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BULLETIN 51

THE STRATIGRAPHY AND STRUCTURAL DEVELOPMENT OF THE FOREST CITY BASIN IN KANSAS

By WALLACE LEE

Investigation conducted under cooperative agreement between the State Geological Survey of Kansas and the United States Geological Survey

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CONTENTS

ILLUSTRATIONS

TABLES

THE STRATIGRAPHY AND STRUCTURAL DEVELOPMENT OF THE FOREST CITY BASIN IN KANSAS

By Wallace Lee

ABSTRACT

This report embodies the results of a study of the stratigraphy and structural history of that part of the Forest City basin lying in northeastern Kansas. It is based on the microscopic examination of samples from wells and the correlation and interpretation of the lithologic units recognized in the area. Well samples of rocks ranging in age from pre-Cambrian to Permian have been examined and identified. They show many similarities to the nearest outcrops of rocks of the same age, but certain differences occur.

The pre-Cambrian rocks penetrated in drilling in northeastern Kansas consist of red granite, but red quartzite is reported in adjoining areas. The overlying rocks of Upper Cambrian age in Kansas consist of the Lamotte sandstone, Bonneterre dolomite, and Eminence dolomite. The Lamotte sandstone is present in most places in the subsurface of northeastern Kansas where it has a thickness of 5 to 30 feet. The Bonneterre dolomite which conformably overlies the Lamotte is a noncherty argillaceous dolomite. It has a maximum known thickness of 91 feet in Douglas county and thins toward the northwest. The Eminence dolomite is unconformable above the Bonneterre. It is a light-colored crystalline dolomite with considerable gray and blue vitreous chert characterized by insoluble residues of dolocastic chert. It is 175 feet thick in Douglas county but wedges out toward the northwest.

Arbuckle rocks of Ordovician age in northeastern Kansas are represented, in ascending sequence, by the undifferentiated Van Buren formation and Gasconade dolomite, the Roubidoux formation, and the undifferentiated Jefferson City and Cotter dolomites. These formations are separated from each other by minor unconformities.

The undifferentiated Gasconade dolomite and Van Buren formations unconformably overlie the Eminence dolomite. The Gasconade and the Van Buren have a thickness of 206 feet in Douglas county, but thin rapidly toward the northwest. The Roubidoux formation consists of alternating sandstone and dolomite. It has a maximum thickness of 175 feet. It is beveled by the St. Peter sandstone in Shawnee county. The undifferentiated Jefferson City and Cotter dolomites consist of cherty finely crystalline dolomite, in part argillaceous, which is 106 feet thick in Douglas county. They are beveled by the St. Peter sandstone and do not extend much farther toward the northwest in Kansas.

The St. Peter sandstone is unconformable above the undifferentiated Jefferson City and Cotter and bevels all the older Ordovician and Upper Cambrian formations. In Washington and Marshall counties it overlies granite. The St. Peter has an average thickness of about 55 feet but greater thicknesses are known from some wells.

Ordovician rocks younger than the St. Peter in northeastern Kansas consist, in ascending sequence, of a possible correlative of the Plattin limestone, the Decorah shale, the Kimmswick limestone, and the Maquoketa shale. The stratigraphic relations of these formations to each other are obscure in the subsurface. The supposed Plattin limestone, which is unconformable on the St. Peter, occurs only in the deeper part of the North Kansas basin. It consists of noncherty lithographic limestone and sucrose dolomite only 15 to 20 feet thick. The Decorah shale immediately overlies the Plattin where this formation is present. In most places it is unconformable on the St. Peter. It consists of sandy dolomite and sandy clay 10 to 50 feet or more thick. The Kimmswick limestone in most places consists of very cherty dolomite but is composed of limestone in the area nearest the Ozark region. Its thickness increases toward the north from 95 to 235 feet. Thin deposits of noncherty limestone and dolomite overlying very cherty phases of the Kimmswick may be correlatives of the Fernvale limestone. The Maquoketa shale in northeastern Kansas is in part dolomitic and cherty. It has an average thickness of 75 feet where not reduced in thickness or entirely removed by pre-Devonian erosion.

Silurian rocks crop out in an area northwest of Jefferson county. They consist almost entirely of coarsely crystalline dolomite with only small amounts of insoluble residues. The following zones, in ascending order, are recognized in the Silurian; a zone with dolomitic oölites, a zone which yields residues of opaque white chert, a zone characterized by the sparse occurrence of foraminifera in the small silty insoluble residues, and a zone which yields residues of drusy quartz. One or more of these zones may be absent. The Silurian rocks were beveled by pre-Devonian erosion and are absent in most of Jefferson county and to the southeast. Their thickness increases to at least 150 feet toward the northwest.

Devonian rocks are represented by lithographic limestone and coarsely sucrose dolomite. The lithographic limestone is dominant in the area bordering the Ozark uplift but interfingers with and grades laterally into dolomite toward the northwest. A sandy limestone marks the base of the Devonian in most wells, but toward the north and west the absence of sand makes the contact with the Silurian difficult to determine. The Devonian was deposited upon an eroded and beveled surface and overlaps all the older rocks from Silurian to upper Arbuckle. Devonian rocks also were eroded and beveled prior to the deposition of the Chattanooga shale and they thus increase in thickness from a few feet in Miami county to at least 250 feet to the north and west.

The Chattanooga shale overlies the post-Devonian surface of erosion and is in contact with all the rocks exposed on this surface from Devonian to the upper part of the Arbuckle. The Chattanooga shale consists of gray and greenish-gray silty and micaceous shale, parts of which are dolomitic. The basal beds are generally darker and contain abundant spores. The thickness increases toward the northwest from 50 feet to more than 250 feet.

All the limestone formations of the Mississippian in Kansas from the Chouteau limestone to the Ste. Genevieve limestone except the correlatives of the Fern Glen are represented in northeastern Kansas. The development of the Nemaha anticline and subsequent erosion removed the Mississippian from the crest of this fold. As a result, the Mississippian is thin on the eastern flank of the fold, and toward the east progressively younger formations underlie the Pennsylvanian. Along Missouri river between Kansas and Missouri, the Mississippian limestones, including the Ste. Genevieve at the top, have a thickness of more than 370 feet.

A normal section of Pennsylvanian and Permian rocks overlies the Mississippian east of the Nemaha anticline. The subsidence of the surface east of this structure and the deformation of the post-Mississippian erosion surface formed the Forest City basin. The Cherokee shale, the lowest division of the Pennsylvanian in Kansas, is exceptionally thick in this basin. However, the Cherokee shale was not deposited upon the elevated crest of the Nemaha fold, which was not completely submerged until Bronson time when the thick early Pennsylvanian deposits finally overlapped upon and buried the escarpment.

Of the many unconformities recognized in the Paleozoic rocks, the most important, from a structural point of view, are at the base of the St. Peter sandstone, the base of the Devonian, the base of the Chattanooga, and the top of the Mississippian. The erosion that is represented by each of these unconformities was preceded by important structural movements, and each epoch of erosion resulted in almost complete base-leveling.

Three periods of structural deformation have been recognized. Data secured from the deep wells of the area reveal that during Upper Cambrian and in pre-St. Peter time (Ordovician) the central Ozark area was sinking slowly and that the surface in southeastern Nebraska and northeastern Kansas was rising slowly. These movements were attended by numerous advances and retreats of the sea. Several hundred feet of limestone was eroded during some of the emergent phases. The deposition of the St. Peter sandstone followed one of the emergent phases in which all the earlier rocks that had survived were again warped, beveled, and peneplaned. After the deposition of the St. Peter, the pattern of structural deformation changed markedly, and before the end of Maquoketa time the Ozark area, which had been subsiding, began to rise, and southeastern Nebraska, which had been rising, began to subside. The initial movements of the Ozark uplift, the Chautauqua arch, and the North Kansas basin thus began in the late Ordovician before the end of Richmond time.

The North Kansas basin continued to be the dominant structural feature of northeastern Kansas from the end of Maquoketa time to the end of Chattanooga time. Local deformation continued in the same pattern, even through the Kinderhookian epoch, but by that time the first movements along the line of the Nemaha anticline were also being felt.

Development of the Nemaha anticline introduced a new and revolutionary structural trend. Structural movements that produced this anticline and other parallel strongly directional folds trending northeast culminated after Mississippian deposition. The Nemaha anticline bisected the North Kansas basin and formed the Salina basin on the west and an unnamed structural basin along Missouri river on the east in which Ste. Genevieve limestone is preserved, but this movement did not immediately form the Forest City basin.

These folded rocks were peneplaned. Renewed movement along the Nemaha anticline resulted in the re-elevation of the region west of the anticline. The line of re-elevation was sharply marked and was probably accompanied in most places by faulting that led to the formation of an eastward-facing escarpment. The erosion surface east of the escarpment was flexed downward forming the Forest City basin. The Forest City basin was separated from an arm of the Cherokee basin of Oklahoma, which was formed at the same time, by a low, broad divide (the Bourbon arch) trending northwest from Bourbon county.

In middle Cherokee time these two basins were joined by the filling of the Forest City basin and by the flooding of the divide. Thenceforth, the Forest City basin was merely a northern extension of the Cherokee basin. Until lower Permian time and possibly even later, the Forest City basin region continued to be dominated structurally by subsiding movements east of the Nemaha anticline and by mild flexing in the Forest City-Cherokee basin syncline. Erosion has destroyed the stratigraphic record of Permian deformation in most of the basin areas.

The western dip given to the surface rocks of Kansas and adjoining states occurred mainly prior to the deposition of the Cretaceous rocks of western Kansas, although there has been some deformation and great elevation of the whole region above sea level since that time.

The widely different changes in regional dip in the structural history of the region have resulted in a lack of parallelism of the strata in different parts of the stratigraphic column. The effect of surface anticlines of low structural relief on tilted datum beds in different parts of the section is illustrated by cross-sectional diagrams.

Most of the anticlines that have been mapped in the surface rocks of northeastern Kansas are of low structural relief. In some places the regional dip has reduced an original low anticline to a structural nose in the surface rocks. Where it has been possible to study the structure in oil and gas fields, the structural relief has been found to increase in depth at a rate more than adequate to compensate for the regional dip.

Local structural features trending northeast or located on axes of folding trending in that direction were initiated after the deposition of the Mississippian rocks and continued active during Pennsylvanian time. In consequence, such anticlines become steeper in depth down to the Mississippian rocks. Structural features initiated prior to the Mississippian and presumably trending toward the northwest may be expected to increase in relief down to the St. Peter sandstone.

Many unconformities occur in the columnar section, but where limestone was deposited upon a porous weathered zone of exposed limestone the porosity seems to have been destroyed by cementation during the deposition of the overlying calcareous sediments. Such porous zones where they were covered by noncalcareous deposits have remained open and constitute most of the limestone reservoirs for oil and gas in eastern Kansas.

In the pre-Pennsylvanian rocks, the wedging out of sandstone beds caused by erosional beveling seems not to form favorable stratigraphic traps for oil and gas accumulation unless some structural deformation is present that will prevent the escape of oil up dip through the weathered zone of adjacent exposed limestone beds. Many productive stratigraphic traps, however, occur in the lower Pennsylvanian shales in which there are porous bodies of lenticular sandstone, shoestring sands, and sand sealed up dip by variations in porosity.

INTRODUCTION

This report represents a part of the results of investigations of the structure and stratigraphy of that part of the Forest City basin lying in Kansas and their relation to the occurrence of oil and gas in northeastern Kansas. The report is primarily a subsurface study based on the examination of samples from wells and supplemented by surface observations on stratigraphy of adjacent regions in which some of the rocks are exposed. The report discusses the stratigraphy and distribution of all the rocks in the Forest City basin in Kansas from the pre-Cambrian to those now exposed at the surface. An attempt has been made to analyze the different major structural movements. Although no detailed structural map of the surface rocks was made, this analysis should prove of value in guiding future exploration of this area.

The work was carried on under a cooperative agreement between the State Geological Survey of Kansas and the Federal Geological Survey during the period from September 1, 1939, to July 1, 1942. As a part of this project, a preliminary report on the McLouth oil and gas field was published in September, 1941, and a final report in collaboration with Thomas G. Payne is now in preparation.

The classification of the rock units in the present report is in accordance with the usage of the State Geological Survey of Kansas. Also, the spelling of the time stratigraphic series terms in the adjectival form is in accordance with usage of the State Survey and does not represent the personal preference of the author.

At the time this work was begun, there were relatively few wells in the area that penetrated the deeper rocks. However, the discovery in November, 1939, of both the Falls City oil field in southeastern Nebraska and the McLouth gas field in northeastern Kansas stimulated drilling and provided greatly increased information in local areas, as well as data in some areas that had previously been unexplored. Up to September, 1942, 140 wells had been

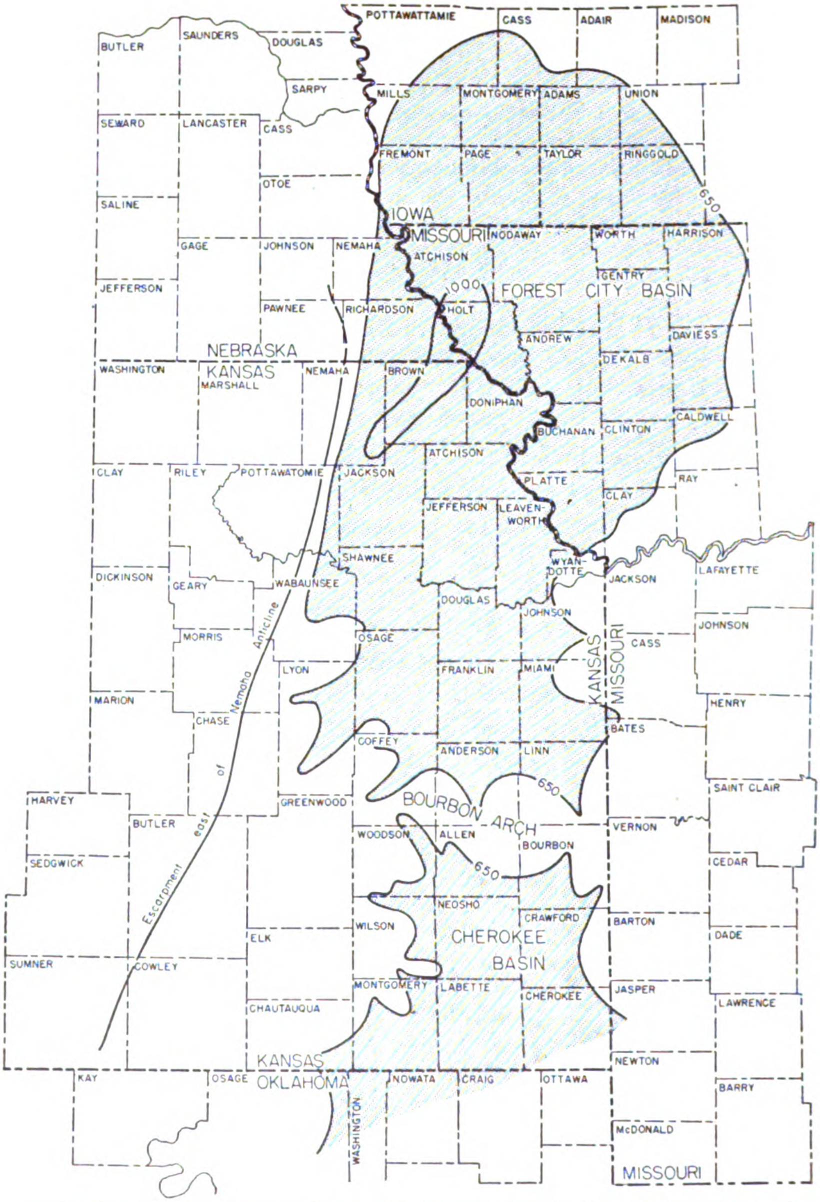

FIG. 1. Map showing outline of the Forest City basin and its relation to the northern end of the Cherokee basin and to the escarpment on the east side of the Nemaha anticline. The basins are outlined by a contour indicating a thickness of 650 feet between the base of the Hertha limestone and the top of the Mississippian limestone. The deepest part of the basin is outlined by the 1,000-foot thickness contour. Data for northeastern Kansas are adapted from figures 17 and 18 of this report; for Missouri in part after McQueen and Greene (1938, pl. 4); for southeastern Kansas after Bass (1936, pl. 1); and for Iowa and Nebraska after Holl (1932).

drilled in and near the McLouth field, and the number is still increasing.

The Forest City basin, the subject of this report, was originally both a structural and a topographic basin. It did not come into existence until after Mississippian time. The surface of the whole region had been raised, with gentle folding, at the end of Mississippian deposition in Kansas. The principal fold was the Nemaha anticline which extends across Kansas from southeastern Nebraska to central Oklahoma. The exposed rocks were then subjected to erosion for such a long period that the surface was worn down nearly to sea level, although locally there was some low relief. The rocks were again deformed before the advance of the Pennsylvanian sea over the area. The beveled crest of the Nemaha anticline was re-elevated, probably with faulting along its eastern side, and the peneplaned surface of the Mississippian rocks east of the fold was warped downward to form a great basin in the adjoining areas of Kansas, Missouri, Iowa, and Nebraska. This depressed area constitutes the Forest City basin. When the region was invaded by the Pennsylvanian sea, thicker deposits accumulated in this basin than on the higher lands surrounding it. The extent and thickness of these deposits are the measure of the extent and depth of the basin.

The Forest City basin had a relatively brief existence. It was formed by the warping of the post-Mississippian peneplain, and was united with the similarly formed Cherokee basin when the low divide separating them was covered by the accumulating deposits of the Cherokee shale, the earliest formation of Pennsylvanian age in Kansas.

Figure 2 shows the principal structural features of Kansas which were not all developed at the same time. The North Kansas basin was developed contemporaneously with the Chautauqua arch in southeastern Kansas, the Ozark uplift of Missouri, and probably the Central Kansas uplift. In post-Mississippian time the Nemaha anticline, the Voshell anticline, the Salina basin, and an unnamed structural basin along Missouri river northwest of Kansas City were probably developed more or less contemporaneously (fig. 2B). The Forest City basin and the Cherokee basin belong to the same general period, but they were not developed in their final form until the rejuvenation of the Nemaha anticline and the warping of the post-Mississippian peneplain occurred.

The study of the Forest City basin in Kansas has been made easier by the fact that most of the holes in the area were drilled with cable tools, which has made it possible to study the rocks represented by the samples without the contamination of cuttings from overlying rocks usual in samples from rotary wells.

Complete sets of samples from all of the recent wells and from many of the older wells were collected and studied and have been placed on file at the State Geological Survey at the University of Kansas in Lawrence. The abundance of sample material from the McLouth pool has shed much light on the conditions of accumulation of gas in the Pennsylvanian rocks in northeastern Kansas. In the McLouth field, however, only a few wells have been drilled below the upper part of the Mississippian, and only two have reached the Arbuckle limestone.

Terminology

Inasmuch as there is no standardized use of words for describing some of the textures of rock materials and insoluble residues, it is desirable to explain the meaning intended for certain adjectives used in this report.

Cotton rock is a soft, porous siliceous rock or insoluble residue composed of white, opaque, uncemented microscopic particles of silica.

Dolocast is a term introduced by McQueen (1931, pp. 8,9) for the impression left by a dolomite crystal removed from chert or other materials in the insoluble residues. Dolocasts may occur singly or be so numerous that they form a porous or spongy texture.

Drusy texture is applied to deposits of crystalline quartz originally in microscopic cavities.

Even-textured rock has a homogeneous character and is microscopically massive.

Grainy texture consists of microscopic crystals of limestone or dolomite or particles of silt sparsely distributed in a dull opaque usually calcareous matrix. The matrix in some rocks is cryptocrystalline, in others earthy. By decrease of the calcareous matrix this texture may become sucrose dolomite or silty limestone.

Hackly texture is applied to deposits of broken or vesicular quartz with few or no crystalline faces.

Matted texture is composed of closely packed fragments of silicified microfossils and sponge spicules cemented in a siliceous matrix.

Mottled texture is composed of parti-colored chert in patches without sharp margins; it is microscopic, but much coarser than a stippled texture.

Porous texture is used for aggregates of quartz or chert or other materials in which the individual cavities are microscopic.

Semigranular texture consists of coarsely crystalline grains, principally

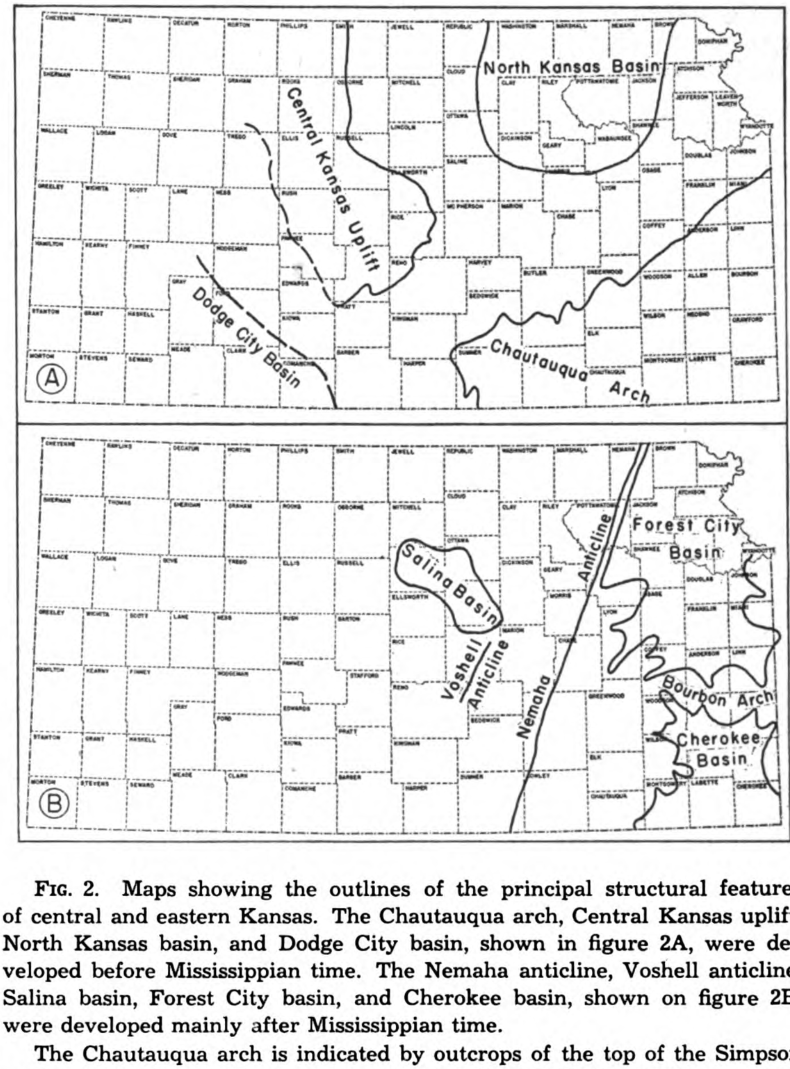

FIG. 2. Maps showing the outlines of the principal structural features of central and eastern Kansas. The Chautauqua arch, Central Kansas uplift, North Kansas basin, and Dodge City basin, shown in figure 2A, were developed before Mississippian time. The Nemaha anticline, Voshell anticline, Salina basin, Forest City basin, and Cherokee basin, shown on figure 2B, were developed mainly after Mississippian time.

