OKLAHOMA GEOLOGICAL SURVEY

CARL C. BRANSON, *Director*

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Geology of Harper County, Oklahoma

By

ARTHUR J. MYERS

With a section on

PETROLEUM GEOLOGY OF HARPER COUNTY

By

Louise Jordan, J. Durwood Pate, and Sidney R. Williamson

NORMAN

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GEOLOGY OF HARPER COUNTY, OKLAHOMA

By Arthur J. Myers

ABSTRACT

Harper County, with an area of approximately 1,075 square miles, is in northwestern Oklahoma. Aerial photographs were used in the field mapping of this semi-arid region. The bed rock consists of Permian clastic and evaporite sediments and Cretaceous clastics approximately 535 feet thick, covered in the southwest by about 135 feet of Pliocene and Pleistocene continental deposits. The region is in the Plains Border of the High Plains Physiographic Province and most outcrops of Permian rocks are bluff exposures.

In ascending order, the unfossiliferous Permian rocks consist of the Flowerpot shale, Blaine formation, Dog Creek shale, Whitehorse group, and Cloud Chief formation. The Flowerpot shale is a brownish-red gypsiferous shale. The Blaine formation consists of four named massive gypsum members separated by red shale: (ascending) Medicine Lodge, Nescatunga, Shimer, and Haskew gypsums. The Dog Creek shale is a brownish-red, even-bedded shale with thin beds of fine-grained sandstone. The Whitehorse group includes the Marlow formation, which is an orange-red, fine-grained, locally cross-bedded sandstone, and the overlying Rush Springs sandstone, consisting of brownish-red interbedded sandstone and shale. The Cloud Chief formation is predominantly a maroon-red shale with some gypsum and contains the resistant Day Creek dolomite at its base. The Cretaceous Kiowa shale in outliers consists of yellow to gray to black shales, sandstones, and conglomerates with some fossiliferous beds. The Pliocene deposits include (ascending) the Laverne formation, buff, blue-gray, and gray shales, sandstone, and conglomerates, and the Ogallala formation, pink, tan, and gray gravels, sands, and silts. The Pleistocene deposits are the Crooked Creek formation of the Meade group, which consists of tan to pink gravels, sands, and silts and the Pearlette volcanic ash lentil, post-Crooked Creek dune sand, and gray to black clay and silt lake deposits. The Recent deposits are the terraces, alluvium, and dune deposits along recent streams.

During Permian time clastics and evaporites accumulated in marine embayments which covered western Oklahoma. Following this a period of erosion lasted during most of the Triassic and Jurassic periods. By Cretaceous time marine seas again covered the extreme western part of Oklahoma, and received clastic sediments from the west. Erosion again predominated during most of the Tertiary, but during the Pliocene two cycles of fluvial deposition by east-flowing streams were separated by an intervening period of erosion. Later Pleistocene melt-water streams from the retreating Rocky Mountain glaciers eroded channels in the pre-Pleistocene surface, but a cycle of fluvial deposition followed soon after. The last episode of Pleistocene history involved the deposition of lacustrine sediments in shallow sink basins of local extent.

The Permian and Cretaceous rocks have a dip of 30 feet per mile to the south. The Tertiary and Quaternary deposits are essentially horizontal. Sink hole development has resulted in minor localized folding in all rocks. Isolated sand and gravel deposits are used locally for road construction. The massive gypsum deposits of the Blaine formation may have economic possibilities. The volcanic ash deposits are small and would not permit large scale operation.

A section on petroleum geology by Louise Jordan, J. Durwood Pate, and Sidney R. Williamson describes subsurface conditions as presently understood. Petroleum exploration in Harper County has resulted in discovery of commercial oil and gas production in at least eight stratigraphically separated reservoirs ranging in age from Lower Ordovician to Permian. Subsurface stratigraphy and structure of the county are described and illustrated with east-west and north-south electric log cross sections, by contour maps at the top of the Mississippian and top of the Oread formation (Pennsylvanian), and with isopach maps of Morrowan and Chesterian rocks. Isopach and structure maps of the Laverty-Hoover sand zone in the Laverne Gas Area are included.

INTRODUCTION

Scope and Purpose of the Work

This report presents the results of a detailed study of the Permian, Cretaceous, Tertiary, and Quaternary rocks that crop out in Harper County, Oklahoma. The primary purposes of this investigation were: (1) to study in detail the character, distribution, and thickness of the rock formations and to prepare detailed geologic maps of surface rocks, (2) to correlate the formations with type localities, (3) to determine structure, and (4) to locate and describe mineral deposits of possible economic value.

Location of the Area

The area includes all of Harper County, which is in northwestern Oklahoma. The county is included in Townships 25 to 29 North and Ranges 20 to 26 West, and has an area of approximately 1,075 square miles. Figure 1 shows the county outline and the position of the county relative to other Oklahoma counties.

Previous Investigation

Prior to this investigation geological reports have included Harper County as part of regional or stratigraphic studies. The principal reports relating to the geology of Harper County are as follows: Gould (1905), Aurin (1917), Clifton, (1926), Gould, and Lewis (1926), Greene (1926), Bullard (1928), Suffel (1930), Evans (1931), Green (1937), Norton (1939), Taylor and Hibbard (1955), and Schoff (1956). Reports including material on the

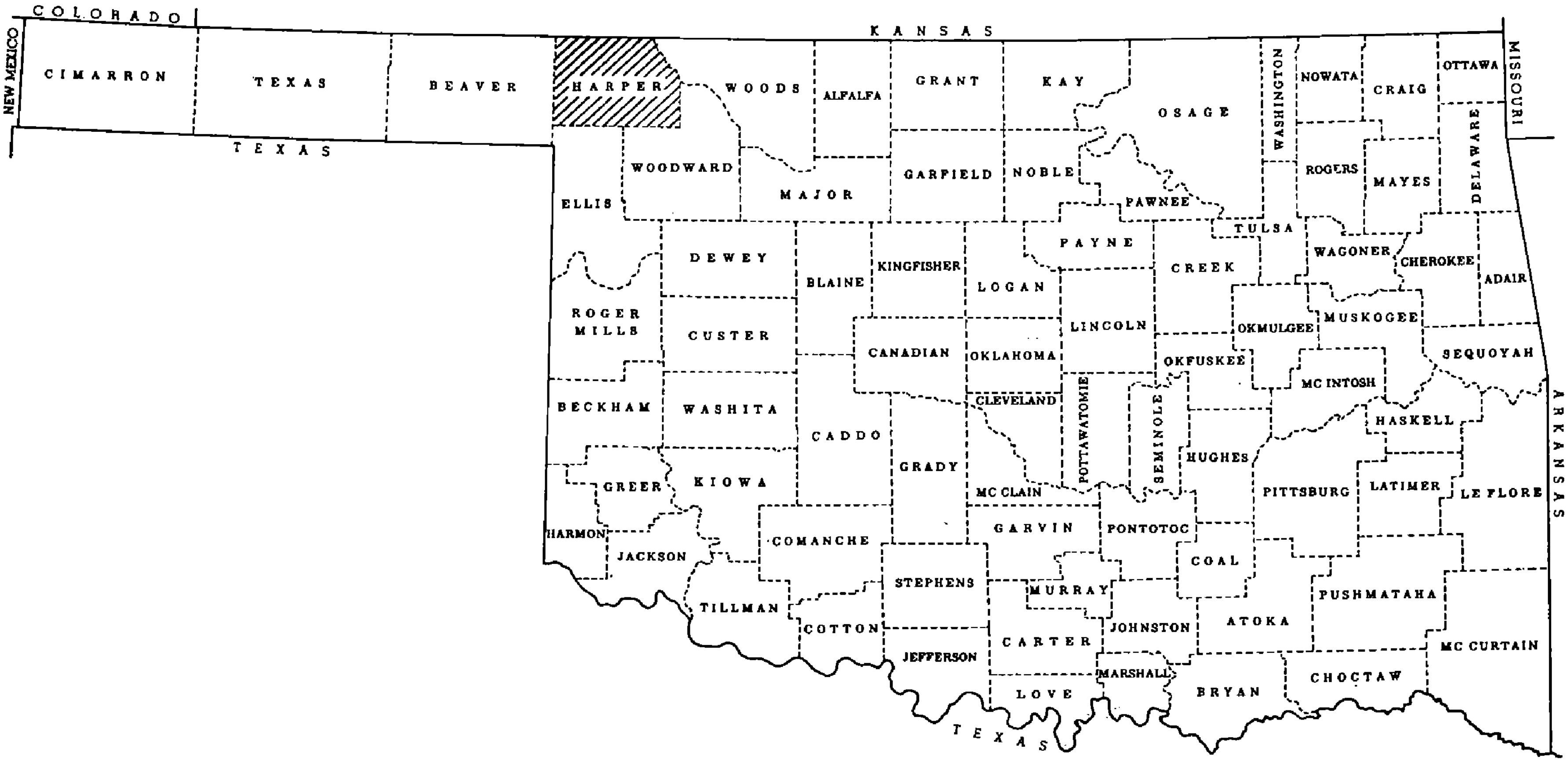


FIGURE 1. Location map of Harper County.

geography of Harper County are: Snider (1917) and Fenneman (1922). The following reports deal with the economic geology: Snider (1913), Burwell and Ham (1949), and Burwell (1956).

Present Investigation

The original investigation was for the purpose of mapping the Cenozoic deposits of Harper, Ellis, and Roger Mills Counties for the Geologic Map of Oklahoma (1954). The field work was of a reconnaissance type and was completed during the summer of 1951.

Later the investigation was changed from reconnaissance to detailed study of sediments and mapping of Harper County. Aerial photographs were obtained from the Department of Agriculture. Transparent cellulose acetate sheets were attached to alternate pictures in each line of flight. Section lines were almost everywhere identifiable and the sections were numbered on the photographs. The photographs were studied stereoscopically and all possible strata and drainage systems were traced. The patterns of drainage, roads, and culture were transferred to a base map.

The field work was completed during the summer of 1955. Prior to each day's field mapping the photos of the area to be covered were stereoscopically studied. Formations were traced by walking along the outcrop and the units observed in the field were located on the acetate covers of the photos. The geology was then transferred to the base maps. Sections were measured at several places and fossils were collected.

ACKNOWLEDGMENTS

Financial support for the detailed mapping (1955) was made available through the Oklahoma Geological Survey and for the reconnaissance mapping (1951) through Robert Dott, at that time director of the Oklahoma Geological Survey. The writer is indebted to Professors W. H. Burt, C. W. Hibbard, K. K. Landes, E. C. Stumm, and J. H. Zumberge for manuscript suggestions. Professor C. W. Hibbard spent several days in the field with the writer, made many valuable suggestions, and identified the vertebrate fossils. Dwight Taylor identified the invertebrate fossils. The report was submitted as a doctoral dissertation to the University of Michigan.

GEOGRAPHY

Harper County lies in the northwestern part of Oklahoma. It is approximately rectangular with the northeast corner cut off by the Cimarron River, and is bounded by Clark and Comanche Counties, Kansas, on the north; Woods and Woodward Counties on the east; Woodward and Ellis Counties on the south; and Beaver County on the west. Harper County comprises all or parts of Tps. 25 to 29 N., and Rs. 20 to 26 W. and totals about 1,075 square miles.

PHYSIOGRAPHY

The County is predominantly in the Plains Border section of the Great Plains province (Fenneman 1931, pp. 25-30). This section consists of a belt of steeper than normal escarpments or slopes formed on the eastern edge of the High Plains section of the Great Plains Province. The High Plains section is composed of Tertiary and Quaternary silts, sands, and gravels, which have a gentle eastward slope from the Rocky Mountains. With the removal of the Tertiary cover the rocks have been highly dissected but not reduced to the low relief which is characteristic of the Osage section of the Central Lowland province to the east.

Physiographically Harper County consists of two plains separated by a distinct escarpment, which faces northeastward and crosses the county diagonally from 4 miles south of the northwest corner to the southeast corner. The escarpment dividing the two plains consists of a sharp slope dissected by V-shaped gullies and valleys; this belt of rough broken land ranges from 1 to 3 miles in width. The sandy Tertiary and Quaternary sediments are generally the scarp former, but in some areas the Permian Day Creek dolomite and Rush Springs formation form the escarpment.

The upper plain which comprises the southwestern half of the county grades from a flat surface to rolling hills with gentle relief and the general slope descends to Beaver River, which crosses diagonally the southwestern ¼ of the county. The rocks are predominantly Pliocene Laverne and Ogallala formations, Pleistocene Crooked Creek formation and dune sand, and Recent dune sand and alluvium. The sandy character of the upper plain results in the absorption of water, and consequently there are few streams to dissect the area. This section consists of the part of the High Plains which has been only slightly eroded, with a remnant of the High Plains remaining in the N ⅓ of T. 27 N., R. 26 W. and all of T. 28 N., R. 26 W. East of this area in the S ½ of T. 28 N., R. 25 W., N ⅓ of T. 27 N., R. 25 W., and W ½ of T. 27 N., R. 24 W. the topography is moderately level but is more highly dissected. A narrow strip extending from the above described area to the southeast corner of the county is similarly eroded. Outliers of Cretaceous Kiowa shale occur in a few buttes in the south central part of this section. A belt of recent sand dunes north of the dry river bed of Beaver River has restricted erosion and checked the northward movement of the river resulting in an apparent gradual shifting of the river channel southwestward. South of Beaver River the Pliocene Laverne formation has been moderately well dissected to a surface of low relief. The extension of the High Plains has been completely removed if it ever did cover this section. In some places the river has eroded its channel into Permian rocks, but no deep valleys have formed.

The Cimarron River has cut its bed approximately 400 feet lower than has Beaver River and as a result the northeastern plain is more highly dissected and has greater relief than the southwestern region. The rocks in this northeastern plain are Permian and form a heavier textured soil than the sandy soils of the southwestern section, resulting in more runoff. The resistant beds of gypsum of the Blaine formation are mainly responsible for the lower plain. Many intermittent streams flowing eastward have cut through the beds of gypsum to form a rough uneven topography, which in places has been rounded somewhat by leaching of the gypsums. Narrow steep-sided valleys are common and some scarps are over 100 feet high, such as those along the Cimarron River. The roughest topography in the county is along Sleeping Bear Creek in the southeastern part of the county. This section of the lower plain is known as the gypsum hills. Buffalo Creek, which is an east flowing tributary of the Cimarron River, has been the main eroding agent in Harper County and has eroded the central part of the county to a surface which slopes gently toward Buffalo Creek. This surface is formed on the Dog Creek shale and Marlow formation. A series of small mesas and buttes whose cap rock is the Day Creek dolomite of the Cloud Chief gypsum form the divide between Buffalo Creek and the Cimarron River.

Sink basins formed in almost all formations are common throughout the country. Some of the more recent basins have only internal drainage, but many basins are an integrated part of the drainage system. Several basins are a mile or more in diameter; one such basin exists in sec. 27, T. 28 N., R. 24 W. and a larger basin has formed near the center of T. 28 N., R. 25 W.

The landscape of Harper County is characteristic of a subhumid climate. The landforms are mesas, buttes, scarps, and canyons which have dolomite and/or gypsum at their tops. Further evidence of the subhumid climate is the formation of a lime-enriched zone 2 to 4 feet below the surface in many of the soil profiles.

DRAINAGE

Harper County is drained by the Cimarron and Beaver Rivers. The Cimarron is a broad stream choked with sands and clays and in places has a broad salt flat. The Beaver is a moderately broad stream with many oxbows and meander scars on its floodplain.

The Cimarron River rises in New Mexico and flows across Oklahoma in an east-southeasterly direction. It enters Harper County 2 miles south of the northwest corner and 9 miles east of this corner flows into Kansas; this area is part of the Englewood basin. With a broad swing in Kansas the Cimarron River flows through the Ashland and Sitka basins and then forms the northeast boundary of Harper County.

The lower physiographic plain is drained by the Cimarron River and its tributaries. Buffalo Creek is the most important tributary in Harper County and with its tributaries drains the central part of the county. Sleeping Bear and Sand Creeks, the major tributaries of Buffalo Creek, are the main scarp formers in the county, but small tributaries of the Cimarron have formed the scarps in northwestern Harper County. The mesas and buttes across the northern part of the county were formed by small north flowing tributaries of the Cimarron and small south flowing tributaries of Buffalo Creek.

The higher physiographic plain is drained by Beaver River and its tributaries. Beaver River heads in New Mexico and in Woodward County, Oklahoma, it joins with Wolf Creek and becomes the North Canadian River. The North Canadian River, including the Beaver, roughly parallels the Cimarron River across the state and merges with the Canadian River east of Eufaula in McIntosh County, Oklahoma. Most of the tributaries are small northeast flowing intermittent streams, but Kiowa and Clear Creeks in Harper County are permanent streams fed by springs from Tertiary sands. Since there is a broad sand dune belt north of Beaver River there are practically no south flowing tributaries.

The large Englewood, Ashland, and Sitka basins have controlled the course of the Cimarron River and similarly the course of minor streams in Harper County has been influenced by the large number of shallow sink basins.

CLIMATE

Harper County has a continental, temperate, subhumid climate (Blair 1942, pp. 184-190) typified by long hot summers and mild winters. The mean summer temperature is 80.5° with uncomfortably hot temperatures during the day and usually nights that are cool. July has the highest average temperature and the highest recorded temperature was 115° on August 13, 1936. Low humidity and the usual breeze make the temperature seem much lower than the thermometer indicates; however, occasionally there are southerly hot dry winds of long duration. Winters are generally mild with a mean temperature of 37.5°, but occasionally there are short periods of cold rain or snow. January is the coldest month and the lowest recorded temperature is -17° on January 4, 1947. The average annual air temperature is 59.0°, which is 1.6° below the average for the state.

From 1931 to 1955 the average number of days between the last killing frost in the spring and the first killing frost in the fall is 200 days. The last killing frost in the spring usually occurs early in April, but has occurred as early as March 19 and as late as May 3. The first frost in the fall is generally in late October or early November with the earliest on October 7 and the latest on November 16.

There are both regional and local storms in the county, which may produce intense rainfall over small areas. The average annual precipitation measured at Buffalo is 22.20 inches. Most of the

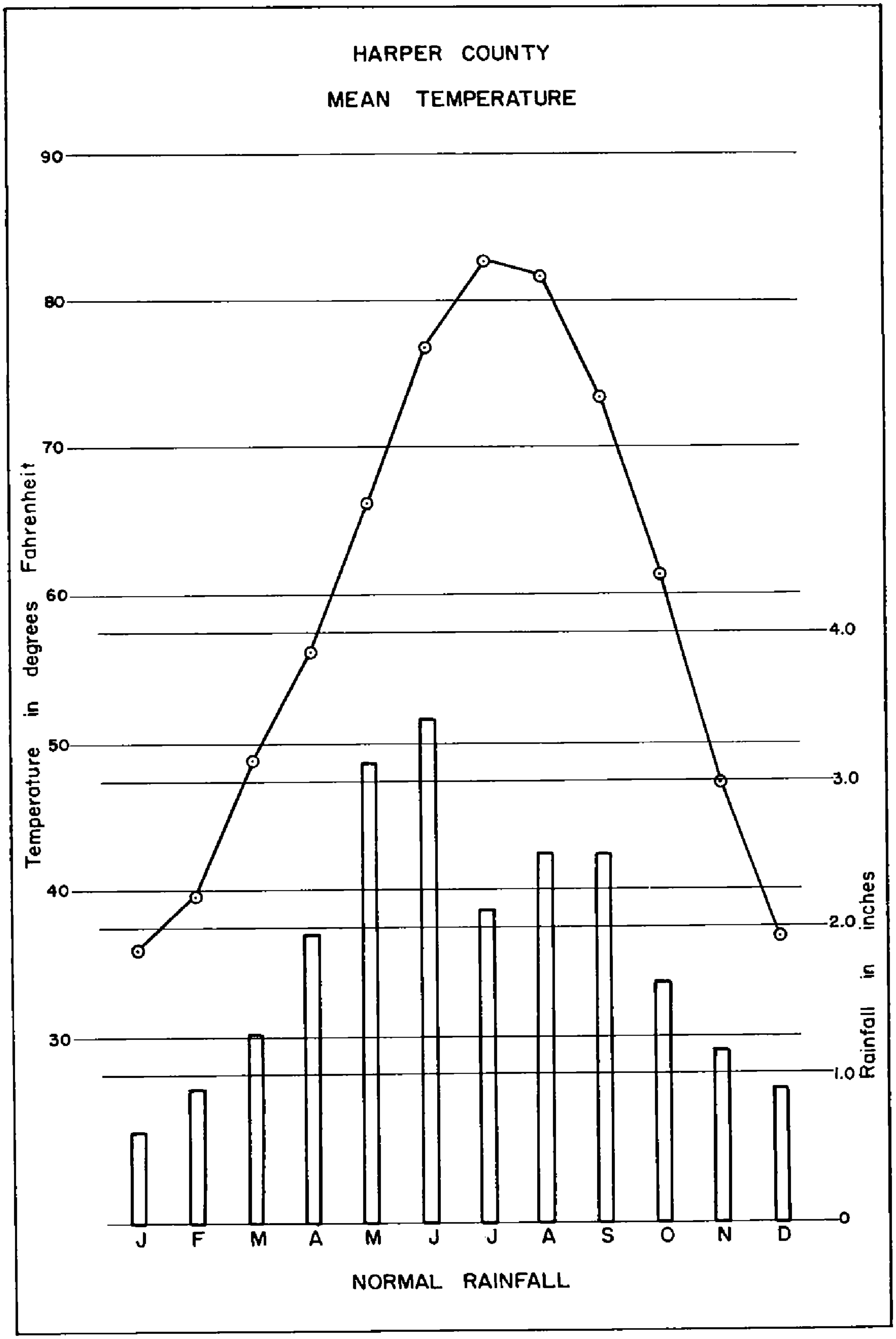

HARPER COUNTY
MEAN TEMPERATURE
90
80
70
60
50
40
30
Temperature in degrees Fahrenheit
4.0
3.0
2.0
1.0
0
Rainfall in inches
J F M A M J J A S O N D
NORMAL RAINFALL

Figure 2

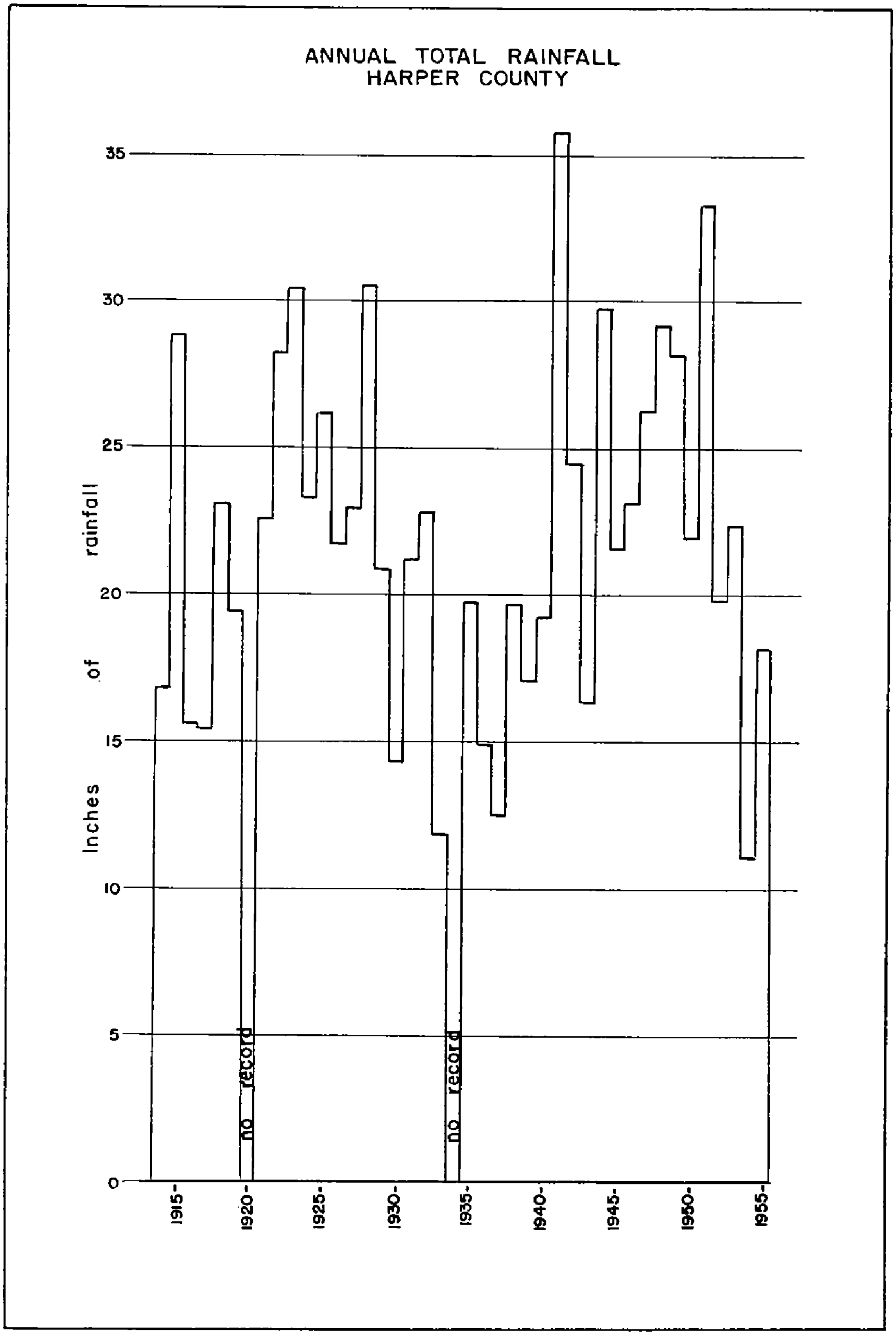

ANNUAL TOTAL RAINFALL
HARPER COUNTY
Inches of rainfall
35
30
25
20
15
10
5
0
no record
no record
1915
1920
1925
1930
1935
1940
1945
1950
1955

Figure 3

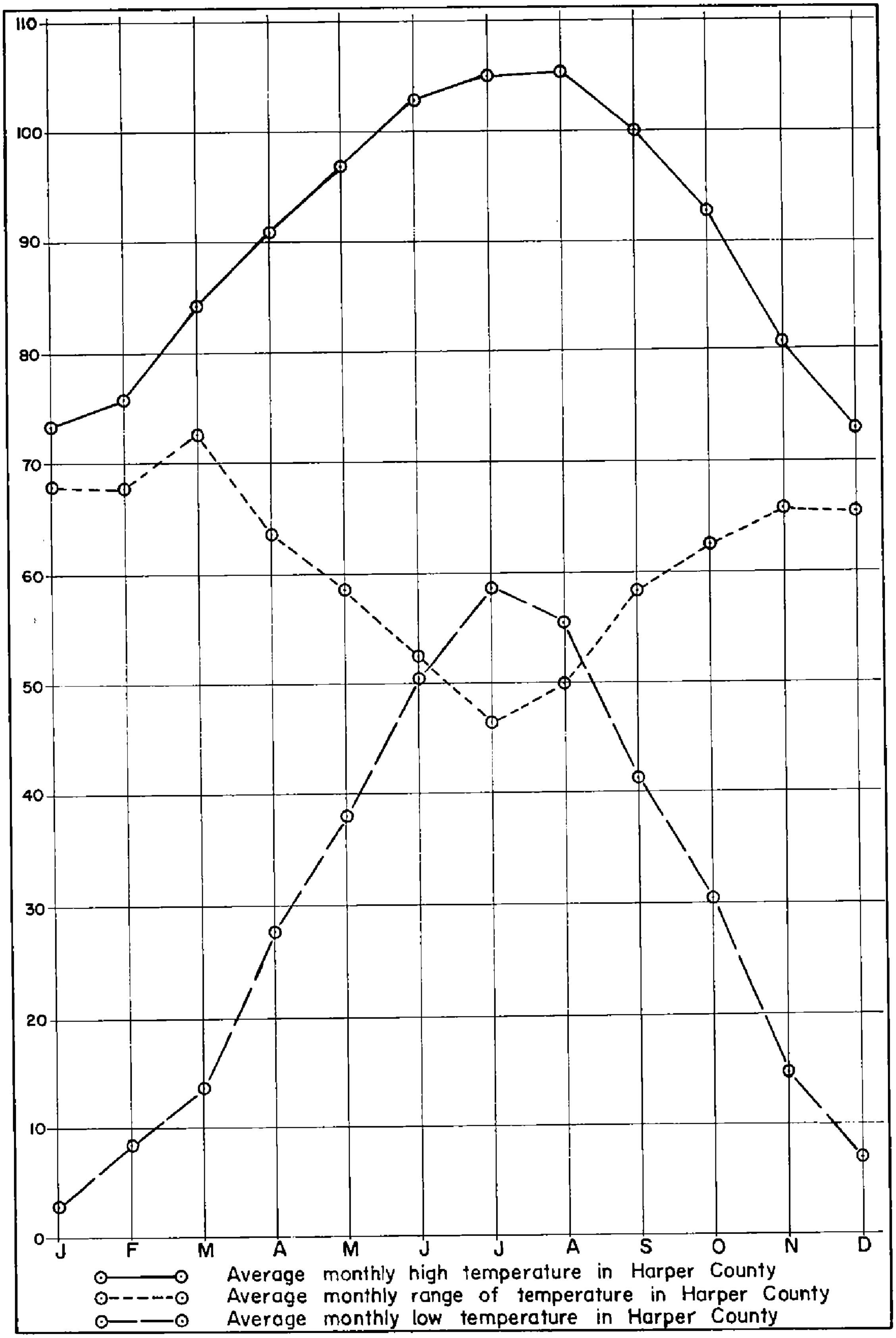

110
100
90
80
70
60
50
40
30
20
10
0
J F M A M J J A S O N D
Average monthly high temperature in Harper County
Average monthly range of temperature in Harper County
Average monthly low temperature in Harper County

Figure 4

rain falls in the period from April through September with the maximum amount in June and a lesser amount from October through March with the minimum monthly average in January. The maximum annual rainfall was 35.75 inches in 1941 and the minimum annual rainfall was 11.11 inches in 1954.

