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GEOLOGY AND MINERAL RESOURCES OF NOBLE COUNTY, OKLAHOMA

JOHN W. SHELTON

With a chapter on Petroleum by
JOHN W. SHELTON and WILLIAM A. JENKINS

and a chapter on Water Resources by
ROY H. BINGHAM

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Title Page Illustration

View of basal Garber Sandstone and claystone of the underlying Wellington Formation about 6 miles west-southwest of Perry, in the NE¼NE¼NE¼ sec. 4, T. 20 N., R. 2 W., southwestern Noble County. The sandstone, 6 feet thick, is a channel type, with clay pebbles in the lowermost part of the lenticular body. The cross-beds indicate a local southwest current direction. The grain size is fine to very fine. The sandstone is dominantly red, but the lowermost part is white to green. The underlying claystone is also red, except at or near the contact with the sandstone. Ink drawing by Roy D. Davis.

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GEOLOGY AND MINERAL RESOURCES OF NOBLE COUNTY, OKLAHOMA

JOHN W. SHELTON[1]

Abstract—Noble County encompasses an area of 747 square miles in north-central Oklahoma. Most of the County lies within the Central Redbed Plains geomorphic province, but some of the easternmost parts extend into the Northern Limestone Cuesta Plains province. The County has an average elevation of approximately 1,000 feet and a total topographic relief of some 400 feet. It is drained largely by eastward-flowing streams and contains low, discontinuous escarpments formed primarily by sandstone beds. Only in the northeastern part of the County are carbonate beds thick enough to be expressed prominently.

The surface rocks, of Late Pennsylvanian and Early Permian age, are characterized by red beds and cyclic or repetitious sequences. Because the regional dip is gently westward, successively younger beds crop out in that direction. Sedimentary rocks of the subsurface, approximately 6,500 feet thick, were deposited on the stable Central Oklahoma platform. The lower 300 feet of the surface section contains key limestone beds that pinch out in a southward direction. Included in the upper 1,000 feet are the Wellington Formation and the lower part of the Garber Sandstone, which are composed of mudrock and sandstone in the southern part of the County and mudrock, thin sandstone beds, and thin carbonate beds in the northern part. The Wellington Formation is particularly well known for uncommon fossil forms that include insects, conchostracans, horseshoe crabs, eurypterids, fish, amphibians, and reptiles.

The sandstones are fine- to very fine-grained quartz-rich subarkoses. They most commonly exhibit crossbedding and initial dip; these sedimentary structures indicate an average paleocurrent direction of N. 50° W. The carbonates include both limestones and dolomites, which texturally are boundstones, grainstones, packstones, and micrites. The mudrock most commonly shows lumpy or massive stratification. The fine size fraction is composed primarily of illite, kaolinite, and chlorite.

The dominant depositional environment is thought to have been that of an arid tidal flat, with its wide variety of local environments. Thus, at any given locality a range of conditions must have occurred repetitiously in response to transgressions and regressions owing to sea-level changes, desiccation, and sediment supply. Paleocurrent indicators suggest the Ouachita Mountain area as the prominent source of sediments. The dominant red pigmentation is thought to be primarily the result of early post-depositional alteration by weathering under arid conditions.

Although the Noble County area is characterized by a gentle westward dip, local dip reversals in surface beds reflect more prominent structures at depth. Surface joints, which are primarily extensional in nature, show northeast-northwest orthogonal sets. The most prominent subsurface structures are faulted anticlinal features in the western part of the County. The zone of faulting, which parallels the Nemaha ridge (to the west), resulted from recurring movement along upthrust (or strike-slip) faults.

Petroleum production in Noble County amounted to some 186 million barrels of oil and 75 billion cubic feet of gas through 1975, the major part of which has come from structural traps in the western part of the County. Trapping conditions for those structures are suggested in the surface beds by gentle folds, which were mapped by early workers. Oil reservoirs include approximately 25 different stratigraphic units ranging in age from Permian to Cambrian. The most important reservoirs are Ordovician and Pennsylvanian units. Presently, stratigraphic traps involving lenticular reservoirs offer the best opportunity for discovery of significant quantities of oil.

Possibilities are considered good for manufacture of brick, tile, and aggregate from various mudrock units.

Obtaining adequate supplies of ground water presents local problems throughout the County, especially in the northern part. Detailed studies of local sandstone trends should improve the situation. Solution of many existing and future problems relative to water supply for industrial and domestic purposes can probably be achieved by careful planning for both surface- and ground-water resources.

[1]Professor of Geology, Oklahoma State University, Stillwater, Oklahoma.

INTRODUCTION

Noble County lies in north-central Oklahoma and is approximately 747 square miles in area (fig. 1). The County's population in 1977 was estimated to be 11,200. Perry, in the southwestern part, is the County seat and has a population of approximately 5,400. Smaller towns or communities are Billings, Red Rock, Lucien, Marland, Ceres, Sumner, Morrison, and Lela. Several earlier settlements, such as Three Sands and Otoe Indian Agency, have been virtually abandoned. U.S. Highway 64 and State Highway 15 extend across the County in an east-west direction. Interstate Highway 35 and U.S. Highways 77 and 177 are north-south arteries. The Cimarron Turnpike extends from Interstate 35 north of Perry southeastward across Noble County and eastward toward Tulsa. The Atchison, Topeka & Santa Fe Railway operates north-south through Marland, Red Rock, and Perry. The St. Louis–San Francisco Railroad extends eastward through the County, connecting Lucien, Perry, Sumner, Morrison, and Lela. The Chicago, Rock Island & Pacific Railroad serves Billings, in the northwestern part of the County.

In the past, wheat, cattle, oil, and gas have been the mainstay of the County's economy. It is expected that the role of industry will continue to increase; the industrial potential is thought to be excellent.

Previous Investigations

Detailed geologic study of Noble County began soon after the turn of the century, when oil geologists conducted surface geologic mapping as part of an exploratory program for structural traps. This type of investigation, supplemented by core-hole drilling, emphasizing structural subtleties, was continued for a number of years after seismic methods were first used in the County. Most of the maps compiled from such studies are not readily available. However, the writer has had access to maps of eastern Noble County by Charles W. Ellison, through the courtesy of William A. Jenkins. Lon B. Turk kindly made available for compilation his maps of the western part of the County. Stratigraphic procedure and terminology utilized in much of Noble County were largely informal until 1946, when Raasch, who had had considerable mapping experience in north-central Oklahoma, made a careful study of the Wellington Formation. Billings (1956) mapped the eastern half of the County, Page (1955) made a subsurface study of the southern part, and Talley (1955) made a similar study of the northeastern part. Undoubtedly scores of geologists have made extensive studies of the subsurface geology for petroleum exploration. Although most of these reports are confidential, certain oil-field studies have been published. Clark and Cooper (1927) presented data on the early oil fields in a four-county area, along with a summary of the general geology. Other reports include Zavoico's study of Lucien field (1934), studies of Tonkawa field by Clark (1926) and Clark and Aurin (1924), and studies of Billings field by Hoffman (1940) and Klaus (1943). Hayes and others (1967) compiled a map of Noble County from available reports which shows the engineering significance of geologic units.

Objective and Methods

The geologic study of Noble County was undertaken for the purpose of compiling a geologic map and summarizing general geologic features including those with economic significance. The map, which presents a framework for stratigraphic studies, has permitted pursuit of a relevant objective, namely, to investigate the paleocurrents of several sandstones exposed at the surface.

The writer's approach in compiling the geologic map has been to utilize the following available data:

1. Local unpublished maps of petroleum geologists.
2. Map prepared by Billings (1956, pl. 1).
3. County soil map (Brensing and others, 1956, sheets 1–8).
4. Aerial photographs.
5. Electric logs of wells drilled for oil and gas.

Stratigraphic units were mapped by photogeologic methods. The selection of contacts on the aerial photographs was continually checked by using the available maps noted above, by field work, and by projecting

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

electric-log correlations to the surface.

Most beds at the surface in Noble County are either too thin to be exposed topographically or too limited in areal extent to be mappable units. However, thin, persistent units are commonly recognizable by their physical properties as recorded on electric logs. For example, the Herington Limestone and Fort Riley Limestone can be recognized on logs essentially throughout their subsurface extent, and key beds (or markers) are present in the Wellington Formation. The uniform thickness of sediments allows one to use the depth of the Herington Limestone as a reference in calculating the stratigraphic position of each well site in the western two-thirds of the County and thereby to trace more accurately the key beds in the Wellington. Similarly, the Fort Riley Limestone can be used as a subsurface datum to map more accurately the Herington Limestone, and the Cottonwood Limestone, to trace the Fort Riley and Wreford Limestones.

Use of the detailed unpublished maps and use of electric-log data for surface study represent two rather unconventional methods employed by the writer. A third is the emphasis of graphic description and presentation of measured sections, as illustrated in the Appendix.

Within the section entitled Economic Geology, water resources have been reported on by Roy H. Bingham of the U.S. Geological Survey. Oil and gas resources have been studied jointly by William A. Jenkins and the writer.

Acknowledgments

Charles J. Mankin, director of the Oklahoma Geological Survey, and the late Carl C. Branson, former director, provided the opportunity and made available needed resources for this compilation and study. The advice and aid of the late Alex. Nicholson and William D. Rose, as editors, and Roy D. Davis, as chief cartographer, are gratefully acknowledged. William H. Bellis, Oklahoma Geological Survey, analyzed the clay-mineral suites of the mudrock samples.

At Oklahoma State University, V. Brown Monnett and John E. Stone made facilities of the Department of Geology available for the study, and the Research Foundation served as administrator of salary funds designated for the study.

As noted heretofore, William A. Jenkins and Lon B. Turk made certain unpublished maps available to the writer.

Appreciation is expressed for the advice and aid of C. J. Hayes, Oklahoma Department of Highways. He visited the field with the writer and noted certain geologic data of interest to the Department of Highways. Everett Dunivan, also of that agency, supplied the data for thicknesses of alluvium in stream valleys.

John S. Cagle and Norman L. Ryker, Soil Conservation Service, U.S. Department of Agriculture, furnished information concerning engineering properties of various soil materials and aided in presentation of the data. Donald R. Vandersypen, also of the Soil Conservation Service, supplied data concerning the size and location of the various lakes.

Cooperation and assistance given by James H. Irwin, U.S. Geological Survey, in the study of the water resources of the County is greatly appreciated.

PHYSIOGRAPHY

Noble County lies mostly within the Central Redbed Plains geomorphic or physiographic province, but some of the easternmost parts extend into the Northern Limestone Cuesta Plains province (see Johnson and others, 1972, p. 3). Cuestas and buttes capped by limestone are present in the northeastern part of the County. Escarpments formed by sandstone beds are particularly common in the southern part. A sequence of sandstone overlying gray-green shale with thin dolomite beds forms prominent escarpments in the Perry-Billings area along or near Interstate 35. Scarplets composed of unconsolidated material are well developed in T. 22 N., Rs. 1 and 2 E. Although the scarplets were formed by water erosion, the basic cause for their formation is not known. Suggested as possible causes are overgrazing, greater dispersion of sodium-rich clay, and a thin cover of loess.

The elevation of the County varies from 850 feet along the Arkansas River to more than 1,200 feet in the southwestern part; it averages about 1,000 feet. The highest known elevation is 1,270 feet 3 miles southeast of Perry. Local topographic relief is generally less than 50 feet. The greatest local relief is 150 feet along the Arkansas River.

The average annual precipitation of Noble County is between 30 and 35 inches. The average temperature is 60° F, with a record high temperature of 113° F and a record low of −20° F. The frost-free growing season lasts 206 days. The prevailing winds are southerly. The average wind speed at 3 p.m. is 14 miles per hour.

Major streams are Red Rock Creek and Black Bear Creek, both tributaries of the Arkansas River. The Arkansas flows southeastward through Oklahoma, and one of its meanders is the county line along the northeasternmost part, known by residents as the "Big Bend." The County is drained in large part by eastward-flowing streams: the Salt Fork of the Arkansas River along the Kay-Noble County line, Red Rock Creek through the north-central part, and Black Bear Creek through the south-central part. That part of the County not in the Arkansas drainage basin is the southernmost part in T. 20 N., where southward-flowing streams are part of the Cimarron River drainage basin.

The drainage pattern is dendritic. Tertiary epeirogeny resulted in an eastward-sloping surface, which has exerted a stronger influence on drainage than the gentle westward dip of the generally nonpersistent and (or) nonresistant surface strata. Ancestral drainage toward the east is suggested by the composition of pebbles found in the upland Albion soil (fig. 2) (Brensing and others, 1956, p. 12), which is included within the terrace deposits mapped by some workers (Billings, 1956, pl. 1; Greig, 1959, pl. 1; Hayes and others, 1967). A terrace of the Arkansas River has been recognized and mapped in the northeastern part of the County. A remnant of an unmapped terrace of Black Bear Creek may be present north of Perry. On the flood plain of the Salt Fork River is a well-developed abandoned meander. Flood plains of both Black Bear and Red Rock Creeks contain scars of abandoned stream courses.

STRATIGRAPHY

The surface rocks of Noble County include approximately 1,300 feet of Upper Pennsylvanian and Lower Permian sedimentary rocks (fig. 3), overlain locally by thin Quaternary sediments. Because the dip of the surface rocks is gently westward, progressively younger beds are exposed in that direction. The sedimentary beds that occur exclusively in the subsurface range in age from Early Permian to Cambrian. Based on two wells in western Noble County that penetrated the entire sedimentary section, the total thickness of these units is approximately 6,500 feet (fig. 4).

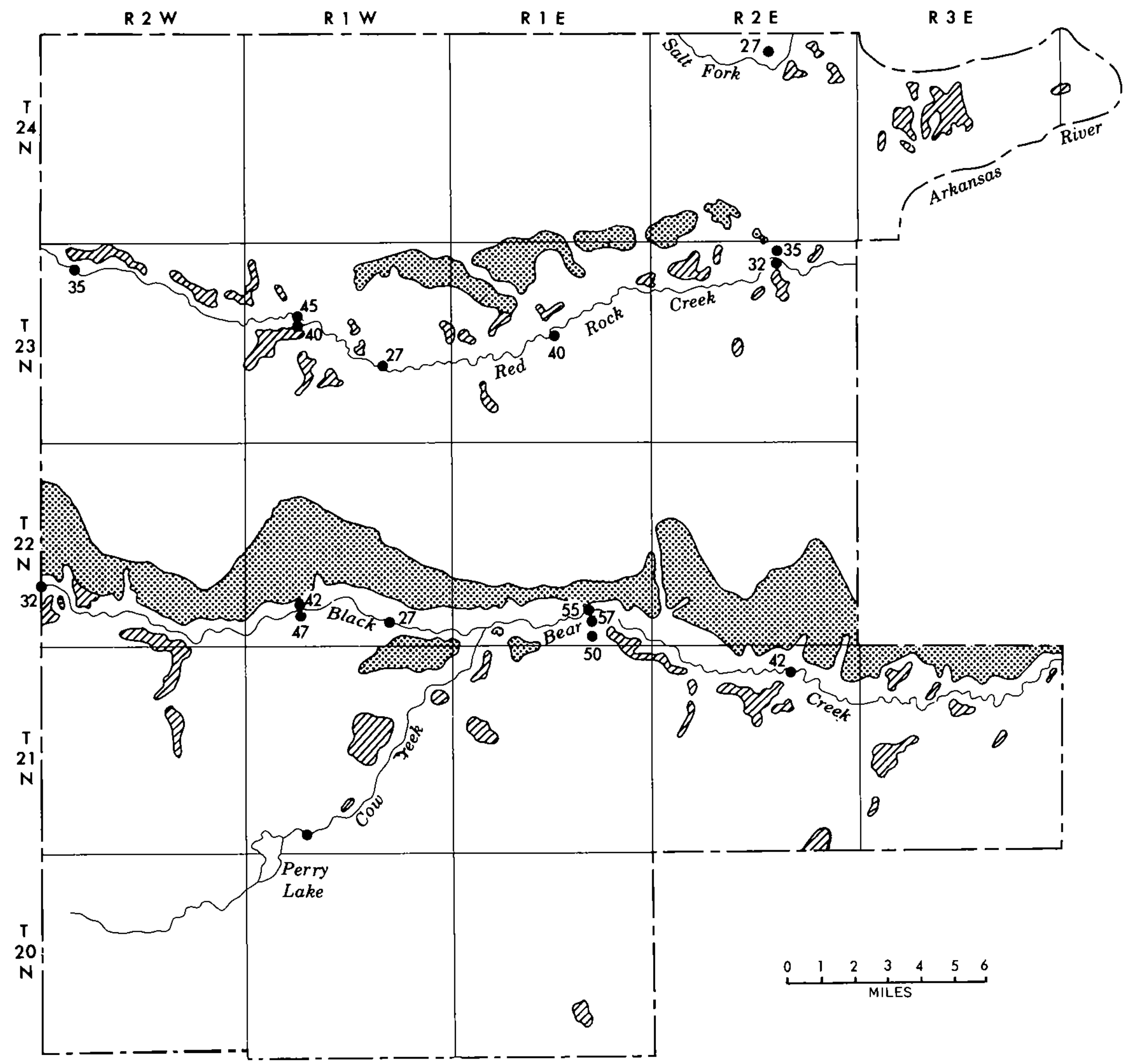


Figure 2. Map showing distribution of graveliferous deposits, exclusive of mapped alluvium and terrace deposits, and thickness of alluvium in stream valleys. Stippling represents upland prairie area with gravel deposits; possible remnant of upland terrace; Albion loam soil series. Diagonal lines represent area marginal to upland prairie with possible gravel deposits; possible redeposited terrace gravels; Norge soil series in association with Vanoss series. Thickness of alluvium shown in feet. Modified from Brensing and others (1956).

Deposition during the Paleozoic was on the stable Central Oklahoma platform, on which unconformities are common. The depositing currents ranged from shallow marine to alluvial, with conditions changing repetitiously or periodically.

For the history of stratigraphic usage and nomenclature involving surface rocks, readers are referred to Billings (1956), Raasch (1946), and Greig (1959).

Surface Stratigraphy

PENNSYLVANIAN SYSTEM

GEARYAN SERIES

Oscar Group

The Pennsylvanian rocks at the surface in Noble County belong to the Oscar Group and are assigned to the Gearyan Series. Although previous usage has generally

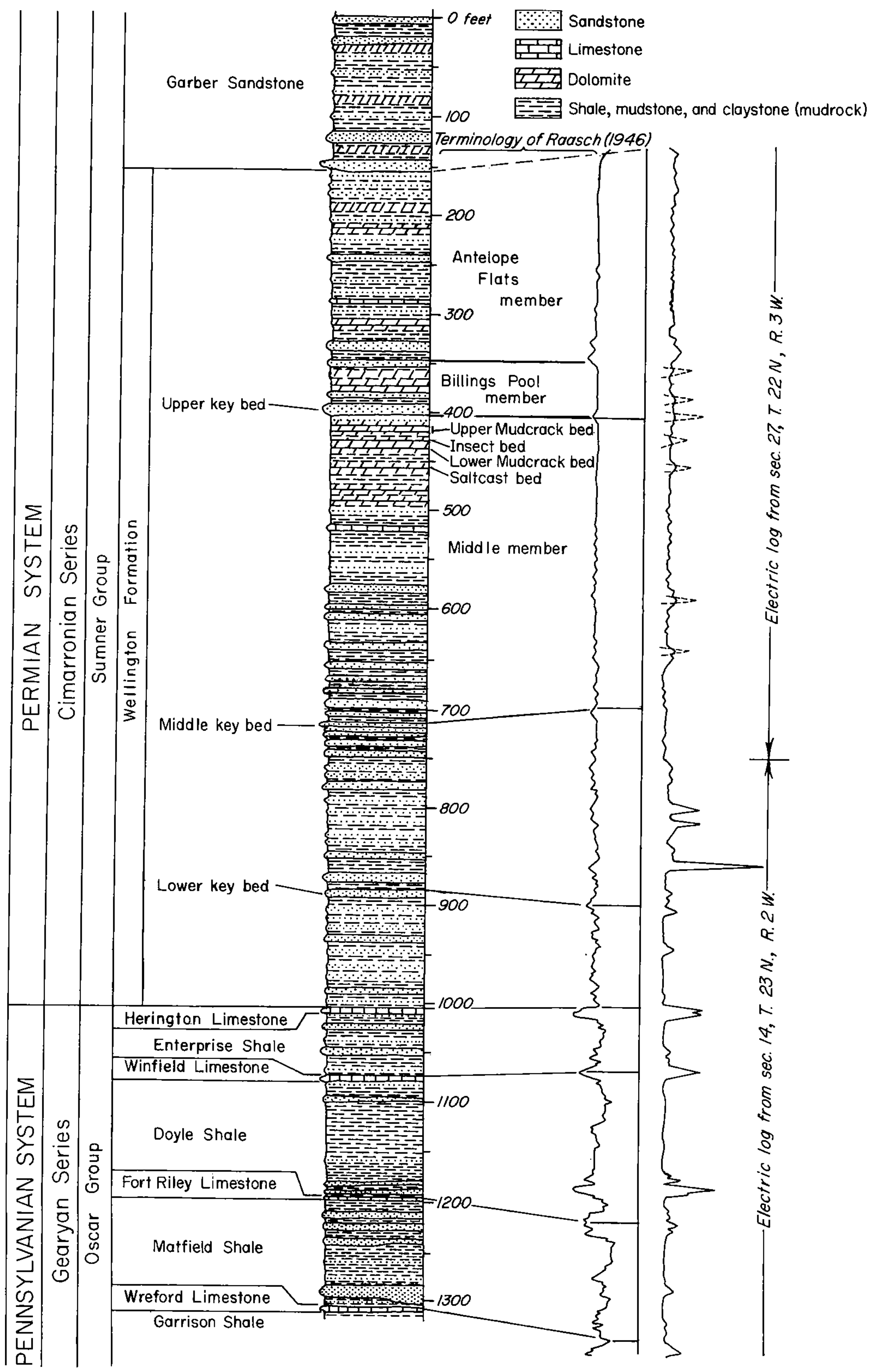


Figure 3. Composite columnar section and electric log of Paleozoic surface rocks of Noble County, showing gross lithologies, thicknesses, key units for mapping, and classification of certain Wellington units by Raasch (1946).

placed this rock sequence in the Wolfcampian Series, lowermost Permian System, the Oklahoma Geological Survey has recommended their reassignment to the Gearyan Series, uppermost Pennsylvanian System, on the basis of recent palynological determinations and physical characteristics (*see* Branson, 1962; Wilson and Rashid, 1971; Clendening, 1971). Also, the group name Oscar is now preferred by the Oklahoma Geological Survey to include these units rather than the Kansas names Council Grove and Chase.

The Oscar Group contains several thin limestone units separated by predominantly argillaceous units. Along the east margin of Noble County, the limestones characteristically exhibit a southward change in facies from carbonate to clastic. The total exposed thickness of the rocks of the Oscar Group in Noble County is about 300 feet. The top of the Oscar, and thus the top of the Pennsylvanian System, is placed at the top of the Herington Limestone.

Garrison Shale

The Garrison Shale is the oldest formation exposed in Noble County. Only the uppermost part is visible below the Wreford Limestone in inliers in the eastern part of T. 24 N., R. 3 E., and below the Wreford equivalent in T. 21 N., R. 3 E. Approximately 30 feet is present in the latter area; Billings (1956, p. 12), however, measured 60 feet of the Garrison in the southeastern part of the County. The formation is predominantly a red claystone.

Wreford Limestone

In the Big Bend part of Noble County (T. 24 N., R. 3 E.), the Wreford Limestone occurs as inliers in terrace deposits. It is composed of two thin gray limestones separated by a red shale. There, the total thickness of the Wreford is 6 feet (sec. 1, Appendix). The lower limestone contains clay pebbles and ellipsoidal algal bodies along with myalinid shells. In the adjoining part of Pawnee County, pectenoids and productids have been observed (Greig, 1959, p. 108). The upper limestone bed is a grain-supported packstone (*see* Dunham, 1962, p. 117–118) consisting of algal filaments and coarse fossil fragments with a micritic cement. It is overlain by a very fine-grained red sandstone at one locality in sec. 13, T. 24 N., R. 3 E.

A southward gradation from a gray to a red facies and a pinchout of limestone are exhibited east of Noble County along the south-trending outcrop in T. 22 N. (Greig, 1959, p. 109; pl. 1). The southernmost exposure of the Wreford Limestone is in sec. 18, T. 22 N., R. 4 E., where it is a nodular red limestone, only a few inches thick, with crinoid fragments (Greig, 1959, p. 109).

South of good limestone development in the southeastern part of Noble County (T. 21 N., R. 3 E.), the base of an overlying sandstone was mapped as the Wreford. The sandstone is a red fine-grained, crossbedded unit up to 16 feet thick (sec. 2, Appendix). A sequence of two thin dolomitic limestones with an intervening shale exposed below the sandstone in a small outlier in sec. 12, T. 21 N., R. 3 E., is thought to be Wreford (Billings, 1956, p. 15).

Matfield Shale

The Matfield Shale is a sequence of red shale or claystone and sandstone approximately 100 feet thick, which lies between the Wreford and the Fort Riley Limestone. Because of the configuration of Noble County, the Matfield is present only in the northeastern and southeastern parts (R. 3 E). Both limestones are well developed in the former area, and contacts of the Matfield are well known. However, the two limestones, for practical purposes, pinch out north of the southeastern part. Consequently, in T. 21 N., R. 3 E., the Matfield is regarded as the sequence between the base of the sandstone utilized in mapping the Wreford and the base of a persistent sandstone directly overlying the Fort Riley Limestone.

Sandstone apparently increases in total thickness southward at the expense of mudrock, which is poorly exposed (Billings, 1956, p. 16; Greig, 1959, p. 110). However, in T. 24 N., R. 3 E., sandstone is present at the top of the Wreford, and several sandstone units are present within the Matfield (sec. 3, Appendix). The sandstones in both areas of outcrop are fine grained or finer. Two sandstones in T. 21 N., R. 3 E., are each 16 feet thick. The thicker sandstones are characterized by crossbedding; the average paleocurrent direction for Matfield sand-

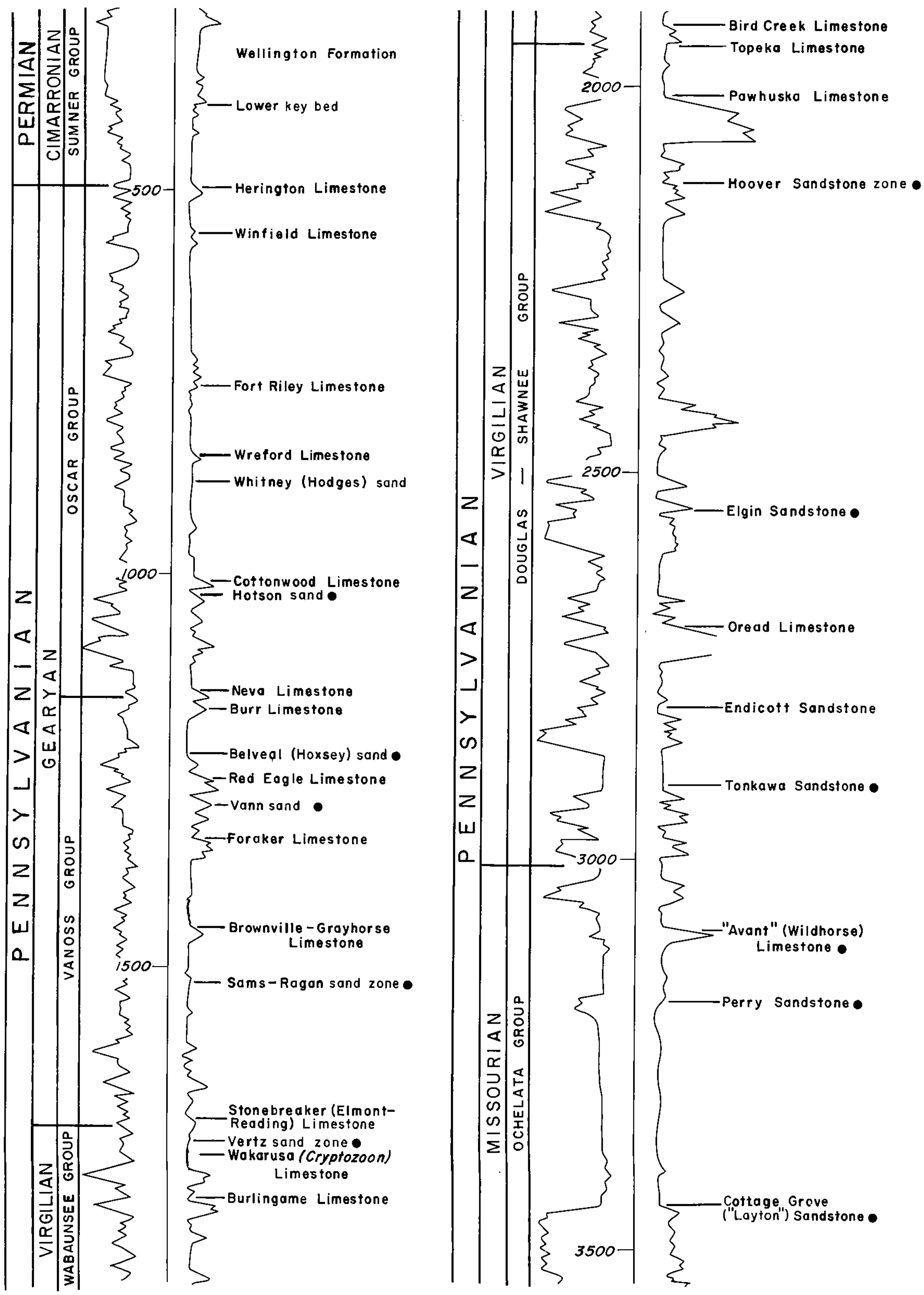
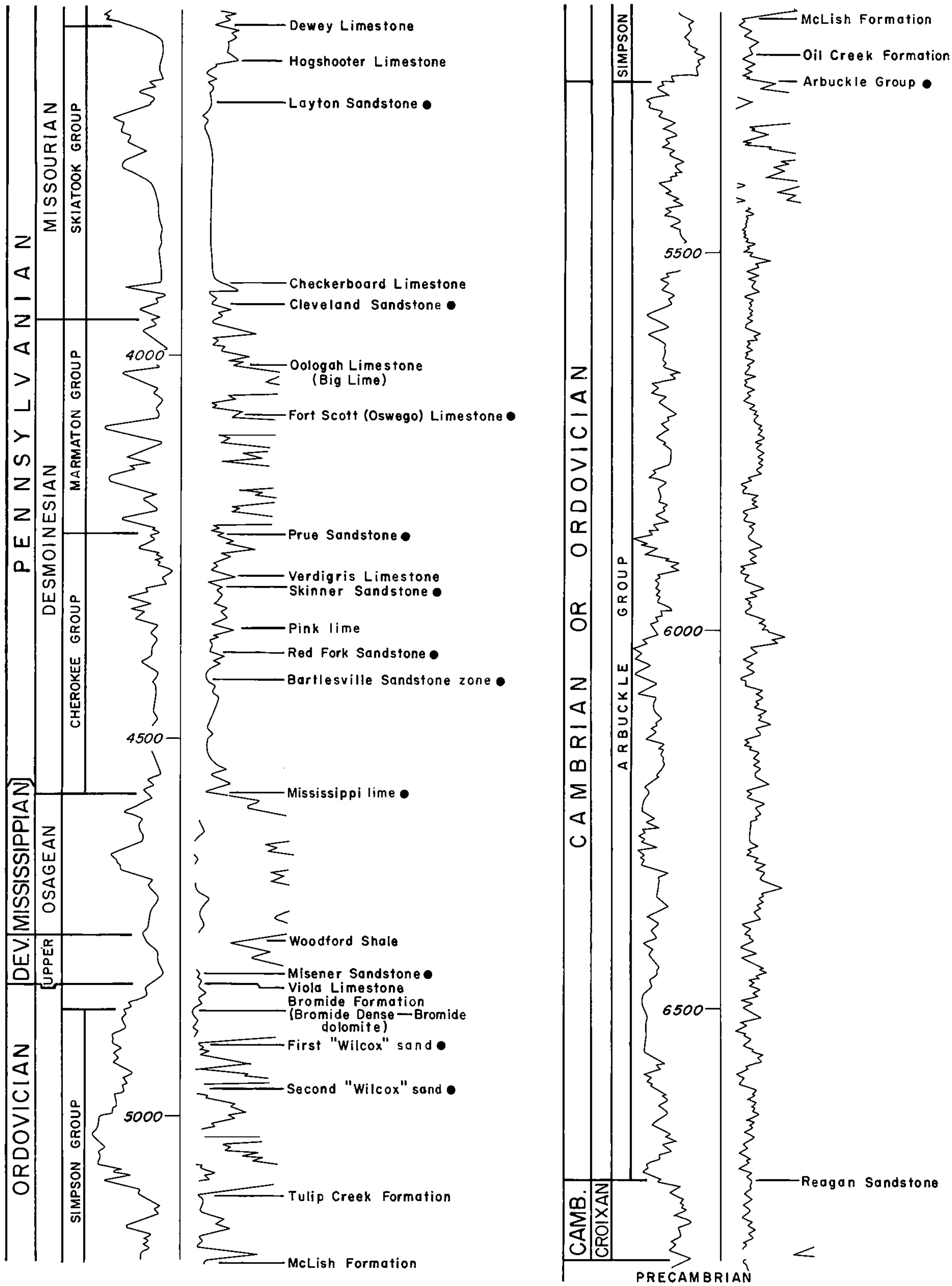


Figure 4. Composite electric-log section of subsurface rocks of Noble County. Section is shown in four segments, with top at upper left and bottom at lower right. Tops of stratigraphic units indicated by horizontal lines. Petroleum-producing reservoirs are indicated by solid circles. Correlations adapted from Lukert (1949), Page (1955), and Talley (1955).