The Chautauqua arch is indicated by outcrops of the top of the Simpson sandstone on the pre-Chattanooga surface (after McClellan, 1930); trends of the Nemaha and Voshell anticlines and the deepest part of the Salina basin are shown on the thickness map of Mississippian limestones (after Lee, 1939, pl. 1); Central Kansas uplift is shown by the area in which Mississippian limestone is absent; Cherokee basin is outlined from thickness map of Cherokee shale by N. W. Bass (1936, pl. 1); North Kansas basin of John L. Rich is outlined from thickness map of Chattanooga shale (Lee, 1940, pl. 3); Dodge City basin after McClellan (1930); and Forest City basin from figure 17 of this report.

fossil fragments, in a microcrystalline matrix. In some rocks crinoidal limestones are semigranular.

Spongy texture refers to aggregates of quartz, chert, silt, or clay in insoluble residues from which the soluble matrix has been removed. The individual openings are submicroscopic.

Stippled texture has a stippled pattern on a smoothly broken chert surface due to the complete replacement by silica of rocks having grainy texture. The sharp outline of the replaced impurities is blurred in some zones, giving a cloudy margin to the dots.

Streaked texture has microfossiliferous fragments of matted chert imperfectly replaced or subsequently modified; consequently the outlines of the inclusions are blurred.

Sucrose texture consists of microscopically coarse or fine crystals—usually dolomite—packed closely (without matrix) like the grains of lump sugar.

Acknowledgments

The collection of samples from the McLouth pool has been aided by the drillers, contractors, and operators in the field, without whose collective help much of the information could not have been assembled; to them the writer extends his thanks and appreciation. Most of the drillers have recognized the value of keeping careful and accurate logs. These records have been valuable for although the microscope reveals many characteristics of the rocks which are not visible to the naked eye, many contacts, such as those between limestone and shale, can be determined more accurately by the driller than by the geologist working with samples only.

The identification of the tops of formations of pre-St. Peter age in the few wells drilled below the St. Peter in the area is the work of R. P. Keroher, assisted by Jewell Kirby. Outcrops of all the Devonian formations in northern Missouri and Iowa were visited and sampled in company with R. C. Moore, and in Iowa with H. G. Hershey of the Iowa Geological Survey.

Thanks are due to H. S. McQueen of the Missouri Geological Survey for samples of some wells in northwestern Missouri and for sample determinations of other Missouri wells against which the lithologic criterion of northeastern Kansas were checked.

Many other persons have contributed directly and indirectly to the investigation. Dalton B. Stover, James Clark, Eugene Maxwell, Hugh Crain, and Philip Kaiser at various periods collected samples and logs that provided complete and reliable information on wells as they were drilled. The samples were prepared and the residues made by the staff of the subsurface laboratory of the

State Geological Survey of Kansas. Much of the microscopic work on the Pennsylvanian rocks, particularly in the McLouth field, was done by Thomas G. Payne. The manuscript was read by H. D. Miser, John C. Frye, and J. M. Jewett.

STRATIGRAPHY

The sequence of rocks in the Forest City basin is shown in generalized form in the columnar section (fig. 3). The structural features are such that nearly every one of the formations below the Pennsylvanian is absent in some part of northeastern Kansas and there is no locality in which all the formational units are now present although almost all were originally deposited throughout the area.

General Features and Relations of Rocks of Pre-Cambrian and Cambrian Age

Outcrops of rocks of pre-Cambrian age nearest to northeastern Kansas are in southeastern Missouri, where they form the core of the St. Francis mountains. They consist chiefly of red and gray granite with subordinate amounts of schist and porphyry, and are unconformably overlain by Upper Cambrian sandstone. Similar rocks are found at the surface in parts of eastern and southern Oklahoma in the same relation to Upper Cambrian rocks. Red quartzite of pre-Cambrian age is exposed in southeastern South Dakota and in small areas in adjoining states.

A great unconformity separates the Cambrian rocks from the pre-Cambrian (crystalline) rocks. The pre-Cambrian surface in the midcontinent region had a low relief when it was covered by Upper Cambrian sedimentary rocks. The pre-Cambrian and younger rocks have been brought to their present position in southeastern Missouri by a number of separate structural movements, and their exposure in that area is the result of long periods of erosion separated by periods of structural movement and deformation. In Kansas the pre-Cambrian rocks have been subjected to similar influences and were exposed in pre-Pennsylvanian time at places along the Nemaha anticline and on the Central Kansas uplift. They were later lowered to a position below sea level and covered by younger sediments and, although re-elevated, have not yet been re-exposed.

The pre-Cambrian rocks of Kansas consist mainly of granite,

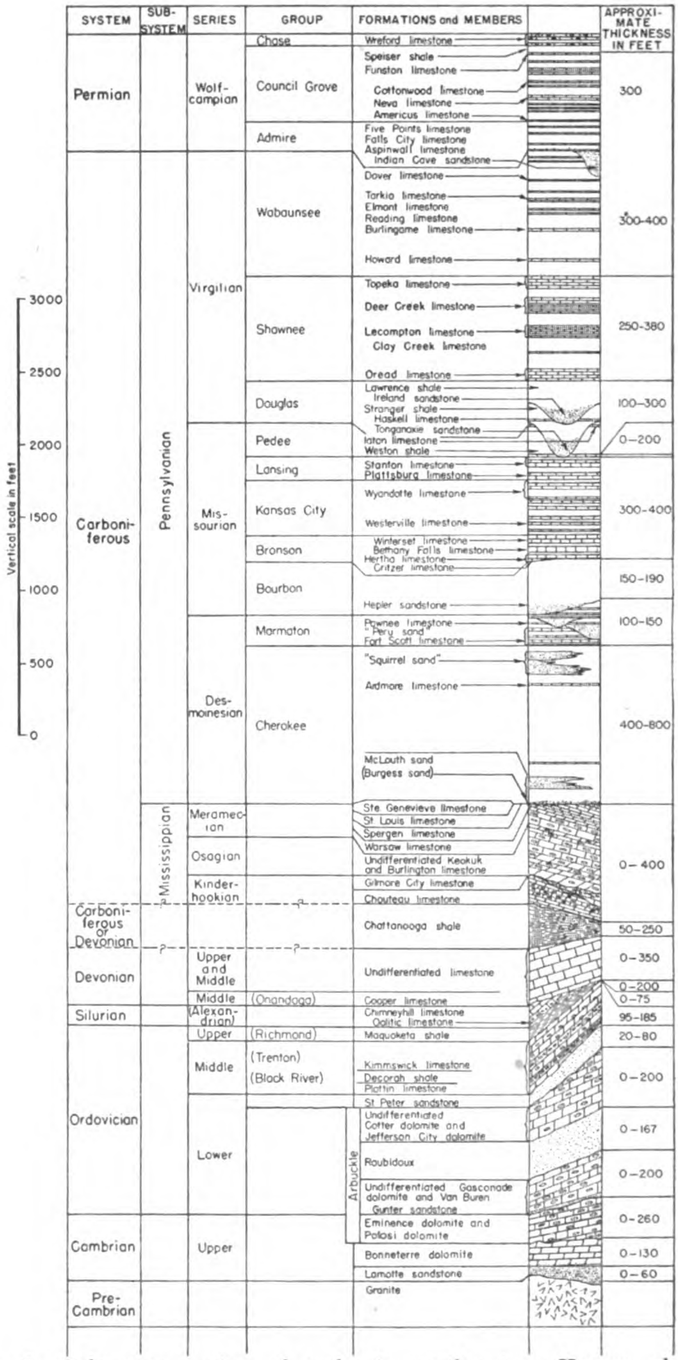

FIG. 3. Columnar section of rocks in northeastern Kansas, showing

gneiss, and schist, but Landes (1927, p. 823) and others have reported wells that penetrated also basic igneous rocks, quartz porphyry, and quartzite. Landes concluded that the pre-Cambrian rocks of Kansas and adjoining states consist of a complex composed principally of granite or granite gneiss or schist; locally it may contain other igneous and metamorphic rocks. Most of the samples of pre-Cambrian rocks now available from wells that penetrated the pre-Cambrian of northeastern Kansas appear to represent red granite; red quartzite is reported by McQueen from Greenwood, Jackson county, Missouri, which adjoins Johnson county, Kansas.

The pre-Cambrian rocks are hard and difficult to drill. The churn drill was used in most of the wells in northeastern Kansas. The cuttings of these wells are, therefore, generally fine and the relatively less resistant feldspars and accessory minerals are reduced to rock flour. For this reason, many of the washed samples consist of a disproportionate amount, or may consist entirely, of fine angular quartz grains and the granite is thus reported as sandstone in the logs of many of the early wells. Even where traces of feldspar, mica, and other minerals can be identified, it is impossible in many cases to determine whether the rock is a granite or gneiss.

The Cambrian and Ordovician rocks in Missouri were grouped together for many years under the term Cambro-Ordovician. Similarly, in Oklahoma the Arbuckle limestone or "Siliceous lime" consisted of undifferentiated Cambrian and Ordovician rocks.

The Arbuckle limestone of Oklahoma was originally defined by Taff (1902) as including all the rocks from the top of the Reagan sandstone up to the base of the Simpson group. The corresponding interval in southeastern Missouri was long presumed to extend from the top of the Lamotte sandstone up to the base of the St. Peter sandstone or the base of the Everton where that formation is present. Ulrich (1911, pp. 624, 642, 666), however, identified the Honey Creek limestone of Oklahoma as of Cambrian age and later (1932, p. 742) excluded it from the Arbuckle. He

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sequence and variations in thickness of stratigraphic units mentioned in this report. The classification is in accordance with the usage of the State Geological Survey of Kansas. Only the more prominent formations and members of the Pennsylvanian and Permian are shown. The angular unconformities in the pre-Pennsylvanian rocks are greatly exaggerated.

also in 1932 identified the Honey Creek as essentially equivalent to the Davis formation of Missouri. In consequence, the underlying Bonneterre dolomite of Missouri is excluded as a correlative of the Arbuckle. Furthermore, the Derby and Doe Run dolomites, which conformably overlie the Davis and underlie a well-defined and widespread unconformity, should also be excluded from the Arbuckle.

The term Arbuckle as redefined by Ulrich, although no longer so inclusive a term as in its original sense, is still a convenient term to indicate undifferentiated pre-St. Peter Ordovician and Cambrian rocks in Kansas. In Missouri (fig. 4) the equivalents of the Arbuckle include the Potosi, Eminence, and Proctor dolomites, the Van Buren formation, the Gasconade dolomite, the Roubidoux formation, and the Jefferson City, Cotter, and some younger dolomites not represented in Kansas.

The following columnar section of St. Peter and older rocks of Ordovician and Cambrian age in Jackson county, Missouri, near the Kansas border, is reported from well cuttings by H. S. McQueen (Letter dated February 18, 1942). Some of the formations shown in figure 4 are missing by reason of unconformities. The thicknesses, however, are only approximate, for the determinations were made from a set of samples that had long gaps between some samples. This well is shown diagrammatically in cross section in figure 5.

TABLE 1. *Sequence and approximate thickness of St. Peter and older rocks of Ordovician and Cambrian age in a well near Greenwood, Jackson county, Missouri, sec. 27, T. 47 N., R. 31 W.*

Rocks of Ordovician age	*Thickness, feet*
St. Peter sandstone	80
Cotter and Jefferson City dolomite	210
Roubidoux formation	135
Gasconade dolomite	192
Rocks of Upper Cambrian age	
Eminence dolomite	263
Potosi dolomite	50
Bonneterre dolomite	130
Lamotte sandstone	60
Rocks of pre-Cambrian age	

Rocks of Cambrian Age

The Cambrian-Ordovician boundary in Missouri (McQueen, 1931) is placed between the Proctor dolomite and the Gunter sandstone member of the Van Buren formation (fig. 4). The Missouri formational names are used in the present report because they antedate the Oklahoma names and also because they have been extended from the outcrops in Missouri to the Kansas border by the Missouri Geological Survey by means of insoluble residue studies of well cuttings.

LAMOTTE SANDSTONE

The Lamotte sandstone of Upper Cambrian age overlies pre-Cambrian granite in southeastern Missouri. In southern Oklahoma, the Reagan sandstone, also of Upper Cambrian age, has a similar relation to the pre-Cambrian rocks. McQueen (1931, pl. 3) described the Lamotte sandstone as yellow to white sandstone with fine to coarse subangular and rounded grains. It is generally arkosic at the base and locally dolomitic in some zones. Sandstones that appear to be of the same age as the Lamotte and Reagan are found in most places in the subsurface of eastern Kansas. If the sandstone is arkosic, it is difficult to distinguish it from the underlying granite or gneiss, and the exact point of contact may be in doubt. A few samples of granite and Cambrian rocks from wells in northeastern Kansas are on file at the State Geological Survey, but most of the deep wells that penetrated the older rocks in this region were drilled before it was customary to preserve well cuttings.

The Lamotte sandstone has a maximum thickness of about 350 feet in southeastern Missouri. In southwestern Missouri it is about 150 feet thick and in northeastern Kansas it is thinner. In the Kasper No. 1 James well, in the NE¼ NW¼ sec. 9, T. 13 S., R. 25 E., the Lamotte is 30 feet thick, and in the Duffens et al. No. 1 Stanley well, in the NW¼ NE¼ sec. 3, T. 14 S., R. 21 E., only 7 feet of Lamotte sand is present. In the Forrester et al. No. 1 Hummer well, in the NW¼ SE¼ sec. 14, T. 11 S., R. 16 E., where samples through an interval of 15 feet are missing, the Lamotte is at least 22 feet thick and may be 40 feet thick. It is less than 5 feet thick in the Turner No. 1 Umschied well, in sec. 32, T. 8 S., R. 9 E.

There is a great unconformity between the Lamotte sandstone and the underlying pre-Cambrian rocks. The Lamotte sandstone is transitional into the overlying Bonneterre dolomite.

BONNETERRE DOLOMITE

The Bonneterre dolomite crops out only in southeastern Missouri, but it is present in the subsurface throughout most of Missouri and in most of eastern Kansas. McQueen (1931, pl. 3) describes the Bonneterre as consisting of fine to coarsely crystalline dolomite and magnesian limestone with almost no chert. The dolomite is light-colored to brown with interbedded green and brown shales, with insoluble residues of dolocastic shale of a type not observed in younger Cambrian and Ordovician formations. Glauconite and sand are characteristic constituents.

The Bonneterre dolomite has a maximum thickness of 440 feet in southeastern Missouri, but is not much more than 200 feet thick in southwestern Missouri. In northeastern Kansas, the Bonneterre has a maximum known thickness of 91 feet in Douglas county and decreases slowly toward the northwest. In Pottawatomie and Riley counties there is 20 feet of noncherty argillaceous limestone which is believed to be of Bonneterre age between a thin section of Lamotte sandstone and the St. Peter sandstone. In the Arab No. 1 Ogle well in sec. 9, T. 1 N., R. 14 E., Nebraska, just across the state line from Kansas, the Bonneterre is absent and the St. Peter sandstone rests directly on the pre-Cambrian.

The Bonneterre conformably overlies the Lamotte sandstone in southeastern Missouri. It is conformably overlain by the Davis formation, which in turn is overlain in conformable sequence by the Derby and Doe Run dolomites. Only the Davis formation extends into southwestern Missouri, as shown in figure 4, and all three are absent in eastern Kansas, so that the Bonneterre is unconformably overlain in most localities by the Eminence dolomite. The Bonneterre in northeastern Kansas becomes thinner toward the west (fig. 5). This thinning seems to be due to erosion which preceded the deposition of the Eminence dolomite.

POTOSI DOLOMITE

The Potosi dolomite is exposed only in southeastern Missouri. McQueen (1931) describes it as brownish-gray to chocolate-colored dolomite with an abundance of dense chert in the insoluble residues. The Potosi was probably deposited in a broad structural and erosional basin centering in southeastern Missouri. The

Potosi has a maximum known thickness of 480 feet and becomes thinner toward the margins of the basin.

The Potosi unconformably overlies the Doe Run, Derby, Davis, and Bonneterre formations, but is conformably overlain by the Eminence dolomite (fig. 4). From southeastern Missouri, the Potosi becomes thinner toward the west and northwest. If present at all in northeastern Kansas, it is represented only by a thin wedge near the Kansas border between the Bonneterre and the Eminence.

EMINENCE DOLOMITE

The Eminence dolomite of southeastern Missouri is described by McQueen (1931) as a crystalline light-colored dolomite in contrast with the light-brown to chocolate-colored dolomite of the Potosi. Gray and light-blue vitreous chert is abundant, and siliceous oölite is common in the Eminence. The insoluble residues of the Eminence are characterized by dolocastic cavities which are so abundant that they resemble a lacelike sponge. The Eminence dolomite is well developed in eastern Kansas, but in northeastern Kansas it contains much less chert than in the deeper parts of the basin of deposition in southern Missouri. The maximum thickness of the Eminence dolomite reported by McQueen in southeastern Missouri is 320 feet. It is about 200 feet thick at Carthage in southwestern Missouri. Keroher has determined its thickness as 175 feet in northeastern Kansas in the Duffens No. 1 Stanley well, in sec. 3, T. 14 S., R. 21 E. The formation is not present on the northwestern edge of the basin (fig. 5).

The Eminence formation is conformable upon the Potosi and conformable below the Proctor dolomite (fig. 4). Both of these formations are absent in northeastern Kansas, so the Eminence unconformably overlies the Bonneterre dolomite and is in turn unconformably overlain by undifferentiated Van Buren and Gasconade dolomites.

PROCTOR DOLOMITE

The Proctor dolomite is a noncherty dolomite conformably overlying the Eminence in south-central Missouri. It does not occur in northeastern Kansas.

Rocks of Ordovician Age

VAN BUREN FORMATION

The Van Buren formation is the oldest Ordovician formation recognized in Missouri. The base of the Van Buren is marked by a basal sandstone member, the Gunter sandstone, which is described by McQueen (1931) as composed of fine-to medium-rounded and frosted sand grains. The Van Buren was originally included in the Gasconade dolomite, from which it was separated by Ulrich and Bridge on faunal grounds and differentiated by McQueen on the basis of insoluble residues.

The Van Buren formation in southeastern Missouri consists of dark bluish-gray, finely crystalline but locally granular dolomite. The chert is described as white, dense, porcelainlike, and oölitic. McQueen (1931, p. 18) distinguishes the Van Buren from the underlying Proctor dolomite by the absence of chert in the Proctor and from the overlying Gasconade by the darker color of the Gasconade chert and by the character and distribution of the dolocasts in the chert of the insoluble residues.

In northeastern Kansas, the Van Buren dolomite has not been differentiated from the Gasconade in cuttings from wells although a sandstone corresponding to the Gunter sandstone has been recognized.

The Van Buren has a thickness of 35 to 235 feet in Missouri but if present is probably thin in northeastern Kansas. The Gunter sandstone member at the base of the Van Buren is 12 feet thick in the Greenwood well, Jackson county, Missouri, and 6 feet thick in the Duffens et al. No. 1 Stanley well, in sec. 3, T. 14 S., R. 21 E. Sandy dolomite 10 feet thick occurs immediately above the Eminence in the Forrester et al. No. 1 Hummer well, in sec. 14, T. 11 S., R. 16 E., but it is possible that it represents basal Gasconade instead of basal Van Buren dolomite.

During the time represented by the unconformity at the base of the Van Buren formation, the central part of the basin was again depressed and the marginal areas raised and eroded. The Proctor was eroded from the marginal areas and the Eminence exposed. Upon this surface the Van Buren formation was deposited, and it thus overlies the Proctor unconformably in central Missouri and overlaps unconformably upon the eroded surface of the Eminence in northeastern Kansas. The Van Buren has not been identified in northeastern Kansas.

GASCONADE DOLOMITE

The Gasconade dolomite crops out in the lower part of most of the valleys of the central Ozarks. McQueen (1931) reports that there is an unconformity between the Gasconade and Van Buren formations and that well samples from the base of the Gasconade contain siliceous oölite accompanied in some localities by small amounts of sand. The Gasconade consists of light-colored finely crystalline dolomite characterized by the dark-blue color of the hard vitreous to quartzose chert.

The strata between the Eminence and the Roubidoux have not been satisfactorily differentiated in Kansas; they would all be referred to the Gasconade on the basis of lithologic characteristics if it were not for the presence of sandstone corresponding to the Gunter at the base.

The Gasconade has a reported thickness of 140 to 200 feet in Missouri. The thickness of the undifferentiated Van Buren formation and the Gasconade dolomite in the Greenwood well, in sec. 27, T. 47 N., R. 31 W., Jackson county, Missouri, is 192 feet. It is 206 feet thick in the Duffens No. 1 Stanley well, in sec. 3, T. 14 S., R. 21 E., and 90 feet thick in the Forrester No. 1 Hummer well, in sec. 14, T. 11 S., R. 16 E.

The hiatus between the Gasconade and Van Buren formations is perhaps no greater than that represented by many other unconformities within the Cambrian and Ordovician formations of the Ozarks. An unconformity also separates the Gasconade and the overlying Roubidoux formation. The unconformity at the base of the St. Peter bevels the top of the Gasconade northwest of the Hummer well, as shown in figure 5.

ROUBIDOUX FORMATION

The Roubidoux formation underlies much of the upland area of the central part of the Ozark plateau in Missouri where it is composed of sandstone and cherty dolomite. Thick sandstone beds occur in the outcrops near the top and at the bottom of the formation. Other sandstone beds, some of which are thin and lenticular, and sandy dolomite beds are interstratified with the dolomite within the formation.

The Roubidoux formation in the subsurface of northeastern Kansas consists mainly of dolomite, sandy dolomite, and fine subangular sand. Sandstone is quantitatively subordinate and constitutes less than 10 percent of the formation in some wells. In well cuttings it is difficult to distinguish dolomite of the Roubidoux formation from other dolomites without the aid of insoluble residues. (R. P. Keroher, oral communication).

The Roubidoux formation shows relatively little variation in thickness. It is 135 feet thick in the Greenwood well in Jackson county, Missouri; 167 feet thick in the Stanley well, in sec. 3, T. 14 S., R. 21 E.; and 175 feet thick in the Hummer well, in sec. 14, T. 11 S., R. 16 E. R. P. Keroher reports (oral communication) that in the Hummer well the Roubidoux is unconformably overlain by the St. Peter sandstone.

The formation is reported by McQueen (1931, pl. 3) to be bounded both above and below by inconspicuous unconformities. The stratigraphic relations of this formation are obscure in Kansas and the Roubidoux is one of the most widely distributed formations of Ordovician age. The Roubidoux was beveled by erosion preceding the deposition of the St. Peter (fig. 5) and was probably removed from structurally positive areas.

JEFFERSON CITY AND COTTER DOLOMITES

Outcrops of undivided Jefferson City and Cotter dolomites flank the Ozark region of Missouri in an irregular broad belt. Lithologically these formations closely resemble each other and no separation of these formations has been made in northeastern Kansas. At surface outcrops in Missouri, the Jefferson City and Cotter are in part dense to finely crystalline dolomite and in part argillaceous dolomite. Chert is common to both formations, but less abundant in the Jefferson City. These formations are differentiated by McQueen (1931, pp. 121-124) in Missouri by characteristics of their insoluble residues; the Jefferson City is reported to be less cherty and contains less siliceous oölite than is common in the cherts of the Cotter. The criteria for distinguishing the Cotter and Jefferson City have proved difficult of application in areas removed from the Ozarks.