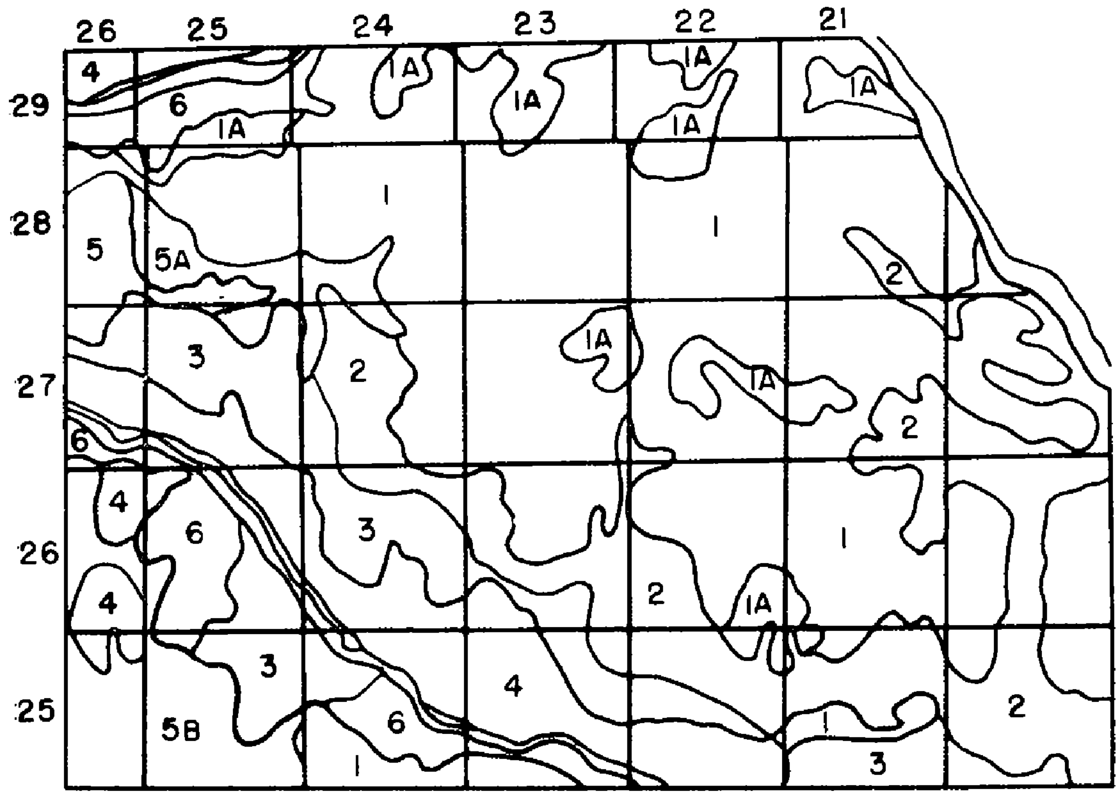
SOILS AND VEGETATION

Most of the soils in Harper County have a sandy texture because they were derived from siliceous formations. The soils developed under a coarse grass cover in a subhumid climate. A horizon of carbonate of lime has accumulated 2 to 4 feet below the surface as a result of the subhumid climate.

The heavier textured soils are red and were derived from Permian formations. The top soil is brown due to the presence of organic material. The heavier textured soils support a heavy sod consisting of buffalo grass, blue grama, side-oats grama, bluestem, and also a scattered growth of prickly pear and various species of plants belonging to the families Leguminosae and Compositae. The smooth soils are well supplied with plant nutrients and are productive. The soils erode rapidly where they slope and as a result are unsuited for agriculture.

The lighter textured soils were derived from Tertiary and Quaternary formations and have a top soil that is grayish brown. Vegetation consists of bluestem and Indian grass as well as sand sage. In some places the soils support small, thinly scattered post oak, blackjack oak, elm, hackberry, gum elastic (shittim wood), soapberry, and wild plum trees. Cottonwood, willow, elm, and persimmon trees and sumac shrubs grow along some of the larger streams. These uneroded soils are moderately productive; however, the eroded soils and loose deep sandy soils are unsuited to the production of cultivated crops. The soils are subject to blowing and drifting in places where the vegetation has been removed.

In a subhumid climate the soil-moisture relationship is important to agriculture. The heavy subsoils are capable of retaining more moisture than the lighter subsoils, which may cause higher yields. Wheat is the most important crop and is grown on most of the cultivated soils. Table 1 lists the principal characteristics of the soil series of Harper County and Figure 5 shows the soil associations (Nichols, personal communication).



SOIL ASSOCIATIONS OF HARPER COUNTY, OKLAHOMA

Soils developed in Permian red beds:
- 1 Smooth to steep soils: St. Paul, Carey, Woodward, Quinlan, Cottonwood
- 1A Smooth soils: St. Paul, Carey, Tipton, Hollister
- 2 Steep to rough broken: Quinlan, Rough Broken Quinlan, Cottonwood

Soils developed in Quaternary sands:
- 3 Smooth to undulating sandy soils: Pratt
- 4 Steep to duney loose sandy soils: Trivoli, steep slope Pratt

Soils developed in High Plains outwash material (Tertiary)
- 5 Smooth soils of the high plains: Richfield, Mansic, Bippus
- 5A Rolling soils of the high plains: Mansker, Potter
- 5B Mixed sandy to loamy soils of the high plains: Mansker, Potter, Dalhart, Otero, Randall

Soils developed in alluvium:
- 6 Spur, Canadian, Yahola, Lincoln

POPULATION AND ECONOMIC DEVELOPMENT

The land included in Harper County was a part of the Louisiana Purchase. It was later included in the Cherokee Outlet, which was land set aside for the Cherokee Indian Nation. This land was bought from the Cherokee Nation and opened for settlement in 1893. Harper County, with its present boundaries, was part of Oklahoma Territory which, combined with Indian Territory, was admitted to the Union as a State in 1907.

TABLE 1

PRINCIPAL CHARACTERISTICS OF THE SOIL SERIES OF HARPER COUNTY, OKLAHOMA[1]

Series	Parent material	Topography	Texture of subsoil
Bippus	Quaternary alluvium	0-1° slopes	clay loam
Canadian	Quaternary alluvium	1-3° slopes	fine sandy loam
Carey	Permian (Marlow) sandstone and shales	1-3° slopes	silt loam
Cottonwood	Permian (Blaine) gypsum	3-8° slopes	loam to no subsoil
Delhart	Tertiary or Quaternary eolian or alluvial sands	0-3° slopes	fine sandy loam
Hollister	Permian shales	0-1° slopes	silt loam
Lincoln	Recent alluvium from Quaternary materials	0° slopes	fine sand
Mansic	Quaternary alluvium	1-3° slopes	clay loam
Mansker	Tertiary or Quaternary calcareous alluvium	0-3° slopes	fine sand
Otereo	Tertiary or Quaternary sandy alluvium	0° slopes	loamy sand
Pratt	Tertiary or Quaternary unconsolidated sandy clays, sandy loams, and sand	0-12° slopes	fine sandy loam & loamy fine sand
Quinlan	Permian calcareous weakly consolidated sandstone	3-8° slopes	loam
Randall	Permian sandstone and shale	0° slopes	clay
Richfield	Tertiary and Quaternary medium to fine grained sediments	0° slopes	clay loam
St. Paul	Permian (Marlow) fine grained sandstones and shales	0-1° slopes	silt loam
Spur	Recent calcareous alluvium of Permian, Tertiary and Quaternary material	0° slopes	clay loam
Tipton and Enterprise	Tertiary or Quaternary alluvium	0° slopes	silt loam
Tivoli	Quaternary eolian sand	0-3° slopes	fine sand
Woodward	Permian (Dog Creek and Rush Springs) calcareous sand or silty shale	1-3° slopes	loam
Yahola	Recent alluvium of largely "Red Beds" material	0° slopes	fine sandy loam

[1] J. D. Nichols, U. S. Dept. of Agriculture, personal communication.

In 1950 the population of Harper County was 5,977, or approximately 5.6 persons per square mile. Buffalo, which had a population of 1,544, is the county seat. The population of other towns in the county in the same year was as follows: Laverne, 1,269; Selman, 161; May, 143; and Rosston, 85.

TABLE 2

CLIMATIC DATA FOR BUFFALO, HARPER COUNTY, OKLAHOMA NORMAL MONTHLY, SEASONAL, AND ANNUAL TEMPERATURE AND PRECIPITATION*

Month	Temperature			Precipitation			
	Mean	Absolute maximum	Absolute minimum	Mean	Total amount for the driest year (1954)	Total amount for the wettest year (1941)	Snow average depth
	°F	°F	°F	Inches	Inches	Inches	Inches
December	36.9	89	- 9	0.90	0.28	0.35	2.8
January	36.0	84	-17	0.67	0.06	1.79	2.4
February	39.7	89	- 8	0.91	0.06	1.45	3.4
Winter	37.5	89	-17	2.48	0.40	2.59	8.6
March	48.9	99	- 8	1.28	0.23	1.33	2.9
April	56.3	99	20	1.95	1.22	2.57	0.2
May	66.3	105	25	3.12	5.58	5.57	T
Spring	57.2	105	- 8	6.35	7.03	9.47	3.1
June	76.9	111	35	3.42	0.30	4.35	
July	82.8	114	46	2.12	0.56	1.31	
August	80.5	115	43	2.49	0.40	1.84	
Summer	80.5	115	35	8.03	1.26	7.50	
September	73.4	109	29	2.50	0.23	5.90	
October	61.4	102	12	1.68	2.19	8.80	T
November	47.6	88	0	1.06	T	0.49	0.8
Fall	60.8	109	0	5.34	2.42	15.19	0.8
Year	59.0	115	-17	22.20	11.11	35.75	12.5

* Data from U. S. Weather Bureau

The Wichita Falls and Forgan branch of the Missouri, Kansas & Texas Railway crosses the southwestern part of Harper County with facilities at Laverne and May. Buffalo is served by a branch of the Atchison, Topeka & Santa Fe Railway from Waynoka in Woods County. Harper County is crossed by improved State highways 34 and 46 and Federal highways 64, 270, 183, and 283. Local roads follow section lines except in the rougher areas.

Farming and stock raising are the chief industries of the county. Oil and gas are the main mineral resources, but most wells are shut-in awaiting pipe line facilities. Gravel pits are worked locally for highway construction.

STRATIGRAPHY

INTRODUCTION

The stratigraphic section of Harper County includes Quaternary, Tertiary, Cretaceous, and Permian rock units (Figure 6). About 400 feet of Permian strata crop out in the county. The sequence includes rocks ranging in age from that of the upper part of the Flowerpot shale of early Guadalupean age to the lower part of the Cloud Chief formation of early Ochoan (?) age.

The Permian rocks consist largely of shales, gypsums, and sandstones and have a gentle southerly dip. The oldest rocks in the area crop out in the eastern part of the county, which is the topographic low; younger Permian rocks crop out to the west, which is topographically higher.

A few Cretaceous outliers with a total thickness of about 60 feet of shale and sandstone crop out in south-central Harper County. The rock is the Kiowa shale of Comanche age.

In the southwestern half of Harper County the Permian and Cretaceous rocks are covered by Cenozoic sediments, which consist of approximately 30 feet of Pliocene and 70 feet of Pleistocene strata. The deposits are predominantly alluvial sand and gravels with a 13-foot bed of volcanic ash.

The Anadarko Basin of western Oklahoma was a deep geosyncline filled with sediments of Pennsylvanian and Permian age. Harper County is on the north flank of the basin and the surface rocks are Permian offshore deposits and evaporites. The Cenozoic rocks of Harper County are predominantly floodplain deposits of eastward flowing streams from the Rocky Mountains, with some lake basin deposits.

THE GEOLOGIC MAP

Two geologic maps were prepared; one to show the bed-rock (pre-Tertiary) geology and one to show the surficial (Cenozoic) deposits. The bedrock includes the Permian and Cretaceous deposits and consists of seven formations. Except for the gypsum members of the Blaine formation and the Day Creek dolomite of the Cloud Chief formation no units could be traced. Only in the southeastern part of the county was it possible to separate the two members of the Whitehorse group. Three Cenozoic formations were mapped. The Pearlette ash of the Crooked Creek

Age		Formation		Thickness in feet	Description
QUATERNARY	PLEISTOCENE	MEADE GROUP	Crooked Creek formation	50	Gravel, sand, silt and clay, pink, tan and gray, containing caliche nodules and beds. Volcanic ash in upper part.
TERTIARY	PLIOCENE		Ogallala formation		Gravel, sand and silt, pink, tan and gray, in part cemented.
TERTIARY	PLIOCENE		Laverne formation	100	Shale, sandstone and conglomerate, yellow, gray and black, in part calcareous.
CRETACEOUS	COMANCHE		Kiowa shale	150	Shale, sandstone and conglomerate, yellow, gray and black. In part fossiliferous and gypsiferous.
PERMIAN	OCHOAN (?)		Cloud Chief formation		Shale, maroon-red, containing lenses of rock gypsum. Day Creek dolomite at base.
PERMIAN	GUADALUPEAN	WHITEHORSE GROUP	Rush Springs sandstone	200, 250, 300	Shale and sandstone, brownish-red. Some beds massive and resistant to erosion. Upper part is thin bedded.
PERMIAN	GUADALUPEAN	WHITEHORSE GROUP	Marlow formation	350	

FIGURE 6

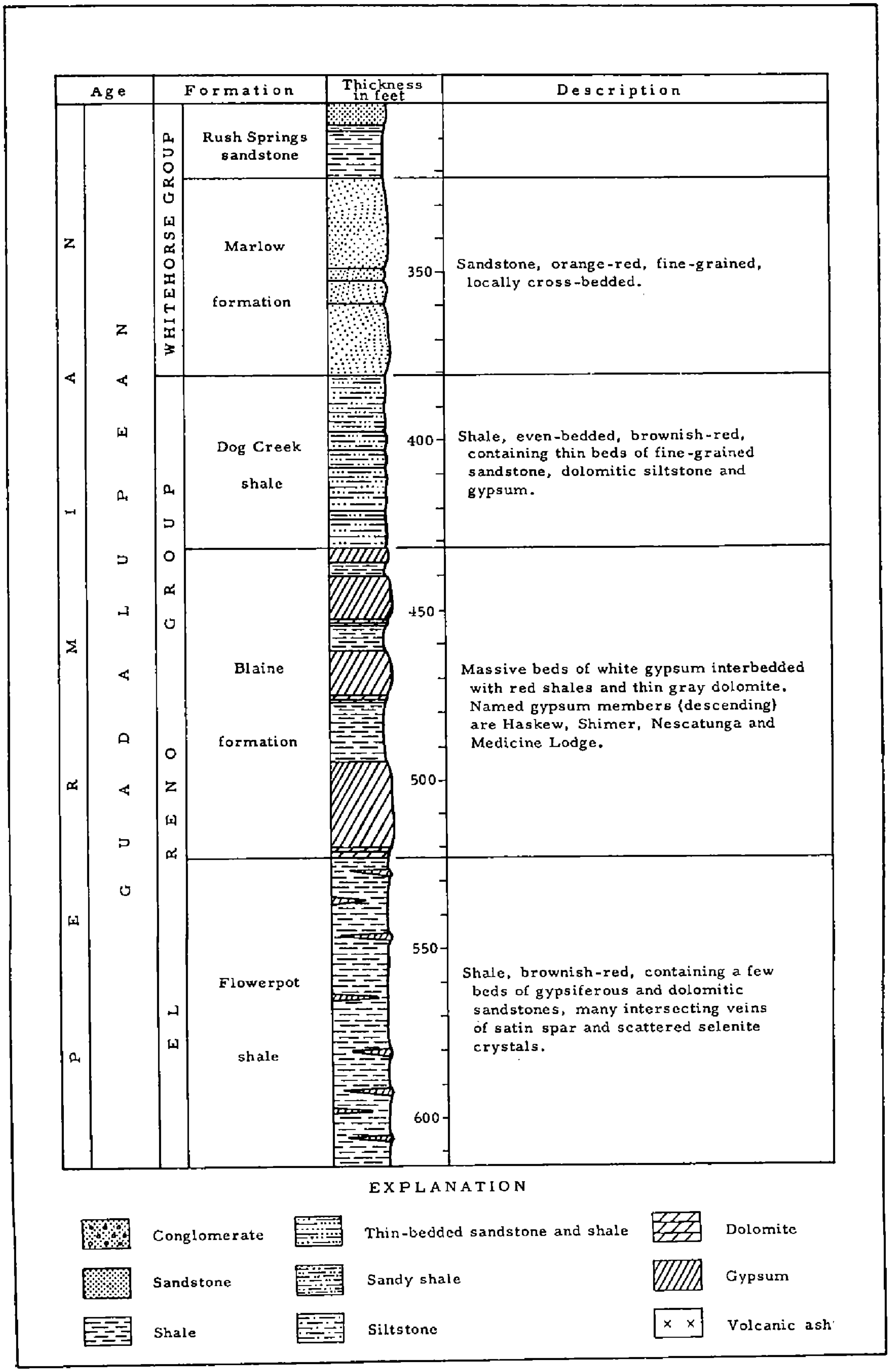


FIGURE 6 (Continued)

formation was the only recognizable unit and it crops out in only one area.

PERMIAN SYSTEM

Most of the exposed bedrock in Harper County belongs to the upper part of the Permian system, which is divided into the Guadalupean series and the Ochoan series.

GUADALUPEAN SERIES

As used in this report the Guadalupean series includes the El Reno group and the Whitehorse group. Newell (1940) stated that the fossil evidence suggests that the Whitehorse should be included in the Guadalupean.

El Reno Group

The El Reno group includes the strata from the base of the Flowerpot shale to the base of the Marlow formation and includes the following formations (ascending): Flowerpot shale Blaine formation, and Dog Creek shale. The maximum measured thickness in Harper County is 200 feet. The base of the Flowerpot shale lies outside the area covered in this report, but is considered unconformable with the underlying Hennessey shale. The upper contact is unconformable with the overlying Whitehorse group.

Flowerpot Shale Formation

The name of Flowerpot shale is applied to the strata lying above the Hennessey shale and below the Blaine formation. At its type locality near Flower Pot Mound in Kansas, it is a somewhat variegated brownish red gypsiferous shale cut by veins of selenite gypsum. Only the uppermost 60 feet of the formation, which crops out in the bluffs along the Cimarron River and Buffalo Creek, is exposed in Harper County

Original description: The Flowerpot shale was named by F. W. Cragin and he designated the type locality as Flower Pot Mound in Barber County, Kansas. Cragin (1896, p. 25) described the Flowerpot shale as follows:

> . . . . in canyon walls .. ., the satin-spar forms a network with irregular rhomboidal meshes, ... warped plates traversing the clay in all directions, ... sometimes is spacious sublenzitoid compartments subject to partition in various directions by intersecting veins. The seams vary from mere paper-seams to plates several inches in thickness. A noticeable and picturesque feature of the

> Flowerpot clays is the manner in which their outcrops are carved by the elements. They are, in fact, a theater of rapid erosion, and many weird spectacles present themselves in their relief forms . . . . they are frequently cut into rather steeply sloped faces having that peculiar pattern of sculpture that is best designated as cone and gully erosion.

Other descriptions: Norton (1939, p. 1792), Moore 1951, p. 39), and Swineford (1955, p. 66) described the Flowerpot shale as reddish brown gypsiferous shale and silty shale, cut by intersecting veins of selenite. A few thin beds of sandstone and siltstone, and locally a thin lenticular dolomite, were noted. Measured thickness ranges from 170 to 190 feet in Kansas.

History of usage: Cragin used the term Flowerpot to describe the formation below the Blaine gypsum and above the Cedar Hills in the type locality. In Oklahoma, Gould (1905, p. 39) used the term Enid formation to describe all the beds below the lowermost gypsum of the Blaine. Evans (1931, p. 408) discarded Gould's Enid formation and followed Cragin's original usage, which now prevails.

Distribution: The Flowerpot shale crops out in a belt from Barber County, Kansas, into central Woods County, Oklahoma. It is also exposed in the bluffs on the south side of the Cimarron River from the Kansas state line southeastward through Woodward County into Canadian County. In Major County the exposures become more extensive and form a belt 10 to 12 miles wide in Blaine, Kingfisher, and Canadian counties. In Harper County it is the lowermost exposed formation and crops out in the bluffs along the Cimarron River and Buffalo Creek.

Character and thickness: The Flowerpot shale conformably underlies the Blaine formation and consists of reddish brown gypsiferous shale and silty shale, with a few thin beds of sandstone and siltstone. Intersecting veins of selenite and satin spar gypsum cut through the formation and varicolored fragments cover eroded slopes. Only the uppermost 60 feet of the formation crops out in Harper County.

Age, correlation, and fossils: According to Davis (1955, p. 51) the Flowerpot shale is the basal formation of the El Reno group in Oklahoma. It is placed in the Nipewalla group of the Leonardian series in Kansas, and can be correlated with the basal part of the Double Mountain formation of Texas. The Duncan sandstone correlates with the lower part of the Flowerpot shale, and the lower part of the Chickasha formation of Stephens and Grady counties with the middle and upper portions. No fossils are known from this formation in Harper County.

Blaine Formation

The Blaine formation in Harper County consists of four named gypsum members, interbedded with red shales and some dolomite, which lie above the Flowerpot shale and below the Dog Creek shale. As used in this report, the named gypsum beds (in ascending order) are Medicine Lodge, Nescatunga, Shimer, and Haskew, and are separated by unnamed red shales. The lower three beds of gypsum rest on thin beds of dolomite. Gould (1902) defined the Blaine formation, but did not trace the gypsum members from Cragin's locality in Kansas.

Original description: C. N. Gould (1905, p. 44-52) named the Blaine formation for outcrops along Salt Creek (Henquenet's Canyon) in northern Blaine County, Oklahoma, and designated that area as his type locality. He described the Blaine formation as follows:

> The Blaine division consists of red shales with interbedded strata of gypsum and dolomite . . . . The characteristic which justifies its recognition as a division is the abundance of gypsum contained in it and its extent and limits are well defined accordingly . . . . The Blaine division consists of five members, three ledges of massive gypsum, and two more or less arenaceous and argillaceous dolomite, interstratified with red shale . . . . The Ferguson gypsum member is the lowermost of the heavy gypsum ledges in the Redbeds of this region. It varies in color from almost pure white to a dirty brown according to the purity of the mineral . . . . Above the Ferguson is a stratum of red shale . . . . Upon this in its turn rests a ledge of arenaceous dolomite named the Magpie dolomite which usually varies in thickness from one to three feet, but in places as on West Creek, Woods County, thickens locally to ten or twelve feet . . . . The Medicine Lodge gypsum rests upon the Magpie and in many places completely covers it . . . . The Altona dolomite is the next notable member above the Medicine Lodge

> gypsum from which it is separated by a stratum of shale—the Jenkins clay of Cragin. It is an arenaceous dolomite which differs in neither lithological character, areal extent or relation to the superjacent gypsum from the Magpie . . . . Resting upon the Altona dolomite is a third gypsum ledge to which Professor Cragin gave the name Shimer gypsum from a township in Barber County, Kansas, where the rock was first studied . . . . The thickness of the Blaine division varies considerably with the locality. An average thickness will approximate 75 feet.

Other descriptions: Snider (1913, p. 119) stated that in northwestern Oklahoma north of the Glass Mountains there are three beds of gypsum in the Blaine. He did not say whether Cragin's Medicine Lodge or Gould's Ferguson was the lowest bed. Miser (1926) mapped the Blaine formation to include all beds from the top of the Chickasha formation to the base of the Dog Creek shale. This modified the definition of the Blaine gypsum so as to include beds above the Shimer gypsum and below the Ferguson gypsum and to discard the Greer formation. Clifton (1930, p. 166) stated that in southeastern Harper County there were four distinct gypsum beds separated by shale and that field evidence indicated that the name Blaine should be dropped and a new name adopted to include the Blaine and Dog Creek beds. According to Sellards (1933, p. 178) the Blaine formation as used in Texas included at least part of the underlying Chickasha and part or all of the overlying Dog Creek of Oklahoma. The top member is the Childress dolomite and gypsum and the Quanah gypsum is near the base. Evans' (1931, p. 409-412) description of the Blaine formation included four gypsum members separated by beds of shale.

Medicine Lodge gypsum member

Original description: The Medicine Lodge gypsum member was first described by Cragin and named for Medicine Lodge River and the town of Medicine Lodge, Barber County, Kansas. Cragin (1896, p. 32) gave the thickness of the Medicine Lodge gypsum as varying between 12 and 30 feet and described it as follows:

> In minor parts, the Medicine Lodge gypsum is nearly pure white; in others it is suffused with leaden-gray or dusky-brown shades; most commonly it is grayish-white mottled with feebly defined dark spots.

Other descriptions: At the type locality of the Blaine formation Muir (1934) mentioned a two-inch bed of dolomite, oolitic and granular in part, which grades into the Medicine Lodge gypsum, which is there 6 feet thick. A series of red shales, 33 feet thick, overlies the gypsum. Evans (1931, p. 410), studying the Medicine Lodge in Harper County, reported a gray to almost black dolomite bed, one foot or less thick, underlying 25 to 30 feet of gypsum. Moore (1951, p. 39) stated that in Kansas the Medicine Lodge gypsum averages 20 feet thick and is underlain by a bed of oolitic dolomite ranging in thickness from 6 inches to 1 foot.

FIGURE 7. Closeup of the Nescatunga gypsum member showing total thickness.

