THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

SURFACE GEOLOGY OF THE BELFORD AREA, OSAGE COUNTY, OKLAHOMA

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BY

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SURFACE GEOLOGY OF THE BELFORD AREA, OSAGE COUNTY, OKLAHOMA

A THESIS

APPROVED FOR THE SCHOOL OF GEOLOGY

ACKNOWLEDGMENT

The writer wishes to express his deep and sincere appreciation to his wife for her steadfast encouragement and moral support in the completion of this thesis.

Appreciation is also extended to Dr. Carl C. Branson for his many helpful suggestions and recommendations in the preparation of the manuscript.

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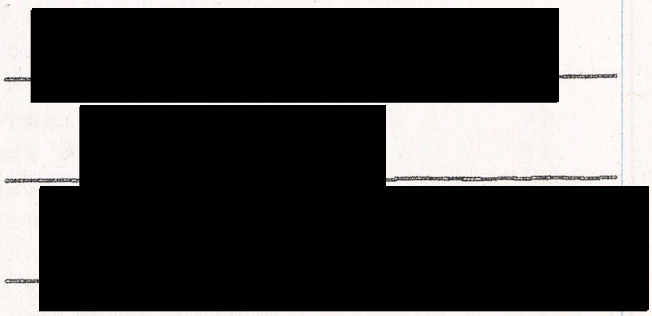

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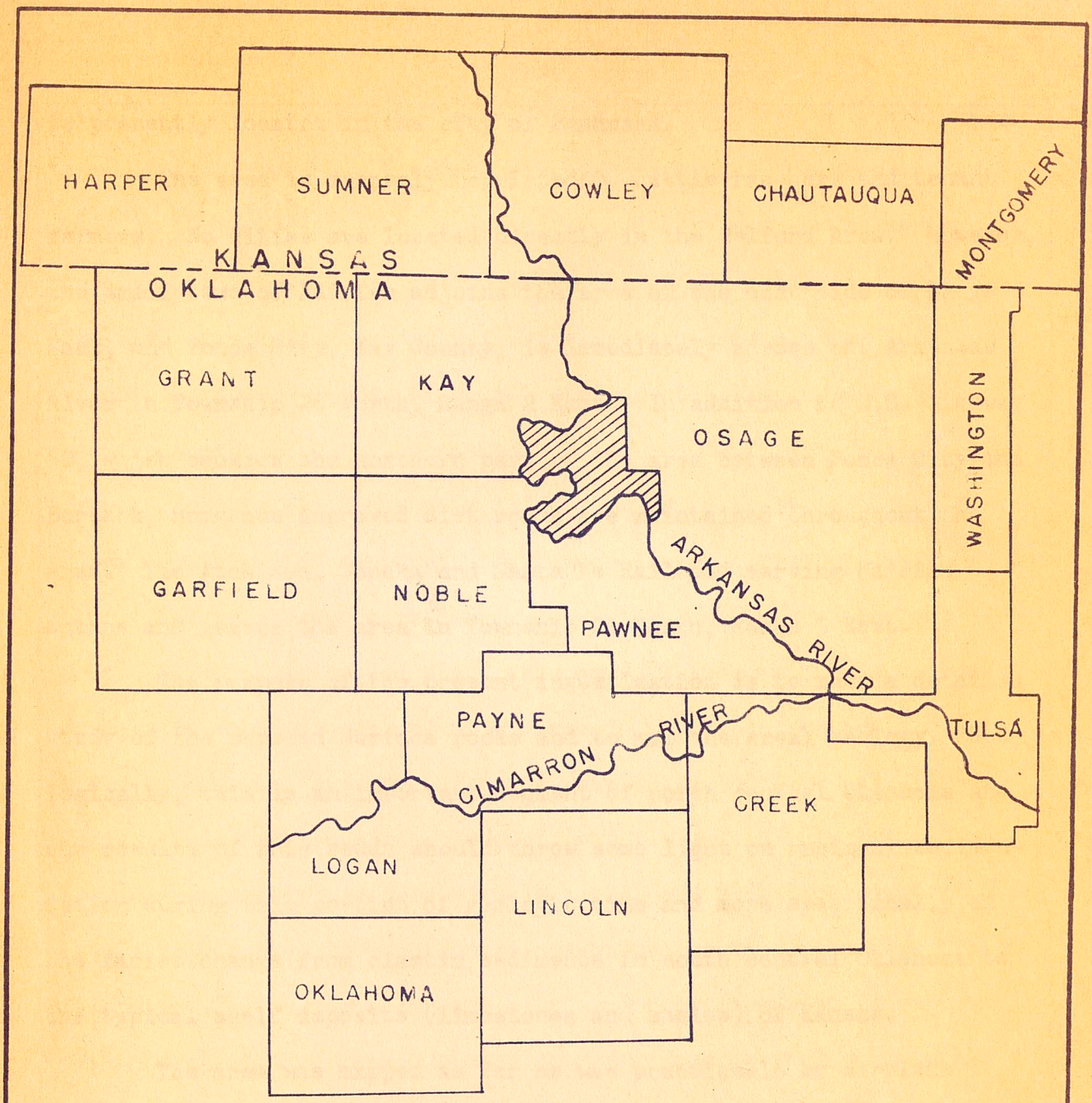
SURFACE GEOLOGY OF THE BELFORD AREA, OSAGE COUNTY, OKLAHOMA

CHAPTER I

INTRODUCTION

The area under investigation is designated the Belford Area after the United States Geological Survey topographic quadrangle of the same name. It is located in north central Oklahoma (Fig. 1), and includes those parts of Townships 25 and 26 North, Ranges 2, 3, and 4 East, and Township 23 North, Ranges 3 and 4 East, and Township 24 North, Ranges 3, 4, and 5 East that lie within the boundary of Osage County. The boundary is marked by the course of the Arkansas River on the north, west, and south sides of the area. The Arkansas River also establishes the county line between Osage, Pawnee, Noble and that part of Kay County south of Township 27 North. The eastern boundary of the area is established along the easternmost edge of Townships 25 and 26 North, Range 4 East, and the northern and eastern edges of Township 24 North, Range 5 East. Salt Creek establishes the boundary of the area in the extreme southeast corner. Parts of twelve townships are included in this report, an area of approximately 188 square miles.

Osage County is also known as the Osage Reservation. The region was acquired by the Osage Tribe by a treaty in 1866. The Indian Agency



LOCATION MAP

OF

BELFORD AREA

FIGURE 1

is presently located in the city of Pawhuska.

The area is sparsely populated by cattle ranchers and tenant farmers. No cities are located directly in the Belford Area. However, the small town of Fairfax adjoins the area on the east side of Range 5 East, and Ponca City, Kay County, is immediately across the Arkansas River in Township 26 North, Range 2 East. In addition to U.S. Highway 60, which crosses the northern part of the area between Ponca City and Burbank, numerous improved dirt roads are maintained throughout the area. The Atchison, Topeka and Santa Fe Railroad serving Fairfax enters and leaves the area in Township 24 North, Range 5 East.

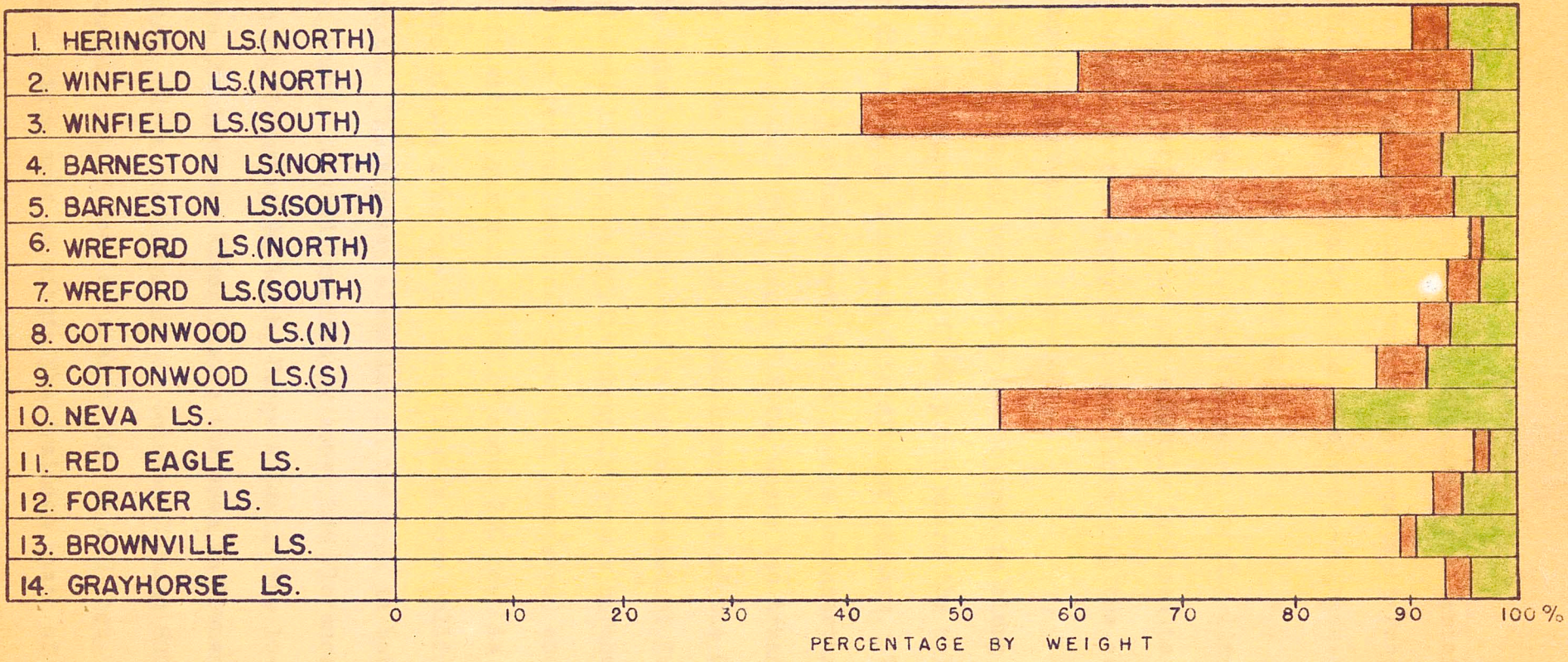
The purpose of the present investigation is to make a detailed study of the exposed surface rocks and to map the areal geology. Geologically, this is an important segment of north central Oklahoma and the results of this study should throw some light on regional sedimentation during this portion of geologic time and more specifically on the facies change from clastic sediments in south central Oklahoma to the typical shelf deposits (limestones and shales) of Kansas.

The area was mapped as far as was practicable by airplane photographs (1954 flight) obtained from the Oklahoma Geological Survey. Field work was started in October, 1955, and completed in March, 1956. A base map was compiled by using the areal photographs and a grid of the same scale. At most places section corners were easily recognized on the photographs and accurate control was obtained by aligning these points with the corresponding point on the grid. Field work consisted of walking outcrops, taking samples and measuring stratigraphic sections.

A sufficient number of samples were collected from each

outcropping unit to allow a petrographic study of them in the laboratory. A ten power hand lens was used for analyzing the samples in the field, and a hand level and steel tape were employed for measuring stratigraphic sections. The dip of the strata is so slight in this area that it was disregarded while measuring sections. Insoluble residue tests were conducted on all the mappable limestone units to show the latereal change in composition of the different units from north to south along the strike. The results of these tests are given in the discussion of each unit in Chapter II and are shown diagrammatically in Figure 2. Two tests were run on the limestone units that have continuity of outcrop across the area and the results show a definite increase in sand content and a decrease in carbonate content along the strike from north to south. Fossils were collected from each limestone unit and the recognizable ones were classified. In but a few cases was an attempt made to correlate the beds by paleontological data.

Regionally, the area under investigation is part of the Great Plains area, which has a surface sloping gently from west to east and south. Much of the prairie plains country in north central Oklahoma and southern Kansas has been described as being characterized by a series of step-like benches ascending in a westward direction. This general feature of step-like topography is evident in this area, but the benches here are not as prominent as they are to the north and east. The cuestas in the eastern part of Osage County are capped by resistant sandstones which produce precipitous east-facing escarpments as do the chert-bearing limestones of extreme northern Oklahoma and southern Kansas. The Florence, Wreford and Foraker limestones contain



INSOLUBLE RESIDUE ANALYSES DIAGRAM

OF

MAPPABLE LIMESTONE UNITS

BELFORD AREA

OSAGE COUNTY OKLAHOMA

CARBONATE MATERIAL

INSOLUBLE RESIDUE

DECANTED MATERIAL

HENRY C. FISHER JR. 1956

FIGURE 2

large quantities of chert in southern Kansas, but contain little or no chert in this area. For this reason the escarpment faces of the cuestas in the Belford area have only a moderately steep grass-covered slope from one limestone bench to the next.

The dip slope surfaces of the bench forming limestones form prominent upland surfaces that are slightly inclined to the west. These surfaces converge along drainage lines with the escarpment face produced by the next higher limestone.

The most rugged topography in the area is along the bluffs adjacent to the Arkansas River flood plain where the upland surfaces have been dissected by numerous intermittent streams. This type of topography is particularly noticeable in the southeastern part of the area in Township 24 North, Range 5 East, where the Arkansas River cuts across the strike of the beds of the lower part of the Council Grove group. At this location, the strike of the resistant Foraker, Red Eagle, and Neva limestones shifts abruptly from a northeast-southwest direction to a general upstream direction (westward) and a steep dissected bluff with a maximum relief of about 200 feet is formed. The central part of the area can be described as open rolling prairie type of topography. The highest elevation in the area is between 1,200 and 1,220 feet and is located immediately above the Florence limestone ledge in section 23, Township 26 North, Range 4 East. The lowest point is found where the Arkansas River leaves the area in Township 24 North, Range 5 East. Here the elevation is between 780 and 800 feet, which gives a maximum relief for the area of 400 to 440 feet.

The entire area is within the drainage basin of the Arkansas

River, a superposed consequent stream of middle to late maturity. Meanders are beginning to form within the flood plain and the flow is sluggish. The large bends or loops in the river along the western edge of this area are probably structurally controlled by the Mervine and Ponca anticlines. The general slope of the land is to the east and southeast, but the dip slope surface of the cuestas is about one-half degree to the west. This situation is responsible for the development of numerous insequent streams which have a dendritic drainage pattern and flow in a direction which is generally perpendicular to the flow of the Arkansas River.

All of the streams in this area with the exception of the Arkansas River and Salt Creek are intermittent and have continuous flow only in wet seasons. Salt Creek is the second largest stream in the area and flows in a general southerly direction. It meanders back and forth over several sections of Township 24 North, Ranges 5 and 6 East. The extreme southeastern boundary of the Belford Area is formed by the course of Salt Creek where it re-enters the area in section 24, Township 24 North, Range 5 East, and empties into the Arkansas River in the western part of section 25.

A few of the tributaries expose bed rock in their drainage floors, but most of the intermittent streams do not have enough erosional force to keep the floor of the drainage clear of rubble or to carry away the surficial material which covers up the bed rock. For this reason it is hard to find good localities to measure stratigraphic sections of the shale intervals between the more resistant bench-forming limestones.

Few articles have been published concerning the immediate area

of investigation. The first work was done by C. F. Bowen, C. S. Ross, and Frank Reeves in 1918. The results of their efforts were published in 1922 under the direction and supervision of the Unites States Geological Survey (White et al., 1922). The field work was rather hastily conducted, with main interest placed on locating subsurface structures by their surface expression. It was hoped that through the efforts of this reconnaissance survey, the petroleum supplies and reserves of the country might be increased. The plane table method of survey was used without the aid of aerial photographs. Since structure or the location of favorable oil reservoris was their main objective, only the "key beds" of the area were studied and described in their report.

H. T. Beckwith combined the above mentioned work of the United States Geological Survey with information obtained from different oil companies and other sources into one complete report on Osage County (Beckwith, 1928). He also describes only the "key beds" in detail.

Recently a tremendous amount of detailed geologic work has been completed by graduate students of the University of Oklahoma on the area immediately surrounding the Belford Area. These theses and other articles and papers pertaining to the regional geology of this general area are listed in the bibliography.

CHAPTER II

STRATIGRAPHY AND LITHOLOGY

GENERAL STATEMENT

The stratigraphic sequence exposed in the Belford Area consists almost entirely of lower Permian rocks of Wolfcampian age. The oldest unit in the area is the Grayhorse limestone of the Upper Pennsylvanian. It is exposed only locally, forming a short line of outcrop along the banks of Salt Creek northwest of Fairfax, in Township 24 North, Range 5 East. The youngest formation represented is the Herington limestone of lower Permian age, which forms the western-most upland surface of the area within the loop of the Arkansas River in Township 24 North, Ranges 2 and 3 East.

PENNSYLVANIAN SYSTEM

Virgilian Series

The Virgilian series derives its name from the town of Virgil, Greenwood County, Kansas, and is defined as occupying the interval between the unconformities at the base of the Wolfcampian series (Lower Permian), and the top of the Missourian series (Upper Pennsylvanian). The unconformity at the top of the Missourian series is marked by the base of the Tonganoxie channel sandstone, and the unconformity at the base of the Wolfcampian series is

marked by the erratic appearance of the channel-filling Indian Cave sandstone. This sandstone is locally developed from Nebraska to Oklahoma, and some say it represents a period of wide-spread erosion. In addition to this evidence, the present position of the Pennsylvanian-Permian boundary is further substantiated by the changes in sedimentary and paleontological environments that took place from Virgilian through Wolfcampian time. The Indian Cave sandstone is not present in the Belford area, however, and all evidence suggests continuous deposition from Pennsylvanian through Permian time. On the basis of lithologic character, the strata of the Virgilian series have been subdivided into three groups. In descending order, they are the Wabaunsee, the Shawnee, and the Douglas groups.