PENNSYLVANIAN
MISSOURIAN
SKIATOOK GROUP
DESMOINESIAN
MARMATON GROUP
CHEROKEE GROUP
MISSISSIPPIAN
OSAGEAN
DEV.
UPPER
ORDOVICIAN
SIMPSON GROUP
4000
4500
5000
Dewey Limestone
Hogshooter Limestone
Layton Sandstone ●
Checkerboard Limestone
Cleveland Sandstone ●
Oologah Limestone (Big Lime)
Fort Scott (Oswego) Limestone ●
Prue Sandstone ●
Verdigris Limestone
Skinner Sandstone ●
Pink lime
Red Fork Sandstone ●
Bartlesville Sandstone zone ●
Mississippi lime ●
Woodford Shale
Misener Sandstone ●
Viola Limestone
Bromide Formation (Bromide Dense—Bromide dolomite)
First "Wilcox" sand ●
Second "Wilcox" sand ●
Tulip Creek Formation
McLish Formation
CAMBRIAN OR ORDOVICIAN
SIMPSON
ARBUCKLE GROUP
CAMB.
CROIXAN
5500
6000
6500
McLish Formation
Oil Creek Formation
Arbuckle Group ●
Reagan Sandstone
PRECAMBRIAN

stones is approximately northward (fig. 5). The sandstone examined for composition is a quartz-rich subarkose.

In T. 24 N., R. 3 E., the Matfield contains two thin limestone beds and a thin limestone conglomerate (sec. 3, Appendix). The lower limestone lies between two sandstone beds; the upper is nodular and red in color. Also at that locality, the uppermost 2 feet is gray shale. A red limestone conglomerate less than 1 foot thick is exposed in sec. 26, T. 21 N., R. 3 E. A number of beds of this rock type and thickness may be present in the Matfield.

Fort Riley Limestone

As a prominent Kansas unit, the Fort Riley Limestone is mappable into Oklahoma southward beyond the Big Bend part of Noble County but pinches out directly north of the southeastern part of the County (Greig, 1959, p. 111). In the northeasternmost part, the Fort Riley is a 30-foot section containing 5 limestone beds. All the beds are 6 feet or less in thickness (sec. 3, Appendix). Two of the beds are separated by a very thin siltstone. The limestones contain invertebrate fossil fragments and algal bodies, with the latter replaced in part by limonite. The limestone examined is a grainstone (calcarenite); the grains are of algal filaments and rods, fossil fragments, and fine-grained quartz particles.

Because of the change in facies across Pawnee County to the east (Greig, 1959, p. 112), the base of the resistant sandstone overlying the Fort Riley is mapped at the position of the limestone in the southeastern part of Noble County. The sandstone has been recognized by Greig (1959, p. 114) and Billings (1956, p. 24) and is present in the shallow subsurface. At one locality in T. 21 N., R. 3 E., a fossiliferous dolomite less than 1 foot thick is present in the middle of a 15-foot sandstone section (sec. 4, Appendix). The sandstone above the bed of dolomite is considered the resistant sandstone used in mapping, and the dolomite is regarded as the Fort Riley. The dolomite exhibits a crystalline texture, and fine-grained quartz sand constitutes 50 percent of the rock.

Doyle Shale

The Doyle Shale is distinguishable primarily by its stratigraphic position between the Fort Riley Limestone and the Winfield Limestone above. The Doyle, 120 to 170 feet thick, is composed predominantly of red claystone or shale and sandstone. Poorly exposed mudrock is generally seen on out-

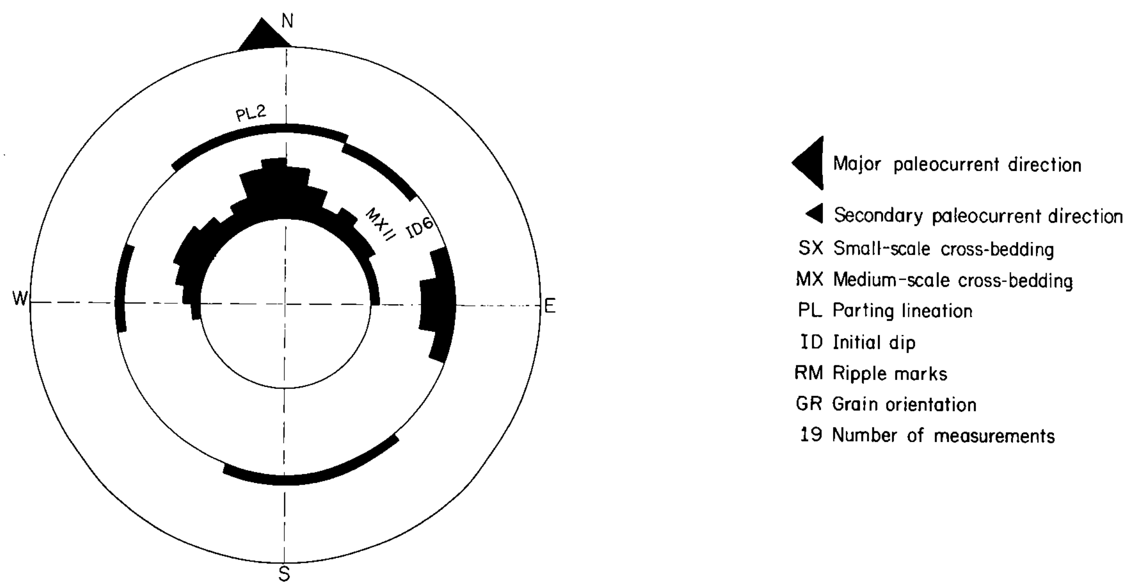


Figure 5. Paleocurrent diagram for sandstones in Matfield Shale, showing primary direction of N. 5° W. Diagrams are circular histograms (Potter and Pettijohn, 1963, p. 263). In obtaining a 30° sliding average, the value plotted for each 10° interval includes paleocurrent orientations of that class and the 2 adjoining 10° intervals.

crop as a thin unit directly below sandstone ledges; the uppermost few inches below the sandstones is commonly green.

At the Pawnee-Noble County line along State Highway 15, the uppermost part of the Doyle is a mottled green and red shale, with interlaminated color variation. A thin white claystone is present below the mottled layer (sec. 6, Appendix).

The lowermost Doyle sandstone, used in mapping the position of the Fort Riley Limestone in T. 21 N., R. 3 E., is persistent in spite of an undulatory base. The escarpment formed by the sandstone has been used by Greig (1959, p. 114) in mapping the Fort Riley in Pawnee County. From well control, the sandstone is developed consistently in R. 2 E. near the outcrop. The unit is characterized by initial dip and parting lineation and exhibits some crossbedding. In T. 21 N., R. 3 E., it is commonly buff and is very fine grained and well sorted. In the northeasternmost part of the County, the lowermost Doyle sandstone bed is finer grained and is characterized by small-scale crossbedding and red color (sec. 3, Appendix).

The percentage of sandstone increases southward; several prominent but lenticular sandstone units are present in T. 21 N., R. 3 E. The distribution of one unit, 100 feet above the base, is shown on the geologic map (pl. 1, in pocket). It is 10 feet thick, very fine grained and crossbedded, with calcitic claystone pebbles at the base. The average paleocurrent direction for Doyle sandstones in the County is approximately N. 15° W. (fig. 6).

Winfield Limestone

The Winfield Limestone is similar to the other limestones of the Oscar Group in exhibiting a facies change in the Noble County area. However, unlike the other units, the best development of limestone in the County is at the midpoint of its linear outcrop belt. In northern Noble County it is a thin-bedded, fossiliferous limestone 2 feet thick. It contains interbeds of horizontally bedded siltstone with abundant small burrows. The limestone is a grainstone, composed of algal filaments and rods, fossil fragments, and a very fine-grained quartz sand. Coarsely crystalline calcite occupies pore spaces. Productid brachiopods are the most common megafossils. The Winfield does not crop out in the southern part of Kay County, to the north, whereas it is 11 feet thick in the northern part of Kay County (Noll, 1955, p. 55).

In the northeastern part of T. 22 N., R. 2 E., the limestone is represented by a 6- to 8-foot section of sandy limestone and calcitic sandstone. The limestone varies from a gray crossbedded grainstone to a thin red boundstone interbed of algal mats (fig. 7) to blebs (or boudins) in a predominantly red sandstone body. The units are characterized by megafossil fragments, including those of pectenoids, crinoids and echinoids, and gastropods. The sandstone facies commonly contains horizontal interbeds, with mottled or burrowed structure and low-angle initial dip. It is a very fine-grained subarkose (fig. 8). Where calcite is not prominent, sericite is an interstitial constituent.

South of the middle of T. 22 N., R. 2 E., the Winfield is largely concealed and is thought to have thinned appreciably. Scattered exposures of red nodular limestone less than 1 foot thick are present in T. 21 N., R. 2 E., which have been identified as Winfield because of their stratigraphic position and because the Winfield is a shallow subsurface marker at that latitude (pl. 2, in pocket). The nodular limestone is a micrite or mudstone with some pellets and secondary crystals.

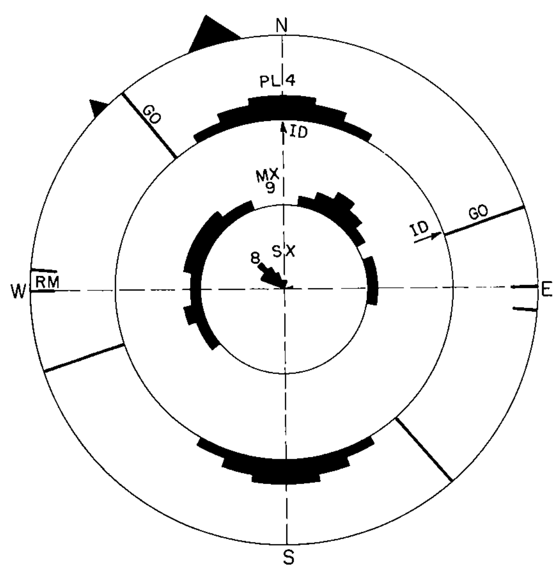


Figure 6. Paleocurrent diagram for sandstones in Doyle Shale; primary direction in N. 15° W.; secondary direction is N. 45° W. See figure 5 for explanation of diagrams.

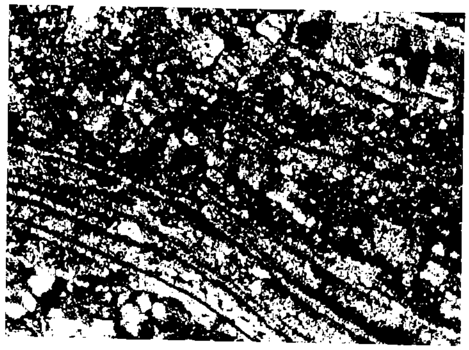


Figure 7. Photomicrograph of Winfield Limestone, SE¼ sec. 1, T. 22 N., R. 2 E. Calcitic boundstone of algal mats interstratified with grain-supported packstone of filaments and several quartz grains along with micrite paste. Crossed nicols, ×60.

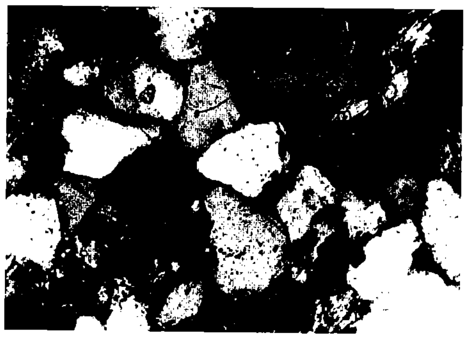


Figure 8. Photomicrograph of sandstone facies of Winfield Limestone, NW¼ sec. 7, T. 22 N., R. 3 E. Quartz-rich subarkose. Very fine quartz grains show close packing; *m*, distorted muscovite sheet. Crossed nicols, ×240.

Enterprise Shale

The Enterprise Shale crops out in the eastern part of the County (R. 2 E.); consequently, it is the oldest unit that extends continuously southward through Noble County, either at the surface or beneath thin alluvium. It is a red shale or claystone with red sandstone and is 70 feet thick. Thin beds of red limestone conglomerate are common in the lower part of the formation in the southern third of the outcrop belt. The red mudrock is largely covered at the surface. The percentage of sandstone increases in an apparent southerly direction. A sandstone body, commonly present in the lower 10 feet of the formation, may be a continuous unit. It is very fine grained with small-scale crossbedding. In some areas one or several thin limestone conglomerates are associated with it. In T. 24 N., R. 2 E., the sandstone is approximately 50 percent calcite, 47 percent quartz, and 3 percent feldspar. Scattered algal bodies are present as part of the calcite. In the southernmost part of the County, there are several lenticular sandstone units within the Enterprise. They are less than 5 feet thick, very fine to fine grained, and crossbedded. The average paleocurrent direction is approximately N. 50° W. for sandstones of the Enterprise Shale (fig. 9) and the sandstone in the Winfield section.

Herington Limestone

The Herington Limestone is the uppermost unit of the Oscar Group. In the northern area of outcrop, the Herington forms cuestas and buttes, although it is less than 8 feet thick. Like the Winfield, it is represented by several rock types and is closely associated with sandstone. Furthermore, it too exhibits a southward facies change. South of Black Bear Creek the Herington is so thin and irregularly developed that it is difficult to map. Nevertheless, its position is shown on the geologic map (pl. 1), because it is readily recognized in the shallow subsurface and the sequence has been identified in northernmost Payne County, to the south, by P. P. Chandler in preliminary mapping.

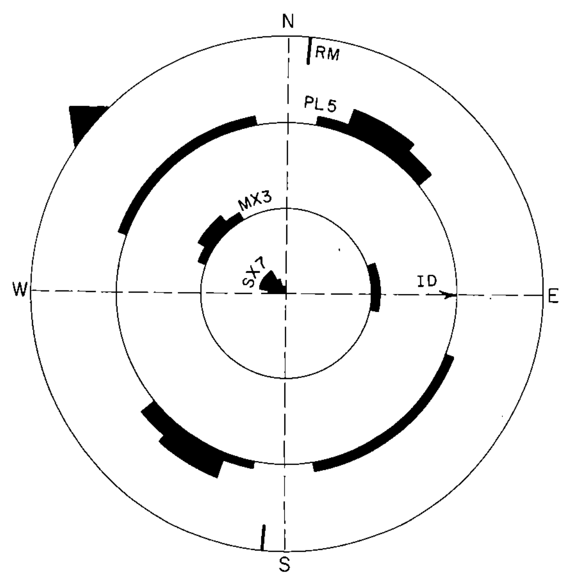


Figure 9. Paleocurrent diagram for sandstones in Enterprise Shale, which show direction of N. 50° W. See figure 5 for explanation of diagrams.

Fossils are abundant in the Herington along the northern half of outcrop belt in the County. Gastropods, cephalopods, pelecypods, brachiopods, bryozoans, ostracodes, and crinoid fragments have been recognized along with algal grains. Typical rock types of that area are packstones (fig. 10) and grainstones (fig. 11), both with variable quartz content. In the southern part of the County the Herington is a thin sequence of red dolomitic limestone with interbedded sandstone. The limestone is a nodular and brecciated micrite with very few sand-sized detritals (fig. 12).

Associated with well-developed limestone beds in Ts. 22 and 23 N. is a dolomitic sandstone that is mottled red brown and fine to very fine grained. The mottling is thought to reflect the weathering of disrupted algal mats. The red sandstone occurring with the nodular limestone in the southern part of the County is very fine grained and has small-scale crossbedding.

PERMIAN SYSTEM

CIMARRONIAN SERIES

Wellington Formation

The Wellington Formation, the lowermost unit of the Cimarronian Series and of the Permian System, as now recognized by the Oklahoma Geological Survey, is a sequence containing red claystone or shale, lenticular sandstones, gray-green shales, and thin dolomite beds. The belt of exposures for the Wellington includes most of the County. It lies between the line of outcrop for the Herington Limestone in eastern Noble County and that of the Garber Sandstone in the southwesternmost part. From a composite measured section, the Wellington is approximately 850 feet thick at the surface (fig. 3).

The most characteristic feature of the Wellington Formation in Noble County, aside from the dominant red color, is the facies change whereby lenticular sandstones are developed southward at the expense of red mudrock and thin dolomites. If traditional stratigraphic procedures were followed rigidly, the Wellington would be divided into an east-trending member of sandstone and mudrock south of a member composed of mudrock, thin sandstones, and very thin dolomite beds. In detail, the contact

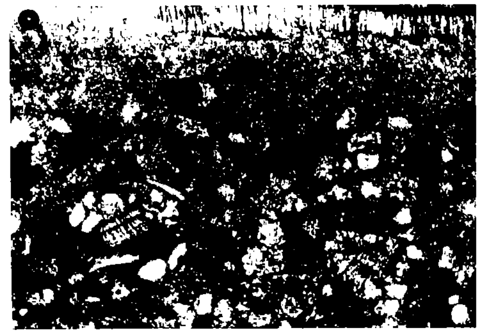


Figure 10. Photomicrograph of Herington Limestone, SW¼SW¼ sec. 19, T. 24 N., R. 3 W. Packstone with skeletal and quartz grains, fossil fragments, and micritic paste. Crossed nicols, ×60.

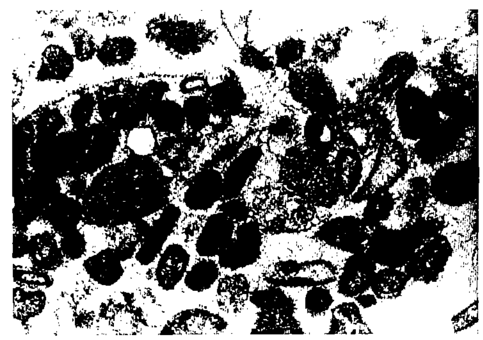


Figure 11. Photomicrograph of Herington Limestone, SE¼ sec. 11, T. 22 N., R. 2 E. Calcitic grainstone of coated and skeletal (algal) grains, with several quartz grains; crystalline calcite cement. Plane-polarized light, ×60.

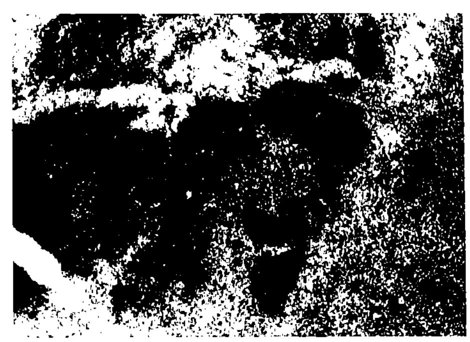


Figure 12. Photomicrograph of Herington Limestone, SW¼NW¼ sec. 35, T. 22 N., R. 2 E. Brecciated micrite of dolomitic limestone with sparry calcite cement in desiccation cracks; dark areas caused by hematite staining. Crossed nicols, ×60.

for such a subdivision would be nebulous. Yet such a procedure would be more representative of the areal distribution of gross lithologies than the practice with precedence in which beds of the Wellington have been grouped into a lower member (Fallis) dominated by sandstone, and an upper member (Iconium) dominated by shale (Patterson, 1933, p. 243).

Because of the difficulty in subdividing the formation traditionally into members, the Wellington is divided into 4 unnamed units by means of 3 key beds. The lower key bed, 120 feet above the underlying Herington Limestone, is a sandstone sequence, which in the southern part of the County is associated with a thin dolomite conglomerate and in the northern part with a dolomite. The middle key bed is also a sandstone that lies approximately 295 feet above the Herington; in the northern part of the County it is thin and overlies a section with one or more thin dolomite beds. The upper key bed is a sandstone sequence overlying a persistent interval of gray shales and thin dolomites; it is approximately 600 feet above the Herington Limestone and 250 feet below the overlying Garber Sandstone. The dolomite beds in the Wellington are generally so thin that exposure is poor, and so one must depend on the more resistant beds associated with them if any significant continuity in surface mapping is to be achieved. In his extensive study of the Wellington, Raasch (1946, p. 8) recognized 4 members and 2 sequences. He made an exhaustive study on outcrop of the upper 300 feet of the formation, which includes in its lowermost part the gray shale-dolomite sequence below the upper key bed. Workers interested in a detailed description of various units, including distribution and fossil content, are referred to Raasch's study.

Lower unit and lower key bed.—The only exposures of this unit are the key bed and an underlying 10 to 30 feet of predominantly red claystone. The bulk of the 120-foot interval at the surface, therefore, is thought to be mudrock. The key sandstone bed forms buttes and a prominent cuesta in the area between Black Bear and Red Rock Creeks (in T. 22 N., R. 2 E). To the north the key bed is rather poorly exposed, and exposures are especially poor in the southern part. The red claystone below the key bed contains thin layers that are white, gray, or green, along with the more diagnostic but very thin carbonates. Dolomite conglomerate is present directly below the cuesta-forming sandstone. The conglomerate is composed of clayey micritic dolomite and limestone pebbles and considerable quartz sand (fig. 13). It also contains secondary dolomite crystals and traces of malachite and secondary kaolinite. Thin dolomites are present below the key bed north of Red Rock Creek. They are concretionary, nodular, or septarian (fig. 14). In thin section the rock shows a disrupted micritic texture (fig. 15). Also exposed in the northern area are thin beds of very fine-grained sandstone, some of which is dolomitic (sec. 9, Appendix).

The key bed is very fine grained, well to very well sorted, and generally less than 6 feet thick. The sandstone interval at 1 northern locality is 11 feet thick (sec. 9, Appendix). The sandstone is a quartz-rich subarkose with sericitic and (or) hematitic

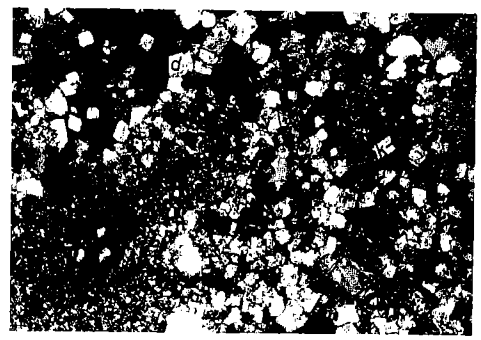


Figure 13. Photomicrograph of sandstone from lower key bed of Wellington Formation, NW¼ sec. 16, T. 22 N., R. 2 E. Dolomite rhombs (*d*) with dolomitic clay pebbles, scattered quartz grains, and patch of kaolinite (*k*) in basal conglomerate. Crossed nicols.

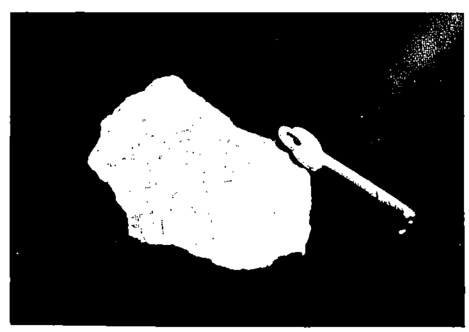


Figure 14. Dolomite in lower unit of Wellington Formation, SW¼SE¼ sec. 10, T. 24 N., R. 2 E., showing burrows and tubes. Specimen is 3.5 inches long.

pore filling. It is characterized by medium-scale crossbeds with diametrically opposed dips, small-scale crossbeds, and initial dip. In the cuesta-forming area of T. 22 N., R. 2 E., the base is irregular, with the dolomite conglomerate being absent by erosional cut-out where the sandstone is thickest. The average paleocurrent direction for the sandstone is S. 80° W. (fig. 16).

In the shallow subsurface the unit is characterized by increasing sandstone percentages in southward and eastward directions (pl. 2). It contains anhydrite and carbonate beds in the western part of the County (pl. 2). From study of subsurface samples, Raasch (1946, p. 9) characterized the lower part of the Wellington Formation as gray-green shale with some anhydrite and dolomite.

Lower middle unit and middle key bed.—This unit, approximately 175 feet thick, is red mudrock and sandstone in the southern part of Noble County and red mudrock, thin sandstone, and dolomite beds in the northern part. Plant remains have been recognized in the unit (Gould, 1925, p. 86; Raasch, 1946, p. 42), as well as a eurypterid (Decker, 1938). Areal distribution is shown on the geologic map (pl. 1) of the more prominent lenticular sandstone bodies in the unit.

The sandstones are very fine grained and well to very well sorted. They are quartz-rich subarkoses, containing approximately 90 percent quartz. Sericite is the most common pore filling; varying amounts of hematite are also present. The thicker sandstone bodies are characterized by medium-

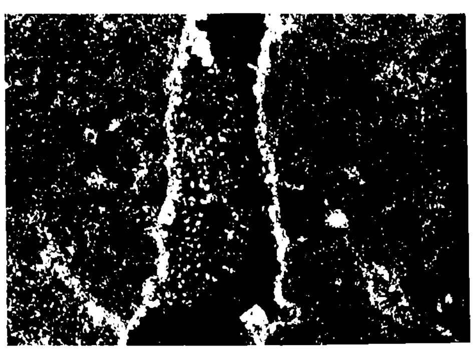


Figure 15. Photomicrograph of Wellington Formation, lower unit, SW¼SE¼ sec. 10, T. 24 N., R. 2 E. Disrupted dolomitic micrite with a large patch of kaolinite in and coarser dolomite crystals along prominent fracture. Crossed nicols, ×60.

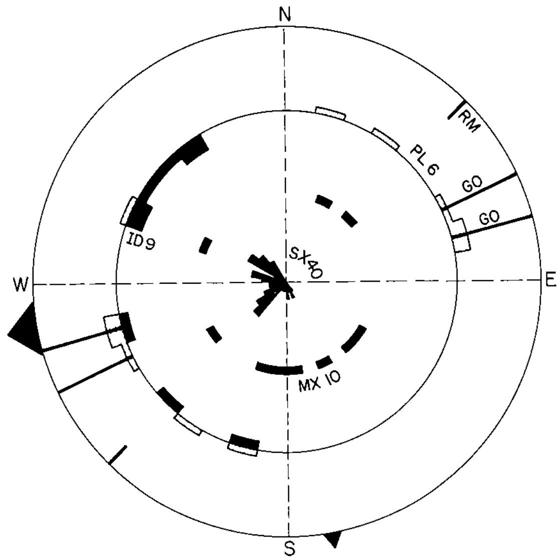


Figure 16. Paleocurrent diagram for sandstones in lowermost unit of Wellington Formation (top of Herington Limestone to top of lower key bed, Pwl). Major direction is S. 80° W.; S. 10° E. is secondary direction. See figure 5 for explanation of diagrams.

scale crossbedding and initial dip. The thinner units contain small-scale crossbeds, along with initial dip. The overall paleocurrent direction is approximately N. 50° W. (fig. 17). A secondary trend of N. 80° E–S. 80° W. also exists.

