neva limestone

47. Limestone outcrop along the west side of Oklahoma Highway 18 in the NE ¼ sec. 31, T. 23 N., R. 5 E.

48. Small abandoned limestone quarry in the SE ¼ sec. 19, T. 23 N., R. 5 E., immediately west of the Victor schoolhouse.

*49. Limestone quarry in the NE ¼ sec. 20, T. 23 N., R. 5 E, about 100 yards east of Oklahoma Highway 18.

**50. Limestone quarry in the SW ¼ sec. 30, T. 24 N., R. 5 E.

51. Limestone outcrop on the east side of road along the west line of the NW ¼ sec. 28, T. 24 N., R. 5 E.

52. Limestone exposure in the bed of Skedee Creek in the NW ¼ sec. 13, T. 22 N., R. 4 E.

Fort Riley limestone

53. Limestone exposures along both sides of the road on the south line of the SW ¼ sec. 33, T. 23 N., R. 3 E., near section corner.

54. Limestone exposures in field immediately east of the road along the west line of the NW ¼ sec. 28, T. 23 N., R. 3 E., and just south of the NW corner of the section.

*Fossils moderately abundant

**Fossils abundant

FOSSIL

FORMATION

Pennsylvanian system

Permian system

APPENDIX D

MEASURED STRATIGRAPHIC SECTIONS

PAWNEE COUNTY, OKLAHOMA[5]

1. NW ¼ Sec. 7, T. 22 N., R. 3 E.: Westward along Oklahoma Highway 15 to county line

Chase group
  Winfield limestone
    4. Sandstone,[6] dark-red to brown, well-bedded in beds to 1 foot thick, partly calcareous, with lenses of dark-gray dense sandy limestone commonly leached, caps hill 7
  Doyle shale
    3. Shale, maroon, green and yellow, variegated, flaky, with a thin bed of dark-gray nodular fresh-water (?) limestone containing steinkerns of a small high-spired gastropod 2
    2. Shale, red, blocky 8
    1. Siltstone, red, shaly, with interbedded red shale, base covered 6

2. NE ¼ Sec. 7, T. 22 N., R. 3 E.: northeastward from old sandstone quarry south of Oklahoma Highway 15 to road cut in outlier of Winfield limestone

Chase group
  Winfield limestone
    5. Sandstone, white to red, thin-bedded, calcareous, with lenticular beds of gray sandy limestone and limy sandstone, caps hill 4.5
  Doyle shale
    4. Shale, green 0.5
    3. Shale, red 15.5
    2. Covered, probably red shale 36
    1. Sandstone, red, massive, solution channels in top, base covered 2.5

---

[5]Additional measured sections in Pawnee County are listed by Oakes (1952), Appendix A, sections 89 to 92.

The following 42 sections have been carefully selected from the field notes in an attempt to build a complete and representative composite section for Pawnee County. The sections are arranged in descending stratigraphic sequence as nearly as possible. Comparison on Plate I of the location, direction of measurement, and key beds of each section should serve to locate the sections and to orient the interested reader in the field so that, if desired, the sections may be re-examined.

The sections were measured upward using hand level and steel tape. Since the dip of the surface beds is generally about one half degree and only a few of the sections extend over one quarter mile horizontally, no correction in thickness has been made for the effect of dip. Many of the sections were measured parallel to strike and need no such correction.

Because of the poor exposures and scarcity of key beds in the western part of the county, it was impossible to obtain complete measurements of the stratigraphic sequence above the Cottonwood limestone. Where gaps occur, thicknesses have been determined from electric logs and are given in the text.

[6]Unless otherwise noted, all sandstones are fine grained.

3. NE ¼ Sec. 20, T. 23 N., R. 3 E.: westward along road on north line of section

Chase group
  Doyle shale
    11. Covered by red shale, not measured

Feet

    10. Conglomerate, red, calcareous, composed of sandstone and limestone pebbles to 2 inches in length 1
    9. Covered, probably red shale 1
    8. Sandstone, red massive to cross-bedded 13.5
    7. Shale, red, mostly covered 23
    6. Siltstone, red, shaly, appears to have channeled surface of underlying shale 2
    5. Shale, green, grading upward to red and gray, with thin beds of red sandstone 10
  Fort Riley limestone
    4. Sandstone, light gray-green, thin-bedded to massive, in beds up to 1.5 feet thick, interbedded with green shale especially in lower part 5
    3. Shale, green 6
    2. Limestone, gray-green, shaly, fossiliferous, limesone pellets stand out on weathered surface 1
  Matfield shale
    1. Shale, green, with a few siltstone laminae, grades downward to red shale, base covered 5

4. NE ¼ sec. 26, T. 23 N., 3 E.: Southwestward from limestone float in drainage channel to top of outlier of Fort Riley

Chase group
  Fort Riley limestone
    10. Sandstone, light tan, bedded, with pothole-like structures up to 1 foot in diameter on top surface, caps hill 2
    9. Shale, gray, containing fragments of fossiliferous gray limestone in float 13
  Matfield shale
    8. Shale, red, mostly covered 55
    7. Sandstone, massive, float only 1
    6. Covered, probably red shale, with limestone nodules containing calcite-filled dessication cracks in float near top 10
    5. Sandstone, red, cross-bedded, base covered 3
    4. Covered, probably shale 10
    3. Sandstone, highly cross-bedded, mostly covered 7
    2. Covered, red shale float 15
  Wreford limestone
    1. Limestone, red to gray, fossiliferous, containing yellow ferruginous pellets (highest float in drainage channel) 0.5