Wabaunsee Group

Prosser in 1895 originally described this group as a formation, and established the boundaries at the base of the Cottonwood limestone and the top of the Nodoway coal in the Howard formation, (Prosser, 1895, p. 688). Since that time, the limiting boundaries have been shifted from one stratigraphic horizon to another and the rank of the unit raised from formation to group. The presently accepted boundaries of the group were established and defined by Condra in 1935 (pp. 9-11). The contact at the top of the Brownville limestone marks the top of the group and the base is established at the top of the Topeka limestone. The group is subdivided into three subgroups which in descending order are the Richardson, Nemaha, and Sacfox. Only the upper three formations of the Richardson sub-group are represented in this area. These three

formations have a total thickness of 66 feet and in descending order are the Brownville limestone, the Pony Creek shale, and the Grayhorse limestone.

Grayhorse Limestone Formation. The Grayhorse limestone was named by Bowen in 1918 for exposures along the crest of the Little Grayhorse anticline in the NW¼, sec. 11, T. 24 N., R. 6 E. (White et. al., 1922, p. 138). At the type locality the rock is a dark brownish-gray, crystalline, conglomeratic limestone. It is a valuable key bed as it can easily be recognized. It is fossiliferous and commonly contains large specimens of Myalina.

The formation is exposed only at one locality in the Belford area, a small outcrop northwest of Fairfax where the line of outcrop shifts up stream and crosses Salt Creek in SE¼ sec. 1, T. 24 N., R. 5 E. No exposures of the formation occur in this area east of Salt Creek. At this locality the formation consists of two limestone beds totaling 1.4 feet in thickness and separated by a thin fossiliferous shale layer. The basal bed is coquinoid with many fossil species represented. Bryozoan, echinoid, brachiopod, and molluscan fragments including Myalina are abundant. Most of the fossil shells have been replaced by calcite which appears as clear curved stringers on fresh surface. The matrix of this rock is light gray, fine crystalline and locally argillaceous. Fossil remains are extremely noticeable on the weathered surface where they stand in relief against a gray to buff background. The upper part of the Grayhorse is only sparsely fossiliferous in its lower part. It is extremely well indurated, light gray to buff, fine crystalline, ferruginous, and weathers to a brownish

color.

Pony Creek Shale Formation. This formation is described as a predominantly shale unit between the Grayhorse and the Brownville limestones. The interval has increased from a maximum of 51 feet in the Foraker area of northern Osage County, Oklahoma, to a maximum of 60 to 65 feet in the Belford area.

The only exposures of the formation in the present area of investigation are along the base of the steep buff south of Salt Creek in the northeastern part of Township 24 North, Range 5 East. The rocks of the upper part of the interval can also be observed below the Brownville limestone north of Salt Creek in section 1, but here it is completely grass-covered. The formation is made up predominantly of varicolored shales, maroon in the middle and greenish-gray to tan in the upper and lower parts, interbedded with fossiliferous, highly argillaceous, thin limestones. The lower three feet is composed of light greenish-gray, irregularly bedded, limy claystone. Bedding planes of this rock in many places contain cylindrical objects resembling animal burrows. This lower claystone unit is interbedded with thin, brittle sheets of greenish-gray, silty shale. These shales at places show current ripple marks on their top surface.

A molluscan facies limestone lies about 15 feet above the Grayhorse top surface and this thin bed is immediately overlain by a characteristically mottled, maroon and greenish-gray, fossiliferous limestone which contains an abundance of the large pelecypod Allorisma sp., which stand in high relief on a pimply-weathered surface. Myalina and other fossil species are also represented in this rock.

Brownville Limestone Formation. Like the other two formations of Pennsylvanian age represented in this area, the line of outcrop of the Brownville limestone is limited to the northeast corner of Township 24 North, Range 5 East. The bluffs south of Salt Creek in section 12 offer the best localities for studying this unit.

The formation was originally named by Condra and Bengston in 1915 (Condra and Bengston, 1915, p. 17) for exposures in the bluffs south of Brownville, Nemaha County, Nebraska. It is the uppermost formation of Pennsylvanian age and is immediately overlain by the lower division of the Admire group.

In this area, the Brownville consists of two persistent limestones separated by about 4 feet of gray, platy, calcareous shale. The upper bed is a fusulinid-bearing limestone which weathers gray to yellowish-brown. The fusulinids are small in the lower part of the bed, and are increasingly larger in the upper part. On the weathered surface large crinoid stem segments are quite abundant and noticeable. The bed is light gray to tan, argillaceous, ferruginous, and fine to medium crystalline. It has an average thickness of 1.3 feet.

The lower bed has about the same thickness as the upper one, but contains no fusulinids. It is light gray to buff, highly argillaceous, and contains many fossil fragments including brachiopods, echinoids, and pelecypods. Many specimens of Myalina were found in the upper part of this bed. Much red to brown chert with white fusulinids is strewn over the outcrop of this formation, but none could be found imbedded in the matrix of the rock.

The insoluble residue of the Brownville consists predominantly

of silicified organic remains and a trace of very fine sand grains.

Permian System

An obvious difference in depositional environments existed along the strike of the rock strata now grouped in the Permian system. Generally speaking, however, the Lower Permian strata are composed of evenly stratified deposits of marine origin. The higher units of the Permian system include a sequence of irregularly bedded deposits of predominantly non-marine origin though deposited close to sea level. These upper units include thick beds of shale, sandstone and anhydrite. The subsurface anhydrite beds of the Permian section of western Oklahoma and Kansas are represented on the surface by thin beds of gypsum and dolomite. Many of the limestones of the non-red lower portion of the Permian are algal limestones and light gray to buff is the predominant color. The shales and sandstones of the upper part range from brown to red. Moore (1951, p. 34) assigns a thickness of 3,000 feet to all the strata of the Permian system.

Wolfcampian Series

The area under investigation is covered almost completely by strata of Wolfcampian age. The Wolfcampian series, previously referred to as the Big Blue series (Condra, 1931, p. 7), includes three groups. All of these groups are represented in their entirety in the present area of investigation. In ascending order, they are the Admire, Council Grove, and Chase groups.

The Wolfcampian series consists primarily of alternating limestones and shales with a considerable amount of lensing and cross-

bedded sandstone, especially in the southern part of the area. A definite facies change is noticeable in all the limestone as they become thinner and more sandy in a southward direction along the strike. The results of the insoluble residue tests of all the mappable limestones in the area (Fig. 2) further substantiates the fact that these limestones do become considerably more sandy to the south.

The limestones are generally light gray to tan and thick bedded, but contain little or no chert. However, the limestones of the Wolfcampian series to the north of this area are reported to contain large quantities of concretionary chert nodules. Due to this chert content, these limestones are most resistant in northern Oklahoma and southern Kansas and form rugged east-facing escarpments. This topographic feature is referred to as the Flint Hills of Kansas. In the area covered by this thesis, the limestones are much less resistant and the rugged Flint Hills type of topography of Kansas has been replaced by rather gentle eastward-facing escarpments and open rolling prairie type of topography. A considerable amount of light brown chert fragments is present on the weathered top surface of the Barneston and Herington limestones, but the Neva limestone of the Grenola formation is the only limestone that actually contains chert nodules or lenses of concretionary chert in the matrix of the bed.

The shales and sandstones of the Wolfcampian series are mostly gray-green and reddish-brown with some tan.

Admire Group

The lack of a clear definition of the formations within the

Admire group has been the source of much confusion in the stratigraphy of the lower Wolfcampian series. The Admire group was originally named the Admire shale by Adams (1903, p. 53) for exposures near Admire in Lyon County, Kansas. It was defined as a shale interval about 40 feet thick and lying between the Emporia limestone (Stonebreaker) and the Americus limestone. Condra (1927, p. 72), said the measurement of this interval by Adams was obviously an erroneous one due to the fact that the Emporia limestone is found much lower in the section and that it does not even crop out in the vicinity of Admire. At this same time, Condra interpretated the interval measured by Adams to be the interval between the Americus limestone of the Foraker formation and the Brownville limestone, and he further suggested that the name Admire shale be redefined or abandoned. It was eventually raised to a group name by Condra in 1935, and the interval definitely established to represent the strata between the Americus and the Brownville limestones (Condra, 1935, pp. 8-9).

In the Kansas section, the Admire group is divided into nine recognizable units with a total thickness of 130 feet. In descending order these units are: Oaks shale, Houchen Creek limestone, Stine shale, Five Point limestone, Falls City limestone, Hawxby shales, Aspinwall limestone, and the Towle shale, which includes the Indian Cave sandstone as its lower member. The Oaks shale, Houchen Creek limestone, and the Stine shale are members of the Hamlin shale formation.

In the Belford area the boundary between the lower five units was not determined. This interval is covered by alluvium and eolian

material for the most part making inspection impossible. This covered interval includes all the strata from the base of the Five Point limestone to the top of the Brownville and represents a total thickness of some 29 feet. This interval will be referred to in this thesis as the lower Admire shale unit. This lower unit is presumably made up of red and gray shales with an occasional thin impure argillaceous gray limestone and one irregularly bedded light tan sandstone bed. This sandstone weathers back into the grass-covered slope between the Americus and the Brownville limestones and the exact thickness or stratigraphic position cannot be determined. It is approximately 5 feet thick and weathered fragments can at most places be found about 10 to 12 feet above the top surface of the Brownville limestone.

Five Point Limestone Formation. Definite correlation of the Five Point limestone cannot be made in the Belford Area. A limestone which falls in the approximate stratigraphic position is exposed on the steep slopes south of Salt Creek in secs. 11 and 12, T. 24 N., R. 5 E. Moore (1951, p. 49) describes the Five Point limestone as being one or more beds of massive fossiliferous limestone with a thickness of 1 to 8 feet. In Kansas and northern Oklahoma the upper part is reported to be locally a thin coquinite. In the Belford area, the upper part of the Five Point limestone is dove-gray, medium crystalline and siliceous, while the lower one-half foot is light greenish-gray, fine crystalline, and argillaceous. The lower part weathers to a yellowish-brown rusty color and the fossil shell fragments which have been replaced by clear calcite stand in relief on the weathered surface. The thin coquinite used by Taylor (1953, p. 42) to identify the Five Point limestone in the

Foraker area was not found in the Belford area, nor was it found by Vosburg (1954, p. 29) in the Burbank-Shidler area immediately to the north.

Hamlin Shale Formation. The Hamlin shale has a total thickness of about 50 feet in the Kansas section and was subdivided into three members by Condra (1935, p. 4). These members in descending order are: Oaks shale, Houchen Creek limestone, and Stine shale. The upper two members of this formation are fairly well exposed in three widely separated outcrops making definite identification possible. In the Belford area, the total thickness of this formation averages 17 feet.

Stine Shale Member. Only the upper five feet of the Stine shale interval is exposed in this area. It is represented by 11.9 feet of section which is presumed to be mostly gray-green shales with an occasional thin, tan, fine-grained sandstone. In the northern part of Township 24 North, Range 5 East, the Stine shale interval is covered by debris from the thick Foraker formation which forms the rim of the steep eastward facing escarpment in secs. 11 and 12, T. 24 N., R. 5 E. South of this location to the Arkansas River the Stine shale interval is covered by a veneer of eolian material and river alluvium.

Houchen Creek Limestone Member. In northern Oklahoma and Kansas, the Houchen Creek is reported to consist of an upper and lower limestone with a total thickness of from 1 to 4 feet. The Houchen Creek limestone consists of two thin resistant limestones in the Belford area, but they are normally not well exposed because of their close proximity to the more massive beds of the Americus limestone above. One of the best exposures of the Houchen Creek limestone can be seen in the railroad cut

east of Salt Creek in the center of sec. 2, T. 24 N., R. 5 E. (see Measured Section IV, Appendix). The thickness varies slightly from north to south along the strike, averaging close to 3 feet, but the lithology is fairly constant. The Houchen Creek consists of two evenly bedded limestones separated by 3 to 7 inches of soft, light gray, silty, calcareous, blocky shale. The lower limestone is battleship gray, fine to medium crystalline, sugary textured, dolomitic and tightly indurated. It has a few rounded pellets scattered through the matrix and has a large number of pelecypod shell fragments which have been replaced by secondary calcite. The upper limestone is similar in lithology to the lower bed except that it is less fossiliferous and more finely crystalline. Both of these limestones weather yellowish-tan to a light blue-gray and the weathered shell fragments stand in relief in an irregular pattern.

Oaks Shale Member. The Oaks shale interval is poorly exposed in the Belford area and the description given here comes from three widely separated exposures. In the railroad cut north of Salt Creek in sec. 2, T. 24 N., R. 5 E., the Oaks shale is light greenish-gray, soft, platy, calcareous, contains a small number of fossil fragments, and has an occasional thin dark gray to black streak. At this exposure the Oaks shale is extremely thin, being only a half foot thick. South of Salt Creek in the north central part of sec. 11, T. 24 N., R. 5 E. (see Measured Section II, Appendix) the Oaks shale reaches a maximum thickness of 2.5 feet.

Council Grove Group

The beds of the Council Grove group include approximately 50 per cent of the strata exposed on the surface in the Belford area. The group was first named by Prosser in 1902 (pp. 709-711) from exposures along the Neosho River near the town of Council Grove, Marion County, Kansas. The present boundaries of this group were established by Moore (1932) to include all the strata from the base of the Wreford limestone to the base of the Americus limestone of the Foraker formation. In the Kansas section, this interval consists predominantly of persistent limestones and shales with an average thickness of from 310 to 330 feet. In the Belford area, the limestones are thinner and shale intervals are thicker than corresponding units in northern Oklahoma and southern Kansas. Both of these lithologic units (limestone and shale) show an increase in sand content from north to south along the strike.

Most of the limestones of the Council Grove group are still recognizable in the Belford area and are persistent enough to be traced across the entire area. Generally speaking, the limestones of this group are thinner and less massive than the limestones of the overlying Chase group.

On the basis of lithology, the Council Grove group is subdivided into fourteen formations and seventeen members. These subdivisions in descending order are: Speiser shale, Funston limestone, Blue Rapids shale, Crouse limestone, Easly Creek shale, Bader limestone (containing three members: Middleburg limestone, Hooser shale, and Eiss limestone), Stearns shale, Beattie limestone (containing three members: Morrill limestone, Florena shale and Cottonwood limestone),

Eskridge shale, Grenola limestone (subdivided into three limestone and two shale members: Neva limestone, Salem Point shale, Burr limestone, Legion shale, and Sallyards limestone), Roca shale, Red Eagle limestone (containing three members: Howe limestone, Bennett shale and Glenrock limestone), and the basal formation is the Foraker limestone (containing three members: Long Creek limestone, Hughes Creek shale, and the Americus limestone).

Foraker Limestone Formation: The Foraker limestone was originally named by Heald (1916, p. 25) for exposures near the town of Foraker, Osage County, Oklahoma. The standard section for the Foraker is in SW¼ of sec. 16, T. 29 N., R. 7 E. where an excellent exposure is located. Heald assigned a thickness of 74 feet to the Foraker limestone, but later work indicated that this measurement undoubtedly included not only the Foraker limestone, but the interval now considered the Admire group and the Brownville limestone. Bowen in 1922 (p. 282) reported the Foraker limestone as being 110 feet thick in the present area of investigation. This is most likely the same interval measured by Heald to the north and, therefore, includes the Admire group and the Brownville limestone.

The present boundaries of the Foraker limestone were defined by Condra (1935, p. 8). He raised the Foraker to a formation and subdivided it into three members. These are in descending order: Long Creek limestone, Hughes Creek shale, and Americus limestone. This interval includes all the strata from the base of the Johnson shale to the top of the Hamlin shale. In the Belford area this interval has a total thickness of about 50 feet.

Americus Limestone Member. The Americus limestone is represented in this area by 12.5 feet of alternating limestones and tan to gray shales. The Americus is a resistant limestone, but exposed at few places because its outcrop is at the base of the steep escarpment produced by the Hughes Creek and Long Creek members. The best exposure is in the railroad cut east of Salt Creek in the center of sec. 2, T. 24 N., R. 5 E. Here the Americus limestone is exposed in its entirety. The most distinctive part of the member is the two basal limestone beds. These beds are separated by about one inch of light gray, fossiliferous, calcareous clay. The basal part of the lower limestone is non-fossiliferous, very fine crystalline, dense and light gray. The upper part of the lower limestone and the entire upper limestone of this basal unit is a medium crystalline, light blue-gray, dolomitic limestone. It is slightly fossiliferous, with medium sized fusulinids, crinoid debris, and brachiopod shell fragments. The fossils of this lower unit have been recrystallized to such an extent that they are almost unrecognizable on a fresh surface. The weathered surface of the basal unit is light gray to buff.

Separating the basal limestone beds from the upper part of the Americus is three feet of silty, calcareous, fossiliferous, light gray shale. The shale interval is broken by an occasional thin stringer of globular calcareous mudstone. The upper limestone of the Americus is 1.4 feet thick and contains an abundance of fusulinids that are white on weathered surface and stand in relief against a light gray to buff background. On fresh surface these fusulinids are flesh colored. The limestone is greenish-gray to buff, argillaceous and irregularly

bedded. On the bottom surface of this limestone are numerous calcareous objects of cylindrical shape that could be animal burrows. Many times these cylindrical objects weather out and can be found strewn on the shale surface below. This bed is not as resistant as the lower limestone and in most natural exposures where the lower bed is exposed, the upper bed is weathered back and is soil covered.