Sandstone bed Pw-160, 40 feet above the base of the unit and 160 feet above the base of the Wellington, is recognized in the northernmost township, where locally it is as thick as 28 feet. The sandstone, which contains several genetic units, is very fine grained to fine grained and well to very well sorted. Initial dip, medium-scale, and small-scale crossbedding are the most common sedimentary structures. The primary paleocurrent direction is approximately N. 55° W.; a secondary direction is N. 35° E.

Sandstone bed Pw-230 is present at the surface in the southernmost part of the County (in parts of Ts. 20 and 21 N., R. 2 E.). It includes several lenticular units at approximately the same stratigraphic position. The average sandstone body is less than ¼ mile wide. The sandstone sequence, which locally is as thick as 10 feet, is very fine grained and well sorted. It contains small- and medium-scale crossbedding, parting lineation, and initial dip. The directional features indicate paleocurrents toward both the northeast (N. 55° E.) and southwest. A subordinate direction is toward the northwest. At one locality (NE 1/4 sec. 35, T. 20 N., R. 2 E.) a 25-foot sequence of channel-type sandstone is present below Pw-230. The lower part of that sequence is characterized by a green color, dolomitic clay pebbles, initial dip, and medium-scale crossbedding. The green sandstone is a quartz-rich subarkose with abundant interstitial sericitic paste (fig. 18). The upper part is characterized locally by well-cemented beds or concretions of interstitial hematite.

Sandstone bed Pw-265 is in reality a series of highly lenticular genetic units at essentially the same stratigraphic position in the southern part of the County. Sandstone at this position is recognized as far north as Red Rock. The sandstone is very fine to fine grained and well to very well sorted. It is a quartz-rich subarkose with interstitial sericite (fig. 19) and some hematite and scattered plant material. At the southernmost exposures it is as thick as 25 feet. Medium-scale and small-scale crossbedding, parting lineation, and initial dip are the most common sedimentary structures in the sandstone. Near Red Rock it is 2 feet thick and is characterized by small-scale crossbedding. The average predominant paleocurrent is approximately N. 75° W.

In the southern part of the area the middle key bed, Pwm, is also a series of lenticular sandstone bodies at about the same stratigraphic position (295 feet above the Herington Limestone). In the Red Rock area and to the north the key bed overlies a mudrock sequence that contains one or more dolomites. The sandstone is very fine or fine grained and well or very well sorted. In T. 20 N., R. 1 E., it is up to 30 feet thick, and there it is characterized by medium-scale crossbedding and initial dip. Thin dolomites in the section below the sandstone extend as far south as the southern part of T. 22 N., R. 1 E. In the northernmost part of the County near Marland, beds of both sandstone and dolomite are less than 2 feet thick. The former is very fine-grained and has small-scale crossbeds (fig. 20). The average primary paleocurrent direction for the key bed in the entire County is approximately N. 25° W. Secondary directions are east-northeast and west-northwest. The sandstone is of the same composition as the other sandstones of the unit. It contains varying amounts of interstitial sericite; where it shows rather close packing it contains little sericite. Molds of carbonized wood are present in some of the sandstone bodies composing the key bed. The associated dolomites are desiccated micrites, with some pellets, or algal-mat boundstone. In the disrupted beds, kaolinite and calcite are present along the fractures.

The lower middle unit in the shallow subsurface contains anhydrite and (or) carbonate beds. The eastern edge of main development of those lithologies is oriented north-northeast, near the center of the County (pl. 2). From subsurface samples, Raasch (1946, p. 9–11) recognized the Otoe Member, 115 feet of sandstone and red lumpy shale between gray-green shales. The top of his Otoe Member is approximately the middle key bed.

Upper middle unit.—The upper middle unit of the Wellington Formation is, for the most part, a sequence of alternating claystones and fissile shales with thin beds of clayey dolomites or dolomitic limestones and

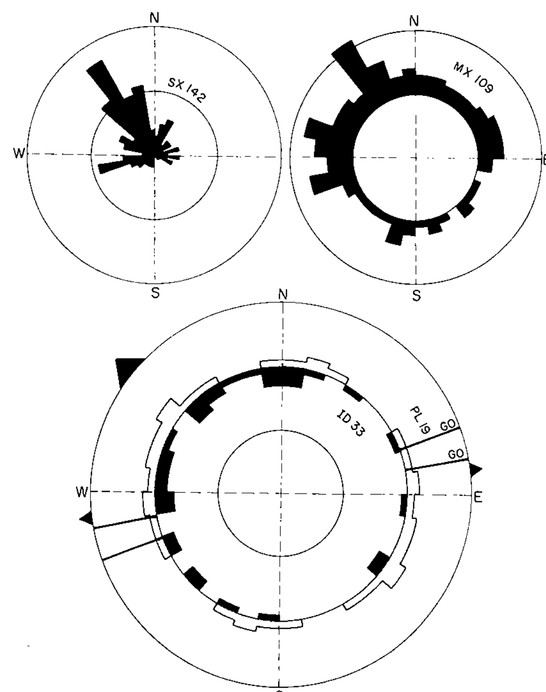


Figure 17. Paleocurrent diagram for sandstones in lower middle unit of Wellington Formation (top of lower key bed, Pwl, to top of middle key bed, Pwm), showing major direction of N. 50° W. and secondary directions of N. 80° E. and S. 80° W. See figure 5 for explanation of diagrams.

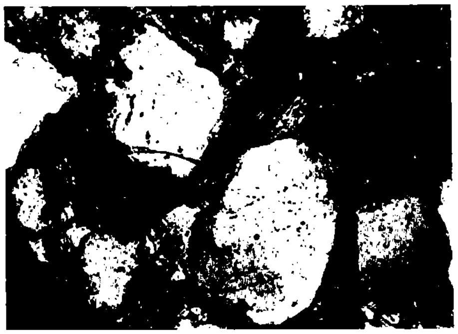


Figure 18. Photomicrograph of sandstone from Wellington Formation below bed Pw-230, SE¼NE¼ sec. 35, T. 20 N., R. 1 E. Interstitial paste of sericite in quartz-rich subarkose. Crossed nicols, ×240.

Figure 19. Photomicrograph of quartz-rich subarkose from Wellington Formation, bed Pw-265, SW¼ sec. 30, T. 21 N., R. 2 E. Some quartz grains show close packing; others with sericite rims. Crossed nicols, ×240.

Figure 20. Small-scale crossbedding in middle key bed of Wellington Formation, SW¼ sec. 23, T. 22 N., R. 1 E. Cross beds, as climbing ripples, dip to right, whereas surfaces on which they migrated dip to left.

sandstones. The best outcrop of the upper middle unit is south of Billings, where Raasch (1946) measured 130 feet of an interstratified section of gray-green and red beds below the upper key bed. Generally, however, the outcrop of the unit in the Billings-Perry area is represented by the upper 40 to 50 feet, exposed below the scarp-forming upper key bed. The lower 250 feet of the unit is largely covered, except in the southernmost part of the County. Present there are lenticular sandstones that are similar to those of the underlying unit. The more prominent bodies are shown on the geologic map (pl. 1).

Raasch (1946) studied in considerable detail the upper part of his Midco Member, which corresponds approximately to the upper middle unit. He traced a number of thin beds, each of which is less than 2 feet thick, over most of the outcrop area and gave to them descriptive names, such as Saltcast Bed, Mudcrack Bed (fig. 21), and Insect Bed. Distinctive fossil forms are the reason for his special attention to this part of the Wellington. Present especially in the upper 50 feet of the unit are insects, conchostracans, horseshoe crabs, lungfish, amphibians, fish and plant remains, ostracodes, and algae (Raasch, 1946; Olson, 1967).

The clayey carbonates are the most fossiliferous beds of the unit. Although most of them pinch out near Perry, the Insect Bed is identifiable as far south as sec. 7, T. 20 N., R. 1 E. (Raasch, 1946, p. 14). The carbonates are clayey micrites (fig. 22) and (or) algal-mat boundstones (fig. 23). The latter type has been studied in some detail by Tasch and others (1969, p. 17). Locally associated with halite impressions in the Insect Bed are chalcocite, malachite, and cuprite (Raasch, 1946, p. 53–54). For detailed descriptions of the thin fossil-bearing beds, workers are referred to the studies by Raasch (1946), Tasch (1964, p. 489), and Olson (1967).

Sandstones of the upper middle unit are very fine to fine grained and are well to very well sorted. Limestone or dolomite pebbles are common at the base of several sandstone bodies. Where they are thickest, generally 10 to 15 feet, the sandstones are fine grained and characteristically contain medium-scale crossbedding and initial dip. The width of thick development is generally

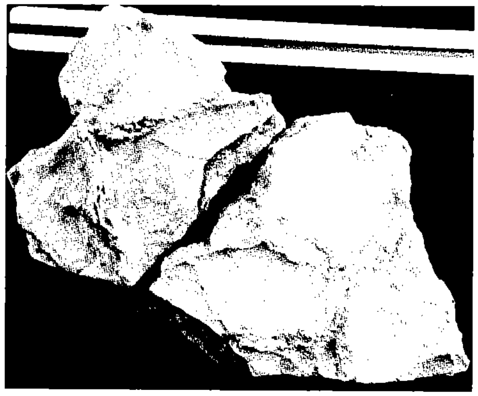


Figure 21. Mud cracks in Wellington Formation, upper part of upper middle unit, NE¼NE¼ sec. 33, T. 22 N., R. 1 W. Mudcrack Bed of Raasch (1946).

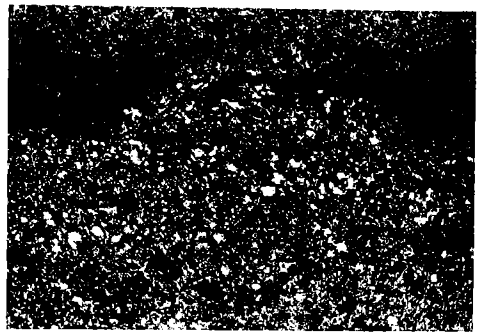


Figure 22. Photomicrograph of dolomite from Wellington Formation, upper middle unit, NE¼NE¼ sec. 33, T. 22 N., R. 1 W. Clayey dolomite micrite with silt grains of quartz and many small patches with hematite. Crossed nicols, ×60.

Figure 23. Algal-mat dolomite from Wellington Formation, upper middle unit, SW¼SW¼ sec. 23, T. 21 N., R. 1 W.

less than ¼ mile and in many cases is measured in terms of a few hundred feet. The thinner sandstone beds more commonly are very fine grained and contain small-scale crossbedding with initial dip. The average primary paleocurrent direction for sandstones of the upper middle unit is west (fig. 24). Apparently secondary directions existed toward the north and southwest.

Sandstone bed Pw-315 is exposed in the northern part of T. 20 N., R. 1 E.. Texturally it is similar to the other sandstones of the unit. It is characterized best by diametrically opposed medium-scale crossbeds that indicate northerly and southerly currrent directions.

Sandstone beds Pw-330, Pw-350, Pw-370, and Pw-400 are exposed in the area east of Perry and (or) south of Red Rock. Each is limited in distribution and is less than 5 feet thick. Internal features are essentially the same as those for the other sandstones of the unit.

Sandstone bed Pw-410 and Pw-430 are present at the surface in the western part of T. 20 N., R. 1 E. At one locality Pw-410 includes several genetic units that show channeling along with medium-scale crossbeds. Pw-410 is fine grained and contains several thin zones of limestone and dolomite pebbles. It apparently exhibits three paleocurrent directions—S. 65° E., N. 55° W., and N. 10° E. Bed Pw-430 also is fine grained and contains intraformational pebbles and molds of plant material. It is characterized by medium-scale and small-scale crossbedding, along with parting lineation, all of which indicate a paleocurrent direction of N. 25° E.

Upper key bed and upper unit.—The upper key bed, approximately 600 feet above the base of the Wellington Formation, is a series of thin sandstone bodies overlying the widespread sequence of shale and thin dolomites. The bed is selected not because it represents the most widespread synchronous depositional unit but because the sandstone is mappable and its stratigraphic position can be determined readily by reference to the dolomite beds, which are not mappable photogeologically.

Overlying the upper key bed is approximately 250 feet of section, the lower 50 to 75 feet of which contains more sandstone than the upper part. To the casual observer the unit appears as a red-bed sequence. However, Raasch (1946, p. 17) and Olson (1967, p. 36–45) indicated that in gross terms the section above the lower sandy interval is mottled, with purple, maroon, and gray green being the most common colors.

Raasch (1946, p. 19–23) recognized, described, and named a number of persistent thin beds of various colors in the upper unit. Almost all the units are less than 4 feet thick; most are carbonate, and the remaining ones are claystone or siltstone. The early petroleum geologists utilized some of these beds in mapping local structures expressed in surface beds. Vertebrate remains have been found in various beds of differing lithologies in the upper unit (Olson, 1967, p. 39). Conchostracans, pelecypods, and plant remains also are present in various beds. Vertebrate fossils at the richest locality in the Wellington are in a red dolomite (fig. 25) with lungfish burrows (fig. 26) and in the underlying and overlying claystone, varying in color from red to gray green.

Three of the more prominent sandstone beds are shown on the geologic map. Characteristics of sandstone in the upper unit are similar to those in the lower units of the Wellington. The percentage of sandstone increases southward on outcrop. The sandstones are fine to very fine grained and are well to very well sorted. Medium-scale crossbedding characterizes the thicker units, whereas small-scale crossbedding characterizes the thinner sandstones. The former are generally less than 10 feet thick. The average paleocurrent direction for sandstones of the upper unit, including the upper

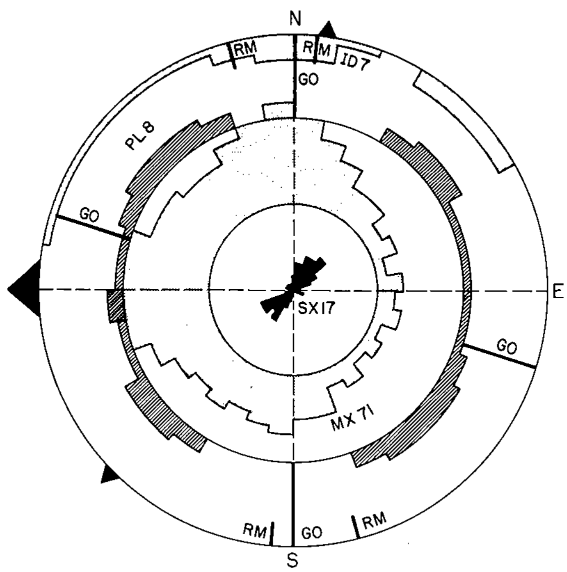


Figure 24. Paleocurrent diagram for sandstones in upper middle unit of Wellington Formation (top of middle key bed, Pwm, to base of upper key bed, Pwu). Primary direction is west; secondary directions are N. 5° E. and S. 45° W. See figure 5 for explanation of diagrams.

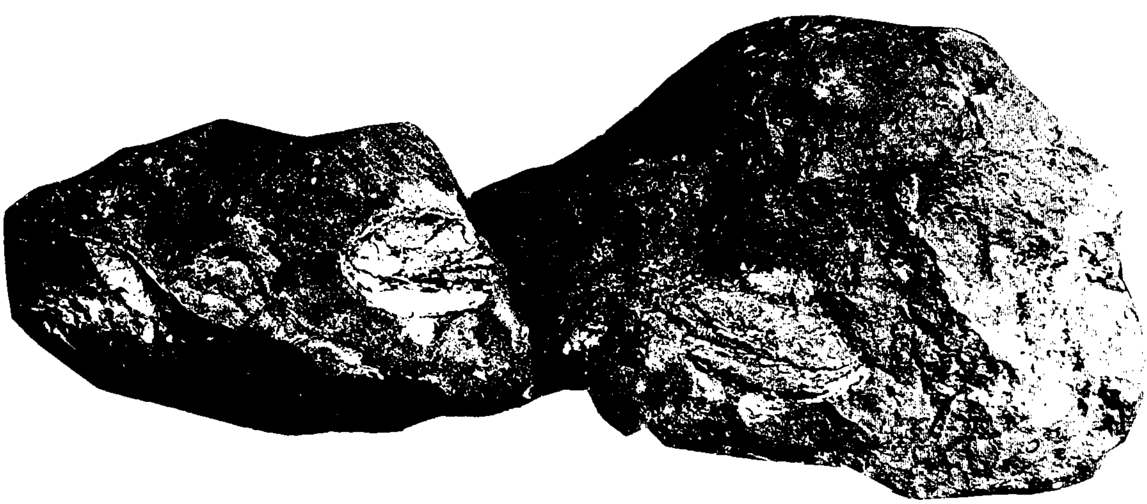


Figure 25. Skulls of *Trimerorhachis insignis* in clayey dolomite from Wellington Formation, upper unit, NE¼NE¼ sec. 10, T. 21 N., R. 2 W. Skulls are about 2 inches long.

Figure 26. Lungfish burrows in clayey dolomite and underlying shale in upper unit of Wellington Formation, NE¼NE¼ sec. 10, T. 21 N., R. 2 W.

key bed, is northerly (fig. 27). Secondary directions are toward the west and south.

The key bed is very fine grained and well to very well sorted. It is a subarkose, with 6 to 8 percent feldspar. Sericite is the most abundant interstitial material; hematite is also common. Where it is well developed, the sandstone is 5 to 10 feet thick and characteristically contains medium-scale crossbedding and initial dip; it also shows channeling. Where it is less than 5 feet thick, small-scale crossbedding predominates. The average paleocurrent direction for the key bed is N. 20° W.; a secondary direction is toward the south-southwest.

Sandstone bed Pw-620 is represented by a series of rather thin and lenticular sandstone bodies, but it is mapped through the southern three-fourths of the County. It is generally exposed at the same outcrop as the upper key bed and underlying section of gray shale and thin dolomites. Most commonly the sandstone is less than 5 feet thick. Just south of Black Bear Creek and directly south of Perry the sandstone is 8 to 10 feet thick. It is fine to very fine grained and well sorted. Small-scale crossbedding is the most common structure, although medium-scale crossbedding, initial dip, and parting lineation are also present. The average paleocurrent direction is N. 30° E. The sandstone is similar in composition to the upper key bed; it is a quartz-rich subarkose with interstitial sericite and hematite (fig. 28). Some 5 miles south of Perry a thin but prominent bone conglomerate is present in the interval between the key bed and Pw-620.

Sandstone beds Pw-650 and Pw-670 are developed in T. 20 N., R. 1 W., and both are similar lithologically. They are up to 8 feet thick. At localities of good development the sandstones are fine grained and well sorted and contain medium-scale crossbedding. The average paleocurrent direction for Pw-670 is S. 85° W.

Garber Sandstone

Only the lower part of the Garber Sandstone is exposed in Noble County, in the westernmost part of the southern three-fifths of the County. Approximately 150 feet of a total thickness of some 600 feet crops out in the area. It, like the Wellington Formation, is characterized by a southward increase in the percentage of sandstone. In Noble County two members have been defined by Aurin and others (1926, p. 794–795): the upper Hayward Member is dominantly sandstone, whereas the underlying Lucien Member contains a high percentage of red mudrock. Raasch (1946, p. 24–25) considered the Garber lithology to be quite distinct from the Wellington. He characterized the former as bands and lenses of red sandstone in a mass of bright-red lumpy clay shale. Even in southern Noble County, according to Raasch, the Wellington contains significant purple, maroon, and blue-gray shades.

The base of the Garber is represented in the area by a number of somewhat prominent sandstone bodies developed at approximately the same stratigraphic position. Those bodies are the only units of the Garber studied in any detail by the writer. Lithologically they are indistinct from Wellington sandstones. They are of comparable grain size (fine to very fine grained) and of similar composition (quartz-rich subarkose, with 6 to 10 percent feldspar) (fig. 29). The basal sandstone contains medium-scale and small-scale crossbedding and initial dip; it also shows channeling at several localities. The average paleocurrent direction for the basal sandstone is S. 65° W. (fig. 30).

The clay-rich part of the Garber contains a number of vertebrate-bearing beds (Olson, 1967, p. 57). In addition to lenticular sandstones, ledge-forming beds are dolomite and siltstone.

QUATERNARY SYSTEM

Terrace Deposits

The only terrace deposits mapped are those in northeastern Noble County formed by the Arkansas River. The material there is dominantly sand, but, as expected for alluvial deposits, materials such as gravel, silt, and clay are also present. Part of the silt is windblown loess, and some sand is wind-deposited material derived from earlier alluvial deposits of the Arkansas. Gravel, which is recognized along Black Bear and Red Rock Creeks (fig. 2), is thought to represent remnants of high terrace deposits. The gravels are granules to very small cobbles in size and consist of quartz, chert, and some feldspar.

Recent Alluvium

Recent alluvial deposits of sand, silt, and clay are present along the major streams of the County. Windblown material is present along the Arkansas River but is unimportant along the other streams. Overall, the grain size increases with depth; basal gravel is present in deposits of Black Bear and Red Rock Creeks and the Salt Fork and Arkansas Rivers. Where a meander loop or a stretch of a stream has been abandoned it has been filled with silt or clay, almost to the exclusion of sand. Alluvial deposits on the flood plain of Black Bear Creek are known to vary from 25 to 55 feet in thickness (fig. 2). Along its course in Noble County the creek bed is as little as 3 feet above the bedrock and as much as 38 feet. Red Rock Creek deposits range from 25 to 45 feet in thickness, and the creek bed is 2 to 22 feet above bedrock. The bed of the Salt Fork of the Arkansas River along U.S. Highway 177 is 10 feet above bedrock, and 25 to 30 feet of deposits is present on the flood plain. Along Interstate Highway 35, Cow Creek deposits are 25 to 30 feet thick. The creek bed is 8 feet above bedrock, and no gravel is present.

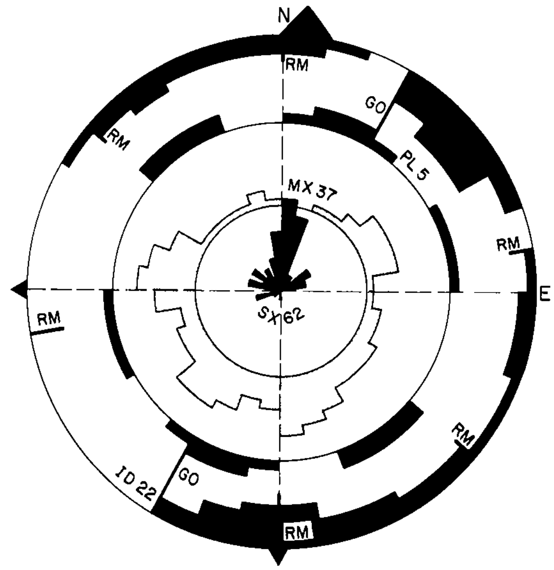


Figure 27. Paleocurrent diagram for sandstones in uppermost unit of Wellington Formation (base of upper unit, Pwl, to top of formation), showing major direction of N. 5° E.; secondary directions are west and south. See figure 5 for explanation of diagrams.

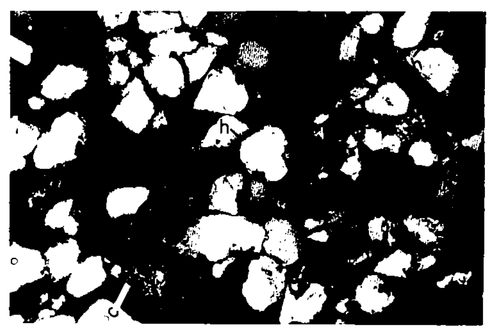


Figure 28. Photomicrograph of sandstone from Wellington Formation, bed Pw-620, SW¼ sec. 14, T. 20 N., R. 1 W. Very fine-grained subarkose; quartz grains with hematite and sericite cement. Crossed nicols, × 60.

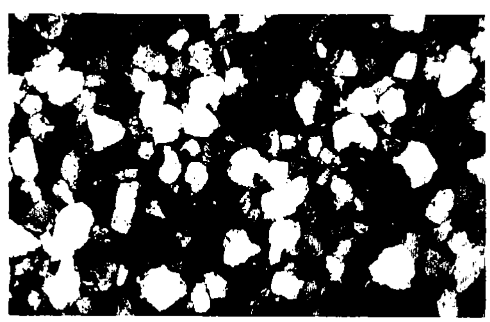


Figure 29. Photomicrograph of Garber Sandstone, SE¼SW¼ sec. 6, T. 22 N., R. 2 W. Predominantly very fine quartz grains in a quartz-rich subarkose; some grains with rims of sericitic cement. Crossed nicols, × 60.

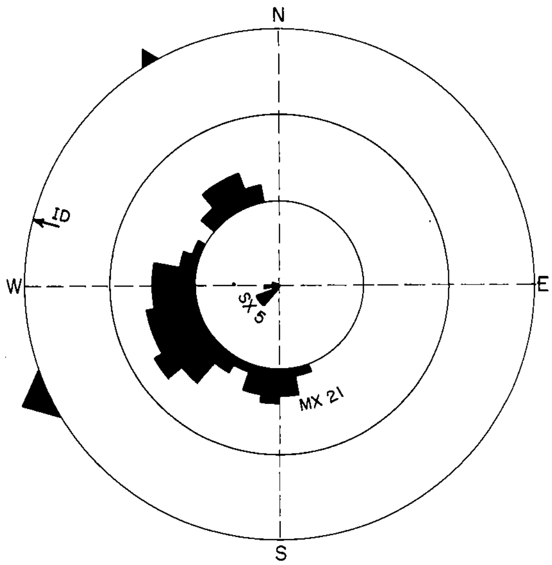


Figure 30. Paleocurrent diagram for sandstones in Garber Sandstone, illustrating average direction of S. 65° W. and secondary direction of N. 30° W. See figure 5 for explanation of diagrams.

Subsurface Stratigraphy

Many petroleum geologists, while investigating the potential oil-generating and oil-bearing rocks of the Central Oklahoma platform, have made extensive studies of the subsurface rocks in Noble County. However, most of this work was not available to the writer. For that reason, and also because the primary purpose of this study was to study surface rocks, the following summary represents in large part a compilation of the findings by Lukert (1949), Page (1955), and Talley (1955). A composite subsurface section, shown in figure 4, gives the stratigraphic positions, thicknesses, and electric-log features of the various stratigraphic units.

PRECAMBRIAN ROCKS

Precambrian rocks have been encountered in two wells in Noble County, one in the Lucien field area and the second in the Billings field area. Rocks from the latter have been described in the field as "pink granite." In the well from the former area, the granite contains white and pink feldspar, biotite, and muscovite. These basement rocks are part of the Central Oklahoma Granite Group, which is characterized by both microcline and oligoclase and is approximately 1,200 m.y. old (Muehlberger and others, 1967, p. 2364–2366).

CAMBRIAN SYSTEM

The Reagan Sandstone, Late Cambrian (Croixan) in age, is as thick as 100 feet in the area, but its distribution is irregular. Where present, it is dolomitic and glauconitic and of variable grain size. Present are interbeds of dolomite; the lower 20 feet commonly consists of a sandy dolomite with feldspar fragments.

CAMBRIAN-ORDOVICIAN ROCKS

In the Lucien area the Arbuckle Group is about 1,500 feet thick. For the most part it consists of cherty dolomite, which is dense to coarsely crystalline. The upper and lower 100 feet of Arbuckle contain less chert than the remaining part. Also present in the group are thin beds of dolomitic sandstone.

ORDOVICIAN SYSTEM

The post-Arbuckle Ordovician rocks are present below the Upper Devonian (pre-Woodford) unconformity, and none of the major units—the Simpson Group, Viola Limestone, and Sylvan Shale—are represented by a complete section throughout the County. The Simpson subcrops in the northeastern part of the County, and the Viola subcrop, lie between those of the Simpson and the Sylvan in the southwestern part of the County. In the southwestern part of the area, post-Arbuckle Ordovician rocks are 550 feet thick.

Simpson Group

The Simpson Group thins from some 450 feet gradually to the north and east. It is composed of the Oil Creek, McLish, Tulip Creek, and Bromide Formations, in ascending order. The lower three formations contain varying amounts of green shale and dolomitic sandstone. The Bromide is 250 to 300 feet thick and contains the famous "Wilcox" sandstones, the Bromide "dolomite," and the Bromide "Dense" limestone.

Viola Limestone

The Viola Limestone is one of the most widely used Lower Paleozoic subsurface markers in Oklahoma. It is chalky to coarsely crystalline and is up to 50 feet thick.

Sylvan Shale

The Sylvan Shale is a green-gray shale that is present only in the southwestern part of the County. Its thickness varies from 0 to 75 feet.

DEVONIAN SYSTEM

Middle and Upper Devonian rocks, composed of the Woodford Shale and the locally developed Misener Sandstone at the base, unconformably overlie Ordovician rocks and are overlain unconformably by post-Woodford Mississippian beds. The total thickness is approximately 60 feet.

Misener Sandstone

The irregularly developed Misener Sandstone occurs at the base of the Woodford Shale. It is typically a dolomitic, quartzose sandstone. It is thought to represent deposits in small channels developed on an erosional surface and preserved during the Woodford transgression.

Woodford Shale

The Woodford thins gradually toward the north and east. It is the well-known and readily recognizable hard, dark-brown to black shale typically containing *Tasmanites* spheres, which have been misidentified as spores. The uppermost part of the Woodford is considered to be Early Mississippian (Kinderhookian) in age.

MISSISSIPPIAN SYSTEM

Mississippian beds above the Woodford, like those of the Devonian, are sandwiched between unconformities. They vary in thickness from 0 to 350 feet and are absent over the most prominent structures. The "Mississippi lime" of Osagean age is dense to crystalline, dolomitic, and at some localities siliceous. A porous zone of weathered chert, known as the "Chat," is developed at the top of the limestone.

PENNSYLVANIAN SYSTEM

Pennsylvanian rocks lie unconformably on older beds, and the lowermost units in Noble County are assigned to the Middle Pennsylvanian Desmoinesian Series. Present also are rocks of the overlying Missourian, Virgilian, and Gearyan Series. The total thickness is 3,900 to 4,400 feet for the Pennsylvanian rocks, which display numerous cyclothemic patterns. In the sedimentologic framework for cyclothems, abundant local unconformities are developed. Some unconformities are of considerable lateral extent. They formed during abnormal sea-level changes on the featureless, stable Oklahoma platform. In gross lithologic terms, the rocks are interbedded shales, limestones, sandstones, and a few coal beds.