Nescatunga gypsum member

Original description: Norton (1939, p. 1797) named the Nescatunga gypsum member for the exposures along Nescatunga Creek in Comanche County, Kansas, and stated:

> The Nescatunga gypsum bed is well exposed along the lower reaches of Nescatunga Creek where it is 8 feet thick and separated from the overlying and underlying gypsums by red shale beds of nearly the same thickness. Two miles west, near Liberty School, the member has thinned to 2 feet although protected by several feet of cover. In this area no dolomite occurs at the base of the bed although it is reported present in Oklahoma.

Other descriptions: Evans (1931, p. 410) described the Nescatunga (his Shimer) gypsum in Harper County as a 13-foot thick bed of gypsum overlying a thin dolomite bed and separated from the Medicine Lodge gypsum by approximately 20 feet of red shale. Muir (1934, p. 1302) described the Nescatunga gypsum member (his Shimer) at the type locality of the Blaine formation as a bed 18 feet thick consisting of a lower 5-foot gypsum bed, a middle 5-foot anhydrite bed, and an upper 8-foot gypsum bed. The anhydrite is lenticular and in places absent, but the thickness of the bed remains the same. At the base is a light gray, granular, laminated soft dolomite. Above the Nescatunga gypsum member is 35 feet of red gypsiferous shales.

Shimer gypsum member

Original description: The Shimer gypsum member was named by Cragin. Shimer Township, Tps. 33, 34, 35 S., R. 17 W., Comanche County, Kansas, was designated as the type locality. Cragin (1896, p. 27) described the Shimer gypsum member as follows:

> The upper gypsum, or Shimer, is less constantly developed (than the Medicine Lodge gypsum) as a distinct bed of massive gypsum, not appearing at all on the valley of the Medicine Lodge river, so far as observed.

He gave the thickness of the Shimer gypsum as varying from 0 to 10 feet and that it is separated from the Medicine Lodge by 7 to 10 feet of red clay, which is the Jenkins clay (named after the former Jenkins postoffice, near Cave Creek).

Other descriptions: Evans (1931, p. 411) described the Shimer gypsum (his Lovedale) as a 13-foot bed of gypsum overlying a 1- to 2-foot dolomite bed. It is separated from the underlying Nescatunga (his Shimer) by 7 feet of red shale. He suggested a possible correlation of this gypsum member with the Mangum dolomite on the south side of the Anadarko Basin. Norton (1939, p. 1797), Moore (1951, p. 39), and Swineford (1955, p. 68) reported that the Shimer gypsum in Kansas is a 24-foot gypsum bed overlying a 6- to 18-inch dolomite bed and that the thickness is reduced in many places by solution and erosion.

Haskew gypsum member

Original description: Evans (1931, p. 411) named the Haskew gypsum member for exposures in Harper and Woodward Counties, Oklahoma, and described this member as follows:

> The Haskew gypsum commonly differs from the lower three in several particulars. It does not ordinarily have a dolomite bed at its base, although a very impure sandy dolomite has been observed in a few places. This member has a maximum thickness, in Harper and northern Woodward counties, of about 4 feet, and is separated from the Lovedale gypsum by 4 feet of red shale. The clusters of interlocking crystals on the surface of this bed are commonly much smaller than those of the other three beds. Also this bed has considerably more reddish color than the other three.

Other descriptions: Moore (1951, p. 38), described the Haskew gypsum member in Kansas as a 1-foot gypsum bed, which in many places has been removed by solution. It is underlain by 5 feet of red shale.

History of usage: Gould gave the name Blaine formation to the interbedded gypsum and shale. The base of the formation is the Ferguson gypsum member, which Gould considered the equivalent of Cragin's upper Flowerpot formation. Cragin applied the name Medicine Lodge gypsum to the lowermost massive gypsum in Kansas. Gould considered this the second bed in Blaine County, but in other areas the Medicine Lodge gypsum is considered the basal member. Norton considered that the gypsum beds in the Blaine formation in Oklahoma have been misnamed and miscorrelated with Cragin's original beds. This was partly owing to the fact that Cragin did not name the gypsum lentil in the "Jenkins clay" and that Evans applied Cragin's term "Shimer gypsum" to this lentil. Norton, therefore, named the gypsum in the Jenkins clay the Nescatunga, and threw out Evans' Lovedale, which he considered was Cragin's original Shimer gypsum. The Shimer gypsum was named by Cragin for the second gypsum in Kansas, and Gould, Evans, and Muir followed this usage in Oklahoma. Norton showed that the Shimer is the third gypsum, since Cragin had missed one bed. The Haskew gypsum is the uppermost member of the Blaine and was named by Evans for exposures in Harper

County. The following correlation chart (after Norton, 1939) shows the historical relationship of the named gypsum beds in the Blaine formation.

Cragin (1896)	Gould (1905)	Evans (1931)	Norton (1939)
		Haskew	Haskew
Shimer	Shimer	Lovedale	Shimer
Jenkins clay	Medicine Lodge	Shimer	Nescatunga
Medicine Lodge	Ferguson	Medicine Lodge	Medicine Lodge

Distribution: The Blaine formation has been traced from southwestern Kansas across western Oklahoma into the Texas panhandle and central northern Texas. Exposures in Oklahoma are in northwestern Woods, eastern Harper, eastern Woodward, Major, Blaine, and Canadian counties. The Blaine formation in Harper County crops out as a band ranging from 1 to 4 miles wide. From the Kansas border south it forms a scarp along the west side of the Cimarron River. Outcrops extend about 14 miles upstream along Buffalo Creek and 6 to 8 miles up its principal tributaries, which are Sand Creek and Sleeping Bear Creek.

On the geologic map, the base and the top of the Blaine formation are on the Medicine Lodge gypsum scarp and the Haskew gypsum scarp, respectively. The position of the Nescatunga and Shimer gypsum scarps within the formation are shown.

Character and thickness: The Blaine formation in Harper County has a total thickness of 90 feet; this includes massive gypsum beds, thin dolomite beds, and brownish red shale beds. Good exposures of the gypsum members of the Blaine formation occur along Sleeping Bear Creek in T. 26 N., R. 20 W., showing the relationship between the members. Most of the gypsum members are relatively well exposed along the lower half of Buffalo Creek. The two lower members are visible along the Cimarron River in T. 27 N., R. 20 W. and in the southernmost sections in T. 28 N., R. 20 W.

The lowermost member of the Blaine formation is the Medicine Lodge gypsum member, which is a massive white-gray crystalline gypsum with a gray one-foot dolomite bed at its base. It has a thickness of 25 to 30 feet. Good exposures of this member are in the NE ¼ sec. 14 and the SE ¼ sec. 24, T. 27 N., R. 20 W.

The Nescatunga gypsum member is separated from the Medicine Lodge gypsum member by 20 feet of red shale. This member consists of 13 feet of massive gypsum and is underlain by a gray dolomite. The dolomite upon weathering has a pitted surface. Good exposures of this gypsum member can be found in the NE ¼ sec. 19, T. 27 N., R. 20 W. and in all the northeast quarter of T. 26 N., R. 21 W.

Overlying the Nescatunga gypsum member is the Shimer gypsum member; seven feet of red shale separate the two members. The Shimer is a massive gypsum 13 feet thick. At the base of the Shimer is a gray dolomite bed 1 to 2 feet thick, which commonly appears pitted and clinker-like as a result of weathering. The weathering is more pronounced than in the dolomite at the base of the Nescatunga. In many places much of the gypsum has been removed by solution. The Shimer gypsum member outcrops are well exposed in the NE ¼ sec. 31, T. 27 N., R. 20 W. and in the NE ¼ sec. 23, T. 26 N., R. 21 W.

The Haskew gypsum member, the topmost member of the formation, consists of 4 feet of gypsum underlain by 4 feet of brownish red shale. In a few places the gypsum has been removed by leaching. Outcrops of this member are visible in the NW ¼ sec. 15, T. 25 N., R. 20 W.

In many localities in Harper County much of the gypsum has been removed by solution and in some areas only the dolomite at the base of the gypsums remains. In the northeastern part of the County along the Cimarron River all of the gypsum has been removed. To the south only the two lowermost gypsum members are present and only in the southeastern part of the County are all four gypsum members present. Since solution has had such a great effect on these evaporites and since the lowermost members are more nearly intact than are the upper members it appears that in the past there have been larger streams than are in existence at the present time. It is possible that the Pleistocene streams which flowed across this county could have removed the gypsum.

Age, correlation, and fossils: The Blaine formation is generally regarded as of Middle Permian age, is the uppermost formation assigned to the El Reno group and is equivalent to beds of the same name in Kansas and Texas. No fossils have been found in Harper County.

Dog Creek Shale

The Dog Creek shale conformably overlies the Blaine formation and is unconformable below the Whitehorse formation. In Harper County it is a reddish-buff gypsiferous shale with thin beds of red sandstone and gypsum, and has a thickness of 25 to 50 feet.

Original description: Cragin (1896, p. 39-40) named the Dog Creek shale, designated the area along Dog Creek in western Barber County, Kansas, as the type locality, and gave the following description:

> The lowest member, or Dog Creek terrane, of the Kiger consists of some thirty feet, or locally of a less or greater thickness, of dull-red argillaceous shales, with laminae of gypsum in the basal part and one or two ledges of unevenly lithified dolomite in the upper. The color of these shales resembles that which prevails in most of the terranes of the Salt Fork division below, more than of the Kiger terranes above the Dog Creek. The dolomite varies from light-gray to dark-gray, and clay-impregnated portions may partake of the red color of the including shales. In lithological character, it varies from solid stone which serves a fair purpose as a building-stone for the the rougher uses, to that which is so contaminated with clay as to be soft and worthless. It is often cellular or cancellated. A dark and cellular variety occurs at the top of a remnantal mound of the Dog Creek at the highest point of the range of lofty tables that forms the eastern front-line of the Gypsum Hills southwest of Medicine Lodge, this mount being the most easterly outlier of the Dog Creek formation in Kansas.
>
> In Oklahoma, it is seen on the bluffs of the Cimarron river in the immediate vicinity of the Great Salt Plain.

Other descriptions: Gould (1924, p. 334) stated that the Dog Creek becomes thicker in Oklahoma than it is at the type locality as described by Cragin. In Woodward County the Dog Creek is

225 feet thick. In Blaine County, where its entire thickness cannot be measured at any one place, it may be as much as 400 to 500 feet thick. Clifton (1930, p. 166) gave the maximum thickness in Harper County as 25 feet. The dolomite within the formation in Woods County, Oklahoma, is replaced by two beds of gypsum in southeastern Harper County, or at least by beds occupying the stratigraphic position of the Dog Creek. Therefore, he believed that the Dog Creek shale should be classified and correlated as a part of the Blaine formation in Kansas and Oklahoma. Evans (1931, p. 412) described the Dog Creek shale in Harper County as 50 feet of gypsiferous red shale with a few thin beds of poorly cemented red sandstone and thin beds of gypsum near the base. Norton (1939, p. 1799) stated that the Dog Creek at the type locality is 53 feet of shale with several layers of dolomite and dolomitic sandstone. On Cave Creek the Dog Creek is only 23 feet thick, and in Oklahoma is 14 feet thick. The topmost member is a one-foot gypsum bed which is commonly absent due to solution.

History of usage: The use of the term Dog Creek shale has followed Cragin's original work.

Distribution: The Dog Creek shale crops out as a thin band in Barber and Comanche Counties, Kansas, and continues as a thin band into Woods County, Oklahoma. In Harper County it crops out as a belt west of the Cimarron River and extends southeastward through northeastern Woodward County where it forms a scarp along the north side of the North Canadian River. The band continues along the North Canadian River through Major, Blaine, and Canadian Counties. It crosses the North Canadian River in the vicinity of El Reno and is exposed in bluffs along the South Canadian River west of Union City and in the hills of northwestern Grady County west of Minco. The formation crops out on the south side of the Anadarko Basin near Mountain View in Kiowa County and as a thin band continues west into Beckham County; thence south as a wide band through western Greer, western Jackson, and eastern Harmon Counties.

In Harper County the Dog Creek shale forms a band generally ¼ to ½ mile wide, but may be as much as 3 miles wide. In the northeastern corner it is a few miles west of the Cimarron River and continues south as a band to the northeast corner of T. 27 N., R. 20 W.; then it swings west parallel to Buffalo Creek. It crosses the creek in the vicinity of Buffalo and then continues southeast to the southeast corner of the county. The belt is within a few miles of Buffalo Creek except where north flowing tributaries of Buffalo Creek cause the band to swing several miles to the south.

Character and thickness: The Dog Creek shale is commonly grouped with the Blaine formation since at many places it is not possible to differentiate the beds. In Harper County the Dog Creek shales are the deposits between the uppermost gypsum of the Blaine formation and the basal beds of the Whitehorse group.

The formation consists predominantly of reddish buff shale or silty shale beds. Also present are thin beds of fine-grained poorly cemented sandstone and thin beds of dolomite, dolomitic and gypsiferous sandstone, and gypsum. At the top of the formation is a one-inch gray dolomitic sandstone. The average thickness of the Dog Creek shale is 50 feet.

Age, correlation, and fossils: The Dog Creek shale is the uppermost formation in the El Reno group, Leonardian series of the Permian, and is the equivalent of beds of the same name in Kansas and Texas. No fossils have been found in Harper County.

Whitehorse Group

The Whitehorse group in Harper County consists of the Permian rocks unconformable above the Dog Creek shale of the El Reno group and unconformable below the Cloud Chief formation. In the northeast quarter and western half of the county the rocks are mapped as Whitehorse group undifferentiated. In the southeast quarter two members are mapped. These are the Marlow formation at the base, which is a soft, fine-grained, poorly cemented sandstone, and the overlying Rush Springs sandstone, which consists of interbedded sandstone, shales, and gypsum. Unconformities both above and below limit the Whitehorse group.

Original description: The Whitehorse group was named by Gould (1905, pp. 55-56) for exposures in the vicinity of Whitehorse Springs, Woods County, Oklahoma. The beds were also described (under the name Red Bluff sandstone) by Cragin (1896, p. 40) and Gould quoted Cragin's description of the Red Bluff sandstone as his description of the Whitehorse sandstone.

> This formation consists of some 175 or 200 feet of light-red sandstone and shales. * * * Viewed as a whole it is very irregularly stratified, being in some cases considerably inclined, in others curved, and this oblique and irregular bedding, being on a much larger scale than that of ordinary cross beddings, at first glance gives the impression of dips, anticlines, synclines, etc., that have been produced by lateral pressure, the dips, however, being in various directions. * * * The Red Bluff beds exhibit the most intense coloration of any of the rocks of the series. When the outcrops are wet with recent rains their vividness of color is still greater, and the contrasts of their almost vermilion redness with other colors of the landscape is most striking. Spots and streaks of bluish or greenish gray sometimes occur in these rocks, but not to nearly so great an extent as in the lower beds. The sandstones of the Red Bluffs are generally too friable for building stone, but in some instances selected portions have proved hard enough for such use and are fairly durable.

Other descriptions: Reeves (1921, p. 51) described the Whitehorse sandstone as a friable reddish-brown cross-bedded to regular-bedded sandstone which weathers rapidly. Clifton (1930, p. 167) stated that the Whitehorse sandstone consists of a series of depositional units which include horizons of massive fine-grained sandstone, shale beds, sandy shale beds, at least 5 gypsum or gypsiferous beds or lenses, and 5 or more fossiliferous lagoonal or shoreline or channel sand deposits. Evans (1931, p. 414) stated that the Whitehorse group consists of soft, poorly cemented, fine-grained reddish buff sandstone, red to maroon shale, and a few white to reddish crystalline gypsum beds. The total thickness is approximately 250 feet; the lower 100 feet is sandstone with one or two non-persistent gypsum beds and the upper 150 feet contains a considerable amount of shale and 6 or 7 beds of reddish white crystalline gypsum.

Marlow Formation

Original description: Sawyer (1924, pp. 314-315) proposed restricting the name Whitehorse sandstone to the upper part of the Whitehorse, and named the lower part the Marlow formation. He (1929, p. 11) renamed his restricted Whitehorse sandstone the

Rush Springs member of the Whitehorse and called the lower part the Marlow member. Sawyer's original description for outcrops in southwestern Oklahoma follows:

> The Marlow formation consists of brick-red shales and even-bedded brick-red sandstone with bands of fine white sand and sandy gypsums. The entire formation is gypsiferous, many of the shales containing veins of satin-spar and the sandstones more or less gypsum. A thin layer of almost pure gypsum about 1 foot thick is found at the top of this formation. The thickness of the Marlow formation is about 120 feet.

Other descriptions: Green (1936, p. 1470) stated that the base of the Marlow is definitely an overlapping contact. The evidence is more easily recognized on the south side of the basin.

Rush Springs Sandstone

Original description: Sawyer (1929, p. 11) considered the Wichita Mountains region of southwestern Oklahoma his type locality and described the Rush Springs as follows:

> The Rush Springs member consists almost entirely of red cross-bedded sandstone and has little or no shale or gypsum in this area.

Other descriptions: Evans (1931, p. 414-417) stated that the Whitehorse formation of Harper County consists of approximately 250 feet of reddish buff sand, red to maroon shale, and a few white to reddish crystalline gypsum beds. He further stated that it is not possible to separate the Marlow member from the Rush Springs member in northwestern Oklahoma and that together they constitute the lower 100 feet or more of the Whitehorse. Green (1936, p. 1472-1473) believed that there is an unconformity at the top of the Rush Springs, and that therefore, the Cloud Chief should be included in the Quartermaster formation. Norton (1939, p. 1802) wrote that the Whitehorse conformably overlies the Dog Creek although many have suggested an unconformity because of the variable thickness of the Dog Creek. In Kansas (Norton 1939, p. 1803 and Moore 1951, pp. 37-38) the Whitehorse can be divided into four characteristic members: the Marlow, the Relay Creek dolomite, an even-bedded sandstone, and an upper shale member. The Marlow sandstone member is a red, fine-grained, locally shaly or silty cross-bedded sandstone which is about 110 feet thick. The Relay Creek dolomite and sandstone member consists of two dolomite beds ranging in thickness from a few inches to about 1 foot separated by red and white fine sandstone which is locally cross-bedded. The thickness is about 22 feet. The even-bedded member is a maroon very fine-grained sandstone and shaly siltstone, mostly even-bedded but locally cross-bedded in the upper part, with a thickness of about 100 feet. The upper shale member consists of about 38 feet of predominantly brick red or maroon silty shale, siltstone, and a minor amount of very fine sandstone with a zone of dolomitic beds in the basal part and a zone of gray green sandy shale in the upper part.

History of usage: Gould (1905, p. 55) proposed the name Whitehorse for exposures in Woods County, Oklahoma. Sawyer (1924, p. 315-316) restricted the name Whitehorse to the upper part of the formation and named the lower part the Marlow formation. Later Sawyer (1929, p. 11) divided the Whitehorse into two members; the Marlow member being the basal one and the Rush Springs member the upper one. Evans (1931, p. 420) added the Cloud Chief gypsum as the top member of the Whitehorse with a middle Rush Springs member and a basal Marlow member. Green (1936, pp. 1471-1473 and 1937, pp. 1525-1529) restricted the Whitehorse to Sawyer's original two members with the Cloud Chief grouped with the Quartermaster.

Distribution: The Whitehorse group crops out on both sides of the Anadarko basin. On the north flank it is a belt 10 to 20 miles wide through Woods, Harper, Woodward, Dewey, Blaine, Custer, and Washita Counties, Oklahoma, and Clark, Comanche, and Barber Counties, Kansas. The formation noses in Caddo and southwestern Grady Counties becoming very extensive at the surface. The south flank is a belt 2 to 3 miles wide through southern Washita and Beckham Counties with an isolated exposure in west central Harmon County.

In the western third, central, and south central part of Harper County the Whitehorse is buried beneath Tertiary and Quaternary deposits. Surface exposures at the Kansas state line are practically the width of the county but near the center of the county are about 8 miles wide; this belt continues diagonally to the southeastern corner of Harper County. Another area of Whitehorse exposures is south of Beaver River in the southwestern part of the county.

Character and thickness: The Whitehorse group consists of approximately 200 feet of reddish sandstone, siltstone, shale, and minor quantities of white to reddish gypsum beds. In the southeast quarter of Harper County the Marlow member is composed of 65 feet of soft, light-red, fine-grained, commonly cross-bedded, and generally poorly cemented sandstone with a few non-persistent gypsum beds. The Relay Creek dolomite, which is near the top of the Marlow, is essentially absent in Harper County. It was either not deposited or has been destroyed, but a few gullies contain a ⅛th inch dolomite bed. The Rush Springs sandstone is composed of about 140 feet of well bedded, red, fine-grained sandstone and siltstone with reddish brown shales and beds of gypsum. The Marlow erodes into low rolling hills whereas the Rush Springs forms a more rugged topography. Good exposures are located in the NW ¼ sec. 17, T. 25 N., R. 20 W. In the northern half of the county it is impossible to separate the two members and in the western part the beds are buried below later deposits. The beds in sec. 1, T. 28 N., R. 26 W. are wholly or partly Rush Springs, but since the Marlow cannot be distinguished the rocks are mapped as Whitehorse undifferentiated.

Age, correlation, and fossils: In northwestern Oklahoma the Whitehorse group consists of the Marlow formation at the base and the overlying Rush Springs sandstone and belongs to the Guadalupean series of the Permian. It can be correlated with the Whitehorse of the Cimarron group of Kansas and with the Whitehorse group of Texas. No fossils have been found in the Whitehorse in the area of this report.

OCHOAN (?) SERIES

The Ochoan (?) series consists of the uppermost Permian strata. In Harper County the Cloud Chief formation is referred to this series. It overlies unconformably the Whitehorse group and is overlain by Cretaceous and Cenozoic rocks.

Cloud Chief Formation

In Harper County the name Cloud Chief formation is applied to the dolomite, red shale, and gypsum overlying the Whitehorse group. The formation crops out in outliers and only the lowermost 25 feet is present. The Day Creek dolomite, a 2-foot dolomite with druse quartz, is the basal member and is overlain by irregular impure gypsum interbedded with gypsiferous shale.

Original description: The Cloud Chief formation was named by Gould (1924, pp. 324-341) for outcrops near the town of Cloud Chief in Washita County, Oklahoma, and was described as follows:

> The Cloud Chief formation consists of ledges of massive gypsum imbedded in red shales. The gypsums vary much, both in number and thickness. In some places, as for instance near Cement, there are, according to Reeves, two beds separated by 15 to 20 feet of gypsiferous shale. The upper bed here varies in thickness up to 85 feet, but the average thickness of the two beds in this region is perhaps not more than 5 feet. In other localities three or more gypsums, separated by clay shales, outcrop on the surface.

Other descriptions: Gould (1925, p. 95) described the Cloud Chief gypsum as a massive white or pinkish gypsum, at most places irregularly bedded with interstratified red clay shales. The thickness varies up to 115 feet. Green (1936, pp. 1473-1475) stated that the Cloud Chief formation consists of a sandstone in which the gypsum facies occur as lenses. The formation has a maximum thickness of 300 feet. Well logs at the type locality show that the basal gypsum is 100 feet thick . The greatest problem is in the correlation of the dolomites.

Day Creek Dolomite

Original description: The Day Creek dolomite was named by Cragin (1896, p. 44) from exposures at the head of Day Creek in Clark County, Kansas, and described as follows:

> The Day Creek dolomite is a persistent stratum of dolomite, varying from less than a foot to five feet or more in thickness * * * It is a true dolomite, containing with the carbonate of lime an equal or even greater percentage of carbonate of magnesia. The stone is nearly white in fresh fracture, weathers gray, and often has a streaked and gnarly grain crudely resembling that of fossil wood. It is more or less cellular and in places, cancellated. Irregular nodules of limonite are here and there imbedded in it.

Other descriptions: Gould (1924, p. 337) wrote that the thickness varies up to 5 feet and that at places there are two distinct ledges of dolomite 2 to 4 feet thick which are separated by red shales. Clifton (1930, p. 170) stated that there are wide lateral variations in the mineral content of the Day Creek. In the shoreward areas both calcite and dolomite are present with chert or flint as an important secondary constituent. Basin-ward the dolomite gives way to gypsum and the chert content decreases or entirely disappears. Evans (1931, pp. 425-426) wrote that the Day Creek dolomite is a 2-foot thick, hard, light gray limestone or dolomitic limestone, which commonly contains aggregates of smoky or reddish chert. Merritt and Ham (unpublished Oklahoma Geological Survey report, 1942) described an outcrop of the Day Creek dolomite in the SW ¼ sec. 18, T. 28 N., R. 22 W. as a 2½ foot thick ledge of white, dense, crenulated dolomite with stringers and irregular masses of bluish botryoidal chalcedony. Thin section study showed that considerable quartz is present in three forms: (1) euhedral, 0.25 to 0.4 mm. long, partially replaced by calcite; (2) anhedral in cavities associated with secondary calcite, with which it seems to be at least in part contemporaneous; and (3) chalcedonic silica replacing carbonate and euhedral quartz.

History of usage: Gould and Lewis (1926, p. 24) suggested that the Day Creek dolomite might well be considered the basal part of Gould's Cloud Chief. Sawyer (1929, p. 12) stated that the Cloud Chief overlies the Whitehorse and underlies the Quartermaster and that Cragin's name Day Creek has been applied to the Weatherford dolomite, the Greenfield dolomite, and the Quartermaster dolomite. Clifton (1930, p. 172) believed that the Cloud Chief as a formation name should be dropped and that a new formation name be adopted to include beds from the base of the Day Creek to the base of the Quartermaster. It would include the Day Creek, the Hackberry, the Big Basin, and the beds overlying the Big Basin to the base of the Quartermaster. Evans (1931, p. 420) stated that the Cloud Chief is a member of the Whitehorse formation. The base is a double gypsum bed and the top is at the base of the Day Creek. Buckstaff in the discussion of Evans' paper did not believe that Evans had proved his interpretation of the stratigraphic relationship. Sellards (1933, p. 179-180) placed the Cloud Chief above the Whitehorse and below the Quartermaster. Green (1936, p. 1473) included the Cloud Chief as the basal member of the Quartermaster formation. Miser (1954) stated that in northwestern Oklahoma the Day Creek is the basal member of the Cloud Chief.

Distribution: The Cloud Chief formation occurs as isolated outliers in north-central, central, and southeastern Harper County. The outcrops are generally less than a mile wide and form the divides between the Cimarron River and Buffalo Creek and between Buffalo Creek and Beaver River.

Character and thickness: The Cloud Chief formation is predominantly a dark maroon shale with one or two thin gypsum beds and the Day Creek dolomite at its base. The Day Creek consists of a single bed of pale-gray to pink dense fine-grained dolomite with a thickness of about 2½ feet. In many localities the member contains chert nodules and finely disseminated chert, which is commonly blue to purple in color. Over much of Harper County the Cloud Chief formation is the uppermost rock and most of it has been removed by erosion. Its presence is due to the resistant basal Day Creek dolomite which has prevented its entire removal. The maximum thickness is 30 feet.

Age, correlation, and fossils: The Cloud Chief formation is doubtfully referred to the Ochoan series of the Permian. It is correlated with the Taloga formation and Day Creek dolomite of Kansas. No fossils have been found in Harper County.

CRETACEOUS SYSTEM

COMANCHE SERIES

Kiowa Shale

The name Kiowa shale is applied in Harper County to the Cretaceous sandstones and shales unconformably overlying the Cloud Chief formation. This formation consists of black to yellow resistant sandstones and thin white somewhat chalky limestones. It crops out as widely scattered outliers and is overlain by Quaternary sand dunes. The maximum observed thickness is 52 feet.