A maximum thickness of 120 feet for the Jefferson City dolomite and 420 feet for the Cotter dolomite in the central Ozarks is reported by McQueen, but both formations become thinner toward the west. The combined thickness of the Jefferson City and the Cotter in northwestern Missouri is generally less than 200 feet. This is due partly to the thinning of the formations toward the northwest but chiefly to the fact that the upper Cotter dolomite, together with the Smithville and Powell formations, was removed by erosion during the interval of deformation and peneplanation that preceded the deposition of the St. Peter sandstone. Undifferentiated Jefferson City and Cotter dolomites are reported by McQueen (1931) to be 210 feet thick in the Greenwood well. Keroher reports that the same unit is only 106 feet thick in the Stanley well and that it is absent in the Hummer well.

The Jefferson City dolomite is separated from the underlying Roubidoux and from the overlying Cotter by inconspicuous unconformities. Both are overlapped unconformably by the St. Peter sandstone (fig. 5).

ST. PETER SANDSTONE

The St. Peter sandstone, named from outcrops at St. Peters Falls near Minneapolis, is exposed in eastern Missouri and at other places in the Mississippi valley, and extends westward beneath the surface for hundreds of miles. The sandstone is composed of unusually pure white sand with a large proportion of well-rounded frosted grains. Thin partings of green shale are present in the upper part in some localities.

Much has been written concerning the stratigraphic position of the St. Peter sandstone and its correlation with Ordovician rocks of other regions. There is, however, a lack of agreement as to its exact age because of the absence of fossils in the formation and the occurrence of unconformities at its top and bottom. Furthermore, the St. Peter sandstone in southeastern Missouri and in Arkansas is underlain by the Everton formation which contains sandstone members that resemble the St. Peter.

The correlative of the St. Peter sandstone in Oklahoma is uncertain because of lithologic changes in the rocks, the presence of unconformities, and the lack of fossils in the St. Peter. Some geologists have proposed that the St. Peter be correlated with some part of the sandy Simpson formation. The St. Peter has been correlated with both the Wilcox sand of drillers and the Burgen sandstone of the outcrops, which closely resemble the St. Peter. It is possible that the true St. Peter is absent in Oklahoma, where, as in parts of Arkansas, the members of the Everton have in some places been mistaken for the St. Peter. The St. Peter sandstone in northeastern Kansas is unconformable above all the older Or-

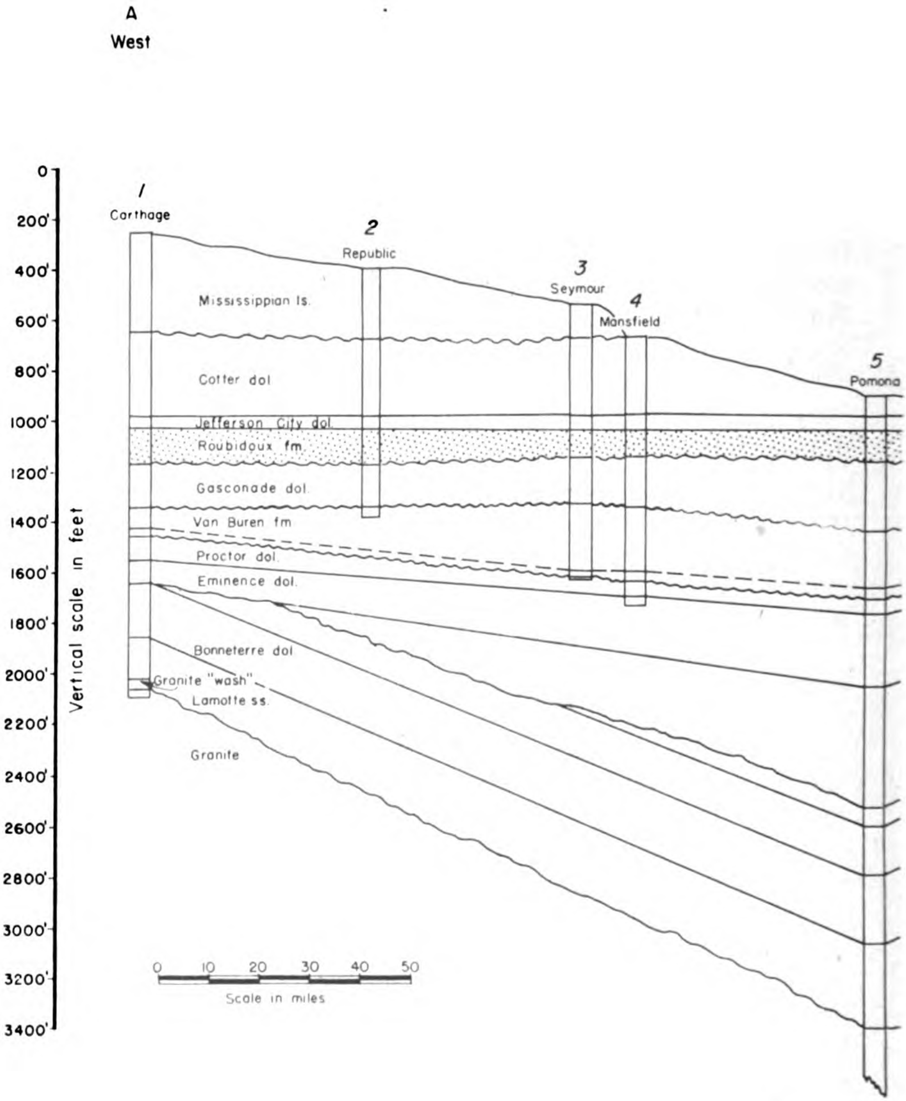


Fig. 4. Cross section in southern Missouri from west to east on line A-B (see also fig. 10) showing structural relations of the Roubidoux formation to pre-Roubidoux rocks. The cross section is based on well logs with the Roubidoux formation as the datum plane. Replotted from cross section by

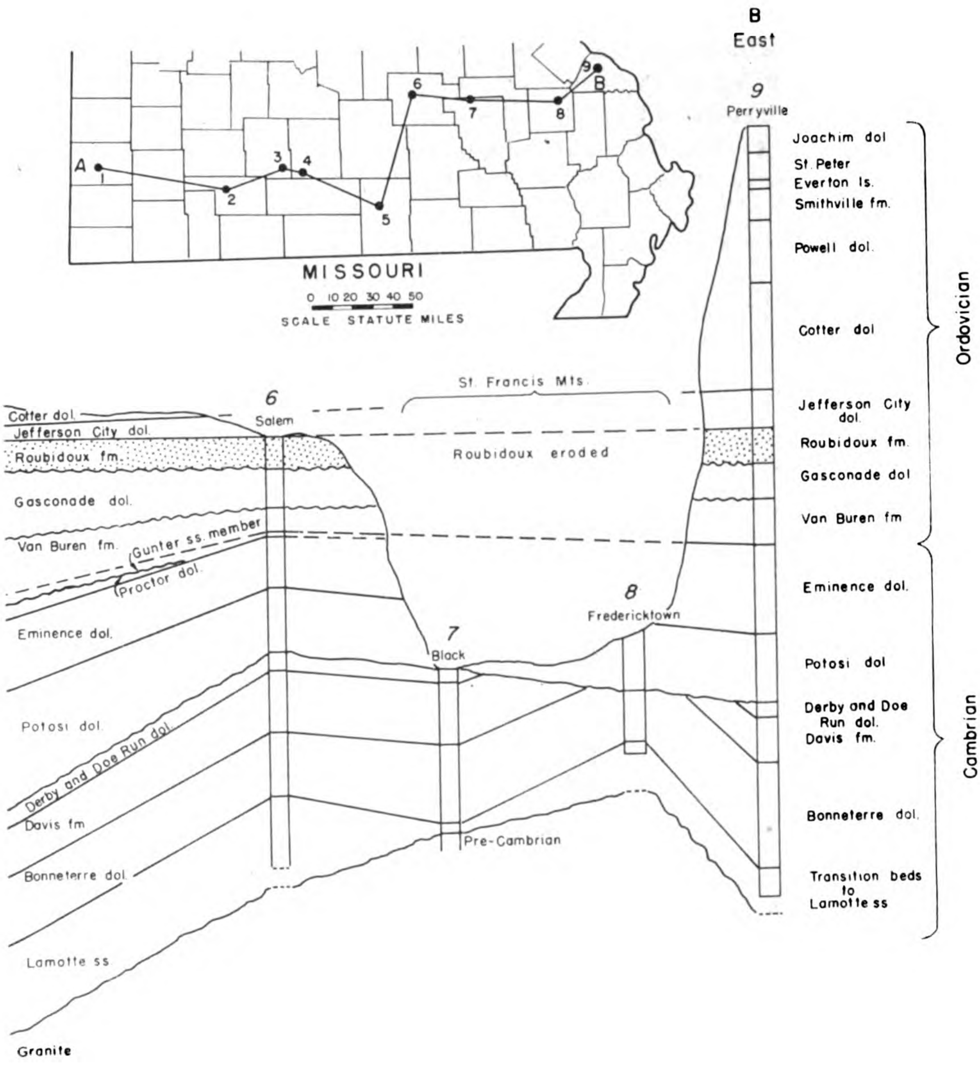


FIG. 4 —*continued*

McQueen (1931, pl. 12). The cross section shows pre-Potosi deformation, peneplanation, and overlap of formations younger than the Potosi dolomite. Similar relations are shown at the base of the Van Buren formation.

dovician formations, and in Washington and Marshall counties it overlaps upon granite. The St. Peter is unconformable below the overlying rocks.

In northeastern Kansas the St. Peter has a surprisingly even thickness, although there are locally a few sharp fluctuations. It has a thickness of 85 feet in Johnson county and thins westward without much variation to about 50 feet in the western part of the Forest City basin. It is 50 feet thick in Doniphan county, the northeastern county of Kansas.

Five hundred to 800 feet of rocks of Smithville, Powell, and upper Cotter age that are present in the Ozark area beneath the Everton formation are absent in northeastern Kansas. Six hundred feet or more of rocks, including, in ascending sequence, the Dutchtown, Joachim, Stones River, and Plattin limestones, were deposited in southeastern Missouri during the hiatus between the top of the St. Peter and the next overlying formations in northeastern Kansas. Because of these facts the regularity of the thickness of the St. Peter sandstone is remarkable. An exceptional thickness of 403 feet of St. Peter sandstone was encountered in northeastern Kansas in the Kasper No. 1 James well, in sec. 8, T. 13 S., R. 25 E., where the St. Peter sandstone and a detrital zone at the base replace all Arbuckle rocks above the top of the Roubidoux. McQueen and Greene (1938, p. 42) attribute the great thickness of the St. Peter in this well to channel filling. The St. Peter is unconformably overlain in most wells by the Decorah shale, but the Plattin limestone has been tentatively identified in wells in the deeper part of the North Kansas basin.

POST-ST. PETER AND PRE-MAQUOKETA FORMATIONS

The rocks between the top of the St. Peter sandstone and the base of the Maquoketa shale in outcrops in the Mississippi valley constitute an easily recognized lithologic unit composed mainly of limestone and dolomite. Rocks in Oklahoma occupying the interval from the top of the sandy Simpson dolomite to the base of the Sylvan shale were called Viola limestone by Taff (1902). An unconformable upper limestone member, the Fernvale limestone (of Richmond age), and a lower limestone member, the Bromide limestone (of Lowville-Black River age), were later separated as formational units from the original Viola limestone. The name Viola limestone is now restricted to the middle part of the original

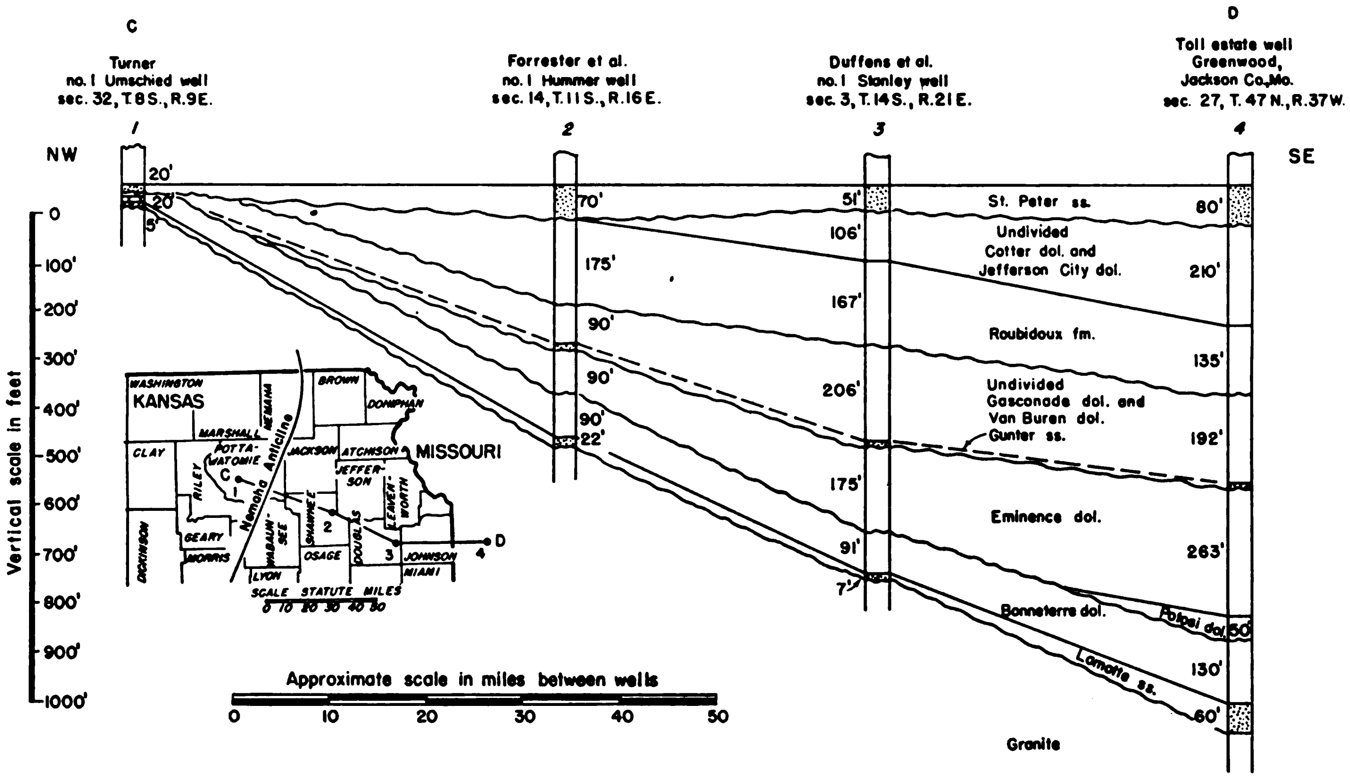


FIG. 5. Cross section from west to east on line C-D (see also fig. 10) from Pottawatomie county, Kansas, to Jackson county, Missouri, showing structural relations of St. Peter sandstone to pre-St. Peter rocks. The chief unconformities are at the base of the Lamotte, Potosi, Van Buren, Roubidoux, and St. Peter formations. Formational boundaries of well No. 1 by Wallace Lee and R. P. Keroher; well Nos. 2 and 3 by R. P. Keroher, State Geological Survey of Kansas; and well No. 4 by H. S. McQueen, Missouri Geological Survey.

formation and probably consists of rocks of late Black River and early Trenton age. However, the name Viola has continued in use in the midcontinent area in its original sense by oil men and many geologists.

The interval between the St. Peter sandstone and the Maquoketa shale in southeastern Missouri was at one time supposed to be the equivalent of the Viola of Oklahoma. The uncertainty regarding the identity of the St. Peter sandstone in Oklahoma and the occurrence in Missouri of a thick sequence of limestones, some of which are older than Black River, have made it difficult to correlate the Viola limestone with the Missouri section. The following formations, listed in ascending order, are recognized in southeastern Missouri between the St. Peter sandstone and the Maquoketa shale: Dutchtown formation, Joachim dolomite, Stones River limestone, Plattin limestone, Decorah shale, Kimmswick limestone, and Fernvale limestone. Of these formations, only the Decorah shale (of Missouri) and the Kimmswick limestone correspond in age to the restricted Viola of Oklahoma.

Plattin limestone and Decorah shale

At the type locality in eastern Iowa, the Decorah shale consists of 25 to 30 feet of very calcareous green shale with bands and nodules of limestone. At that locality it overlies the Platteville limestone (of Black River age) and underlies the Galena limestone (of Trenton age). The Decorah shale, as originally defined by Calvin (1906, pp. 97, 98), included a group of alternating calcareous green shales and limestones separating the Platteville limestone (of Black River age in the standard eastern section) from the overlying Galena limestone (of Trenton age), and was presumed to be of Black River age. Kay (1928, p. 16, and 1931, p. 370) subdivided it into three members and redefined their ages; the two uppermost members, Ian and Guttenberg, were reported to be of Trenton age and the lowest member, Spechts Ferry, which is separated from the others by an unconformity, was said to be of Black River age. The Spechts Ferry member at the base of the Decorah is regarded by some paleontologists as an upper member of the Platteville or Plattin.

Allen (1932, pp. 259-269) traced a layer of metabentonite (altered volcanic tuff) in the lower part of the Decorah (of Black River age) from the type locality of the Decorah to southeastern

Missouri, where the overlying lower Kimmswick rocks are reported by Ulrich to be of Black River age. If the various paleontologic identifications are accepted, only the lower Spechts Ferry member of the Decorah (of Black River age) can be represented in southeastern Missouri, for McQueen (1939, p. 62) and Ulrich (1939, p. 107) classify also that part of the Kimmswick above the metabentonite Decorah of that area as Black River. The Spechts Ferry shale is reported to be conformable upon the underlying Platteville in Iowa, as is the Decorah of southeastern Missouri upon underlying Plattin. Therefore, it appears that the Kimmswick of Missouri includes beds of Black River age younger than occur at outcrops in Iowa where the Spechts Ferry is reported to be the highest Black River formation. There appears to be no conflict in correlating the Plattin of Missouri with the Platteville of Wisconsin and other areas.

There is a shaly and sandy zone below the Kimmswick limestone in most wells drilled in northeastern Kansas, but paleontologic discrimination is impossible from well samples. The term Decorah shale as used herein is applied to a shaly and slightly sandy zone underlying the Kimmswick with seeming conformity and unconformably overlying the St. Peter sandstone.

The Decorah shale of the Forest City basin is characteristically a sandy dolomite interstratified with dark and gray-green shale. It includes, however, gray sublithographic limestone with some shale in Pottawatomie and Riley counties and in the Arab No. 1 Ogle well in Nebraska. Rocks believed to be of Decorah age in some wells in Johnson county, Kansas, and adjoining counties also consist in part or entirely of gray lithographic limestone and shale. Elsewhere in northeastern Kansas the Decorah is composed of brown to buff crystalline dolomite interstratified with dark to dark-gray clay or very dark-green clay in which microscopic pyrite crystals are disseminated. Some of the clay encloses disseminated frosted sand grains and grades vertically into argillaceous sandstone. Black to cinnamon-brown clay shale is widely present near the base of the formation. Opaque black and brown chert occurs at or near the base of the formation in Shawnee, Douglas and adjoining counties. Some of the sand grains in the Decorah are subangular and show secondary growth, but there is also much well-rounded and frosted sand. It is similar to that in the St. Peter, but nearly everywhere less coarse. The sand disseminated in the dolomite becomes increasingly abundant toward the base, although the increase is irregular. In the Turner No. 1 Umschied well, in sec. 32, T. 8 S., R. 9 E., in the deeper part of the North Kansas basin in Pottawatomie county, a sandstone 25 feet thick either in the base of or below the Decorah is separated from the St. Peter sandstone by 20 feet of dolomite and limestone. In the Arab No. 1 Ogle well, in sec. 9, T. 1 N., R. 14 E., Nebraska, this dolomite directly underlies the Decorah shale and overlies the St. Peter sandstone. In this locality the dolomite bed has generally been correlated with the Plattin limestone, but the occurrence of sandstone above the dolomite in the Turner-Umschied well and in other wells in the Salina basin casts some doubt on this correlation. An unconformity has been reported in Iowa between the upper and lower parts of the Decorah, but no sandstone has been reported in the outcrops nor in the subsurface within or at the base of the Decorah although parts of the Decorah in the subsurface are slightly sandy. On the other hand, there seems to be a possibility not yet completely investigated that the dolomite bed in question may represent the limestone member at the top of the Everton formation of Arkansas or some other part of the Simpson formation of Oklahoma.

The thickness of the Decorah shale, together with the Plattin limestone if it is present, increases irregularly toward the north and west. The Decorah seems to be absent in some wells in southern Douglas and Johnson counties. Including the 20 to 25 feet of beds which may be of Plattin age, the Decorah has a thickness of 85 feet in Riley county; 75 feet in Pottawatomie county; 95 feet in Brown county; and 110 feet just north of the Kansas line in Richardson county, Nebraska (Arab No. 1 Ogle well). In the McCain No. 1 Doane well, in sec. 34, T. 12 S., R. 22 E., Johnson county, the Decorah alone is 27 feet thick, but in extreme northeastern Kansas, in the Plymouth and Barnholdt No. 1 Elliot well, in sec. 31, T. 3 S., R. 20 E., Doniphan county, it is 42 feet thick.

The Decorah shale is definitely unconformable upon the underlying St. Peter sandstone. The relation of the Decorah to the overlying Kimmswick limestone is somewhat obscure, partly because there is some doubt concerning the age of the lower part of the Kimmswick. In many wells the Decorah seems to be merely a slightly clastic sandy and shaly basal member of the Kimmswick. Under this interpretation, these beds would be correlated with the upper Decorah of Ian and Guttenberg age, thus implying that the overlying Kimmswick is of Trenton age. In areas where the Decorah includes beds of limestone instead of dolomite, the Kimmswick also is composed of limestone; this suggests that the Decorah is closely allied with the overlying rocks, for limestone is unusual at this horizon in the Kansas part of the Forest City basin. If, on the other hand, the lower part of the Kimmswick is of Black River age, the Decorah of this area must be in part the lower Decorah of Spechts Ferry age (Black River).

Kimmswick limestone

The Kimmswick limestone crops out in the Mississippi valley in eastern Missouri and in southern Illinois. In most locations in this region it consists of coarse-grained limestone exceptionally free of chert. The United States Geological Survey (Wilmarth, 1938, pt. 1, p. 1095) classifies the Kimmswick as of Trenton age "but possibly including at base some beds of Black River age." Ulrich (1939, p. 107) considers the greater part of the Kimmswick outcrops at Cape Girardeau, Missouri, as of Black River age, placing in the Trenton only a thin member at the top of the exposure.

McQueen (1939, p. 62) traced the contact between Kimmswick rocks of Black River age and Kimmswick rocks of Trenton age northward from Cape Girardeau, and in this direction he found a progressive increase in the amount of chert in the Black River part of the Kimmswick. He also reported that much chert occurs in the middle Kimmswick in the subsurface in western Missouri. McQueen and Greene (1938, p. 40) divide the Kimmswick of northwestern Missouri into three divisions. Their uppermost division consists of bluish-gray to brown crystalline dolomite with small amounts of white to dark-brown chert. The middle division is very cherty dolomite, the upper part of which is almost wholly chert. The lowest division is again dolomite with small amounts of gray and brown chert. McQueen (McQueen and Greene, 1938, p. 41) regards the top of the very cherty member as the top of rocks of Black River age and believes the uppermost division to be of probable Trenton age unconformably overlying the cherty Black River.