Desmoinesian Series

This series embraces the lower Cherokee Group and the overlying Marmaton Group. The former is composed of lenticular sandstones, dark shales, and several thin but persistent limestones. The thickness of the Cherokee varies from about 100 feet over prominent structures to 450 feet. Stratigraphic units of the group that have been widely recognized are, in ascending order, Bartlesville Sandstone, Inola Limestone, Red Fork Sandstone, Pink lime, Skinner Sandstone, Verdigris Limestone, and Prue Sandstone.

The Marmaton Group, approximately 250 feet thick, is composed of thick limestones and interbedded shales. Recognizable limestones are the Fort Scott or Oswego Limestone and the overlying "Big Lime" or Oologah Limestone.

Missourian Series

Rocks assigned to this series are approximately 900 feet thick. They include the Skiatook Group and the overlying Ochelata Group. The Skiatook, approximately 400 feet thick, is composed lithologically of three parts. The lower sequence, equivalent to the Seminole Formation, contains shales, thin coal beds, and sandstones, including the Cleveland Sandstone. The middle part is largely shale and at its base is the widespread Checkerboard Limestone, a good subsurface marker. The upper part contains the Layton Sandstone and the overlying Hogshooter Limestone and Dewey Limestone.

In the past, several units of the Ochelata Group on outcrop have been correlated incorrectly with subsurface counterparts. The result has been confusion in nomenclature, with at least two names of the series carrying dual stratigraphic connotations. The Ochelata Group includes the prominent Cottage Grove ("Layton") Sandstone at the base, overlain by the Perry Sandstone, and the irregularly developed "Avant" (Wildhorse) Limestone.

Virgilian Series

The Douglas, Shawnee, and Wabaunsee Groups compose the Virgilian Series. The total thickness of Virgil rocks is on the order of 1,300 feet, with a gradual thinning toward the northeast. In the area of Noble County the Douglas and Shawnee Groups are not readily distinguished individually because of poor development of the Toronto Limestone, the top of which is the boundary between them. In addition to varying shale intervals, the combined group contains prominent sandstone and limestone units the lowermost of which is the widespread but variable Tonkawa Sandstone. Also present are the overlying Endicott Sandstone, Oread Limestone, Elgin Sandstone, the thick Hoover sand zone, Pawhuska Limestone, and Topeka Limestone at the top.

The Wabaunsee Group, some 250 feet thick, is characterized by marine shales, thin limestones, and locally developed sandstones. Limestones of the group are the Bird Creek at the base, overlain by the Burlingame and the Wakarusa ("Cryptozoon"). The "Cryptozoon" Limestone is a good marker.

Gearyan Series

The Gearyan Series is now recognized by the Oklahoma Geological Survey as the topmost series of the Pennsylvanian System in Oklahoma. In the past, most of the rocks now assigned to the Gearyan were assigned to the Wolfcampian, traditionally considered the lowermost series of the Permian in the southern Midcontinent.

As presently defined in Noble County, the Gearyan Series comprises the Vanoss Group, about 550 feet thick, and the overlying Oscar Group, about 650 feet thick. The Vanoss and the lower part of the Oscar are known in the County only from subsurface data, whereas the interval in the upper Oscar containing the Wreford Limestone and the overlying Fort Riley, Winfield, and Herington Limestones is present at the surface. The top of the Herington is now considered the Pennsylvanian-Permian boundary in north-central Oklahoma.

As with the underlying Pennsylvanian rocks, cyclic deposition has characterized the Gearyan of the subsurface. Two changes in the Gearyan are noted, however. The limestones are thinner, more dolomitic, and more subject to facies change. Also, the shales contain a larger percentage of various shades of red.

The marker units of the Vanoss Group include, in ascending order, the Stonebreaker (Elmont-Reading), Brownville-Grayhorse, Foraker, and Red Eagle Limestones. The Red Eagle, which is composed of dolomitic limestone, is underlain and overlain by oil-productive lenticular sandstones. The Burr Limestone occurs near the top of the Vanoss.

That portion of the overlying Oscar Group present only in the subsurface includes the Neva Limestone, at the base, and the Cottonwood Limestone.

FOSSILS

Paleontological material is sparse in several depositional units of Noble County but abundant in others. Most of the red beds are barren; some red dolomites do contain algal mats, and vertebrate fossils are present in red beds. In spite of an overall low density of fossils, Noble County, and particularly the Wellington Formation, is known best for the occurrence of uncommon types. Present are insects, conchostracans, horseshoe crabs, and a eurypterid, as well as lungfish, amphibians, and reptiles. One of the richest Permian vertebrate sites in the United States is west-northwest of Perry (Olson, 1967, p. 39–40).

The more common upper Paleozoic invertebrate fossils are restricted almost entirely to units in the uppermost part of the Pennsylvanian Oscar Group (equivalent to the Chase Group of Kansas), especially the well-developed limestones. Fusulinids, brachiopods, pelecypods, gastropods, bryozoans, crinoids, cephalopods, and ostracodes have been noted. Algae are common constituents of these limestones.

Plant megafossils consist primarily of

unidentified, poorly preserved wood fragments in various sandstones or associated sandy shales. Nevertheless, workers have recognized remains of scouring rushes, lycopods, ferns, seed ferns, and conifers. Studies have been made of shale beds by L. R. Wilson and his co-workers at The University of Oklahoma.

Fossils identified by various workers are listed in table 1, with the arrangement there primarily for the nonpaleontologist. Readers interested in paleontological descriptions or location of fossil sites are referred to the work of Billings (1956), Carlson (1968), Carpenter (1947), Decker (1938), Gould (1925, p. 82–86), Greig (1959, p. 105–116), Hall (1966), Raasch (1946), Raymond (1944, 1946), Smith (1927, p. 37–41), Tasch (1961; 1962, p. 817, 820–821), Tasch and Zimmerman (1962), and Tasch and others (1969).

PETROGRAPHY

The three major rock types present at the surface in Noble County are mudrock, sandstone, and carbonate, in order of abundance. Some characteristic features of each type are noted, but by no means do the data and results represent an exhaustive petrographic study. Perhaps they may stimulate further study and serve as a partial basis for it.

Sandstones

The fundamental attributes of sandstone—structure, texture, and composition—were studied in varying detail. They are discussed in order of amount of study.

The most characteristic sedimentary structures of sandstone in Noble County are three types of cross stratification. They are initial dip (or accretionary crossbedding) and two scales of foreset beds formed by migratory ripples. The initial dip, or depositional slope, is variable in magnitude but generally is greater than 10°. This type characteristically overlies cutouts and channels. Internally the units are composed either of foreset beds or beds paralleling the initial-dip surfaces. The two types of crossbedding present are the medium and small scale (fig. 20); they are equally common. Small-scale crossbedding is present throughout some thin sandstone bodies. In good exposures it is accompanied by rib-and-furrow. Medium-scale crossbedding is more common where the average grain size is greater than 0.088 mm and where the sand body is thicker than 3 or 4 feet. Not uncommonly the direction of dip is the same for the foreset beds and the enclosing initial-dip surfaces. Another common feature of the medium-scale crossbedding is the diametrically opposed dip directions of successive sets of crossbeds.

Parting lineation is found commonly in horizontally bedded sands and on the surfaces of some medium-scale crossbeds. Less common are ripple marks, organic structures such as burrows and mottled structure, and deformed features. Features of disruption were not observed in sandstones, but most of the clay-carbonate pebbles in the sandstones probably are products of mud-crack formation.

Some 700 directional readings were made of paleocurrent indicators. These include the types of inclined stratification, parting lineation, ripple marks, and grain orientation that is discussed with textural features. The data were grouped according to major stratigraphic units and are plotted on paleocurrent diagrams (figs. 5, 6, 9, 16, 17, 24, 27, 30, 31). The average current direction for sandstones in the Matfield Shale is N. 5° W. (fig. 5). The map direction for sandstones in the Doyle Shale is N. 15° W.; a secondary direction is N. 45° W. (fig. 6). Enterprise sandstones have an average direction of N. 50° W. (fig. 9). Sandstones in the lowermost unit of the Wellington Formation are characterized by a major direction of S. 80° W. and a secondary direction of S. 10° E. (fig. 16). The major direction is approximately N. 50° W., and the secondary directions are N. 80° E. and S. 80° W. for sandstones in the lower middle unit of the Wellington (fig. 17). For the upper middle unit the major current direction is N. 90° W.; secondary directions are approximately N. 5° E. and S. 45° W. (fig. 24). The major direction for sandstone in the uppermost unit of the Wellington Formation is N. 5° E.; secondary directions are west and south (fig. 27). The Garber sandstone bodies are characterized by an average current direction of S. 65° W. and secondarily by a direction of N. 30° W. (fig. 30).

TABLE 1.—STRATIGRAPHIC OCCURRENCE OF FOSSILS IN NOBLE COUNTY

Fossils	Stratigraphic unit												
		Wellington											
	Garber	Upper unit	Upper middle unit	Lower middle unit	Lower unit	Herington	Enterprise	Winfield	Doyle	Fort Riley	Matfield	Wreford	Garrison
ALGAE		*13	12, 13	13	13	13		1					
Osagia?						1				1		1	
Ulva?			8										
FUSULINIDS						8							
BRYOZOANS												1	
Bascomella fusiformis										5			
Rhombopora sp.							8						
CRINOIDS													
Stems and fragments								13				1	
ECHINOIDS													
Fragments								13					
BRACHIOPODS													
Orbiculoidea missouriensis										5			
Lingula sp.			6			1	7			1			
Derbyia cymbula						1	8			1			
Composita sp.							8						
Linoproductus sp.								14				5	
GASTROPODS						1		1	5	1		1	
PELECYPODS						1			5				
Myalina copei										1		1	
Allodesma sp.		8											
Pleurophorus sp.		8											
Aviculopecten sp.										5			
Pectenoids							14					5	
CEPHALOPODS													
Pseudorthoceras knoxense						1				1			
Nautiloids												1	
BRANCHIOPODS													
Conchostracans (5 families)		8	3, 8, 9, 10										
Isauridae			3										
Asmussidae			3										
Limnadiidae			3										
Leaiadidae			3										
Vertexiidae			10										
OSTRACODES			12			8							
HORSESHOE CRABS													
Anacontium carpenteri			8, 9										
Anacontium breve			8, 9										
EURYPTERID													
Eurypterus oklahomaensis				4									

TABLE 1.—*Continued*

Fossils	Stratigraphic unit											
		Wellington										
	Garber	Upper unit	Upper middle unit	Lower middle unit	Lower unit	Herington	Enterprise	Winfield	Doyle	Fort Riley	Matfield	Wreford	Garrison
INSECTS													
(12 orders)			3, 8										
			11										
Megasecoptera			3, 11										
Protodonata			3										
Odonata			3, 11										
Protorthoptera			11										
Protoperlaria			11										
Caloneurodea			11										
Protelytroptera			11										
Ephemeroptera			11										
Blattaria			11										
Corrodentia			11										
Homoptera			11										
Neuroptera			11										
FISH													
Gnathorhiza sp.		7	7										
Sphaerolepsis arctata		7											
Xenacanthus sp.	7	7	7										
AMPHIBIANS													
Trimerorhachis insignis	7	7											
Eryops megacephalus	7	7											
Eryops sp.			7										
Diplocaulus magnicornis		7											
Diplocaulus sp.	7												
Archeria sp.		7							7				
Cricotillus brachydens		7											
Crossotelos annulatus		7											
Lysorophus tricarinatus		7											
Seymouria baylorensis		7											
Diadectes sp.	7												
REPTILES													
Labidosaurus oklahomaensis		7											
Dimetrodon, cf. *D. limbatus*		7											
Dimetrodon, cf. *D. giganhomogenes*	7												
Dimetrodon sp.	7												
Ophiacodon uniformis		7											
Edaphosaurus, cf. *E. boanerges*		7											
Pleuristion brachycoelus		7											
Captorhinus, cf. *C. aguti*		7											

TABLE 1.—*Continued*

	Stratigraphic unit												
		Wellington											
Fossils	Garber	Upper unit	Upper middle unit	Lower middle unit	Lower unit	Herington	Enterprise	Winfield	Doyle	Fort Riley	Matfield	Wreford	Garrison
SCOURING RUSHES													
Annularia stellata		8											
Sphenophyllum, cf. *S. latifolium*		8											
Sphenophyllum stoukenbergi?		8											
LYCOPODS													
Sigillaria sp.		8											
FERN-LIKE FOLIAGE (pteridophylls)	8												
Pecopteris cyathea		8											
Pecopteris geinitz		8											
Pecopteris sp.					1								
Neuropteris sp.		8											
Taeniopteris multinervis		8											
Taeniopteris abnormis		8											
SEED FERNS (pteridosperms)													
Gigantopteris americana		1		13									
Callipteris, cf. *C. whitei*			8										
Callipteris conferta			8										
CONIFERS													
Araucarites sp.		8											
Brachyphyllum terui			8										
Walchia imbricata?		8											

*Number refers to worker reporting occurrence, according to following key:

1, Billings (1956)
2, Carlson (1968)
3, Carpenter (1947)
4, Decker (1938)
5, Greig (1959)
6, Hall (1966)
7, Olson (1967)
8, Raasch (1946)
9, Raymond (1944, 1946)
10, Tasch (1956, 1961, 1962)
11, Tasch and Zimmerman (1962)
12, Tasch and others (1969)
13, Shelton (this report)

The overall average direction of sand-depositing currents for the eight units is approximately N. 50° W. (fig. 31). The wide range in orientation of directional features reflects not only the variation in orientation between individual sandstone bodies but also the variability of paleocurrents within a genetic sandstone body.

Grain-size analysis by sieving was made of 42 samples, representing various stratigraphic units from various localities in the County. Parameters for each sample, along with average values, are listed in table 2. Cumulative frequency curves for representative samples are shown in figure 32. The sandstones are generally very fine

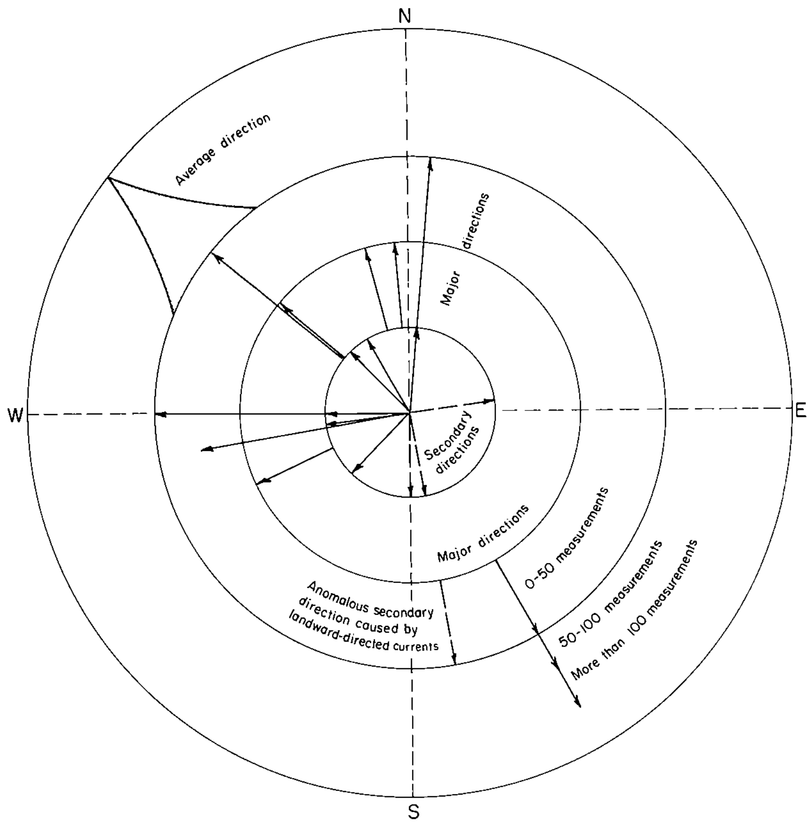


Figure 31. Paleocurrent diagram for sandstones of Noble County, showing major and secondary directions for separate stratigraphic units and overall average direction of approximately N. 50° W. See figure 5 for explanation of diagrams.

grained and well sorted. The average median diameter is 0.098 mm (or 3.38 ϕ units); average sorting coefficient is 1.22, and average standard deviation is .42 ϕ units. The coarsest median diameter is 0.140 mm (2.82 ϕ units). The best sorting coefficient is 1.14; the smallest standard deviation in ϕ units is 0.25. The data suggest that systematic variations do not exist stratigraphically or geographically. However, from qualitative field observations, the number of coarser units is thought to be greater in the southern part of the County.

Intraformational pebbles are not uncommon in basal beds of sandstone bodies and in several thin conglomeratic beds. The most common type of pebble is green or red clayey carbonate (fig. 13).

Significant compaction is indicated by close packing. The number of contacts between grains is relatively large, and some contacts are long or embayed (figs. 8, 19). Yet the sandstones unexplainably are quite friable on outcrop.

For those sandstones sufficiently coarse to allow calculation of the sorting coefficient, the silt and clay content averages 14 percent. Some of the clay is present as a thin film or rim around the sand grains (figs. 18, 19, 29) and as such is thought to be secondary, that is, to have formed subsequent to deposition.

No permeability tests were conducted, but an estimate of original permeability was calculated by use of the empirical equation formulated by Krumbein and Monk (1943). The calculated permeability varies from 2.87 darcys (27.6×10^{-4} cm/sec.) to 8.71 darcys (83.8×10^{-4} cm/sec.) and averages 4.81 darcys (46.6×10^{-4} cm/sec.) (table 2). It is speculated that present permeabilities at or near the surface do not approach the same

TABLE 2.—GRAIN-SIZE PARAMETERS FOR SANDSTONES OF NOBLE COUNTY

Formation Sandstone unit	Location	Median diameter mm	Median diameter φ	Sorting: Trask's coefficient	Sorting: Standard deviation (φ)	Calculated original permeability: Darcys	Calculated original permeability: 10^{-4}cm/sec
Garber	NW¼ 3-20N-2W	0.107	3.22	1.47	—		
	SW¼ 6-22N-2W	.104	3.26	1.14	0.29	5.33	51.2
Wellington							
Pwu (600 feet above base)	SW¼ 14-20N-1W	.072	3.80	1.30	—		
	NW¼ 23-23N-1W	.089	3.50	1.18	.36	3.74	35.9
(525 feet above base)	SW¼ 18-20N-1E	.136	2.88	1.24	.45	7.43	71.4
		.115	3.12	1.23	.43	5.71	54.9
		.140	2.82	1.20	.43	8.71	83.8
Pw-315	SW¼ 23-21N-1E	.091	3.46	1.27	.52	3.19	30.7
		.113	3.15	1.25	.45	5.40	51.9
Pwm (295 feet above base)	SE¼ 26-21N-1E	.079	3.66	1.27	—		
		.100	3.32	1.23	.45	4.21	40.5
		.102	3.29	1.18	.42	4.64	44.6
	SW¼ 23-22N-1E	.070	3.70	—	—		
	NW¼ 23-22N-1E	.077	3.70	1.33	—		
	NW¼ 27-23N-1E	.102	3.29	1.17	.36	4.93	47.4
		.073	3.78	1.34	—		
	NE¼ 28-23N-1E	.094	3.41	1.22	.41	3.93	37.8
(270 feet above base)	NE¼ 35-20N-1E	.096	3.38	1.34	.68	2.87	27.6
Pw-265	NW¼ 26-20N-1E	.086	3.54	1.22	.49	2.96	28.4
		.094	3.41	1.30	.39	3.81	36.6
	SW¼ 30-21N-2E	.105	3.25	1.20	.41	4.89	47.0
		.069	3.86	—	—		
		.098	3.35	1.18	.40	4.25	40.8
Pw-160	SW¼ 15-24N-2E	.100	3.32	1.15	.35	4.81	46.6
		.120	3.06	1.19	.27	7.68	74.3
		.108	3.21	1.17	.36	5.53	53.1
		.096	3.38	1.16	.45	3.88	37.3
		.091	3.46	1.18	.39	3.78	36.4
	SE¼ 17-24N-2E	.104	3.27	1.16	.25	5.93	57.4
Pwl (120 feet above base)	NE¼ 30-22N-2E	.095	3.40	1.21	.51	3.50	33.6
	NW¼ 20-22N-2E	.065	3.94	—	—		
	SE¼ 16-22N-2E	.078	3.68	1.29	—		
		.091	3.49	1.16	.40	3.68	35.4
	SE¼ 8-22N-2E	.112	3.16	1.19	.41	5.58	53.6
	NE¼ 30-23N-2E	.096	3.38	1.27	.49	3.68	35.4
Doyle							
(10 feet above base)	NE¼ 1-24N-3E	.076	3.72	1.17	.31	2.93	28.2
(5 feet above base)	SW¼ 2-21N-3E	.121	3.04	1.24	.46	5.99	57.5
Matfield							
(70 feet above base)	NE¼ 1-24N-3E	.108	3.21	1.22	.42	5.70	54.8
(40 feet above base)	NE¼ 1-24N-3E	.133	2.91	1.19	.47	7.26	69.8
		.128	2.97	1.24	.42	5.19	49.8
Average							
Median		.098	3.38	1.22	.42	4.81	46.6
Mean		.098	3.37	1.23 avg.	.42	4.79	46.1

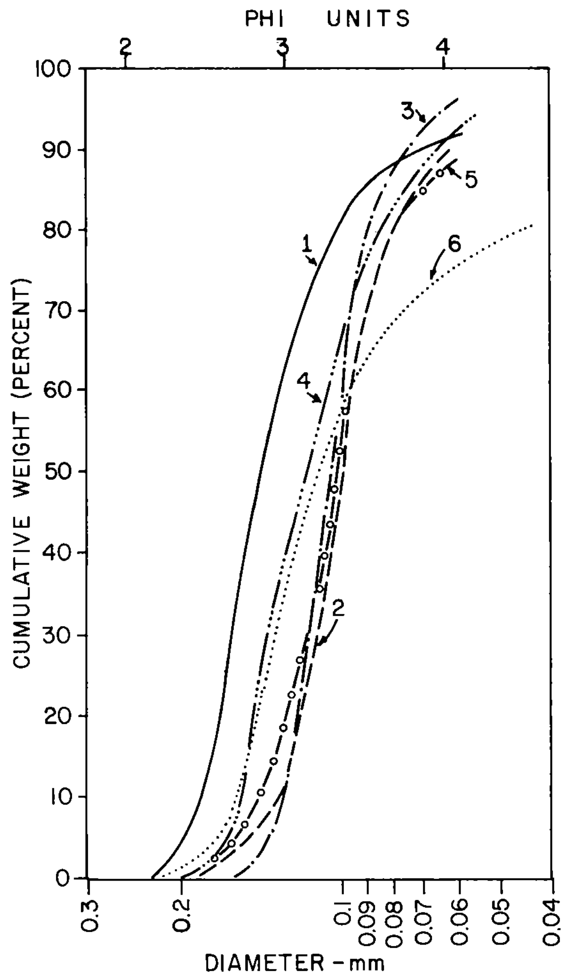


Figure 32. Representative cumulative frequency curves from grain-size analysis of Noble County sandstones. Sandstones are very fine grained or fine grained; they show little variation in grain size and sorting. Key: *1*, coarsest median diameter (0.140 mm), Wellington Formation, Pw-525, SW1/4 sec. 18, T. 20 N., R. 1 E. *2*, average median diameter (0.098 mm), Wellington Formation, Pw-265, SW1/4 sec. 30, T. 21 N., R. 2 E. *3*, best sorting (1.14), Garber Sandstone, SW1/4 sec. 6, T. 22 N., R. 2 W. *4*, average sorting (1.23), Wellington Formation, Pw-525, SW1/4 sec. 18, T. 20 N., R. 1 E. *5*, average sorting (1.23), Wellington Formation, Pwm, SE1/4 sec. 6, T. 21 N., R. 2 W. *6*, poorest sorting (1.47), Garber Sandstone, NW1/4 sec. 3, T. 20 N., R. 2 W.

order of magnitude because of the compaction experienced.

Trends of preferred grain orientation were determined by measuring the dielectric anisotropy in prepared samples in an instrument patented by Shell Development Co. (Arbogast and others, 1960; Nanz, 1960). The equivalent of approximately 125,000,000 grains was measured from 16 samples. For samples in which it was possible to calibrate the method with megascopic paleocurrent features, good agreement exists. Grain-orientation trends are included with plots of other directional features in the paleocurrent diagrams (figs. 5, 6, 9, 16, 17, 24, 27, 30). The variation in trend of grain orientation is consistent with the rather wide range in the orientation of individual sandstone bodies in the County.

All the sandstones are quartz-rich (figs. 8, 13, 18, 19, 28, 29, 33); the framework grains include some feldspar and lesser amounts of rock fragments and fine micas. On the average, the framework is composed of 91 percent quartz, 7 percent feldspar, and 2 percent rock fragments (fig. 33). Accordingly, the sandstones are classified as quartz-rich subarkoses (McBride, 1963; Folk, 1954). The potassium feldspars are more common than plagioclase, and orthoclase is more abundant than microcline. It is probable that the estimated content of orthoclase is excessive because of misidentification of some weathered grains.

The matrix is composed dominantly of sericite, with varying amounts of hematite (and/or other iron oxide minerals) and calcite (figs. 8, 13, 18, 19, 28, 29). Accessory minerals of the matrix are chert, quartz, kaolinite, and gypsum. Most of the matrix from the latter category is secondary in origin. The calcite and at least some of the hematite and sericite also formed subsequent to deposition. The secondary origin of the hematite is suggested by green intraformational clay-carbonate pebbles in red sandstones. The sericite that coats the grains as rims is thought to be authigenic. Coarser sericite has formed by recrystallization, and some of it may be authigenic as well.

Carbonates

Beds of both limestone and dolomite are present in Noble County. According to classifications by Dunham (1962) and Folk (1962), the limestones are generally grainstones (sparites) (fig. 11) or (grain-supported) packstones (fig. 10). The grains are skeletal, coated skeletal, quartz, coated quartz, and coated carbonate lithoclasts. Less common are algal calcitic boundstones (biolithites) (fig. 7) (Dunham, 1962; Folk, 1962). Using

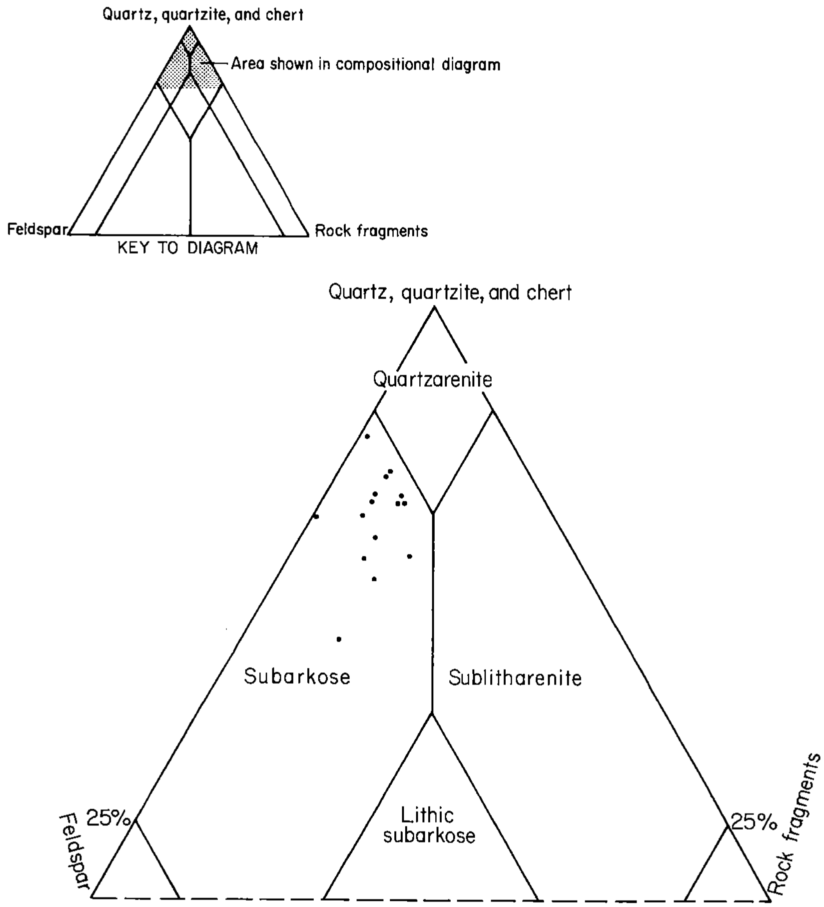


Figure 33. Composition diagram of sandstones of Noble County.

the same classifications, the dolomites are most commonly micrites (mudstones) (fig. 22), dismicrites (disturbed micrites) (fig. 7), and algal-mat boundstones (biolithites) (fig. 23).

The carbonates of the uppermost Pennsylvanian System (Oscar Group) are more calcitic than those of the Permian Wellington Formation and overlying Garber Sandstone. It is common for the named limestones of the Oscar Group to change to dolomite in a southerly direction and change from gray to red in color. The Herington Limestone exemplifies this geographic variation in lithology and petrographic character (figs. 10–12). In the northern part of the County it is a packstone; it is a grainstone in the central part of the outcrop belt. South of the middle of T. 22 N., the Herington is a red nodular, dolomitic micrite or dismicrite. The Fort Riley Limestone maintains the texture of grainstone in a southward direction, but terrigenous clastics increase progressively at the expense of the carbonates.

Mudrock

The two most characteristic features of the finer grained terrigenous clastics are the reddish color and the lumpy, blocky, or massive stratification. Green to gray is not an uncommon color, and a bed or two of dark-gray shale is present in the shale-dolomite sequence below the upper key bed of the Wellington Formation. The green-gray and the dark-gray beds are shales, because they are laminated or fissile. The relationship between reddish rock and green-gray rock may be quite intimate. For example, in the uppermost part of the Doyle Shale along State Highway 15 (sec. 6, Appendix), red and green are delicately interlayered. Directly below the Garber Sandstone in T. 21 N., R. 2 E. (sec. 15, Appendix), the red color extends upward into the gray as a convolute-shaped feature. Most commonly the mudrock directly below a sandstone body is green gray, and the pebbles in a basal conglomeratic bed are green dolomitic clay.