Original description: The Kiowa shale was named by Cragin (1895, p. 70) for outcrops in Kiowa County, Kansas, and was described as follows:

> The designation, Kiowa shales, is proposed for the inferiorly dark colored and superiorly light colored shales that outcrop in several of the counties of southwestern Kansas, resting upon

> the Cheyenne sandstone in their eastern and upon the "Red Beds" in their middle and western exposures, and being overlaid by brown sandstone of middle Cretaceous age, or Tertiary, or Pleistocene deposits according to the locality.
>
> The Kiowa shales are a locally modified northern extension of part of Hill's Comanche series, cut off from the main part by erosion. They are named for the place of their typical occurrence, Kiowa County, Kansas. The fossils of the shales are chiefly those which, in Texas, are common in the Fredericksburg division (Comanche series).

Other description: Bullard (1928, p. 56) gave the following description of the Kiowa shale in Harper County, Oklahoma:

> The Kiowa shale consists typically of thinly laminated black shale grading into a yellowish clay in the upper part. The black shale of the lower portion of the Kiowa is especially characteristic consisting of very thinly laminated, paper-like shale. The upper portion contains more lime and has a distinctly yellow color, standing out in marked contrast to the lower portion. There are numerous thin layers of soft yellowish sandstone, particularly in the upper part. The formation contains throughout thin limestone layers, almost a fossil coquina consisting of fragments of oyster shells. Fossils are exceptionally abundant, occurring in the limy and sandy layers through the formation. The black shale rarely contains fossils.

History of usage: Marcou (1858, p. 17) stated that the fossiliferous beds in western Oklahoma were of Neocomian age because the fossils are characteristic of beds of this age in Europe. Gould (1905, p. 78) stated that the outliers in western Oklahoma are remnants of the Comanche beds, which extend from Texas to Kansas. Bullard (1928, p. 73-74) correlated the outliers in Harper County with those of the Kiowa of Kansas.

Distribution: The Cretaceous outliers of western Oklahoma extend from the Avilla Hills on the Kansas line southward to within a few miles of the Wichita Mountains. Small isolated outcrops occur in Harper County in secs. 6 and 24, T. 26 N., R. 23 W. A disconnected series of outliers extends from sec. 17, T. 25 N., R. 23 W. in an easterly direction to secs. 11 and 12, T. 25 N., R. 21 W.

Thickness and character: The Kiowa shale consists of gray to black thinly laminated shale grading into a yellow clay interbedded with yellow sandstone and sandy conglomerate. The basal portions contain many fragments derived from Permian red beds. Pebbles of the conglomerate are black iron-stained sandstone grading in size up to a foot in diameter. Fossils are exceptionally abundant, occurring in both limy and sandy layers and in places forming a calcareous coquina. Selenite gypsum crystals are abundant in some of the black shales.

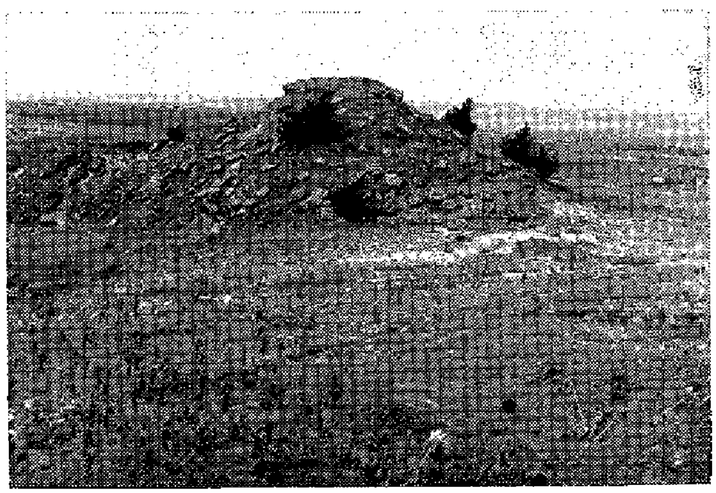


FIGURE 8. Outlier of Cretaceous Kiowa shale.

Outcrops occur on the divide between Buffalo Creek and Beaver River. A prominent north-facing escarpment with the Kiowa shale exposed on the crest is formed by the Day Creek dolomite overlying the soft easily eroded Whitehorse formation. Recent dune sand from Beaver River covers the southern edge of these southward dipping beds.

In Harper County erosion has removed most of the once extensive Kiowa shale, leaving a few isolated outliers. The maximum measured thickness is 52 feet located in sec. 14, T. 25 N., R. 22 W.

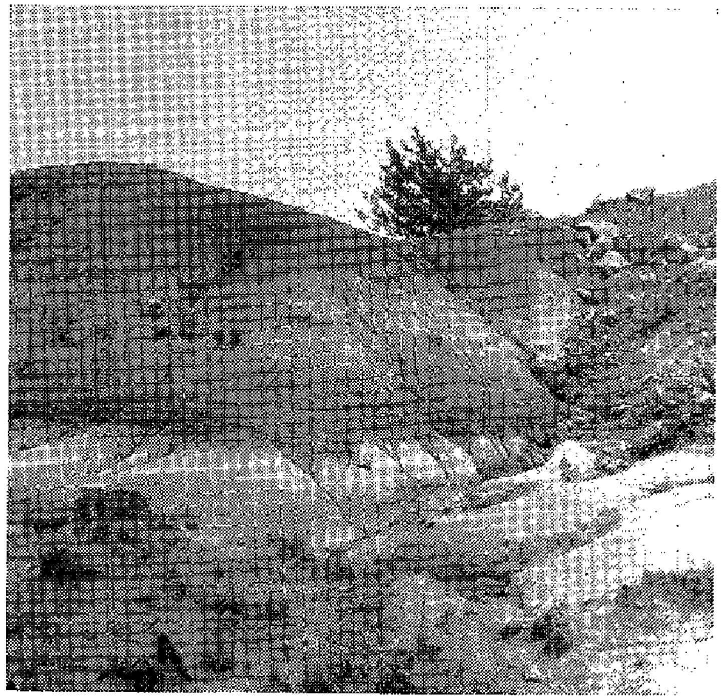


FIGURE 9. Closeup of the Kiowa shale.

Age, correlation, and fossils: According to Bullard (1928, p. 73) the outliers in Harper County are correlative directly with the Comanchean Kiowa shale of Kansas. There are two important fossiliferous horizons common to the two main areas, a *Cyprimeria* zone and a *Gryphea corrugata* zone. Other fossils are *Exogyra texana, Trigonia* sp., *Turritella* sp., *Oxytropidoceras belknapi*, and *Gryphea navia.*

TERTIARY SYSTEM

PLIOCENE SERIES

Only rocks of the Pliocene series of the Tertiary system are present in Harper County, Oklahoma. As used in this report the Pliocene series includes the Laverne formation and the Ogallala formation.

Laverne Formation

The Laverne formation consists of resistant interbedded limestones, shales, sandstones, and conglomerates. In Harper County it is unconformable above the Whitehorse formation and is covered in a few places by Pleistocene outwash and dune sand deposits. Its exposed thickness in Harper County varies from 0 to 35 feet, but is known to be as thick as 500 feet in the subsurface on the Stevens—Seward county line in Kansas.

Original description: The Laverne formation was named by Waite and it is assumed that the type locality is in the vicinity of Laverne in Harper County, Oklahoma. The original manuscript has been lost, but Gould and Lonsdale (1926, p. 33) gave the following description of the Laverne formation, which is an excerpt from Waite's manuscript:

> The limestone of this formation varies from a pure white to a buff-colored limestone that has a conchoidal fracture. This member is prolific with fossils. Mollusca occur in great abundance. Bones and teeth are very often found. A great many leaves of many varieties are found in the buff-colored limestone.

Other descriptions: Smith (1940, pp. 37-38), Frye and Hibbard (1941, p. 398), Frye (1942, pp. 94-97), and Byrne and McLaughlin (1948, pp. 68-72) have described the Laverne formation in Kansas as dipping beds of gray, fine-grained, thin-bedded sandstone, chalky sandstone, sandstone containing conglomerate, blue gray to tan even-bedded shale, and tan soft silty limestone which typically contains a thin bed of gray dense limestone at the top. Schoff (1956, p. 3) gave the following description of the Laverne formation:

> The formation consists of sand, gravel, caliche, limestone, silt, and clay, most of which are not readily distinguishable lithologically from other Tertiary beds. Beds are gray, blue-gray, tan, yellow, pink, maroon, light green, and white. The distinctive beds in the formation are soft, massive,

sandy chalk (or chalky sandstone), hard fossiliferous gray to white limestone, hard carbonaceous limestone, and coaly shale, but all exposures do not include such distinctive beds. No bed or group of beds is sufficiently persistent laterally to serve as a stratigraphic marker within the formation, and no subdivisions of the formation have been proposed.

History of usage: Gould and Lonsdale (1926, p. 33) followed Waite's usage. Gould (1927, p. 238) declared the name obsolete, but later workers reinstated it.

Time units			FRYE, SWINEFORD and LEONARD 1948	FRYE and LEONARD 1952	HIBBARD, 1958	This Report
PLEISTOCENE	Wisconsin	Mankato Cary	Sanborn formation: Bignell member	Sanborn formation: Bignell member; sand and gravel	Sanborn group: Vanhem formation	Lake deposit (unnamed)
		Brady	Brady soil			
		Tazewell Iowan	Peoria member	Peoria member; sand and gravel		
	Sangamon		("Lower" Kingsdown and "Upper" Meade — Kingsdown Silt — Isolated basin fillings)		Kingsdown formation	
	Illinoian		Loveland member	Loveland mem.; Crete member		
	Yarmouth		Meade formation: Sappa member; Pearlette ash	Meade fm.: Sappa member	Meade group, Crooked Cr. fm., Atwater mem.: Buried Caliche	Meade group, Crooked Cr. fm.: Pearlette ash mem.
	Kansan		Grand Island member	Pearlette ash; Grand Island mem.	Pearlette ash lentil; Stump Arroyo mem.	Silt and clay unnamed; Stump Arroyo mem.
	Aftonian		? Type Rexroad formation	Blanco fm.: Fullerton mem.	Ballard formation: Buried Caliche; Missler member	Ballard formation
	Nebraskan		? ?	Holdrege member	Angell member	
PLIOCENE	Upper			Ogallala fm. (Kimball member); Late Hemphillian	Rexroad fm.: Buried Caliche; XI member	
	Middle					Ogallala formation
	Lower				Laverne formation	Laverne formation

FIGURE 10. Correlation chart of Pliocene and Pleistocene strata.

Distribution: The Laverne formation crops out in northwestern Ellis, southwestern Harper, eastern Beaver, and southwestern Texas Counties, Oklahoma, and in Meade and Seward Counties, Kansas. Younger rocks probably cover it in much of Seward, Haskell, Stevens, and Grant Counties, Kansas, and in western Beaver County, Oklahoma. Surface exposures of the Laverne formation in Harper are located in the southern half of T. 26 N., R. 26 W., all of T. 25 N., R. 26 W., and most of the southern and western three-quarters of T. 25 N., R. 25 W.

Character and thickness: The basal part of the Laverne formation is a coarse conglomerate containing an abundance of black iron-stained pebbles. The conglomerate is not continuous and was probably early basin fillings. Most of the exposures in Harper County consist of interbedded gray to blue-gray sandy chalk, blue-gray to tan shales, gray fine-grained thin-bedded sandstone, and massive tan to pink coarse-grained sandstone. The rock is well indurated and resistant to erosion. The thickness varies from 0 to 35 feet.

One of the peculiarities of the Laverne formation is that its beds generally dip up to as much as 15 degrees. Within one section isolated outcrops normally dip in different directions. On aerial photographs in many places the Laverne formation is seen as rings, averaging 300 to 400 feet across. Field examination showed the rings to be in small structural basins with a resistant limy sandstone forming the rims. The basins are the result of subsidence following the solution of the salt and gypsum from the underlying Permian beds. Good examples are in the SW¼ section 16 and SW¼ section 36, T. 25 N., R. 25 N. The basins explain the wide variations in dip in local areas.

According to Frye and Schoff (1942) the Meade basin was formed by fault movement during late Pliocene time (post-Laverne, pre-Ogallala), the fault planes allowing groundwater to dissolve deep seated salt and gypsum. Water flowed down the fault, eastward through the Permian beds, and then issued forth as springs along the ancestral Cimarron River and Salt Fork of the Arkansas River. As a result of this solution there was subsidence of overlying beds to form the structural basins in the Laverne formation. The process continues today at a much slower rate forming sinkholes and structural basins in the overlying rocks.

At no place is the Ogallala in contact with the Laverne formation. Byrne and McLaughlin (1948, p. 72) suggested that either the resistant Laverne formed hills over which the Ogallala was not deposited or that post-Ogallala erosion has removed the latter. The unconformity above the Laverne formation is the greatest break in the sedimentation record of the Pliocene and Pleistocene, as horizontal Pleistocene beds rest upon the Laverne, which has dips as great as 15 degrees.

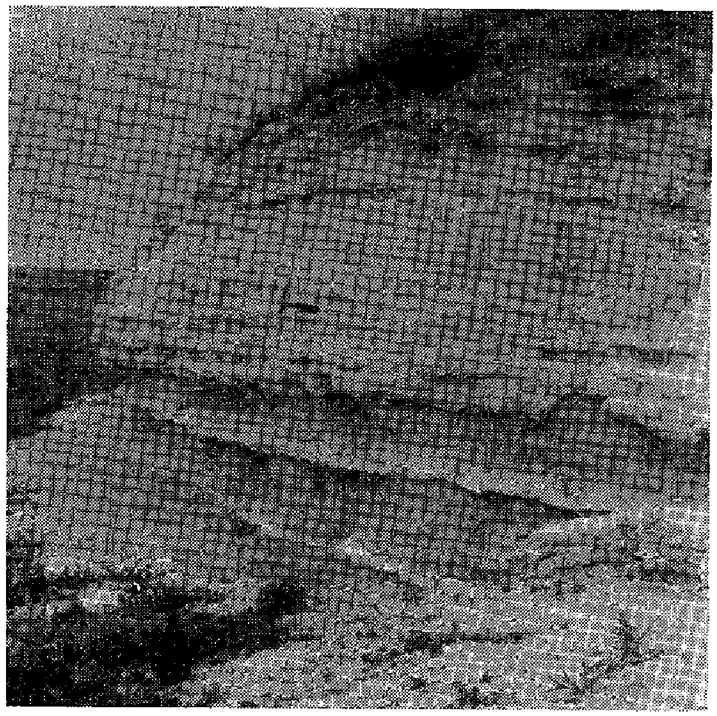


FIGURE 11. Closeup of the Laverne formation.

Age, correlation, and fossils: The Laverne formation is considered by most workers to be early Pliocene in age; however, it is possible that it might be late Miocene at least in the lower part. Schoff (1956, p. 4) stated that it correlates approximately with the Valentine formation of the Ogallala group, but that the U. S. Geological Survey has not accepted the name Valentine formation.

The Laverne formation in Oklahoma is the equivalent of the Laverne formation in Kansas.

Chaney and Elias (1936, pp. 1-72) have described the flora and have included a chapter by Hesse describing the vertebrates. Hibbard (personal communication, 1956) has identified horse teeth from the SW¼ sec. 10, T. 25 N., R. 26 W. as typical Laverne horses as reported by Hesse (1936).

Ogallala Formation

The Ogallala formation in Harper County includes sand, silt, and gravel of middle Pliocene age. It unconformably overlies late Permian beds and is overlain by Pleistocene and Recent material.

Original description: Darton (1899, p. 734) named the Ogallala formation, designated the type locality as near Ogallala station in western Nebraska, and gave the following description:

> Extending from Kansas and Colorado far into Nebraska, there is a calcareous formation of late Tertiary age to which I wish to apply the distinctive name Ogalalla [now spelled Ogallala] formation * * * In its typical development the Ogalalla formation is a calcareous grit or soft limestone containing a greater or less amount of intermixed clay and sand, with pebbles of various kinds sprinkled through it locally, and a basal bed of conglomerate at many localities * * * The pebbles it contains comprise many crystalline rocks, which appear to have come from the Rocky Mountains * * * The general thickness of the Ogalalla formation varies from 150 to 300 feet, the greater amount being along the Wyoming line in the northeastern corner of Kimball County.

Other descriptions: Elias (1931, 1942, and 1948) stated that the Ogallala formation at the type locality is poorly sorted, everywhere somewhat pinkish, and the "mortar beds" form prominent escarpments. The upper limit is a persistent hard algal limestone precipitated largely by the agency of *Chlorellopsis bradleyi,* which was probably deposited along the shores of lakes on the flat fluviatile sediments. Except for the uppermost part, fossil herbaceous seeds provide a means for zoning. Lugn (1939, pp. 1260-1263) assigned the rank of group to the Ogallala of Nebraska with four formations (in ascending order): Valentine, Ash Hollow, Sidney, and Kimball. He described the Valentine formation as more or less unconsolidated fine gray sands, 175 to 225 feet thick. The Ash Hollow, the typical "mortar beds," consist of layers of gravel and sand, silt, and fine sandy clay, with some beds of volcanic ash, all more or less indurated into caliche beds. The thickness varies from 100 to 150 feet. The Sidney gravel, 15 to 50 feet thick, ranges from fine to medium river sand to pebbles and cobbles, the coarse material generally having a dark coating of mineral matter and clay. The Kimball formation ranges in thickness from 25 to 50 feet and consists of silt, clay, and fine sand, partly cemented with caliche, with one or two algal limestone beds at the top. In Kansas, according to Frye, Leonard, and Swineford (1956, pp. 51-64), the Valentine member of the Ogallala formation is composed predominantly of fine to medium, relatively well-sorted, gray to greenish gray feldspathic sand, containing disseminated calcium carbonate and tubules and irregular concretions of opal. Thickness ranges from 30 to 100 feet. The Ash Hollow member is generally a fine to coarse feldspathic sand, 35 to 200 feet thick, locally with zones of gravel, silt, clay, and volcanic ash. The texture is more uniform than the Valentine member and the color is pink to tan. The Kimball member, except for the basal Sidney gravel lentil, is an ash gray to reddish tan to red-brown feldspathic, richly calcareous, medium to fine sand and silt. The calcium carbonate content increases upward and the upper part is a relatively soft impure limestone locally capped by an "Algal limestone" bed.

History of usage: Elias (1931) and Hesse (1935) proposed a type section at the Feldt ranch (SE¼ sec. 33, T. 14 N., R. 38 W.) approximately two miles east of the town of Ogallala, Nebraska. Lugn (1938, 1939) assigned the rank of group to the Ogallala and divided it into four formations. Moore, Frye, and Jewett (1944) and Moore and others (1951) have classed the Ogallala as a formation in Kansas, with three members.

Distribution: The surface of the Ogallala formation forms the High Plains, which extends from Texas to South Dakota, with the exception of Seward and Meade Counties, Kansas, and eastern Beaver and northwestern Harper Counties, Oklahoma, where early Pleistocene overlies the Ogallala. Outcrops of the Ogallala formation in Harper County form a discontinuous belt from a point about 4 miles south of the northwestern corner to the west central part of the county. In the northwest the formation crops out as a belt about 1/16th of a mile wide, overlain by Pleistocene deposits. In the west central part of the county exposures are as much as a mile wide since the younger rocks have been removed by erosion.

Thickness and character: In Harper County the Ogallala formation consists of beds of moderately well-sorted to poorly sorted sand and gravel, some of which are partially cemented by calcium carbonate. In some areas, such as in sec. 18, T. 28 N., R. 22 W., the beds are dark-colored and contain an abundance of Cretaceous oyster shells, material probably derived from the Kiowa shale and possibly from the Dakota sandstone. More commonly the beds are buff to pinkish arkosic sands with small pebbles of red Permian sandstone. Some layers are well indurated while others are loose sand, locally cross-bedded. Good exposures are in sec. 1, T. 27 N., R. 26 W., and sec. 34, T. 27 N., R. 24 W. The thickness ranges from 0 to 35 feet.

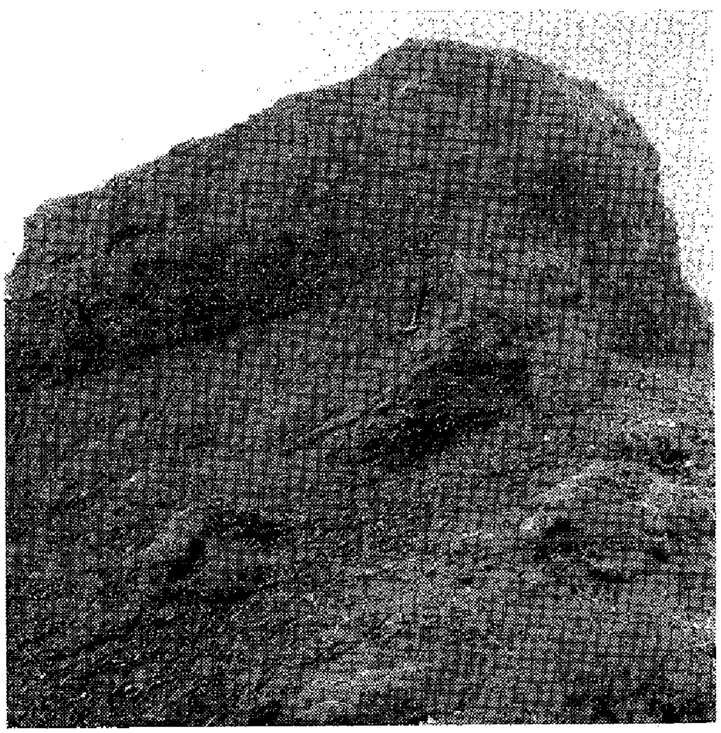


FIGURE 12. Basal Ogallala gravels.

Age, correlation, and fossils: The Ogallala formation of the High Plains consists of non-marine rocks, Neogene in age (Miocene and Pliocene); however, in Harper County the Ogallala is middle (Hemphillian) Pliocene. Although no continuous beds exist, except for the "Algal limestone," the formation is distinct from beds above and below and can be traced as a unit. The Ogallala of Harper County can be correlated with rocks of the same name in Texas, Kansas, Nebraska, and South Dakota. Fossil molluscan assemblages, fossil seeds, and other plants have been described in Kansas (Elias 1931, pp. 132-163, and 1942, pp. 9-122 and Frye, Leonard, and Swineford 1956, pp. 28-47) and in Nebraska (Lugn 1939, pp. 1258-1263).

QUATERNARY SYSTEM

PLEISTOCENE SERIES

The rocks which were deposited during the glacial and interglacial stages make up the Pleistocene series. These deposits in Harper County are non-glacial and include the Meade group, dune sand, and lake deposits.

Meade Group

In Harper County the Meade group includes the fluvial gravels, sands, and silts and volcanic ash that lie above the Pliocene Ogallala formation or above the Permian Rush Springs sandstone or Whitehorse group where the Ogallala is missing. The thickness varies from 0 to 70 feet.

In the mid-continent area the group has been divided into two formations: the Ballard formation below and the Crooked Creek formation above. The Ballard formation has not been recognized in Harper County, but the Crooked Creek formation containing the Pearlette ash lentil is present.

Original description: The Meade formation was named by Cragin (1896, p. 33) for exposures in the immediate vicinity of the old Vanhem post office (NW¼ sec. 13, T. 30 S., R. 23 W.) in Clark County, Kansas. The original description read:

> These gravels are mostly unconsolidated, but frequently contain hard ledges in Meade County and elsewhere. They are generally 10 to 30 or 40 feet in thickness and frequently grade into the Pearlette.

Other descriptions: McLaughlin (1946, p. 123) described the Meade formation as a thick deposit of coarse sand and gravel at the base, overlain by red silt and sand which contain abundant nodules of caliche and lenticular beds of volcanic ash.

History of usage: Cragin (1896, p. 53) gave the name "Meade gravels" to sands and gravels laid down in deep and broad valleys near Meade Center, Meade County, Kansas. Frye and Hibbard (1941, p. 411) redefined the Meade formation to include Cragin's Meade gravels and Pearlette ash, Smith's Odee formation, Smith's *Equus niobrarensis* bed, Smith's Jones Ranch beds, and all other beds of Pleistocene age above the Rexroad member of the Ogallala formation and below the Kingsdown silt, and designated the Pleistocene beds along Crooked Creek valley in sec. 21, T. 33 S., R. 28 W. as the type locality. McLaughlin (1946, p. 123) defined the Meade formation in the same manner as Frye and Hibbard except that he removed the Jones Ranch beds and placed them in the Kingsdown silt. Hibbard (1949, p. 66) restricted the Meade formation to include only the original deposits designated by Cragin as the "Meade gravels" in the area of the old Vanhem post-office and the overlying silts and caliche exposed on a tributary of Spring Creek, west of Crooked Creek. He gave the name Crooked Creek formation to the overlying beds below the Kingsdown silt. Frye, Swineford and Leonard (1948, p. 521) restricted the Meade formation to the Pleistocene strata overlying the Ogallala formation in NW¼ sec. 21, T. 33 S., R. 28 W., Meade County, Kansas. This is the type locality of Hibbard's Crooked Creek formation. They introduced the term Blanco formation for the strata which Hibbard had assigned to the Meade formation and the underlying Rexroad formation. At a conference held in Lawrence, Kansas, in June, 1956, the name Meade formation was abandoned. As the Meade formation in many reports included deposits ranging in age from Nebraskan to Yarmouth, and, as it is desirable to divide the Pleistocene into upper and lower Pleistocene for mapping, the name Meade was elevated to group status to include all deposits from the base of the Nebraskan to the top of the Yarmouth sediments. The Meade group in northwestern Oklahoma and southwestern Kansas consists of the Ballard and Crooked Creek formations, the latter the Meade formation of Frye, Swineford, and Leonard (1948) and Frye and Leonard (1952).

The name Ballard formation was proposed to replace the Meade formation of Hibbard (1949 and 1956) and the equivalent part of Frye and Leonard's (1952) Blanco formation. The name Angell member was also proposed to replace the name Meade gravels member of Hibbard's (1949 and 1956) classification.

Distribution: Outcrops of the Meade group are found in Clark, Meade, Seward, Grant, Haskell, and Stevens Counties, Kansas, and Beaver and Harper Counties, Oklahoma. The deposits in Harper County crop out as a thin discontinuous belt from the northwestern to the southeastern corner of the county. At this time it is not possible to assign a formational name to the sands and gravels in T. 25 N., Rs. 20 and 21 W., accordingly they are mapped as belonging to the Meade group undifferentiated. The beds in the northwestern part of the county belong to the Crooked Creek formation; this dating is made possible by the presence of the Pearlette ash.

Character and thickness: The Meade group consists of deposits of silt, sand, gravel, and volcanic ash. In T. 25 N., R. 20 and 21 W. the beds are mapped as Meade group undifferentiated since there are no known fossils or volcanic ash. The basal portion is coarse grained and well cemented while the upper part is more silty with a few pebbles and contains some consolidated beds, 2 to 5 feet thick. The sands are generally tan, whereas the colors of the silt beds range from buff to tan and gray to black. The maximum thickness is 70 feet.

The bank of a Pleistocene stream channel eroded into the Permian Rush Springs sandstone and subsequently refilled is visible in the NE¼ sec. 33, T. 25 N., R. 20 W. Within the old channel are boulders of red sandstone up to one foot in diameter. Pebbles are commonly of a black iron-stained sandstone, and reworked Cretaceous oyster shells are abundant.