E. C. Reed, of the Nebraska Geological Survey, and H. G. Hershey, of the Iowa Geological Survey, have traced the rocks into the subsurface of areas bordering northwest Missouri and conclude that the cherty rocks of the Kimmswick represent the Prosser limestone of the outcrops (Conference of April 15, 1942). They agree that whatever the age of the rocks referred to the Kimmswick in northwestern Missouri, these are the same rocks that are classified in adjoining parts of Iowa and Nebraska as Prosser limestone, which is of early Trenton age and above the Ian and Guttenberg rocks.

In northeastern Kansas the Kimmswick is mainly dolomite. The formation changes from dolomite in the north to limestone toward the south in Johnson, Douglas, and adjoining counties. The change begins in the upper part of the formation, and toward the south the change to limestone extends progressively to lower parts of the formation. This relation is reversed, however, toward the west in Riley and Pottawatomie counties and in Richardson county, Nebraska, where the lower part of the Kimmswick is limestone and only the upper part is dolomitic.

The distribution of dolomite and limestone in northeastern Kansas and northern Missouri and the belt of transition from limestone to dolomite is shown in figure 6. In northern Missouri the available information concerning the Kimmswick is from a limited number of wells studied by the writer and from reports by McQueen and Greene (1938). The dolomite phase lies toward the deeper part of the basin of deposition. It is apparent that the areas of dolomite and limestone deposition in Kansas are extensions of similar areas in northeastern Missouri.

The chert of the Kimmswick has some unique features, although there is considerable regional variation. Most of the samples of chert show irregularly distributed black flecks from the size of silt grains to dustlike particles. These flecks are composed mainly of pyrite but some may be phosphatic. Some of the chert contains silicified masses of broken foraminifera in which there are many microscopic circular black patches suggesting broken tubes. Although these markings are not unique, they are a prominent characteristic of parts of the Kimmswick.

The Kimmswick limestone in northeastern Kansas in areas where it is overlain by the Maquoketa shale increases in thickness toward the north. It is 95 feet thick in northern Douglas county, 107 feet thick in central Wabaunsee county, 180 feet thick in Doniphan county, and 248 feet thick in the Arab No. 1 Ogle well, in sec. 9, T. 1 N., R. 14 E., Nebraska. The Kimmswick is thin or absent where it was exposed to pre-Devonian erosion.

The stratigraphic relation of the Kimmswick limestone to the underlying Decorah shale is obscure. However, the lithologic relation of the Decorah and Kimmswick in some wells suggests, at least locally, that the rocks reported as Decorah in northeastern Kansas are basal clastic beds of the Kimmswick. The Kimmswick is definitely unconformable below the Maquoketa shale. It seems possible that the upper or noncherty zone is of Fernvale age. The possibility of an unconformity between this zone and the middle Kimmswick has already been mentioned.

The three divisions of the Kimmswick described by McQueen and Greene (1938, pp. 40-42) in northwestern Missouri are recognized in northeastern Kansas. These consist of an uppermost zone of dolomite with minor amounts of insoluble residues, a middle cherty zone, and a basal sparsely cherty zone.

The uppermost or noncherty zone was reported by McQueen and Greene to be of probable Trenton age. The rocks of this zone are mainly dolomitic, but locally include some limestone, as in the Smith et al. No. 1 Al Smith well, in sec. 28, T. 12 S., R. 19 E. The rocks of this zone are reported to contain small amounts of white and brown chert in Missouri, but in Kansas no chert was noted. The insoluble residues are characterized by semiopaque, vesicular quartz and drusy and fibrous quartz resulting from incomplete and imperfect replacements of shells of brachiopods. The amount of insoluble residues is ordinarily from 3 to 10 percent, but in a few samples it constitutes 15 to 25 percent. This zone is absent in some wells in parts of Johnson and adjoining counties where pre-Devonian erosion removed the upper part of the Kimmswick. The thickness of this zone increases somewhat irregularly from 5 to 10 feet in northern Johnson county and northern Douglas county to 20 to 40 feet farther north and varies inversely with the thickness of the underlying cherty zone in such a way as to suggest the presence of a disconformity between these zones. If the Prosser age of the cherty beds of the Kimmswick is accepted, this zone probably represents the Stewartville which is reported by Kay (1935, p. 295, fig. 211) to be disconformable above the Prosser. In the Arab No. 1 Ogle well, in sec. 9, T. 1 N., R. 14 E., Nebraska, this noncherty quartzose zone is 37 feet thick and is overlain by 55 feet of cherty dolomite. The insoluble residues of this upper dolomite consists of 20 to 60 percent yellow-gray opaque chert mottled with patches of semiopaque vitreous chert containing spicules and some dark-gray coarsely dolocastic chert. This higher zone was not found in the nearest wells in Kansas, about 50 miles to the south. The insoluble residues from the noncherty dolomite zone at the top of the Kimmswick in Kansas closely resemble the residues described by Ireland (1936, p. 1101) in the Fernvale of Oklahoma. Residues from samples of the Fernvale in southwestern Illinois consisted almost entirely of partial replacements of shells by fibrous quartz that Ireland described as "acicular white fossil replacements."

The middle or cherty zone of McQueen and Greene is well developed in Kansas where it is divisible into three members: a very cherty member at the top, a sparsely cherty member in the middle, and a cherty member at the bottom of the zone. The chert in the uppermost member of this zone varies considerably in different parts of the area, but maintains a strong similarity. In Pottawatomie and Riley counties it is buff to brownish-gray and is composed of masses of finely broken foraminifera poorly preserved in either semivitreous or opaque chert. The semiopaque chert of these counties is irregularly splotched with tripolilike dust giving the chert a texture that may be described as curdled. The foraminiferal content decreases toward the east where the chert becomes grainy with occluded silt or shows a stippled pattern on the smooth fractures. The color changes from buff to light gray toward northwestern Missouri. The chert reflects the change from dolomite to sublithographic limestone in Johnson county, where, instead of being foraminiferal or silty, it is massive and either semiopaque or semitranslucent. Chert constitutes from 10 to 20 percent of the volume of the cuttings at the top of the upper member of the cherty zone and increases to 70 to 80 percent at the base, below which there is an abrupt decrease in the amount of chert. The break from high to low chert content is striking and presents a sharp datum horizon throughout much of the area. The upper part of the cherty zone is 20 feet thick in Shawnee county, Kansas, and 55 feet thick in the Arab No. 1 Ogle well, in sec. 9, T. 1 N., R. 14 E., Nebraska. The relation of the thickness of the uppermost member of the cherty zone above the datum horizon mentioned to the thickness of the overlying noncherty quartzose zone suggests an unconformity at the top of the cherty zone, and tends to confirm McQueen's conclusions that an unconformity exists above the cherty zone in northwestern Missouri. Toward the southeast the upper part of the cherty zone was removed by pre-Devonian erosion.

The middle member of the middle or cherty zone in Kansas is generally dolomitic, but it is calcareous in Riley and Pottawatomie counties and in Johnson and adjoining counties on the southeast. The chert rarely exceeds 5 percent of the sample and usually constitutes only a trace. It is almost invariably accompanied in the insoluble residues by small amounts of drusy crusts and crumbs of clear to semitranslucent quartz and fibrous quartz. These residues represent the imperfect and partial replacement of coarse fossils by quartz. Some of the semiopaque fibrous quartz recovered in the insoluble residues shows the imprint of brachiopods and is flecked with fine pyrite crystals. The thickness of this noncherty middle member varies widely because it becomes cherty and merges with the rest of the cherty zone in northwestern Missouri and because toward the west the lowest member of the cherty zone is less sharply defined. The middle member of the cherty zone has a thickness of 60 feet in Pottawatomie county, where it encroaches on or replaces a part of the underlying cherty beds. It has a thickness of 15 to 20 feet toward the east where it is encroached upon or becomes equivalent to part of the underlying chert member.

The lower cherty member of the middle zone of the Kimmswick limestone in northeastern Kansas is similar to the upper cherty member except that the chert shows a stippled or grainy pattern instead of the foraminiferal character. However, toward the east, where the chert in the uppermost member becomes grainy and silty, the lower member is finely microfossiliferous. As in the upper cherty member, the color changes from buff to gray and white toward the east. The amount of chert is more variable than in the upper part of the zone. In some wells the amount of chert in the cuttings is nearly 100 percent but the average is much less. The amount of chert in the lower member of the zone gradually increases downward breaking off sharply at the base in some wells. This member becomes less cherty toward the west in Shawnee and Wabaunsee counties where only 5 to 20 percent of the rock is chert. Similar amounts of chert occur in Riley and Pottawatomie counties where the cherty zone is calcareous. In a few places some fine sand occurs in the lower member of the cherty zone. Chert with black flecks of pyrite is particularly characteristic of the lower part of the cherty zone. The thickness of the lower member of the cherty zone is less than 10 feet in Pottawatomie county but increases to more than 50 feet in Doniphan county where the Kimmswick closely resembles that in northwestern Missouri.

The basal sparsely cherty zone of the Kimmswick limestone resembles the sparsely cherty parting of the middle zone. This zone overlies the Decorah shale in most wells; however, it is absent in some wells and the cherty or middle zone thus directly overlies the Decorah shale. This basal zone of the Kimmswick is composed of sucrose to crystalline dolomite or sublithographic limestone, depending on the area. The insoluble residues contain traces of grainy opaque chert, but are characterized by drusy and fibrous quartz of partially replaced fossils. The zone commonly has traces of disseminated, medium fine, rounded sand grains which are particularly abundant in places where shale beds of the Decorah are not recognized. The thickness of this member ranges from a feather-edge in the west, where the Decorah is thick, to 40 feet in Atchison county, where the Decorah is thin. The sandy parts of the formation may be partial equivalents of the Decorah.

MAQUOKETA SHALE

The Maquoketa shale (of Richmond age) is the youngest Ordovician formation known to be represented in northeastern Kansas. The type locality of the Maquoketa shale is in Dubuque county, northeastern Iowa. The Maquoketa shale crops out in eastern Missouri, Illinois, and elsewhere in the Mississippi valley. It is equivalent to the Sylvan shale of Oklahoma.

Ladd (1929) described the Maquoketa shale at outcrops in Iowa as consisting of 190 feet of green or blue shale "with a few feet of thin limestone layers at the top and an even thinner zone of indurated beds at the base." The formation thickens northwest from the type locality. It has been divided into four members: the Brainard shale member at the top with a variable thickness up to 100 feet; the Fort Atkinson member consisting of 40 feet of cherty dolomite and limestone; the Clermont member consisting of 10 to

40 feet of bluish plastic shale; and the Elgin member at the base composed of 70 feet of variable shaly limestone, calcareous clay, and dolomite. Rowley (1908) describes the Maquoketa at outcrops in Pike county, northeastern Missouri, as about 100 feet thick and consisting of light-blue shale, sandy in places; the softer shales are separated by hard beds that are argillaceous in some places and calcareous in others.

The Maquoketa shale in Kansas is variable in character. In some parts of the area, as in the Arab No. 1 Ogle well, in sec. 9, T. 1 N., R. 14 E., Nebraska, where the upper part of the formation has been eroded, the Maquoketa is composed almost entirely of shale. Elsewhere, however, it is roughly separable into an upper and a lower part, but each presents considerable lithologic variety. Throughout most of the area the upper zone is an impure dolomite, the insoluble residues of which consist of loose aggregates of dolocastic siltstone and fine sand. Some spongy dolocastic shale is also present. Part of the residual silt is densely cemented by semiopaque bluish to gray dolocastic chalcedonic chert. Some residues reveal the presence of spicular chert and loose coarse siliceous spines. Glauconite has been observed in the insoluble residues of the coarser parts of the silty dolomite. This silty and cherty dolomite may be roughly equivalent to the Fort Atkinson member of Iowa. The Brainard shale member is generally not present, though it may be represented locally in Atchison and Brown counties.

The lower part of the formation is much more argillaceous and consists for the most part of dolomitic slightly silty dark clay or clay shale. In Pottawatomie and Riley counties micaceous clay shale, mixed or interstratified with silty clay, forms the lower part of the Maquoketa shale. The insoluble residues of the lower part are dolocastic. Much of the insoluble residue is loosely spongy silty clay which originally formed a matrix for closely set fine crystals of dolomite. Black flakes of organic material which suggest broken fragments of graptolites are common in the lower or argillaceous zone. Pseudo-graptolite fragments occur locally in the upper part of the formation also, but they are uncommon in Kansas. The lower dolomitic and silty clay shale may be the approximate equivalent of the Elgin and Clermont members of the Maquoketa in northeastern Iowa which were described by Calvin (1906).

The thickness of the Maquoketa shale in northeastern Kansas shows little variation except in those wells in which pre-Devonian or pre-Silurian erosion has reduced its original thickness. It is 75 feet thick in central Wabaunsee county, 75 feet thick in eastern Riley county, 82 feet thick in Pottawatomie county, and 64 feet thick in Shawnee county. The thickness has increased to 111 feet in northwestern Missouri in the Birkett et al. No. 1 McGee well in Andrew county. The formation continues to thicken slightly toward the northeast at outcrops in Iowa.

The Maquoketa shale lies unconformably on the Kimmswick limestone. The pre-Maquoketa surface must have been extremely flat, for, although the Maquoketa shale was deposited upon the middle or cherty member of the Kimmswick toward the southeast and upon 92 feet of the upper Kimmswick member toward the northwest, it has in northeastern Kansas a singularly uniform thickness without pronounced local variations.

The Maquoketa shale is unconformable below the Silurian rocks in the Arab Ogle well. Hematitic "flaxseed" oölite in red shale forms the base of the Silurian in this well. The upper dolomitic zone of the Maquoketa is absent and the upper beds consist of red weathered shale. In the Isaacks No. 1 Magor well, in sec. 15, T. 5 N., R. 15 E., Nebraska, only about 20 feet of probable Maquoketa intervenes between the base of the Silurian and the Kimmswick. The well was drilled with rotary tools, however, and the thickness as determined from well cuttings may be incorrect. A thinning of the Maquoketa has also been noted in northwestern Missouri in the Jackson and Rust No. 1 Hayes well, in sec. 22, T. 66 N., R. 42 W.

The Maquoketa shale was originally deposited throughout northern Missouri and Kansas and probably across the Chautauqua arch in continuation with the Sylvan shale of Oklahoma. Large areas of Maquoketa shale together with older and younger rocks were stripped from southeastern Kansas and from northern Missouri, as shown by the unconformity at the base of the Devonian rocks (fig. 6). The Maquoketa was very generally eroded from the northern end of the Nemaha anticline at the end of Mississippian time when that area was raised and peneplaned. The Maquoketa may be expected beneath the Pennsylvanian rocks in a narrow belt encircling this truncated fold, but elsewhere Devonian and Silurian rocks intervene.

Rocks of Silurian Age

The term Hunton limestone was introduced in 1902 by Taff (1902) for the Devonian and Silurian limestones and dolomites in southeastern Oklahoma between the Sylvan shale (Maquoketa shale) and the Woodford chert (Chattanooga shale). The term Hunton limestone is a widely used name, especially in the subsurface of Oklahoma and Kansas, in places where it is impossible or immaterial to distinguish the various formations into which the Hunton can be divided. However, at least four limestone forma-

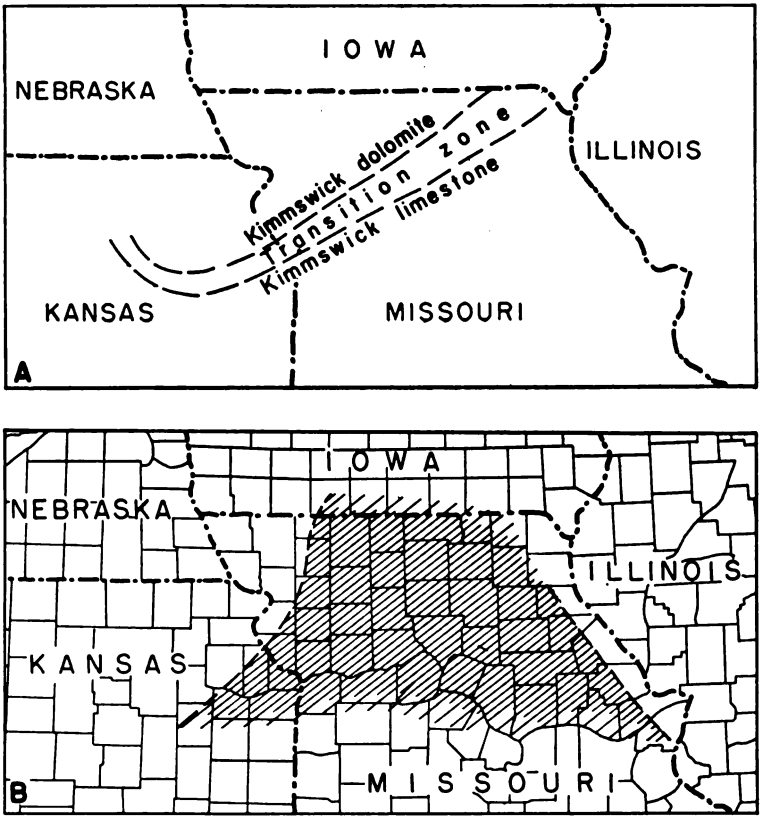


Fig. 6. *A*, Sketch map showing distribution of calcareous and dolomitic phases of the Kimmswick limestone and intervening transition zone in northeastern Kansas and northern Missouri. *B*, Sketch showing by crosshatching the areas in northeastern Kansas and northern Missouri from which Maquoketa shale was removed by pre-Devonian erosion. Data in northeastern Missouri after Grohskopf, Hinchey, and Greene (1939, pl. 2).

tions, two of which are of Devonian age and two of Silurian age, are now recognized in the Hunton rocks of Oklahoma.

At outcrops in southern Oklahoma, the upper or Devonian part of the Hunton consists of the Bois d'Arc limestone underlain by the Haragan shale. The lower or Silurian part consists of the Henryhouse shale underlain by the Chimneyhill limestone. These formations are separated from each other and from the overlying Woodford chert or Chattanooga shale and from the underlying Sylvan shale by unconformities of a magnitude adequate to account for the local absence of any of these formations. In some localities in Kansas and Oklahoma the Hunton is composed exclusively of Silurian rocks and in others exclusively of Devonian rocks. It is obvious, therefore, that the Hunton is a group of formations of variable continuity and character rather than a constant unit.

The most complete Silurian section in Missouri is in the southeastern part of the state where the following formations, listed in ascending order, are exposed: the Girardeau limestone, the Edgewood limestone, and the Brassfield limestone, of lower Silurian age, and the Bainbridge limestone of middle Silurian age. In southeastern Missouri, the equivalent of the Maquoketa shale in some localities is conformably overlain by Girardeau limestone. Some geologists consider the Girardeau limestone the final deposit of the Ordovician because no hiatus intervenes between it and the Maquoketa whereas there is a pronounced unconformity at its top.

The Chimneyhill limestone is the oldest Silurian formation in Oklahoma. It consists, in ascending order, of a basal white oölitic limestone member, a glauconitic limestone member, and a pink crinoidal limestone member (Reeds, 1911, pp. 258-260). According to Ulrich (1930, p. 73) the Chimneyhill corresponds, in ascending order, to the Noix limestone (of Edgewood age) of Missouri and to the Brassfield and St. Clair limestones of Arkansas. The Henryhouse shale which overlies the Chimneyhill in Oklahoma consists of earthy limestone and marly beds with intercalated shale. According to Ireland (1939, p. 190) both the Henryhouse shale and the Chimneyhill limestone are represented in the St. Clair of eastern Oklahoma. Ball (1939, p. 126) suggests the correlation of the Henryhouse shale of Oklahoma with the Bainbridge limestone of Missouri and Illinois.

Studies of Silurian outcrops in areas outside the Forest City basin reveal frequent interruptions of sedimentation. Most of the Silurian formations are separated from overlying and underlying strata by unconformities. Unconformities are also recognized or suspected between the several members of the Edgewood.

Ireland (1939), who studied the insoluble residues of Silurian and Devonian rocks of Oklahoma, reported that certain species of foraminifera are found exclusively in the Silurian. Ireland's work provides the criteria by which it is inferred that the Silurian rocks of northeastern Kansas were at one time continuous with those of Oklahoma and Missouri.

CHIMNEYHILL LIMESTONE

The Silurian rocks of northeastern Kansas consist of the Brassfield and Edgewood limestones which are represented in Oklahoma by the more inclusive term Chimneyhill. In the Coronado No. 1 Parks well, in sec. 16, T. 10 S., R. 8 E., Riley county, the Silurian rocks are 150 feet thick. Elsewhere in northeastern Kansas they are somewhat thinner, because the Silurian was cut off by erosion that preceded the deposition of the Devonian rocks. Thicker sections of the Silurian are known toward the north in southeastern Nebraska. Four lithologic zones have been differentiated in the Silurian of northeastern Kansas mainly by insoluble residues.

Oölitic zone.—The lowest zone of the Silurian rocks recognized in northeastern Kansas consists of coarsely sucrose to crystalline dolomite characterized by the presence of dolomitized oölites. The oölites, like the matrix, are composed of coarsely sucrose dolomite and their surfaces are rough with minute crystals of dolomite. The concentric banding usual in oölites has been destroyed by recrystallization. The insoluble residues from one well revealed a few thin white cherty oölitic crusts but the residues from this zone are essentially noncherty. In many of the samples the oölites impinge upon each other and when drilled do not break free and are only partly and imperfectly rounded. Some of them resemble grains worn to roundish surfaces in drilling. In some samples from wells drilled with rotary tools the oölitic character is recognized by the shape of the interstitial cavities. The insoluble residues of the oölitic zone are less than 2 percent by volume and consist mainly of clear hackly quartz and drusy quartz. The oölitic zone is 15 to 30 feet thick and includes a band of nonoölitic dolomite at the base 5 to 15 feet thick.

White chert zone.—The white chert zone which overlies the oölite member consists of similar coarsely sucrose white porous dolomite characterized by residues of opaque white chert. The amount of chert is ordinarily only 1 to 5 percent by volume, but in Riley county and in some other localities some samples from this zone yield 12 to 20 percent insoluble residues. In addition to the white chert, the insoluble residues include some gray chert which is slightly dolocastic. Quartz is absent or subordinate in the lower part of the zone, but where the zone is thick some quartz is present in the residues from the upper part but in amounts less than that of the white chert.

In the Empire No. 1 Schwalm well, in sec. 19, T. 12 S., R. 11 E., Wabaunsee county, traces of anhydrite were found in the residues of nearly every sample from this zone. The largest amount, only 1 percent, was found at the top of the zone, which is thicker in this well than in any other well examined. It is possible that at the top of this thick section the anhydrite was either locally deposited or locally preserved from erosion. However, in two wells in Shawnee county traces of anhydrite were detected at the base of the white chert zone or at the top of the oölite zone. Traces of crystalline anhydrite are common in the lower 150 feet of the Silurian in the Carter stratigraphic test well No. 4 in sec. 24, T. 4 S., R. 16 E., Brown county. It is not certain that anhydrite occurs in this zone exclusively in these counties, but it was not detected elsewhere. Where the anhydrite is associated with harder rocks, most of the anhydrite is reduced to mud in drilling and is lost when the samples are washed. Some anhydrite is also lost by solution when the samples are treated with acid. Failure to discover anhydrite in the samples, therefore, does not necessarily imply its absence. The discovery of anhydrite in the Silurian of Oklahoma by Ireland (1936, p. 1094) suggests that anhydrite may have been widely distributed.