Above the upper limestone of the Americus member, to the base of the Hughes Creek member is approximately 6.5 feet of olive to dark gray, soft blocky shale alternating with thin stringers of fine-grained, dense, battleship gray limestone. Brachiopods, pelecypods, crinoid stems, fusulinids and fragments of other fossil organisms are found in this shale zone.

An insoluble residue test shows the basal bed of the Americus limestone to be composed of 92.7 per cent carbonate, 5.2 per cent decanted material, and 2.0 per cent residue. The residue consists predominantly of very fine to fine, subangular, sand size quartz grains with a small per cent of crystalline pyrite and siliceous organic skeletons.

Hughes Creek Limestone Member. The Hughes Creek is described by Moore (1951, p. 49) as being made up predominantly of a light to dark gray shale broken by an occasional thin fusulinid bearing limestone. This member increases in limestone content in a southerly direction, and in southern Kansas and northern Oklahoma it is reported to be almost continuous limestone containing only a few shale breaks. In northern Oklahoma where this limestone is best developed, it is highly fossiliferous, with fusulinids and brachiopods, Composita subtilita being the most prominent species. This limestone is also

reported by Taylor (1953) and Vosburg (1954) in areas to the north of the Belford area as containing an abundance of concretionary chert which is spotted with white fusulinids. North of the Belford area, the abundant chert content of this limestone makes it the most resistant member of the Foraker formation, and consequently, it forms the rim of one of the most prominent eastward facing escarpments of western Osage County, Oklahoma.

In the Belford area, the Hughes Creek member is represented by 22 feet of various shades of gray shale and olive-gray to buff calcareous sandstone. Near the upper part of the interval there are two thin, gray, fusulinid-bearing limestones interbedded with fossiliferous gray shale and claystone. No chert is present in the strata of the Hughes Creek member in the Belford area, even though a considerable amount of blue, red and brown chert spotted with white fusulinids is present among the broken weathered fragments and debris on the slopes below the Hughes Creek outcrop.

One of the best exposures of the Hughes Creek member can be seen in the road cut along the south-central part of sec. 11, T. 24 N., R. 5 E. (see Measured Section III Appendix). At this location, the base of the Hughes Creek is marked by a 1.3 foot bed of very fine-grained, porous, irregularly bedded, buff to olive-gray sandstone. Next above is 5.1 feet of covered interval which is probably occupied by alternating soft, olive-gray shales and gray to buff, fine-grained sandstone. Next above this covered interval is 11.5 feet of lensing shale and fine-grained sandstone or siltstone. The shales of this zone are dark to olive-gray, locally they are calcareous, soft, platy and become slightly

fossiliferous in the upper part. The lenticular sandstones of this zone are very fine-grained, tight to friable, barren of fossils, and buff to olive-gray. Locally they are slightly calcareous and the bedding varies from thin to massive. The upper part of the Hughes Creek is represented by two thin irregular limestone beds separated by a foot of soft, medium to olive-gray, thin bedded, fossiliferous shales. Above the upper limestone to the basal limestone of the Long Creek member is 2.1 feet of poorly bedded, argillaceous, yellowish to light greenish-gray, fossiliferous claystone. The lower of these two limestones is light gray to yellowish-green, fine crystalline, argillaceous, and fossiliferous, with an abundance of fusulinids which are pink to flesh colored on fresh surface. Also, on a fresh broken surface, many of the fusulinids do not fracture and appear as small lobate pebbles. This limestone weathers to an irregular broken bed with light colored fusulinids standing in slight relief against a light gray to buff background. The highest limestone of the Hughes Creek member is represented here by a 0.5 foot bed which is similar to the limestone below except that it appears to contain considerably more ferruginous and argillaceous material with fewer fossils. The next well-defined limestone member above marks the base of the Long Creek limestone member.

The facies change of the Hughes Creek member from a massive thick-bedded cherty limestone in northern Oklahoma to a lensing sandstone and shale zone in the Belford area, accounts for the fact that from north to south toward the Arkansas River progressively higher and more resistant beds of the Long Creek member form the rim of the escarpment and the Hughes Creek member forms the steep sides. In a few

localities, as in the northeastern part of sec. 1, T. 24 N., R. 5 E., the Hughes Creek member is made up almost entirely of massive, cross-bedded, fine-grained sandstone that weathers into an almost vertical wall below the rim of the escarpment.

Long Creek Limestone Member. In the southern part of Kansas, the Long Creek member is composed of 4.5 to 17 feet of shale and light gray limestone which is massive in its upper and lower parts (Moore, 1951, p. 48). The Long Creek in the Belford area consists of thick upper and lower limestones separated by 2.4 feet of gray shale and 7.9 feet of covered slope which is also probably composed of gray shale with thin siltstone stringers.

The lower limestone of the Long Creek member is thick, even-bedded, compact, medium crystalline, and light gray with buff limonite stains of fresh surface. The weathered surface is a dirty dull-gray with medium sized light colored fusulinids and other replaced fossil shell fragments standing in relief. The upper part of this lower bed is flaky bedded in places.

Immediately below the upper limestone of the Long Creek member is a six inch zone of buff marly sandstone. This sandstone weathers into distinctive irregularly shaped globules of buff color and has a mottled appearance due to the dirty white marly material. This bed is rarely exposed in the Belford area and could possibly be an extremely local facies.

The upper limestone of the Long Creek member is represented by approximately five feet of thin limestone separated by gray shale. The lower 1.8 feet of this upper limestone is made up of three beds which

are conformable with each other. They are compact, medium crystalline, ferruginous, and contain an abundance of small light gray fusulinids and crinoid debris which stand in slight relief against a dull weathered background. The upper 2.5 feet of the Long Creek consists of 5 to 6 layers of flaky bedded limestone alternating with thin beds of tan to olive-gray, fossiliferous, calcareous, platy shale. These upper flaky limestone beds are light to medium gray, argillaceous, and contain an abundance of small light gray to pink fusulinids. The weathered surface is olive-gray to buff and occasionally bright yellow as a result of limonite content.

Two beds of the Foraker were mapped for inclusion in this thesis. They are the uppermost bed of the Long Creek member and the basal bed of the Americus limestone member. Both of these beds form easily traceable outcrops except in the vast area covered by eolian material in the eastern part of Township 24 North, Range 5 East, and north of the Arkansas River in the western part of the same township.

Paleontology. Fossils identified from the Foraker formation include:

Neospirifer dunbari King
Composita subtilita (Hall)
Lophophyllidium sp.
Hustedia mormoni (Marcou)
Wellerella sp.
Neospirifer condor (Orbigny)
Lissochonetes geinitzianus ? (Waagen)
Bryozoan and crinoid fragments

Johnson Shale Formation. The unit was originally part of the Elmdale formation named by Prosser (1902, p. 708). The Elmdale was subdivided by Condra in 1935 (p. 8) and the name Johnson shale

formation was established and defined as the shale from the base of the Red Eagle limestone to the top of the Long Creek member of the Foraker formation.

In the Kansas section, the Johnson shale is described as being gray and green shales with an occasional bed of argillaceous limestone, (Moore, 1951). The Johnson shale is covered at most places in the Belford area and offers only one poor exposure of the lower 18 feet in an abandoned quarry located on the steep river bluff north of the highway in sec. 10, T. 24 N., R. 5 E. At this location, the basal unit of the formation immediately above the Long Creek limestone is composed of three to six feet of fissile, dove-gray to tan, silty shale. Next above are two thick beds of limestone separated by a ten-inch soft greenish-gray claystone. The lower of these two limestones is light gray to buff, medium crystalline, scarcely fossiliferous and has a considerable amount of silt size material in the lower part. The upper limestone is light greenish-gray and very fine crystalline. The bottom surface of this limestone has numerous cylindrical objects that could be animal burrows. Above this limestone is approximately nine feet of variegated shale. The upper part of the Johnson shale is soil covered and forms a typical shale slope to the base of the relatively inconspicuous shoulder formed by the Red Eagle limestone.

Red Eagle Limestone Formation. The Red Eagle was originally named by Heald in 1916 (p. 24) from excellent exposures near Red Eagle School, located near the center of sec. 26, T. 27 N., R. 6 E. The school has since been destroyed. Condra (1931, p. 8) established and defined the present boundaries of the Red Eagle limestone. He defined

it as the rocks of the interval between the Roca shale and the Johnson shale, and subdivided it into three members. In descending order they are: Howe limestone, Bennett shale, and Glenrock limestone. The Bennett shale member is predominantly a limestone unit in northern Oklahoma and it will be recognized as a limestone member in this thesis. Vosburg (1954) in the Burbank-Shidler area immediately north of this area definitely identified the Howe and Bennett members and made a tentative correlation for beds of the Glenrock member.

All three members thin rapidly in a southerly direction and in the Belford area one member only remains as an identifiable unit. Because of its lithology and stratigraphic position, it is believed to be a correlative of the Bennett limestone member. The Howe and the lower Glenrock limestones are either absent or they have changed lithologic character so completely that they can no longer be distinguished from the shale sections above and below. Consequently, the covered units immediately above and below the Bennett limestone are here included in the Roca and Johnson shale formations respectively.

Subord.?

Bennett Limestone Member. In the Belford area, the Bennett limestone consists of two thick limestone beds with a total thickness of approximately 5 to 6 feet. The lower bed is the thicker and more resistant of the two, averaging a little more than 3 feet in most places. The lower bed is an extremely dense, light gray to yellow, medium crystalline limestone. It contains an abundance of lobate oval bodies that resemble elongated grains. These oolitic type of structures contain a concentration of yellow to buff limonite and could possibly represent an algal growth. The upper limestone is also dense, but not so dense

as the lower one. It is similar in lithology to the lower bed and in addition exhibits a faint pink tinge. Both of these beds weather to a dirty white or dull gray.

The insoluble residue test of the Red Eagle limestone shows it to be composed of 96.4 per cent carbonate, 1.02 per cent residue and 2.5 per cent of decanted clay size material. The residue contains mostly white siliceous organic remains and a smaller amount of clear, very fine sand grains.

Roca Shale Formation. The measured interval in the Belford area, from the Bennett limestone to the Neva limestone of the Grenola formation, corresponds closely to the same interval measured by Vosburg (1954) in the Burbank-Shidler area immediately to the north. In the Belford area, however, this interval becomes quite sandy making it impossible to determine the exact boundary between the lower member of the Grenola formation and the top of the Roca shale formation. In the Belford area an arbitrary point has been established as the top of the Roca shale. No sedimentary break occurs at this point and the location was determined to correspond with the stratigraphic position of this boundary as definitely determined a few miles to the north.

The Roca shale was named by Condra (1927, p. 86) from exposures near Roca, Lancaster County, Nebraska. Here it is composed primarily of various shales of shale with a few thin limestone stringers. The Roca shale is defined as being the shale between the Red Eagle formation and the Grenola formation.

In the Belford area, the rocks assigned to the Roca shale have a measured thickness of approximately 42 feet, which is considerably

more than the thickness reported for the same formation in southern Kansas. This southerly increase in thickness is believed to be the result of a slight increase in thickness of the shale section and a considerable thinning of the limestones in the same direction.

In this area, the strata composing the Roca shale are rarely exposed and at most places combine with the lower members of the Grenola formation to form the relatively steep soil and rubble covered slope between the faint shoulder produced by the Red Eagle limestone and the prominent bench produced by the Neva limestone. Locally, as in sec. 10, T. 25 N., R. 5 E., the sandstone of the upper Roca shale and lower Grenola formation are quite resistant to weathering and form a massive outcrop with a steep vertical escarpment. This is a massive distorted zone of light gray to tan, fine-grained sandstone. On a fresh surface it is speckled with spots of yellowish-brown limonite. It is locally limy and exhibits streaks of lenticular and distorted, bedded, impure limestone (Fig. 3). The lower 27 feet of the Roca shale is not exposed in the Belford area, but is presumed to be composed of maroon to light gray shales.

Grenola Limestone Formation. The Grenola formation was named by Condra and Busby (1933, p. 9) from exposures west of Grenola, Elk County, Kansas. The formation is defined as the strata between the Eskridge and Roca shale formations, and is subdivided into five members. In descending order they are: Neva limestone, Salem Point shale, Burr limestone, Legion shale, and Sallyards limestone. In the Kansas section, the Grenola formation is represented by a stratigraphic thickness of 38 to 48 feet.

The Neva limestone and the Salem Point shale can definitely be identified in the Belford area, but a massive sandstone occupies the interval represented by the lower three members of this formation making the boundary of the Burr limestone, Legion shale, and Sallyards limestone indistinct. For convenience of description these lower three members will be referred to as the lower Grenola division. The Grenola formation has a stratigraphic thickness of 50 to 55 feet in this area.

Lower Grenola Division. In the Kansas section, this portion of the Grenola formation consists of two thick shaly limestone zones separated by 4 to 12 feet of gray to black shale. In the Belford area this lower division is represented by 27 feet of massive lenticular sandstone broken by an occasional lensing impure clastic limestone. The sandstone is tan to buff, friable, evenly sorted and cemented by a calcareous cement. The fresh surface is speckled with small brown limonite spots. The weathered surface is yellowish to light gray. The limestones of this interval are impure, containing much clay and fine sand size material and a small amount of silicified fossil fragments. The clay material is concentrated in pockets and appears to have been deposited as small clay balls. The fine sand size grains of the limestone are the same size and shape as the sand grains of the surrounding sandstone. The bedding of this zone is irregular and locally highly distorted (Fig. 3).

The boundary between the lower Grenola division and the Roca shale formation is indistinct in the Belford area. Its position has been arbitrarily established to correspond with the stratigraphic position of the same boundary as definitely identified a few miles to

the north of this area in Osage County.

Salem Point Shale Member. The Salem Point shale is rarely exposed in this area. The upper 8.5 feet immediately below the Neva limestone is nowhere exposed. From surficial material this covered section is probably composed of tan to light gray shale. The lower 5 feet of this member is exposed in a few places, the best exposures being found immediately above the massive sandstone in sec. 10, T. 24 N., R. 5 E. At this location, the lower part of the Salem Point is composed of maroon blocky shale.

Neva Limestone Member. The Neva outcrop enters and leaves the Belford area several times along the northern border of Township 24 North, Range 5 East, as it forms the rim of the high valley walls of the tributaries flowing into the Arkansas River. The Neva finally disappears under the alluvium in sec. 24, T. 24 N., R. 4 E.

Several outliers are capped by the Neva limestone in the north central part of Township 24 North, Range 5 East giving rise to the most rugged topography and the greatest local relief in the area. The Neva retains a fairly constant thickness of 10 to 13 feet through the area with evidence of only minor erosion of the upper part in secs. 3 and 10, T. 24 N., R. 5 E.

Lithologically the Neva interval can be divided into three limestone zones separated from each other and interbedded with light gray to buff shale. One of the best easily accessible exposures is in the road cut on the north side of the hard-surfaced road approximately one hundred yards from the NW corner of sec. 18, T. 24 N., R. 5 E. Here the Neva has a total outcrop thickness of 13 feet. The basal bed

immediately above the Salem Point shale is 1.5 feet thick and is a medium blue-gray, dense, slightly fossiliferous limestone. This rock weathers light gray and is broken by an occasional thin, gray, calcareous shale. Next above is an 0.5 foot limestone-shale zone, which is overlain by a distinctive light gray, fine to lithographic limestone which averages one foot in thickness. It contains much secondary calcite, a minor amount of limonite stain and weathers to a characteristic gray or dirty white color. At most places this is a most resistant bed and plays a major role in supporting the bench formed by the Neva member (Fig. 4). Next above is a series of three shale and two limestone beds referred to as the middle zone. The limestones of this zone are light gray, slightly fossiliferous, argillaceous and weathers to a characteristic buff color. These limestones contain fusulinids, but relatively few when compared to the limestones of the upper zone. The limestones of this zone contain large quantities of chert in some localities. The chert occurs as irregular nodules. It is dark blue on fresh unweathered surface, brown on weathered surface, and contains small white fusulinids. The upper zone of the Neva averages 3.4 feet in thickness and is composed of two irregular, massive to flaky, bedded limestones. Both of these limestones are light gray to yellowish, abundantly fossiliferous with fusulinids, and locally cherty (Fig. 5). The lower part of this upper zone contains more fusulinids and is not as flaky bedded as the upper part. The fusulinids at many places serve as locations for the concentration of brown ferruginous material, giving the fresh surface a speckled appearance. The weathered surface is yellow to buff and at many places highly pitted

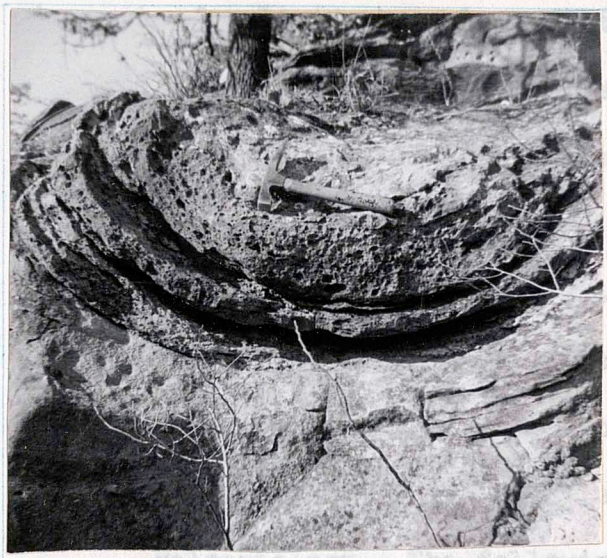


Figure 3 - Distorted bedding typical of the upper part of the Roca and lower part of the Grenola formations. SE¼ sec. 10, T. 24 N., R. 5 E.