Clay-mineral analysis of 14 mudrock samples by W. H. Bellis, Oklahoma Geological Survey, indicates that major differences in the composition of the fine-size fraction do not exist. These analyses were of reddish, green-gray, and dark-gray samples from various stratigraphic positions. They include the Doyle Shale (sec. 6, Appendix), the lower unit of the Wellington Formation (sec. 10), its lower middle unit (sec. 11), its upper middle unit (sec. 13), and its upper unit (sec. 15). Illite, kaolinite, and chlorite are the most common clay-mineral constituents. It is common for the illite to be degraded. Kaolinite is absent in the samples from the upper middle member of the Wellington, whereas some vermiculite is present. Four of the five samples apparently containing mixed-layer illite-chlorite are reddish in color. The two samples with possibly some montmorillonite are reddish. The virtual absence of montmorillonite and the presence of kaolinite are somewhat surprising, for these Permian mudrock units exhibit significant shrinkage and swelling. Furthermore, the degree of moisture penetration is low. Perhaps the vermiculite, while it is not common, plays an important role in influencing soil properties.

STRUCTURE

Surface Structure

The main structural feature of the surface rocks of Noble County is the dominant gentle westward dip. The area lies in the western part of the Prairie Plains homocline, where dip is characteristically less than 1°. Local reversals of dip direction were mapped by early petroleum geologists in the western part of the County, especially in the Tonkawa, Billings, and Lucien field areas. In the area of the Tonkawa and Billings structures, dip can be observed visually. There, the outcrop pattern of the upper key bed in the Wellington Formation reflects the syncline and anticline shown on the shallow structural map (pl. 1). The outline of the Garber Sandstone in the southeastern part of T. 21 N., R. 2 W., and northeastern part of T. 20 N., R. 2 W., lies north of the anticlinal nose of the Lucien structure (pl. 1). Subtle local variations in dip generally reflect gentle anticlinal noses at depth. This relationship exists in the West Otoe field area (sec. 22, T. 22 N., R. 1 E.) and the Liberty-Marathon area (northeastern part of T. 22 N., R. 2 E.) (pls. 1, 2).

No faults were observed at the surface by the writer. Along atypically straight creeks, Billings (1956, p. 7, pl. 1) tentatively mapped several faults for which he found no supporting field evidence. Open joints are present at the surface in sandstone, limestone, and dolomite beds. The joints are considered to be extension fractures, because most of them exhibit vertical dips. However, scattered joints dip at angles as low as 60°, a feature more commonly characteristic of shear joints in flat-lying beds. Compilation of the strike directions for the joints indicates orthogonal sets. The average is N. 45° W. for one set and N. 50° E. for the other set (fig. 34). These directions parallel the *en-echelon* fault pattern east of the County and are subparallel to the joint sets Melton (1931) mapped in the Central Plains north and northwest of the Ouachita Mountains. The overall trend of the plunging folds of the Billings-Tonkawa area in the shallow subsurface is approximately N. 35° E. (pl. 1). The average directions for joints are also strike directions for several subsurface faults (pl. 3; fig. 35).

Subsurface Structure

The most prominent structural feature of Noble County is the area of faulted anticlinal structures that are present in the western third of the County (pl. 3). The eastern part of the County is characterized by gentle westward dip, interrupted in a number of local places by gentle folds. Some of the folds are closed features, whereas others are noses with a unidirectional plunge.

The faults are part of a zone that parallels the Nemaha ridge to the west. Some

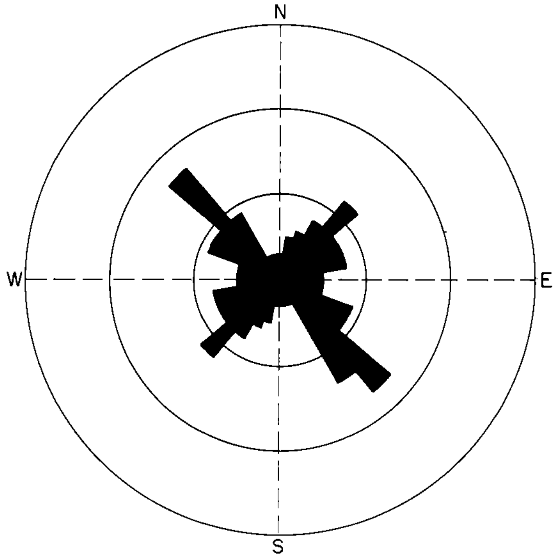


Figure 34. Strike-frequency diagram for joints, showing orthogonal sets averaging N. 45° W. and N. 50° E.

show an *en-echelon* pattern, and bifurcation apparently is not uncommon. The predominant strike direction is approximately N. 30° E. (fig. 35). Movement along the faults is thought to have been primarily responsible for the associated anticlinal features. Movement occurred repeatedly during the Paleozoic (Arbenz, 1956). Apparently the earliest movement was during the Ordovician Period; the most intense was during the Pennsylvanian, and the latest was during the Permian or later. Erosion of upthrown blocks accompanied movement along the faults and gave rise to the characteristic paleogeologic patterns (figs. 36, 37) and to marked unconformities. The unconformities at the base of the Upper Devonian Woodford Shale and at the base of the Pennsylvanian are especially significant, and the associated subcrop patterns record the effect of recurring movement along the faults (pl. 3; figs. 36, 37); Jordan, 1962; Tarr and others, 1965).

Genetically the faults are thought to be upthrusts or strike-slip faults with significant amounts of dip-slip displacement. The faults were initiated in the basement; displacement diminishes upward, and folded beds are draped over fault blocks. For example, folded Permian and Pennsylvanian rocks overlie fault blocks at the prominent Tonkawa, Billings, and Lucien structures. Along the northeast-trending fault at Billings the vertical displacement, or separation, is as much as 1,200 feet.

It is thought that faulting at unpenetrated depths may be responsible for some of the unfaulted structures. For example, a deep-seated, east-west fault zone may be present east of the Polo structure (named for Polo, an abandoned community); a northwest-trending zone may extend southeastward from the Otoe City anticline; and a curved zone may lie in the northeastern part of T. 22 N., R. 2 E.

The Central Oklahoma platform was a mildly positive feature recurrently during the early Paleozoic. East of the faulted structures in Noble County and west of its subcrop edge, the Viola Limestone was eroded locally in a northwest-trending zone (pl. 3; Tarr and others, 1965). The resulting local subcrops of the Simpson Group are present as a series of inliers southwest of the broad belt of Simpson subcrop that extends across the northeasternmost part of Noble County (pl. 3; Tarr and others, 1965). The Sylvan Shale is present only in the southwestern part of the County, and the subcrop edge of the Hunton Group lies south and west of that area (Tarr and others, 1965).

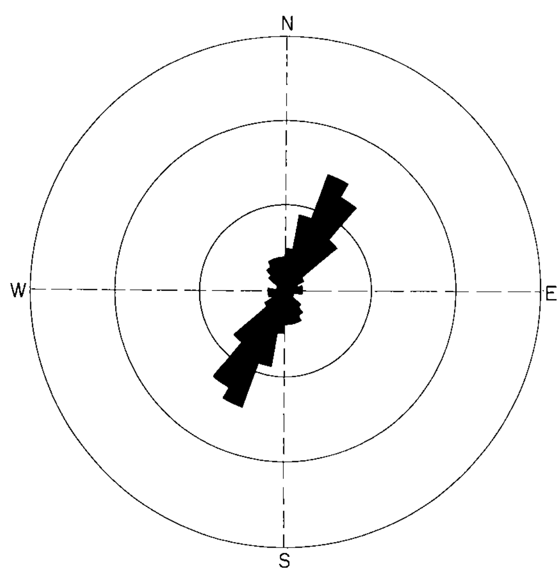


Figure 35. Strike-frequency diagram for faults; frequency based on length or extent of strike rather than on number of faults. Predominant strike direction is N. 30° E.

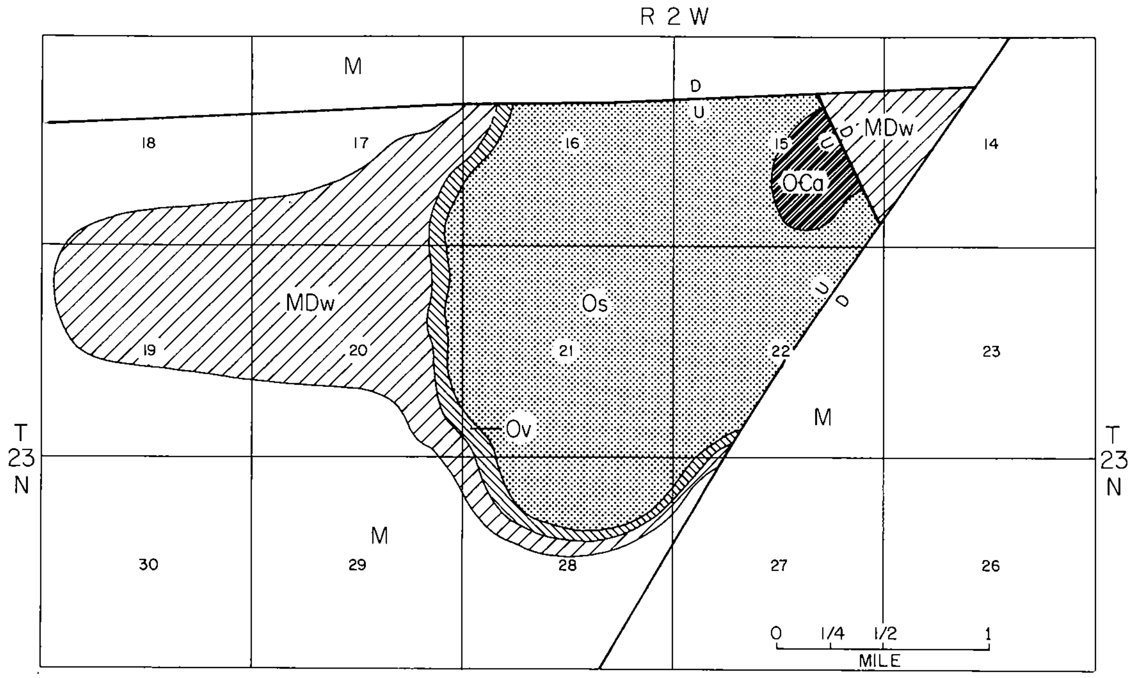


Figure 36. Pre-Pennsylvanian geologic map of Billings field area. *M*, "Mississippi Lime," undifferentiated; *Dw*, Woodford Shale; *Ov*, Viola Limestone; *Os*, Simpson Group; *OЄa*, Arbuckle Group.

DEPOSITIONAL FRAMEWORK FOR SURFACE ROCKS

Although the Upper Pennsylvanian and Lower Permian rocks of Noble County were deposited in a variety of depositional environments, together they represent an upward transition from rather typical upper Paleozoic cyclic sequences to desiccation cycles. Areal variation in depositional environments were also common in the Noble County area. Units of the upper Oscar Group (Pennsylvanian), equivalent to the Chase Group of Kansas, with repetitious sequences keyed to thin limestones, are somewhat similar to the underlying Pennsylvanian cyclothems. In Noble County, however, the beds are commonly red; some of the carbonates are dolomitic, or they are absent.

During late Oscar transgressions, normal-marine waters apparently were present as far south as the northern half of the County. Directly to the south, intertidal and supratidal dolomites (the algal mats and desiccated muds) formed under arid conditions. A higher part of the tidal flat lay in the southeastern part of the area, where carbonate-free sediments were deposited. Some marine sands were deposited in the northern part of the County. They include the sandstone at the position of the Winfield Limestone and sandstone in the Herington section. Part of the rather extensive sandstone that overlies the Fort Riley Limestone is thought to represent a shoreline deposit. During regression the tidal flat became larger; tidal creeks and an occasional small stream crossed the wide mudflat. Tidal-creek deposits are considered to be those with an undulatory base, initial dip, and small-scale crossbedding that shows much local variation in paleocurrent direction. A locally thick sandstone with medium-scale crossbedding showing rather consistent paleocurrent direction is regarded as a stream deposit. The average depositional strike, or shoreline orientation, was apparently east-northeast (N. 60° E. to N. 70° E.). The paleocurrents indicate that the depositional slope was north-northwest (figs. 5, 6, 9). Also, in the shallow subsurface the limestones are more difficult to recognize on electric logs from the southeastern part of the County (pl. 2).

The characteristic difference between

the upper Oscar Group (Pennsylvanian) and the overlying Wellington Formation (Permian) is the absence of marine limestone beds in the latter. Nevertheless, cyclic conditions existed, as Raasch (1946, p. 55), Tasch (1964, p. 482, 483), and Olson (1967, p. 39) noted. The dominant, general environment of deposition is thought to have been tidal flat. On the flat were creeks, an occasional larger channel, and lakes and ponds. Although widely spaced streams crossed the tidal flat, major delta building did not extend into Noble County.

Even during transgressions, water in the depositional area was highly saline; dolomites and anhydrites/gypsums formed under these conditions. Most of the dolomites are supratidal deposits. The thin sandstones with opposedly directed crossbeds, steep initial dip, and locally varying paleocurrents are regarded as tidal-creek deposits. Thicker sandstone bodies with opposing crossbeds are thought to be tidal-channel sediments, and those with more consistent paleocurrent indicators are apparently stream deposits. The abundance of the first-noted type suggests that tidal-flat conditions were dominant. A minimum of subaerial exposure before final burial is considered likely for the sequence of gray-green shales with thin dolomites

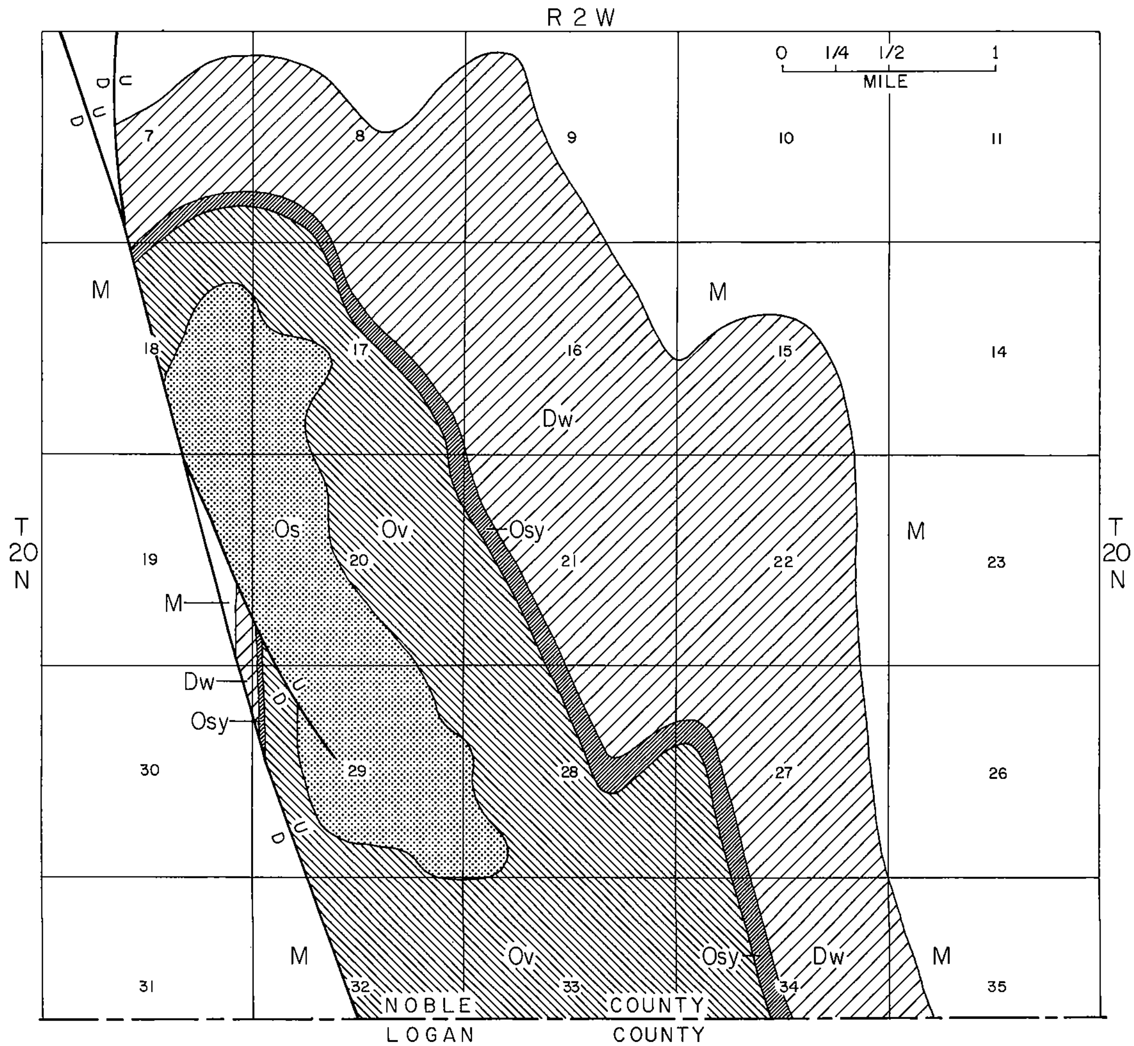


Figure 37. Pre-Pennsylvanian geologic map of Lucien field area. Modified from Page (1955, fig. 4). *M*, "Mississippi Lime," undifferentiated; *Dw*, Woodford Shale; *Osy*, Sylvan Shale; *Ov*, Viola Limestone; *Os*, Simpson Group.

below the upper key bed of the Wellington Formation. The vertebrates, which are especially well known from the upper part of the Wellington Formation, probably lived in the vicinity of the ponds on the tidal flat. With the repetitious expansion of the flat, beds of the higher tidal flat, which formed under more nearly terrestrial conditions, overlie lower tidal-flat deposits. Within the Wellington, the change of dominant (or average) depositional environment was from lower tidal flat during deposition of the lower and the two middle units of the formation to upper tidal flat during deposition of the upper unit.

In Noble County, average depositional conditions for the Garber Sandstone were similar to those for the upper unit of the Wellington. Although sandstones are more common in the southern part of the County, deltaic and alluvial features are not representative of the area. However, they are apparently common in equivalent beds south of Noble County.

The average shoreline trend is thought to have been northeasterly during deposition of the Wellington and Garber. Paleocurrents from sandstone bodies suggest a prevailing northwesterly depositional slope. The eastern edge of anhydrite beds in the lower part of the Wellington Formation, while it may reflect some secondary leaching, points to a depositional strike of north-northeast. For the lower part of the Wellington the shallow subsurface shows a southeastward increase in sand bodies, which also suggests a northeasterly strike.

Noble County during deposition of the Lower Permian or Cimarronian beds was part of a much larger area that was repetitiously connected to the open Permian sea some distance to the southwest. During those times the area was a very shallow, restricted sea that experienced regression by desiccation and gradual extension of the tidal flat. Undoubtedly local lacustrine environments existed repeatedly on the mudflat, as Raasch (1946, p. 83–88), Tasch (1964, p. 487–495), and Carlson (1968, p. 654–657) indicated, but designation of a lacustrine environment as the average environment seems unwarranted.

Possible source areas for terrigenous clastics were the Ozark uplift area to the east, the Ouachita area to the southeast, and the Amarillo-Wichita-Criner and Arbuckle elements to the south and southwest. The paleocurrent data, along with the facies changes, point to the Ouachita system as the predominant source area.

The red beds are thought to have formed largely after deposition during subaerial exposure as weathering occurred under arid conditions. Conditions for formation are thought to have been similar to those proposed by Walker (1967, p. 357–363) for red pigmentation in sediments of northeastern Baja California. However, most of the data are inconclusive. For example, clay-mineral suites for both red and green clay are similar, because both contain illite, chlorite, and kaolinite. The first two might be associated with authigenic pigmentation, but kaolinite in red mudrock is generally thought to have entered a depositional area from a source area where weathering was intense. Also, field relations are less than conclusive. The abundance of green dolomitic clay pebbles in various intraformational conglomerates within red-bed sequences suggests post-depositional formation; red pebbles, however, are common in other conglomerates. The association of red beds and evaporites is well established in Noble County, and that association does suggest a secondary origin for the red color.

ECONOMIC GEOLOGY

Petroleum

John W. Shelton and William A. Jenkins[1]

During the more than 50 years since oil was first discovered in the Noble County area at Tonkawa field, some 186 million barrels of oil and 75 billion cubic feet of gas were produced through 1975 (International Oil Scouts Association, 1976). The major part of production has come from structural traps in the western half of the County in an overall north-south belt (pl. 3; fig. 38). Most structures were formed by faulting in a zone that lies east of the Nemaha ridge. Faulted structures at depth change upward into gentle folds. Recurrent movement is probably the most significant

[1]Independent geologist, Durango, Colorado.

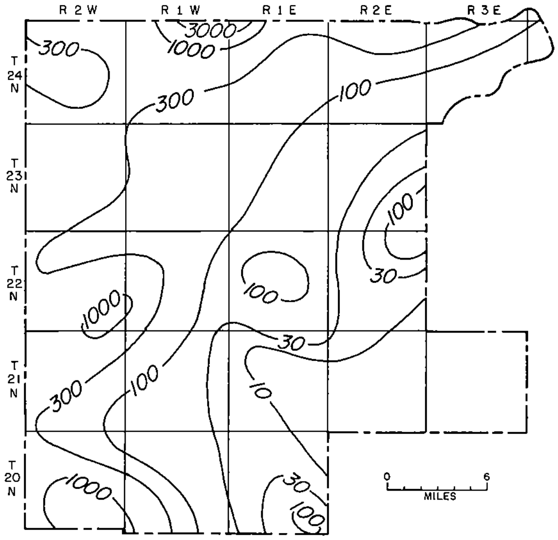


Figure 38. Generalized petroleum-production map of Noble County. Contour values represent thousands of barrels per square mile, based on a quarter-township grid. A smoothing routine was used in contouring. Data from International Oil Scouts Association (1976) and Vance Rowe Reports (1971).

feature of the faulting. Early and continued structural growth formed traps for fluids as they migrated from the source rocks, and late movement permitted detection of the structures by the surface mapping of pioneer geologists. Based on convergence of stratigraphic units, it would be reasonable to conclude that traps were probably formed as early as Middle Ordovician time. Prior to deposition of the Woodford Shale, movement had formed significant structures (Tarr and others, 1965). Although structural activity culminated during the Pennsylvanian (Arbenz, 1956), movement during the Permian, or later, is reflected by gentle folds or noses at the surface.

At least 80 percent of the cumulative oil production and 60 percent of the cumulative gas production are from structural traps, 90 percent of which are suggested by gentle folds in surface rocks. Through 1975 approximately one-fourth of 1 percent of the oil and 11 percent of the gas produced had been contributed by fields discovered since 1960, and 8 percent of the oil and 4 percent of the gas from fields discovered since 1950.

Detailed accounts of oil developments in Noble County were given by Bullard (1928), Clark (1926), Clark and Aurin (1924), Clark and Cooper (1927, p. 88–96), Zavoico (1934), Klaus (1943, p. 364–365), Page (1955, p. 16, 18, 24–25), and Talley (1955, p. 5–7).

The large quantity of hydrocarbons produced indicates that the three requirements for production—source rock, reservoir, and trap—have been abundantly satisfied in parts of Noble County. Furthermore, the various shapes and trends of fields and the range in age of producing reservoirs from Ordovician to Pennsylvanian suggest that the conditions were met in a variety of ways.

SOURCE ROCK

Although no geochemical data are available to the writer concerning source-rock quality, empirical relationships suggest that a number of source beds are present. Regionally the Woodford Shale has been considered a prime source rock. In Noble County, producing reservoirs commonly lie unconformably below the Woodford. On some structures, basal Pennsylvanian beds have a similar relationship to producing lower Paleozoic reservoirs. A multiplicity of source beds in the Pennsylvanian is suggested by the large number of productive stratigraphic units and by the presence of stratigraphically trapped oil.

RESERVOIRS

Some 25 stratigraphic units are oil-producing reservoirs (fig. 4). Four Gearyan sandstones in the uppermost Pennsylvanian have produced small amounts of oil. Pennsylvanian sandstone reservoirs of the underlying Virgilian Series include the Elgin-Hoover zone and the Tonkawa Sandstone. Missourian reservoirs include the "Avant" (Wildhorse) Limestone, Cottage Grove ("Layton") Sandstone, and Cleveland Sandstone. The oldest Pennsylvanian reservoirs belong to the Desmoinesian Series. The Fort Scott (Oswego) Limestone of the Marmaton Group is productive along with the well-known sandstones of the underlying Cherokee Group, the Prue, Skinner, Red Fork, and Bartlesville.

Ordovician reservoirs include the "Wilcox" sandstones and dolomites of the Simpson and Arbuckle Groups. In field areas the distribution of the Simpson Group reservoirs is limited more by pre-Upper Devonian and pre-Pennsylvanian erosion than by depositional conditions. Production from the Arbuckle is most commonly from the upper 100 feet of the thick carbonate sequence, where dolomitization has enhanced porosity.

TRAPS

Known traps include faulted and folded structures (pl. 3; figs. 36, 39) and stratigraphic traps (pl. 3; figs 39, 40). Most commonly the structural traps for Pennsylvanian oil are gentle folds draped over faulted lower Paleozoic beds. For the most part the lower Paleozoic reservoirs produce in upthrown fault blocks, where erosion associated with several periods of uplift has resulted in significant paleogeologic (subcrop) patterns (figs. 36, 37).

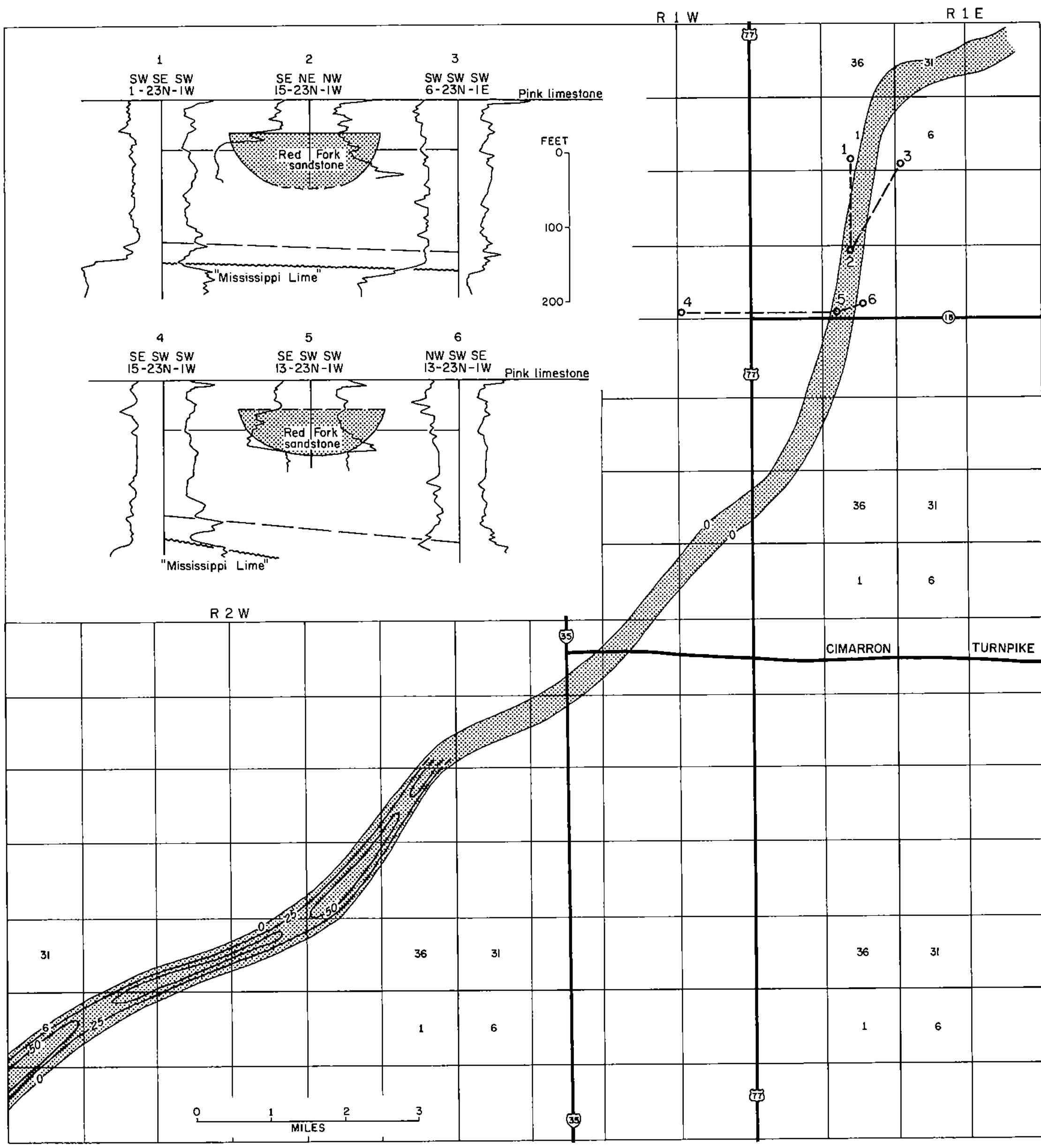


Figure 39. Thickness and trend map of Red Fork Sandstone in South Ceres field area, showing narrow belt of sandstone development. Contour interval, 25 feet. Correlation sections of lower part of Cherokee Group show Red Fork development and configuration.