Foraminiferal zone.—Overlying the white chert zone, is a zone of coarsely sucrose white dolomite which is indistinguishable from the underlying dolomites except by the insoluble residues. The insoluble residues from this zone are characterized by small numbers of arenaceous foraminifera accompanied by small amounts of several forms of clear secondary quartz (hackly, drusy, semiopaque, etc.) and by coarse angular silt or very fine sand. The residues are less than 1 percent of the volume in most samples, but they amount to 5 to 6 percent in some samples. The basal bed of the foraminiferal zone is characterized by traces of glauconite. The small and silty residues are to some extent characteristic of this zone. In several wells the presence of the silt had led to more careful preparation and re-examination of insoluble residues and the ultimate discovery of foraminifera.

Foraminifera from this zone were first observed in small quantity in the Empire No. 1 Schwalm well, in sec. 19, T. 12 S., R. 11 E., Wabaunsee county, but none could be found in other nearby wells although residues similar in other characteristics had been observed. When duplicate residues were prepared and examined it was discovered that in most wells the light hollow discoidal tests had been decanted in washing the residues because sufficient time had not been allowed to permit them to settle. Although nowhere present in large numbers, patient examination of the residues of samples from this zone has in almost every case revealed one or more foraminifera.

The foraminiferal remains consist in part of flat, closely coiled, discoidal tests having the aperture at the end of a tube extending sharply at right angles to the coil. These foraminifera resemble *Lituotuba* and *Ammodiscus* described by Moreman (1930) and Ireland (1939) from the Silurian of Oklahoma. Henbest expressed the opinion after casual observation of some of the specimens that some of them are new and undescribed species. Similar foraminifera have not been reported from the Devonian of Oklahoma. The foraminifera observed in Kansas have all been found in samples below the sandy zone that characterizes the base of the Devonian. It is concluded, therefore, that the rocks from the top of the Maquoketa up to and at least including the foraminiferal zone are of Silurian age.

The base of the Devonian rocks in northern Missouri is marked by sandy limestone and calcareous sand. In following this sandy member from well to well in the well cuttings it was discovered that toward the west an increasing thickness of dolomite intervenes between the Maquoketa shale and the base of the Devonian. The presence of Silurian rocks had, therefore, been suspected before the discovery of Silurian foraminifera. The foraminiferal zone is 20 to 50 feet thick. The limits of the zone are based on the recognition of foraminifera in the residues, in some cases represented by a single test. The characteristic silty nature of the residue of some samples in which, however, foraminifera were not found suggests that they are a part of this zone and that locally the thickness of the zone may be greater than indicated by the observed fossils.

In the Arab No. 1 Ogle well in sec. 9, T. 1 N., R. 14 E., Nebraska, both the oölitic zone and the white chert zone are missing. In this well the foraminiferal zone rests unconformably upon the weathered and eroded surface of the Maquoketa shale, suggesting uplift and erosion of the Maquoketa at the beginning of Silurian time and overlap of Silurian rocks. This relation is probably the expression of the unconformity recognized in the outcrops at many places in the Mississippi valley at the base of the Brassfield. Similarly, in the McNab No. 1 Fritz well, in sec. 4, T. 12 S., R. 14 E., the white chert zone of the Silurian is missing and the foraminiferal zone immediately overlies the oölitic zone. An unconformity is recognized in the Mississippi valley outcrops also between the Brassfield and the underlying Edgewood limestone.

Drusy quartz zone.—The drusy quartz zone, which overlies the foraminiferal zone (fig. 7), consists of coarsely sucrose white dolomite similar to earlier Silurian dolomite. The insoluble residues constitute 2 to 4 percent of the samples and consist of small particles of angular, drusy, hackly, clear to semiopaque quartz. Some opaque white chert also occurs in the lower part.

A change in the character of the dolomite occurs in many wells at the contact of the basal Devonian rocks (identified by the sand content) and the underlying Silurian dolomite. The Silurian dolomite is a coarsely sucrose white dolomite with angular microscopic vugs lined with dolomite crystals. The Devonian dolomite is sucrose but generally dense and more or less impervious. Toward the west this change in lithologic character occurs at somewhat varying intervals up to 50 feet above the base of the drusy quartz zone. In the absence of a sandy zone at the base of the Devonian the contact is tentatively placed at this change in lithology. This, however, is not an entirely satisfactory expedient for in some wells there are alternating beds of dense and porous dolomite of unknown age.

Correlation.—The Silurian of the Forest City basin is believed to be the correlative of the Chimneyhill limestone of Oklahoma. The basal dolomitized oölite zone corresponds to the Noix oölite member of the Edgewood limestone of Missouri. The correlation of the overlying zone which yields insoluble residues of white chert is uncertain, but it also may be a part of the Edgewood. The fairly regular thickness of the overlying foraminiferal zone and the considerable irregularity in thickness of the underlying white chert zone suggests unconformable relations between them (see fig. 7). There is certainly an unconformity at the base of the foraminiferal zone in the Arab-Ogle well in Nebraska where the foraminiferal zone overlies an abnormally thin section of weathered Maquoketa shale and also in the Carter stratigraphic test well No. 4, in sec. 24, T. 4 S., R. 16 E., where also the foraminiferal zone rests on the Maquoketa (fig. 7). The presence of glauconite at the base of the foraminiferal zone suggests its correlation with the corresponding glauconitic limestone of the Chimneyhill of Oklahoma which has been correlated with the Brassfield by Ball (1939). In the Arab No. 1 Ogle well, the foraminiferal dolomite zone contains some pink and salmon-colored dolomite, a characteristic of the Brassfield, but these colors are not as conspicuous in this zone in Kansas as in the outcrops, although fragments of pink limestone have been observed in some well samples. Pink and reddish limestones have been noted by Ball (1939, p. 119) in the upper part of the Brassfield or its correlatives from Indiana to Oklahoma, and the occasional occurrence of this lithologic feature in Kansas is additional reason for regarding this zone as of Brassfield age. The correlation of the drusy quartz zone is uncertain; it may represent part of the upper Brassfield of Arkansas or the still younger St. Clair of that state.

Rocks of Devonian Age

GENERAL DESCRIPTION

Devonian rocks crop out in eastern Iowa, central and eastern Missouri, parts of northern Arkansas, and southeastern Oklahoma. The upper or Devonian part of the Hunton limestone of the outcrops in southern Oklahoma consists of the Bois d'Arc limestone above and the Haragan shale below. The Haragan shale, as described by C. A. Reeds (1911), consists of alternating blue and white shales and thin-bedded earthy limestones. It somewhat resembles the Henryhouse shale of Silurian age, but Ireland (1936, p. 1098) was able to distinguish the Haragan by the absence of foraminifera of the type common in the Henryhouse. He concluded for this reason that the Haragan is absent in northern Oklahoma. The Haragan is of Lower Devonian (Helderbergian) age. It has been correlated by Ireland (1936, p. 1095) and others with the Bailey limestone of southeastern Missouri (also of Helderbergian age).

The Bois d'Arc limestone, the youngest Devonian in southern Oklahoma, is described by Ireland as a white dense cherty limestone with insoluble residues of white dense chert and small amounts of sand grains. The beveled edge of the Bois d'Arc is overlain in most wells in northern Oklahoma by Mississippian rocks, and it is even more restricted in its subsurface distribution than the Haragan shale. The Bois d'Arc is of Lower Devonian (Oriskany and Becraft?) age, and is a partial equivalent of the Little Saline limestone of southeastern Missouri.

The Devonian outcrops nearest to northeastern Kansas are in north-central Missouri on the eastern border of the Forest City basin. E. B. Branson (1923, pp. 19-47; 1941) distinguishes in the outcrops the following Devonian formations, in ascending order: Cooper limestone, Ashland limestone, Callaway limestone, and Snyder Creek shale.

The Cooper limestone at the outcrops in north-central Missouri is composed chiefly of dark to bluish-gray dense lithographic limestone which is very sparingly fossiliferous. It is flecked with crystals of calcite and includes sparsely disseminated rounded and frosted grains of sand. A bed of sandstone, calcareous sandstone, or sandy limestone of variable thickness and character almost invariably occurs at the base of the formation; this provides an important datum bed for determining the base of the Devonian in the subsurface. The thickness of the Cooper at the type locality in Cooper county, Missouri, is 30 feet. The few fossils obtained from the formation do not determine its age very definitely. Its correlative farther east in northeastern Missouri, the Mineola limestone, is more varied in lithology and contains crinoidal and fossiliferous limestones by means of which it has been correlated by Branson with the Grand Tower limestone of southeastern Missouri and with some part of the Wapsipinicon of southeastern

Iowa. On account of the stratigraphic relations of the Cooper to the Mineola, the Cooper is also correlated with the Grand Tower of Middle Devonian (Onondaga) age.

The Ashland limestone was described by Branson (1941, p. 83) as a formation because of its "distinct lithology, unique fossils, and its relationship to adjoining formations." The name Ashland has, however, already been pre-empted for a Silurian limestone in Maine. The Ashland of Missouri is described by Branson as composed of limestone, crowded with fossils, but it is so dense that few good specimens have been recovered. It occurs in small areas of only a few acres extent between Jefferson City and Hannibal, Missouri, and has a maximum observed thickness of only 15 feet. The Ashland is reported to be unconformable below the Callaway and unconformable above the pre-Devonian rocks. The Ashland is believed by Branson to occur stratigraphically between the Cooper and Callaway, but it is not known to be anywhere in contact with either the Cooper or the Mineola.

At surface outcrops the Callaway formation is also a fine-textured limestone but it is more fossiliferous than the Cooper limestone and contains some beds of semigranular limestone. Lithologically, it resembles the Mineola, but Branson differentiates them by paleontologic criteria. The Callaway, like the Mineola, has a basal sandy zone, but sandy limestones crop out higher in the formation also. The Callaway is "roughly correlated" by Branson with the Cedar Valley limestone of southeastern Iowa and with the St. Laurent limestone at the top of the Devonian section in southeastern Missouri, which is of Middle Devonian (Hamilton) age.

The Snyder Creek shale, which in some localities in north-central Missouri overlies the Callaway limestone, consists of thin impure and nodular limestones interbedded with shale, sandy shale, and thin beds of silt and fine sandstone. Branson correlates the Snyder Creek shale with the Tully or Genesee (Upper Devonian) of New York. Stainbrook (1935, p. 260) suggests its correlation with the upper part of the Cedar Valley of Iowa. It appears, therefore, that the Devonian rocks of this part of Kansas are not older than Middle Devonian. The Devonian beds included in the Hunton of northeastern Kansas are, therefore, younger than the Devonian beds (Lower Devonian) of the Hunton in Oklahoma, a fact well illustrating the varied age of the rocks included under the term Hunton. The following table shows the correlation of the Devonian in northeastern Kansas with the Devonian of Oklahoma and northern Missouri.

TABLE 2.—*Correlation of Devonian formations*

	Northern Missouri *E. B. Branson* *(1923 and 1941)*	*Southeastern Oklahoma* *C. A. Reeds* *(1911)*	*Northeastern Kansas*
Upper Devonian	Snyder Creek shale		Undifferentiated limestone and dolomite
Middle Devonian	Callaway limestone Ashland limestone Cooper limestone		Cooper limestone Lithographic limestone Sandy limestone or calcareous sandstone
Lower Devonian		Bois d'Arc limestone Haragan shale	

MIDDLE DEVONIAN LIMESTONES OF COOPER AND YOUNGER AGE

Rocks lithologically similar to the Cooper limestone of central Missouri have been traced by means of well cuttings into northeastern Kansas where, as in Missouri, a much greater thickness of Devonian rocks occurs in the subsurface toward the north than toward the south. The Devonian as well as the Silurian rocks are characterized by relatively small amounts of insoluble residues when compared with the Mississippian limestones above and the Kimmswick and earlier limestones below. In general, however, the Devonian is slightly more siliceous than the Silurian, for although a large part of the Devonian is very pure limestone or dolomite some zones are highly siliceous. Traces of anhydrite have been observed in the insoluble residues from samples of the basal Devonian deposits and occur sporadically in younger Devonian rocks, but no well-defined zone of anhydrite deposition has been identified.

In the outcrops of central and northeastern Missouri, the Devonian is less than 100 feet thick and consists entirely of limestone, much of which is lithographic. The limestone phase of the

Devonian prevails at the surface and westward in the subsurface in a belt flanking the Ozark region. In Clay and Platte counties, Missouri, near the Kansas line, about 200 feet of Devonian rocks is present, all of which is limestone. North of this area and of the area of outcrop in Missouri, the limestone is interstratified with bands of dolomite that are vaguely traceable from well to well and become thicker until they merge into a continuous section of dolomite more than 400 feet thick in the deeper parts of the North Kansas basin. Similar stratigraphic changes occur in Kansas except that the transition from limestone to dolomite toward the north and west is more abrupt than in Missouri.

Outcrops of the Devonian formation in northern Missouri and Iowa were visited by the writer accompanied by R. C. Moore and H. G. Hershey. More than 100 samples of Devonian rocks were collected. These samples and others from southeastern Missouri and their insoluble residues were studied in an attempt to correlate the surface rocks with samples of the subsurface rocks secured from wells.

The various formations into which Branson has divided the Devonian of northern Missouri, with the exception of the Cooper, have not been recognized as lithologic units in the subsurface of northeastern Kansas. The Snyder Creek shale was reported by McQueen in the subsurface in northwestern Missouri, but it has not been identified in northeastern Kansas. Although the subdivisions of the Devonian at the surface, other than the Cooper, have not been identified in wells in northeastern Kansas, some datum zones have been recognized by means of insoluble residues and microscopic study of samples.

The Cooper limestone is identified in the subsurface by its characteristic lithographic texture, its disseminated sand grains, and particularly by the sandy limestone member which is easily recognized in most wells at its base. The Cooper in its typical character has been traced by well cuttings from the outcrops into Clay and Platte counties in west-central Missouri and into adjoining areas in Kansas, but, although the base is well marked, its upper limit is indeterminable by lithology in the subsurface as well as in the outcrops.

The lithographic limestone phase of the Cooper predominates as far west as central Douglas county and as far north as southern Jefferson county. The Cooper limestone becomes dolomitic west and north of these limits and loses its typical lithology, although most of the dolomite, like the lithographic limestone, is densely crystalline. The Devonian dolomite which corresponds to the lithographic limestone is generally more sucrose and more dense than the Silurian dolomite which is composed largely of coarsely crystalline dolomites with many vugs lined with sparkling crystals of dolomite of the same grain as the rock. The change in texture provides a satisfactory point of separation where the Devonian and Silurian are thin, but the upper part of thick sections of the Silurian in some wells consists of alternating zones of dense and coarsely crystalline dolomite so that the contact cannot be determined on this basis alone.

The amount of sand in the basal beds of lithographic limestone and the corresponding dolomite is extremely variable. In some wells, such as the Landsprecht et al. No. 1 Griffin, in sec. 4, T. 14 S., R. 18 E., and the Ramsey Petroleum Company No. 1 Kaul, in sec. 2, T. 11 S., R. 11 E., the basal sand bed has so little cementing material that cuttings from the underlying rocks are contaminated by cavings. In other wells the sand is sparingly disseminated in limestone or dolomite and is revealed only by insoluble residues, although sand grains enclosed in limestone or dolomite are occasionally seen. The sandy character of the basal beds gradually fades out toward the west and north, and the base of the Devonian in those areas is difficult to determine and can be established only by other criteria. The amount of sand in the basal beds diminishes roughly in proportion to the distance from the pre-Devonian outcrops of St. Peter sandstone, from which it is presumed to have been derived, but the topography of the pre-Devonian surface may also have influenced the amount of sand deposited locally. Thus the basal lithographic Cooper limestone shows only small traces of disseminated sand in the McCain No. 1 Doane well, in sec. 34, T. 12 S., R. 22 E., and in the Dunn No. 1 Morgan well, in sec. 6, T. 13 S., R. 22 E., but the basal Cooper yielded over 50 percent sand in the Roxane No. 1 Fisher well in sec. 19, T. 11 S., R. 22 E., and the Ryan Consolidated No. 1 Laming well, in sec. 22, T. 11 S., R. 21 E., 6 miles farther from the pre-Devonian St. Peter outcrop.

The amount of sand, although irregularly distributed, decreases toward the north and west so that in parts of southeastern Nebraska and in Wabaunsee and Riley counties, Kansas, no sand is recovered in the residues except such as might be introduced by contamination from higher formations.

The quartzose chert zone is characterized by cryptocrystalline quartz, but it is quite varied in character and locally includes other types of siliceous residues. In samples from most localities the insoluble residue consists of gray to brown semiopaque rough cryptocrystalline chert. In some places this chert appears to be a final stage of quartz replacement, for residues grade from hackly quartz at the top of the zone to quartzose chert at the base. In some places the chert is associated in the residues with spongy dolocastic siltlike chert. The quartz content of the rocks is generally not apparent in the samples but is revealed in the insoluble residues. In counties around Kansas City in both Missouri and Kansas much smoothly fractured semiopaque gray chert occurs in this zone. Some of this chert is very dark and some is black. The quartzose chert zone is 5 to 30 feet thick and is 5 to 70 feet above the base of the Devonian. The amount of chert in this zone, as indicated by the insoluble residues, constitutes 5 to 65 percent by volume of the sample. The actual quantity of chert in the rocks, however, is probably not so great because of the partial loss of calcareous components in wells drilled by standard tools.

The quartzose chert zone has not been reported in the outcrops of central Missouri, so its relation to the Cooper and Callaway formations is uncertain. It may be that this zone contains relatively little chert in the areas of outcrop of the Cooper and Mineola and has thus escaped observation. This zone has been noted in wells in northwestern Missouri, where thicker sections of the Devonian occur than in the outcrops. The quartzose chert zone occurs with varying characteristics in nearly all wells in northeastern Kansas.

The interval between the top of the quartzose zone and the base of the Devonian increases irregularly down dip toward the center of the North Kansas basin. In wells in Johnson county, near the margin of the basin, the black and dark chert of this zone forms a part of the basal deposit. In Platte county, Missouri, the black chert which is a part of the quartzose chert zone is 25 feet above the base of the Devonian. In northern Buchanan county, Missouri, the black chert is 60 feet above the base. In Kansas a similar increase of this interval occurs, but the black chert is generally not present. The relations are interpreted as indicating more or less complete peneplanation of the pre-Devonian surface with differential subsidence of the peneplaned surface in the North Kansas basin during early Devonian deposition. Thus, the earliest Devonian deposit, the sandy zone, was laid down as a basal deposit transgressing toward the southeast (see fig. 7) with the quartzose chert zone converging on the sandy zone as the latter overlapped upon the sloping surface.

The quartzose zone is so widely distributed that it furnishes an approximate datum bed for determining the base of the Devonian when the basal sandy member is absent. Thus in the Coronado Oil Company No. 1 Parks well, in sec. 16, T. 10 S., R. 8 E., Riley county, a quartzose chert zone, with residues of dolocastic almost siltlike quartz sponge grading downward into quartzose chert, was reached at a depth of 1,480 feet. No sandy zone indicates the base of the Devonian in this well, but a change in the character of the dolomite from dense crystalline dolomite to porous sucrose dolomite with coarse vugs at 60 feet below the top of the quartzose zone is believed to indicate the base of the Devonian. The samples from the upper part of the Devonian in this well are contaminated by cavings of shale from the Pennsylvanian basal conglomerate. The sand in the insoluble residues is believed to have come from the same source and thus is not indicative of the base of the Devonian.

Neither the quartzose chert zone nor the basal sandy zone was satisfactorily identified in the Turner et al. No. 1 Umschied well, in sec. 32, T. 8 S., R. 9 E., Pottawatomie county. In this well there are several alternations from sucrose to dense crystalline dolomite above the foraminiferal zone of the Silurian so that the base of the Devonian remains in doubt. Sand is present in the residues to a depth of 1,385 feet, but it is associated with sandy clay which might have been derived from the Pennsylvanian basal conglomerate. No sand was found enclosed in the dolomite so for this reason, too, the evidence of sand in the residues is discounted.

Other lithologic zones yielding insoluble residues of porous and spongy quartz, hackly quartz, and various types of semiopaque chert and chalcedony have been observed, but it has not been possible to trace them from well to well. Traces of anhydrite and sphalerite have been noted in samples roughly 200 feet above the base of the Devonian. The erratic discontinuity of these zones of insoluble residues leads to speculation that one or several obscure unconformities may be present within the 300 or 400 feet of Devonian rocks represented in the subsurface of this area.

A well-defined zone, about 30 feet thick and about 300 feet above the base of the Devonian, was traced across northern Missouri in wells in the deeper parts of the basin near the Iowa border where the Devonian rocks are thick. This zone is characterized by insoluble residues of fine quartz crystals partially filling the cavities of what were probably incompletely preserved bryozoans. The crystals do not have a common orientation nor were they deposited in crusts or in drusy masses; they occur irregularly linked and partially joined together in loose viscera-like assemblages. This "bryozoan quartz" is accompanied by other siliceous residues, some of which are persistent and others are of only local development. Among the more common types is a dense gray finely microfossiliferous and spicular chert which is found in small amounts. A limestone outcrop of similar microfossiliferous chert was seen near the top of the Devonian outcrops in Ralls county, Missouri, but the position of the outcrop in the Devonian section there could not be determined. Microscopic flattened exfoliating cabbage-shaped pellets of blue-gray opaque chalcedony of possible foraminiferal origin occur also in the residues of some zones. None of the wells in northeastern Kansas encountered Devonian sections thick enough to include the zones containing these siliceous residues.

The thickness of the Devonian in Kansas is variable. It decreases toward the southeast and increases toward the North Kansas basin until it attains a thickness of at least 250 feet in Kansas. It is even thicker in southeastern Nebraska and extreme northwestern Missouri.

The Devonian rocks are separated from the overlying and underlying rocks by important angular unconformities. The Devonian rocks in the area of outcrop in northern Missouri were deposited unconformably upon Ordovician rocks. In parts of Franklin county, Kansas, the Devonian overlies the St. Peter sandstone and toward the northwest progressively transgresses rocks of Kimmswick, Maquoketa, and Silurian age (fig. 7).

The relations shown in figure 7 indicate that prior to the deposition of the Devonian in northeastern Kansas there was regional subsidence toward the northwest in east-central Nebraska and elevation toward the southeast where the Ozark area was rising. These tilted rocks were deeply eroded and beveled to a relatively perfect plain. The Devonian rocks were thus deposited across the beveled edges of the earlier rocks and probably extended originally toward the southeast far beyond the limits of their present distribution, perhaps covering part of the Ozark region.

The widespread distribution of the quartzose zone near the base of the Devonian and the convergence of this zone with the basal sandstone toward the rising area to the southeast suggests that there had been renewed subsidence in the North Kansas basin just before or during Devonian submergence. It is probable that the center of this basin was sinking faster than the margin and that other units of the Devonian are thicker in the center of the basin than on the margin. It is also probable that younger deposits of considerable thickness overlapped the marginal land toward the Ozarks but that these overlapping Devonian beds which are still preserved in the basin were removed from the margin during the pre-Chattanooga upheaval and peneplanation. It is believed, therefore, that most of the increased Devonian section of the subsurface is younger than the outcrops in central Missouri. Inasmuch as the Cooper has been correlated with some part of the Grand Tower limestone, it is inferred on purely stratigraphic grounds that most of the Devonian of the subsurface is of Grand Tower age or younger. The Devonian rocks in the subsurface of northeastern Kansas are, therefore, chiefly of Middle but perhaps in part of Upper Devonian age. One of several possible relations of the deposits north and south of the Chautauqua arch is shown in figure 8.