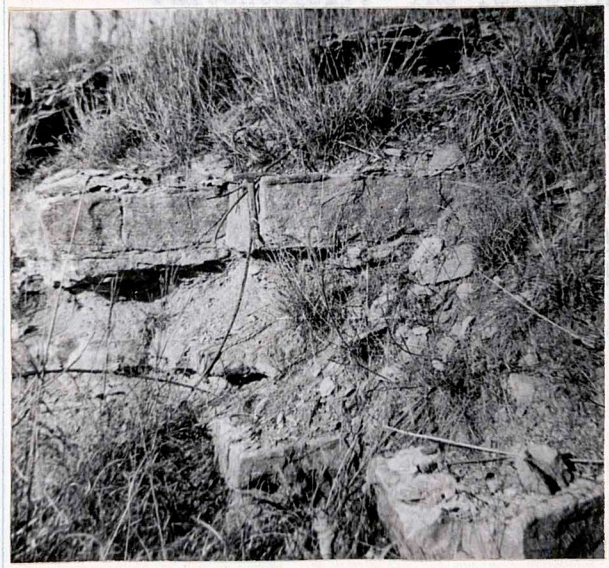


Figure 4 - Lower resistant beds of the Neva formation. NW¼ sec. 18, T. 24 N., R. 5 E.

Figure 5 - Upper flaky beds and fusulinid zone of the Neva formation. NW¼ sec. 18, T. 24 N., R. 5 E.

where the fusulinids have been weathered out.

The upper flaky bedded limestone of the Neva is immediately overlain by the Eskridge shale formation.

The insoluble residue test run on the upper massive bed of the Neva shows it to be composed of 54.2 per cent carbonate material, 16.0 per cent decanted clay size material, and 29.7 per cent residue. The residue consists mostly of light to medium gray, speckled chert grains and irregular white siliceous masses.

Paleontology. The following fossils were collected and identified from the Neva in the SE¼ sec. 10, T. 24 N., R. 5 E.:

Wellerella sp.
Neospirifer condor (Orbigny)
Juresania sp.
Dictyoclostus americanus Dunbar and Condra
Composita subtilita (Hall)
Crurithyris sp.
Crinoid debris

Eskridge Shale Formation. The formation was named by C. S. Prosser and J. W. Beede in 1902 (p. 709) from exposures in the vicinity of Eskridge, Wabaunsee County, Kansas. It is defined as being a predominantly shale unit with an average thickness of 30 feet in the Kansas section. It is underlain by the bench-forming Neva limestone and overlain by the Cottonwood limestone of the Beattie formation.

In the Belford area, the Eskridge shale interval is represented mostly by open and gently sloping grass covered prairie slopes. In the southern part of the area, the lower part of the interval becomes increasingly sandy and supports a rather dense growth of blackjack oaks and shrubs. Outcrops of the Eskridge shale are extremely rare and accurate stratigraphic measurement is difficult. The average thickness

is about sixty to seventy feet.

The lower 20 feet of the interval is exposed on the west bank of Dogy Creek in SW¼ sec. 1, T. 24 N., R. 4 E. Here, immediately overlying the Neva limestone, is a 10 foot zone of alternating thin limestones and shales. This zone becomes increasingly sandy upward and is overlain by a well-developed sandstone. The limestones of this zone are many colored with maroon, greenish-gray, and buff being the dominant colors. They are essentially non-fossiliferous, and contain a large percentage of clay and silt. The green coloring of some of the rocks of this zone could be the result of a small amount of glauconite. The shales of this zone are predominantly light green to maroon in color, and exhibit a blocky bedding. These shales are calcareous in the lower part, but lose their carbonate content in the upper part and become more and more silty. The thick sandstone interval overlying this lime-shale sequence is buff to tan with spots of yellow. It is porous, loosely cemented, and the bedding is extremely irregular ranging from thin to massive. Occasionally it is highly cross-bedded. This sandstone increases in thickness and resistance from north to south and has a marked influence on the topography in the southern part of its outcrop where it caps the steep river bench produced by the Arkansas River. The remainder of the Eskridge shale interval to the base of the Cottonwood limestone is covered except for a few small exposures up creek drainages and ditches. At these localities, the upper part of the Eskridge shale is composed predominantly of maroon and olive-gray shales.

Beattie Limestone Formation. The Beattie limestone formation

is defined in the Kansas section as the rocks of the interval between the Stearns shale and the Eskridge shale. It is named from the town of Beattie, Marshall County, Kansas, and is subdivided into two limestones separated by a shale member. In descending order they are: Morrill limestone, Florena shale, and Cottonwood limestone. Of these terms, the Cottonwood is the most widely approved and accepted. The Beattie formation is essentially devoid of topographic expression in the Belford area and is represented almost entirely by the grass covered slope between the benches formed by the Wreford and Neva limestones.

Cottonwood Limestone Member. The Cottonwood limestone was once thought to be the basal bed of the Permian system. It was not until 1934 that sufficient evidence of a stratigraphic unconformity was found to substantiate the lowering of the Pennsylvanian-Permian boundary to its present location at the base of the Admire group (Moore and Moss, 1933, p. 100). The Cottonwood has a relatively narrow outcrop belt which at few places exceeds one mile. The Cottonwood limestone crops out in a NE-SW direction from the banks of the East Fork of Dogy Creek in sec. 13, T. 25 N., R. 4 E. to the east central part of sec. 27, T. 24 N., R. 4 E. where the outcrop is covered by eolian material. It is also exposed for a short distance in the northern part of the area where it is near the foot of the steep escarpment south of the Arkansas River.

The most complete section of the Cottonwood limestone as represented in the Belford area is along the floor and banks of a tributary of Dogy Creek in the northern part of sec. 2, T. 24 N., R. 4 E. Here it has a thickness of approximately 4 feet and consists mostly of

argillaceous limestone with some shale. The limestone is peculiarly distinctive with its weathered pimply appearance. It is variegated with maroon, greenish-gray, and buff being the dominant colors. The rock is highly argillaceous and contains an abundance of well-rounded pebbles ranging from spherical to oval in shape. The majority of the pebbles definitely show a concentric structure and are probably algal deposits similar to those of the genus Osagia. Non-carbonate pebbles show no structure and are believed to be clay pebbles. The lower 2 feet of the member contains an abundance of fossil fragments and may be referred to as a spergenite. The upper part is only scarcely fossiliferous with shale fragments and may be properly classified as an oolitic calcarenite. The upper surface of the Cottonwood commonly exhibits a pitted surface. These solution pits are small, averaging 3/4 to 1 inch in width and 1/2 inch in depth (Fig. 6). At most places, the Cottonwood can only be traced by the pimply fragments found on the covered slopes, but in the extreme southern part of its outcrop the upper part becomes more resistant and weathers out in large slabs.

The insoluble residue of the Cottonwood is composed predominantly of very fine sand to silt size quartz grains with a trace of silicified shell fragments.

Florena Shale Member. The Florena shale is rarely exposed in the Belford area. The best exposure is along the banks of a small creek in the north-central part of sec. 2, T. 24 N., R. 4 E. Here the unit is composed of 7 feet of soft, blocky, maroon shale underlain by 8.8 feet of interbedded calcirudites and shale.

The calcirudites exhibit a gray to purple color and weather

Figure 6. Pitted top surface of the Cottonwood limestone. NE¼, sec. 27, T. 24 N., R. 4 E.

Figure 7. Typical pimply surface on weathered fragments of the Cottonwood limestone. NE¼, sec. 13 T. 26 N., R. 4 E.

with a rough surface. Most of the limestone pebbles weather to a tan color, giving the weathered surface a mottled appearance. The limestone pebbles of this rock are fine crystalline, well-rounded, and range in color from greenish-gray to dark maroon. The diameter of the pebbles ranges from a few millimeters to as much as 6 centimeters. The shales of this zone are calcareous, fossiliferous, locally silty, and range in color from maroon to greenish-gray.

Morrill Limestone Member. The Morrill member consists of two thin limestone beds. Generally, these beds are of little resistance to weathering and are grass covered, with no topographic expression. The lower bed is light gray, fine crystalline, and weathers to a smooth light gray surface. The upper, thicker bed is buff to bluish-gray, with maroon blotches. This bed is characterized by an abundance of oval oolitic structures filled with yellow limonite and resembling the small grain-shaped objects of the Wreford limestone.

Interval Between Beattie and Wreford Formations. The interval between the Beattie and Wreford formations is occupied by seven formations of alternating limestone and shale. They are in descending order: Speiser shale, Funston limestone, Blue Rapids shale, Crouse limestone, Easly Creek shale, Bader limestone, and the Stearns shale. The limestones of this interval are either absent or extremely thin and covered in the Belford area, making it impossible to establish definite correlatives with the different formations of the Kansas section. In the Belford area only one thin limestone was observed in this interval. It is a persistent bed and on the basis of its stratigraphic position, about 60 feet below the base of the Wreford, it is believed to be a

correlative of the Crouse limestone. In this thesis, the strata above the Crouse limestone and below the Wreford are placed in the Speiser shale. The strata below the Crouse and above the Beattie formation are included in the Easly Creek shale.

The Easly Creek shale is exposed at few places and is represented throughout most of the area by a moderately inclined grass-covered slope forming the lower part of the escarpment capped by the Wreford limestone. The best exposures of these rocks are along the steep bluff south of the Arkansas River in secs. 12 and 13, T. 26 N., R. 4 E. Here the shales are predominantly red and blocky bedded. The only noticeable break in this shale interval is introduced by a fairly resistant, thick-bedded, red, fine-grained sandstone which occurs about 22 feet above the top of the Cottonwood limestone.

The limestone identified as the Crouse limestone in this area is thin but extremely persistent. The formation has a maximum thickness of 1.4 feet in the northern part of the area and thins to about one-half foot in thickness in the southern part. The thinning of this bed is typical of the way all the limestones of this general area thin and become more sandy to the south. Slight indications are that this limestone shales out from the top in a north-south direction. The upper part of the bed is light gray, fine crystalline, slightly fossiliferous and contains only a small percentage of clay size material in the northern part of the area in sec. 12, T. 26 N., R. 4 E. whereas the upper part of the bed in the southern part of the area is sec. 27, T. 24 N., R. 4 E. is buff to light gray with a high percentage of ferruginous and argillaceous material. The lower part of the bed

maintains a fairly constant lithologic character throughout its line of outcrop. It is light gray, dense and fossiliferous, with an abundance of brachiopod shell fragments. It weathers light gray to tan and many of the brachiopod shells appear as clear calcite stringers on fresh surface.

The Speiser shale is represented by approximately 59 feet of gray and maroon shales and tan to maroon sandstones. This interval forms the steepest part of the escarpment below the Wreford outcrop. A small outcrop in the bluffs south of the Arkansas River in sec. 12, T. 26 N., R. 4 E. reveals the shales immediately above the Crouse to be red with blocky bedding. A fine-grained, tan to reddish-brown sandstone occurs about in the middle of this interval and increases in thickness and resistance to the south where it forms a slight topographic break and caps several small outliers. It ranges from thin to massive bedded, and at places is highly cross-bedded (Fig. 8). The shales of the upper part of the Speiser shale interval are occasionally exposed in drainage ditches immediately below the Wreford outcrop. A fair exposure of these upper shales is located along the banks of the drainage south of the section road in sec. 22, T. 24 N., R. 4 E. Here they are predominantly gray, soft, and exhibit "paper" bedding. The Speiser shale is the youngest formation of the Council Grove group.

Chase Group

The Chase group was first defined by Prosser in 1895 (pp. 771-786). Later this classification was revised and the Herington limestone was added as the topmost formation of the group. The present

Figure 8. The highly cross-bedded sandstone of the lower part of the Speiser shale formation in the southern part of the area. NE¼, sec. 27, T. 24 N., R. 4 E.

nomenclature subdivides the Chase group into seven formations. They are in descending order: Herington limestone, Enterprise shale, Winfield limestone, Doyle shale, Barneston limestone, Matfield shale and Wreford limestone.

The Chase is the topmost group of the Wolfcampian series and has an average thickness of 363 feet in the Belford area. The strata consist of alternating limestones and shales with a few sandstone lenses within the shale interval. The sandstones are lenticular and increase noticeable in thickness to the south. The limestones are tan to gray, predominantly algal and are thicker than the limestones of the underlying Council Grove group. All of these limestones thin and become increasingly sandy to the south. A considerable amount of chert is reported in the lower limestone formations of this group farther north in Oklahoma and Kansas, but no chert could be found in any of these units in the Belford area. The shales of this group are predominantly maroon and form a grass-covered slope between limestone benches.

A large part of the upper part of the Chase group is covered by eolian material between the loop of the Arkansas River in Township 25 North, Ranges 2 and 3 East and the two lower units are partially covered by eolian material in Township 23 and 24 North, Range 3 East.

Wreford Limestone Formation. The Wreford formation was previously known as the "Strong flint". It was first described by Robert Hay in 1893 for exposures near Wreford, Geary County, Kansas (Condra and Upp, 1931, p. 31). It is presently subdivided into three members which in descending order are: Schroyer limestone. Havensville shale,

and Threemile limestone. These members are not distinguishable in this area and the interval is described simply as the Wreford formation.

The formation was mapped and identified by the United States Geological Survey in 1918 (White et. al., 1922, p. 285) as being the Crouse limestone. Subsequent workers (Hruby, 1955, and Noll, 1955) have traced the formations of the Chase and upper part of the Council Grove groups from Kansas south to the northern edge of the Belford area in northern Oklahoma. From their correlations and stratigraphic intervals, the formations described and mapped by the United States Geological Survey as the Crouse and Wreford limestones are actually the Wreford and Barneston limestones respectively. Previous to the tracing of these formations into Oklahoma, Vosburg (1954) also identified the Wreford limestone as being the Crouse and mapped it as such in the Burbank-Shidler area immediately to the east of the present area of investigation.

The Wreford forms a conspicuous outcrop and is one of the most easily traceable units in the Belford area. Its outcrop supports the rim of a moderately steep eastward facing escarpment which transverses the central part of the area in a northeast-southwest direction. In the southern part of the area the sandstone above the Wreford forms the rim of this escarpment. The base of the Wreford is about 125 feet above the Cottonwood limestone. It has a thickness of from 12 to 16 feet in the northern part of the area, and thins to not more than 11 feet in the south. In some localities it is not more than 2 or 3 feet thick. In the central and northern part of the area the Wreford characteristically weathers into large rectangular blocks (Fig. 9).

Figure 9. Typical rectangular blocks of the buff phase of the lower part of the Wreford limestone formation.
SE¼, sec.4, T. 24 N., R. 4 E.

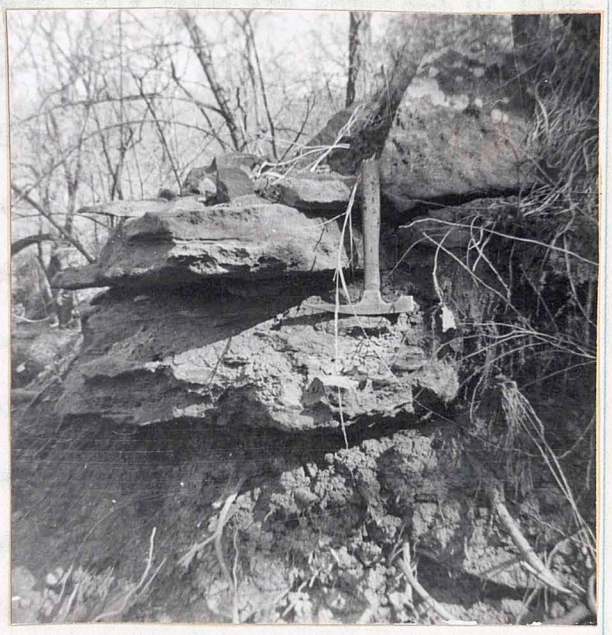


Figure 10. One of the best exposures of the Wreford in the southern part of the area.
NW¼, sec. 22, T. 24 N., R. 4 E.

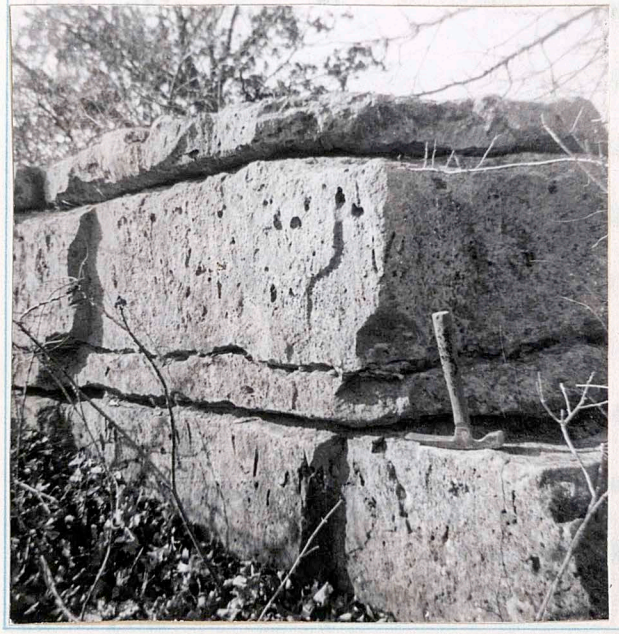


Figure 11. The lower part of the Wreford in the northern part of the area, showing pitted side surface.
SW¼, sec. 12, T. 26 N., R. 4 E.