5. NE ¼ sec. 5, T. 22 N., R. 3 E.; eastward along road on north line of section

Chase group

Doyle shale

6. Shale and sandstone, red, not measured

5. Sandstone, thin-bedded, shaly, with interbedded shale 3

Fort Riley limestone

4. Limestone, brown, rotten, composed largely of algal pellets most of which have altered to limonite, contains molluscan fauna and *Orbiculoidea*; top covered 3.5

3. Limestone, gray-brown, well-bedded, silty, contains molluscan fauna, in beds to 1 foot thick with interbedded shale 15

Matfield shale

2. Shale, gray, interbedded with thin beds of calcareous siltsone 3.5

1. Shale, red and gray, calcareous, grading upward to gray, non-calcareous, silty, weathers buff, base covered 10

6. SE ¼ sec. 4, T. 22 N., R. 4 E.; eastward along Oklahoma Highway 15 along south line of section

Chase group

Wreford (?) limestone

4. Limestone, gray, sandy, siliceous, partly fossiliferous, with abundant myalinids, apparently lenticular in underlying sandstone, locally recrystallized, vuggy 1.5

3. Sandstone, white with brown spots, well-bedded, calcareous but mostly leached, with numerous solution pits and channels 3.5

2. Limestone, thin-bedded, highly fossiliferous (myalinids and pectinoids), interbedded with red shale in lower 1 foot 2

Council Grove group

Garrison shale

1. Shale, red with light-gray mottling, partly calcareous, base covered 5

7. SW ¼ sec. 5, T. 22 N., R. 4 E., westward along Oklahoma Highway 15 along south line of section

Feet

Chase group

Wreford (?) limestone

6. Sandstone, white with dark brown spots, calcareous to leached, numerous solution pits and channels, base covered 3

Council Grove group

Garrison shale

5. Shale, dark red and brown, partly calcareous, sandy, top covered 31

4. Sandstone, dark red, shaly, highly cross-bedded, probably lenticular 6

3. Shale, red, containing a few beds of cross-bedded sandstone to 8 inches thick 12

2. Sandstone, light-gray fine- to medium-grained cross-bedded, thin bedded to massive probably lenticular 14

1. Shale, red sandy near top, base covered 20

8. NW ¼ sec. 15, T. 23 N., R. 4 E.; southward along creek from spring below sandstone scarp

Council Grove group

Garrison shale

11. Sandstone, light-tan with dark-brown beds and spots, massive at top to highly cross-bedded near base, vertical jointing in upper part, lower part containing cross-bedded lenses of conglomeratic limestone to 1.5 feet thick with pebbles up to 1 inch in diameter 6

10. Shale, red, with calcareous nodules, largely covered 40

9. Siltstone, yellow, highly calcareous, poorly exposed 2

8. Shale, red, with calcareous nodules 22

7. Sandstone, thin-bedded, partly calcareous, interbedded with red shale 5

Cottonwood limestone

6. Limestone, mottled silty, shaly, with molluscan fauna and abundant algal pellets 0.5

5. Covered, probably shale and limestone 3

4. Limestone, gray, shaly, composed of minute pellets, probably algal 1.5

Eskridge shale

3. Shale, red and green, variegated, partly silty, flaky, with beds of siltstone, grading upward to red shale with about 8 feet of thin-bedded highly cross-bedded sandstone in upper part 41.5

2. Sandstone, cross-bedded to massive to contorted, with thin lenses of green silty shale especially near base 18

1. Shale, red, with thin beds of green shale near top, base covered 2.5

9. SE ¼ sec. 2, T. 23 N., R. 4 E., eastward along road on south line of section

Council Grove group

Garrison shale

5. Covered, capped by limestone float Morrill limestone?) light gray with algal pellets and small shells evident on weathered surface 23

4. Sandstone, thin-bedded, base covered........ 1

3. Shale, red, with calcareous nodules 8

Cottonwood limestone

2. Limestone, light greenish-gray, crystalline, sparse molluscan fauna 2.2

Eskridge shale

1. Shale, red, with lenticular beds of well-bedded, partly contorted sandstone up to 3.5 feet thick, base covered 20

10. E ½ sec. 2, T. 23 N., R. 4 E.; southward from Neva limestone exposure in creek south of Oklahoma highway 18 to outlier of cottonwood limestone

Council Grove group

Garrison shale

- 6. Covered, capped by thin-bedded sandstone 6

Cottonwood limestone

- 5. Limestone surface, gray, weathered 1

Eskridge shale

- 4. Covered by Quaternary terrace 98

Neva limestone (lower member)

- 3. Limestone, gray-brown, fossiliferous 0.5
- 2. Covered 5
- 1. Limestone, brownish-gray, siliceous, fossiliferous, well bedded in beds up to 1 foot thick separated by thin beds of silty gray fossiliferous shale, zone of chert nodules in limestone about 7 feet above base, base covered 13