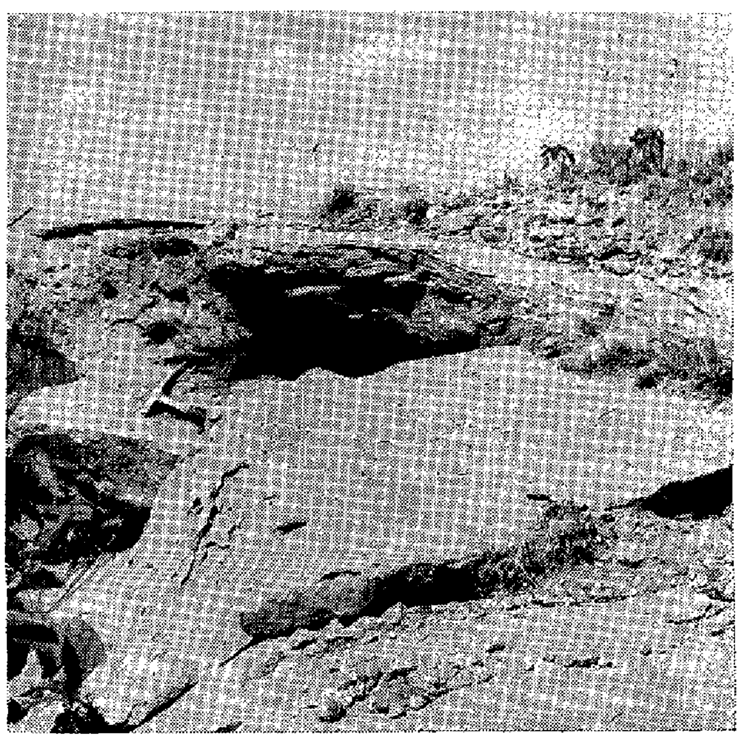


FIGURE 13. Closeup of the Crooked Creek formation showing cross-bedded resistant bed.

Crooked Creek Formation

The name Crooked Creek formation is applied in Harper County to the gravels, sand, silt, and the Pearlette volcanic ash lentils which unconformably overlie the Ogallala formation and the Whitehorse group and are generally blanketed by post-Crooked Creek sand dunes. In Kansas two named members are described: the basal Stump Arroyo member and the Pearlette ash member, but in Harper County the Pearlette ash is the only recognizable unit. The maximum thickness of the formation is 60 feet.

Original description: Hibbard (1949, p. 71) named the Crooked Creek formation and gave the following description of the type locality in S½ sec. 16, W½ sec. 15 and N 1/2 sec. 21, T. 33 S., R. 28 W. on the east side of Crooked Creek, Meade County, Kansas:

> Silt, sand and some clay, tan to buff brown massive. Contains sand and some caliche. The surface at the top of bluff is covered with rubble of caliche . . . . 14.8 feet.
>
> Silt, sandy, gray to tan . . . . 5.4 feet.
>
> Clay, with some silt and sand, light gray, massive. Breaks with a conchoidal fracture when dry . . . . 4.5 feet.
>
> Silt, clay, and some sand, gray massive, containing a few calcareous nodules (Borchers fauna) . . . . 6.4 feet.
>
> Pearlette ash member. Volcanic ash, pearl-gray, lenticular, somewhat impure . . . . 7.1 feet.
>
> Clay, silt and some sand, tan gray and brown gray, massive. Cudahy fauna occurs in top 12 inches and base of ash . . . . 9.5 feet.
>
> Sand, silt and coarse gravel, brown, contains abundant nodules. Grades upward into red-brown to reddish sandy silt . . . . 8.8 feet.
>
> Stump Arroyo member. Sand coarse, reddish to light tan, and well sorted, containing white quartz pebbles, grading upward into finer more poorly sorted sand, calcareous nodules at top . . . . 10.1 feet.

Pearlette Ash Member

The Pearlette formation was named by Cragin (1896, pp. 53-54) from the old postoffice of Pearlette, Meade County, Kansas. He described it as a "wide horizon of white to brownish (rarely greenish) volcanic ash. The ash attains a thickness of 13 feet in a bed southwest of Meade Center, considerably less in Clark and the many other counties of Kansas (especially western Kansas), Nebraska, etc., in which the ash has been found." Hibbard (1949, p. 71) considered the Pearlette formation of Cragin of member rank in the Crooked Creek formation. At the Pleistocene Conference in Lawrence, Kansas, June 28-29, it was recommended that the Pearlette volcanic ash member be reduced in rank to lentil.

Distribution: Exposures of the Crooked Creek formation crop out in Comanche, Clark, Meade, and Seward Counties, Kansas, and Beaver and Harper Counties, Oklahoma. In Harper County outcrops of the formation form a continuous belt, ½ to 3 miles wide, across T. 28 N., R. 24, 25, and 26 W., and T. 27 N., R. 24 W.

Character and thickness: The Crooked Creek formation in Harper County is composed of volcanic ash, clay, sand, and gravel. Some of the sands and gravels are unconsolidated while others are cemented by calcium carbonate to form resistant beds, which are in part cross-bedded. The interstratified clay and sands are thin-bedded and range from white to blue-gray to tan. Some of the gravels have a pink cast owing the presence of feldspar pebbles. Nodules of caliche are abundant at various horizons, particularly at the top of sandstone beds and in the clay. The Pearlette volcanic ash forms a 13-foot lenticular bed in the NW¼ sec. 10, T. 28 N., R. 26 W., but is absent elsewhere in the county. The thickness of the formation varies from 0 to 70 feet.

Age, correlation, and fossils: The Crooked Creek formation is Pleistocene in age and is the equivalent of the Kansan-Yarmouth of the glaciated area. Hibbard (1949, pp. 73-77) has described the Cudahy and Borchers faunas from deposits in Kansas. No fossils have been found in Harper County.

Dune Sand

The late Pleistocene sand dunes consist of well sorted, medium- to fine-grained sand which has been deposited by the wind. The sand of the post-Crooked Creek dunes was probably derived from the alluvium of Crooked Creek and later Pleistocene streams and buries some of the Crooked Creek formation. These dunes cover an area 6 to 8 miles wide south of the exposures of the Crooked Creek formation in northwestern Harper County.

Lake Deposits

Twenty small isolated silt and clay deposits, unconformable above various Permian beds and also above the Pleistocene Crooked Creek formation have been mapped in Harper County.

These late Pleistocene deposits average 500 feet in diameter and 8 to 15 feet thick. They are composed predominantly of gray silt and clay which is more or less homogeneous throughout its thickness, but in places grades into a black silt. The material was derived locally and deposited in fresh water lakes which were probably small shallow sink-hole depressions.

Mollusk shells were found in all deposits and a few scutes of an extinct armadillo were found in the NW¼ sec. 13, T. 28 N., R. 22 W. Taylor and Hibbard (1955, pp. 1-23) described the Bar M local fauna from the deposits in NW¼ sec. 13, T. 28 N., R. 22 W. and SE corner sec. 14, T. 26 N., R. 23 W. in Harper County and considered it of Illinoian age. They tentatively correlated the Bar M local fauna with the Berends fauna, which was found in the adjacent township in Beaver County. The isolated deposits of clay, silt, and reworked ash are present in sec. 5 and 6, T. 5 N., R. 28 ECM of Beaver County, Oklahoma. These beds were laid down in a large sink or series of sinks and are approximately the age of basin deposits in Meade County, Kansas, which are considered to belong to the base of the Kingsdown formation and are probably Illinoian in age. Mengel (1952) described a white pelican, Rinker and Hibbard (1952) a beaver and associated vertebrates. Taylor (1954) proposed the name Berends fauna for the vertebrates and mollusks from these deposits. Smith (1954) described the fish fauna and Starrett (1956) described some new mammals and compiled a complete list of the mammals of the Berends fauna.

Taylor (1954, p. 8) and Smith (1954, p. 288) postulated that the Berends local fauna existed at a time of cool moist climate. Taylor and Hibbard (1955, pp. 6-7) stated that the Bar M local fauna indicates a climate with summers like those of North Dakota, and with winters no colder and perhaps warmer than those of northern Kansas.

Taylor (personal communication) considered the mollusks from Doby Spring, sec. 10, T. 27 N., R. 24 W. to be of the same age as the Berends fauna. Probably the Berends is early Illinoian and the Doby Spring is late Illinoian or early Wisconsin.

Since these deposits are not continuous and the faunal assemblages are comparable it is difficult to correlate and assign all of them to particular glacial or interglacial stages. It is possible that all the basin deposits were laid down at about the same time, but each basin is different and presents its own problems; however, because of the similarity in the sediments and in the faunal assemblages, all of these deposits in Harper County are tentatively assigned to the Illinoian stage.

RECENT SERIES

Terraces, alluvium, and dune sand have been deposited in Recent time since the retreat of the Wisconsin glacier.

Terrace and Alluvium

Alluvium consisting of the gravel, sand, and silt or clay deposited by streams in Recent geologic time underlies the floodplains of present streams. It is generally thickest near the middle of a valley, and usually is thicker along major streams than along small creeks.

Terrace deposits also consist of material laid down by streams in late geologic time, but are somewhat older than alluvium. Since the time of deposition the streams have cut to a lower level. The terrace deposits are adjacent to and topographically higher than present streams and their alluvium. A large terrace is present in T. 26 N., R. 25 W. and represents material deposited by Beaver River. The thickness of the sand and gravel in this terrace is 97 feet as shown by driller's logs on file with the Ground-water Branch of the U. S. Geological Survey in Norman, Oklahoma. Much of this material is probably alluvium filling a large sinkhole basin.

Dune Sand

Recent sand dunes consist of well sorted, medium- to fine-grained sand derived from the alluvium of the present day streams, and border the north sides of Cimarron River, Beaver River, and part of Buffalo Creek. The dunes along Beaver River form a band 2 to 8 miles wide and overlap the earlier Pleistocene dunes, as well as Crooked Creek, Meade, Ogallala, Whitehorse, Rush Springs, and Kiowa rocks. Those along Buffalo Creek average one mile wide and cover the Whitehorse and Dog Creek formations. North of the Cimarron River in the northwest corner there are dunes on the floodplain. The major portion of this belt of dunes is in Kansas. Two small isolated deposits of dune sand are located north of Sand Creek and an unnamed creek in the southwestern part of Harper County.

GEOLOGIC HISTORY

PERMIAN AND CRETACEOUS HISTORY

The interpretation of the geologic history of the Permian is based primarily on "The Rhythm of the Permian Seas" by J. M. Hills (1942). The Cretaceous history follows the work of Bullard (1928).

Hills (1942, p. 230) makes a distinction between seas of different salinities as reflected by the chemical composition of their sediments. Marine seas are those where there are deposits of black to gray sands and shales, gray limestones, and brown to buff dolomites. Saline seas include areas where there are evaporite sediments, which include anhydrite, halite, and potash salts. Brackish seas are the near-shore areas exemplified by clastics, most of them red. The boundaries between the phases are rather arbitrary because the exact point of transition is difficult to pick.

A recent classification of seas is based upon chlorine content and salinity. Redeke's original classification was related to the chlorine content and Välikangas amended this work and set up a classification based on salinity and chlorine content. Hedgpeth's (1951, p. 50) classification is based upon the chlorinity and salinity of the water.

The most extensive neritic sea of Wolfcampian time had extended across western Texas and western Oklahoma into Kansas between the ancestral Rockies in New Mexico and the mountains occupying the site of the former Llanoria, Ouachita, and Marathon geosynclines. The Amarillo Mountains in the Texas Panhandle and the Wichita Mountains in southwestern Oklahoma were elongate islands athwart this sea.

There was a gradual southward retreat of the shallow neritic sea until by late Hennessey time, it was restricted to southwestern Texas. A saline sea extended across the Texas and Oklahoma Panhandles with a brackish sea bordering it to the east. In Oklahoma and Kansas the lands were apparently low and the fine-grained Salt Plain and Hennessey formations were deposited. The Wichita uplift on the south of this basin and the Ouachita uplift to the southeast were the source for much of the clastic sediments of the Hennessey and Garber formations. The Duncan-Chickasha wedge of clastics, which are near-shore and deltaic brackish sea sediments, were derived partly from the Arbuckle uplift and possibly partly from the Wichita and Ouachita uplifts. North and west in the saline sea the Duncan-Chickasha sediments graded into the Flowerpot shale.

Following the deposition of the Flowerpot shale there was a comparatively rapid change in marine conditions with deposition of the basal Blaine gypsum in the marginal saline sea. The lands to the east must have been low because only fine clastic sediments were deposited close to shore. The Wichita uplift and the ancestral Rockies remained elevated and were the source of considerable relatively coarse material on the west side of the basin. Uplifts in the Arbuckle Mountains are related to the fluctuations of the seas resulting in the interbedding of dolomite, gypsum, and shale in the Blaine formation. As the marine sea withdrew, the Dog Creek formation consisting of shales, gypsum, and sand with dolomite stringers was deposited. Conditions were similar to those of Blaine time because in some areas the two formations are so similar that it is not possible to differentiate them.

The Whitehorse sediments were deposited in an oscillating sea which formed shallow depositional basins. Some were shallow arms of the sea, some were lagoons, and some were lakes. As a result the Whitehorse formation consists of a series of depositional units of sandstones and shales with gypsum lenses. The Verden sandstone is believed to have been a calcareous barrier beach probably closing the mouth of a bay (Newell, 1940).

The Marlow formation was deposited in a quiet, nearly isolated branch of the sea, surrounded by low deeply weathered lands from which enough fresh water drained to keep the salinity of the water below the evaporite-depositing point. Thin beds of fine clays and sands were deposited at this time. The middle Permian late Guadalupean Marlow sea occupied the Anadarko basin and probably joined the main Permian basin by a shallow connection. The Marlow sands were derived from the Wichita-Red River uplifts to the south. Streams transported the major portion of these sands, but some was probably wind transported. A retreat of the sea to the main Permian basin and the Delaware basin owing presumably to the uplift of the sea floor resulted in a sharp change in sedimentation. The former sea floor was covered with a complex of shifting subaqueous sand and sand dunes which formed the

Rush Springs sandstone. Clay and gypsum formed in short-lived saline lagoons which eventually became shallow ponds and small lakes in the Permian desert.

In late Permian time this low topography was once again flooded by a neritic sea. As the sea retreated the water became more saline with the deposition of the Day Creek dolomite and Cloud Chief gypsum. Fluctuations of the climate caused shales to be interbedded with gypsum beds.

During most of the Triassic western Oklahoma was undergoing erosion. The non-marine Dockum red beds were deposited in late Triassic early Norian time. This formation is present today in Cimarron and Texas Counties in the Oklahoma Panhandle. If the rocks once existed in Harper County, subsequent erosion has removed them.

Erosion of western Oklahoma continued through most of the Jurassic. The middle late Jurassic Kimmeridgian non-marine Exeter sandstone and Morrison formation crop out in Cimarron County, Oklahoma. If these beds were present they were eroded before the Cretaceous seas covered Harper County because the Cretaceous Kiowa shale is unconformable above the Permian Cloud Chief formation.

The last great flood of the interior of the continent occurred during early Cretaceous time. The Trinity sea overlapped the Ouachita and Arbuckle Mountains. but it is not known whether the sea extended north of the mountains. If Cretaceous deposits were laid down to the north, they have been removed by erosion. During this time there was vigorous erosion with the deposition of conglomerate and coarse sand near shore and finer sediments farther from shore. By Fredericksburg time the land masses had been reduced to areas of low relief and the deposition of limestone predominated.

The Lower Cretaceous late Comanchean Washita sea had expanded as a great embayment around the western end of the Wichita Mountains into western Oklahoma and southern Kansas, across the Texas Panhandle into eastern New Mexico and Colorado; and as far to the north as central Wyoming. The land masses which furnished most of the sediments to this great interior sea were to the north and west. In this shallow embayment oysters grew in abundance and in some areas formed shell beds as much as three feet thick. The size of the shells indicated that life conditions were exceedingly favorable for oysters. Sandstones, sandy conglomerates, and shell beds composed of broken shells, which are interbedded with shale and clay, show that the bottom was within reach of currents and wave action of an occasional violent storm. The great embayment covering western Oklahoma was of short duration. For most of Washita time the sea slowly retreated to the south with many minor oscillations, but at the close of the epoch withdraw entirely from this region.

The upper Cretaceous Cenomanian-Turonian sea extended from the Gulf of Mexico to the Arctic ocean. The Dakota sandstone, Graneros shale, Greenhorn limestone and Carlile shale were deposited in this sea and outcrops of the Dakota sandstone, Graneros shale, and Greenhorn limestone are present in Cimarron County, Oklahoma. The Niobrara formation was deposited in the Upper Cretaceous Coniacian-Santonian (Niobrarian) sea which was a broad embayment from the Gulf of Mexico into Canada. The sea probably covered the Oklahoma Panhandle and may have covered at least the western part of Harper County. The Upper Cretaceous Campanian-Maestrichtian sea was a more restricted embayment in which the Pierre shale, Fox Hills sandstone, and Hell Creek formation were deposited. The sea extended from the Gulf of Mexico into southern Canada and probably covered the Oklahoma Panhandle. If any beds of late Cretaceous age were deposited in Harper County subsequent erosion has removed them.

The Laramide revolution at the close of the Cretaceous caused renewed uplift and folding along the Wichita-Amarillo axis resulting in a series of gentle folds in the Cretaceous and underlying Paleozoic rocks.

TERTIARY AND QUATERNARY HISTORY

During most of Tertiary time Harper County was an area of erosion; however, by late Miocene or early Pliocene time aggrading streams from the Rocky Mountains began to deposit the Laverne formation on a surface of considerable relief. Byrne and McLaughlin (1948, p. 72) reported that test holes indicate the thickness of the Laverne may be in excess of 500 feet. Coarse material was deposited in the lower areas and consists in part of material that was derived locally. Later deposition smoothed the surface and on the floodplains formed some calcareous and diatomaceous lake deposits, which were also interbedded with sands and silts.

The Laverne formation was moderately folded and the folded beds then truncated by erosion (Frye and Schoff, 1942, p. 36). The axis of the fold strikes north-south in north central Beaver County, Oklahoma, and southwestern Meade County, Kansas.

The Laverne formation was more resistant to erosion than the underlying Permian rocks and formed highs while valleys developed in the Permian beds. In middle Pliocene time the streams from the Rocky Mountains were once again aggrading streams in northwestern Oklahoma. Deposition of the Ogallala formation took place on the eroded surface, first filling in the lowest part of the valleys. As the valleys filled there was lateral overlapping until the whole surface became a coalescing alluvial plain surrounding the Laverne hills. During this time small ponds were probably common, formed in part by unequal deposition and in part by sinkhole development. These channel and floodplain deposits grade from moderately well sorted gravel to poorly sorted sandy silt and are variable in thickness because of the unevenness of the land surface on which they were deposited. Caliche deposits are common and extensive and indicate that during part of the time an arid climate existed.

The Meade basin of southwestern Kansas was formed by fault movement during Pliocene time. The lower part of the Ogallala formation was cut by the Crooked Creek and Fowler faults during middle Pliocene time. The oldest sinkhole fillings are Pleistocene, whereas the sinks were formed in post middle Pliocene. The sinks are on the upthrown side of the faults, but down dip of the beds and down gradient of surface streams.

According to Frye and Schoff (1942, p. 38) ground-water under hydrostatic pressure moved down the fault to the deep seated soluble Permian beds, then eastward through sandstones and possibly through anhydrite, dissolving salt and gypsum, and emerged as salt springs to the east. Sinks formed as a result of the subsidence of surface deposits in places where the underlying beds had been removed by solution. This action, which must have been prevalent over a large area, has resulted in the Laverne formation generally having erratic dips. Further evidence for the subsidence is the presence of small structural basins 200 to 1,000 feet in diameter. As the sinks developed and possibly because of renewed uplift, erosion began.

According to Hibbard (personal communication) the hydrostatic pressure has resulted in upward movement of water through soluble beds. Salt water springs have formed in areas where a sink has broken through to bed rock. Also drilling in the area has hit artesian salt water; some wells had a strong flow. Sinks are not common in areas where there is a good cover of Cretaceous shale and clay, but have generally formed where there is exposed Permian or Ogallala overlying Permian without intervening Cretaceous clay and shale. The Cretaceous has sealed off downward movement of ground-water, but circulation takes place where this cover is removed. In section 7, T. 25 N., R. 21 W. sink hole development is reflected in Cretaceous cover where Cretaceous overlies Permian. In some areas the Cretaceous probably stops the formation of sinks, but in other areas lateral movement of ground-water may form sinks under a Cretaceous cover.

A period of erosion followed, removing any Ogallala that may have been deposited on the Laverne formation. Since the Ogallala and Laverne are not in contact Byrne and McLaughlin (1948, p. 72) suggested that either the resistant Laverne formed highs over which Ogallala was not deposited or that post-Ogallala erosion has removed the latter. The writer believes that it is probably a combination of the two processes.

During the Nebraskan glacial stage of the Pleistocene the melt water streams from the Rocky Mountain glaciers eroded deep channels into the older rocks. As the glaciers retreated the competence of the streams was reduced causing deposition of the Ballard formation of the Meade group. Coarse sands and gravels were first deposited and later the finer sands and sandy silts practically filled the channels and may even have spread out to form floodplain deposits. Sinkhole development continued during this time and some of the deposits are probably fillings of these sinks. The sediments deposited in channels eroded into the Permian in southeastern Harper County may belong to this sequence.

With the advance of the Kansas glaciers in the Rocky Mountains the melt water streams eroded channels into the Pliocene Ogallala and Permian Whitehorse rocks in Harper County. Sinkhole development continued. As the glaciers retreated the Crooked Creek formation was deposited filling the channels, spreading out as a floodplain, and filling sinks. The bedding of the Crooked Creek formation indicates frequent periodic floodings. A wide spread ash fall was carried into local ponds forming the Pearlette ash lentil of the Crooked Creek formation. At the close of this time the streams were nearly in equilibrium and the Crooked Creek formation had filled the stream channels to the level of the high plains. North winds during late Kansan and Yarmouth time formed sand dunes to the south of the Crooked Creek stream channels.

Late Pleistocene time has been predominantly a period of erosion with sinks continuing to form. During Illinoian time many of the sinks contained ponds which were filled with material washed into them from the surrounding land. These lake deposits represent a range of time as not all the basins were formed and filled at the same time.

Some large basins such as Ashland and Englewood of Clark County, Kansas, were formed by the coalescing of several small sinks. The Cimarron River developed its channel through these sinks in either Illinoian and/or Wisconsin time. Subsequent erosion has connected many of the smaller localized sinks with the main rivers. Cimarron and Beaver Rivers eroded deep channels into the Permian rocks and then partially filled them and the sink basins with later sediments. The terrace deposit of Beaver River in T. 26 N., R. 25 W. is, in part, probably a sink basin filling as are both the Englewood and Ashland basins.

Extensive late Pleistocene and Recent sand dunes have formed on the north sides of Beaver River and Cimarron River.

NONMETALLIC MINERAL AND WATER RESOURCES

VOLCANIC ASH

There are two small deposits of volcanic ash in Harper County. At the present time neither is being worked, but there has been production from the deposit in sec. 10, T. 28 N., R. 26 W. The thickness of this deposit ranges from 1 to 15 feet with an estimated area of 25 acres. The average thickness of the overburden is 3 to 8 feet. The deposit in secs. 28 and 33, T. 26 N., R. 26 W. ranges from 1 to 5 feet thick, with an estimated reserve of 10,000 cubic yards. Overburden is 1 to 2 feet thick. An analysis of the ash shows it to be a volcanic glass with trace carbonate; some anisotropic feldspar grains (Burwell 1949, p. 45).

The ash was probably carried by the wind from volcanoes in north-central New Mexico to its present site. The deposits are associated with high river terraces and show evidence of deposition in quiet water, suggesting they were formed as the ash settled from the air into lakes on the flood plains of rivers, with some additional concentration of ash by local run-off into lakes. A fresh-water molluscan fauna at the base of some deposits supports the idea of lacustrine deposition. The ash in sec. 10, T. 28 N., R. 26 W. has been correlated with the Pleistocene Pearlette ash lentil of the Crooked Creek formation of Kansas.

GYPSUM

An all-time high tonnage and value of gypsum was recorded in Oklahoma in 1954 with all production from the Blaine formation in Blaine County. Ample reserves of gypsum in workable ledges crop out in Harper County along the Cimarron River and Buffalo Creek. The gypsum is in the Blaine formation and consists of 4 beds which are 25, 13, 13, and 4 feet thick separated by beds of shale.

SAND AND GRAVEL

Sand and gravel has been quarried at several places in Harper County for local use in highway construction. Practically all of the production is from the basal Laverne and basal Ogallala formations.

WATER RESOURCES

In Harper County the Cenozoic deposits are the best sources of ground-water. The yield from wells in southwestern and northwestern Harper County ranges from 500 to 1,000 gallons per minute. Wells in a belt north of Beaver River yields 50 to 500 gallons per minute. Wells in the Permian yield from 0 to 50 gallons per minute and the water in many wells contains a large concentration of dissolved gypsum.

Springs are common along the contact of the porous Cenozoic rocks and the underlying Permian. One of the largest is Doby Springs (sec. 10, T. 27 N., R. 24 W.), which is the source of water for Buffalo. Laverne, which is located on a Pleistocene terrace deposit, obtains its water from wells drilled into the terrace.

PETROLEUM GEOLOGY OF HARPER COUNTY, OKLAHOMA

by

Louise Jordan, J. Durwood Pate[1] and Sidney R. Williamson[2]

INTRODUCTION

Harper County is in an oil and gas province of some 9,000 square miles on the northern platform of the Anadarko Basin in northwestern Oklahoma. Previous to 1950 only three areas of gas production and one of oil production had been discovered in this province. Two wells two miles apart in Harper County produced gas. The Light Gas Area in Beaver County and the Ringwood Oil Field of Major County had been discovered. In 1950, oil was found at North McWillie in Alfalfa County in Desmoinesian limestone (basal Marmaton). Then, in 1952, gas condensate was found in Morrowan rocks at South Salon Field in Ellis County and also in Harper County about two miles south of the town of Laverne; and in the same year more discoveries were made in Beaver County at Camp Creek, Forgan, Floris, Greenough, Knowles, and Mocane. Yellowstone Field in Woods County in 1953 was a multizone discovery which produced from the Arbuckle. During the same year a well about 4 miles south of Arapaho in Custer

[1] Consulting geologist, Oklahoma City.
[2] Consulting geologist, Mid-Continent Geological Services, Inc., Oklahoma City.

County tested gas-condensate in Morrowan rocks, but the well was junked and abandoned. Reserves of oil and gas continued to be discovered in new areas and in new reservoirs in Beaver and Alfalfa Counties in 1954 and 1955. In 1956, the pace of exploratory drilling was intensified in other counties of the province and this resulted in the first discoveries of hydrocarbons in Blaine, Dewey, and Woodward Counties, and in more fields in Harper, Beaver, Alfalfa, and Woods Counties.

In Harper County, oil and gas have been discovered primarily in stratigraphic traps in Pennsylvanian and Mississippian rocks ranging in depth from about 3,600 to 7,600 feet. Arbuckle oil has been found in a structural trap at a depth of 7,764 feet in northern Harper County, but the depth to Arbuckle rocks increases to over 10,000 feet in the southern part of the county. In this area of multiple-pay discoveries, it is possible that production will be found in Wolfcampian (Permian) rocks as well as in more horizons within the Pennsylvanian, Mississippian and Ordovician. Sandstone reservoirs which have been discovered include the Laverty-Hoover (Virgilian), Tonkawa (Missourian) and Morrow, all in the Pennsylvanian. Limestone reservoirs range in age from Early Ordovician through Late Pennsylvanian and include the following: Arbuckle (Lower Ordovician), Chester (Upper Mississippian), "Oswego" (Desmoinesian, Middle Pennsylvanian), and limestones in the Kansas City and Lansing groups (Missourian, Upper Pennsylvanian).

Major reserves of natural gas are present in Harper County. In the Laverne district as many as four gas-condensate reservoirs have been found in a single well. Most of the wells are dually completed and some have produced from one reservoir at the rate of 80 million cubic feet per day on open flow initial tests. The marketed value of gas from such multiple-reservoir wells may be as high as $4,000,000. Proved reserves of gas in the Laverne district were estimated at approximately 1.5 trillion cubic feet in 1957. Production of gas and condensate has been limited by pipeline facilities, as only six wells were producing prior to July 1957 and only 37 in the county were connected to a pipeline by June 1958. Oil is produced from the Southeast Stockholm Field and is transported by truck to Enid. Discovered in January 1957, the field produced 77,370 barrels from 20 wells which were completed during the year.