This is particularly true in the southern part of Township 25 North, Range 4 East where the middle and lower parts of the Wreford are quite sandy and it has taken on a brown to yellow color. The upper zone of the Wreford is composed of alternating gray, fine crystalline, thin-bedded limestones and gray shales. These limestones are non-fossiliferous and brittle with well developed bedding planes. The upper part of this zone thins to the south where it is overlain by a maroon to greenish-gray, fossiliferous, argillaceous, conglomeratic, clastic limestone. A large number of the grains of this rock are composed of fine-grained limestone, but others are oval and show a definite concentric growth. These oval objects are believed to be algal pellets similar to the genus Osagia, as described by Twenhofel in 1919 (Johnson, 1946, pp. 1102-1119). This bed contains considerably more argillaceous material than the thin-bedded limestones immediately below. The middle part of the formation carries a considerable amount of limonite. The limestones of the middle and lower parts of the formation are predominantly gray, fine to medium crystalline, thick-bedded and algal. The algal pellets acting as nuclei for the concentration of limonite. Many of the fossil fragments are silicified and stand in relief on the weathered surface. The lower limestones thin and the intervening shales thicken to the south, but the ratio between carbonate and insoluble material for any one particular bed remains fairly constant. The insoluble residue of a sample from the middle zone contained 25 per cent cream colored, fine, subangular chert grains; 70 per cent clear to white, very fine, quartz sand grains; and a trace of porous silicified fossil skeletons.

Matfield Shale Formation. The Matfield formation was named by Prosser in 1902 (p. 714) for the strata forming the sides of the escarpment above the Wreford limestone near Matfield, Chase County, Kansas. It is subdivided in the Kansas section into three members. They are in descending order: Blue Springs shale, Kinney limestone, and Wymore shale. The Kansas terminology has been applied to the rocks occupying the same interval in northern Oklahoma, even though they are of a different lithologic character. Noll (1955) suggested the possibility of the Kinney members disappearing north of the present area of investigation and this theory is further supported by this thesis since no evidence of the Kinney was found in this area. Since the Kinney limestone is not present this far south, no subdivision is made and the interval from the top of the Wreford limestone to the base of the Barneston limestone will be recognized as the Matfield shale.

The Matfield interval forms a typical shale slope above the Wreford and below the Barneston limestones. It is grass covered for the most part and exposures are extremely rare. Two lenticular sandstone zones are present in the middle and lower part of the interval. The upper one is present in the northern part of the area in Township 26 North, Range 4 East. where it is approximately 8 feet thick and occupies a position 44 feet above the top of the Wreford. Here it is poorly indurated and forms only a slight topographic break in the predominantly shale slope. This sand zone becomes increasingly thicker and more resistant southward and forms a prominant bench below the Barneston limestone south of Twonship 25 North. It is a red to chocolate, very fine-grained, micaceous sandstone. The bedding is irregular ranging

Figure 12. The massive cross-bedded sandstone of the lower part of the Matfield shale formation. SE$\frac{1}{2}$, sec. 4, T. 24 N., R. 4 E.

from thin to massive and locally highly cross-bedded.

The lower sandstone is either thin or absent in the Belford area north of Township 25 North, Range 4 East. From this point south, it increases in thickness to a maximum of 25 to 30 feet in Township 24 North, Range 4 East where it has cut out part of the upper beds of the underlying Wreford limestone. This sandstone is similar to the one above except for being lighter in color. It is reddish-yellow to light brown and is laminated by an occasional dark streak parallel to bedding planes. South of Township 25 North, Range 4 East this sandstone forms a bench immediately above the Wreford and in many places the debris of this bed completely obscures the Wreford outcrop below. In Township 24 North, Ranges 3 and 4 East a thick sandstone occurs immediately below the Barneston limestone. At many places, this sandstone grades upward into and completely replaces the Barneston limestone. This sandstone is fine-grained, light gray to yellowish-tan, speckled with brown limonite spots and is locally calcareous. Its induration varies widely depending on the degree of cementation. Locally this bed is highly fossiliferous with brachiopods.

Barneston Limestone Formation. This formation was named by Condra (1931, p. 41) for exposures near Barneston, Gage County, Nebraska. In northern Oklahoma and Kansas it is subdivided into two members on the basis of its chert content. To the north of the present area of investigation, the upper Fort Riley member is predominantly algal and is chert free. The lower more massive Florence member is less fossiliferous and contains large quantities of irregularly bedded nodular chert. In the Belford area neither member contains chert, making it

impossible to differentiate between the two. It is possible that the Fort Riley member is not present in this area at all and the entire Barneston interval is represented only by the lower massive Florence member. The Fort Riley was named by Swallow in 1866 for outcrops along the bluffs of Cottonwood Creek and Kansas River in the vicinity of Fort Riley, Kansas (Prosser, 1902, p. 714-715). Later in 1895 Prosser (1902, p. 714) named the Florence member for exposures in the vicinity of Florence, Kansas.

The Barneston outcrop is broken into three distinct segments across the area from north to south. The northern segment is located in Township 26 North, Range 4 East, where it forms the rim of a moderately steep eastward facing escarpment and supports a gently inclined, grass-covered dip slope. It also caps the outlier in sections 14 and 15. The highest elevation in the area is upheld by the leading outcrop edge of this formation in section 23.

Southward through the central segment, in Township 25 North, Ranges 3 and 4 East the Barneston forms an easily traceable outcrop which forms the rim of a prominant escarpment. Also in this central segment, several Barneston outliers and buttes are located on the dip slope of the Wreford limestone.

In the extreme southern part of the area, the Barneston becomes quite sandy and in certain localities (sec. 29, T. 24 N., R. 4 E.) it changes from a siliceous limestone to an irregularly bedded sandstone in a distance of less than 50 feet. The Barneston probably sands out from both the top and bottom in a southerly direction, but the sanding out of this formation from the bottom is much more obvious. In the

above-mentioned locality the lower beds of the Barneston are extremely arenaceous and form dark gray to brown lenses in the encroaching sandstone. (Fig. 13).

One of the best outcrops of the Barneston is located along the rim of the steep valley walls in the northern part of sec. 29, T. 26 N., R. 4 E. (Fig. 14). Here the formation consists of four thick beds of similar lithologic character. The lower three beds are gray to tan with an occasional limonite speck. The upper bed is buff to yellow and is more fossiliferous. Crinoid, bryozoan, and brachiopod specimens including Composita subtilita are abundant throughout the formation. The middle beds of the formation become highly argillaceous and flaky bedded in the southern part of the area. As a result, they are more vulnerable to erosion leaving a notch between the upper and lower beds. All the beds of this formation contain small algal pellets that have the appearance of wheat grains and resemble fusulinids from a distance. Many of these pellets are silicified, contain a concentration of limonite and stand in relief on weathered surface. The upper buff layer contains more algal deposits than the lower beds and is locally flaky-bedded, causing it to weather back from the main ledge of the outcrop. The top and side surfaces are at many places pitted with solution holes averaging one to 2 inches in diameter and 1/2 inch deep (Fig. 15). The Barneston is less algal in the southern part of the area, contains more ferruginous material, considerably more arenaceous material, and generally weathers darker gray or brown.

Insoluble residue tests of the Barneston shows it to contain 24.3 per cent more calcareous material in the northern part of the area

Figure 13, Lenses of the lower part of the Barneston limestone in a sandstone in the northern part of the area. sec. 29, T. 26 N., R. 4 E.

Figure 14. Typical Barneston outcrop in the northern part of the area. sec. 23, T. 26 N., R. 4 E.

Figure 15. Pitted exposed side surface of the Barneston limestone in the northern part of the area.
SW¼, sec. 29, T. 24 N., R. 4 E.

than in the south. The residue consists predominantly of clear, well-sorted, subangular to rounded, very fine quartz grains. It also contains a trace of heavy minerals and a few silicified fossil remains.

Doyle Shale Formation. The formation was first described by C. S. Prosser and J. W. Beede in 1902 for exposures along Doyle Creek southwest of Florence, Marion County, Kansas (Condra and Upp, 1931, p. 43). Condra and Upp in 1931 subdivided the formation into two shale units separated by a thin limestone member. In descending order, they are the Gage shale, Towanda limestone, and the Holmesville shale.

In the Belford area the Doyle shale formation is composed of maroon and gray shales with some siltstones in the upper part and gray shales with thin light blue-gray to buff, fossiliferous, limestones in the middle and lower parts. The interval is represented by relatively steep grass-covered slopes immediately below the Winfield bench and gradually leveling out to merge with the upland dip slope surface of the Barneston limestone. This interval is almost completely covered by eolian material, making exposures, especially of the middle part, difficult to find. In this area, the Doyle has a total thickness of 125 to 135 feet.

Holmesville Shale Member. This unit was named for exposures in the vicinity of Holmesville, Gage County, Kansas (Condra, 1931, p. 43). In the Kansas section, Moore describes it as consisting of varicolored shales and impure limestones with a thickness ranging from 7 to 30 feet. This member is generally covered in the Belford area with a few scattered exposures of the lower part in drainage ditches and gullies immediately above the Barneston top surface. It is composed of thin

light, blue-gray, arenaceous, slightly fossiliferous limestone interbedded with tan to gray shales and lensing siltstones. A thickness of 27.5 feet is assigned to this member.

Towanda Limestone Member. E. A. Fath, in 1921, named this member from exposures just north of Towanda, Butler County, Kansas (Condra, 1931, p. 44). North and south from the type locality, the Towanda varies widely in thickness and lithologic character. At most places, however, its presence can be determined by the irregularly shaped yellowish-brown limestone slabs into which it weathers.

In the Belford area the Towanda member crops out in the western part of Township 26 North, Range 4 East where it is deeply weathered and caps a small hill. Irregular slabs of yellowish-brown siliceous limestone are found on the covered shale slopes immediately below the main outcrop. The bed is a tan to buff, argillaceous and ferruginous, coquinoid limestone. Pieces or fragments of echinoids, crinoids, brachiopods and other organic remains including algal deposits are found in the rock. Most of the shells are fragmentary and rotten, but some are silicified and recrystallized, making them extremely dense and resistant to weathering. They are blue-gray on fresh surface, tan on weathered surface, and resemble chert nodules. The weathered surface is tan to buff, becoming grayer in the lower part, and the sides are highly pitted.

Gage Shale Member. The Gage shale member was named by Condra in 1931 (p. 45) for exposures between one and two miles south of the west side of Wymore, Nebraska. It is defined as the shale lying between the Towanda and Winfield limestones, with an average thickness in Kansas

of approximately 45 feet.

Because of the thick and extensive eolian coverage in this area, the thickness of the Gage member could not be accurately determined, but, it has an approximate thickness of 105 feet. The upper part of this unit is locally exposed in dry washes along the eastward facing escarpment below the Winfield bench. Here the shales are varicolored (predominantly maroon) are are interbedded with an occasional thin, light tan to maroon, fine-grained, friable sandstone stringer.

Winfield Limestone Formation. The Winfield formation was named and defined by C. S. Prosser in 1897 (Condra, 1931, p. 46) for exposures in the bluffs of the Walnut River valley west of Winfield, Kansas. In the Kansas section it consists of two cherty limestone members separated by about 10 feet of fossiliferous shale. These members converge in a southerly direction and become indistinguishable in northern Oklahoma.

In the Belford area, the Winfield formation forms a slight and at some places prominent topographic break below the more conspicuous bench of the Herington limestone. Its outcrop closely parallels that of the Herington and is confined within the loop of the Arkansas River in Township 25 North, Ranges 2 and 3 East. It disappears to the north under the alluvium of the Arkansas River in sec. 5, T. 25 N., R. 3 E. and becomes covered in the southern part of the same township by eolian material in section 28. In the eastern part of Range 3 East, it forms a discontinuous outcrop close to the base of the escarpment capped by the Herington.

The best exposure of the Winfield in the area is along the banks of the drainage ditch in the center of sec. 16, T. 25 N., R. 3 E. Here

it is approximately 15 feet thick and can be divided into three limestone zones separated by red siltstones and shales. The upper limestone is extremely vuggy and displays a characteristic purple to maroon color. It is marly in places with a high percentage of clay and silt sized material. This bed is relatively non-resistant and weathers back into the grass-covered slope above the main ledge. The middle limestone is the most resistant bed and is normally the only exposed bed of the formation. It is light gray, fine crystalline, siliceous, slightly fossiliferous, and locally it contains many oval algal pellets. This bed weathers into large pitted blocks that slump down, covering the lower beds (Fig. 16). The lower zone is composed of three medium crystalline, light blue-gray limestone beds. These beds are algal and contain fragments of brachiopods, crinoids, bryozoans, and traces of other organic remains in moderate amounts. The upper bed is limonitic in places and more coarsely crystalline than the lower two beds. The middle bed is generally flaky bedded.

Insoluble residue tests of the Winfield shows it to be 19.1 per cent more calcareous in the northern part of the area than in the south. The residue consists of white and cream to colorless, well sorted, subrounded to rounded, very fine, sand sized quartz grains.

Enterprise Shale Formation. This formation was named by Beede in 1908 (Condra and Upp, 1931, p. 58) from exposures near Enterprise, Dickenson County, Kansas. It is defined as the shale interval lying below the Herington and above the Winfield formations. In this area the interval is rarely exposed and is represented by moderately steep grass-covered slopes. At places where the escarpment below the

Herington is steepest and especially along the bluffs east of the Arkansas River in Range 2 East, the Enterprise shale is covered with rubble from the Herington outcrop above. A thickness of 48 feet is assigned to the Enterprise shale in this area. It is composed predominantly of red, soft, blocky bedded shales with an occasional thin, red to maroon siltstone stringer.

Herington Limestone Formation. The Herington is the youngest stratigraphic unit cropping out in the Belford area, and is the uppermost formation of the Chase group. Beede, named the formation in 1908 from exposures in the vicinity of Herington, Dickenson County, Kansas, (Condra and Upp, 1931, p. 62). Because of its development in subsurface, the Herington is a most important and reliable reference horizon (Bass, 1929, p. 98).

In the Belford area the formation forms a prominant upland area with a moderately steep eastward facing escarpment and a gently inclined undulating dip slope. Much of the top surface as far east as the center of Range 3 East is covered by a veneer of eolian sands. The upland area is characteristic of open rolling prairie type topography. The Herington forms a conspicuous ledge and is an easily traceable unit throughout most of its line of outcrop.

The formation consists of two limestone zones separated from each other by approximately 3.5 feet of soft, gray, blocky claystone and interbedded with occasional thin gray shale. The upper zone is a coquinoid limestone composed almost entirely of reworded broken shell fragments. Many of the shells have limonite fillings which stand out against the light gray, medium crystalline matrix. The sides of the

weathered surface are rough where part of the matrix has been dissolved. This rock is relatively nonresistant and generally weathers back from the main ledge which is formed by the lower zone.

The lower zone is composed of 8 to 10 feet of gray and buff, fossiliferous, algal pellet limestone. This zone weathers into large rectangular blocks with highly pitted side surfaces (Fig. 18). The solution holes are conical, rarely exceeding 3/4 inches in depth, with an average diameter of 1 1/2 inches (Fig. 19). At some places, as in the abandoned quarry in SE¼, sec. 24, T. 25 N., R. 2 E., the lower zone is immediately overlain by a highly fossiliferous, buff, argillaceous limestone. Crinoid segments, bryozoan skeletons, brachiopod fragments, and other organic remains are in abundance in this rock. The middle part of this lower zone commonly contains large quantities of ferruginous material, which gives the rock a buff color, and it appears rotten where deeply weathered. The basal bed of the formation is a light gray calcarenite which is developed extremely well in sec. 11, T. 25 N., R. 3 E. where it is more than 3 feet thick. Many small clam shells and coiled gastropods in addition to algal pellets are found in this rock. The pellet grains have a limonite coating which gives the rock a yellow tint.

The insoluble residue of the formation contains well sorted, clear, sand sized quartz grains and silicified porous organic remains.

Quaternary Deposits

Extensive deposits of fluvial and eolian material of Pleistocene and Recent age cover much of the area immediately east of the Arkansas

Figure 16. One of the best exposures of the Winfield limestone. sec. 21, T. 25 N., R. 3 E.

Figure 17. View of the bench formed by Herington limestone. sec. 4, T. 25 N., R. 3 E.

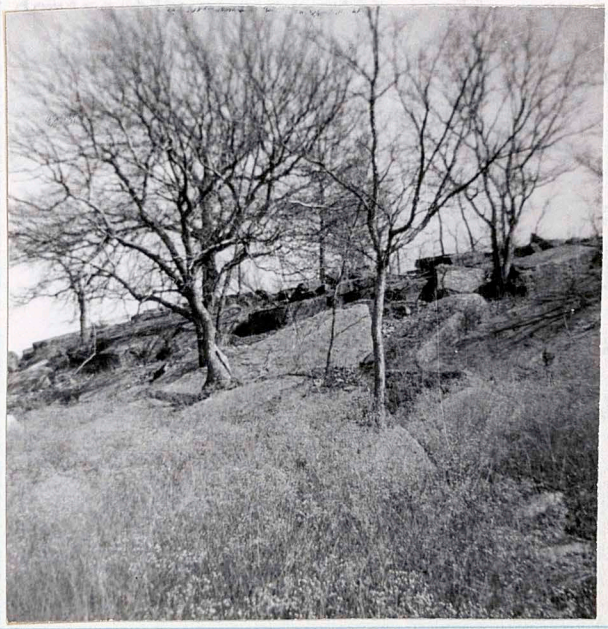


Figure 18. The large weathered blocks of the Herington limestone. SE¼, sec. 31, T. 26 N., R. 3 E.