An unconformity separates the Devonian limestone from the overlying Chattanooga shale. At the end of deposition of the Devonian limestone and dolomite the region was again deformed along the same lines as those which preceded the deposition of the Devonian, that is flexing on the axis of the Chautauqua arch. The North Kansas basin again subsided and erosion proceeded to peneplanation, leaving the wedge-shaped edge of the Devonian rocks extending beyond and concealing the previously baseleveled surface of the Silurian rocks, the Maquoketa shale, the Kimmswick formation, in some places the St. Peter sandstone, and locally even the upper formations of the Arbuckle. The Chattanooga shale was deposited upon this peneplaned surface.

The Devonian rocks are a prolific source of oil in parts of central and western Kansas. Most of the oil produced in the southeastern Nebraska pools is from porous Devonian rocks. Many of the dry holes drilled into the Devonian in northeastern Kansas have revealed oil stains and shows of oil in the limestones and dolomites of the upper part of the Devonian, but the Devonian rocks encountered to date in northeastern Kansas have been uniformly dense and lack the porosity necessary to provide a reservoir for oil.

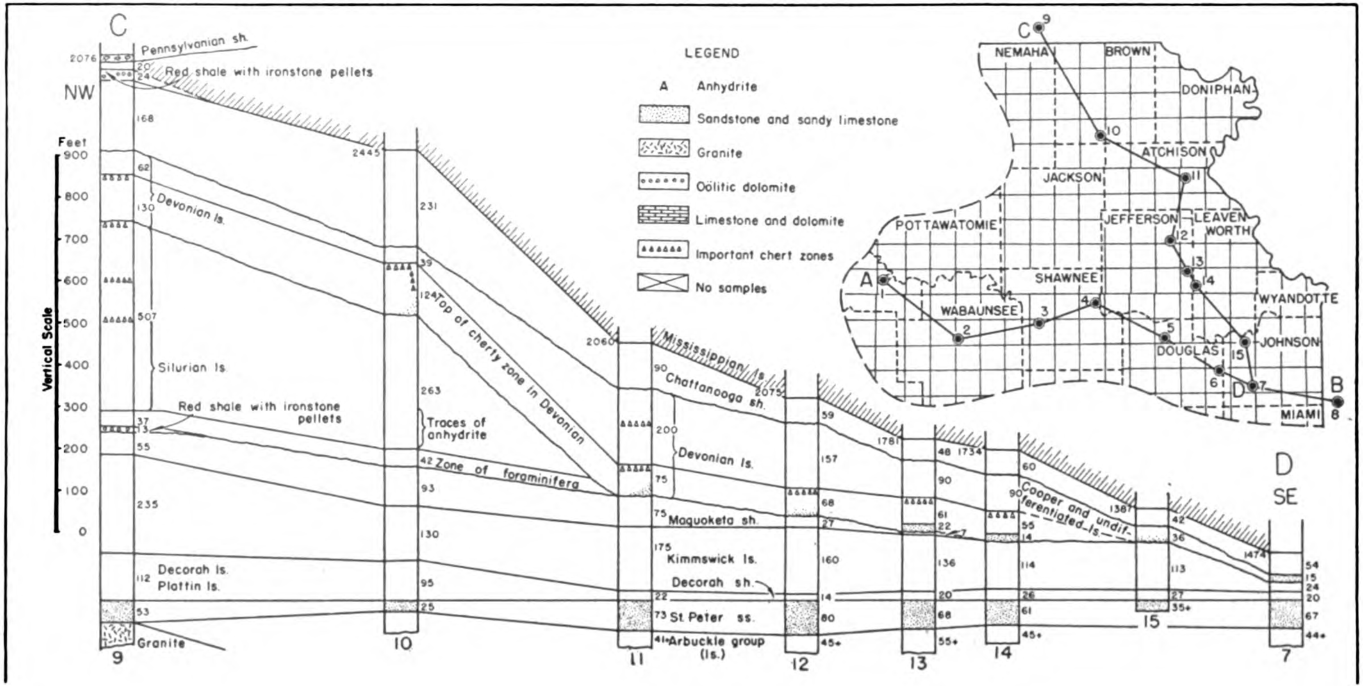
Because of the beveling of the Devonian rocks prior to Chattanooga time different parts of the Devonian sequence were exposed to weathering in different places (fig. 7). The lowest and oldest beds of the Devonian were exposed toward the southeast and progressively younger Devonian rocks were at the surface toward the northwest. The exposed edges were ultimately covered and sealed by the Chattanooga shale. Some of the beveled strata of the the Devonian were more susceptible to the development of porosity during pre-Chattanooga weathering than others. Such zones under favorable structural conditions may be expected to yield oil. It is obvious that wells reaching the Devonian at successive points toward the north would penetrate different zones of the Devonian, so a single test well under favorable structural conditions does not exhaust the possibilities or condemn the Devonian as a source for oil. Other Devonian beds that may warrant testing may be exposed on the pre-Chattanooga surface under other anticlines.

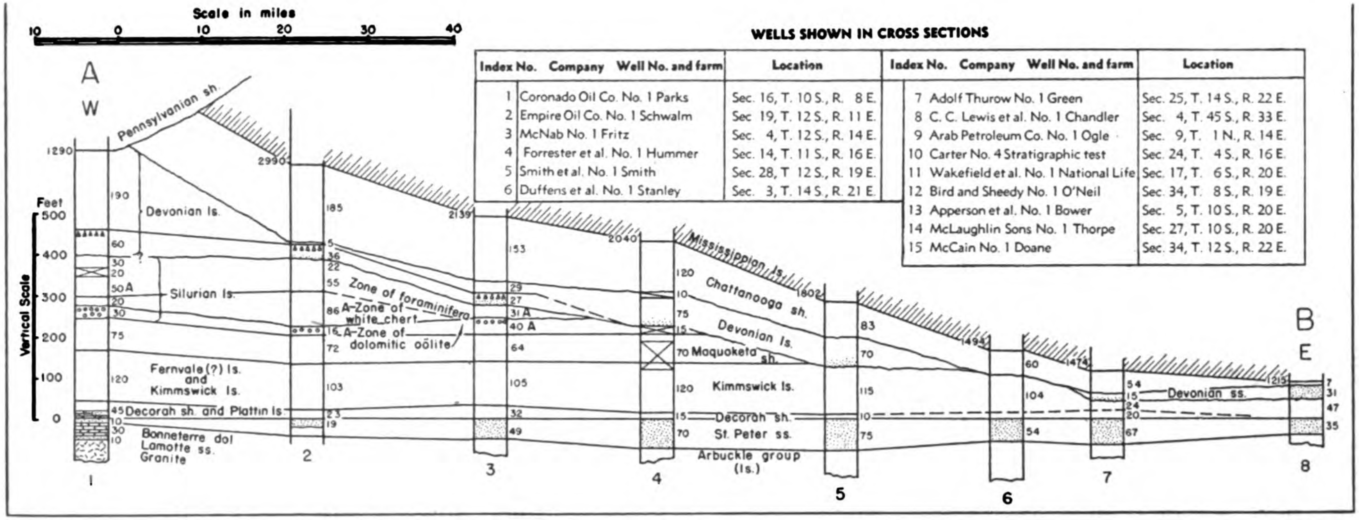
Rocks of Devonian or Mississippian Age

CHATTANOOGA SHALE

The Chattanooga shale is a black to gray fissile shale known by various names in outcrops from Tennessee, Alabama, and Georgia to the Mississippi valley and in the subsurface of Oklahoma, Kansas, and Iowa. There is evidence to indicate its Devonian age in some areas and its Mississippian age in others. Some geologists have concluded that it is in part Devonian and in part Carboniferous.

The outcrops of the Chattanooga shale nearest to northeastern Kansas are in southwestern Missouri and in northeastern Missouri. In both of these areas the formation is black to dark thinly laminated fissile shale, in part slightly silty and finely micaceous. Plant spores are present in both regions.


C
NW
SE
D
Pennsylvanian sh.
Red shale with ironstone pellets
Devonian ls.
Silurian ls.
Red shale with ironstone pellets
Decorah ls.
Plattin ls.
Granite
Top of cherty zone in Devonian
Traces of anhydrite
Zone of foraminifera
Mississippian ls.
Chattanooga sh.
Devonian ls.
Maquoketa sh.
Kimmswick ls.
Decorah sh.
St. Peter ss.
Arbuckle group (ls.)
Cooper and undifferentiated ls.
Feet
Vertical Scale
LEGEND
A Anhydrite
Sandstone and sandy limestone
Granite
Oölitic dolomite
Limestone and dolomite
Important chert zones
No samples
NEMAHA
BROWN
DONIPHAN
ATCHISON
JACKSON
POTTAWATOMIE
JEFFERSON
LEAVENWORTH
SHAWNEE
WABAUNSEE
WYANDOTTE
JOHNSON
DOUGLAS
MIAMI



WELLS SHOWN IN CROSS SECTIONS

Index No.	Company Well No. and farm	Location
1	Coronado Oil Co. No. 1 Parks	Sec. 16, T. 10 S., R. 8 E.
2	Empire Oil Co. No. 1 Schwalm	Sec 19, T. 12 S., R. 11 E.
3	McNab No. 1 Fritz	Sec. 4, T. 12 S., R. 14 E.
4	Forrester et al. No. 1 Hummer	Sec. 14, T. 11 S., R. 16 E.
5	Smith et al. No. 1 Smith	Sec. 28, T 12 S., R. 19 E.
6	Duffens et al. No. 1 Stanley	Sec. 3, T. 14 S., R. 21 E.
7	Adolf Thurow No. 1 Green	Sec. 25, T. 14 S., R. 22 E.
8	C. C. Lewis et al. No. 1 Chandler	Sec. 4, T. 45 S., R. 33 E.
9	Arab Petroleum Co. No. 1 Ogle	Sec. 9, T. 1 N., R. 14 E.
10	Carter No. 4 Stratigraphic test	Sec. 24, T. 4 S., R. 16 E.
11	Wakefield et al. No. 1 National Life	Sec. 17, T. 6 S., R. 20 E.
12	Bird and Sheedy No. 1 O'Neil	Sec. 34, T. 8 S., R. 19 E.
13	Apperson et al. No. 1 Bower	Sec. 5, T. 10 S., R. 20 E.
14	McLaughlin Sons No. 1 Thorpe	Sec. 27, T. 10 S., R. 20 E.
15	McCain No. 1 Doane	Sec. 34, T. 12 S., R. 22 E.

Fig. 7. Cross sections showing unconformities at the base of the Devonian limestone and at the base of the Chattanooga shale, on lines A-B and C-D of inset map. The cross sections are correlated on the top of the St. Peter sandstone. The relations shown at the top of the Silurian were produced by a regional tilting toward the northwest after Silurian deposition and by subsequent erosional beveling. The Devonian rocks were deposited upon this surface. The region was again tilted in the same direction after Devonian time and again peneplaned. This was followed by deposition of Chattanooga shale.

Figures at left of wells at top show depth in feet below the surface. Figures at right of well show thickness in feet of lithologic units.

In northeastern Missouri, the Chattanooga shale, 3 to 60 feet thick, is known as the Grassy Creek shale. It is overlain, in ascending order, by the Louisiana limestone, the Hannibal shale, and the Chouteau limestone (Grohskopf, Hinchey, and Greene, 1939, p. 14). The Louisiana limestone and the Hannibal shale crop out only in northeastern Missouri where they lie on the eastern side of a northerly trending structural arch.

The Hannibal shale overlaps the Louisiana limestone toward the west and comes in contact with the Grassy Creek shale in the subsurface. The overlap suggests an unconformity between the Grassy Creek and the overlying Louisiana or between the Louisiana and the Hannibal. Both the Grassy Creek and Hannibal are cut off farther west by the Chouteau limestone of early Mississippian age which overlies the Devonian limestone on the Northeast Missouri structural arch. Where older beds come in again beneath the Chouteau west of the arch, in northwestern Missouri, the Grassy Creek appears unaccompanied by either Hannibal or Louisiana. Condra and Reed (1943, p. 60) report the presence of Hannibal shale unconformably overlying Grassy Creek shale farther down the flank of the arch toward the northwest in southeastern Nebraska. The Grassy Creek shale can be traced in the subsurface west of the Northeast Missouri arch around the north and west flank of the Ozarks to the outcrops of Chattanooga shale in southwestern Missouri. The Chattanooga shale of the outcrops in southwestern Missouri is overlain, in ascending order, by the Compton limestone and the Northview shale (correlatives of the Chouteau limestone of Mississippian age).

The Chattanooga shale of southwestern Missouri can be traced in the subsurface from the outcrops into the Forest City basin. It becomes thicker toward the north and changes from black and dark gray to gray and gray-green. In northeastern Kansas, the lower 15 to 20 feet is generally darker than the upper part and in some localities is black, but black shales are present at the top in some places. Plant spores are abundant in the lower dark phases of the formation but are very sparsely distributed on the thick upper gray shales. In a few wells in northeastern Kansas a zone of red weathered shale occurs at the top of the Chattanooga shale (Lee, 1940, pl. 8).

In the central part of the North Kansas basin the Chattanooga shale has a thickness of more than 250 feet, but it is less than 50 feet thick in that part of the Forest City basin bordering the Ozark uplift toward which it wedges out.

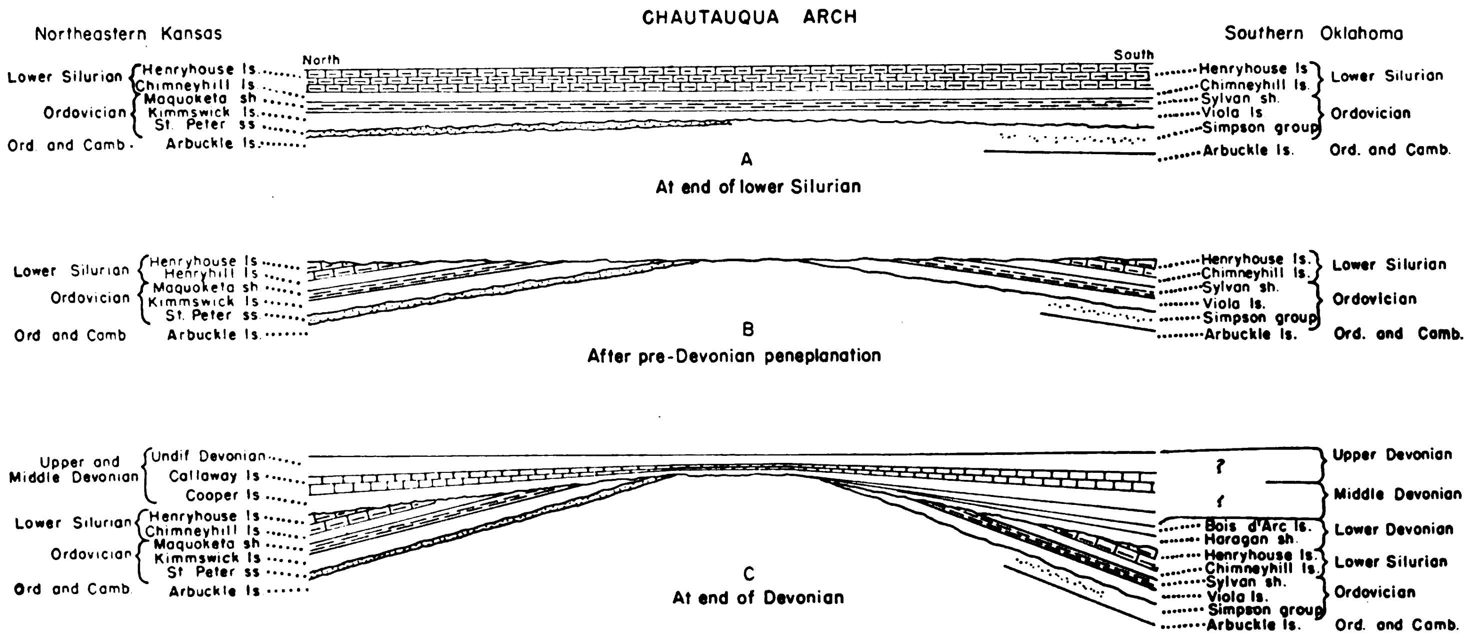
From the standpoint of diastrophism, the base of the Chattanooga marks one of the most important unconformities in this region. In the Paleozoic history of this area the pre-Chattanooga unconformity is exceeded or rivaled in amount of deformation and thickness of rocks removed only by the unconformity at the base of the St. Peter and by that at the base of the Devonian. The Chattanooga shale is overlain unconformably in northeastern Kansas east of the Nemaha ridge anticline by the Chouteau limestone of Kinderhookian age. West of the ridge its weathered surface is overlain by noncherty dolomite of upper Chouteau age.

In northwestern Missouri and southeastern Nebraska a zone of red shale with hematitic flaxseed oölites is reported below the top of the shale section heretofore regarded as of Chattanooga age. The weathered shale noted at the top of the Chattanooga in some northeastern Kansas wells (Lee, 1940, pl. 8) may represent a corresponding period of weathering. Condra and Reed (1943, p. 60) refer the shale above this weathered zone to the Hannibal shale and the shale below it to the Sheffield shale of Iowa which they regard as possibly the equivalent of the Grassy Creek.

The wells in northeastern Kansas do not contribute much direct evidence bearing on the separation of the Hannibal shale from the Chattanooga shale and the possible occurrence in Nebraska of the Louisiana limestone, as suggested by Condra and Reed (1943, p. 62). A series of thickness maps for northeastern Kansas reveals that the Ozark area of Missouri was flanked on the north and northwest by a structural depression that had been slowly deepening from St. Peter through Kinderhookian time. It would be consistent with the structural history revealed by the thickness maps if a correlative of the Hannibal shale or even the Louisiana limestone had been deposited unconformably upon the Chattanooga in the deeper part of the basin in southeastern Nebraska and southwestern Iowa under conditions similar to those in northeastern Missouri.

Rocks of Mississippian Age

The Mississippian rocks are exposed at the surface in wide areas in the Mississippi valley in Missouri and Illinois and extend


CHAUTAUQUA ARCH
Northeastern Kansas
Southern Oklahoma
North
South
Lower Silurian
Henryhouse ls
Chimneyhill ls
Ordovician
Maquoketa sh
Kimmswick ls
St. Peter ss
Ord. and Camb.
Arbuckle ls.
Henryhouse ls
Chimneyhill ls.
Sylvan sh.
Viola ls
Simpson group
A
At end of lower Silurian
Henryhill ls
B
After pre-Devonian peneplanation
Upper and Middle Devonian
Undif Devonian
Callaway ls
Cooper ls
Upper Devonian
Middle Devonian
Lower Devonian
Bois d'Arc ls.
Haragan sh.
C
At end of Devonian

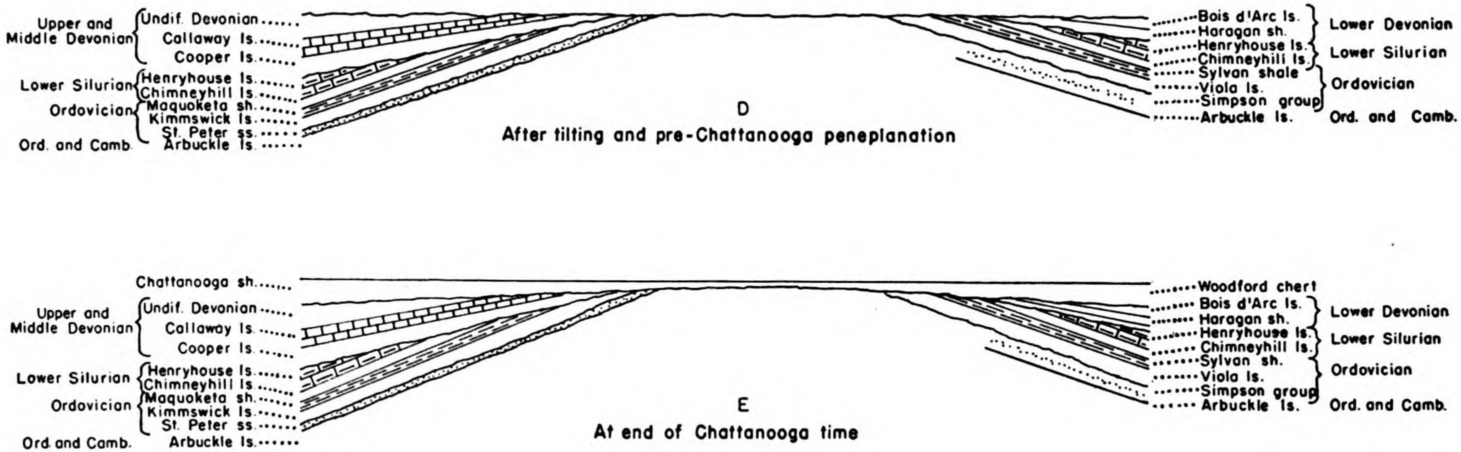


Fig 8. Diagrammatic cross sections showing evolution of Chautauqua arch and the relation of Lower Devonian rocks in southern Oklahoma and adjacent areas to Middle Devonian rocks of northeastern Kansas and adjacent areas.

Cross section A represents initial movement of Chautauqua arch between end of St. Peter time and end of Maquoketa time (see fig. 11). Cross section B represents pre-Devonian peneplanation of deformed Silurian and older rocks. Cross section C represents deformation during deposition of Devonian rocks. The earliest Devonian rocks of Oklahoma are older than those in northeastern Kansas. Cross section D represents increased deformation of the Chautauqua arch, tilting of the region toward the north, and pre-Chattanooga peneplanation. Cross section E represents renewed movement on Chautauqua arch before or during deposition of Chattanooga shale and shows the relations of older rocks to the Chautauqua arch at the end of Chattanooga deposition. The relation of the St. Peter sandstone on the north side of the Chautauqua arch to the Simpson group on the south side of the arch is uncertain. The former occurrence of Upper and Middle Devonian rocks in Oklahoma is assumed. The occurrence of a correlative of the Henryhouse limestone in the deeper parts of the North Kansas basin has not yet been proved.

westward hundreds of miles in the subsurface of Kansas and adjoining states.

The Mississippian limestones represented in northeastern Kansas consist of the following formations, listed in descending order.

Meramecian series
- Ste. Genevieve limestone
- St. Louis limestone
- Spergen limestone
- Warsaw limestone

Unconformity

Osagian series
- Keokuk and Burlington limestones (undifferentiated)

Unconformity

Kinderhookian series
- Gilmore City limestone

Unconformity

- Chouteau limestone

Unconformity

Rocks of Devonian or Mississippian age
- Chattanooga shale

Unconformity

KINDERHOOKIAN SERIES

Chouteau limestone

The outcrops of Chouteau limestone nearest to northeastern Kansas are in Pettis county, Missouri, on the southeastern side of the Forest City basin. This county includes the type locality of the Chouteau named by Swallow in 1855. Swallow recognized upper and lower members of the Chouteau. Moore (1928, p. 149) restricted the name Chouteau to the lower member because he found the upper member, which he termed Sedalia, to be lithologically and faunally different from the lower member. He correlated the upper member of the outcrops, which is a cherty dolomite, with some part of the Fern Glen limestone (of early Osagian age).

The Chouteau restricted, or lower Chouteau, consists of light bluish-gray to dark-drab compact earthy to silty impure limestone banded with dull-gray chert nodules 1 to 4 inches thick. In the outcrops its thickness ranges from 20 to 55 feet. The correlatives of the lower Chouteau in southeastern Kansas and southwestern Missouri are the Northview shale and the underlying relatively pure semigranular Compton limestone.