This report is the result of the cooperative efforts of Louise Jordan, J. Durwood Pate, and Sidney R. Williamson. On November 1, 1957 J. Durwood Pate, consulting geologist in Oklahoma City, presented in Tulsa before the Mid-Continent Regional Meeting of the American Association of Petroleum Geologists a paper entitled "Stratigraphic traps along the northern shelf of the Anadarko Basin".[1] The geologic maps and cross sections pertaining to Harper County, Figures 14-20 and Panel I, Plate B of this report, were taken from his illustrations for that meeting. His interpretation and correlation of stratigraphic units for rocks of Pennsylvanian and Permian age are used. Sidney R. Williamson, geologist, Mid-Continent Geological Services, Inc., Oklahoma City, contributed the lithologic descriptions and correlations of pre-Pennsylvanian rocks, and the results of his study of the lithology of four wells are illustrated on Panel I, Plate A. Louise Jordan of the Oklahoma Geological Survey wrote the report and compiled additional historical, statistical and stratigraphic information to make a more comprehensive study of the petroleum geology and fuel resources of the county. Some lithologic descriptions of Pennsylvanian and Permian rocks were taken from a Master of Science thesis in the University of Oklahoma (Gallaspy, 1958). Roy D. Davis of the Oklahoma Geological Survey drafted all plates and figures.

HISTORY OF OIL AND GAS EXPLORATION

At the end of 1951, an oil, gas and dry hole map of the county would have shown two gas wells and thirteen dry holes. By August 1, 1958, twelve gas fields and two oil fields (Plate III) had been discovered and are in the process of development. Reservoirs of gas, condensate and oil have been found in at least eight stratigraphic horizons ranging in age from Ordovician Arbuckle to Upper Pennsylvanian. In the Laverne Gas district (including Northwest Highland Field) the reserves of gas were estimated to

[1] To be published in *American Association of Petroleum Geologists,* Bulletin, vol. 43, no. 1, January 1959.

be about 1.5 trillion cubic feet when 53 wells had been completed in November 1957. With the limits of the field not yet defined, this gas district (including the Laverne Gas Area, West Stockholm, Southwest Stockholm and Northwest Laverne Fields) covers 67 square miles in Harper County.

According to records now available, the earliest test for oil was drilled in 1921 by the Buffalo-St. Louis Company on Tucker land (sec. 9, T. 27 N., R. 22 W.) about three miles east of the town of Buffalo. It was abandoned as dry at a reported depth of 4,070 feet. The next dry hole was drilled by the Hoffer Oil Corporation on Cooper land (sec. 14, T. 25 N., R. 22 W.) to a depth of 4,106 feet. No further exploration was done until 1930 when Sinclair Prairie Oil Company drilled the No. 1 Howell (sec. 14, T. 26 N., R. 24 W.) to a depth of 8,589 feet, the deepest test in the state at that time (Ley, 1931 p. 246). Below the Permian and Pennsylvanian sections, the well penetrated about 1,600 feet of Mississippian rocks, a thickness considerably greater than expected at that time. Production was accidentally discovered in the Tonkawa sand at 5,350 to 5,400 feet when casing was being pulled. It tested 11.1 million cubic feet of gas and 65 barrels of condensate per day when completed September 18, 1930. This well has been the source of supply of gas for the towns of Laverne and Buffalo since that time. As of May 1, 1956, it has produced 11,800 barrels of condensate and over 1 billion cubic feet of gas with little decline in pressure.

On January 1, 1931, Empire Oil and Refining Company abandoned as a dry hole at 7,935 feet the No. 1 Bruce (sec. 12, T. 25 N., R. 20 W.) near the eastern boundary of the county. Empire reported the top of the Mississippian at 6,735 feet and the well penetrated about 2,000 feet of rocks of this age. In November 1934, Sinclair drilled a dry hole (No. 1 Neff, sec. 21, T. 26 N., R. 24 W.) 1.5 miles southeast of their gas well. Then in 1939, Sinclair made another attempt to find production in the No. 1 George (sec. 5, T. 27 N., R. 23 W.) which was drilled into Mississippian rocks to a depth of 7,420 feet. There was no more activity in the county until 1946 when Continental Oil Company drilled about 100 feet into the Arbuckle in the No. 1 Howard (sec. 15, T. 27 N., R. 21 W.) to a total depth of 7,782 feet.

In July 1947, the Huber Corporation made the next discovery in the county in the No. 1 Hieronymus (sec. 3, T. 26 N., R. 24 W.). Located about 2 miles north of the Howell well, it tested 834,000 cubic feet of gas per day from the Tonkawa sand. Seven dry holes, most of which penetrated the entire section of Pennsylvanian rocks, were drilled in the following years before new production was found in 1952. One of these tests (Superior No. 1 Blasdell, sec. 12, T. 27 N., R. 22 W.) drilled into Viola limestone (Middle Ordovician) and another, Continental No. 1 Benton (sec. 2, T. 25 N., R. 22 W.), penetrated Arbuckle (Lower Ordovician).

In April 1952, Sunray Oil Corporation discovered the Laverne Gas Area when it completed the No. 1 Wolfe (sec. 4, T. 25 N., R. 25 W.). The well tested 5.2 million cubic feet of gas and 47 barrels of 68.2° gravity condensate per day through a 1-inch choke from sandstone in the Morrow at 7,192 to 7,230 feet (This area was originally named South Laverne). This well was followed in September by another Morrow gas well (Sunray No. 1 Long) about one mile east. During 1952 only three other tests, all unsuccessful, were drilled in the county. K. A. Ellison et al. No. 1 Cooper (sec. 2, T. 25 N., R. 22 W.) and Lynn Drilling Co. No. 1 White (sec. 3, T. 25 N., 20 W.) drilled into Mississippian rocks, and Deep Rock drilled the No. 1 Lamunyon (sec. 21, T. 28 N., R. 24 W.) to 8,500 feet penetrating approximately 300 feet of Arbuckle carbonate rocks.

The Sunray discovery started leasing and exploratory programs by operators, but only eight wildcats were drilled during the three year period 1953-1955, and of these only two found production. Sun Oil Company No. 1 Holmes (sec. 30 T. 26 N., R. 24 W.) extended Morrow production about four miles northeast of the Long well to open a field originally termed East Laverne. However, it was the An-Son Petroleum Corporation No. 1 Laverty (sec. 26 T. 26 N., R. 25 W.), two miles east of the Holmes well, finding the new and shallower gas-condensate "Laverty-Hoover" pay as well as gas in the Morrow reservoir, which set off widespread drilling and development throughout the county.

In 1956, Keating Drilling Company found a Morrow gas-condensate pay at a depth of 6,364 to 6,372 feet to open Northeast Gate Lake Field in the No. 1 Dunn (sec. 22, T. 28 N., R. 26 W.).

On initial open flow test the well produced 7.5 million cubic feet of gas and 71.6 barrels of 50° gravity condensate per day. An-Son discovered the North Rosston Field in No. 1 Freeman (sec. 6, T. 27 N., R. 25 W.) which flowed 2.92 million cubic feet of gas per day through 20/64-inch choke from Morrow sandstone at 6,520-6,530 feet.

Woods Petroleum Co. found gas at 6,965 to 6,989 feet in the Viola (Middle Ordovician) limestone in No. 1 Seevers (sec. 6, T. 27 N., R. 20 W.) to discover North Lovedale Field. Because of water this zone was plugged and in 1958 the well was completed as a flowing oil well from limestone in the Marmaton group.

In the Laverne Gas Area, gas production from the Laverty-Hoover reservoir was extended northwest of Laverne by Sunray Mid-Continent No. A-1 Barby (sec. 1, T. 26 N., R. 26 W.). This field was originally called Northwest Laverne. It was also extended two miles east by the Magnolia Petroleum Company No. 1 Odell (sec. 1, T. 25 N., R. 25 W.). Two new gas pays, Tonkawa (Missourian) and Chester (Mississippian) were discovered in the field by the Magnolia No. 1 Stinson (sec. 12, T. 26 N., R. 25 W.) which was completed dually in the Morrow and Tonkawa reservoirs. This well extended Morrow production 4 miles northeast of Laverne. The initial production on open flow from the Tonkawa was 22.5 million cubic feet of gas and 204.75 barrels of 67.8° gravity condensate per day. Since the Magnolia well did not complete in the Chester reservoir, Cities Service No. A-1 McClung (sec. 11, T. 26 N., R. 25 W.) is considered to be the discovery well of Chester production. Dually completed in Chester and Tonkawa reservoirs, this well on open flow tested initially 10.5 million cubic feet of gas and 52.5 barrels of 60° gravity condensate. Oil of 45° gravity was found by Gulf Oil Corporation No. 1 McClung (sec. 23, T. 26 N., R. 25 W.). This well tested 263 barrels of oil with 3.5 million cubic feet of gas per day from the Morrow at 6,922 to 7,000 feet.

In Harper County approximately 217,000 feet of hole or an average of about 6,800 feet per test (Table 3) was drilled in 1956. Exploration and development continued and more than twice as much footage was drilled in 1957. Seventy of the 129 tests which have been drilled in the county were completed in 1957. Only

18 of these 70 wells were dry, being divided equally between wildcat and development wells. The *Oil and Gas Journal* reported that 16 exploratory holes were drilled. These resulted in the discovery of five new fields. Gas from the Chester was found at North Fort Supply (sec. 13, T. 25 N., R. 22 W.) and gas-condensate at Northwest Doby Springs (sec. 36, R. 28 N., R. 25 W.). East Stockholm Field (sec. 17, T. 26 N., R. 23 W.) was discovered by Eason & Wilcox No. 1 Crawford with a gas-condensate pay in the Tonkawa sand. Southeast Stockholm, an oil field, was discovered by Eason and Wilcox No. 1 Price (sec. 21, T. 26 N., R. 23 W.). This well flowed 384 barrels of 46° gravity oil per day through 20/64-inch choke with a gas-oil ratio of 264 to 1 from Tonkawa sand at 5,490 to 5,492.5 feet. Woods Petroleum Company found gas in the Morrow in its No. 1 Randall (sec. 29, T. 26 N., R. 22 W.) at Southwest Kibby.

TABLE 3

OIL WELLS, GAS WELLS, DRY HOLES AND FOOTAGE DRILLED IN HARPER COUNTY, 1921-1957

	Exploratory wells					Development wells				
Year	Oil	Gas	Dry	Total	Footage	Oil	Gas	Dry	Total	Footage
1921-1927	0	0	2	2	7,596					
1930	0	1	0	1	8,589					
1931-1946	0	0	4	4	30,515					
1947	0	1	0	1	7,007					
1948-1951	0	0	7	7	50,218					
1952	0	1	3	4	30,902	0	1	0	1	7,311
1953	0	0	1	1	6,500	0	0	0	0	
1954	0	0	3	3	20,399	0	0	0	0	
1955	0	2	2	4	27,272	0	0	0	0	
1956	0	9	6	15	102,056	1	16	0	17	115,269
1957*	5	2	9	16	109,350	31	14	9	54	342,663
TOTAL	5	15	37	58	400,404	32	31	9	72	465,243

* From *Oil and Gas Journal* review issue. The number of oil wells must include gas and condensate discovery and development wells since the only field classified as an oil field is Southeast Stockholm discoverd in 1957 and two wells in the Laverne Gas Area found Morrow oil.

Continued drilling activity in 1958 has resulted already in discovery of two oil fields and two gas fields. The most outstanding exploratory result has been the discovery of oil in the Arbuckle (Lower Ordovician) at North Buffalo by the Sinclair Oil and Gas Company No. 1 Holcomb (sec. 7, T. 28 N., R. 22 W.). Testing gas in four other zones, the well flowed 314 barrels of

48.5° gravity oil through 30/64-inch choke with gas estimated at 450,000 cubic feet daily from the Arbuckle at a depth of 7,664 to 7,717 feet. This well is 35 miles west of the only other Arbuckle producer, Yellowstone Field in Woods County, in the Oklahoma portion of the northwestern Anadarko Basin. It is over 120 miles southeast from the only Arbuckle producer in western Kansas, Grigston Field of Scott County, and about 100 miles northwest from a similar field at Laketon in Gray County, Texas. A well (Sinclair No. 1 Kuhn) drilled one half mile north of the Holcomb recently tested oil flowing from a Lansing limestone at 4,560 feet and also from a Kansas City limestone at 5,210 feet. Oil was discovered in the "Oswego" lime (Desmoinesian) at North Lovedale (sec. 1, T. 27 N., R. 21 W.). Morrow gas was found at Northeast Doby Springs (sec. 1, T. 27 N., R. 24 W.) and Chester gas at Southwest Lovedale (sec. 26, T. 26 N., R. 21 W.). At the present time Calvert No. 1 Selman (sec. 8, T. 26 N., R. 20 W.) just south of Lovedale is testing gas from the Tonkawa and Morrow which will open another field this year.

Production of gas and condensate in Harper County was confined to six wells up until June 1957 when new pipe lines were completed. The then existing pipeline owned by State Fuel Supply Company had supplied the towns of Laverne and Buffalo since the completion of the Sinclair No. 1 Howell in 1930. At the end of 1957 the accumulative production from these six wells amounted to 2.4 billion cubic feet of gas of which nearly 1.5 billion cubic feet had been produced by the Sinclair well. During the last half of 1957, 29 additional wells were connected to new pipelines of the Cities Service Gas Company, Colorado-Interstate Company, and Northern Natural Gas Company, and in this six-month period marketed production was nearly 567 million cubic feet of gas. As of June 1958 only 37 of the wells in Harper County were producing and their accumulative production was 4,414 million cubic feet. Construction of the Michigan-Wisconsin Company pipeline, which will connect with about 150 wells surrounding Laverne, commenced in September, 1958. A gasoline plant to process 100 million cubic feet of gas and to produce some 100 thousand gallons of liquids daily will be built at Laverne by the Sun Oil Company at a cost of $3.5 million.

Oil and condensate produced in the county is transported by truck. At the end of 1957, 116,479 barrels had been produced of which 77,370 barrels were from 20 wells in Southeast Stockholm Field discovered and developed during the year. The location and number of producing wells, date of first production and accumulative production to January 1, 1958 are given in Table 4.

TABLE 4

LOCATION AND NUMBER OF PRODUCING WELLS, DATE OF DISCOVERY, PRODUCING RESERVOIRS, AND CUMULATIVE PRODUCTION, HARPER COUNTY, OKLAHOMA

Field	Number of wells producing	Date of discovery	Cumulative production 1-1-1958 (barrels)	Producing reservoir
Doby Springs, Northwest 36, 28N-25W	1	9-1957	111	Chester
*Laverne, Northeast 10-13, 22, 23, 26N-25W	6	3-1956	16,087	Chester, Tonkawa, Morrow, Laverty-Hoover
*Laverne, South 4, 6, 25N-25W	2	4-1952	3,282	Morrow, Laverty-Hoover
*Laverne, Northwest 6, 26N-25W	1	8-1956	62	Chester
Lovedale, North 6-27N-20W	1	9-1956	290	Viola
Stockholm, East 8, 26N-23W	1	7-1957	6,855	Chester
Stockholm, Southeast 19-21, 28-30, 26N-23W	20	1-1957	77,370	Tonkawa
Stockholm, Southwest 12, 26N-24W	2	7-1930	12,422	Tonkawa
TOTAL	34		116,479	

* Now included in Laverne Gas Area. Data from Vance Rowe Report for 1957, *The Petroleum Statistical Guide, Inc.*

STRATIGRAPHY AND PRODUCTIVE RESERVOIRS

The geological formations penetrated by wells in Harper County belong to the Ordovician, Devonian, Mississippian, Pennsylvanian and Permian systems. The Arbuckle group, oldest rock unit encountered, has been penetrated only a few hundred feet. Those rocks above the Arbuckle range in thickness from approximately 7,700 feet in sec. 7, T. 28 N., R. 22 W., southward to 9,400 feet in sec. 2, T. 25 N., R. 22 W., and southwestward to 10,300 feet in sec. 12, T. 25 N., R. 26 W.

ORDOVICIAN

The Ordovician system is represented by rocks of the Arbuckle and Simpson groups and the Viola limestone. The Sylvan shale has not been found in any of the tests drilled to the stratigraphic level of this unit, but it may be represented by dolomite which is at present included in the Viola.

Arbuckle group: The oldest sediments known in Harper County are rocks of the Arbuckle group which have been penetrated nearly 300 feet. The Arbuckle is primarily dolomite with a few thin (5 to 10 feet) beds of dolomitic quartz sandstone. The dolomite is light gray to brown, fine to medium crystalline, contains scattered medium- to fine-grained, rounded frosted quartz grains and white to gray chert in varying proportions. Oolitic chert has been seen in several wells. The sandstones are white to buff, normally dolomitic and well-cemented, and are composed of fine- to medium-sized rounded, frosted quartz grains. Correlation of these sandstones from one well to another has not been established. The eight Arbuckle tests in Harper County are noted by a triangle symbol on the oil and gas map (Plate III). Two of these wells are included in the southwest-northeast cross section A-A' (Panel I, Plate A). The northeastern well, No. 4 (Sinclair No. 1 Holcomb, sec. 7, T. 28 N., R. 22 W.), discovered oil in the top of the Arbuckle at 7,649 feet (-5,682).

Simpson group: Rocks of this group rest unconformably upon the Arbuckle and range in thickness from about 100 feet in the northwest corner of the county to slightly over 150 feet in the northeast and southwest corners. The Simpson group consists of dolomites, sandstones and shales. Normally the base is marked by a gray-white to tan, fine- to medium-grained poorly sorted dolomitic sandstone containing rounded, frosted quartz grains and interbedded with dark-green to olive-green waxy shale. Whereas the dolomite in this lower part is similar to that of the underlying Arbuckle, the occurrence of this sandstone with typical green Simpson-type shale, affords a reliable subsurface criterion for establishing the Simpson-Arbuckle contact. Detrital Arbuckle, if present, is not evident in rock cuttings.

The middle part of the Simpson is predominantly shale about 30 to 50 feet thick with thin beds of dolomite and dolomitic sandstone. The shale is dark green to olive green, sub-waxy to waxy and at places contains imbedded fine- to medium-grained, rounded, frosted quartz grains. The thin beds of dolomite associated with this section are gray to tan, fine crystalline and contain quartz grains similar to those occurring in the shale. The thin sandstone beds are white to tan, fine to medium grained, dolomitic and compact.

The upper one-third of the Simpson is dolomite and sandstone with thin interbeds of sub-waxy to waxy green shale. Dolomite predominates and is gray to light tan, fine to medium crystalline with imbedded fine- to medium-grained, rounded, frosted quartz grains and with minor amounts of chert. The chert is normally dull gray and opaque and at places faintly speckled. The dolomite in this part of the Simpson is slightly porous, having both inter-crystalline and vuggy porosity. The sandstones are generally dolomitic and are of the same type as those found in the lower part of the Simpson.

The top of the Simpson, as here defined, is recognized readily both by electric and lithologic characteristics. A thin unit of typical green waxy shale occurs immediately at the top. It is thought that dolomites of the Simpson and Viola can be separated by the absence or presence of chert. However, since overlying rocks which are called Viola are also dolomite, and may or may not contain chert, it is possible that the criteria now used to separate these two rock units are not valid.

Dietrich (1955, p. 16) in his study of the Simpson group in northwestern Oklahoma concluded that Oil Creek, McLish, Tulip Creek and Bromide formations are present in the 150-foot section of Simpson rocks in the Sinclair No. 1 Berry (sec. 14, T. 24 N., R. 25 W.) just south of Harper County, but that the upper part of the Bromide is missing. He stated that truncation of at least 110 feet of the Simpson group occurs in a distance of 30 miles between the Sinclair No. 1 Morrow (sec. 6, T. 23, N., R. 19 W.) and the No. 1 Berry. If his correlations are correct, it may be inferred that part of the Bromide is also missing in Harper County.

Viola formation: Rocks termed Viola in Harper County range in thickness from 200 to 500 feet and rest unconformably upon the Simpson group. The maximum thickness occurs in the southern part of the county. They consist of gray limestone, white to brown dolomitic limestone, calcareous dolomite and dolomite, ranging from fine- to medium-coarse crystalline textures. Normally they contain an abundance of gray dense opaque chert. There appears to be little correlation of individual beds of limestone and dolomite between wells, although a zone containing dark gray opaque chert occurring 50 to 80 feet above the base of this unit is present in the majority of wells which have penetrated the section. Solution and weathering of the Viola limestone during post-Hunton, pre-Woodford time may have created the reservoir from which gas was obtained in the Woods Petroleum No. 1 Seevers (sec. 6, T. 27 N., R. 20 W.).

SILURIAN AND DEVONIAN

Rocks of the Hunton group have not been recognized definitely in wells, and they are thought to have been removed from this area by post-Hunton erosion. However, they may be present in the southeastern corner of Harper County where at present no deep tests have been drilled, and some geologists believe they are present in the Sunray Mid-Continent No. 1 Klinger (sec. 12, T. 25 N., R. 26 W.) and Continental No. 1 Benton (sec. 2, T. 25 N,. R. 22 W.). (Note section which may be Hunton on Panel I, Plate A.).

About 5 to 10 feet of Woodford shale occurs in the northeastern part of the county. The Woodford here is a dark brown to black bituminous shale containing amber *Tasmanites*. The Woodford, where present, rests unconformably on the Viola. Lee (1940, Plate 4) shows a southward-trending line in the western portion of T. 35, S., R. 22 W. (just north of T. 29 N., R. 21 W.), west of which no Woodford is present in Kansas.

In the Continental No. 1 Benton (sec. 2, T. 25 N., R. 22 W.) rock cuttings at 8,765 to 8,775 feet contain a dark gray shale underlain by an estimated 5 feet of white medium-grained calcareous sandstone with rounded quartz grains, and white fine-crystalline cherty limestone. Oxley (1958) described a core at the depth of 7,470 to 7,495 from the Superior No. 1 Blasdel (sec. 12, T. 27 N., R. 22 W.) below a dark brown carbonaceous shale called Woodford. The top six feet of this core contains 3 one-foot beds of waxy green shale separated by two feet of brown limestone containing glauconite and pink crinoid fragments, and by one foot of detrital material consisting of tubes, frosted sand grains, blue chert, and brown and green shale. The remaining 19 feet of the core contains dolomitic limestone, siliceous limestone and chert and 2 feet of dense dolomitic limestone with beds of dull olive-green shale. This 25-foot section he considers may be equivalent to the Misener. However, such material is typically present on an irregular limestone surface which has been subjected to solution and weathering and might well be considered part of the Viola.

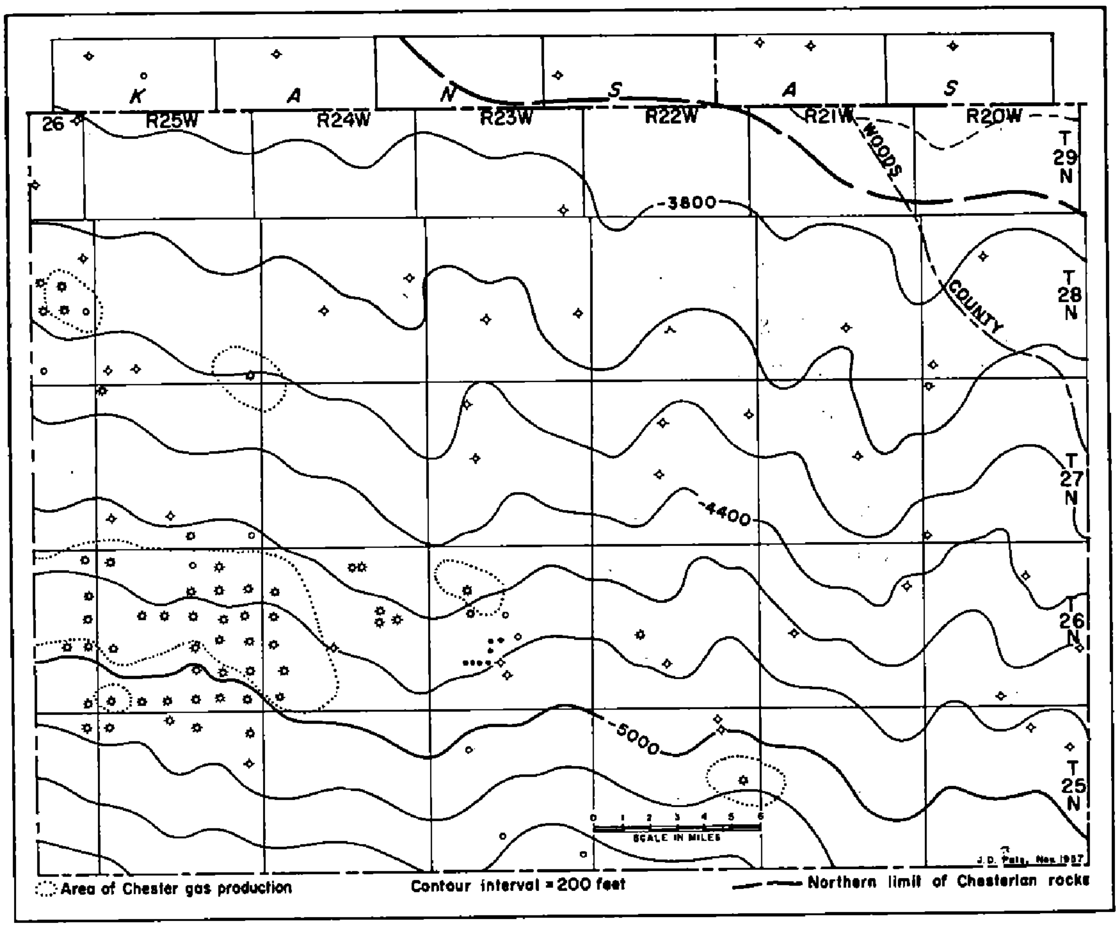


FIGURE 14. Contour map of pre-Pennsylvanian surface on eroded Mississippian rocks in Harper County.

MISSISSIPPIAN

Mississippian strata are approximately 2,200 feet thick in the southwest corner of Harper County and 1,300 feet in the northeast corner. The present position of the top of the eroded surface of Mississippian rocks is shown in Figure 14. The Mississippian has been divided into the following four series (ascending): Kinderhookian, Osagean, Meramecian and Chesterian.

Kinderhookian: A shale section 15 to 50 feet thick is assigned a Kinderhookian age. This shale is normally gray to green gray and commonly is calcareous. Near its base, the shale at many places is dark brown and resembles the Woodford, but is less bituminous and lacks *Tasmanites*. It rests unconformably upon Viola except in wells in the vicinity of the Woods Petroleum No. 1 Seevers (sec. 6, T. 27 N., R. 20 W.) where approximately 45 feet of gray and pale-green shale rests upon 10 feet of gray-black to brown bituminous shale termed Woodford shale. It is possible that at places some of the overlying limestones assigned to the Osagean should be placed in the Kinderhookian since Maher and Collins (1949) place 130 feet of section in their Kinderhook group in the Gulf No. 1 Ratzlaff (sec. 9, T. 3 N., R. 21 ECM) in Beaver County.

Osagean: A highly siliceous and cherty limestone overlies the Kinderhookian shale and is considered to be Osagean in age. The limestone is gray to light brown, normally argillaceous and commonly dolomitic, and contains medium- to coarse-grained glauconite pellets in the basal 10 to 20 feet at some places. It ranges in thickness from slightly less than 500 feet in the southern part of the county to slightly over 300 feet in the north. This unit of rocks is uniform lithologically and therefore is easily identified both in well cuttings and on electric logs.