11. SW ¼ sec. 6, T. 20 N., R. 5 E.; southward along road on west line of section
(Around corner to south and east, this section is overlain by thick complex sequence of shale and sandstone, largely red)

Council Grove group

Neva limestone

- 5. Limestone, gray, crystalline, siliceous, crinoidal, with red shale inclusions, caps hill 1.5
- 4. Shale, gray 13
- 3. Limestone, gray, weathers dirty brown, crystalline, siliceous, crinoidal in three beds separated by shale, molluscan fauna in upper bed 2.5

Roca shale

- 2. Shale gray, mottled with red in center 13
- 1. Sandstone, massive to cross-bedded to contorted, base covered 25

12. NW ¼ sec. 32, T. 23 N., R. 5 E; southward along east side of Oklahoma Highway 18 from limestone exposure near culvert

Council Grove group

Eskridge shale

- 7. Shale, gray to red, not measured

Neva limestone

- 6. Limestone, greenish-gray, dense, with shell fragments 1
- 5. Sandstone, with interbedded shale in lower part 3
- 4. Shale, gray, mostly covered 13
- 3. Limestone, dark-gray, dense, sparsely fossiliferous, base covered (bed 6 of section 13) 1
- 2. Covered, gray shale in float 9
- 1. Limestone, brownish-gray, cherty, fossiliferous, base covered 5

13. SE ¼ sec. 30, and NE ¼ sec. 31, T. 23 N., R. 5 E.; southward along Oklahoma Highway 18 through section corner

Council Grove group

Neva limestone

- 6. Limestone, gray to reddish-gray, sparsely fossiliferous, algal at base, caps hill (bed 3 of section 12) 2.5
- 5. Shale, gray, with siltstone laminae 5.5
- 4. Limestone, gray to gray-brown, dense, fossiliferous, partly siliceous, containing chert nodules and lentils and a few thin beds of fossiliferous shale 11
- 3. Limestone, blue-gray, weathers buff, silty and siliceous, grading downward to siltstone 2

Roca shale

- 2. Shale and sandstone, interbedded 2
- 1. Shale, gray, weathers drab, containing calcareous concretions, base covered 13

14. SW ¼ sec. 29, T. 23 N., R. 5 E.; southward along Oklahoma Highway 18 from limestone outcrop on east side of road

Council Grove group

Neva limestone

- 5. Limestone, gray to gray-brown, cherty, fossiliferous, with thin intercalations of gray shale, grades downward to siltstone, caps hill 10

Roca shale

- 4. Shale, gray, with a few thin beds of highly fossiliferous shaly limestone and thin-bedded siltstone 16
- 3. Shale, gray fossiliferous interbedded with thin beds of highly fossiliferous limestone containing a molluscan fauna 5
- 2. Shale, red at base grading upward to reddish-brown, with gray-green siltstone laminae 22
- 1. Limestone, green to reddish-green, shaly, algal, sparsely fossiliferous, underlain by green shale, base covered (This section continues upward from bed 4 in section 15.) 0.5

15. NW ¼ sec. 29, T. 23 N., R. 5 E.; southward along Oklahoma Highway 18 from limestone outcrop east of highway on south bank of Coal Creek

Council Grove group

Roca shale

- 5. Shale, red grading upward to gray, top covered 10
- 4. Limestone, gray-green to maroon, mottled, sparsely fossiliferous, algal in lower part, base covered 0.5
- 3. Shale red, with a few thin beds of nodular limestone and light-colored siltstone 23
- 2. Covered, probably red shale 12
- 1. Limestone, gray, gray-green, and brown, sandy, containing irregular sandstone masses, base covered (bed 11 of section 16) 2

16. NE ¼ sec. 30, T. 22 N., R. 5 E.; northward along road on east line of section

Council Grove group

Roca shale

11.	Limestone, sandy, containing large irregular sandstone masses, molluscan fauna (bed 1 of section 15)	1.5
10.	Limestone, gray-green, crinoidal, with abundant shell fragments, containing recrystallized calcite	1.5
9.	Shale, green, brown, and red, partly silty	1.5
8.	Siltstone, thin-bedded	0.5
7.	Shale, brown, green, and red, partly silty	11.5
6.	Shale, gray	2
5.	Covered, probably shale with some sandstone	24

Red Eagle limestone

4.	Limestone, dark-gray, partly shaly, highly fossiliferous, with abundant "*Marginifera*"	1.5
3.	Shale, gray, calcareous, highly fossiliferous	1
2.	Limestone., gray, shaly, fossiliferous	0.5

Johnson shale

1.	Shale gray, not measured	

17. Sec. 23 T. 20 N., R. 5 E.; westward along road on south line of section from sandstone exposure in creek south of road

Council Grove group

Red Eagle limestone

13.	Limestone, gray, fossiliferous, in several beds separated by thin beds of gray shale, fusulinids abundant in middle beds	5.5

Johnson shale

12.	Shale, red at base grading to gray, marly at top, mostly covered	20
11.	Sandstone, thin-bedded, mainly red	1
10.	Covered, probably red shale	10
9.	Sandstone, purple and yellow mottled, highly calcareous	9
8.	Shale, gray, grading upward to red and gray mottled, mostly covered	14