Three members of the Chouteau are recognized in the subsurface of northeastern Kansas: a relatively pure semigranular limestone at the base that corresponds to the Compton limestone of southeastern Kansas, an impure very cherty sucrose gray dolomite in the middle that corresponds to the Northview shale, and a brown to buff sucrose dolomite containing only small amounts of chert at the top. The uppermost member may correspond to one of the lithologically similar formations of the upper part of the Hampton formation of Iowa, or to the original upper Chouteau of Swallow.

The Compton limestone maintains its identity at the base of the Chouteau, but its upper limit is transitional and in areas of the Chouteau limestone is not sharply separable. The Compton is 25 to 40 feet thick in most wells in northeastern Kansas but locally, as in part of Franklin county, it is less than 10 feet thick and it wedges out near the Oklahoma border.

The middle or cherty member of the Chouteau limestone is generally impure and grades southward into the Northview shale. The amount of chert is somewhat exaggerated in the samples of wells drilled by standard tools. The chert is commonly 50 to 95 percent of the volume but the same zones represented by rotary samples have a maximum of only 25 percent chert. This member of the Chouteau varies much in thickness. It is 10 to 20 feet thick in the belt bordering the Nemaha anticline on the east, but in counties in Kansas bordering the Missouri river its thickness increases to 75 or 80 feet. There is considerable variety in the character of the chert. Some is dull gray and mealy in texture and some breaks with conchoidal fracture and shows a stippled pattern. Most of the chert, however, has unique characteristics and is easily identified.

The uppermost member of the Chouteau is buff to brown sucrose dolomite. It has very small amounts of insoluble residue and in many localities is noncherty to sparsely cherty. Even in wells where it includes 5 to 10 percent chert it contrasts sharply with the underlying very cherty middle member. This member occupies the same position as the Sedalia limestone of the outcrops in Pettis county, Missouri, but the Sedalia is reported to be conspicuously cherty and is of Fern Glen (Osagian) age. This member was described in an earlier report (Lee, 1940, p. 37) as equivalent to the Sedalia limestone with which it has been correlated in northwestern Missouri. The rocks of this member, however, are conspicuous because of their lack of chert and are overlain in the subsurface by the Gilmore City limestone of Kinderhookian age. These considerations seem to prevent this member from being correlated with the Sedalia limestone which is accepted as of Osagian age in northeastern Missouri. The uppermost member of the Chouteau is more regular in thickness than the other members of the Chouteau and is more widely distributed toward the west. It is the oldest Mississippian limestone west of the Nemaha anticline where it averages about 10 feet in thickness but ultimately it wedges out toward the west upon the red, weathered surface of the Chattanooga shale. Toward the east its thickness increases to 30 feet near the Missouri river. East of the Nemaha anticline it overlies the middle member of the Chouteau which is absent west of the anticline.

The combined thickness of the three members of the Chouteau is 53 feet just east of the Nemaha anticline, but it increases to 141 feet in Johnson county (Lee, 1940, cross section D-C, pl. 6). The Chouteau becomes thinner again toward the outcrops in Missouri where its upper member appears in the stratigraphic position of the Sedalia.

The absence of the Hannibal shale and the Louisiana limestone between the Chouteau and Chattanooga formations in northeastern Kansas indicates unconformable relations between these formations. Unconformable relations occur also at the top of the Chouteau limestone, for there are many places where the uppermost member of the Chouteau is thin or absent. In some wells the upper member is replaced by or is overlain by the Gilmore City formation implying an unconformity between the Chouteau and the Gilmore City. In other wells the Chouteau is overlain unconformably by rocks of undifferentiated Burlington and Keokuk limestones in contact with either the upper or middle member of the Chouteau.

Gilmore City limestone

The only known outcrops of the Gilmore City limestone are in north-central Iowa on the northeastern margin of the Forest

City basin. The fauna of these rocks was studied by Laudon (1933) who reported them to be of late Kinderhookian age. The limestones are characterized lithologically by oölitic beds in parts of the formation. According to Laudon, the Gilmore City limestone thickens into a basin trending toward the southwest in southeastern Iowa. The distribution of the limestone suggests that its area of deposition was related to deformation of the North Kansas basin. Its maximum thickness, as reported in the subsurface by Laudon, exceeds 250 feet.

Limestone above the Chouteau in northeastern Kansas, which is believed to represent the Gilmore City, has been described by Lee (1940, p. 40). It is semigranular, ordinarily slightly buff or yellowish-gray, noncherty or only slightly cherty, and includes many crinoid stems and shell fragments. The matrix is opaque and so soft that most of the cuttings are lost in washing. Oölites in the limestone are irregular in size and form. Some of the oölites are black or have black cores.

The maximum known thickness of the Gilmore City limestone in north-central Kansas is 76 feet in Cloud county. It is 45 feet thick in southern Jackson county. A recent well, the Duffens et al. No. 1 Stanley, in sec. 3, T. 14 S., R. 21 E., revealed the presence of 15 feet of Gilmore City limestone in east-central Douglas county which extends the known area of deposition about 45 miles to the southeast.

Considerable new information concerning the stratigraphic relations of the Gilmore City limestone has been secured since the publication of the report on the subsurface Mississippian rocks of Kansas (Lee, 1940). The theories expressed therein regarding the relations of the Gilmore City and the underlying rocks have been confirmed by more recent drilling. Several wells now show oölitic Gilmore City limestone overlying the Chouteau, and also in several wells the Gilmore City has been found replacing the eroded top member of the Chouteau in the position of the Sedalia limestone. The Gilmore City is overlain by limestone of undifferentiated Burlington and Keokuk age. In some wells the Gilmore City has been eroded and its position is occupied by the Burlington-Keokuk sequence. The Duffens et al. No. 1 Stanley well revealed the Gilmore City limestone replacing the eroded top member of the Chouteau. Similar relations occur in the McCain No. 1 Doane well, in sec. 34, T. 12 S., R. 22 E., but the Dunn

No. 1 Morgan well, in sec. 6, T. 13 S., R. 22 E., 3 miles distant, showed the Burlington-Keokuk sequence resting on middle Chouteau, both the Gilmore City and the top member of the Chouteau being absent.

A normal sequence of the Gilmore City limestone overlying the uppermost Chouteau member occurs in McLaughlin Sons No. 1 Thorpe well, in sec. 27, T. 10 S., R. 20 E., Continental et al. No. 1 Berridge well, in sec. 8, T. 9 S., R. 17 E., and Bird and Sheedy No. 1 O'Neill well, in sec. 34, T. 8 S., R. 19 E. From these relations, it is evident that the Gilmore City is unconformable upon the underlying Chouteau and also that it is separated from the overlying undifferentiated Burlington and Keokuk by an unconformity.

OSAGIAN SERIES

Rocks of Fern Glen age, including the St. Joe limestone and the Reeds Spring limestone which crop out in southwestern Missouri, were not generally deposited in northeastern Kansas, although thin overlapping wedges of rocks of upper Fern Glen age may be present beneath the Burlington in some places in the southern part of the synclinal belt east of the Nemaha anticline.

Burlington and Keokuk limestones (undifferentiated)

The Burlington and Keokuk limestones are widely distributed throughout the interior of North America at the surface and in the subsurface. Their type localities are in southeastern Iowa, where these formations consist of cherty limestone and dolomite. They are distinguishable lithologically and faunally at the type locality, but the lithologic characteristics are not persistent enough to serve as a safe guide in differentiating the Burlington and Keokuk at distant points. They have not as yet been satisfactorily identified in the subsurface, although some local lithologic criteria seem to furnish basis for differentiation.

The Burlington-Keokuk sequence in the subsurface of northeastern Kansas consists of two dissimilar members. The lower part of the Burlington-Keokuk sequence is a very cherty sucrose dolomite. Some of the samples consist almost entirely of chert, but there has been some concentration of chert and loss of dolomite in drilling. The chert is opaque or semiopaque and gray or white. Much of it breaks with a smooth fracture but some is dull and breaks with a rough surface. Drusy quartz and splintered fragments of quartz crystals are common constituents of the insoluble residues. The lower 10 to 30 feet in Douglas, Franklin, and Johnson counties consists of limestone nearly free from chert. This may represent the northern edge of rocks of Fern Glen age which are thick in southeastern Kansas but wedge out toward the north, or the change to limestone may be merely another example, as yet unexplained, of local transition from limestone to dolomite or dolomite to limestone that is common in some formations of the Mississippian.

The top of the lower member is porous and most wells fill with water from this contact zone. In the McLouth pool, wells drilled to this porous zone yield oil on the crest of the anticline. An unconformity is suspected at this contact. Some wells find the top of this zone to consist of nearly 100 percent chert. Other wells reach the zone of maximum chert content lower in the formation. The lower member of the Burlington-Keokuk sequence has a thickness of 50 to 90 feet, a variation, if it were local, that might be regarded as an indication of unconformity between the upper and lower members.

The upper member is composed predominantly of semigranular limestone with chert amounting in some samples to 50 percent of the volume. The chert is somewhat irregularly distributed both vertically and horizontally. Some noncherty zones can be traced short distances. The limestones are fossiliferous and crinoidal. A few widely disseminated grains of glauconite are found in some samples. The matrix of some zones, 5 to 15 feet thick, consists of sucrose dolomite cementing fragments of broken fossils. Such fragments are subordinate to the dolomite in some wells or may be entirely absent. These dolomite zones, like the zones free of chert, are persistent in some localities and locally serve as convenient reference markers.

Some of the chert breaks with a conchoidal fracture and some with rough fracture. The chert may be stippled or grainy, opaque or semiopaque, particularly near the top of the formation where it contrasts with the opaque microfossiliferous chert of the overlying Warsaw limestone. In some areas, notably in the McLouth pool, the lower part of the upper member contains a large amount of microfossiliferous and spicular chert which in some respects is similar to that in the Warsaw limestone. It is, however, distinguishable from the Warsaw chert which is opaque by the semi-translucent to vitreous character of the microfossils. This type of chert is sparsely present near the base of the upper member of the undifferentiated Burlington and Keokuk in the Kasper No. 1 James well, in sec. 8, T. 13 S., R. 25 E., but in the McLouth field and adjacent areas it occurs throughout the middle and lower parts of this member. It disappears toward the west and has not been observed in the residues of samples of wells from other parts of Kansas.

Some tripolitic chert occurs in the upper part of the Burlington-Keokuk sequence but it is less common than it is in the rocks of southeastern Kansas which are tentatively correlated with the Keokuk. Some irregularly distributed drusy quartz in sparse amount has been noted in the insoluble residues.

In one well, the Duffens et al. No. 1 Stanley, in sec. 3, T. 14 S., R. 21 E., a bed of noncherty oölitic and semigranular limestone lies a few feet below the top of the Burlington-Keokuk unit. This bed is 284 feet above the top of the Chattanooga shale and may represent the Short Creek oölite noted in the upper part of the Keokuk in a number of wells in southeastern and central Kansas (Lee, 1940, p. 61) where the interval down to the Chattanooga east of the Nemaha anticline is 250 feet.

The top of the undifferentiated Burlington and Keokuk limestones in the McLouth field has been placed at the top of a bed of sucrose dolomite, 5 to 20 feet thick, immediately underlying the Warsaw limestone with its characteristic microfossiliferous chert. The insoluble residues of this dolomite consist of spongy crumbs of interlocking spicules accompanied by only minor amounts of chert. This spicular sponge is of a type common in residues of the Spergen dolomite above the Warsaw limestone. Possibly this bed of dolomite should be excluded from the Burlington-Keokuk sequence and considered as the basal member of the Warsaw limestone. Its inclusion in the Burlington-Keokuk sequence is arbitrary, but provides a sharp contact at the base of the Warsaw. The dolomite bed has not been recognized outside the McLouth field.

The thickness of the upper member of the Burlington-Keokuk sequence varies from 55 to 90 feet. Its greatest thickness is in Jefferson, Douglas, and Johnson counties. Toward the west this member is cut off by post-Mississippian erosion.

The combined thickness of the undifferentiated Burlington and Keokuk limestones where they are overlain by Warsaw limestone varies from 135 feet to 170 feet. The thickness decreases irregularly toward the north. The upper part of the Mississippian rocks was beveled by post-Mississippian peneplanation toward the Nemaha anticline, and on its flank the upper part of the Burlington-Keokuk sequence along with all the younger Mississippian limestones was eroded (fig. 16).

The Burlington-Keokuk unit is underlain unconformably by the Gilmore City limestone or the Chouteau limestone. West of the Nemaha ridge the Burlington-Keokuk overlies the Chattanooga shale in some places. The St. Joe and Reeds Spring limestones which normally intervene between the Burlington-Keokuk unit and the Chouteau in southeastern Kansas are generally absent in northern Kansas where they are overlapped toward the north by the Burlington and Keokuk limestones. The rocks of Burlington and Keokuk age are unconformably overlain by rocks referred to the Warsaw in southeastern Kansas. They overlie the Burlington and Keokuk also in northeastern Kansas but in this area the unconformable relations are not obvious.

MERAMECIAN SERIES

Warsaw limestone

The Warsaw limestone at its type locality near Warsaw, Illinois, across the Mississippi river from northeastern Missouri, consists of fossiliferous earthy limestone and blue marl. In the subsurface it loses its characteristic lithology and consists of cherty limestone and dolomite. In southwestern Missouri, the Warsaw has been identified by the Missouri Geological Survey in the Carthage quarries and in other outcrops. This limestone is characterized by a somewhat unique chert enclosing the silicified remains of a great number of microfossils and spicules. It has been traced in the cuttings of wells into the Forest City basin.

The rocks in northeastern Kansas which correspond to the Warsaw of southwestern Missouri and southeastern Kansas consist of semigranular cherty limestone in most wells. In Douglas county and western Johnson county, however, the Warsaw consists chiefly of cherty sucrose dolomite in some places interstratified with semigranular limestone or with broken shell fragments in a dolomite matrix.

The chert is opaque and crowded with masses of microfossils whether the rock itself is limestone or dolomite. Some of the beds contain chert with masses of coarser but still microscopic fossils among which minute crinoid joints and minute fragments of broken shells are recognizable. In the McLouth area the Warsaw overlies a zone of sucrose dolomite, 5 to 20 feet thick, with spongy residues of spicules. This dolomite zone is not present in other areas where the contact is determined by the change in the character of the chert from microfossiliferous to massive or grainy and stippled.

The Warsaw has a thickness in northeastern Kansas of 30 to 40 feet, although it is thinner in some wells and has an abnormal thickness of 75 feet in the Kasper No. 1 James well, in sec. 8, T. 13 S., R. 25 E.

The Warsaw is unconformable above the Burlington-Keokuk sequence but it appears to be conformable beneath the overlying silty dolomite called Spergen in this report. The interval from the top of the Warsaw to the top of the porous dolomite that yields oil in the undifferentiated Burlington and Keokuk ranges from 125 to 128 feet in the McLouth gas field. Elsewhere the interval is generally greater, amounting to 140 to 160 feet in some areas and up to 220 feet in the Kasper James well where the Warsaw is abnormally thick. Like other intervals in the Mississippian, this interval thins toward the north, and it is only 29 feet thick in sec. 31, T. 3 S., R. 20 E. Nevertheless, the top of the Warsaw is locally a reasonably reliable datum bed from which to measure the interval to the oil-producing zone of porous dolomite.

Spergen limestone

This limestone, named for outcrops at Spergen Hill in Indiana, is widely distributed in southern Indiana, Illinois, and adjoining states. It is the Bedford limestone of Indiana where it is known also as the Salem limestone. It is reported by Ulrich (1905, pp. 28-30) to consist generally of light to dark oölitic limestone with interbedded limestone of various kinds and thin seams of yellowish shale. Weller and St. Clair (1928, p. 204) describe as follows the varied lithologic features of the Spergen in eastern Missouri and Iowa:

In the north it is for the most part an impure limestone in places arenaceous and very commonly magnesian. To the south it becomes more and more a pure limestone until the impure magnesian beds have almost or quite disappeared in Ste. Genevieve county.

A zone of somewhat variable rocks overlying the Warsaw in northeastern Kansas is believed to represent the Spergen limestone. These rocks contain only small amounts of chert or none at all in contrast to the Warsaw rocks which are conspicuously cherty. In some wells, as the Kasper No. 1 James well in Johnson county, the entire section of 50 feet consists of semigranular limestone.

In most of the area of northeastern Kansas where the Spergen limestone has been preserved it consists chiefly of silty buff to gray, finely sucrose dolomite. In a few wells the dolomite has a greenish cast and contains enough silt to remain slightly coherent after the solution of the dolomite. The silty nature of the dolomite is ordinarily not apparent, however, without treating the dolomite with acid. The dolomite in some wells is interstratified with semigranular limestone.

Some of the Spergen samples of both limestone and dolomite have small amounts of chert which resembles the microfossiliferous chert of the Warsaw. Insoluble residues of some samples show molds of microfossils in the chert, the chert having replaced the matrix but not the calcareous material of the organisms. Another not infrequent characteristic of the residues of the Spergen limestone is the occurrence of white, pink, or salmon-colored chalcedonic chert occasionally recognizable as secondary crusts. This material may be the expression of post-Spergen exposure and weathering, for the same type of chert is occasionally encountered in the Warsaw limestone where the Spergen limestone has been eroded. Spongy masses of siliceous spicules are common in the insoluble residues.

The foraminifer *Endothyra baileyi* is an important fossil in the outcrops of the Spergen. This fossil has been noted not only in the limestone phase of the Spergen in the Kasper No. 1 James well but also in limestone interstratified with silty dolomite in the McCain No. 1 Doane well, in sec. 34, T. 12 S., R. 22 E., and in many of the wells in the McLouth field.

The thickness of the Spergen limestone in northeastern Kansas is fairly constant at about 35 feet although variations in thickness occur. It is 50 feet thick in the Kasper No. 1 James well and 47 feet thick in the Plymouth and Barnholdt No. 1 Elliot well, in sec. 31, T. 3 S., R. 20 E. In the McLaughlin No. 1 Frazier well, in sec. 22, T. 9 S., R. 18 E., where the Spergen is overlain by the St. Louis limestone, it is less than 15 feet thick. It is only 29 feet thick in the Cohen No. 1 Decker well, in sec. 12, T. 8 S., R. 20 E.

The Spergen limestone overlies the Warsaw limestone conformably so far as known. It may be unconformable below the St. Louis, but the variations in thickness encountered in certain areas may be the expression of transitional deposition from the Spergen to the St. Louis.

St. Louis limestone

The type locality of the St. Louis limestone is within the city of St. Louis. The outcrops nearest to northeastern Kansas are in east-central Iowa and in southwestern Missouri. In southwestern Missouri the St. Louis limestone has been preserved in a faulted block in Dade county (Clark, 1937, p. 8), where lithographic limestone is interstratified with fossiliferous limestone. Some beds are oölitic. The St. Louis limestone in Ste. Genevieve county in southeastern Missouri is a compact dense limestone of lithographic to sublithographic texture. Locally some beds are dolomitic.

The St. Louis limestone underlies a relatively small area of northeastern Kansas in counties near or bordering the Missouri river. It consists of lithographic to sublithographic limestone interstratified with semigranular limestone. In some localities it includes beds of oölitic limestone.

Pre-Pennsylvanian erosion removed the top of the St. Louis and the overlying Mississippian rocks in most areas of northeastern Kansas. The St. Louis limestone where it is overlain by the Ste. Genevieve limestone has been drilled in only two wells in northeastern Kansas. In one of these, the Plymouth and Barnholdt No. 1 Elliot well, in sec. 31, T. 3 S., R. 20 E., its thickness is 44 feet. In the other, the Wakefield et al. No. 1 National Life, in sec. 17, T. 6 S., R. 20 E., the thickness is 33 feet. Greater thicknesses of the St. Louis, however, have been noted in several wells in which the Ste. Genevieve has not been recognized. In the Kasper No. 1 James well, the St. Louis is 50 feet thick and in the Cohen No. 1 Decker well, in sec. 12, T. 8 S., R. 20 E., it is 49 feet thick.

In both these wells the St. Louis is overlain unconformably by Pennsylvanian rocks.

The St. Louis limestone was once more widely distributed than at present. In northeastern Kansas it survived post-Mississippian erosion only in the post-Mississippian syncline along Missouri river northwest of Kansas City, as revealed by the Mississippian thickness map (fig. 16). In this area it is generally unconformable below Pennsylvanian rocks, but in the deepest part of the syncline the St. Louis is overlain by Ste. Genevieve limestone. Weller and St. Clair (1928, p. 214) observed slight unconformity in southeastern Missouri between the Ste. Genevieve and the St. Louis, but it is impossible to confirm this relation in the subsurface in Kansas. The presence of traces of sand in the overlying Ste. Genevieve limestone and the variable thickness of the St. Louis limestone suggest that the formations are unconformable. The St. Louis is probably conformable upon the underlying Spergen.

Ste. Genevieve limestone

Outcrops of the Ste. Genevieve limestone are found in eastern Missouri, southern Illinois, and in parts of adjoining states. This formation was named for Ste. Genevieve, Missouri, where outcrops of the formation were first described. It is reported in the subsurface from such widely separated areas as Scott county in western Kansas and central Illinois. Post-Mississippian erosion removed the Ste. Genevieve from much of the intervening region. It has survived locally only where synclinal structural conditions have favored its preservation. In Ste. Genevieve county, Missouri (Weller and St. Clair, 1928, p. 217), the Ste. Genevieve limestone exhibits considerable diversity. The lower 60 feet of the formation consists mainly of cross-bedded oölitic and sandy limestones locally interbedded with crystalline limestone. The oölite and the sand grains, however, are thinly disseminated in most of the beds. The lower part is free of chert but the upper parts of the formation, which consist of evenly bedded limestones, have a great deal of chert in discontinuous lentils.

The Ste. Genevieve limestone has been identified in only two wells in northeastern Kansas—the Plymouth and Barnholdt No. 1 Elliot and the Wakefield et al. No. 1 National Life, whose locations have already been given. The limestone is gray to white in color and finely granular to mealy in texture. It includes 10 to 20 percent of fine grains of broken angular quartz sand but no chert. In the Plymouth and Barnholdt well a thin band of slightly oölitic sandy limestone occurs at the base. In the Wakefield et al. No. 1 National Life well, the limestone is overlain by about 20 feet of coarse subangular calcareous sand that is probably of Ste. Genevieve age but may be of Chesterian or basal Cherokee age. Only a part of the Ste. Genevieve is preserved in northeastern Kansas. In the Elliot well the Ste. Genevieve is 30 feet thick; in the National Life well it is 28 feet thick.

Inasmuch as unconformable relations have been observed between the Ste. Genevieve limestone and the St. Louis limestone at the outcrops in Ste. Genevieve county, Missouri, similar relations probably exist in the subsurface in northeastern Kansas, although the evidence is inconclusive. Great areas of the Ste. Genevieve were undoubtedly stripped from the surface during post-Mississippian erosion and the small surviving remnants were covered by Cherokee shale, the oldest of the Pennsylvanian rocks of Kansas.

POST-MISSISSIPPIAN CAVE DEPOSITS

Deposits closely associated with the younger Mississippian rocks but almost certainly of post-Mississippian age have been encountered in a number of wells in and near the McLouth gas field. These deposits consist chiefly of slightly silty and micaceous black shale. Some samples are distinctly silty and include a few grains of sand. Some samples enclose fine particles of green shale thinly disseminated in the black shale. Some of the black shale displays rough irregularly shaped microscopic white siliceous aggregates cementing the constituents of the shale. Much of the shale is well laminated but clastic deposits with grains of older shale are common and silt, sand, and even particles of weathered chert occur locally.