Meramecian: Rocks assigned a Meramecian age consist of approximately 800 to 900 feet of limestone. The lower 600 to 700 feet is predominantly light-gray to buff-tan limestone which contains abundant fragments of crinoids, brachiopods and bryozoans. While the crystallinity varies from microcrystalline to coarse, the Meramec is characterized by being predominantly medium to medium-coarse crystalline. Zones of oolitic limestones are confined to the upper half of the unit, which is also characterized by abundant light gray and white opaque to sub-transparent chert. Minor amounts of chert occur in the lower half. The top 200 feet is composed of light gray to light tan silty limestone and calcareous siltstones. This silty section is used to separate the Meramec from the overlying Chester. The exact contact, however, is not so readily established since it appears that there are calcareous siltstones in the lower part of the section which have been assigned to the Chester. The top of the Meramec is commonly placed by electric logs at the top of a continuous sequence of limestones, but the actual top of the series may occur as much as 100 feet above this electric log point.

Chesterian: Rocks which are considered Chesterian in age consist of alternating limestone and shale strata which are approximately 900 feet thick in the southwest corner of Harper County and thin out by truncation in the northeast corner of the county

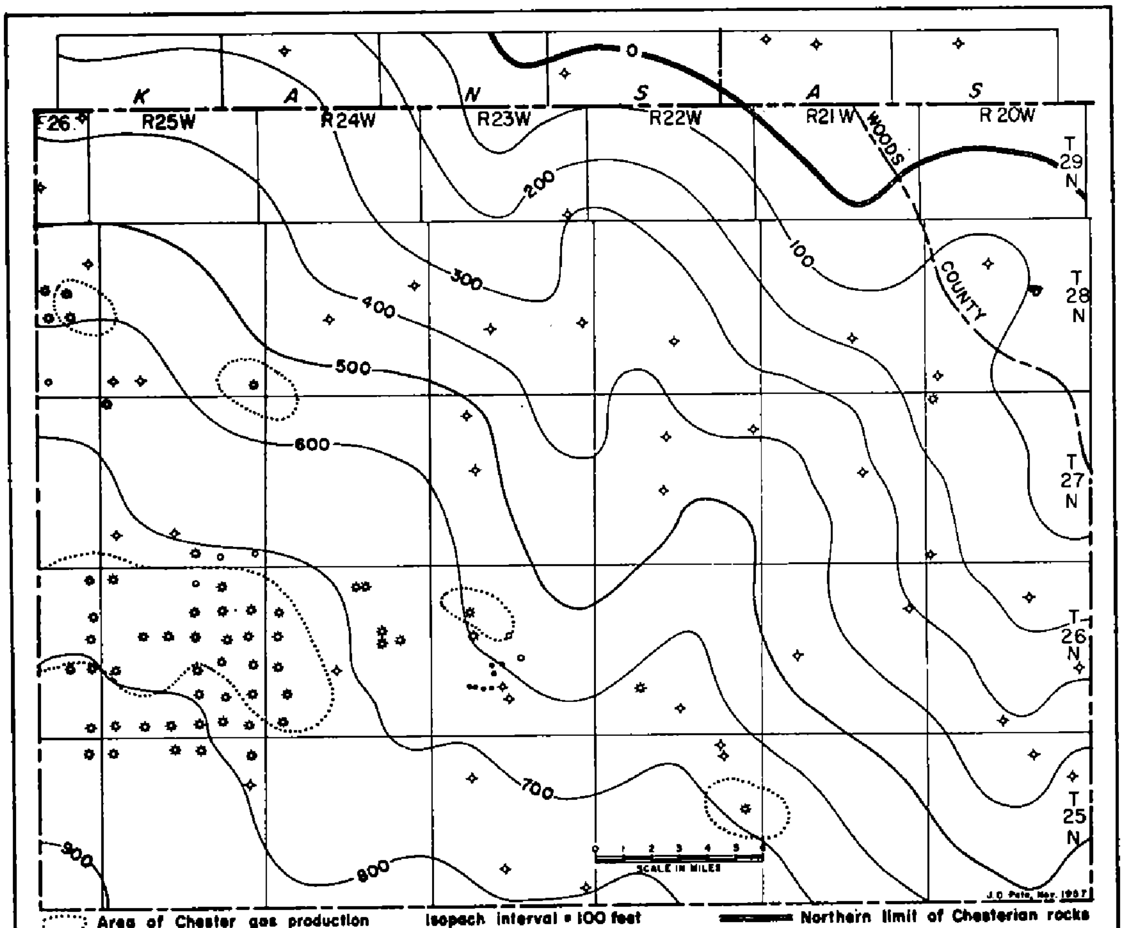


FIGURE 15. Isopach map of Chesterian rocks in Harper County.

(Figure 15). In Harper County, limestones predominate and are normally gray buff to tan, fine to medium crystalline, at places mottled, oolitic and fossiliferous. Cores obtained from this reservoir rock show a slightly fractured limestone with relatively low porosity and permeability. Some of the limestone has minor amounts of intercrystalline porosity, and oolitic limestones may exhibit oomoldic porosity. Gas production from Chester limestone has been found at Northeast Gate Lake, Northwest Doby Springs, North Fort Supply, East Stockholm Fields and the Laverne Gas Area.

PENNSYLVANIAN

The Pennsylvanian system is represented by carbonate and clastic rocks which thicken in a general southwesterly direction from approximately 2,300 feet in the northeast to 3,700 feet in the southwest part of the county. These rocks range in age from Morrowan through Virgilian (ascending).

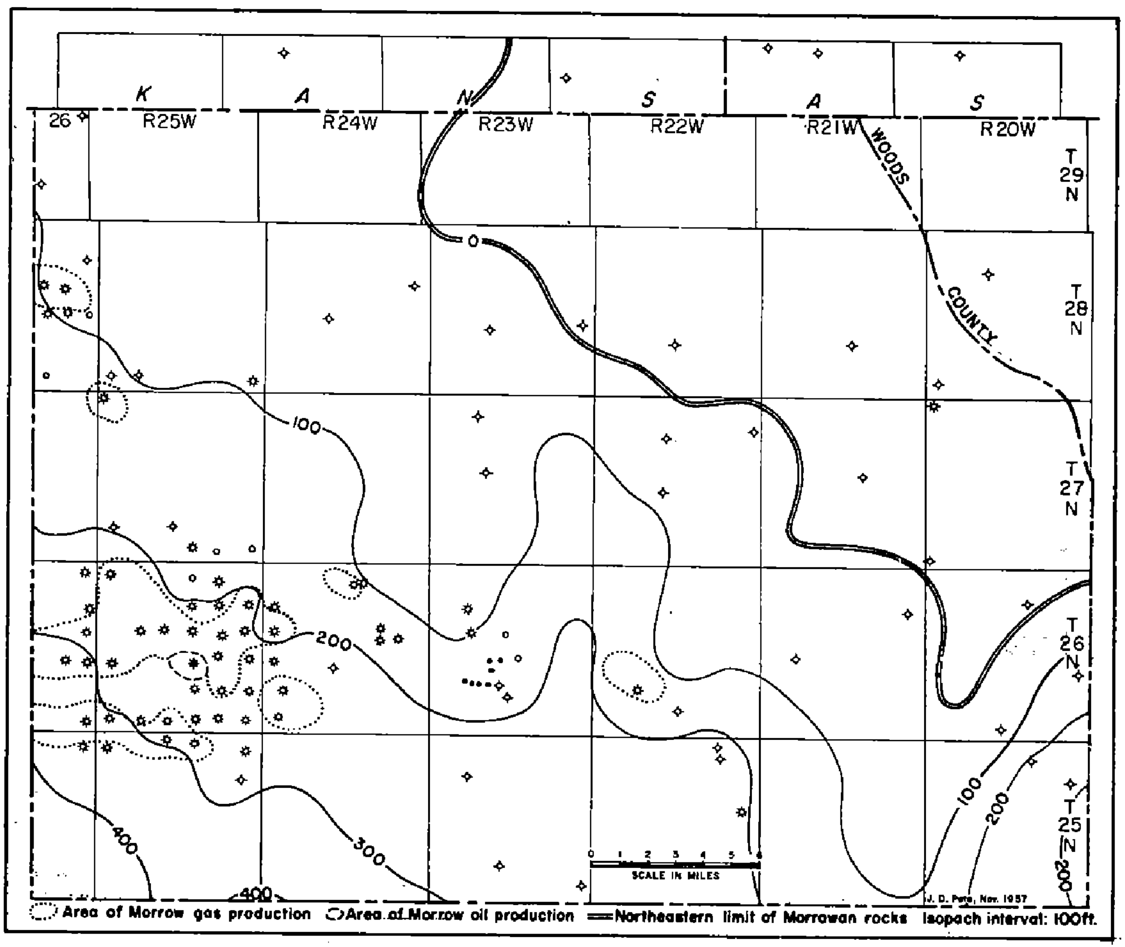


FIGURE 16. Isopach map of Morrowan rocks in Harper County.

Morrowan: A unit of rocks consisting of dark gray carbonaceous and dark green shales with several normally well-cemented glauconitic sandstone and limestone lenses in the lower part of the section, is being called "Morrow". Faunal evidence for this age is absent but regional studies suggest such a correlation. Overlying the truncated surface of Chesterian rocks, the "Morrow" is absent in northeast Harper County (Figure 16) but reaches a thickness of approximately 500 feet in the southwest. Gas and condensate are being produced from sandstones (termed "Lower Morrow") in Northeast Gate Lake, North Rosston, Northeast Doby Springs, Southwest Kibby and East Stockholm Fields and gas-condensate and oil wells are present in the Laverne Gas Area.

Atokan-Desmoinesian: Atokan-Desmoinesian rocks have been divided in this area into Atoka, Cherokee and Marmaton (ascending). They range in thickness from about 300 feet in the northeastern part of Harper County to 800 feet in the southwestern part.

The term "Thirteen Finger" lime is applied to a section of dark gray to black radioactive shales interbedded with gray to brown fine-crystalline, in part siliceous, dense limestones which overlie "Morrow" shale or Mississippian rocks where the "Morrow" is absent. This limestone, considered to be Atokan in age by some geologists and Desmoinesian by others, onlaps the underlying rocks and within the county appears to be conformable with the overlying Desmoinesian (Cherokee group) rocks. If the top of the "Atoka" is placed at the point illustrated on the east-west section (Panel I, Plate B), the unit is approximately 300 feet thick in the southwest corner and thins out to the north and east within Harper County. No shows of oil or gas have been obtained from this unit in the county. However, it is productive of both oil and gas in minor quantities in Beaver County to the west and in Lipscomb County, Texas, to the southwest.

The Cherokee group, consisting of alternating limestone and shale and an occasional thin sandstone, overlies the Atokan rocks. The limestones are light gray to tan, fine crystalline, normally dense, siliceous and oolitic in part. The shales are dark gray to black, finely micaceous and silty. No production has been found in the county and only a few minor shows of oil and gas have been encountered.

The Marmaton group, resting conformably upon the Cherokee, is essentially limestone with three to four thin dark gray to black shale interbeds, none of which is normally over 10 feet thick. The limestones are buff to brown, fine crystalline, siliceous in part, normally dense, but at places are bioclastic, oolitic and porous. The basal formation of the Marmaton, probably equivalent to the Fort Scott limestone of the surface, called "Oswego lime", has had shows of gas at several places. In June, 1958, Hamilton Brothers, Ltd. No. 1 Dies (sec. 1, T. 27 N., R. 21 W.) was completed as an oil well from the "Oswego" flowing 226 barrels of 44.3° gravity oil with 1.5 million cubic feet of gas per day on initial test.

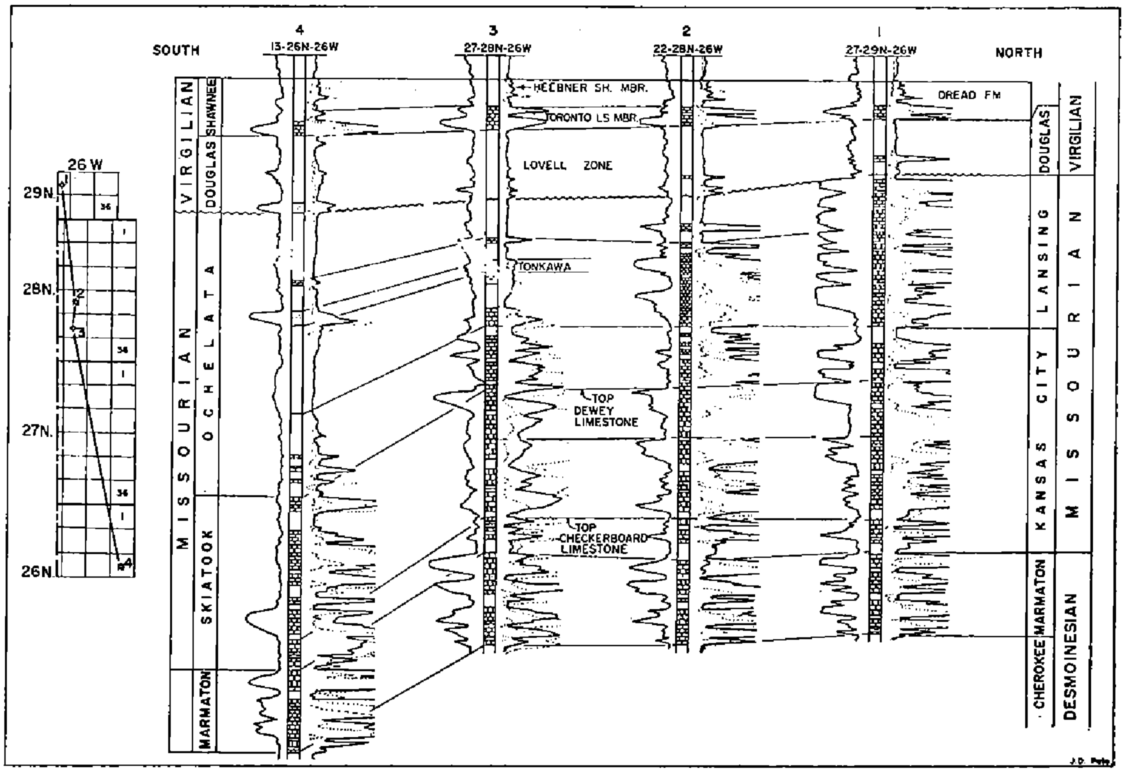


FIGURE 17. North-south cross section showing correlation of Missourian rocks in western Harper County.

Missourian: The boundary between Missourian and Virgilian rocks has been raised in this report to a point higher in the section of the Pennsylvanian than it had been placed by previous writers (Lukert, 1949, and Winchell, 1957). It is shown (Figure 17) that the sandstone of the Tonkawa and some of the overlying and underlying shale are equivalent to all or part of the carbonate Lansing group of Kansas. Using this boundary, the thickness of rocks of Missourian age which dip in a general southerly direction ranges between 700 and 1,000 feet, being thinner in the north. They are divided into Skiatook and Ochelata groups (ascending). The lower group, Skiatook, is everywhere predominantly limestone with some shale. Limestones are normally light gray to tan, fine crystalline, in part fossiliferous and siliceous. The shales are essentially dark gray, calcareous, and micaceous, and locally silty.

In the eastern part of the county, a few wells have had thin beds of fine-grained sandstone in the shale near the base of the group.

In the southern part of the county the overlying Ochelata group is mostly shale with limestone in the lower part, shale and the sandstone called Tonkawa or "Lower Tonkawa" in the upper part. Northward limestones rise in the section until the entire unit is predominantly limestone. The Tonkawa grades into shale along a irregular east-west line roughly at the northern boundary of Township 26 North. The postulated limits of the sandstone, shale and limestone facies of the Tonkawa are shown on Figure 18. Tonkawa sands were not deposited as a continuous uniform sand body, but rather appear to be in the form of lenses or bars since at least four separate reservoirs exist in the Laverne-Southeast Stockholm-Northwest Highland district. Tonkawa reservoirs produce gas-condensate in the Laverne Gas Area, West, Southwest and East Stockholm Fields and oil at Southeast Stockholm. Gas has recently been discovered in this zone about one mile southeast of the town of Lovedale. The discovery well at North Buffalo tested nearly 10 million cubic feet of gas in limestone of the Lansing group, and oil has been found in both Lansing and Kansas City limestones in the offset well one-half mile north.

Virgilian: Rocks deposited during Virgilian time lie unconformably upon Missourian rocks and range in thickness from approximately 950 feet in the north to 1,150 feet in the south. They thicken at an average rate of less than 8 feet per mile. The Brownville limestone, uppermost member of the series, dipping in a general south-southeast direction at a rate of about 12 feet per mile, is reached at a subsea depth of 1,400 feet in the northwest and of 2,100 feet in the southeast. A structure map contoured on the top of the Oread formation (Figure 18), basal member of the Shawnee group, presents much the same picture as one contoured on top of the Brownville. Rocks deposited during Virgilian time are divided (ascending) into Douglas, Shawnee and Wabaunsee groups.

The Douglas group lies conformably below the Toronto limestone member of the Oread formation. It is predominantly shale with siltstone, sandstone and oolitic limestone, and it ranges in thickness from 100 to 200 feet. The sandstones are light gray, micaceous, calcareous and argillaceous, and contain fine- to medium-sized frosted quartz grains. Oil- and gas-productive sandstones in this unit have been called "Upper Tonkawa", "Middle Tonkawa", or "Lovell" by various operators in areas to the east. Both the names "Upper Tonkawa" and "Lovell" are being applied to this sandstone in which as yet no production has been found in Harper County. It is hoped that when and if hydrocarbons are found that the more correct term "Lovell" will be used.

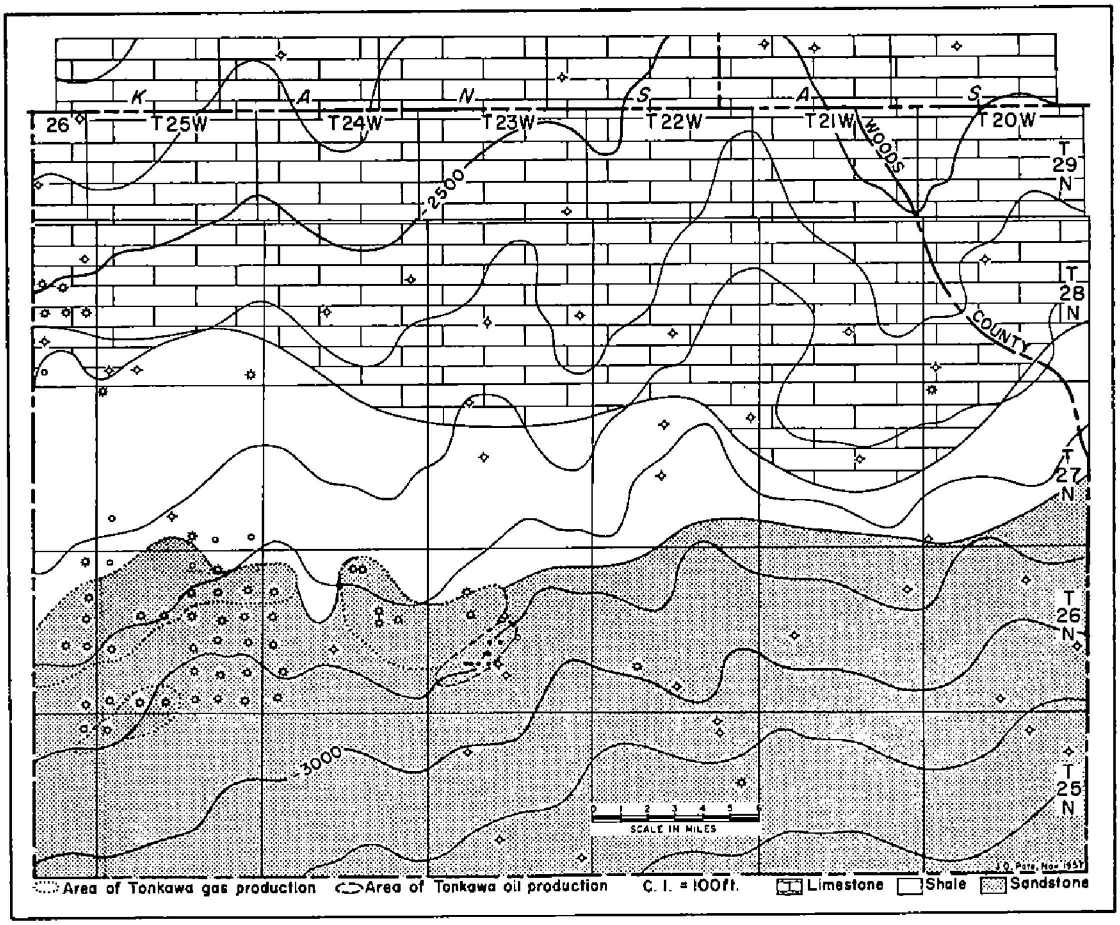


FIGURE 18. Structure contour map on top of Oread formation and lithofacies map of Tonkawa zone in Harper County.

Overlying the Douglas, the Shawnee group is predominantly dark gray finely micaceous shale with a few limestone beds in the Oread formation, lowermost formation of the group. The limestones are tan to brown, fine to medium crystalline, dolomitic, siliceous and argillaceous with occasional intercrystalline or intergranular porosity. Sandstones, locally well-developed, are light in color, fine grained, calcareous, micaceous and normally well-cemented. They are developed in what is termed to the east the Endicott sand zone, which lies above the Toronto limestone and below the Heebner shale, and also in the Elgin sand zone, which lies above the Oread formation and below the Deer Creek limestone. It is within this latter section that the true Hoover (not "Hoover" of Harper County, see below) lies above the Elgin to the east in north-central Oklahoma. The Endicott and Elgin sands are as yet non-productive in Harper County, but gas is produced from the Elgin in southern Barber County, Kansas, to the northeast. Sinclair recently tested a small amount of gas from the Toronto limestone at 4,465 to 4,510 feet in their No. 1 Holcomb, Arbuckle discovery well of North Buffalo Field.

The Wabaunsee group is essentially limestone with thin interbeds of shale in the eastern part of Harper County (Panel I, Plate B). These limestones are tan to light brown and gray, fine crystalline, locally siliceous, dolomitic and oolitic, normally highly fossiliferous and at places exhibit intergranular and vuggy porosity. Westward the group thickens, and clastic sediments replace the lower part of the carbonate section. Within this clastic unit at the stratigraphic position of the Burlingame limestone, a gas-productive sandstone was discovered in 1955 by An-Son Petroleum Corporation No. 1 Laverty (sec. 26 T. 26 N., R. 25 W.) from which 44 barrels of 70° gravity condensate and 11 million cubic feet of gas flowed per day on initial potential test. Unfortunately due to miscorrelation, the name "Hoover" was applied to this new gas reservoir. This sandstone lies within the Wabaunsee group and is stratigraphically above the true Hoover (Shawnee group), which is absent in Harper County. As this sandstone is an important reservoir in Harper County, and it clearly is not the Hoover sand of north-central Oklahoma, it will be called in this report the Laverty-Hoover from its discovery in the Laverty well.

In the areas where the Wabaunsee group consists of more shale and sandstone than limestone, the shales are commonly gray, reddish brown and greenish gray, micaceous, blocky to fissile, calcareous, silty and sandy. The Burlingame limestone grades to shale and sandstone between wells No. 9 and No. 10 on cross section B-B' (Panel I, Plate B). This sandstone is called Laverty-Hoover. A line drawn at the approximate position of this change of facies trends in a general northeasterly direction and passes between the dry holes located in sec. 28, T. 28 N., R. 22 W. and sec. 27, T. 28 N., R. 21 W. The Laverty-Hoover present in the

Laverne district and also in the northwest corner of the county is a light gray, calcareous, micaceous, fine-grained sandstone. Near or at the base of the group at places occurs another sandstone which is fine grained, micaceous, calcareous and normally argillaceous as shown on cross sections A-A' and B-B' (Panel I, Plates A and B).

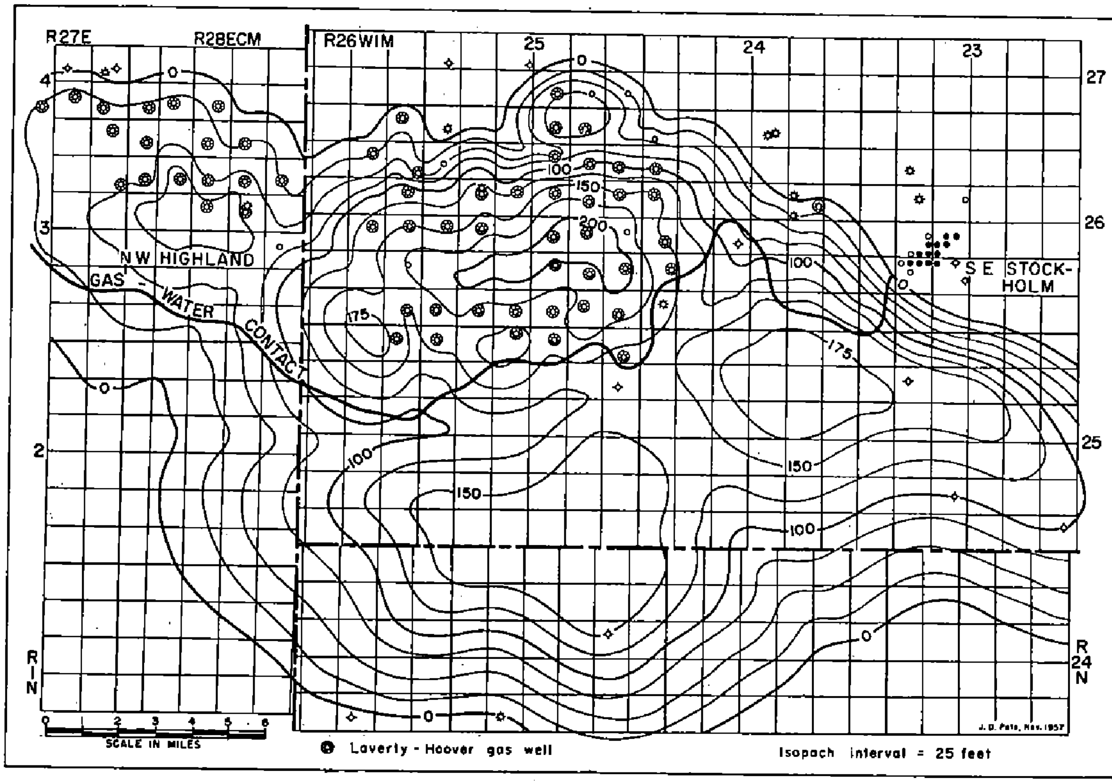


FIGURE 19. Isopach map of Laverty-Hoover sand zone in the Laverne district.

Maps of the Laverne district (Figures 19 and 20) prepared in late 1957 show the locations of wells completed to produce from the Laverty-Hoover sand, thickness of the sandstone, and structure on top of the sandstone body. Together they portray the shape of the sand body which reaches a thickness of 210 feet in Laverne Township. It thins out more or less in all directions but more rapidly northward from sec. 3, T. 26 N., R. 25 W. Structural noses are present at Northwest Highland, Laverne and Southwest Stockholm. In this district the total gas reserves in the Laverty-Hoover reservoir are estimated to be in the neighborhood of 1,125 billion cubic feet. Production in this zone has not been discovered in other areas in Harper County.