Long Creek limestone

7.	Limestone, gray, dense, party shaly crinoidal, in three beds separated by thin shale, fusulinids in middle bed	2
6.	Shale mostly covered	11.5
5.	Limestone, purplish-gray, crinoidal capped by two inches of gray coquinoid detrital limestone	1
4.	Shale, gray, containing abundant small limestone nodules	3
3.	Limestone light brownish-gray, containing abundant shell fragments, base covered	1.5

Hughes Creek shale

2.	Shale, gray	9.5
1.	Sandstone, light-brown, massive, with some contorted bedding, base covered	40

18. NE ¼ sec. 9, T. 23 N., R. 5 E.; westward along road on north line of section

Council Grove group

Long Creek limestone

9.	Limestone, brownish-gray, dense, fossiliferous, with a few fusulinids, caps hill	1
8.	Shale, gray	4.5
7.	Limestone and shale interbedded in beds up to 6 inches thick	7.5
6.	Limestone dark-gray shaly, dense, fossiliferous, containing crinoid debris and small fusulinids	1.2
5	Shale, gray, weathers buff, marly, fossiliferous, with bryozoans, crinoids, and large fusulinids (*Triticites* and *Schwagerina*)	5
4.	Limestone, gray, shaly, dense, fossiliferous, containing crinoid debris and abundant large fusulinids	1.3
3.	Shale, gray, weathers buff, marly, fossiliferous, containing bryozoans, crinoids, and fusulinids	4.5
2.	Limestone, dark-gray shaly, fossiliferous	0.3

Hughes Creek shale

1.	Shale, gray, not measured	

19. SW ¼ sec. 2, T. 21 N., R. 5 E.; westward along road on south line of section

Council Grove group

Long Creek limestone

16.	Limestone, weathers brown, thickbedded, fossiliferous, caps hill	3
15.	Shale, gray, calcareous	3
14.	Limestone, brownish-gray, shaly, partly fossiliferous, mostly covered	0.5

Hughes Creek shale

13.	Covered, gray shale with sandstone fragments in float	7
12.	Sandstone, base covered	23
11.	Covered, probably shale	9

Americus limestone

10.	Limestone, greenish-gray to gray, dense, massive, highly fossiliferous, shaly in upper part, containing fusulinids near base	1
9.	Covered probably shale	1
8.	Limestone, dense, crystalline thin-bedded, nonfossiliferous (bed 7, section 20)	1.5

Admire group

7.	Shale, reddish-brown and gray, mottled	4
6.	Covered, probably shale	12.5
5.	Sandstone, iron-stained, partly contorted massive at base grading upward to thin-bedded, cross-bedded, with interbedded shale lenses	22
4.	Shale, red, with green silty streaks near base, mostly covered	11
3.	Limestone, light greenish-gray, nodular, crinoidal, highly fossiliferous, containing *Hustedia* and pectinoids, with interbedded variegated shale	1.5
2.	Shale, red and green, variegated	1.5
1.	Sandstone, base covered	1

20. NE ¼ sec. 2, T. 21 N., R. 5 E.; southward from Brownville limestone exposure to top of outlier in center of sec. 2

Council Grove group

Americus limestone (basal bed)

7.	Limestone, gray, dense, crystalline, thin-bedded, abundant in float capping hill (bed 8 of section 19)	2

Admire group

6.	Covered	25
5.	Sandstone, massive, float only	16
4.	Covered probably shale	22
3.	Limestone, gray and gray-green, mottled containing small fusulinids and limestone pellets, in float only	1
2.	Covered float contains shale and sandstone with some thin-bedded and nodular limestone and calcareous sandstone	71

Wabaunsee group

Brownville limestone

1.	Limestone, gray-brown, crystalline, fossiliferous, base covered	3

21. SW ¼ sec. 36, T. 23 N., R. 5 E., and NE ¼ sec. 2, T. 22 N., R. 5 E.: southward along road through section corner

Council Grove group

Hughes Creek shale

17.	Sandstone, massive, caps hill	3
16.	Covered, probably shale	9

Americus limestone

15.	Shale, gray, partly calcareous, with interbedded fossiliferous limestone	16.5
14.	Limestone, greenish-gray, shaly, fossiliferous especially on top surface	1.5
13.	Shale, gray, partly calcareous	5
12.	Limestone, brownish-gray, dense, abundant molluscan fauna (pectinoids), with interbedded shale	9

Admire group

11	Shale, gray and red	16.5
10.	Limestone, gray fossiliferous, thin-bedded, in float only, contains abundant high-spired gastropods, other mollusks and brachiopods	2
9.	Shale, red, with light-colored siltstone beds	9
8.	Sandstone, massive to thin-bedded, calcareous, hard	7
7.	Shale, red, with thin beds of light-colored siltstone and sandstone especially in upper part	21
6.	Limestone gray-green, shaly, highly fossiliferous, crinoidal	0.5
5.	Shale, red, silty, calcareous fossiliferous	2
4.	Limestone, gray-green and purple, fossiliferous, abundant fusulinids	0.5
1.	Shale, red, base covered	5

22. SE ¼ sec. 30, T. 22 N., R. 6 E.; northward along road on east line of section

Admire group

8.	Sandstone	1
7.	Covered, probably red shale	2.5
6.	Limestone, brown, silty, in large lenticular masses	1.5
5.	Covered, probably red shale	4.5
4.	Sandstone, iron-stained, well-bedded, containing solution channels	11
3.	Shale and sandstone, interbedded in 3 to 4 inch beds	1
2.	Covered, probably shale	3