River along the western and southern boundaries of the Belford area. A few sand dune accumulations are located within the Arkansas River flood plain, but most of the wind-blown material is on the higher elevations and the boundary between the alluvium and the eolian material is placed at the first abrupt topographic break above the flood plain.

Sieve analyses of the alluvium material shows it to be composed of silt, sand, and gravel sized grains. Light colored minerals predominate, but a small proportion of heavy minerals are present in addition to traces of tan to gray chert grains. The sorting of the river sand is typically poor and the grains are polished and show a considerable amount of wear, with subrounded to rounded corners.

The eolian material occurs as a veneer cover over vast upland areas adjacent to the flood plain and is composed of sand, silt, and clay sized particles. The modal class of the coarser wind-blown material varies from fine to medium sand. The grains are generally well rounded and exhibit a frosted surface. The composition is predominantly quartz with small amounts of other acidic minerals and a trace of heavy minerals, but no chert could be found. The composition of the wind blown material has a striking similarity to that of the Arkansas River deposits, which suggests a similar origin.

The silt and clay sized eolian deposits are characteristically buff to orange, barren, and form steep vertical walls up most of the tributaries that flow into the Arkansas River. These sediments are similar to loess deposits.

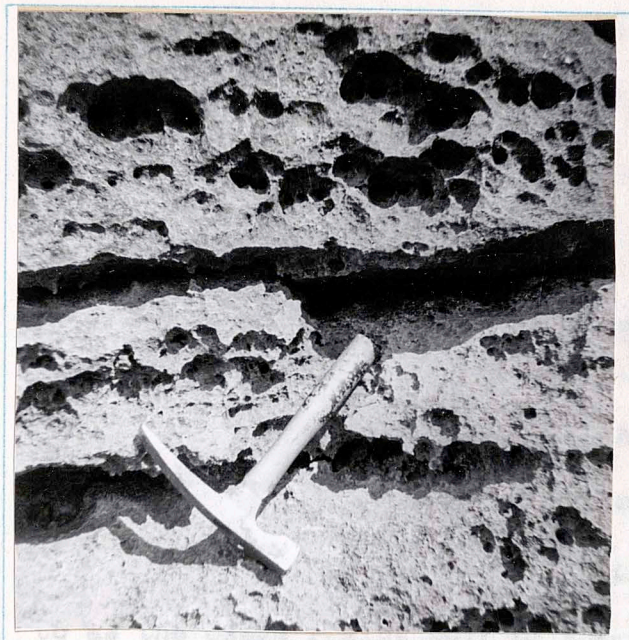


Figure 19. The pitted exposed side surface of the Herington limestone. sec. 4, T. 25 N., R. 3 E.

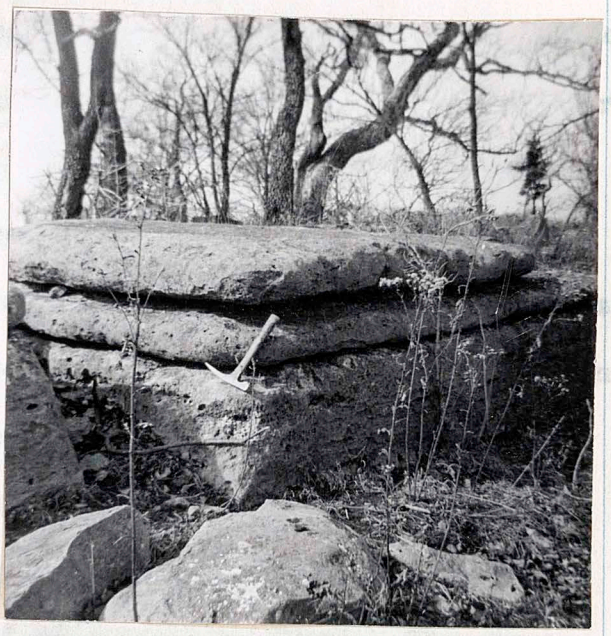


Figure 20. A natural exposure of the Herington limestone in the northern part of the area. SE¼, sec. 31, T. 6 N., R. 3 E.

Figure 21. Excellent exposure of the Herington limestone in an abandoned quarry. SE¼, sec. 24, T. 25 N., R. 2 E.

CHAPTER III

HISTORICAL GEOLOGY

Northeastern Oklahoma is located on the west flank of the Ozark plateau area and forms the southern extension of the vast region referred to as the Osage Plains unit of the Interior Lowlands. In this area, Pennsylvanian and Permian rocks appear in long roughly parallel lines of outcrop extending from Nebraska and Iowa southward into south central Oklahoma. The dip ranges from 30 to 50 feet per mile and the direction of dip ranges from northwest in Kansas to southwest in Oklahoma.

The Belford area is directly underlain by approximately 4,000 feet of sediments representing long periods of sedimentation broken by an occasional hiatus or period of structural movement. The structural movement during Ordovician time was the most important period of folding in so far as effect on sedimentation is concerned, in that the topography established at that time is reflected in the overlying sediments. Subsequent rejuvenation of these anticlines has resulted in a thinning of the section immediately above and has produced a reflection of the deep-seated anticlines on the present erosional surface.

In the Belford area rock units from upper Virgilian through Wolfcampian age are represented with a total stratigraphic thickness

of 833 feet. The rock units of this area are similar to the typical shelf deposits and the persistent limestones to the north in Kansas, but are transitional through a change of facies into clastics (sandstones and shales) in south central Oklahoma. In addition to the persistent limestones becoming more sandy in a southerly direction, numerous tongues and lenses of sandstone appear within the thick shale sections. This evidence indicates that this area received clastic sediments from the south at a much faster rate than did areas of equivalent rock units farther north.

Cyclic sedimentation is evident in this area, but is obscured to a large degree by the increase in clastic content of the sediments. M. K. Elias has done extensive work on the cyclothems of this sequence of rocks in the Kansas section and has determined from the faunal assemblage that the maximum depth of the seas during this period of geologic time was 200 feet or less (Elias, 1937, p. 427).

An uplift marked the close of the Pennsylvanian period producing a somewhat obscure unconformity at the base of the Admire group. The Lower Permian rocks of this area represent a transitional zone from the predominantly marine environment which existed during Pennsylvanian time to the predominantly terrestrial environment of the Permian. Many fossil species became less abundant with each successive fluctuation of the sea and as the water became more shallow and was restricted during late Wolfcampian and Leonardian times many fossil species disappeared completely from the region.

The cyclic sedimentation producing the succession of beds (limestones and shales) is explained by the repeated retreat and

advance of the epeiric seas. In addition to the cyclic appearance of stratigraphic units, the orderly occurrence of molluscs, brachiopods, fusulinids, and algae was found most helpful in determining the cyclic character of the sediments of the Wolfcampian series (Elias, 1937, p. 408).

The Brownville limestone is the uppermost formation of the Pennsylvanian system and is reported by Taylor (1953, p. 80) and others to contain a thin coal bed in northern Oklahoma. The Brownville is present in the Belford area and exhibits cyclic characteristics, but the thin coal bed was not observed. This indicated that the coal bed is covered or that phase of the cyclothem is missing in this immediate area.

Much of the surface, especially in the west and southern parts of this area, is covered by recent deposits of alluvium and eolian material. An earlier and higher erosional surface is indicated in this area by the presence of fluvial material (sand and gravel) on the uppermost upland surfaces. This, combined with essentially concordant summit levels, suggests the presence of a perched degradation surface or "rock plain" similar to that described by Melton (1935, p. 91-92). Th is surface has been described as the Pawhuska Rock Plain and according to Ham (1939, pp. 28-32) was formed between post-Permian and pre-middle-Pleistocene time. The origin of the surface is attributed to lateral planation by streams.

CHAPTER IV

STRUCTURAL GEOLOGY

Northeastern Oklahoma, including Osage County, lies in the Osage Plains which is located on the south and western flank of the Ozark Plateau province. The strike of the formations is essentially parallel to the western margin of the Ozark uplift, which is in a general northeast-southwest direction, and the dip of the strata is 30 to 50 feet per mile to the west. This section of the Osage Plains with its gently westward dip has been referred to as the Prairie Plain homocline.

The most important structures of this general region are faults, terraces, low domes, and folds of anticlinal type of which the plunging anticline or nose is the most common. The major faults are in echelon systems and are restricted to the middle Pennsylvanian section of northern Oklahoma. The strike of these fault systems as well as the axes of the major folds roughly parallel the western margin of the Ozark uplift, thus suggesting a genetic relationship. The faults are short, averaging one to two miles in length, and disappear with depth, most of them within the Pennsylvanian section. These faults also disappear westward and are not found in the upper Pennsylvanian or lower Permian rocks of western Osage County.

According to Powers (1924, pp. 381-385) the anticlines are of

two different types, reflected and surficial. The surficial folds are shallow, and supposedly were formed during late Pennsylvanian or early Permian time. These folds have no relationship to deeper structures and most of them disappear with depth, normally within the Pennsylvanian section. Economically as well as structurally speaking, the reflected folds are the most important type. These folds are the result of periodic if not continuous rejuvenation of Ordovician anticlines and buried hills. On the surface these folds are small, with low relief, but they increase proportionately in size and height with depth. This reflected fold has been termed by Powers as "Plains type folding".

Brown (1928, p. 501) states that the folds of Osage County are primarily the result of settling over buried hills and the horizontal movement along fault planes. He also suggests that the domal form of many of these folds indicates that they are the result of compressional forces acting in all horizontal directions with nearly equal intensity. Still another hypothesis has been presented by Kitson (1928, p. 1026) who stated that many of the folds of this general area were produced by shear stresses as well as compressive forces.

The topography of the pre-Cambrian crystalline rocks prior to deposition of Cambrian and Ordovician sediments was a low level peneplane broken by occasional small isolated hills or ridges. These hills were rejuvenated by folding during Cambrian and Ordovician time to form anticlines of high relief. The next advance of the sea covered this Ordovician erosional surface and deposited Silurian and Devonian beds with onlap. Some of the Ordovician highs were covered by

this period of sedimentation, but some were not covered. Even those that were covered show tremendous stratigraphic thinning. This period of deposition was brought to a close by uplift, probably associated with structural movement in the Ozark Dome area. The following hiatus produced erosion and truncation of some of the topographic highs. The next advance of the seas deposited the Chattanooga black shale and the Mississippian limestone by onlap. Slight uplift, retreat of the sea, erosion and possibly some faulting preceded the next sea advance, which deposited the Pennsylvanian and Permian sediments. Southward tilting is also indicated at this time by northward truncation and overlap of older beds by the Chattanooga shale from south to north.

Because of the extremely low dip of the strata in the Belford area, the folds are mapped only with difficulty. The United States Geological Survey in 1918 (White et. al., 1922) mapped the structures of this area, by the plain table method of survey, and a brief discussion of their findings is presented here.

West Bluff Creek Dome

The West Bluff Creek dome is a gentle oblong upwarp which lies in secs. 13 and 24, T. 26 N., R. 4 E., and has a closure of about 20 feet over an area of nearly one square mile. The east dip of this structure is about 8 feet per mile and the dip in all other directions is gentle. The crest of the dome is a few hundred feet northwest of the south quarter corner of section 13.

Schoolhouse Anticline

The Schoolhouse anticline is a westward plunging nose located

mostly in section 27 and occupying parts of sections 28 and 21. The dip to the north is gentle and averages 20 feet per mile and the dip to the west is about 90 feet per mile. The high point of the structure lies in the NE¼, sec. 27, T. 26 N., R. 4 E. At this location, the "Mississippi lime" is at a depth of about 3,600 feet.

Dogy Dome

The Dogy dome occupies an area of approximately two square miles and is located in parts of secs. 7 and 18, T. 24 N., R. 4 E. It has only slight closure and does not offer good possibilities for the accumulation of oil and gas. There is a gentle dip in all directions away from the center of the dome, which is located about 1,500 feet north of the southeast corner of sec. 28, T. 24 N., R. 4 E.

West Belford Dome

The West Belford dome is a small fold covering most of the SE¼ sec. 30 and the NE¼ sec. 31, T. 24 N., R. 4 E. It has a closure of about 10 feet over an area of approximately a quarter of a square mile. It has a dip of 15 to 20 feet per mile to the northeast and south with a steeper dip of nearly 30 feet for the first half mile to the west. The crest of the fold runs almost north-south through a point about 1,500 feet west of the southwest corner of section 30. At this point the "Mississippi lime" is at a depth of about 3,635 feet.

Sand Creek Anticline

The Sand Creek anticline is a north-south trending fold with no closure on the north. It encompasses parts of four sections at the

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intersection of Twps. 23 and 24 N., Rs. 3 and 4 E. The east lime is truncated by a northwestward trending fault which has a maximum displacement of 50 feet in the center of sec. 6, T. 23 N., R. 4 E. The extent of this fault has not been determined. Its displacement decreases to the north and south of the point of maximum displacement and appears to die out in the SE¼ sec. 31, T. 24 N., R. 4 E. To the south it is covered by terrace and eolian material. The Sand Creek anticline plunges to the south and near the southern end there is a small dome with about 8 feet of closure. Lack of exposures makes it impossible to map the structure accurately on the west side.

The surface formations of Township 25 North, Ranges 3 and 4 East vary only slightly in a few locations from the regional westward dip. A large part of Range 3 East and part of Range 4 East is covered with eolian and alluvial material, making it extremely difficult to map structures on the surface.

T. 25 N., R. 4 E.

Generally the westward dip prevails over the entire township. A few variations and reversals of dip were noticed in the center of the township including parts of sections 15, 16, 21 and 22. Just south of this point there is a structural flat.

T. 25 N., R. 3 E.

From the limited exposures in Township 25 North, Range 3 East structural contours of the top of the Bird Creek limestone were extended to the north of the Arkansas River in Township 26 North, Range 3 East. These studies revealed a westward pitching syncline extending

across secs. 34, 35 and 36, T. 26 N., R. 3 E. and secs. 1 and 2, T. 25 N., R. 3 E. Also a northwest trending nose is suggested in secs. 2, 3, and 4, T. 25 N., R. 3 E.

The only other deviation from the gentle westward dip is introduced by a well-defined flat-topped nose located in the western half of section 20 and the eastern half of section 19.

CHAPTER V

ECONOMIC GEOLOGY

The economic products of geologic nature are limited for all practical purposes in the Belford area to petroleum. The limestones are impure and sandy, making them undesirable for building purposes or for use in lime products. The intervening shale sections are also sandy, especially in the southern part of the area, making them undesirable for the production of clay products. A few of the loosely cemented thin-bedded sandstones weather in rectangular blocks and are used by some of the local residents for building purposes, but the rock is of inferior quality for commercial production.

The first oil produced in Osage County was in the eastern part of the county near Bartlesville. This production was from the Bartlesville sand, which is one of the most prolific oil sands of the county. Most of the early wells drilled in the western part of the county were dry holes and others had only slight shows of oil. The oil possibilities of western Osage County were not realized until 1920 when the Marland Oil Company discovered the Burbank Field. This field is located immediately east and north of the Belford area in Range 6 East.

Active drilling operations did not get underway in the Belford area until late 1939. Today there are nine proven pools in the area

with a total accumulative production of 4,057,473 barrels. The average depth of production is shallow, ranging from 2,500 to 3,500 feet. Multiple pay zones make reworking operations profitable. The deepest production comes from the "Mississippi chat" and the shallowest production is from the Perry gas sand. Between these limits, production is obtained from the Osage Layton, Lower Layton, Cleveland, Prue, and Skinner sands of Pennsylvanian age. The quality of the oil is high, averaging 40° A.P.I. gravity.

With the aid of seismic exploration, drilling activities have increased tremendously in this area since 1950. In the past year a total of 15 wells were completed as producers and drilling operations are currently being conducted at several localities. Considering the multiple pay zones and the possibility of numerous stratigraphic traps in addition to the already proven fields, the future oil possibilities of this area are good.

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APPENDIX

MEASURED STRATIGRAPHIC SECTIONS

Measured from floor of Salt Creek in SE¼ sec. 1, T. 24 N., R. 5 E. through railroad cut and up drainage to top of hill in NE¼, sec. 12.