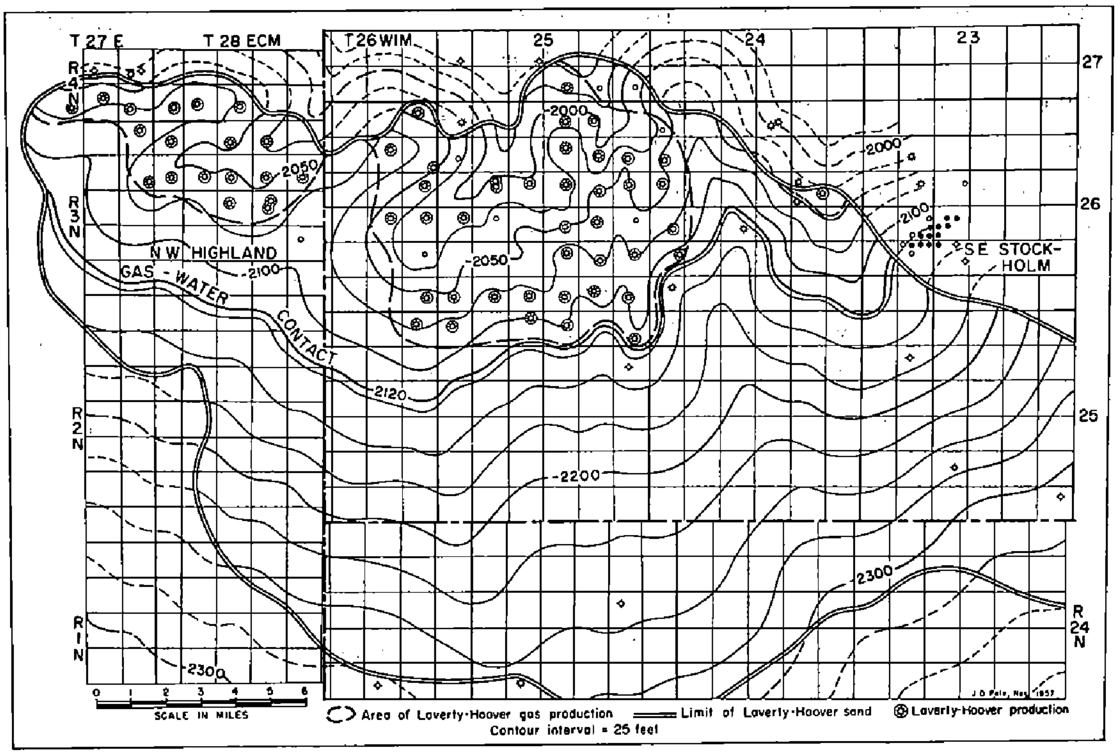


FIGURE 20. Contour map on top of Laverty-Hoover sand zone in the Laverne district.

PERMIAN

Rocks of the Permian system in the subsurface of Harper County range in age from Wolfcampian, the oldest, to those exposed at the surface, the youngest recognized being the Cloud Chief formation of Ochoan (?) age, cropping out in the central part of Harper County.

Wolfcampian: Rocks deposited during this epoch rest with apparent conformity upon the Pennsylvanian and range in thickness from approximately 950 feet in the north to 1,050 feet in the south. The rocks are divided into three groups (ascending): Admire, Council Grove and Chase.

The Admire group consists of limestones and shales below the Foraker limestone and above the Brownville limestone. This basal group maintains an average thickness of about 125 feet. The limestones are light gray to brown, finely crystalline or granular, oolitic and fossiliferous and are interbedded with finely micaceous, calcareous, blocky shales that vary in color from gray to greenish gray to reddish brown.

Rocks of the Council Grove group resting upon the Admire are essentially limestone with thin interbeds of shale. The group averaging nearly 450 feet in thickness includes all strata from the top of the Admire to the base of the Wreford limestone, lowermost formation of the overlying Chase group. In the subsurface, three limestones can be readily followed from one well to the next: the Foraker at the base, the Neva limestone, and the Cottonwood limestone near the top. All the limestones are fossiliferous and oolitic, locally dolomitic and porous. At places the Foraker limestone is cherty with oomoldic porosity. The shales are calcareous, gray and reddish brown. Small gas production has been obtained from the Neva limestone at several places in northern Oklahoma, (Northwest Avard Field in Woods County and Blackwell Field in Kay County), but none has been found as yet in Harper County.

The Chase group, which includes all the rocks from the base of the Wreford to the top of the Herington limestone, is predominantly limestone interbedded with gray to brown, calcareous shale. The limestones are dolomitic, oolitic, fossiliferous and siliceous in part. They exhibit intergranular and vuggy porosity and normally are denser near the base of the group. Several units of the group have electrical characteristics permitting correlation for considerable distances. Some of these are (ascending order): Wreford, Florence, Fort Riley, Winfield, Krider and Herington. No shows of oil or gas in the Chase group have been found in Harper County. However, the dolomites and dolomitic limestones of this group are the gas-producing reservoirs in the Guymon-Hugoton Field to the west, a major gas reserve containing helium.

Post-Wolfcampian: In the western part of the county, Permian rocks younger than Wolfcampian range in thickness from about 2,500 feet in the north to slightly over 3,000 feet in the south. They consist of three sequences of evaporite deposits overlain by variegated shales, silty shales and shaly sandstones. The lowermost unit of anhydrite with interbeds of shale, the Wellington formation, is at places as much as 1,000 feet thick. This is overlain by a section of variegated and sandy shales with thin beds of anhydrite. A middle unit of anhydrite and salt underlies the Stone Corral dolomite (Cimarron anhydrite). Above the Stone Corral lie gypsiferous variegated partly sandy shales containing salt casts. These shales are overlain by the Blaine formation which is essentially anhydrite or gypsum. In drilling for oil and gas in Harper County, beds above the Wolfcampian have not and probably will not be productive and they have not been investigated in detail.

SELECTED REFERENCES

Aurin, Fritz (1917), Geology of the redbeds of Oklahoma: Okla. Geol. Survey, Bull. 30, p. 7-66.

Becker, Clyde M. (1930), Structure and stratigraphy of southwestern Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 14, p. 37-56.

Blaik, William M. (1958), Important wells in Oklahoma: Shale Shaker, vol. 8, no. 5, p. 8.

Blair, T. A. (1942), Climatology, Prentice Hall, Inc., p. 184-190.

Bullard, F. M. (1928), Lower Cretaceous of western Oklahoma: Okla. Geol. Survey, Bull. 47, p. 1-116.

Burwell, A. L., and W. E Ham (1949), Cellular products from Oklahoma volcanic ash: Okla. Geol. Survey, Circular No. 27, p. 1-89.

.... (1955), An investigation of industrial possibilities of Oklahoma gypsum and anhydrite: Okla. Geol. Survey, Mineral Report 29, p. 1-21.

Byrne, Frank E. and Thad G. McLaughlin (1948), Geology and ground-water resources of Seward County, Kansas: Kansas, State Geol. Survey, Bull. 69, p. 1-140.

Chaney, R. W. and Elias, M. K. (1936), Late Tertiary floras from the High Plains. With a chapter on the Lower Pliocene vertebrate fossils from the Ogallala Formation (Lavern Zone) of Beaver County, Oklahoma, by Curtis J. Hesse: Carnegie Inst. Washington, Publ. 476, paper I, pages 1 to 72, 7 plates and 11 text-figures.

Clifton, R. L. (1926), Oil and gas in Oklahoma; Woods, Alfalfa, Harper, Major, Woodward, and Ellis counties: Okla. Geol. Survey, Bull. 40-A, p. 4-24.

.... (1930), Permian structure and stratigraphy of northwestern Oklahoma and adjacent areas: Amer. Assoc. Petroleum Geologists, Bull., vol. 14, p. 161-173.

Cragin, F. W. (1894), Description of invertebrate fossils from the Comanche series in Texas, Kansas, and Indian Territory: Colo. College Studies, Fifth Ann. Publ., p. 49-69.

.... (1895), Vertebrata from the Neocomian of Kansas: Colo. College Studies, vol. 5, p. 69-73.

.... (1896), The Permian system in Kansas: Colo. College Studies, vol. 6, p. 1-54.

.... (1896), Preliminary notice of three late Neocene terranes: Colo. College Studies, vol. 6, p. 53-54.

.... (1897), Observation on the Cimarron series: American Geologist, vol. 19, p. 351-363.

Darton, N. H. (1899), Preliminary report on the geology and water resources of Nebraska west of the 103rd meridian: U. S. Geol. Survey, 19th Ann. Rept., pt. 4, p. 719-785. Reprinted, also, as U. S. Geol. Survey, Prof. Paper 17 (1903).

.... (1920), U. S. Geol. Survey, Geol. Atlas, Syracuse-Lakin folio (no. 212), p. 1-10.

Davis, L. V. (1955), Geology and ground water resources of Grady and northern Stephens Counties, Oklahoma: Okla. Geol. Survey, Bull. 73, p. 1-184.

Dietrich, Ray Francis, Jr. (1955), The Simpson group along the north flank of the Anadarko basin: Shale Shaker, vol. 5, no. 5, p. 5.

Elias, M. K. (1931), The geology of Wallace County, Kansas: Kansas, State Geol. Survey, Bull. 18, p. 1-254.

———— (1942), Tertiary prairie grasses and other herbs from the High Plains: Geol. Soc. America, Special Paper no. 41, p. 1-176.

———— (1948), Ogallala and post-Ogallala sediments: Geol. Soc. America, Bull., vol. 59, p. 609-612.

Evans, Noel (1931), Stratigraphy of the Permian beds of northwest Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 15, p. 405-440.

Fenneman, N. M. (1922), Physiographic provinces and sections in western Oklahoma and adjacent parts of Texas: U. S. Geol. Survey, Bull. 730, p. 115-139.

Frye, John C. (1942), Geology and ground-water resources of Meade County, Kansas: Kansas, State Geol. Survey, Bull. 45, p. 1-152.

———— (1945), Problems of Pleistocene stratigraphy in central and western Kansas: Jour. Geology, vol. 53, p. 73-93.

———— (1946), Review of the studies of Pleistocene deposits in Kansas: Amer. Jour. Science, vol. 244, p. 403-416.

Frye, J. C., and C. W. Hibbard (1941), Pliocene and Pleistocene stratigraphy and paleontology of the Meade basin, southwestern Kansas: Kansas, State Geol. Survey, Bull. 38, p. 389-424.

Frye, J. C., and A. B. Leonard (1952), Pleistocene geology of Kansas: Kansas, State Geol. Survey, Bull. 99, p. 1-230.

Frye, J. C., Leonard, A. B., and Swineford, A. (1956), Stratigraphy of the Ogallala formation (Neogene) of northern Kansas: Kansas, State Geol. Survey, Bull. 118, p. 1-92.

Frye, J. C., and S. L. Schoff (1942), Deep-seated solution in the Meade basin and vicinity, Kansas and Oklahoma: Amer. Geophys. Union, Trans., p. 35-39.

Gallaspy, Irvin Lee, (1958), Permian and Pennsylvanian (Post-Cherokee) geology of Harper County, Oklahoma: unpublished Master of Science thesis, University of Oklahoma.

Gould, C. N. (1905), Geology and water resources of Oklahoma: U. S. Geol. Survey Water-Supply and Irrigation Paper 148, p. 1-178.

———— (1924), A new classification of the Permian redbeds of southwestern Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 8, p. 322-341.

———— (1925), Index to the stratigraphy of Oklahoma: Okla. Geol. Survey, Bull. 35, p. 7-115.

———— (1926a), The correlation of the Permian of Kansas, Oklahoma, and northern Texas: Amer. Assoc. Petroleum

Geologists, Bull., vol. 10, p. 144-153.
.... (1926b), Our present knowledge of the Permian of the Great Plains: Jour. Geology, vol. 34, p. 415-421.
Gould, C. N., and F. E. Lewis (1926), The Permian of western Oklahoma and the Panhandle of Texas: Okla. Geol. Survey, Circular 13, p. 1-29.
Gould, C. N., and J. T. Lonsdale (1926), Geology of Beaver County, Oklahoma: Okla. Geol. Survey, Bull. 38, p. 5-71.
Gould, C. N., and Robin Willis (1927), Tentative correlation of the Permian formations of the southern Great Plains: Geol. Soc. America, Bull., vol. 38, p. 431-442.
Gould, C. N., and R. A. Wilson (1927), The upper Paleozoic rocks of Oklahoma: Okla. Geol. Survey, Bull. 41, p. 5-66.
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.
.... (1937), Major divisions of Permian in Oklahoma and southern Kansas: Amer. Assoc. Petroleum Geologists, Bull., vol. 21, p. 1515-1533.
Greene, F. C. (1926), Oil and gas in Oklahoma, subsurface stratigraphy of western Oklahoma: Okla. Geol. Survey, Bull. 40-D, p. 4-14.
Hedgpeth, J. W. (1951), The classification of estuarine and brackish waters and the hydrographic climate: Report of the committee on a treatise on marine ecology and paleoecology, Nat. Research Council No. 11, p. 49-56.
Hesse, C. . (1935), A vertebrate fauna from the type locality of the Ogallala formation: Kansas Univ. Science Bull., vol. 22, no. 5, p. 79-117.
Hibbard, C. W. (1944), Stratigraphy and vertebrate paleontology of Pleistocene deposits of southwestern Kansas: Geol. Soc. America, Bull., vol. 55, p. 707-754.
.... (1948), Late Cenozoic climatic conditions in the High Plains of western Kansas: Geol. Soc. America, Bull., vol. 59, p. 592-597.
.... (1949), Pleistocene stratigraphy and paleontology of Meade County, Kansas: Michigan Univ., Mus. Paleontology. Contr., vol. 7, no. 4, p. 63-90.
.... (1950), Mammals of the Rexroad formation from Fox Canyon, Meade County, Kansas: Michigan Univ., Mus. Paleontology, Contr., vol. 8, no. 6. p. 113-192.
.... (1955), The Jinglebob interglacial (Sangamon?) fauna from Kansas and its climatic significance: Michigan Univ., Mus. Paleontology, Contr., vol. 12, no. 10, p. 179-228.
.... (1956), Vertebrate fossils from the Meade formation of southwestern Kansas: Michigan Acad. Sci., Papers, vol. 41, p. 145-200.
Hills, J. M. (1942), Rhythm of Permian seas—a paleogeographic study: Amer. Assoc. Petroleum Geologists, Bull., vol. 26, p. 217-255.

Kulstad, R. O., Fairchild, P., and McGregor, D. (1956), Gypsum in Kansas: Kansas, State Geol. Survey, Bull. 113, p. 1-110.

Lee, Wallace, (1940), Subsurface Mississippian rocks of Kansas: Kansas, State Geol. Survey, Bull. 33.

Ley, Henry A. (1931), Production in Oklahoma during 1930: Amer. Inst. Min. Metal. Engineers, Petroleum Development and Technology, p. 420-432.

Lugn, A. L. (1939), Classification of the Tertiary system in Nebraska: Geol. Soc. America, Bull., vol. 50, p. 1245-1276.

Lukert, L. H. (1949), Subsurface cross sections from Marion County, Kansas, to Osage County, Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 33, no. 2, p. 131-152.

Maher, J. C., and Collins, J. B. (1949), Pre-Pennsylvanian geology of southeastern Kansas, southeastern Colorado, and the Oklahoma Panhandle: U. S. Geol. Survey, Oil and Gas Investigations, Preliminary Map 101, sheets 1-4.

McLaughlin, T. G. (1946), Geology and ground-water resources of Grant, Haskell, and Stevens counties, Kansas: Kansas, State Geol. Survey, Bull. 45, p. 1-221.

Mengel, R. M. (1952), White pelican from the Pleistocene of Oklahoma: Auk, vol. 69, p. 81-82.

Merriam, D. F., and J. C. Frye (1954), Additional studies of the Cenozoic of western Kansas: Kansas, State Geol. Survey, Bull. 109, p. 53-64.

Miser, H. D. (1954), Geologic map of Oklahoma: U. S. Geol. Survey and Oklahoma Geol. Survey.

Moore, R. C., Frye, J. C., and Jewett, J. M. (1944), Tabular description of outcropping rocks in Kansas: Kansas, State Geol. Survey, Bull. 52, p. 137-212.

Moore, R. C., and others (1951), the Kansas rock column: Kansas, State Geol. Survey, Bull. 89, p. 1-132.

Muir, J. L. (1934), Anhydrite-gypsum problem in Blaine formation, Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 18, p. 1297-1312.

Newell, N. D. (1940), Invertebrate fauna of the late Permian Whitehorse sandstone: Geol. Soc. America, Bull., vol. 51, p. 261-336.

Norton, George H. (1937), Lower redbeds of Kansas: Amer. Assoc. Petroleum Geologists, Bull., vol. 21, p. 1557-1558.

.... (1939), Permian redbeds of Kansas: Amer. Assoc. Petroleum Geologists, Bull., vol. 23, p. 1751-1819.

Oxley, Marvin L. (1958), A subsurface study of the Hunton in northwestern Oklahoma: unpublished Master of Science thesis, University of Oklahoma.

Pate, J. Durwood (1958), Stratigraphic traps along northern shelf of Anadarko basin (Abstract): Amer. Assoc Petroleum Geologists, Bull., vol. 42, no. 1, p. 214.

Reeves, Frank (1921), Geology of the Cement oil field, Caddo County, Oklahoma: U. S. Geol. Survey, Bull. 726, p. 41-85.

Rinker, G. C., and C. W. Hibbard (1952), A new beaver and associated vertebrates from the Pleistocene of Oklahoma: Jour. Mammalogy, vol. 33, p. 98-101.

Sawyer, R. W. (1924), Areal geology of a part of southwestern Oklahoma: Amer. Assoc. Petroleum Geologists, Bull., vol. 8, p. 312-321.

.... (1929), Kiowa and Washita counties, Oklahoma: Okla. Geol. Survey, Bull. 40, p. 311-321.

Schoff, S. L. (1939), Geology and ground-water resources of Texas County, Oklahoma: Okla. Geol. Survey, Bull. 59, p. 1-248.

.... (1943), Geology and ground-water resources of Cimarron County, Oklahoma: Okla. Geol. Survey, Bull. 64, p. 1-317.

.... (1955), Map, showing ground-water reservoirs in Oklahoma: Okla. Geol. Survey.

.... (1956), Laverne formation: Oklahoma Geology Notes, vol. 16, no. 1, p. 3-5.

Sellards, E. H. (1933), The pre-Paleozoic and Paleozoic systems in Texas: Texas, Univ., Bull. 3232, p. 15-238.

Smith, C. L. (1954), Pleistocene fishes of the Berends fauna of Beaver County, Oklahoma: Copeia, no. 4, p. 282-289.

Smith, H. T. U. (1940), Geological studies in Southwestern Kansas: Kansas, State Geol. Survey, Bull. 34, p. 1-212.

Snider, L. C. (1913), The gypsum and salt of Oklahoma: Okla. Geol. Survey, Bull. 11, p. 1-218.

.... (1917), Geography of Oklahoma: Okla. Geol. Survey, Bull. 27, p. 1-325.

Starrett, A. (1956), Pleistocene mammals of the Berends fauna of Oklahoma: Jour. Paleontology, vol. 30, p. 1187-1192.

Stovall, J. W. (1932), the Jurassic in Oklahoma: Science, new ser., vol. 76, p. 122-123.

.... (1942), The Mesozoic of western Oklahoma: Compass, vol. 22, no. 4, p. 327.

Suffel, G. G. (19300), Dolomites of western Oklahoma: Okla. Geol. Survey, Bull. 49, p. 1-155.

Swineford, Ada (1955), Petrography of upper Permian rocks in south-central Kansas: Kansas, State Geol. Survey, Bull. 111, p. 7-179.

Taylor, D. W. (1954), A new Pleistocene fauna and new species of fossil snails from the High Plains: Michigan Univ,. Occ. Papers Mus. Zoo., no. 557, p. 1-16.

Taylor, D. W., and C. W. Hibbard (1955), A new Pleistocene fauna from Harper County, Oklahoma: Okla. Geol. Survey, Circular No. 37, p. 3-23.

U. S. Dept. of Agriculture Weather Bureau (1930), Climatic summary of the United States, sec. 42, p. 1-25.

Winchell, Richard L. (1957), Relationship of the Lansing Group and the Tonganoxie ("Stalnaker") sandstone in south-central Kansas: Kansas, State Geol. Survey, Bull. 127, pt. 4.

MEASURED SECTIONS

Upper part of the Flowerpot shale and lower part of the Blaine formation in the SE¼ sec. 24, T. 27 N., R 20 W.

	Feet
Blaine formation	
6. Gypsum (Nescatunga), massive, white	10.0+
5. Dolomite, dense, gray	0.8
4. Shale, red	20.0
3. Gypsum (Medicine Lodge), massive, white	27.0
2. Dolomite, shaly, black	1.0
Flowerpot shale	
1. Shale, gypsiferous, reddish brown	85.0
	143.8

Lower part of the Blaine formation in the NE¼ sec. 29, T. 27 N. R. 20 W.

Blaine formation	
6. Dolomite, dense, gray, pitted and clinker-like as a result of weathering, overlying gypsum removed by solution	1.0
5. Shale, red	9.5
4. Gypsum (Nescatunga), massive, white	11.0
3. Dolomite, dense, gray	0.8
2. Shale, red	11.0
1. Gypsum (Medicine Lodge), massive, white	15.0+
	48.3

Upper part of the Blaine formation in the NW¼ sec. 15 , T. 25 N., R. 20 W.

Blaine formation	
7. Gypsum (Haskew), massive, pink	3.8
6. Shale, red	4.0
5. Gypsum (Shimer), massive, white	13.0
4. Dolomite, dense, gray	1.5
3. Shale, red	7.0
2. Gypsum (Nescatunga), massive, white	13.0
1. Dolomite, dense, gray	0.7
	43.0

Dog Creek shale in the SE¼ sec. 10, T. 25 N., R. 20 W.

Dog Creek shale	
6. Sandstone, fine-grained, a ¼-inch gray dolomite bed at top	15.2
5. Clay shale, silty, red	6.6
4. Siltstone, light red	4.5
3. Clay shale, reddish-brown	13.0
2. Siltstone, light reddish-brown	2.5
1. Clay shale. brownish-red	9.0
Blaine formation	
	50.8

Whitehorse group in the NW¼ sec. 17, T. 25 N., R. 20 W.

Cloud Chief formation		
17.	Dolomite (Day Creek member, siliceous, white	1.8
Rush Springs sandstone		
16.	Sandstone and shales, thin-bedded, red	50.0
15.	Sandstone, resistant, red	7.0
14.	Shale, red	6.2
13.	Sandstone, resistant, red	5.0
12.	Shale, red	10.0
11.	Sandstone, fine-grained, red	2.5
10.	Shale, red	13.8
9.	Sandstone, resistant, red	5.0
8.	Shale, red	15.0
7.	Sandstone, resistant, red	6.3
6.	Shale, gray	0.5
5.	Shale, red	14.5
Marlow formation		
4.	Sandstone, fine-grained, interbedded gypsum, orange-red	27.0
3.	Sandstone, medium-grained, red	4.0
2.	Sandstone, fine-grained, orange red	6.0
1.	Sandstone, cut by ¼-inch intersecting gypsum stringers, orange-red	22.0
Dog Creek shale		
		196.6

Whitehorse group in the NW¼ sec. 23, T. 25 N., R. 22 W.

Rush Springs sandstone		
15.	Shale, gypsiferous, red	8.0+
14.	Shale, thin beds of gypsum, gray	1.0
13.	Shale, red	8.0
12.	Sandstone, coarse-grained, red	1.0
11.	Shale, red	3.0
10.	Sandstone, resistant, tan-gray	0.5
9.	Shale, gray	2.0
8.	Shale, red	4.6
7.	Sandstone, resistant, red	3.0
6.	Shale, red	5.5
5.	Shale, gray	2.0
4.	Shale, red	8.5
3.	Dolomite, gray	0.2
2.	Shale, red	1.0
1.	Dolomite, gray	0.3
		48.6

Upper part of the Whitehorse group and the lower part of the Ogallala in the SE¼ sec. 1, T. 28 N., R. 26 W.

Ogallala formation		
19.	Sandstone, red sandstone pebbles, tan	6-10.0
Whitehorse group, undifferentiated		
18.	Sandstone, shaly, gypsiferous, red	17.0
17.	Sandstone, red	1.0
16.	Shale, sandy, slightly gypsiferous, red	25.0
15.	Sandstone, red	1.7
14.	Shale, gray	0.7
13.	Shale, red	16.0
12.	Sandstone, thin-bedded near top, red	6.2
11.	Shale, sandy, red	16.4
10.	Sandstone, red	2.0
9.	Shale, red	5.0
8.	Sandstone, massive, red	5.6
7.	Shale, red	6.0
6.	Sandstone, red	8.5
5.	Shale, gray	5.0
4.	Gypsum, white	0.1
3.	Shale, red	5.2
2.	Shale, gray	0.3
1.	Sandstone, red	14.0
		145.7

Lower part of the Cloud Chief formation and part of the Crooked Creek formation in the SE¼ sec. 18, T. 26 N., R. 23 W.

Crooked Creek formation		
5.	Sand and gravel, unconsolidated	7.0+
4.	Conglomerate, cross-bedded	1.0
Cloud Chief formation		
3.	Gypsum, white	0.8
2.	Shale, maroon	15.0
1.	Dolomite, siliceous, bluish-white	1.2
		25.0

Lower part of the Cloud Chief formation and part of the Crooked Creek formation in the NW¼ sec. 25, T. 28 N., R. 24 W.

Crooked Creek formation		
4.	Sand and gravel, unconsolidated, caliche nodules	10.0+
3.	Conglomerate, black iron-stained pebbles up to 12″ x 4″, abundant oyster shells	1-3.0
Cloud Chief formation		
2.	Shale, maroon	14.0
1.	Dolomite, siliceous, bluish-purple	1-2.0
		29.0

Kiowa shale in the SE¼ sec. 14, T. 25 N., R. 22 W.

Kiowa shale		
10.	Shale, shell horizon at top, gray to yellow	8.5
9.	Shale, sandy, yellow	0.6
8.	Shale, bluish-black grading to yellow	22.0
7.	Shale, sandy, yellow	4.8
6.	Sandstone, breaks into large blocks, yellow	1.8
5.	Sandstone, erodes readily, yellow	1.5
4.	Shale, grades from yellow to black	6.0
3.	Sand, pebbly, yellow	5.6
2.	Shale, sandy, gray grading to black	10.0
1.	Shale, sandy, gray-green	0.8
Permian		
		61.6

Laverne formation in SW¼ sec. 23, T. 26 N., R. 26 W.

Laverne formation	
8. Sandstone, gray	0.8
7. Shale, gray	0.2
6. Sandstone, gray	0.3
5. Shale, snail horizon, gray	1.0
4. Sandstone, gray	0.5
3. Shale, gray	1.1
2. Shale, thin-bedded, gray	1.3
1. Shale, sandy, snail horizon, gray	2.1
	7.3

Crooked Creek formation in the NE¼ of the NW¼ sec. 10, T. 28 N., R. 26 W.

Crooked Creek formation	
7. Clay, sandy, caliche pebbles, gray	18.0+
6. Sandstone, brown caliche pebbles at top, light gray	3.6
5. Sandstone, white	3.0
4. Sandstone, erodes unevenly, buff	23.0
3. Sandstone, resistant, erodes evenly buff	7.8
2. Sandstone, poorly consolidated, caliche at top, white	4.0
Ogallala formation	
1. Sandstone, pink sandstone pebbles, white	1.1
Whitehorse group	
	19.0

Crooked Creek formation in the SW¼ of the NW¼ sec. 10, T. 28 N., R. 26 W.

Crooked Creek formation	
7. Overburden	4-6.0
6. Volcanic ash, gray	13.0
5. Clay, caliche pebbles	23.0
4. Gravel, pink feldspar pebbles give it a pink cast	12.0
3. Conglomerate, cross-bedded, resistant	4.0
2. Gravel	15.0
Ogallala formation	
1. Sandstone, small pebbles of pink sandstone, buff	3.5
Whitehorse group	
	76.5

Crooked Creek formation in the SE¼ sec. 17, T. 28 N., R. 25 W.

Crooked Creek formation	
2. Gravel, pink feldspar pebbles, tan pebbles, bone fragments	14.0+
Ogallala formation	
1. Sandstone, buff	5.0
Whitehorse group	
	60.5

Meade group undifferentiated in the NW¼ sec. 29, T. 25 N., R 20 W.

Meade group, undifferentiated	
7. Shale, gray	8.0
6. Shale, tan	1.4
5. Shale, buff	13.0
4. Shale, banded gray and tan	14.0
3. Shale, buff	4.0
2. Shale, black grading into gray	5.0
1. Shale, buff	15.0
	70.4

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