Wabaunsee group

Brownville limestone

1.	Limestone, brownish-gray, dense, base covered	5

23. SW ¼ sec. 13 and NW ¼ sec. 24, T. 21 N., R. 5 E.; southward along creek bed

Wabaunsee group

Brownville limestone

8.	Limestone light brownish-gray, sublithographic to finely crystalline, top part stylolitic, crinoidal, lower 2 feet containing abundant fusulinids. A zone of solution channels up to 6 inches in diameter occurs 1.5 feet below top	6

Pony Creek shale

7.	Covered	9
6.	Shale, grayish-brown, fissile	6
5.	Shale, grayish-brown, calcareous, containing limestone nodules and *Myalina*	0.5
4.	Shale, grayish-brown, carbonaceous at base	1.5
3.	Coal	0.5
2.	Sandstone, gray, lenticular, fine-grained, calcareous, partly contorted, with surface striations striking northeast	0 to 1
1.	Shale, light-gray to brown, clayey, carbonaceous, base covered	1.5

24. NE ¼ sec. 1, T. 22 N., R. 6 E.; southward from Arkansas river alluvium to top of small Brownville limestone outlier

Wabaunsee group

Brownville limestone

27.	Limestone float, caps hill	1

Pony Creek shale

26.	Covered, probably gray shale	10
25.	Covered shale in float, with a zone of fossiliferous calcareous nodules at top	11
24.	Sandstone, thin-bedded to massive	2
23.	Covered, shale in float, contains lenses of conglomeratic limestone	27
22.	Covered, probably shale tabular blocks of sandstone in float, bench at top	25

"Grayhorse" limestone

21.	Shale, weathers buff, calcareous, highly fossiliferous, with abundant *Myalina*, contains a few thin beds of buff fossiliferous limestone, top covered	2

Gano shale

20.	Shale, red, with red calcareous nodules, grading upward to green shale containing green nodules in lower part	20
19.	Sandstone, thin-bedded, silty, base covered	1
18.	Covered, red shale in float	30

Elmont limestone

17.	Limestone, light-brown to green and red mottled crystalline, partly shaly, fossiliferous, with abundant small fusulinids, base covered	1
16.	Covered, gray shale in float containing *Myalina*, *Chonetes*, and crinoid debris	4.5
15.	Limestone, gray, sandy, thin-bedded, conglomeratic, with pebbles to 2 mm	0.5
14.	Covered, probably shale, with a one-foot sandstone bed in lower 5 feet	13
13.	Limestone, light-gray, crystalline dense, containing abundant fusulinds especially near base, base covered	1.5

Harveyville shale

12.	Covered, probably shale with thin beds of sandstone	13.5
11.	Sandstone, massive to cross-bedded, contorted	10
10.	Covered	18
9.	Sandstone, thin-bedded, calcareous	2
8.	Limestone, brown, conglomeratic, sandy	1.5
7.	Covered	4
6.	Limestone, green, shaly, fossiliferous	0.5
5.	Covered probably shale	3.5
4.	Shale, green, calcareous, containing fusulinids, top covered	0.5

Reading limestone

3.	Limestone, dark-gray, shaly, containing abundant small fusulinids	0.5
2.	Shale, green, calcareous, base covered	1
1.	Alluvium, not measured	

25. SE ¼ Sec. 21, T. 22 N., R. 6 E., northward along road on east line of section.

Wabaunsee group

Pony Creek shale

19.	Sandstone, highly cross-bedded thin-bedded, interbedded with gray shale at base, grading upward to massive, contract with underlying suggests channeling, caps hill	26
18.	Shale, red	4
17.	Limestone, gray-brown, conglomeratic, with abundant shell fragments	1.5
16.	Shale, gray	1
15.	Sandstone, shaly, thin-bedded, with interbedded shale	2
14.	Shale, gray	7

"Grayhorse" limestone

13.	Shale, gray, calcareous, containing calcareous nodules and thin beds of fossiliferous limestone, *Myalina* abundant	4

Gano shale

12.	Shale, gray, partly red, mostly covered	27.5
11.	Sandstone and shale, interbedded	2
10.	Sandstone, light-colored, massive	8
9.	Shale, red	6.5

Elmont limestone

8.	Limestone, gray-green, silty, abundant shell fragments	1
7.	Shale, red	5
6.	Shale, red, fossiliferous, containing abundant small limestone nodules and fusulinids	1
5.	Limestone, gray-green and maroon, mottled, shaly, fossiliferous, abundant shell fragments and bryozoans	1.5
4.	Shale, green, with thin beds of nodular shaly limestone with molluscan fauna	5
3.	Siltstone, thin-bedded, grading upward to calcareous, upper 1 inch is silty limestone containing a molluscan fauna and *Linoproductus*	2.5
2.	Shale, brownish-gray, silty, lower 15 feet covered	17.5
1.	Limestone gray, containing abundant fusulinids, base covered	1

26. NE ¼ Sec. 15 and NW ¼ Sec. 14, T. 21 N., R. 6 E., eastward along road on north line of section from just west of section corner