LOWER ADMIRE DIVISION:

Sandstone, light tan, friable, contains many small limonite specks, irregularly bedded, about. 5.5

Covered interval, probably gray shale 5.0

Limestone, gray to tan, argillaceous, sparsely fossiliferous (no fusulinids) conglomeratic with light gray, very fine crystalline limestone pebbles 0.4

Shale, gray to tan. 2.5

BROWNVILLE LIMESTONE FORMATION:

Limestone, light gray to tan, compact, argillaceous, ferruginous, weathers to yellowish-brown, Contains abundance of fusulinids and crinoid segments. Fusulinids small in lower part, pink colored on fresh surface. Few red to brown chert pebbles with small white fusulinids strewn on weathered surface 1.3

Shale, gray, soft, platy, calcareous. 4.2

Limestone, light gray to buff, highly argillaceous, contains many replaced fossils, no fusulinids, but abundance of brachiopods, echinoids, and pelecypods, including many Pyalina, irregular thickness; red and brown chert pebbles containing white fusulinids found strewn over outcrop. 1.3

PONY CREEK SHALE FORMATION:

Limestone-shale zone; limestone, buff to light gray, argillaceous, irregularly broken beds. Alternating shales, light greenish-gray, platy, calcareous 5.0

Covered interval. 4.0

Argillaceous limestone, tan to light blue-gray, impure, irregular bedded; interbedded with streaks of thin, tan, flaky beds of siltstone and shale. 3.1

Shale, varicolored, gray to yellowish-tan, platy; streaks of tan, lensing siltstone 5.5

Shale, maroon, soft, blocky 21.0

Limestone, mottled greenish-gray and maroon, fine to coarse crystalline, fossiliferous with large pelecypods (Pyalina and Allorisma) fossils have coarse crystalline fillings and stand in relief on pimply weathered surface. Limonite spots

MEASURED STRATIGRAPHIC SECTIONS

1. Measured from floor of Salt Creek in SE¼ sec. 1, T. 24 N., R. 5 E. through railroad cut and up drainage to top of hill in NE¼, sec. 12.

LOWER ADMIRE DIVISION:

Sandstone, light tan, friable, contains many small limonite specks, irregularly bedded, about.	5.5
Covered interval, probably gray shale	5.0
Limestone, gray to tan, argillaceous, sparsely fossiliferous (no fusulinids) conglomeratic with light gray, very fine crystalline limestone pebbles	0.4
Shale, gray to tan.	2.5

BROWNVILLE LIMESTONE FORMATION:

Limestone, light gray to tan, compact, argillaceous, ferruginous, weathers gray to yellowish-brown. Contains abundance of fusulinids and crinoid segments. Fusulinids small in lower part, pink colored on fresh surface. Few red to brown chert pebbles with small white fusulinids strewn on weathered surface	1.3
Shale, gray, soft, platy, calcareous.	4.2
Limestone, light gray to buff, highly argillaceous, contains many replaced fossils, no fusulinids, but abundance of brachiopods, echinoids, and pelecypods, including many Myalina, irregular thickness; red and brown chert pebbles containing white fusulinids found strewn over outcrop.	1.3

PONY CREEK SHALE FORMATION:

Limestone-shale zone; limestone, buff to light gray, argillaceous, irregularly broken beds. Alternating shales, light greenish-gray, platy, calcareous	5.0
Covered interval.	4.0
Argillaceous limestone, tan to light blue-gray, impure, irregular bedded; interbedded with streaks of thin, tan, flaky beds of siltstone and shale.	3.1
Shale, varicolored, gray to yellowish-tan, platy; streaks of tan, lensing siltstone	5.5
Shale, maroon, soft, blocky	21.0
Limestone, mottled greenish-gray and maroon, fine to coarse crystalline. fossiliferous with large pelecypods (Myalina and Allorisma) fossils have coarse crystalline fillings and stand in relief on pimply weathered surface. Limonite spots	

concentrated in fossil replacements. 0.5
Limestone, molluscan facies limestone, greenish-gray, medium crystalline, contains mostly small pelecypods and coiled gastropods, coarse crystalline calcite replacements 0.2
Shale, varicolored, mostly tan and greenish-gray, soft . 11.0
Limy claystone, light greenish-gray, irregularly bedded, bottom surface of bedding planes exhibit small cylindrical objects resembling animal burrows, interbedded with brittle, greenish-gray shale. 3.0

GRAYHORSE LIMESTONE FORMATION:
Limestone, light gray to buff, ferruginous, sparsely fossiliferous in lower part, calcite fillings, siliceous, well indurated; weathers gray to brown. 1.0
Shale, gray, soft, fossiliferous 0.1
Limestone, coquinoid, light gray, fine to medium crystalline, locally argillaceous and ferruginous, fossil shells commonly replaced by calcite, echinoid, bryozoan, brachiopod, and pelecypod fragments including Myalina are in relief on weathered surface 0.2

II. Measured in southerly direction in dry wash just south of Salt Creek and east of the gravel road in the north-central part of sec. 11, T. 24 N., R. 5 E.

FORAKER LIMESTONE FORMATIONS:
Long Creek limestone member:
Limestone, light gray, medium crystalline, ferruginous, fossiliferous and weathers to a dirty dull gray. Contains an abundance of medium sized fusulinids which stand in relief on weathered surface and are pink on fresh surface. Not measured 2.4
Covered interval 38.5
Americus limestone member:
Limestone, blue-gray, medium crystalline, dense, sparsely fossiliferous in lower part becoming more fossiliferous in upper part 1.1

HAMLIN SHALE FORMATION:
Oaks shale member:
Shale, gray to tan, "paper" bedded, calcareous barren. . 2.5
Houchen Creek member:
Limestone, medium blue-gray, fine crystalline, sparsely fossiliferous with brachiopods. Contains no fusulinids and weathers light bluish-gray to buff in places. 0.5
Shale, soft, gray. 0.2

Limestone, dark blue-gray, fine to lithographic, dense, and sparsely fossiliferous. Weathers to a smooth powder blue surface. 0.4

Stine shale member:

Covered, probably variegated shale 11.9

FIVE POINT LIMESTONE FORMATION:

Limestone, dove-gray, medium crystalline, siliceous, barren of fossils. Weathers to a smooth surface . . 1.0

Limestone, light greenish-gray, fine crystalline, argillaceous, fossiliferous with fossil shell fragments replaced by clear calcite. Weathered surface is yellowish-brown. Contains no fusulinids 0.5

III. SW¼ sec. 11, T. 24 N., R. 5 E. Measured in road cut on south side of highway.

FORAKER LIMESTONE FORMATION:

Long Creek limestone member:

Limestone, light to medium gray, argillaceous, ferruginous, fine to medium crystalline, contains an abundance of small light gray to pink fusulinids. Flaky bedded, and weathered surface is olive-gray to buff. Alternating with thin beds of tan to olive-gray, fossiliferous, platy, shale. 2.5

Limestone, blue-gray, medium crystalline, argillaceous, compact, fossiliferous with small light colored fusulinids crinoid debris, brachiopods and pelecypod shell fragments. Weathered surface dull, smoky, gray. 1.8

Shale, light olive-gray to tan, soft blocky, fossiliferous. Upper six inches is a marly mudstone, buff in color and mottled with blotches of dirty white 2.4

Covered interval, probably gray shale 7.9

Limestone, light gray with buff stains, ferruginous, medium crystalline, dense, siliceous, and thick-bedded. Contains an abundance of small fusulinids and other shell fragments. Weathered surface, dull dirty gray 2.4

Hughes Creek shale member:

Claystone, yellowish to light greenish-gray, poorly bedded, fossiliferous 2.1

Limestone, light to dark blue-gray, medium crystalline, dense, argillaceous, slightly dolomitic and thin-bedded. 0.5

Shale, medium to olive-gray, fossiliferous, soft and thin bedded. 1.0

Limestone, light gray with some limonite stain, fine crystalline, argillaceous, irregular broken bedded. Contains abundance of fusulinids which are pink or flesh colored on fresh surface. 0.9

Sand-shale zone, lenticular beds of dark to olive-gray, soft, calcareous, platy, shale; and buff to olive-gray, non-fossiliferous, locally calcareous, fine-grained sandstone. Upper part of zone more fossiliferous than the lower part. 12.0

Covered interval, probably alternating soft gray shale and tan to buff fine sandstone 5.1

Sandstone, tan to light olive-gray, very fine crystalline, porous, broken irregular beds. . . . 1.2

Americus limestone member:

Shale, medium to light gray, soft, thin bedded. Contains an occasional thin, buff, fine sandstone stringer. 2.9

Limestone, light blue-gray, silty, fine-grained, well indurated and limonitic in spots. Consists of three irregular beds separated by buff to olive-gray soft, platy shale 2.2

Covered interval, probably gray shale with occasional thin limestone stringer. 5.0

Limestone, battleship gray, medium crystalline, dolomitic, dense. 1.2

HAMLIN SHALE FORMATION:

Oaks shale member:

Shale, light to dark gray, silty. 0.4

Houchen Creek limestone member:

Limestone, medium gray, light, siliceous, slightly fossiliferous, dolomitic, medium crystalline, and even-bedded. Weathered surface tan to buff 0.4

Shale, light gray, soft, platy, barren. 0.6

Limestone, medium gray, very fine to lithographic, dense. Has occasional stringer of clear calcite 0.5

Shale, olive-gray to buff, soft, platy. 2.8

IV. Measured in the railroad cut at the curve of the railroad in the central part of sec. 2, T. 24 N., R. 5 E.

FORAKER LIMESTONE FORMATION:

Hughes Creek shale member:

Sandstone, orange to tan, fine-grained, friable, massive, cross-bedded. Weathers to a reddish-brown 5.5

Covered interval. 11.0

Americus limestone member:
Limestone-shale zone, limestone is thin-bedded, battleship gray, fine crystalline, dense, sparsely fossiliferous in upper part. Alternating shales are olive to dark gray, soft, blocky. Occasional pebble to buff, subangular chert spotted with small white fusulinids found strewn on weathered top surface 6.1
Limestone, tan to light greenish-gray, argillaceous, fine crystalline, fossiliferous, thick-bedded. Contains abundance of medium sized fusulinids. Bottom surface covered with cylindrical objects 1.4
Shale, light gray, silty, calcareous, fossiliferous. Broken by occasional globular calcareous, mudstone or silty limestone 2.3
Limestone, light blue-gray, medium crystalline, greasy, sugary textured, fossiliferous. 0.9
Claystone, limy, gray, fossiliferous. 0.1
Limestone, upper part is light blue-gray, medium crystalline, fossiliferous. Lower part, light gray, non-fossiliferous, very fine crystalline, dense 1.9

HAMLIN SHALE FORMATION:
Oaks shale member:
Shale, dark to light greenish-gray, silty, fossiliferous and platy bedded. 0.5
Houchin Creek limestone member:
Limestone, dark gray, fine crystalline, well indurated, slightly fossiliferous 0.4
Shale, gray, calcareous, slightly fossiliferous, silty 0.3
Limestone, medium gray, fine to medium crystalline, greasy, dense. Contains abundance of replaced brachiopod shell fragments and other organic remains. No fusulinids. Bed separated in middle by 1-inch highly fossiliferous gray claystone 0.8
Shale, dove-gray to tan, soft, platy. 5.0

V. Measured in northerly direction up hillside from just below dam to top of Neva outlier located in the southwest corner of sec. 11, T. 24 N., R. 5 E.

ESKRIDGE SHALE FORMATION:
Shale, variegated, soft, blocky, not measured . . . . .

GRENOLA LIMESTONE FORMATION:
Neva limestone member:
limestone, light blue-gray to buff, fossiliferous,

with fusulinids, crinoid debris, and brachiopod fragments. Flaky bedded 2.2

Limestone, buff to light blue-gray, argillaceous, fossiliferous with abundance of fusulinids. Irregularly bedded with pitted side surfaces. . . 1.8

Claystone, light tan to gray, calcareous, fossiliferous 1.1

Limestone, light blue-gray, fine crystalline, dense, sparsely fossiliferous, weathers to smooth light blue surface 1.0

Covered interval, probably gray shale 1.2

Limestone, light gray, almost lithographic, sparsely fossiliferous, contains many crescent clear, calcite stringers which may be replaced fossil fragments. Weathers powder blue 2.2

Covered interval. 82.5

RED EAGLE LIMESTONE FORMATION:

Limestone, tan to light gray, silty, fine to medium crystalline, well indurated. Contains small oval objects which resemble oolitic structures 1.9

JOHNSON SHALE FORMATION:

Covered interval. 42.1

Limestone, medium gray, sandy, medium crystalline, dense. Contains a few small fusulinids and weathered surface dull yellow in places as result of varying limonite content. 1.6

Covered interval, probably maroon and gray shale. . . 5.5

FORAKER LIMESTONE FORMATION:

Long Creek limestone member:

Limestone, drab-yellow, fine crystalline, dense with abundance of medium sized fusulinids, not measured

VI Measured up hillside from abandoned quarry north of highway in south-central sec. 10, T. 24 N., R. 5 E. to the top of the outlier capped by the Neva.

GRENOLA LIMESTONE FORMATION:

Neva limestone member:

Interval not measured

Salem Point shale member:

Covered interval, probably tan to gray shales 8.5

Shale, maroon, soft, blocky 5.0

Lower Grenola Division:

Sandstone, tan to buff, varying degree of induration, fine-grained, massive. Broken by an occasional lensing, light gray, clastic limestone. 26.0

ROCA SHALE FORMATION:

Sandstone, tan to buff, fine-grained, calcareous, massive and distorted bedding. Contains occasional impure, clastic limestone lens	16.0
Covered interval.	27.5

RED EAGLE LIMESTONE FORMATION:

Limestone, light gray to yellow with faint pink tinge, medium crystalline, dense, contains protuberances of oval objects resembling oolites (probably algal pellets).	1.0
Limestone, light gray, siliceous, medium crystalline, tightly indurated and thick bedded. Contains much secondary calcite and many lobate oval objects. Weathers dull gray to white	3.1

JOHNSON SHALE FORMATION:

Covered interval.	29.0
Shale, maroon, soft, blocky	8.8
Limestone, greenish light gray, silty, fine crystalline, with considerable amount of secondary calcite. Cylindrical objects on bottom surface.	1.5
Claystone, greenish-gray, soft.	0.9
Limestone, light gray to buff, medium crystalline, argillaceous, extremely well indurated, sparsely fossiliferous and limonitic	3.0
Shale, dove-gray to tan, silty, fissil.	5.0

FORAKER LIMESTONE FORMATION:

Long Creek limestone member:

Limestone, tan to buff, ferruginous, highly fossiliferous, evidence of considerable weathering. Weathered surface rough and pimply with fossil fragments.	1.8
Shale, gray, calcareous, fossiliferous.	0.2
Limestone, medium gray, fine to lithographic, dense, sparsely fossiliferous. Contains clear secondary calcite stringers	1.0
Shale, light gray, silty, calcareous, fossiliferous	0.3
Limestone, light greenish-gray with spots of yellow, argillaceous, fossiliferous, with abundance of fusulinids.	1.0
Shale, light gray to tan, calcareous, fossiliferous .	0.2
Limestone, light greenish-gray with yellowish tinge, highly argillaceous. Contains abundance of large fusulinids which are flesh colored on fresh surface and stand in relief on weathered surface . .	0.8
Limestone, medium gray, fine to medium crystalline, fossiliferous, compact; has few isolated spots	

of yellow limonite. About 4 beds separated by light gray, silty, calcareous shale 2.9

VII. Measured in road cut on north side of hard-surface road in extreme NW¼, sec. 18, T. 24 N., R. 5 E.

ESKRIDGE SHALE FORMATION:
Sandstone, maroon to tan, fine-grained, friable, thick-bedded; not measured
Covered interval. 21.0

GRENOLA LIMESTONE FORMATION:
Neva limestone member:
Limestone, buff to gray, dense, siliceous, abundantly fossiliferous with crinoid debris, brachiopod shell fragments and medium sized fusulinids. 1.3
Limestone, greenish-gray to yellow, argillaceous, highly fossiliferous with fusulinids. Fusulinids act as locus points for concentration of brown ferruginous material. Weathered surface buff and pitted 2.1
Shale, light gray, soft, silty. 2.0
Limestone, light gray, fine to medium crystalline, fossiliferous with few fusulinids and crinoid debris. Fusulinids pink on fresh surface, weathers tan. 1.3
Shale, light gray to tan, soft. Contains shell fragments 0.9
Limestone, light gray, well indurated, sparsely fossiliferous. Contains small amount of limonitic clay sized material giving yellowish tinge. Locally cherty. 0.5
Shale, light gray to tan, soft. 0.4
Limestone, light gray, extremely dense, lithographic, contains noticeable amount of thin clear calcite stringers. Weathers almost white 1.0
Lime-shale zone, thin, light gray, argillaceous, limestone, and soft, gray shale 0.5
Limestone, medium blue-gray, dense, slightly fossiliferous with small brachiopod fragments. Weathers light gray. Broken by occasional gray, calcareous shale. 1.5

VIII. Measured on west bank of Dogy Creek in SW¼ sec. 1, T. 24 N., R. 4 E.

ESKRIDGE SHALE FORMATION:
Sandstone, buff to tan, friable, porous, well sorted, irregularly bedded ranging from thin to massive, locally highly cross-bedded 3.0

Zone, variegated, siltstone, shales and limestones. Maximum thickness 2 to 3 inches each. 4.5
Shale, variegated mostly maroon and olive-gray, soft, blocky. 3.5
Limestone, maroon, gray, and buff, limonitic, fine crystalline, highly argillaceous with small amount of glauconite. Two beds separated by a thin bed of maroon shale. 0.9
Shale, maroon to olive-green, soft, blocky. 1.0
Shale and mudstone, light green to maroon, calcareous, marly, fissile to medium bedded. 0.9

GRENOLA LIMESTONE FORMATION:
Neva limestone member: not measured

IX. Measured section in floor and along banks of tributary of Dogy Creek in north central part of sec. 2, T. 24 N., R. 4 E.