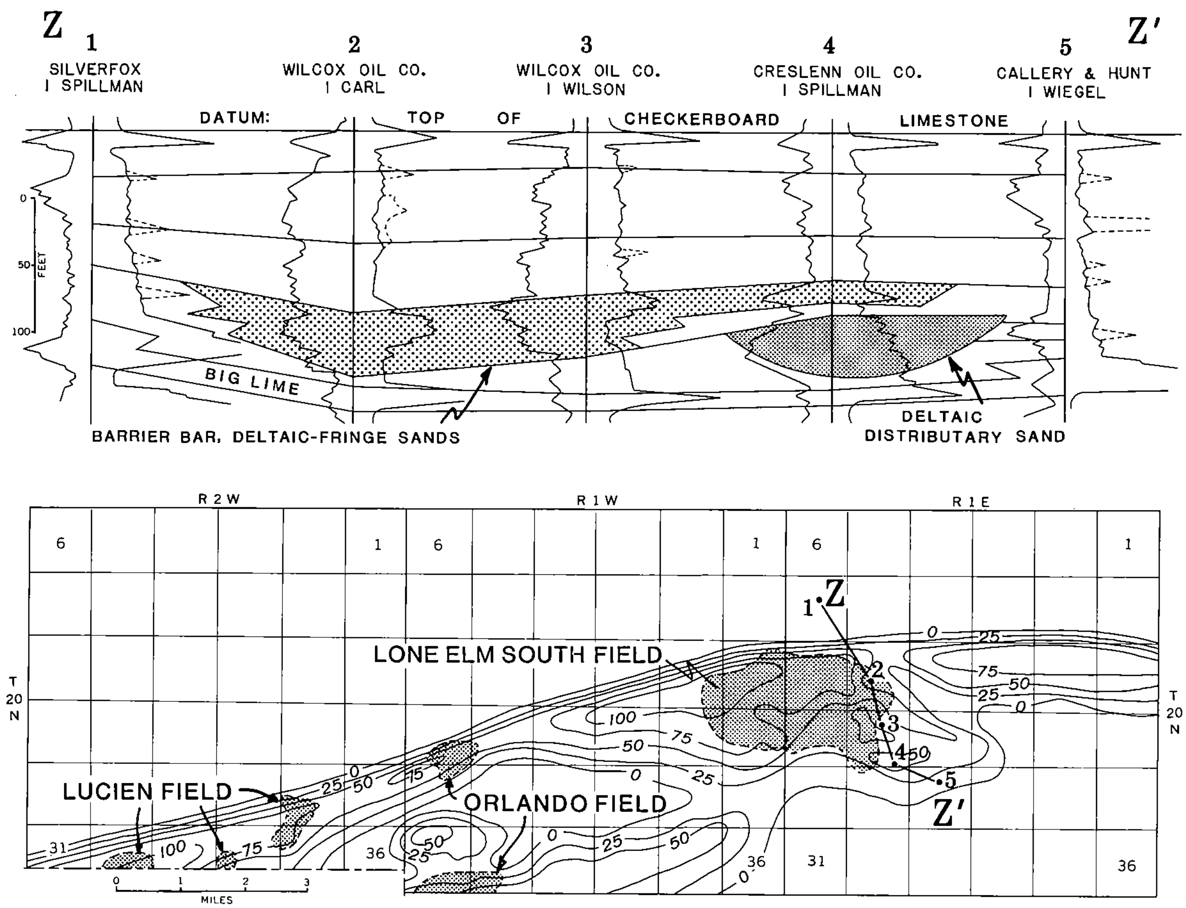


Figure 40. Thickness map of lower part of Cleveland Sandstone, Lucien-South Lone Elm field area. Contour interval, 25 feet. Correlation section shows development of Cleveland Sandstone bodies.

Structures such as Fourdee and Otoe City are unfaulted at the top of the Ordovician, but faulting may have affected lower beds and (or) the basement.

Oil is stratigraphically trapped at South Ceres (fig 39) and South Lone Elm fields (fig. 40) by lateral facies changes. The Red Fork Sandstone at South Ceres is deltaic-distributary sand, which is 1,000–1,500 feet wide and extends 10 miles south-southwestward parallel to the structural strike. The complex of Cleveland Sandstone trends east-west, parallel to the local structural strike. The sandstone is thought to have been deposited as a coastal complex of barrier-bar, delta-fringe, and distributary sands.

FUTURE DEVELOPMENT

Chances for future discoveries are probably greatest where prospects are drilled for stratigraphic or stratigraphic-structural traps after environmental study of reservoir conditions has delineated reservoir trend and geometry.

Copper

Malachite has been observed by Raasch (1946, p. 53–54, 59, 104, 154), R. O. Fay (Oklahoma Geological Survey, oral communication, 1972), Heine (1975, p. 62–67), and the author in several beds at various stratigraphic positions. Raasch (1946, p. 54) also noted cuprite and chalcocite in association with malachite. The following are localities and stratigraphic positions where copper minerals are known to be present.

An abandoned mine shaft is present in sec. 24, T. 20 N., R. 1 W., where there was limited activity between about 1890 and

Location	*Stratigraphic position*	*Reference*
NE 1/4 sec. 3, T. 21 N., R. 3 E.	Wreford Limestone—Matfield Shale	Heine (1975, p. 62)
SE 1/4 sec. 3, T. 21 N., R. 3 E.	Fort Riley Limestone—Doyle Shale	Heine (1975, p. 67)
NE 1/4 sec. 12, T. 21 N., R. 3 E.	Garrison Shale—Wreford Limestone	Heine (1975, p. 62)
SE 1/4 sec. 13, T. 21 N., R. 3 E.	Matfield Shale	Heine (1975, p. 62)
NW 1/4 sec. 19, T. 21 N., R. 3 E.	Doyle Shale	Heine (1975, p. 62)
NW 1/4 sec. 25, T. 21 N., R. 3 E.	Fort Riley Limestone—Doyle Shale	Heine (1975, p. 67)
SW 1/4 SE 1/4 sec. 25, T. 21 N., R. 3 E.	Fort Riley Limestone	R. O. Fay
NE 1/4 sec. 26, T. 21 N., R. 3 E.	Matfield Shale—Fort Riley Limestone—Doyle Shale	Heine (1975, p. 67)
SE 1/4 sec. 27, T. 21 N., R. 3 E.	Matfield Shale—Fort Riley Limestone	Heine (1975, p. 62)
SE 1/4 sec. 28, T. 21 N., R. 3 E.	Doyle Shale	Heine (1975, p. 62)
SW 1/4 sec. 33, T. 21 N., R. 3 E.	Doyle Shale	Heine (1975, p. 62)
NW 1/4 SE 1/4 sec 16, T. 22 N., R. 2 E.	Pw-160 (lower key bed, Wellington Formation)	
E 1/2 sec. 3. T. 21 N., R. 1 W.	"Lower Insect Bed" (Pw-570, upper middle unit, Wellington Formation)	Raasch (1946, p. 103–104)
W 1/2 sec. 19, T. 20 N., R. 1 E.; E 1/2 sec. 24, T. 20 N., R. 1 W.	Pw-580 (upper middle unit, Wellington Formation)	R. O. Fay

1910 (R. O. Fay, oral communication, 1972).

Undoubtedly a number of other localities exist where copper minerals are present, for Raasch (1946, p. 59) indicated that "copper" is widespread in the thin limestone units in the upper middle Wellington unit, some 10 to 40 feet below the upper key bed. Also, "galena" was recorded from a 40-foot shaft in the NE 1/4 NW 1/4 sec. 35, T. 21 N., R. 1 W., in field notes of soil scientist O. H. Brensing on file in the office of the Noble County Surveyor (S. R. Beasley, oral communication, 1973).

Engineering and Construction

CONSTRUCTION MATERIALS

Mudrock suitable for brick, tile, and aggregate is thought to be present in Noble County. Sections are present that are relatively carbonate free. Kaolinite and vermiculite in samples analyzed and the presence of gray shale in an area dominated by red beds suggest that additional study is warranted of mudrock in the County by industrial users. In the past, sandstone beds in the upper part of the Wellington south of Perry have been used as building stone. However, sandstone in the County is considered to be unsuitable for modern construction because of inadequate induration and high permeability.

Gravel deposits that are best developed on the north side of Black Bear Creek (fig. 2) constitute good subbase material for highway construction. The calcareous sandstone at the Winfield Limestone position is satisfactory riprap material. The Herington and Winfield Limestones in the northern part of their outcrop belts might be thick enough for use as riprap. The only limestone that could be considered a possible source for road metal in major highway construction is the Fort Riley Limestone in the "Big Bend" part of the County (sec. 3, Appendix). It seems possible, however, that, with a portable crusher, metal for county roads could be obtained from the Winfield and Herington as well as from the Fort Riley. For county roads in the Perry-Billings area, considerable use has been made recently of the sequence of gray shale and thin dolomites below the upper key bed of the Wellington Formation. Additional study is needed to determine the reason for the relatively favorable properties of the sequence, which may also possess desirable properties for other uses.

CONSTRUCTION PROBLEMS

Excluding the volume changes by clay soils, the major problem for highway construction is probably seepage. Lenticular sandstones cap almost every hill in the county, except for the northeastern part. Generally, excessive seepage occurs at the bases of such sandstones on hill slopes.

Nearly all the rock materials are rippable. Those units that are marginally rippable or require blasting are found almost entirely in the northeastern part of the County. The Fort Riley Limestone, the Winfield Limestone and associated sandstone, and the Herington Limestone are of this category. Caution, however, should be exercised in considering all locally thick sandstones as being rippable.

Neither joints nor landslides are thought to present a significant problem in highway construction in Noble County.

ENGINEERING PROPERTIES OF SOILS

Highway-engineering characteristics for various soil series present in Noble County, which include grain size, certain constants, and suitability, have been determined and summarized by Hayes and others (1967). In addition, laboratory tests have been made by the U.S. Soil Conservation Service on soil samples at small dam sites in Noble County. Some of the data from the dam sites are summarized here and are tabulated in table 3. The samples are almost entirely from alluvial and residual soils formed on the outcrop belt of the Wellington

TABLE 3.—ENGINEERING PROPERTIES OF SOILS IN OUTCROP BELT OF WELLINGTON FORMATION, NOBLE COUNTY

		Index-test data					Shear-test data	
Soil type (Unified Soil Classification)	Number of samples	Grain size % finer than .005 mm	Grain size % finer than .074 mm	LL Liquid limit	PI Plastic index	γ_d Unit dry weight (g/cc)	ϕ Angle of internal friction	C Cohesion (g/cm^2)
*CH								
Embankment	1	68	91	55	31	1.65	7	170
CL								
Shale	2	23-26	72-76	25-26	10	1.67	13.5-15.5	75-195
Embankment	35	20-68	58-96	25-48	7-25	1.61-2.02	0-19.5	120-850
	Avg:	29	75	30	13	1.81	11.5	290
Foundation	39	20-71	60-89	23-38	8-23	1.50-1.81	1.5-23.5	50-560
	Avg:	29	77	30	15	1.67	13	245
CL-ML								
Embankment	6	20-25	69-73	24-25	7	1.84-1.89	15.5-22.5	210-365
	Avg:	21	7	25	7	1.86	16.5	270
Foundation	7	16-25	63-83	22-27	5-7	1.52-1.74	10.5-25	60-620
	Avg:	18	80	24	6	1.60	21	120
ML								
Embankment	5	14-18	64-68	19-22	0-3	1.61-1.73	17-28.5	85-390
	Avg:	16	66	20	3	1.62	17.5	245
SM	3	14-17	38-44	18-23	0-7			
GP-GC	5	1	4	28	11	1.67-1.81	19-31.5	120-340
	Avg:	1	4	28	11	1.78	24.5	290

*CH, clay with high plasticity
CL, clay with low plasticity
CL-ML, clay-silt with low plasticity
ML, silt with low plasticity
SM, silty sand
GP-GC, sandy gravel, clayey gravel

Embankment soils are composite and remolded samples.

Unit dry weight and associated shear-strength parameters for embankment soils were obtained at 95 percent of maximum density obtained in test procedures ASTM D-698.

Formation. Properties of two available shale samples are very similar to those of the clay soil with low plasticity (CL). The CL type of soil, which composes almost 80 percent of the samples, averages about 30 percent clay-size particles and 75 percent silt and clay. The average liquid limit is 30, and the plastic limit is 15 to 17, with a resulting plastic index of 13 to 15. In saturated, consolidated-undrained tests, the angle of internal friction varies from 0 to 23.5°, with an average of some 12°. The range in cohesion for the same tests and materials is 75 grams/cm^2 to 850 grams/cm^2; the average is 270 grams/cm^2. The CL soils in the Red Rock Creek drainage basin in northwestern Noble County are more plastic than the average. The only sample of highly plastic clay noted in the summary has a liquid limit of 55 and a plastic index of 31. The angle of internal friction is 7°, and the cohesion is 170 grams/cm^2. The other samples for which data are available are soils with low plasticity. They include clay-silts, silts, silty sands, and clayey or sandy gravels.

Permian red mudrock in north-central Oklahoma is characterized by high plasticity (J. V. Parcher, Oklahoma State University, oral communication, 1968). Although variation exists in grain size, the liquid limit approaches 50, and the plastic limit is quite low. Consequently, the mudrock is subject to considerable change in volume with change in moisture content.

Water Resources

Roy H. Bingham[1]

INTRODUCTION

The purpose of this chapter is to provide general information on the occurrence, availability, chemical quality, and use of the water resources in relation to the geologic framework in Noble County. Information in this chapter was obtained in the field and from records of State and Federal agencies. Much of the information was supplied by individual well owners and by water-plant officials at several towns. Their cooperation and assistance are gratefully acknowledged.

[1]Hydrologist, U.S. Geological Survey, Tuscaloosa, Alabama. Publication authorized by the director, U.S. Geological Survey.

GROUND WATER

SOURCE AND OCCURRENCE

The source of ground water in Noble County is precipitation on the area. According to data published by the National Weather Service, the average annual precipitation at Perry is 32 inches. Of this, approximately 85 percent, or 27 of the 32 inches, is returned to the atmosphere annually through evaporation and transpiration by plants (Dover and others, 1968, p. 9). Approximately 1.5 inches is available annually to recharge the ground-water reservoir.

During the principal recharge period, from November to April, a small part of the rainfall percolates from the land surface downward to the water table (fig. 41). The capacity of underlying rocks to absorb and transmit water depends upon the number, size, shape, and arrangement of openings in them. Openings in the rock provide storage space for ground water and serve as passageways for ground-water movement from points of recharge to points of discharge.

Water generally moves very slowly through fine-grained rocks such as siltstone and shale because the openings between the rock particles are too small to transmit water freely. Movement of water through sandstone varies with grain size, sorting, and degree of cementation. Poorly cemented medium-to coarse-grained sandstone transmits large quantities of water, whereas well-cemented fine-grained sandstone generally transmits small quantities.

AVAILABILITY

Major Aquifers

Alluvium.—Of the various rock formations in the County, the most favorable source of ground water is the alluvium along the Arkansas River, the Salt Fork of the Arkansas, Red Rock Creek, and Black Bear Creek. The thickness of the alluvium ranges from 25 to 55 feet along Black Bear Creek and from 25 to 45 feet along Red Rock Creek. The thickness of the alluvium along the Arkansas River and the Salt Fork of the Arkansas is not known. However, alluvium along the Salt Fork is as thick as 35 feet near Marland; the maximum thickness is estimated to be about 45 feet. The thickness of alluvium along the Arkansas River is

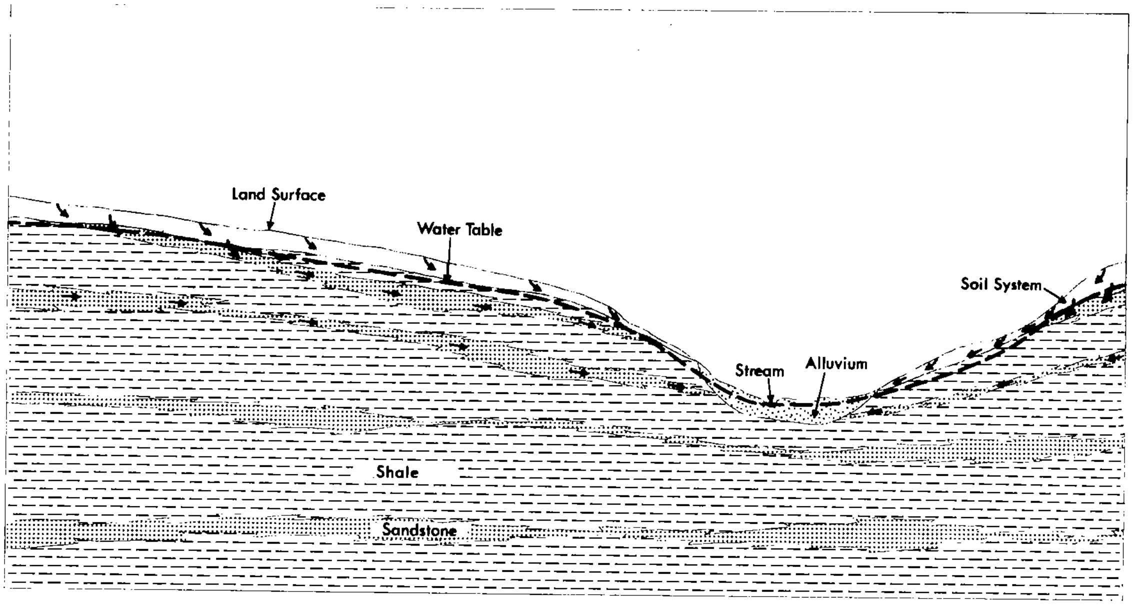


Figure 41. Schematic section illustrating occurrence and movement of ground water in Noble County.

estimated to range from 30 to 60 feet. Grain size of the alluvium generally increases from silt, clay, and fine sand at land surface to gravel at the base of the deposits.

The yield of wells in alluvium depends largely upon the thickness of the basal gravel. The towns of Billings and Red Rock obtain sufficient amounts of water for municipal supply from shallow wells developed in basal gravel of the alluvium along Red Rock Creek. The town of Marland pumps about 25 gpm (gallons per minute) for municipal supply from a well developed in gravel of the alluvium along the Salt Fork of the Arkansas River (fig. 42). Yields from other wells in the alluvium range from 5 to 35 gpm. Although the maximum reported yield from alluvium is 35 gpm, larger yields probably could be obtained locally where the layer of gravel is thickest.

Wellington Formation.—Most of Noble County is underlain by the Wellington Formation of Permian age (pl. 1, in pocket), which consists of red claystone or shale, fine- to very fine-grained well-sorted lenticular sandstone, gray-green shale, and thin layers of dolomite. The thickness of the sandstone layers ranges from a few inches to about 30 feet. The lenticular nature of the sandstone and low permeability of the shale retard ground-water movement, thus limiting the yield of the formation. The Wellington Formation is less favorable than the alluvium as a potential source of ground water; however, in selected areas where the sandstone layers are thickest, yields up to 30 gpm might be obtained. Reported yields of privately owned wells, most less than 100 feet deep, range from a few gallons per day to approximately 10 gpm. Although substantiating data are meager, probably 20 to 25 percent of the wells drilled into the Wellington do not yield adequate supplies of water for household use.

Minor Aquifers

Other than alluvium and the Wellington Formation, none of the formations cropping out in Noble County are known to yield significant amounts of water. Some formations, such as the Matfield and Doyle Shales, locally contain lenticular beds of sandstone as thick as 16 feet. However, these beds probably will not provide more than enough water for household use because of their lenticularity, fineness of grain, and limited extent. Limestone formations, such as the Wreford, Fort Riley, and Herington, are all too thin and too silty to yield water. Locally, however, small amounts of water, possibly enough for household use, may be obtainable at the tops or just below the bases of these

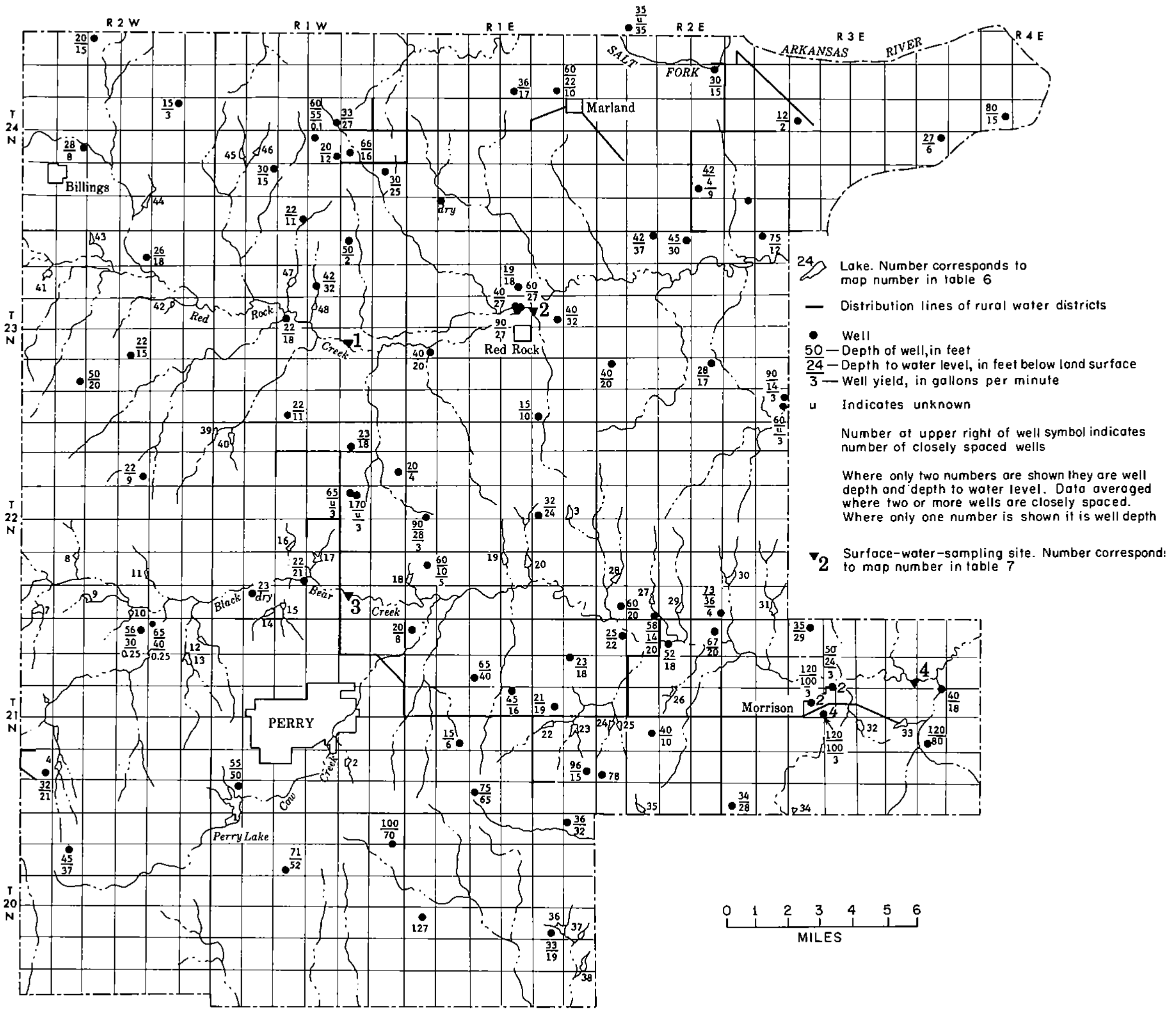


Figure 42. Map showing locations of lakes, rural water-distribution lines, and data on selected wells.

formations. The various shale and claystone formations are not likely to yield enough water for household use.

Some of the more deeply buried formations underlying Noble County may yield water, but in most places the water is probably too highly mineralized for nearly all purposes.

CHEMICAL QUALITY

All ground water contains substances dissolved from air, soil, and rock. The concentration of these substances is related to their solubility, the temperature and chemical character of the water, and the length of time the water is in contact with the air, soil, or rock. High concentrations of dissolved substances may restrict the use of water for many purposes.

In general, concentrations of dissolved minerals increase with depth, and even at depths less than 50 feet dissolved minerals may restrict the use of ground water for domestic purposes. For example, shallow test wells drilled in alluvium at Morrison and Perry were abandoned because the water contained excessive amounts of chloride. Water from selected wells in Noble County was analyzed, and the results are listed in table 4. Data indicate that the water is of fair quality. The dissolved-solids concentra-

TABLE 4.—CHEMICAL ANALYSES OF GROUND WATER FROM SELECTED WELLS IN NOBLE COUNTY

(Analyses from Havens, 1978, p. 82-83)
Results in milligrams per liter

Section location	1-20N-1W	2-21N-2W	32-22N-2E	15-23N-1E	33-23N-1W	22-23N-2W	11-24N-1E
Date sampled	8-14-73	8-14-73	5-17-73	8-14-73	5-18-73	8-14-73	5-18-73
Calcium (Ca)	41.0	63.0	70.0	130.0	120.0	150.0	69.0
Magnesium (Mg)	31.0	18.0	26.0	62.0	57.0	96.0	17.0
Sodium (Na)	200.0	180.0	99.0	100.0	130.0	110.0	170.0
Bicarbonate (HCO_3)	450	507	488	658	482	365	464
Carbonate (CO_3)	0	0	0	0	0	0	0
Chloride (Cl)	96.0	91.0	43.0	110.0	130.0	410.0	42.0
Nitrate (NO_3)	*	*	3.9	*	86.0	*	120.0
Sulfate (SO_4)	150.0	70.0	27.0	110.0	150.0	110.0	58.0
Dissolved solids	734	636	522	802	948	1160	722
Hardness	[1]230	230	280	580	540	770	240
				[2]40		470	

*Not analyzed.
[1]Top line: hardness as Ca + Mg.
[2]Bottom line: noncarbonate hardness.

tion of the samples collected ranged from 522 to 1,160 mg/l (milligrams per liter). Hardness ranged from 230 to 770 mg/l, and bicarbonate ranged from 365 to 658 mg/l. Chloride concentrations were below 250 mg/l, the maximum recommended for drinking water by the U.S. Public Health Service, except for a well in sec. 22, T. 23 N., R. 2 W., which recorded 410 mg/l. The water at Morrison is of the sodium bicarbonate type and may be unsuitable for irrigation purposes; it also contains sulfate in excess of 250 mg/l, the maximum recommended by the U.S. Public Health Service. The fluoride content is far above 1.7 mg/l, the maximum recommended for drinking water. Although fluoride reduces the incidence of tooth decay, it may cause mottling of the teeth when the concentration exceeds 1.5 mg/l.

SURFACE WATER

The greatest potential source of surface water in Noble County is the Arkansas River. The Arkansas forms the northeastern part of the County boundary, known locally as the "Big Bend." The Salt Fork of the Arkansas River also provides large quantities of surface water to the northeastern part of the County.

Continuous streamflow records are not available for streams in Noble County. However, table 5 summarizes streamflow at nearby gaging stations on the Arkansas River, on the Salt Fork of the Arkansas, and on Black Bear Creek.

Black Bear Creek and Red Rock Creek, which are tributaries of the Arkansas River, provide drainage in most of the County. Precipitation averages about 32 inches annually at Perry, and runoff averages about 3.5 inches. The amount and intensity of precipitation are major factors in stream runoff. During and immediately after rainfall, the overland flow of water constitutes a major part of streamflow. At times, rainfall causes flooding along some of the streams. During dry periods, however, streamflow is

TABLE 5.—SUMMARY OF SURFACE-WATER RECORDS FROM NOBLE COUNTY

Stream and location	Station number	Drainage area (square miles)	Period of record	Discharge Cubic feet per second: Maximum	Minimum	Average	Remarks
Arkansas River at Ralston	7-1525	54,465	1925-1977	211,000 (gage height, 22.98 ft)	14	[1]4,826	Maximum known stage 23.8 ft, June 11, 1923.
Salt Fork Arkansas River at Tonkawa	1510	4,528	1935-1977	97,300 (gage height, 28.98 ft)	0	738	Flood of October 11, 1973, reached a stage of 28.98 ft. No flow August 31 to October 12, October 14-16, 1956.
Black Bear Creek at Pawnee	1530	576	1944-1977	30,200 (gage height, 31.43 ft)	0	178	No flow at times in 1954, 1956-57, 1964-68.

[1]Average to 1975 prior to filling of Kaw Lake.

derived chiefly from ground-water discharge into the streams through their beds and banks. Thus, small streams in the County have no flow during the summer months when evaporation and transpiration loss is greatest. Surface reservoirs are needed to provide a year-round surface-water supply.

Surface reservoirs provide the major part of the water in the County and are the prime source of water for municipal and industrial use. Although the prime purpose of the reservoirs is to impound water for flood control and water supply, recreation is an important secondary benefit. The locations of the reservoirs are shown in figure 42, and pertinent data are summarized in table 6.

Forty-eight of the largest lakes have a combined drainage area of about 100 square miles. The total surface area of all the lakes ranges from about 725 acres of permanent pool to about 2,700 acres of flood pool. Water storage in the reservoirs ranges from a minimum of about 11,000 acre-feet to a maximum of about 30,000 acre-feet. In addition to the lakes listed in table 6, numerous small ponds and lakes provide water for stock and other farm uses.

CHEMICAL QUALITY

During periods of low flow, water from most of the major streams in Noble County contains high concentrations of dissolved minerals (table 7). Generally the water is unsuitable for municipal use and some types of industrial use. In addition, high SAR (sodium-adsorption-ratio) values during low flow restrict the use of surface water for irrigation purposes. Water supplies of suitable chemical quality for most uses, however, are obtained from lakes constructed along tributaries of major streams (fig. 42).