Wabaunsee group		
Elmont limestone		
18.	Limestone, gray-brown, dense, conchoidal fracture, containing abundant fusulinids, caps hill	2.5
Harveyville shale		
17.	Covered, probably shale	3
16.	Sandstone, tan, massive	1
15.	Covered, probably gray shale with thin beds of sandstone	13.5
14.	Sandstone, orange, massive, base covered	12
13.	Shale, red, mostly covered	18.5
12.	Limestone, gray, abundant shell fragments and fusulinids	1
11.	Shale, gray	4.5
Reading limestone		
10.	Limestone, gray, shaly, containing shell fragments and fusulinids, base covered	1
9.	Covered, shale in float	2
8.	Limestone, gray, silty containing shell fragments	1
7.	Covered, probably shale	5.5
6.	Sandstone, calcareous, containing impressions of myalinids, pectinoids, and other mollusks	2
5.	Shale, red, grading upward to green, calcareous	12
4.	Limestone, mottled red and gray-green, massive, crinoidal	2
3.	Limestone, light gray-green, silty, crinoidal, containing algal pellets, interbedded with and grading upward into red shale	1
Auburn shale		
2.	Sandstone, with lenses of red shale	1.5
1.	Shale, red, base covered	6

27. NW ¼ Sec. 1, T. 20 N., R. 6 E., southward along road on west line of section from exposure of Wakarusa limestone in creek in SE ¼ Sec. 35, T. 21 N. R. 6 E.

Wabaunsee group		
Harveyville shale		
19.	Shale, with a bed of sandstone in middle, poorly exposed, caps hill	10
18.	Limestone, gray, dense, abundant shell fragments	1
Reading limestone		
17.	Covered, shale and fusulinid limestone in float	12
16.	Limestone, light-gray, sandy, thin-bedded, containing fossil impressions and interbedded shale	5
15.	Covered, float contains shale and thin-bedded sandstone	7
14.	Covered, capped by red limestone float on bench in field to east of road	14
Auburn shale		
13.	Sandstone, massive to thin-bedded, base covered	9.5
12.	Covered, probably red shale	18
11.	Shale, red	2
10.	Limestone, fossiliferous, nodular	0.5
9.	Shale, green, grading upward to red, with a lenticular sandstone bed to 3 feet thick near base	26
Wakarusa limestone		
8.	Limestone, gray-green, fossiliferous, partly shaly, fusulinids abundant, interbedded with green shale (bench mark on NW corner sec. 1 is 31 feet above top of limestone	3
7.	Shale, green calcareous, fossiliferous, containing calcareous nodules and abundant fusulinids	1
6.	Limestone, as above	0.5
5.	Shale, green, as above	1
4.	Limestone, as above	0.6
3.	Shale, green, as above	2.5
2.	Limsestone, as above, top surface shaly	1
Hallet shale		
1.	Shale green, as above, below water, not measured	

28. NE ¼ Sec. 20, T. 22 N., R. 7 E.: northward from Arkansas River alluvium to top of Wakarusa outlier

Wabaunsee group		
Auburn shale		
11.	Shale capped by sandstone float	13
Wakarusa limestone		
10.	Limestone, gray shaly, sparsely fossiliferous, with abundant fusulinids, base covered	5
Hallet shale		
9.	Covered, probably shale and sandstone, bench 6 feet from base	34
8.	Sandstone, brown thin-bedded, partly calcareous, shaly with interbedded shale	4
7.	Covered, probably sandstone and shale bench 33 feet above base	51
6.	Limestone, light-gray to brown, silty, with abundant brown fusulinids (colloquial "wheat" limestone)	2
5.	Covered, probably shale	32
Bird Creek limestone		
4.	Limestone, dark-gray shaly	2
3.	Covered, probably shale	18
2.	Covered, capped by sandstone bench, contains Turkey Run limestone	30
1.	Alluvium, not measured	

29. NE ¼ Sec. 31, T. 20 N., R. 7 E. westward along north line of section from limestone exposure in creek

Wabaunsee group	
Auburn shale	
13. Sandstone, medium-grained, massive to contorted, caps hill	12
Wakarusa limestone	
12. Limestone, light-gray, fossiliferous, contains *Triticites*, poorly exposed	2
Hallet shale	
11. Shale, gray, weathers buff, calcareous, with *Triticites* near top, thin beds of siltstone toward base	7
10. Sandstone, buff fine-to-medium grained cross-bedded to contorted	11
9. Covered, probably shale	26
8. Sandstone, cross-bedded	4
7. Shale, mostly covered	20
6. Sandstone, white, massive speckled with brown iron stains	3
5. Shale, mostly covered	2.5
4. Sandstone, buff, massive	1.5
3. Covered, probably shale with beds of sandstone and sandy limestone (in float)	29
Bird Creek limestone	
2. Limestone, dark-gray, shaly, fossiliferous, contains *Triticites*	0.5
Severy shale	
1. Shale, gray, not measured	

30. SE ¼ Sec. 29, T. 21 N., R. 7 E.; southwestward from limestone exposure in creek bed to road cut in road on south line of section