BEATTIE LIMESTONE FORMATION:
Morrill limestone member:
Limestone, buff to bluish-gray, with blotches of maroon, contains elongated oval objects many of which filled with limonite. Tightly indurated . . 1.0
Limestone, light gray, dense, fine crystalline, weathers light gray 0.4
Florena shale member:
Shale, maroon, soft, blocky 7.0
Limestone, calcirudite, maroon, argillaceous, limestone pebbles, light gray to brown. 0.8
Shale, gray to yellowish-green, calcareous; contains few gray and maroon, fine crystalline, limestone pebbles up to one-inch in diameter. 1.2
Shale, red, soft, blocky, some red siltstone in lower part. 4.0
Limestone, calcirudite, gray to purplish; many of the pebbles are reddish-brown. Pebbles composed mostly of carbonate detritus. 0.9
Shale, maroon to gray-green, highly calcareous, uneven bedding. 2.0
Cottonwood limestone member:
Limestone, light gray to buff, argillaceous, non-resistant, weathers in globules with small lobate protuberances. 0.5
Limestone, gray to maroon, with buff limonite stains, argillaceous. Contains elliptical and oval objects with concentric structure; weathered top surface pitted. 0.8
Limestone, spergenite, greenish-gray to maroon, argillaceous, fossiliferous, oolitic. Upper part contains considerable amount of maroon shale partings. Weathers in globules with pimple surface . 2.7

ESKRIDGE SHALE FORMATION:
Shale, red, blocky, soft, mostly covered. 38.5

X. Measured from head of drainage up south side of small hill in northeast corner of sec. 27, T. 24 N., R. 4 E.

SPEISER SHALE FORMATION:
Sandstone, dark-reddish-brown with occasional darker streak, friable, irregularly bedded from thin to massive and highly cross-bedded. . . 16.5
Covered interval. 8.5

CROUSE LIMESTONE FORMATION:
Limestone, buff to light gray much limonite stain in upper part, argillaceous, fine to medium crystalline, fossiliferous. Fossil shells appear as curved calcite stringers on fresh surface. . . 0.7

EASLY CREEK SHALE FORMATION:
Shale, maroon, soft, blocky 5.5
Covered interval. 44.0
Sandstone, tan to reddish-brown, fine-grained, well sorted, porous, loosely cemented. 2.0
Covered interval. 17.0

BEATTIE LIMESTONE FORMATION:
Florena shale member:
Shale, purplish to greenish-gray, mottled, silty occasional thin siltstone stringer. 5.4
Cottonwood limestone member:
Limestone, buff to maroon with greenish tinge, conglomeratic, with limestone oolites and clay pebbles 0.3
Limestone, yellowish-gray to maroon, conglomeratic with limestone oolites, probably algal pellets and clay pebbles; weathered top surface is pitted. 1.2

XI. Measured up steep east face of Wreford escarpment in extreme south-central part of sec. 12, T. 26 N., R. 4 E.

WREFORD LIMESTONE FORMATIONS:
Limestone, light gray, fine crystalline, silty, brittle, thin platy bedded. 5.9
Covered interval. 5.5
Limestone, light gray, with yellow limonite stains; medium crystalline, fossiliferous. Concentration of limonite in oval objects with concentric structure. Many fossil shell fragments replaced by calcite and dark ferruginous material, four or five thick beds 4.3

SPEISER SHALE FORMATION:
Covered interval, probably red shale. 55.0
Shale, red, soft, blocky. 5.5

CROUSE LIMESTONE FORMATION:
Limestone, light gray, dense, fine crystalline, sparsely fossiliferous, clear calcite replacing fossil fragments, even-bedded, weathers light gray to tan. 1.2
Limestone, light gray, fine crystalline, fossiliferous with abundance of brachiopod shell fragments. Clear calcite replacements. 0.3

EASLY CREEK SHALE FORMATION:
Shale, red, soft, blocky. 9.9
Covered interval, probably red shale. 27.5
Sandstone, reddish-brown, fine-grained, friable 2.1
Shale, red, blocky, silty 5.0

BEATTIE LIMESTONE FORMATION:
Shale, red, blocky with some thin siltstone 17.0
Cottonwood limestone member:
Limestone, maroon to light purple, conglomeratic with subangular limestone fragments. Weathers in globs averaging 1 to 2 inches in diameter. . . . 1.3
Limestone, purplish to yellowish-gray, conglomeritic with algae and clay pebbles. 2.0

XII. Measured section from south of dam to SW corner of sec. 11, T. 25 N., R. 4 E. to top of escarpment in SE corner of section 10.

BARNESTON LIMESTONE FORMATION:
Limestone, light blue-gray to buff, medium crystalline, algal; limonite replacements, brittle . 0.4
Limestone, medium blue-gray, fine crystalline, arenaceous, well indurated. 1.4
Limestone, light gray to tan, medium crystalline, fossiliferous, oval algal pellets with limonite fillings. 0.4
Limestone, light to bluish-gray, dolomitic, limonitic, lower part irregular flaky bedded, siliceous, well indurated, and brittle 1.4

MATFIELD SHALE FORMATION:
Covered interval, probably red shale. 30.0
Sandstone, red to chocolate, fine-grained, friable, micaceous, thin to massive bedded, locally highly cross-bedded 16.5
Shale, red, silty, blocky 22.0
Covered interval, probably red shale. 16.5
Sandstone, reddish-brown to tan, friable with

occasional dark streak. 16.5

WREFORD LIMESTONE FORMATION:
Limestone, light gray, algal, medium crystalline, side surface pitted 0.6
Limestone, light gray, well indurated, siliceous, weathered surface pitted. 1.3
Limestone, light blue-gray, dense, sparsely fossiliferous. Solution pits on top surface average 3/4 inches in diameter and 1/2 inches deep. . . . 1.4

XIII. Measured up drainage in northern part of sec. 22, T. 24 N., R. 4 E. to section road, thence up borrow ditch to first Barneston outlier in north-central part of section 21.

BARNESTON LIMESTONE FORMATION:
Limestone, gray to buff, limonitic, weathers in large blocks, algal 1.0
Limestone, light blue-gray, medium crystalline, flaky bedded, weathers light gray 1.1
Limestone, bluish-gray, with limonite spots, sparsely fossiliferous, weathers dull gray and in large slabs. 0.9

MATFIELD SHALE FORMATION:
Covered interval. 35.0
Sandstone, red to chocolate, fine-grained, well sorted, cross-bedded, occasional dark streak. . . 12.0
Covered interval, probably maroon shale 13.0
Sandstone, red to chocolate, fine-grained 0.9
Covered interval, probably maroon shale 7.5
Sandstone, maroon to yellowish-brown, massive weathers maroon, laminated. 11.0
Covered interval. 4.0
Shale, red; streaks of lenticular reddish-brown to tan, fine-grained, sandstone 15.0

WREFORD LIMESTONE FORMATION:
Limestone, light purple, fine crystalline, dense arenaceous, weathers dull gray with maroon tinge 0.7
Limestone, maroon to yellowish-gray, highly argillaceous, silicified fossil fragments, weathered surface gray and rough. 1.9
Limestone, gray with streaks of buff, fine crystalline, dense and thin-bedded. 1.3
Limestone, maroon to greenish-gray, conglomeratic, argillaceous, contains crystalline limestone, and algal pellets, weathered surface pimply . . . 2.2
Limestone, light gray to tan, fine crystalline, siliceous and thin-bedded. Separated by

streaks of gray shale 1.8
Shale, gray, soft 0.9
Limestone, buff to gray, limonitic, medium crystalline, arenaceous, well indurated, weathers dull gray with tan specks. 0.8
Shale, light gray, calcareous 0.2
Limestone, light blue-gray, medium crystalline, dolomitic, slightly fossiliferous, limonite specks, silicified fossil fragments in relief on weathered dull gray surface. Two beds separated by a thin light gray calcareous shale 1.1

SPEISER SHALE FORMATION:
Shale, light gray, soft "paper" bedded. 11.0

XIV. Measured in southerly direction up drainage in western part of sec. 21, T. 24 N., R. 4 E. to top of Barneston outlier in SW corner of section 21.

DOYLE SHALE FORMATION:
Sandstone, orange to tan, fine-grained, weathers back from main ledge of Barneston; thick bedded . 1.0

BARNESTON LIMESTONE FORMATION:
Limestone, light gray to buff, medium crystalline, limonitic, irregularly bedded, upper part flaky . 1.2
Limestone, blue-gray, fine crystalline, few limonite spots, flaky bedded, forms notch. 1.4
Limestone, light blue-gray, fine crystalline, thick bedded, siliceous, limonitic. 1.1

MATFIELD SHALE FORMATION:
Covered interval. 42.0
Sandstone, red to chocolate, speckled in places, with ferruginous material, fine, loosely consolidated, massive, irregularly bedded, locally slightly cross-bedded 11.0
Covered interval, probably red shales 32.0
Sandstone, fine-grained, dark maroon, massive, cross-bedded. 16.5

WREFORD LIMESTONE FORMATION:
Limestone, not measured

XV. Measured section of Barneston capping small outlier in SW$\frac{1}{4}$ sec. 29, T. 24 N., R. 4 E.

BARNESTON LIMESTONE FORMATION:
Limestone, brown to buff, limonitic, argillaceous, fossiliferous, predominantly algal, fine to

medium crystalline, upper part more resistant. . . 2.0
Limestone, light gray to buff, arenaceous, weathers dull; separated by 2-inch sandstone layer with gradational contact. 0.9
Limestone, blue-gray, fine crystalline, brittle, siliceous, flaky bedded resembling bark on oak tree, spotted brown by iron stain, forms notch 1.3
Limestone, blue-gray, fine crystalline, siliceous, contains orange-brown limonite spots, weathers brown 1.0

MATFIELD SHALE FORMATION:
Sandstone, tan speckled with brown limonite, fossiliferous with brachiopods, induration varies with degree of cementation, evenly thick bedded with upper part becoming calcareous. Upper part contains lenses of extremely compact light gray, siliceous limestone which weathers light brown 5.0

XVI. Measured in southerly direction from Barneston limestone to top of hill in north-central part of sec. 29, T. 26 N., R. 4 E.

DOYLE SHALE FORMATION:
Towanda limestone member:
Limestone, tan to buff, argillaceous, coquinoid, contains algal overgrowths and broken fragments of echinoids, crinoids and brachiopods; weathered surface pitted. 2.3
Covered interval, flaky fragments of a buff to yellow, fine crystalline, dense, locally sandy, sparsely fossiliferous limestone with calcite replacements occurring in the middle and upper part of the interval. 27.5

BARNESTON LIMESTONE FORMATION:
Limestone, buff to yellow, fine to medium crystalline, fossiliferous, predominantly algal, argillaceous and limonitic. 1.1
Limestone, light gray with yellow tinge, fine crystalline, slightly fossiliferous, contains specks of limonite fillings, three beds 5.0

XVII. Measured up bluff east of road to abandoned quarry in SE$\frac{1}{4}$, sec. 24, T. 25 N., R. 2 E.

HERINGTON LIMESTONE FORMATION:
Limestone, coquinoidal, light gray, limonite fillings and replacements; matrix medium crystalline, weathered surface rough. 2.4

Claystone, gray, blocky	3.5
Limestone, buff, highly fossiliferous, argillaceous, contains crinoid segments, bryozoan skeletons, brachiopod and other shell fragments	0.1
Limestone, light blue-gray, fine to medium crystalline, argillaceous; weathers tan. Alternating with thin, gray, platy shale.	3.6
Limestone, buff to yellow, ferruginous, argillaceous, rotten appearance, few algal pellets	4.7
Limestone, light gray, clayey, medium crystalline, compact, thick bedded	1.2

ENTERPRISE SHALE FORMATION:

Covered interval, probably red shale and siltstone. .	54.0
Shale, variegated (maroon and gray) blocky.	2.0

WINFIELD LIMESTONE FORMATION:

Limestone, light gray to reddish-brown, extremely argillaceous, sparsely fossiliferous, few limonite spots.	1.3
Siltstone, maroon with purplish tint, well sorted, calcareous cement, non-fossiliferous, resistant	3.9

XVIII. Measured on south side of road in SE$\frac{1}{4}$ sec. 31, T. 26 N., R. 3 E. about 200 yards from intersection with Highway 11.

HERINGTON LIMESTONE FORMATION:

Limestone, light gray, slightly fossiliferous with brown and yellow iron replacements, dense	0.8
Limestone, gray to yellowish-brown, argillaceous, algal, weathers with pitted surface	1.3
Limestone, light gray with yellow tinge, siliceous, contains spherical pellets resembling oolites, weathers dull with pitted surface, thick massive bedded.	2.9
Shale, red soft with thin red siltstone stringers . .	40.0

XIX. Measured up head of drainage in east-central part of sec. 16, T. 25 N., R. 3 E.

ENTERPRISE SHALE FORMATION:

Covered interval, probably red shales and siltstone to base of the Herington limestone. . .	30.0
Shale, variegated (maroon and gray) soft, blocky. . .	16.5

WINFIELD LIMESTONE FORMATION:

Limestone, maroon to gray with streaks of white.

sandy; fossils dissolve out leaving rock vuggy. .	2.5
Siltstone, maroon with light colored blotches, gray, porous, well sorted, calcareous	2.6
Limestone, light gray, fine crystalline, argillaceous, sparsely fossiliferous, few limonite spots in lower part.	2.5
Siltstone, maroon to brown, friable, porous; maroon shale partings	0.5
Shale, variegated (maroon with leached layers) occasional limonite stain	2.4
Limestone, yellow to light gray, medium to coarse crystalline, dense; limonite and coarse crystalline calcite replacements, fossiliferous .	1.5
Limestone, light bluish-gray, dense, fossiliferous with few limonite fillings. Contains fragments of crinoids, brachiopods, and other organic remains. Upper part flaky bedded	1.4

XX. Measured from upper Barneston in drainage ditch in extreme eastern part of section 23 to Winfield ledge close to top of small hill in extreme southern part of sec. 11, T. 25 N., R. 3 E.

WINFIELD LIMESTONE FORMATION:	
Limestone, buff to brown, silty, fine to medium crystalline, sparsely fossiliferous; weathers in large blocks with gray to yellow color	1.2
DOYLE SHALE FORMATION:	
Shale, variegated (maroon and gray), platy, occasional thin, light tan, fine sandstone stringer.	33.5
Covered interval, mostly covered by eolian material approximate thickness	85.0
Sandstone, light gray to buff, friable, fossiliferous	1.2
Limestone-Shale-Sandstone Zone; alternating thin beds; buff, clayey, friable, sandstone; shale, gray, soft, platy; limestone, light blue-gray, sandy	3.5
Siltstone, gray with yellow streaks, friable, thin-bedded.	2.2
Limestone, light gray, siliceous, fossiliferous, medium crystalline, dense, thick bedded	2.0
Shale, gray, soft, platy; few thin beds of ferruginous, calcareous mudstone	4.5
BARNESTON LIMESTONE FORMATION:	
Limestone, medium to light gray, dense, argillaceous, limonite fillings, fossiliferous (predominantly algal) flaky bedded in upper part	5.5

MEASURED SECTION OUTSIDE AREA

T. 25 N., R. 5 E.

Measured up hillside southeast of spillway at Fairfax Lake.

FORAKER LIMESTONE FORMATION:

Hughes Creek shale member:

Limestone, light blue-gray, dense flaky bedded, fossiliferous; fusulinids abundant, flesh colored on fresh surface. 0.4

Covered interval. 2.0

Sandstone, tan to buff, irregularly bedded, friable, fine-grained; beds lenticular and broken by thin beds of gray to buff silty shale. 22.0

Sandstone, buff to light tan, fine-grained, friable, massive and cross-bedded 7.2

Americus limestone member:

Covered interval, probably silty shale. 8.8

Limestone, light blue-gray to buff, fine crystalline, argillaceous, limonitic. Contains abundance of crinoid debris and small plump fusulinids. 1.2

Shale, gray to buff, silty, loosely cemented, calcareous, highly fossiliferous 3.0

Limestone, battleship gray, limonitic in spots, dense fine to medium crystalline, thick bedded. Only slightly fossiliferous. 1.1

HAMLIN SHALE FORMATION:

Oaks shale member:

Shale, gray, calcareous, silty, loosely cemented. . . . 0.7

Houchin Creek limestone member:

Limestone, light gray, limonitic, argillaceous, slightly fossiliferous, Myalina, weathers buff. . . 0.8

Shale, dark blue-gray, fissile, brittle 1.0

Limestone, medium blue-gray, dense, medium crystalline; weathers tan to brown. 0.8

Shale, light gray, calcareous, crumbly. 0.2

Limestone, medium blue-gray, dense, fine crystalline, weathers with irregular tan surface 0.7

Covered interval. 32.5

Shale, maroon, soft, blocky 6.0

Limestone-shale zone; limestone, light greenish-gray to yellowish-brown, argillaceous, irregularly bedded; shale, tan to gray, fissile fossiliferous 2.8

Limestone, greenish-gray to light brown, argillaceous, fossiliferous, irregular lumpy bedded 0.5

Lime-shale zone; limestone, gray, argillaceous; shale, tan to gray, calcareous, fossiliferous . . . 1.2

BROWNVILLE LIMESTONE FORMATION:

Limestone, light greenish-gray, argillaceous, fine crystalline; abundance of fusulinids and crinoid stems.	1.1
Shale, greenish-gray, fossiliferous, limy.	5.5
Limestone, greenish-gray, clayey, thick irregularly bedded, slightly fossiliferous; no fusulinids. .	1.2
Shale, gray, soft, platy	1.8

[redacted]