WATER USE

Noble County residents use approximately 82.3 million gallons of water per month. The city of Perry, which also supplies five industries with water, used most of the 29.5 million gallons consumed by Perry residents in 1977. All other municipal water-supply systems collectively use about 12 million gallons per month. Many home owners depend upon cisterns or ponds for their domestic water supply, and in some areas of the County the U.S. Farmers Home

TABLE 6.—LAKES IN NOBLE COUNTY

Map number	Name	Section location	Drainage area (square miles)	Flood pool Surface area (acres)	Flood pool Storage (acre-feet)	Permanent pool Surface area (acres)	Permanent pool Storage (acre-feet)
1	Perry Lake	6-20N-1W	16.22	—	—	—	7,096
2	Perry Park Lake	26-21N-1W	—	—	—	—	147
3	Donahue	13-22N-1E	—	—	—	—	96
	Flood-control structures (U.S. Soil Conservation Service)						
Upper Black Bear Creek							
4	Site 51	29-21N-2W	4.03	138	1,188	19	183
5	Site 50	20-21N-2W	1.63	47	378	13	102
6	Site 47	18-21N-2W	2.03	69	468	22	103
7	Site 44	31-22N-2W	1.32	50	308	18	72
8	Site 22	29-22N-2W	1.52	60	353	15	73
9	Site 45	33-22N-2W	2.23	86	514	25	139
10	Site 46	34-22N-2W	1.76	64	408	20	116
11	Site 20	27-22N-2W	1.70	65	392	15	74
12	Site 58	1-21N-2W	2.73	74	625	12	138
13	Site 57	12-21N-2W	5.01	134	1,130	36	227
14	Site 59	32-22N-1W	.72	30	170	8	42
15	Site 60	33-22N-1W	1.97	56	454	17	110
16	Site 17	21-22N-1W	1.00	34	235	12	73
17	Site 16	27-22N-1W	.65	30	153	7	40
18	Site 15	30-22N-1E	.91	38	213	12	49
19	Site 12	27-22N-1E	1.13	43	265	8	48
20	Site 11	27-22N-1E	1.94	60	448	10	56
21	Site 69	35-22N-1E	.60	23	142	5	23
22	Site 71	23-21N-1E	3.44	85	1,107	20	174
23	Site 72	24-21N-1E	2.06	66	622	14	110
24	Site 73	19-21N-2E	1.01	51	307	18	57
25	Site 74	19-21N-2E	.75	32	231	11	46
26	Site 75	16-21N-2E	1.28	60	298	14	65
27	Site 7	32-22N-2E	2.45	101	565	20	65
28	Site 8	30-22N-2E	2.38	88	548	18	63
29	Site 6	33-22N-2E	2.75	80	630	15	73
30	Site 5	26-22N-2E	1.29	44	301	9	35
31	Site 2	36-22N-2E	2.95	95	675	18	78
Long Branch Creek							
32	Site 11	21-21N-3E	1.43	48	313	17	65
33	—	22-21N-3E	—	—	—	—	—
34	Site 10	31-21N-3E	.97	48	313	17	65
35	Site 4	32-21N-2E	1.03	42	225	14	49
Stillwater Creek							
36	Site 39	24-20N-1E	.54	18	146	5	22
37	Site 38	24-20N-1E	.92	36	248	9	37
38	Site 37	25-20N-1E	.61	24	164	6	24

TABLE 6.—*Continued*

Map number	Name	Section location	Drainage area (square miles)	Flood pool Surface area (acres)	Flood pool Storage (acre-feet)	Permanent pool Surface area (acres)	Permanent pool Storage (acre-feet)
Upper Red Rock Creek							
39	Site 54	6-22N-1W	3.82	149	890	33	153
40	Site 55	6-22N-1W	1.08	48	263	10	47
41	Site 48	7-23N-2W	1.26	65	301	22	80
42	Site 51	14-23N-2W	1.06	39	257	16	63
43	Site 13	4-23N-2W	1.21	45	288	14	64
44	Site 9	34-24N-2W	1.13	51	270	15	53
45	Site 6	19-24N-1W	.96	64	307	17	52
46	Site 5	20-24N-1W	1.17	81	374	18	62
47	Site 2	9-23N-1W	1.94	69	464	21	71
48	Site 1	15-23N-1W	1.11	51	270	15	53

Administration has constructed distribution systems (fig. 42) to provide water where home owners could not obtain adequate supplies from shallow wells. The number of residents in Noble County depending on privately owned water supplies is estimated to be 3,000.

SUMMARY

In most of Noble County, ground water is available only in small quantities. Moderate amounts of water, however, are available to wells developed in alluvium along major streams. Locally, shale and fine-grained sandstone yield only a few gallons of water per day to drilled wells.

The greatest potential source of surface water is the Arkansas River. The other streams are intermittent and require surface reservoirs for a year-round water supply. Structures originally built for flood-control purposes furnish adequate amounts of water for towns, small industries, and several rural areas in the County.

During low flow, water in major streams is of poor chemical quality and unsuitable for many uses. In some areas, high concentrations of dissolved minerals restrict the use of ground water.

The estimated use of water in Noble County during 1976 was 82.3 million gallons per month.

Table 7.—Summary of Chemical Analyses of Surface Water in Noble County

Results in milligrams per liter, except as indicated

Location number	Stream and location	Type of sampling,[1] water year, (number of analyses)	Sulfate mg/l Max	Sulfate mg/l Min	Chloride mg/l Max	Chloride mg/l Min	Dissolved solids mg/l Max	Dissolved solids mg/l Min	Hardness mg/l Max	Hardness mg/l Min	SAR[2] Max	SAR[2] Min	Specific conductance[3] Max	Specific conductance[3] Min
1	Red Rock Creek near Ceres	M, 58(10), 59(2)	25	24	44	20	341	290	198	81	1.5	0.9	560	250
2	Red Rock Creek near Red Rock	M, 51(4), 52(6), 53(5), 55(4), 56(10)	171	18	535	6.2	1,170	177	550	34	7.1	.4	2,040	93
3	Black Bear Creek near Perry	M, 50(10), 58(16), 59(2)	61	40	4,500	84	7,420	1,010	2,800	126	8.0	1.9	12,300	512
4	Black Bear Creek near Morrison	M, 51(4), 58(16), 59(2)	51	16	2,410	42	4,940	288	1,720	71	6.2	1.1	7,480	249

[1]M, miscellaneous.
[2]Sodium adsorption ratio.
[3]Micromhos at 25°C.

REFERENCES CITED

Arbogast, J. L., and others, 1960, Method and apparatus for determining directional dielectric anisotropy in solids: U.S. Patent no. 2,963,642.

Arbenz, J. K., 1956, Tectonic map of Oklahoma: Oklahoma Geological Survey Map GM-3, scale 1:750,000.

Aurin, F. L., Officer, H. G., and **Gould, C. N.,** 1926, The subdivision of the Enid formation: American Association of Petroleum Geologists Bulletin, v. 10, p. 786–799.

Billings, R. L., 1956, Geology of eastern Noble County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 56 p.

Branson, C. C., 1962, Pennsylvanian System of the Mid-Continent, *in* Branson, C. C. (editor), Pennsylvanian System in the United States—a symposium: American Association of Petroleum Geologists, p. 431–460.

Brensing, O. H., Talley, E. C., Fitzpatrick, E. G., and **Templin, E. H.,** 1956, Soil survey of Noble County, Oklahoma: U.S. Department of Agriculture Soil Conservation Service ser. 1941, no. 16, 67 p.

Bullard, B. M., 1928, Digest of Oklahoma oil and gas fields, *in* Oil and gas in Oklahoma: Oklahoma Geological Survey Bulletin 40, v. 1, p. 101–276.

Carlson, K. J., 1968, The skull morphology and estivation burrows of the Permian lungfish, *Gnathorhiza serrata:* Journal of Geology, v. 76, p. 641–663.

Carpenter, F. M., 1947, Introduction and the orders Megasecoptera, Protodonata, and Odonata, *pt. 1 of* Lower Permian insects from Oklahoma: American Academy of Arts and Sciences Proceedings, v. 76, p. 25–54.

Clark, G. C., 1926, Wilcox sand production, Tonkawa field, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 10, p. 885–891.

Clark, G. C., and **Aurin, F. L.,** 1924, The Tonkawa field, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 8, p. 269–283.

Clark, G. C., and **Cooper, C. L.,** 1927 [1930], Kay, Grant, Garfield and Noble Counties, *in* Oil and gas in Oklahoma: Oklahoma Geological Survey Bulletin 40, v. 2, p. 67–104.

Clendening, J. A., 1971, Palynological evidence for assignment of the Gearyan Stage of Kansas to the Pennsylvanian [abstract]: Geological Society of America Abstracts with Programs, v. 3, no. 3, South-Central Section 5th Annual Meeting, p. 234–235.

Decker, C. E., 1938, A Permian eurypterid from Oklahoma: Journal of Paleontology, v. 12, p. 396–397.

Dover, T. B., Leonard, A. R., and **Laine, L. L.,** 1968, Water for Oklahoma: U.S. Geological Survey Water-Supply Paper 1890, 107 p.

———1962, Spectral subdivision of limestone types, *in* Ham, W. E. (editor), Classification of carbonate rocks—a symposium: American Association of Petroleum Geologists Memoir 1, p. 62–84.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, *in* Ham, W. E. (editor), Classification of carbonate rocks—a symposium: American Association of Petroleum

Geologists Memoir 1, p. 108–121.

Folk, R. L., 1954, The distinction between grain size and mineral composition in sedimentary-rock nomenclature: Journal of Geology, v. 62, p. 344–359.

Gould, C. N., 1925, Index to the stratigraphy of Oklahoma; with lists of characteristic fossils by Charles E. Decker: Oklahoma Geological Survey Bulletin 35, 115 p.

Greig, P. B., 1959, Geology of Pawnee County, Oklahoma: Oklahoma Geological Survey Bulletin 83, 188 p.

Hall, S. A., 1966, *Lingula* in the Wellington Formation (Permian) of Oklahoma: Oklahoma Geology Notes, v. 26, p. 258–259.

Havens, J. S., compiler, 1978, Water-quality records for wells, test-holes, and springs, *part 2 of* Groundwater records for eastern Oklahoma: U.S. Geological Survey Open-File Report 78-357, 139 p.

Havens, J. S., and **Bergman, D. L.**, 1976, Records of wells, test-holes, and springs, *part 1 of* Groundwater records for northeastern Oklahoma: U.S. Geological Survey Open-File Report, 100 p.

Hayes, C. J., **Hartronft, B. C.**, and **McCasland, W.**, 1967, Idealized cross section—Noble County, *in* Engineering classification of geologic materials and (related soils), Division Four: Oklahoma Highway Department, Research and Development Division, in cooperation with U.S. Bureau of Public Roads, p. 84–85.

Heine, R. R., 1975, Geochemistry and mineralogy of the Permian red beds and related copper deposits, Payne, Pawnee, and Noble Counties, Oklahoma: Oklahoma State University unpublished M.S. thesis, 70 p.

Hoffman, M. G., 1940, Structural history of Billings field, Noble County, Oklahoma, interpreted in terms of isostasy: American Association of Petroleum Geologists Bulletin, v. 24, p. 2006–2018.

International Oil Scouts Association, 1976 [1977], Oklahoma, *in* Production, *pt. 2 of* International oil and gas development, yearbook 1976 (review of 1975), U.S. and Canada: v. 146, p. 332–426.

Johnson, K. S., **Branson, C. C.**, **Curtis, N. M., Jr.**, **Ham, W. E.**, **Marcher, M. V.**, and **Roberts, J. F.**, 1972, Geology and earth resources of Oklahoma—an atlas of maps and cross sections: Oklahoma Geological Survey Educational Publication 1, 8 p.

Jordan, Louise, 1962, Geologic map and section of pre-Pennsylvanian rocks in Oklahoma: Oklahoma Geological Survey Map GM-5, scale 1:750,000.

Klaus, Helmut, 1943, Faulting in the Billings oil field, Oklahoma, as interpreted from torsion balance data, and from subsequent drilling: Geophysics, v. 8, p. 362–378.

Krumbein, W. C., and **Monk, G. O.**, 1943, Permeability as a function of size parameters of unconsolidated sand: American Institute of Mining and Metallurgical Engineers Technical Publication 1492, 11 p.

Lukert, L. H., 1949, Subsurface cross sections from Marion County, Kansas, to Osage County, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 33, p. 131–152.

McBride, E. F., 1963, A classification of common sandstones: Journal of Sedimentary Petrology, v. 33, p. 664–669.

Melton, F. A., 1931, Joint studies in the southwest and their bearing on tectonic history [abstract]: Geological Society of America Bulletin, v. 42, p. 231.

Mize, L. D., 1975, Statistical summaries of streamflow records, Oklahoma, through 1974: U.S. Geological Survey Open-File Report, 399 p.

Muehlberger, W. R., **Denison, R. E.**, and **Lidiak, E. G.**, 1967, Basement rocks in continental interior of United States: American Association of Petroleum Geologists Bulletin, v. 51, p. 2351–2380.

Nanz, R. H., 1960, Exploration of earth formations associated with petroleum deposits: U.S. Patent no. 2,963,641.

Neal, E. P., 1951, South Ceres—Oklahoma's oddest shoestring field: World Oil, v. 133, no. 7 (Dec.), p. 92–98.

Noll, C. R., 1955, Geology of southeastern Kay County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 88 p.

Olson, E. C., 1967, Early Permian vertebrates of Oklahoma: Oklahoma Geological Survey Circular 74, 111 p.

Page, K. G., 1955, The subsurface geology of southern Noble County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 69 p. (*Published in* Shale Shaker, v. 5, no. 10 (June 1955), p. 5–21, 24–25, 34, 42.)

Patterson, J. M., 1933, Permian of Logan and Lincoln Counties, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 17, p. 241–256.

Potter, P. E., and **Pettijohn, F. J.**, 1963, Paleocurrents and basin analysis: New York, Academic Press, 296 p.

Raasch, G. O., 1946, The Wellington Formation in Oklahoma: University of Wisconsin unpublished Ph.D. dissertation, 157 p.

Raymond, P. E., 1944, Late Paleozoic Xiphosurans: Harvard College Museum of Comparative Zoology Bulletin, v. 94, p. 496–497.

———1946, The genera of fossil Conchostraca—an order of bivalved Crustacea: Harvard College Museum of Comparative Zoology Bulletin, v. 96, p. 215–307.

Shelton, J. W., 1963, Measured sections of sandstones and shales: American Association of Petroleum Geologists Bulletin, v. 47, p. 2047–2050.

Smith, G. N., 1927, The Permian vertebrates of Oklahoma: University of Oklahoma unpublished M.S. thesis, 46 p.

Talley, J. B., 1955, The subsurface geology of northeastern Noble County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 58 p.

Tarr, R. S., **Jordan, Louise**, and **Rowland, T. L.**, 1965, Geologic map and section of pre-Woodford rocks in Oklahoma: Oklahoma Geological Survey Map GM-9, scale 1:750,000.

Tasch, Paul, 1956, Three general principles for a system of classification of fossil conchostracans: Journal of Paleontology, v. 30, p. 1248–1257.

———1961, Data on some new Leonardian conchostracans with observations on the taxonomy of the family Vertexiidae: Journal of Paleontology, v. 35, p. 1121–1129.

———1962, Taxonomic and evolutionary significance of two new conchostracan genera from the midcontinent Wellington Formation: Journal of Paleontology, v. 36, p. 817–821.

———1964, Periodicity in the Wellington Formation of Kansas and Oklahoma, *in* Merriam, D. F. (editor), Symposium on cyclic sedimentation: Kansas Geological Survey Bulletin 169, v. 2, 481-496.

Tasch, Paul, Kidson, Evan, and **Johnson, J. H.,** 1969, Lower Permian algal stromatolites from Kansas and Oklahoma: University of Kansas Paleontological Contributions, Paper 43, 19 p.

Tasch, Paul, and **Zimmerman, J. R.,** 1962, The *Asthenohymen-Delopterum* bed—a new Leonardian insect horizon in the Wellington of Kansas and Oklahoma: Journal of Paleontology, v. 36, p. 1319-1333.

U.S. Public Health Service, 1962, Drinking-water standards: Publication 956, 61 p.

Vance Rowe Reports, 1971, Index and summary of production by fields, northern Oklahoma: Petroleum Statistical Guide, Inc., Tulsa, Oklahoma.

Walker, T. R., 1967, Formation of red beds in modern and ancient deserts: Geological Society of America Bulletin, v. 78, p. 353-368.

Wilson, L. R., and **Rashid, M. A.,** 1971, Palynological evidence for a Pennsylvanian age assignment of the Gearyan Series in Kansas and Oklahoma [abstract]: Geological Society of America Abstracts with Programs, v. 3, no. 3, South-Central Section 5th Annual Meeting, p. 248.

Zavoico, B. B., 1934, Geology and economic significance of the Lucien field: World Petroleum, v. 5 (Nov.), p. 416-424.

APPENDIX

Measured Stratigraphic Sections

Representative sections of the key stratigraphic units are given in graphic form. Although the form utilized has been described (Shelton, 1963), several explanatory notes are given herein. The form allows the lithology, thickness, and resistance to weathering to be shown graphically. A list for sedimentary structures serves as a checklist that can be keyed to the appropriate bed. Grain size and sorting are shown as graphic vertical sections. The list of constituents is given in such a manner that, by shading in the appropriate areas, qualitative values of rare, common, and abundant can be noted for the frequency of each material. Photographs, paleocurrent measurements, notes, and samples can be plotted opposite the appropriate bed.

The form is thought to allow for more meaningful correlation and comparison of different sections, including the subsurface. It is thought further that the form can aid in reducing operator error and aid in obtaining a greater degree of reproducibility by subsequent workers. The desired end result is greater utilization of the measured sections not only in the original work but also in later studies of an area.

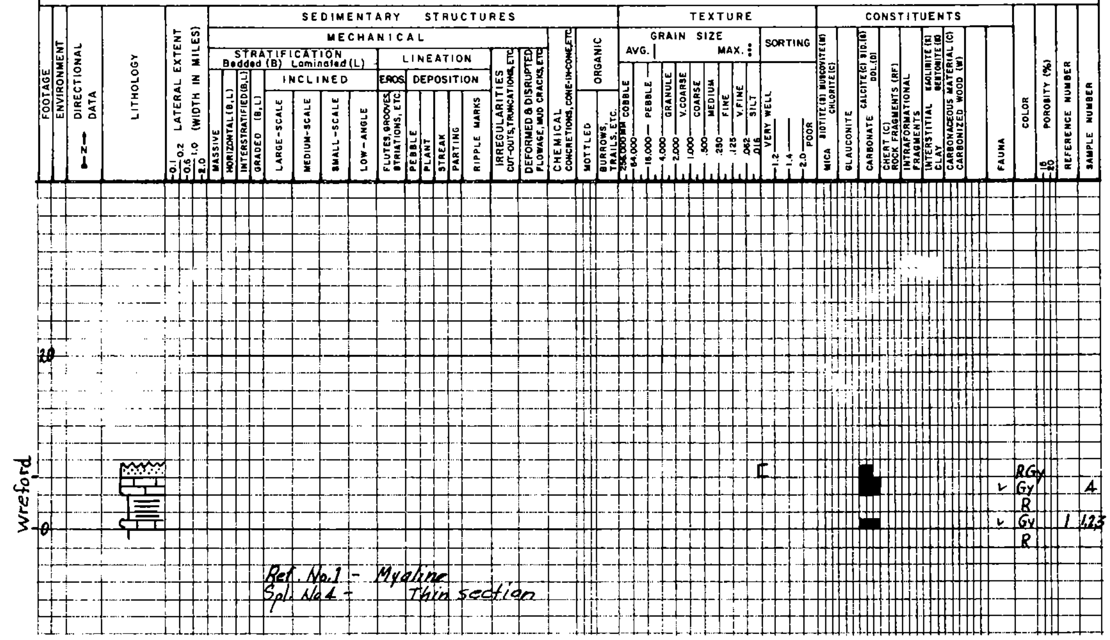
1. Wreford Limestone

SW¼SW¼ Sec. 13 T.24N R. 3E Map ______ Photo OL-3BB-215

Noble Co., Oklahoma Section No. 1

Area Arkansas terrace; creek crossing Structural Dip <1° By ______

Outcrop Pattern--Linear inlier belt ______ Formation Wreford



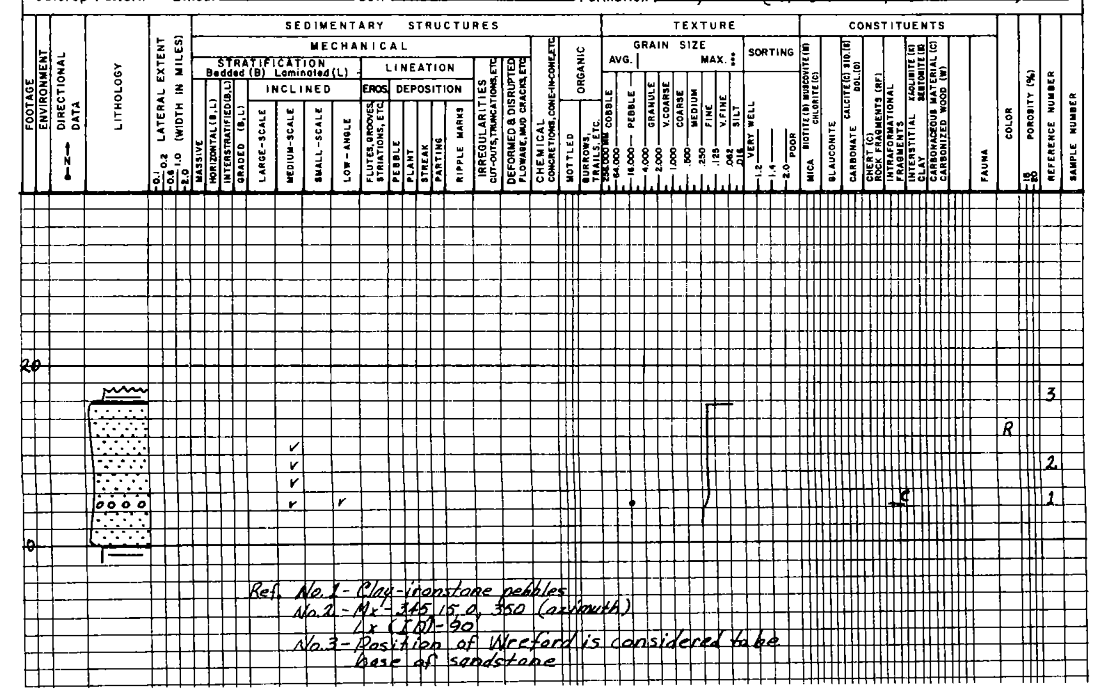
2. Wreford Limestone

SE¼SE¼SW¼ Sec. 13 T.21N R. 3E Map ______ Photo OL-3BB-6

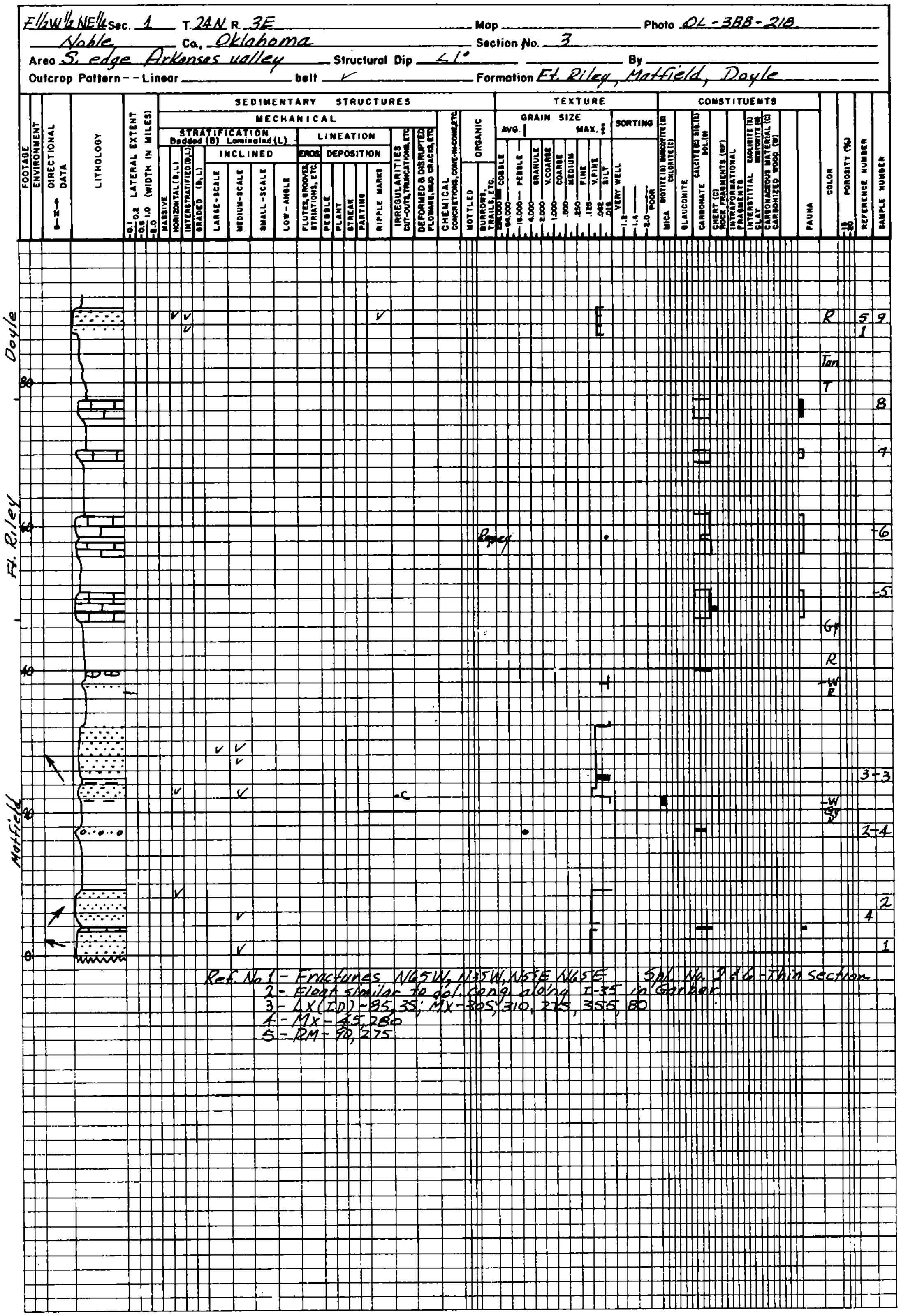
Noble Co., Oklahoma Section No. 2

Area along county road Structural Dip <1° By ______

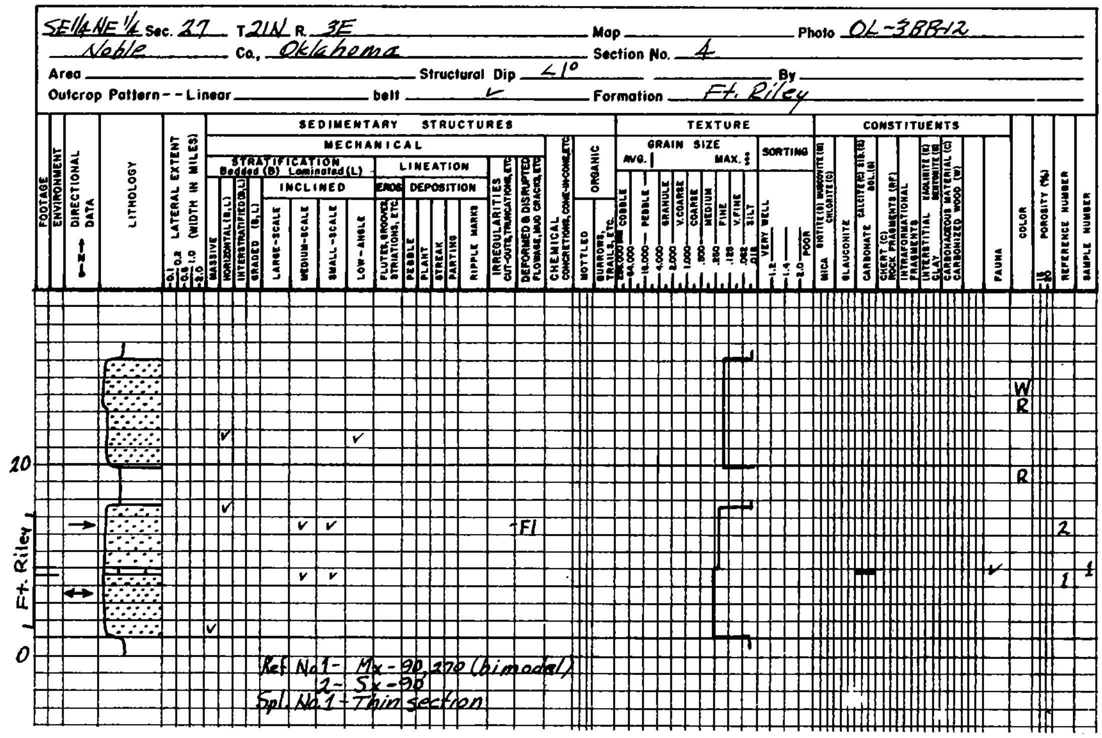
Outcrop Pattern--Linear ______ belt ✓ Formation Wreford (at base of sandstone)