Wabaunsee group	
Hallett shale	
14. Sandstone, cross-bedded to massive, thin-bedded at top, contains lenses of calcite cement, caps hill	4
13. Shale, red and gray, with silty streaks	5
12. Sandstone, massive	0.7
11. Shale, gray, silty	2
10. Shale, purple, with gray-green silty laminae	0.5
9. Shale, gray, partly silty	26
Bird Creek limestone	
8. Limestone, gray, dense, fossiliferous, contains *Triticites*	1.3
Severy shale	
7. Shale, light-gray clayey	6
6. Shale, red and gray, with beds of siltstone	8
5. Covered, probably shale and sandstone	26
Pawhuska formation	
Turkey Run limestone member	
4. Limestone, dense, dark-gray, jointed, fossiliferous toward base, containing *Triticites*	1.5
3. Shale, dark-gray carbonaceous	1
2. Lignite	1
1. Shale, gray, not measured	

31. NW ¼ Sec. 23, T. 21 N., R. 7 E.; westward in road cut along U. S. Highway 64

Wabaunsee group	
Severy shale	
20. Sandstone, massive, buff, speckled with brown iron stain, caps hill	3.5
19. Sandstone, bedded, buff, speckled with brown iron stain	1
18. Shale, dark-gray and brown, fissile, becomes marly and fossiliferous near base	13
Pawhuska formation	
Turkey Run limestone member	
17. Limestone, gray-brown, dense, argillaceous, fossiliferous	0.5
16. Lignite	0.5
15. Underclay (?)	0.5
14. Shale gray to dark-gray	12
13. Sandstone, calcareous friable, finely cross-bedded at top grading to hard, massive toward base (base covered)	17.5
12. Covered probably shale	7
11. Shale, buff, gray, and maroon mottled, blocky	7
10. Sandstone, buff, coarsely cross-bedded to massive, partly calcareous, with a 6-inch argillaceous bed 3 feet from base	5.5
9. Shale gray and gray-green, variegated	3.5
8. Sandstone, buff massive, with a 6-inch bed of fine-bedded argillaceous sandstone 6 feet from base	13
7. Shale, gray, interlaminated with light-gray siltstone	10.5
Lecompton limestone member	
6. Limestone fusulinid coquina	0.25
5. Shale, gray, calcareous fossiliferous	1.25
4. Limestone, gray, finely crystalline, dense, flaggy, fossiliferous	5
3. Shale gray, calcareous, fossiliferous	2.25
2. Limestone, gray, dense, massive	1.25
Vamoosa formation	
Kanwake shale member	
1. Shale, gray, base covered	7

32. NE ¼ Sec. 27, T. 20 N., R. 7 E.: westward along county road from NE corner of section

Wabaunsee group

Severy shale

16.	Sandstone, caps hill	10
15.	Covered, probably shale	7

Pawhuska formation

Turkey Run limestone member

14.	Limestone, gray, dense	1.5
13.	Shale, largely covered	16
12.	Sandstone, massive	20
11.	Covered, probably shale	8

Lecompton limestone member

10.	Limestone, gray, flaggy, nodular fossiliferous, containing *Triticites*	11

Vamoosa formation

Kanwaka shale member

9.	Shale, red	8
8.	Shale gray	8

Elgin sandstone No. 4

7.	Sandstone, bedded crossbedded, contorted, lenticular, with thin shale beds	7
6.	Shale, red and light-gray, silty	7
5.	Shale, gray with thin siltstone beds	10
4.	Sandstone, massive, lenticular bedded toward base	7
3.	Shale, gray	11
2.	Covered, probably shale	4

Elgin sandstone No. 3

1.	Sandstone, massive, base covered	5

33. NE ¼ Sec. 14, T. 20 N., R. 7 E.: westward from NE corner of section to small hill just south of road

Pawhuska formation

Lecompton limestone member

6.	Limestone, apparently a lens of agal origin, looks conglomeratic, caps hill	0.8

Vamoosa formation

Kanwaka shale member

5.	Shale, red, with thin beds of white siltstone	10
4.	Covered, probably shale	7

Elgin sandstone No. 4

3.	Sandstone, massive	11
2.	Covered, probably shale	7
1.	Sandstone, flaggy, well-bedded, jointed base covered, not measured	

34. Sec. 12, T. 20 N., R. 7 E.: wesward from creek bed along abandoned road on south line of section

Vamoosa formation

Kanwaka shale member

Elgin sandstone No. 4

10.	Sandstone, fine-to-medium-grained, shaly, thin-bedded at base, massive at top, caps hill	15
9.	Shale, gray, partly red, poorly exposed with occasional thin beds of sandstone and siltstone, sandy beds increase toward top	40
8.	Sandstone, buff, bedded	4
7.	Shale	10
6.	Covered, probably shale	11

Elgin sandstone No. 3

5.	Sandstone thin-bedded, shaly at base becoming massive to cross-bedded at top, partly speckled with brown iron stain	7
4.	Shale, gray silty, weathers buff	8
3.	Sandstone, shaly cross-bedded	1.5
2.	Shale, gray, silty, weathers buff	3

Elgin sandstone No. 2

1.	Sandstone, massive to cross-bedded ripple-marked toward base, poorly exposed, base covered	20

35. SE ¼ Sec. 8, T. 20 N., R. 8: westward along road from creek bed near SE corner of section

Vamoosa formation

Kanwaka shale member

Elgin sandstone No. 1

9.	Sandstone, caps hill	2
8.	Shale, gray	5
7.	Sandstone, partly covered	7
6.	Shale, gray	12

Elgin sandstone No. 2

5.	Sandstone, poorly exposed	11
4.	Shale, gray	9
3.	Sandstone, base covered	1
2.	Shale, gray, with occasional thin sandstone beds, largely covered	13

Elgin sandstone No. 1

1.	Sandstone massive to cross-bedded, base covered	35

36. NE ¼ Sec. 17, T. 21 N., R. 8 E.; southward along road from bridge in N. E. corner of section

Vamoosa formation

Kanawka shale member

Elgin sandstone No. 3

12. Sandstone, massive to cross-bedded, caps hill 50
11. Shale, gray
10. Sandstone, thin-bedded 3
9. Shale, gray 10

Elgin sandstone No. 2

8. Sandstone, massive, largely covered 12
7. Shale, gray, with interbedded sandstone 8
6. Sandstone, with thin interbedded shales 2
5. Shale, gray, with occasional thin beds of siltstone and sandstone 81

Wynona sandstone member

4. Sandstone thin to thick-bedded, cross-bedded, with thin interbedded shales 12
3. Shale, gray, weathers brown, poorly exposed 5
2. Sandstone, thick-bedded to cross-bedded, with thin interbedded shales, partly covered 20
1. Shale, gray with thin sandstone beds, poorly exposed, base covered 13

37. Sec. 22, T. 20 N., R. 8 E. northward along pipeline from south line of section

Vamoosa formation

Wynona sandstone member

9. Sandstone, cross-bedded to massive, caps hill 12
8. Shale, olive with streaks of red and a few thin sandstone beds, largely covered 50
7. Sandstone cross-bedded 2
6. Shale, red and olive, with thin beds of light-gray siltstone 12
5. Sandstone, cross-bedded 3
4. Shale, red with thin beds of light-gray siltstone 12
3. Siltstone, light-gray, cross-bedded 2
2. Shale, gray, largely covered 2
1. Sandstone cross-bedded, silty, base covered, not measured

38. NE ¼ Sec. 25, T. 20 N., R. 8 E.; westward to top of bluff from large boulder in Cimarron River along road

Tallant formation

Bigheart sandstone, upper member

8. Sandstone, medium-grained, massive, blocky, caps bluff 30
7. Covered, gray shale in float 41
6. Shale, dark-gray 2
5. Shale, gray 2
4. Sandstone, siliceous, cross-bedded 4
3. Shale, gray-green and purple, interbedded with thin beds of siltstone toward top 10

Bigheart sandstone, lower member

2. Sandstone, massive, containing lenses of gray shale up to 1 foot thick 3
1. Sandstone, fine- to medium-grained, cross-bedded to massive, contains clay pebbles, top 11 feet covered, base below river level 13

39. Sec. 32, T. 20 N., R. 9 E., and Sec. 5, 19 N., R. 9 E. (Creek County); southward along county road from creek bed

Tallant formation

Revard ? sandstone member

11. Sandstone, blocky, massive below to cross-bedded above, caps hill 8
10. Shale, gray, with silty beds 10
9. Sandstone, blocky, massive 2
8. Shale, gray with maroon streaks 30
7. Shale, maroon and light-gray, silty with lenticular beds of sandstone up to 2 feet thick 12
6. Shale, maroon and light gray, silty 10
5. Sandstone and shale, interbedded 1
4. Shale, maroon and light gray, silty .... [illegible]
3. Shale, maroon, with thin beds of sandstone and sandy siltstone; top 1½ feet contain a lenticular sandsone bed up to 1½ feet thick 5
2. Shale, maroon, with light-gray silty streaks, partly covered 15

Bigheart sandstone member

1. Sandstone, massive to cross-bedded with non-resistant shaly and silty streaks up to 1 foot thick, base covered 31

40. NE ¼ Sec. 27, T. 20 N., R. 9 E.; gulley on northwest slope of small outlier

Tallant formation

Bigheart sandstone member

5. Sandstone, well-bedded, caps hill 8

Barnsdall formation

Unnamed shale member

4. Shale, gray and gray-green, partly covered 72
3. Sandstone, massive 2
2. Shale, gray and gray-green, partly covered 25

Okesa sandstone

1. Sandstone, massive to cross-bedded, base covered 5

41. Sec. 30, T. 20 N., R. 10 E.; northward up gulley in north-central part of section

Barnsdall formation

Okesa sandstone member

12. Sandstone, massive to contorted 16

Wann formation

Unnamed shale member

11. Shale, gray and gray-green with ironstone concretions 45
10. Shale, interbedded dark-maroon and gray-green 5

Clem Creek sandstone member

9. Sandstone, cross-bedded, interbedded with gray silty shale in beds up to 1 foot thick 7
8. Sandstone, cross-bedded 6
7. Siltstone, shaly, thin-bedded, light-yellow to gray-brown 2
6. Sandstone, medium- to coarse-grained, massive, well bedded to cross-bedded toward top 7
5. Siltstone, shaly, thin-bedded, light-yellow to gray-brown 1
4. Sandstone, well-bedded to massive 27
3. Shale, gray 1
2. Covered, probably shale 36
1. Terrace, not measured

INDEX

Q

R

S

T

U

V

W