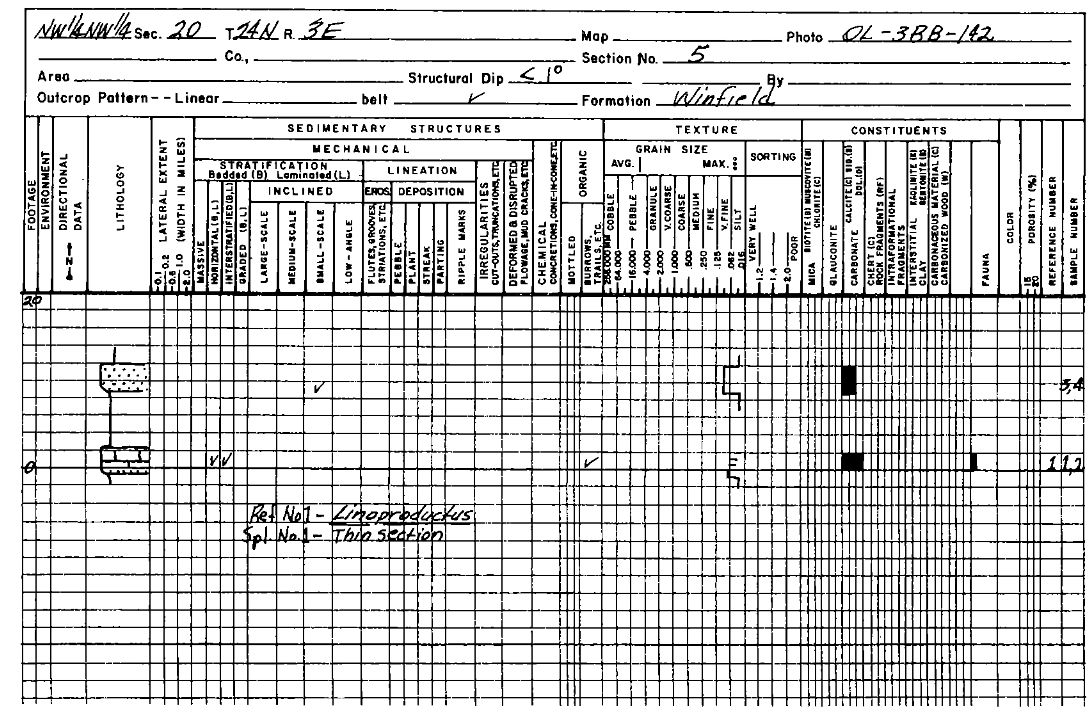
3. Fort Riley Limestone



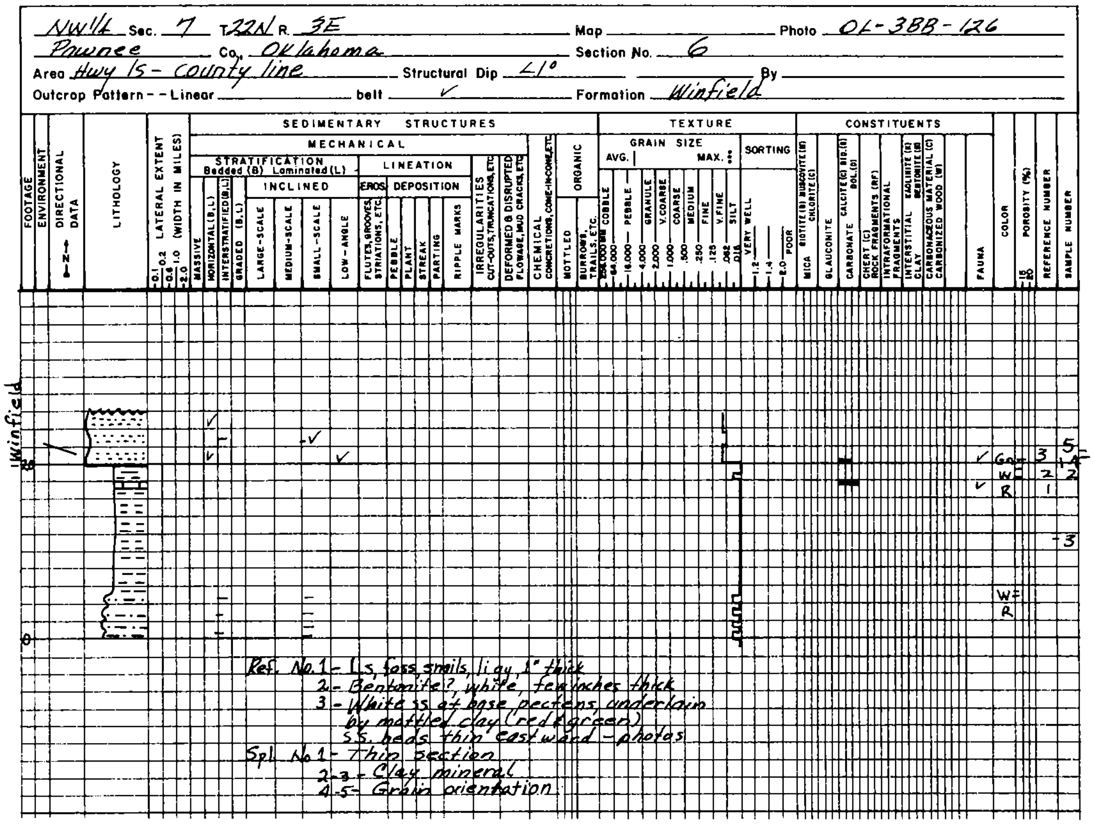
4. Fort Riley Limestone



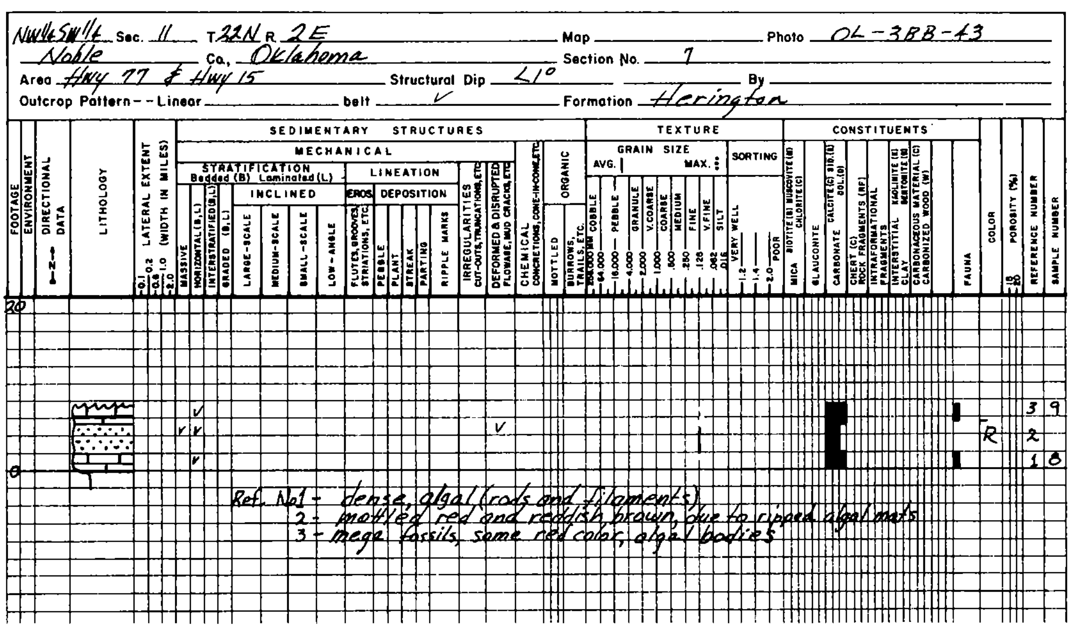
5. Winfield Limestone



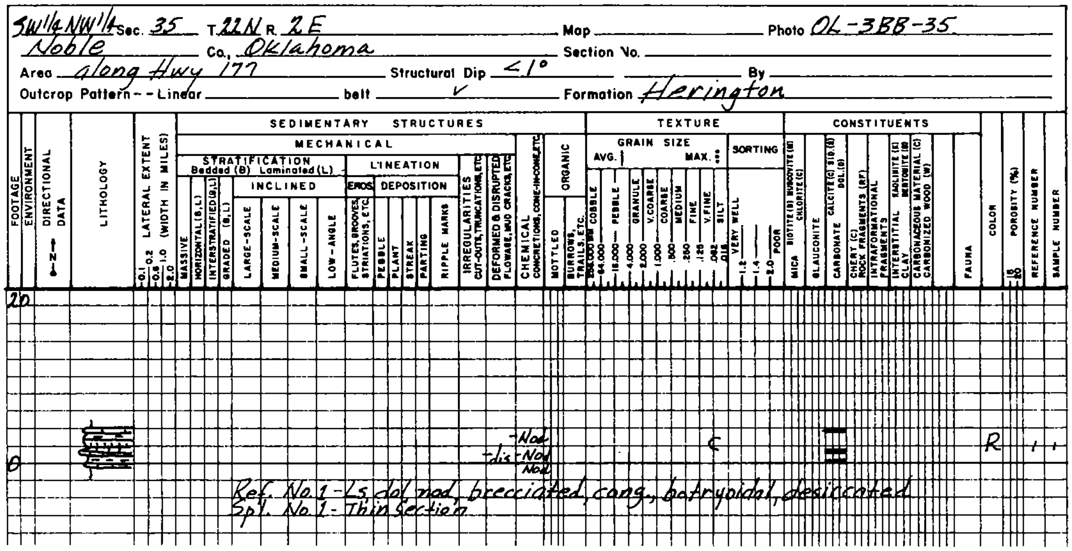
6. Winfield Limestone



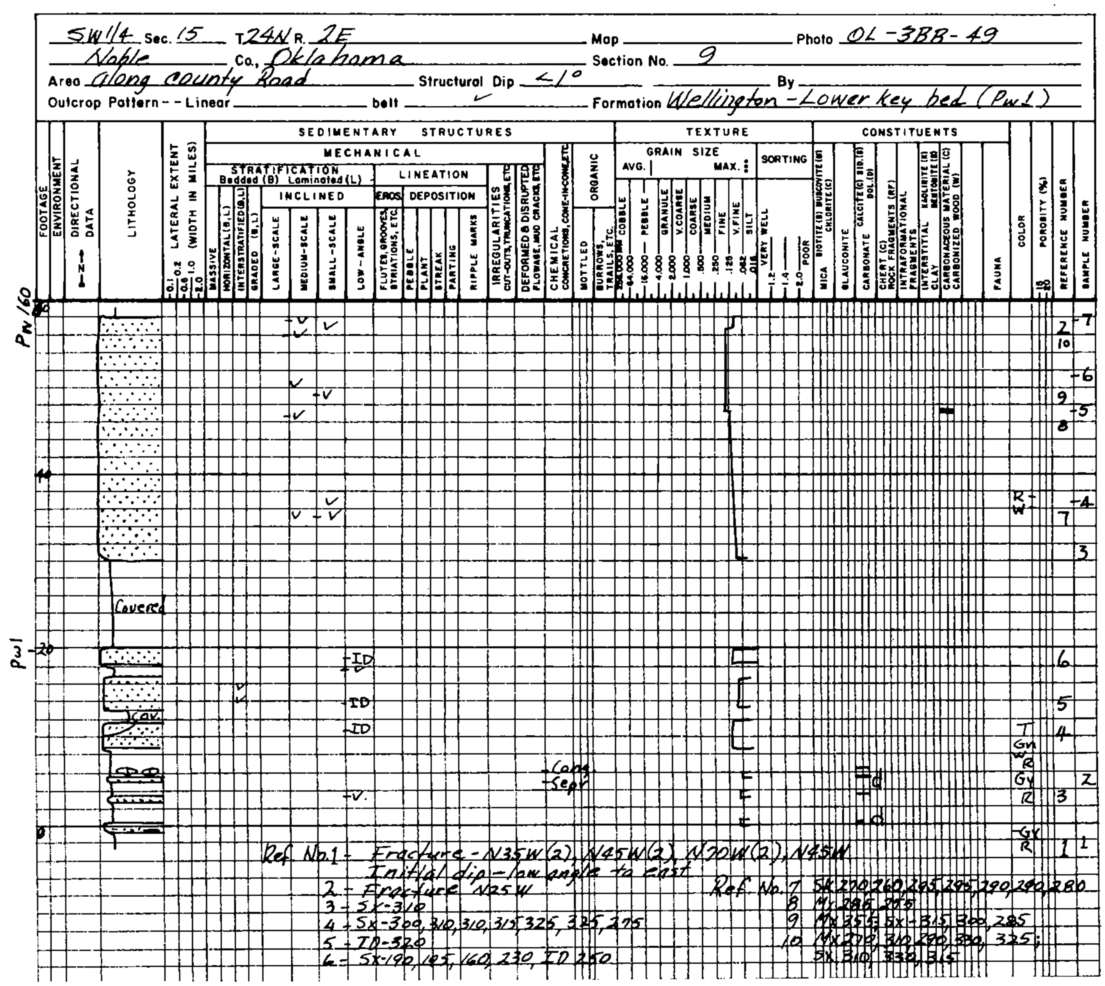
7. Herington Limestone



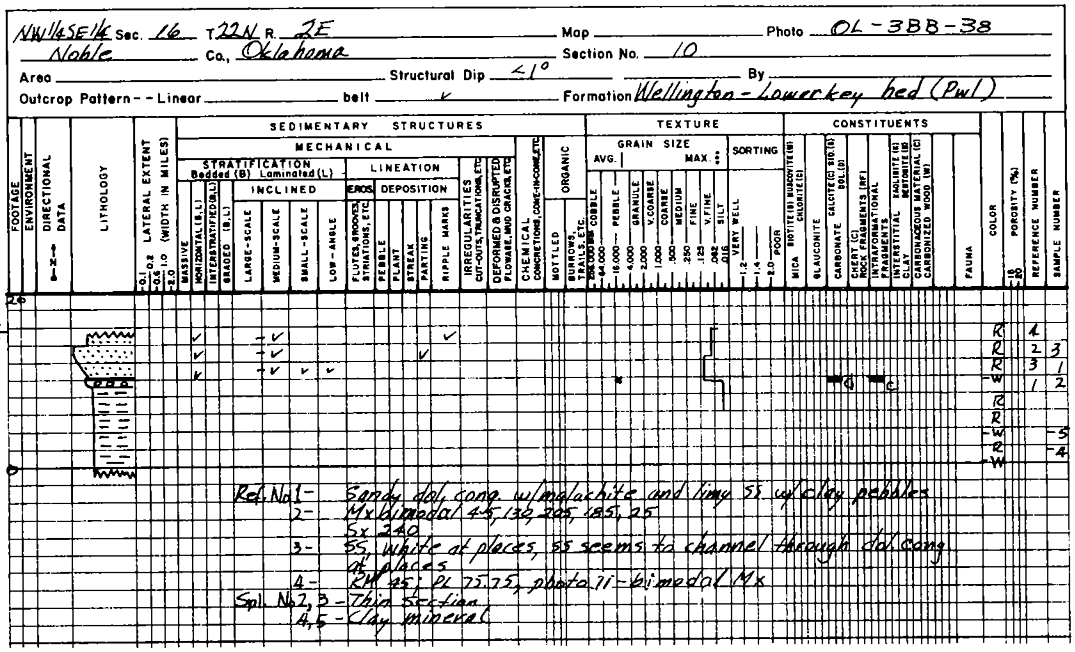
8. Herington Limestone



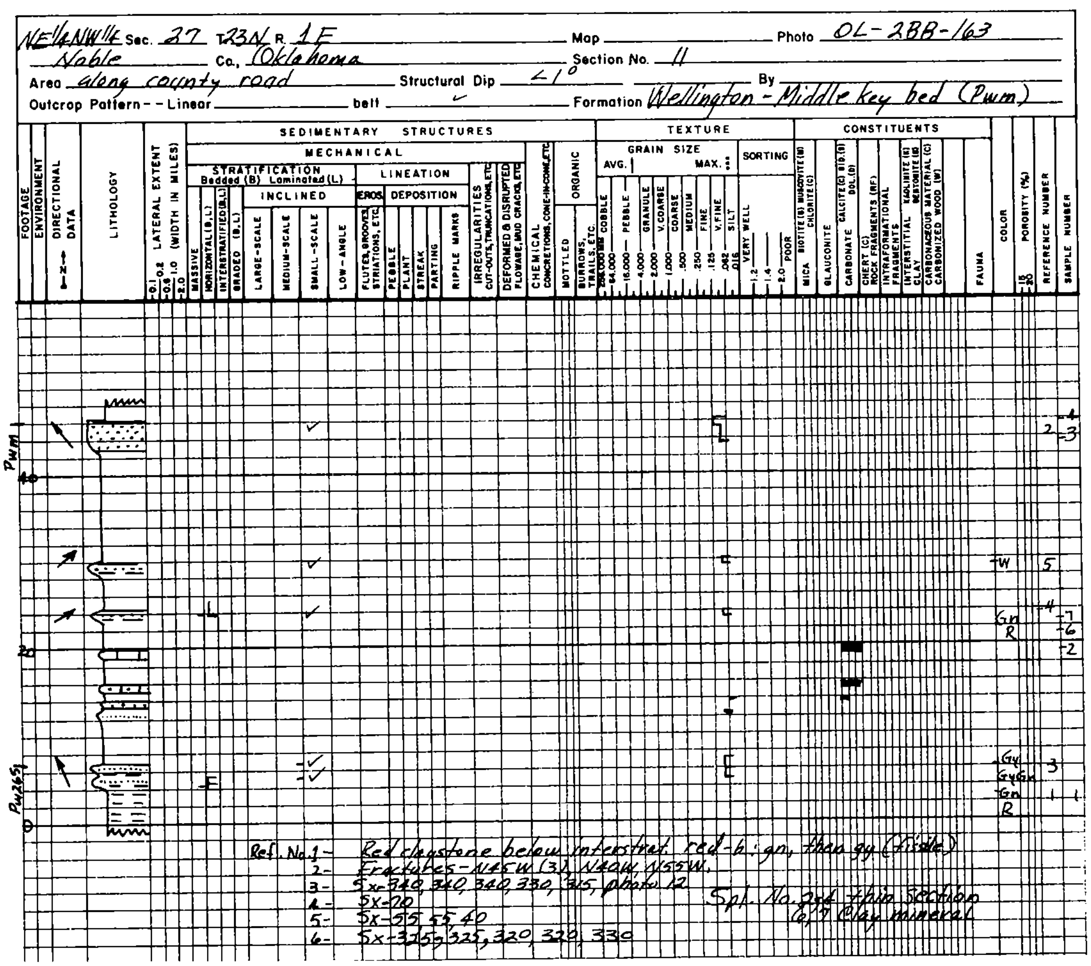
9. Wellington Formation



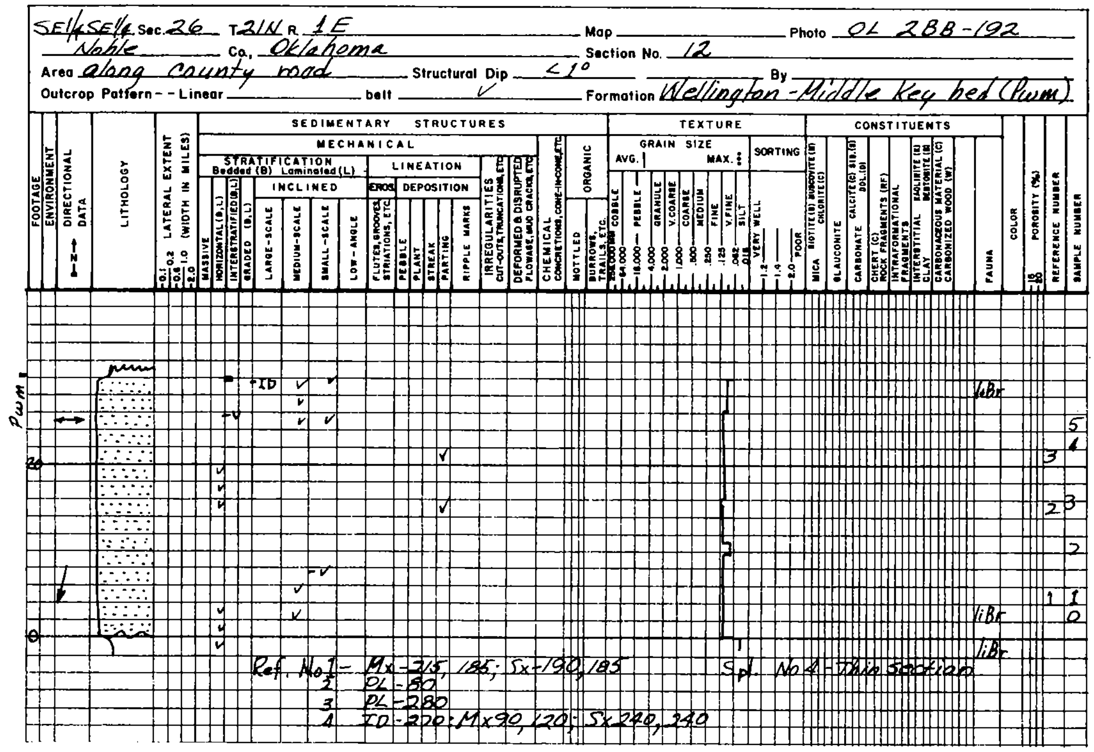
10. Wellington Formation



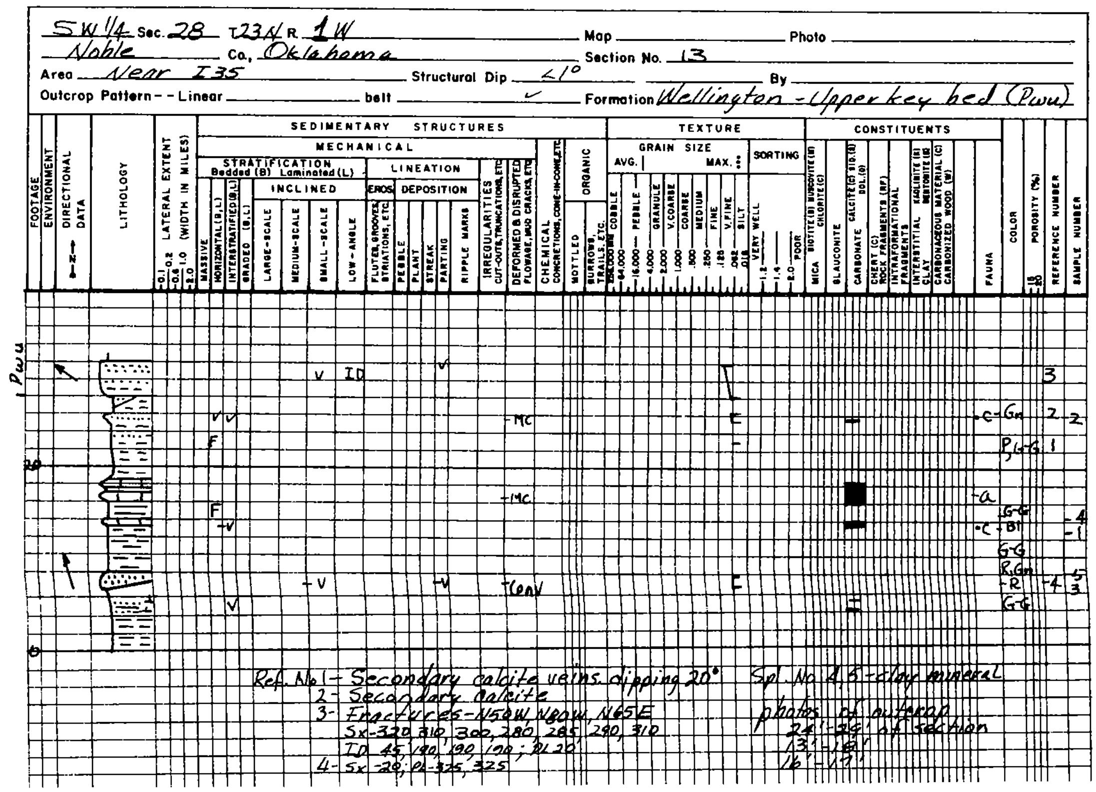
11. Wellington Formation



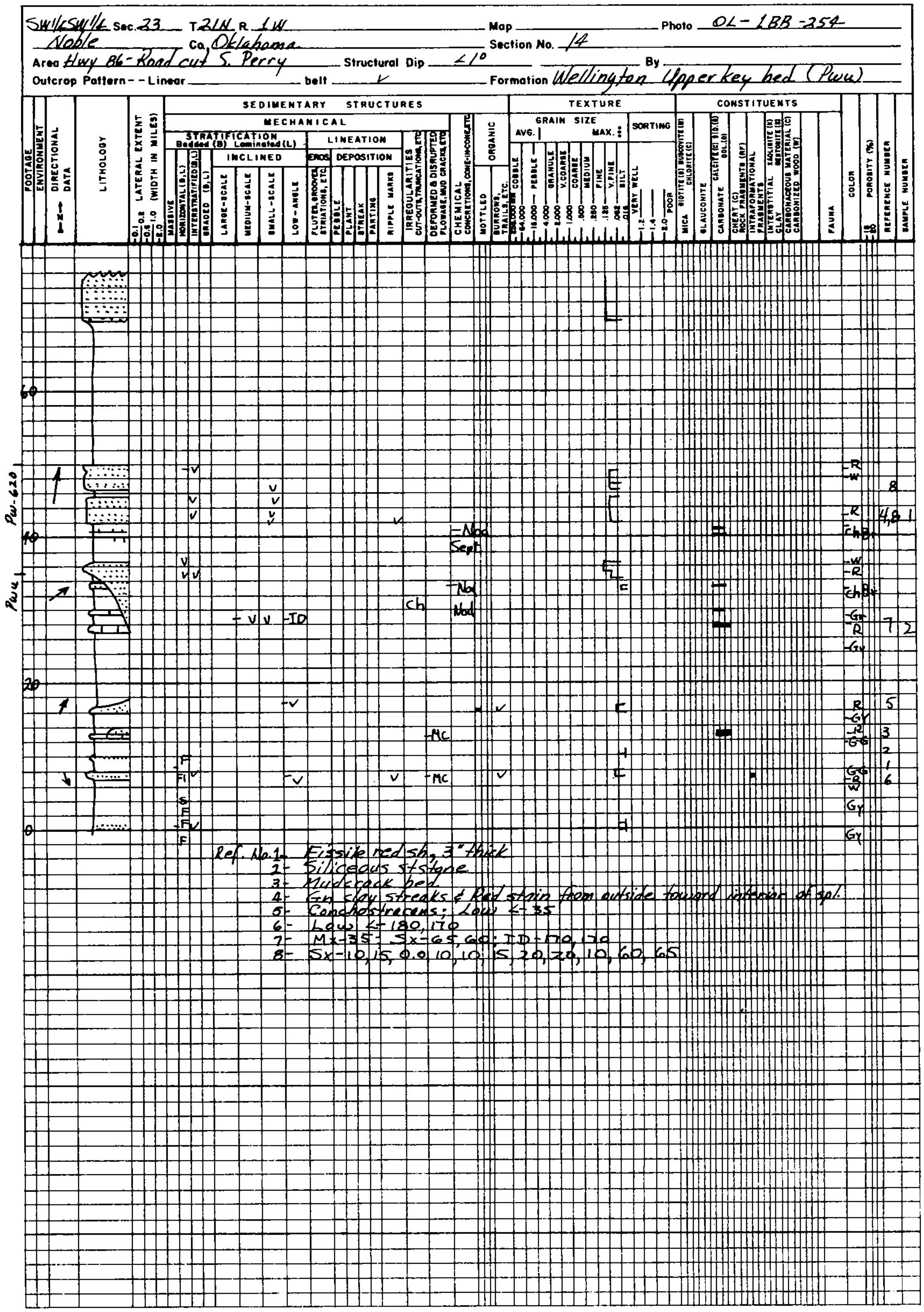
12. Wellington Formation



13. Wellington Formation



14. Wellington Formation



15. Garber Sandstone

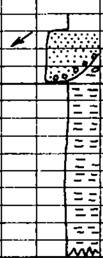
NW¼NW¼ Sec. 3 T. 20N R. 2W Map ____ Photo OL-1BB-177

Noble Co., Oklahoma Section No. 15

Area ____ Structural Dip <1° ____ By ____

Outcrop Pattern--Linear ____ belt ✓ Formation Garber

20



Ch Conv (color)

core

R 2-3

4

NGy-Gn 1-1

R 0-2

R

0

Ref. No. 0 - Veinlets in claystone at low angle

1 - Clay pebble Cong. w/ some conc.

2 - Mx - looks marine - mega-ripples (like E carbonates) SSW

Mx - 230, 330, 330, 230, 245, 260, 180

Sx - 230, 230, 235, 270

Low angle (IO) 285

3 - Fractures N5°E N40W

4 Photos - gn-red color (convolute-like contact)

- gn-red claystone + SS above

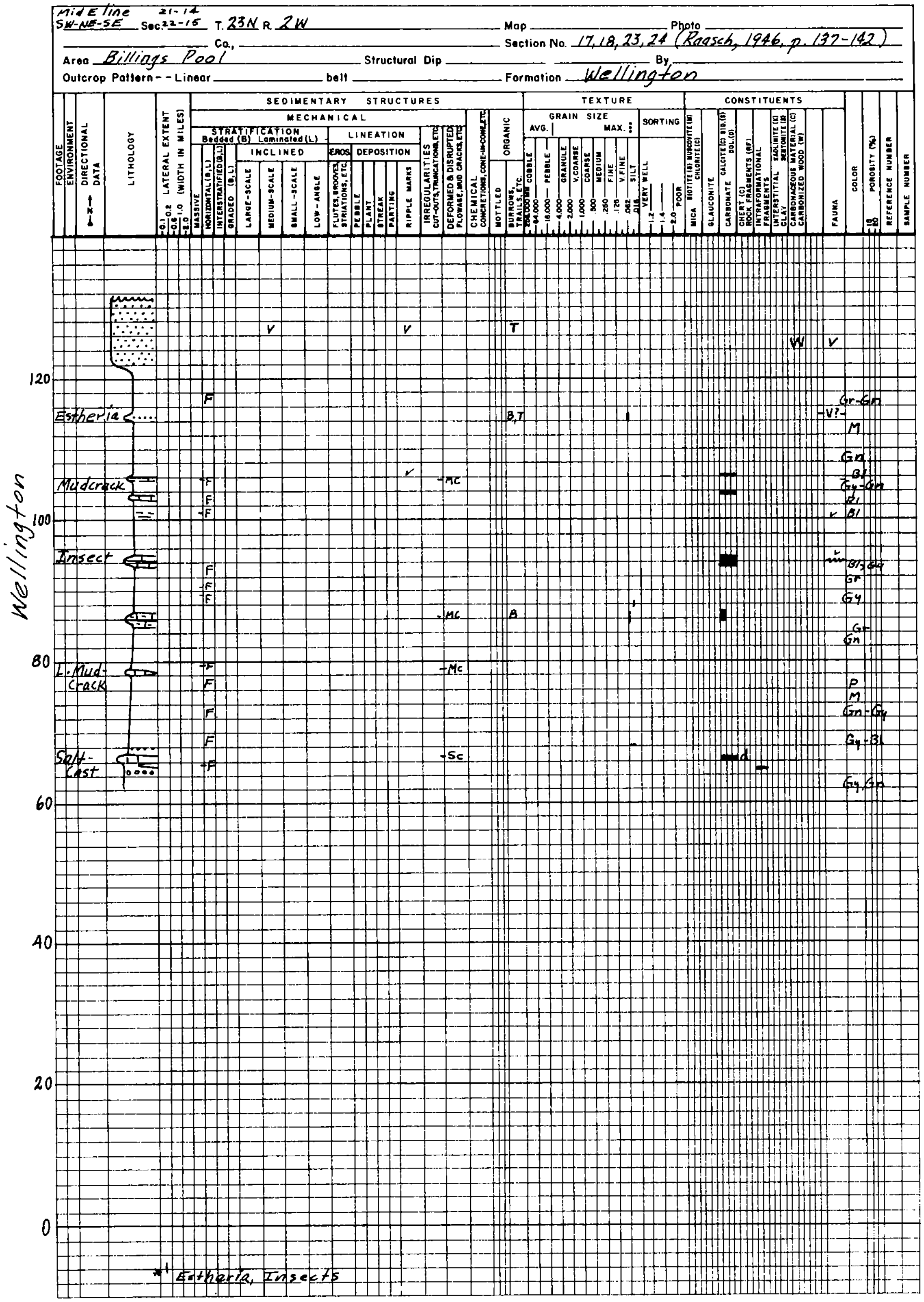
Marine Like Mx

Channeling of SS

Sp. No. 1, 2 - Clay mineral

3 - Thin Section

16. Wellington Formation (Adapted from Raasch, 1946)



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