These deposits were noted in the Jackson et al. No. 1 Fevurly well, in sec. 1, T. 9 S., R. 20 E., where they were at first attributed to cavings from lower Cherokee shale which they closely resemble. It was later learned that casing had been set in the Mississippian limestone and that neither the shale with green grains nor that with the siliceous cement could be found in cuttings from above the Mississippian. Similar cuttings were later found in samples from several other wells in the McLouth field and in parts of Leavenworth and Johnson counties. In some cases where the Cherokee had not been cased off these deposits were accompanied by unquestionable lower Pennsylvanian cavings.

The shales under consideration have been found in all parts of the Mississippian down to the top of the lower member of the undifferentiated Burlington and Keokuk limestones but not below. They do not have a sedimentary relation to the Mississippian limestone nor to each other, and in nearby wells they may not occur in the same part of the Mississippian. They cannot, therefore, be considered as deposits interstratified with the Mississippian limestones. The theory that they might represent gouge in shattered zones connected with faulting was considered. These shales are especially abundant in the Young No. 1 McLeod well, in the NW¼ SW¼ sec. 4, T. 10 S., R. 20 E., which did in fact drill through a fault with a shortening of the Mississippian section by about 60 feet. No shortening or lengthening of stratigraphic intervals, however, has been shown in any of the other wells in which these shales have been recovered. The shales have been found not only at various stratigraphic depths, but in some wells the deposit is repeated at greater depths. Many wells, however, find the shale at the porous dolomite zone in the middle of the Burlington-Keokuk sequence. The writer believes that these erratically occurring black shales were deposited in solution openings and caves in the upper part of the Mississippian and that they occur in the faulted well because the faulting favored the formation of solution openings and caverns. The source of the clastic materials is uncertain, but some of the constituents have not been found in the Pennsylvanian. Porous zones more than 100 feet below the top of the Mississippian limestone have been noted in Reno and McPherson counties (Lee, 1939, p. 40). In Jefferson county the average depth of the lowest black shale body is about 160 feet below the top of the Mississippian.

Rocks of Pennsylvanian Age

The Pennsylvanian rocks of northeastern Kansas and northwestern Missouri are well known, and the Missouri and Kansas Geological Surveys are in essential agreement as to the sequence and correlation of almost all of the minor units. Moore (1936) re-examined the Pennsylvanian rocks as a whole from the standpoint of cyclical deposition and paleontologic development, and as a result introduced many new formational names and redefined the limits of many of the older terms. This new classification was adopted for the State Geological Survey of Kansas.

The principal changes of the group and series units as adopted by Moore consist of the separation of the upper part of the earlier Missouri series as the Virgilian series, the redefinition of the Wabaunsee, Shawnee, and Douglas groups, the redefinition and restriction of the Lansing and Kansas City groups, and the segregation of the lower part of the original Kansas City group as the Bronson group. The differences in classification by the Missouri and Kansas Geological Surveys of the Pennsylvanian beds into series, groups, and formations have been shown by McQueen and Greene (1938, pl. 5). The series and groups as now used by the Geological Survey of Kansas for the Pennsylvanian rocks are listed below, in descending order.

- Virgilian series
  - Wabaunsee group
  - Shawnee group
  - Douglas group
- Missourian series
  - Pedee group
  - Lansing group
  - Kansas City group
  - Bronson group
  - Bourbon group
- Desmoinesian series
  - Marmaton group
  - Cherokee shale

Because Moore (1936) has discussed in detail the classification, thickness, lithology, and stratigraphic relationships of the Pennsylvanian rocks in northeastern Kansas, an extended discussion of these rocks in their surface manifestations is unnecessary in this report. Only a brief resumé of the essential lithologic features of the Pennsylvanian rocks in outcrops of northeastern Kansas will be presented. Additional data bearing on the structure and stratigraphy derived from a study of these rocks in the subsurface are added, with special emphasis on features that may have a bearing on the search for oil and gas.

The distribution of the Pennsylvanian and Permian rocks in the area covered by this report, as well as in other parts of Kansas, is shown on the geologic map of Kansas published by the State Geological Survey in 1937. This map not only shows the outcrops of the groups described herein, but also the outcrops of the most prominent limestones. It is particularly useful in indicating to operators which beds occur at the surface in a given locality and hence the approximate depth necessary to drill to reach a chosen oil sand.

DESMOINESIAN SERIES

Cherokee shale

Outcrops of Cherokee shale extend in a broad belt from eastern Oklahoma through Cherokee county, Kansas, around the flanks of the Ozark dome into parts of northeastern Missouri. The deposits consist of several hundred feet of various kinds of shale, beds of sandstone, and infrequent thin beds of limestones and coal. The lower limit of the Cherokee shale in Kansas is the eroded surface of the Mississippian limestone. Its upper limit has been set at the base of the Fort Scott limestone, a conspicuous and persistent limestone at the bottom of the Marmaton group.

The Cherokee shale is argillaceous, micaceous, silty, and sandy with gradations of all types. The sandstones are mainly micaceous and not very porous; some of them, however, are relatively pure in places and have good but unpredictable porosity. The lack of porosity is due to several causes—among others, the secondary cementation of the grains and the original inclusion of clay. However, some of the sandstones, such as the Bartlesville, are elongate lenticular bodies of clean sand known as shoestring sands. The limestones are thin and inconspicuous. The characteristics of the Cherokee are its predominant shaly deposits, its impure sandstones, and the subordinate amounts of limestone and coal.

The Cherokee shale in the Forest City basin in northeastern Kansas differs little in general character from that in its outcrops in the Cherokee basin farther south. The re-elevation of the Nemaha anticline at the time of the formation of the Forest City basin produced an eastward-facing escarpment bounding the basin on the west. North of Geary county, the crest of this escarpment consisted mainly of granite and probably other pre-Cambrian rocks. To the south, the crest of the escarpment was underlain mainly by rocks of Arbuckle age.

It might be supposed that the weathering of this granite ridge would yield a large amount of coarse-grained arkose, at least on the west side of the Forest City basin. The information from the few wells available indicates that only a relatively small quantity of coarse-grained arkosic sediments was deposited at the base of the Cherokee in the Forest City basin. In the Ladd et al. No. 1 Achten well, in sec. 12, T. 4 S., R. 14 E., in the deepest part of the basin only 12 to 15 miles from the escarpment, the lower 500 feet of the Cherokee consists almost exclusively of black and dark micaceous shale with only small amounts of fine sand and no arkose. The next overlying 150 feet, however, includes several beds of coarse-grained arkosic material and some gray chert probably derived from the ridge to the west. Even in the Arab No. 1 Ogle well, sec. 9, T. 1 N., R. 14 E., in Nebraska, less than 6 miles east of the buried escarpment, the lower 300 feet of the Cherokee consists almost exclusively of black shale, although the remainder of the section through the Marmaton and up to the base of the Hertha limestone consists mainly of arkose and coarse, poorly sorted red sand.

Farther out in the basin the lower part of the Cherokee is also dominantly shale, much of which is black and micaceous. The shale beds higher in the section are interstratified with micaceous impure sand, generally not very porous. The sandstones seem to be in part lenticular and in part to grade locally into bodies of pervious sandstone, ill-sorted nonmarine sandy shale, or shaly sand.

The Burgess sand, one of the well-known oil and gas sands in the Cherokee shale, is primarily a basal conglomerate. It is a sandstone consisting of coarse quartz sand and in some places includes chert fragments from the Mississippian limestones. It is composed of whatever detrital materials were available to the advancing Cherokee sea and accumulated in large measure in local depressions on the pre-Cherokee land surface. The Burgess sand has been observed in wells in Franklin county, but it is not common in the Forest City basin where the basal Cherokee beds are generally black shale. The Burgess sand should not be confused with the McLouth sand, to be described later, which in most wells is separated from the Mississippian by black shale.

Many unnamed sand bodies of only local distribution occur in the Cherokee shale. Some of these are sufficiently porous to contain water. Under favorable structural conditions many of them might serve as reservoirs for gas and oil.

The McLouth gas sand immediately overlies the Mississippian limestone in some wells, but in most wells it is separated from the Mississippian by black micaceous shale. In the McLouth field the top of the sand is about 450 feet below the Fort Scott limestone, and about 350 feet above the deepest part of the Forest City basin. It appears to have been deposited at or about the time that the Forest City and Cherokee basins were joined. This sand, which has been carefully studied during the development of the McLouth field, is really a sandy, apparently nonmarine zone, about 40 feet thick. The McLouth sand includes several beds of impure and poorly sorted sandstone of irregular thickness, some parts of which are porous. The varying porosity results in varying gas yields.

The Bartlesville and associated sands are lenticular shoestring sands that, as Bass (1936) has shown, are buried offshore sand bars. The Bartlesville shoestring sands have not been identified in the Forest City basin, and probably were not deposited there. Their base is 250 to 300 feet below the Fort Scott limestone, and they are, therefore, younger than the McLouth sand and were probably deposited after the union of the Forest City and Cherokee basins. The Bartlesville was deposited on the shores of a shallow embayment caused mainly by the gentle flexing of the Cherokee basin.

The Squirrel sand is a sandy zone in the upper part of the Cherokee shale. It is a well-known and widely distributed gas sand, but its thickness and yield are subject to abrupt variations. It is reported to lie 25 to 102 feet below the top of the Fort Scott limestone and to have a thickness of 10 to 80 feet. In strata whose deposition was locally so regular as the lower Pennsylvanian rocks of northeastern Kansas, such reported fluctuations in position are interpreted as indicating a sandy zone whose variations in porosity are due to the amount of clay and other impervious materials that were deposited with the sand. The Squirrel sand has not been studied as carefully as the McLouth sand. It is probably not a homogeneous entity like the Bartlesville shoestring sands but a sandy zone like the McLouth sand, which is dependent for production upon the development of porosity in one or several of its impure sandstone beds in anticlinal areas. The pay sand may lie at different depths in the sandy zone under the same anticline. The Squirrel sand is a valuable gas producer in Johnson, Leavenworth, Wyandotte, and other counties in eastern Kansas and northwestern Missouri. It received its name from drillers who early observed that it "hopped around" in relation to recognized datum beds like the Fort Scott limestone (Greene, 1933, p. 16).

The only named limestone in the Cherokee shale is the Ardmore limestone member, 90 to 110 feet below the top of the formation. The Ardmore member is commonly a thin bed 1 to 3 feet thick and is thus frequently not recorded in well logs. Some other locally developed limestone lenses occur in various parts of the Cherokee shale but they have not been named and in general they represent calcareous sandstones or shales rather than true limestone beds.

A limestone bed which occurs 20 feet above the McLouth sand in the McLouth field appears to have a wide distribution. Although highly argillaceous, it is crinoidal and probably includes other marine fossils. Because it is thin and black to chocolate-colored and resembles the adjacent shales, it is easily overlooked in the examination of samples. This limestone is a good datum bed, however, and in the McLouth field is underlain by a thin bed of white siltstone that is more easily seen than the limestone. Traces of coal, apparently from between these datum beds, have been found in the cuttings of some wells.

On the structurally high areas of the McLouth field, which lies on a structural arch, this limestone is 620 feet below the base of the Hertha limestone. Near the deepest part of the basin, in the Ladd et al. No. 1 Achten well, in sec. 12, T. 4 S., R. 14 E., a crinoidal dark calcareous shale, believed to represent the same limestone, occurs 735 feet below the Hertha limestone. An impure dark fossiliferous limestone that seems to be the same bed is reported by McQueen and Greene (1938, p. 174) in the Forest City well in Holt county, Missouri. This marine argillaceous limestone has been noted in many other wells. It is believed to indicate a brief invasion of marine waters into the Forest City basin at about the time the Bourbon arch, which separated the Forest City and Cherokee basins, was submerged. On the assumption that the thin limestone was deposited upon an essentially flat surface, it is presumed that the variations in the interval from this bed to the base of the Hertha limestone represent structural warping of the bed during the corresponding time interval and that the depth of the Forest City basin was gradually increased 50 to 75 feet by warping during the interval.

The thickness of the Cherokee shale is variable. Its exact thickness is difficult to determine because in many places in the Forest City basin the Fort Scott limestone, which immediately overlies the Cherokee, is not well developed and in some wells is neither logged nor sampled. The Cherokee shale is thickest in the Ladd et al. No. 1 Achten well, in sec. 12, T. 4 S., R. 14 E., where it is 805 feet thick. It is thinnest on the divide between the Forest City and Cherokee basins, where Bass (1936, pl. 1) reports only 350 to 400 feet of Cherokee shale. On the northerly trending arch upon which the McLouth field is located the Cherokee has a minimum thickness of 467 feet. The thickness of the Cherokee shale is dependent upon three factors: the original structural configuration of the Forest City basin, the topographic relief of the surface upon which it was deposited, and the deformation of the basin that took place during its deposition.

The Cherokee shale is thicker in southeastern Kansas and in northeastern Kansas than elsewhere in the state. It is by means of this thickening of the Cherokee rocks in their respective areas that the Cherokee basin of southeastern Kansas and eastern Oklahoma and the Forest City basin of northeastern Kansas and parts of adjoining states are known. The Cherokee basin was the arm of a deep structural basin on the north flank of the Ouachita mountains of Oklahoma and Arkansas and from it extended northward on the west side of the Ozark dome into southeastern Kansas. A basin in Illinois, known as the Illinois basin, was somewhat similar to the Cherokee basin and flanked the Ozark region on the east.

The broad low structural divide (the Bourbon arch) of Mississippian rocks that separated the Forest City and Cherokee basins trends vaguely toward the northwest across Bourbon, Allen, and Coffey counties, Kansas (Lee, 1939, pl. 2). The Forest City basin was separated from the Illinois basin in northeastern Missouri by a similar arch of Mississippian rocks, the Northeast Missouri arch, trending northward from the Ozark dome. These two divides were barriers confining the Forest City basin, and each is now overlain by Cherokee shale of about the same thickness. The Cherokee shale in the center of the basin is about 400 feet thicker than on the divides. This thickness represents the approximate structural relief of the basin at the time of deposition of the Fort Scott limestone. After the flooding of the divides, the Forest City basin ended its brief existence as a separate unit and became merely an extension of the Cherokee basin.

Rocks of Morrowan age were deposited in parts of Arkansas and Oklahoma but are not known to have reached Kansas. They are, however, separated from correlatives of the Cherokee rocks by an unconformity.

The Cherokee sea advanced from Oklahoma into Kansas, but the deposits did not entirely bury the re-elevated Nemaha anticline except in southern Kansas. Cherokee deposits beginning with a basal conglomerate encroached on the anticline from the east, but most of the re-elevated crest remained an elongate island or peninsula until Marmaton time and some places on its northern crest were not covered until Bronson time. No marked unconformity separates the Cherokee shale from the Marmaton rocks.

Marmaton group

The Marmaton group includes the rocks from the top of the Cherokee shale to the unconformity at the base of the Missourian series. These rocks consist of thick and thin limestone beds alternating with shale, and include some thin coal beds and thick channel sands. The details of Marmaton stratigraphy in Kansas have been discussed at length by Jewett (1941).

The Fort Scott limestone is important as the lowest formation of the Marmaton group. Its base is used as a datum horizon in determining the thickness of the Cherokee shale. In the outcrops it is made up of three members: a limestone bed, 5 to 16 feet thick, at the base broken locally by limy shale; a middle member, 7 to 12 feet thick, of dark shale and black fissile shale including a thin lenticular limestone and a local bed of coal; and an upper bed of limestone, averaging about 16 feet in thickness (Jewett, 1941, pp. 302-309). The total thickness averages about 30 feet in the outcrops of southeastern Kansas where limestone constitutes about two-thirds of the formation.

The Fort Scott limestone is overlain by the Labette shale. This formation is of importance because locally it includes thick lenticular bodies of sandstone, known as the Peru sand, which have yielded gas in several counties in eastern Kansas and northwestern Missouri. Some of these sandstones seen in outcrops are channel deposits and locally replace eroded parts of the Fort Scott limestone. The Labette shale in the Kansas outcrops is 40 to 80 feet thick (Jewett, 1941, p. 309). The Pawnee limestone, as described by Jewett, is a formation about 30 feet thick which consists of two limestone members and two shale members. The lower shale member includes a thin sheet of limestone which thickens into northeastern Oklahoma.

The upper formations of the Marmaton group include the Bandera shale and overlying limestones alternating with shale. The Bandera shale, like the Labette shale, includes deposits of channel sandstone in some places. These sands yield oil and gas in Linn and neighboring counties. It is possible that some of the gas sands of eastern Kansas which have been called Peru sand are in the Bandera shale instead of the Labette. Several of the limestone beds in the upper part of the Marmaton group are thin. All of the Marmaton formations and most of the members have been traced great distances along the outcrops.

The limestone units of the Marmaton group are well developed in outcrops in southeastern Kansas, where they constitute about 20 percent of the group. In the subsurface of northeastern Kansas, particularly north of Kansas river, these limestones become thinner and correlation with the limestones in the outcrops becomes increasingly difficult. In areas where the basal limestone (the Fort Scott limestone) is thin, it is not recorded in some logs. In some wells it does not even appear in the samples; hence it may be absent in considerable areas. The same difficulty exists in regard to the higher limestones of the group. The Marmaton is represented in nearly all logs by a group of thin limestones, but there is doubt as to their specific identification.

Limestones of Marmaton age are not well developed in the Arab No. 1 Ogle well, in sec. 9, T. 1 N., R. 14 E., Nebraska. Because this well is only 5 to 6 miles east of the escarpment bounding the basin on the west, it is presumed that the accumulation of clastic materials from the bordering land area prevented the normal development of limestones during Marmaton time.

The Peru sand, which occurs in the upper part of the Labette shale between the Fort Scott and Pawnee limestones, has yielded gas in counties from Wyandotte to Linn and in neighboring counties both in Kansas and Missouri. Some gas and oil have come from a sand in the Bandera shale above the Pawnee limestone. This sand is known as the Wayside sand.

From the available information it is difficult or impossible to give a definite thickness for the Marmaton in the subsurface of northeastern Kansas. Its top is an eroded surface and its base is obscure in places. Its thickness probably does not exceed 150 feet and is less in some wells. Jewett reports the thickness of the Marmaton as about 250 feet in Kansas outcrops. The Marmaton is probably represented partly by arkose in some places near the Nemaha anticline, as in the Arab No. 1 Ogle well. On this anticline in Riley and Pottawatomie counties the Marmaton group is less than 100 feet thick and its basal beds are probably not represented.

The Marmaton group overlies the Cherokee shale without notable disconformity. Where the Cherokee failed to cover the escarpment formed by the re-elevation of the Nemaha anticline, the Marmaton overlapped the Cherokee shale and covered the crest on which it unconformably overlies Mississippian rocks toward the south end of the Nemaha escarpment and Devonian and even older rocks toward the north. An important unconformity marks the top of the Marmaton group. The period of exposure and erosion was long enough to effect an important faunal break before the deposition of the overlying Missourian series, but the Lenapah limestone near the top of the Marmaton in Kansas was only locally eroded. The Warrensburg channel deposits of Missouri are reported by Jewett (1941, p. 294) to be of Labette age. This means that an unconformity within the Marmaton is locally more conspicuous though less important than that at its top. The local relief at the top of the Marmaton, as reported by Jewett, is small and regionally is of the order of 50 feet.

MISSOURIAN SERIES

The Missourian series, as redefined by Moore (1936), consists of a basal group of sandy shale (the Bourbon group), three groups of rocks that are composed principally of limestone (Bronson, Kansas City, and Lansing groups), and a shale group (the Pedee group) at the top.

Bourbon group

The Bourbon rocks include sandstone, sandy shale, and dark-blue and dark shale, and in addition some dark-blue flaggy limestones in the upper part (Jewett, 1940) in outcrops in Linn and Bourbon counties. The basal formation of the Bourbon group is the Hepler sandstone, 3 to 20 feet thick, which, according to Jewett, is not to be correlated with the Warrensburg sandstone. Other sandstones of local development occur in the middle and upper parts of the formation.

The Bourbon rocks in the subsurface do not differ much from the outcrops. A sharp boundary between the Marmaton shale and the Bourbon shale is not recognizable in well cuttings except where the Hepler sandstone is well enough developed to be identified. This sandstone, which is 10 to 20 feet thick near Lawrence, has been noted also in many wells in the McLouth field and as far north as the Lebsack and Wamoff No. 1 Maduska well in sec. 36, T. 8 S., R. 20 E.

The unconformable relations at the base of the Bourbon group give it an irregular thickness. Jewett reports a thickness of 150 to 190 feet in outcrops in Linn county. The fact that the uppermost limestone members of the Marmaton are identified with some misgivings in well and sample logs adds to the difficulty of determining the exact thickness of the Bourbon. The interval from the top of the Bourbon shale to the uppermost recognized limestone of the Marmaton, although not the true thickness of the group in all wells, gives a rough measure of its thickness. This interval is fairly regular and as far north as the McLouth pool is 100 to 150 feet. It is thinner farther north. On the Nemaha ridge in Pottawatomie and Riley counties, where it overlies the Marmaton, the Bourbon is only 15 to 20 feet thick. This suggests continued or renewed activity of the Nemaha anticline during Bourbon times.

The relations of the top of the Bourbon to the overlying Hertha limestone (of Bronson age) are obscure in the subsurface. Although no marked unconformity occurs at this contact, it is worthy of note that a variety of different types of rocks underlies the Hertha limestone. The Hertha generally overlies shale, but in some wells the underlying rocks are sandstone, dolomite, or impure limestone. The thinning of the Bourbon interval toward the north and the variety of rocks underlying the Hertha suggest that there may have been a slight southerly tilting of the region accompanied by some erosion prior to the deposition of the Hertha. Such an hypothesis is consistent with the structural movements indicated by the thickness of the combined Bronson, Kansas City, and Lansing groups shown in figure 17B and in the thinning of the Bourbon over the Nemaha anticline.

Bronson, Kansas City, and Lansing groups

These three groups consist of alternating beds of limestone and shale, with limestone predominating. The several limestone and shale sequences present an interesting sequence of cyclical sedimentation in which certain types of sediments succeeded each other with extraordinary fidelity in response to the rhythmic advances and retreats of the sea. The Bronson group was originally included in the Kansas City group, from which it was separated in Kansas by Moore (1936, pp. 75-77). At the same time the boundary between the restricted Kansas City group and the Lansing was raised and a regrouping of some of the limestone members was made.

The lowest formation of the Bronson group is the Hertha limestone which consists of two limestone members, the Sniabar limestone above and the Critzer limestone below (Jewett, 1932, p. 99), separated by a thin shale bed. The base of the Hertha is an important datum bed because it is easily recognized in most wells.

A local impure limestone in the top of the Bourbon has been mistakenly included in the Hertha in the logs of some wells. The examination of samples has resulted in corrections of as much as 15 or 20 feet in a few logs to exclude these pre-Hertha deposits. The Hertha is overlain in ascending sequence by the thin gray Ladore shale, the Middle Creek limestone, the Hushpuckney shale, and the Bethany Falls limestone, the last three of which are members constituting the Swope limestone. The Hushpuckney shale is a black and fissile shale which is easily recognized 10 to 20 feet above the base of the Hertha limestone. There is, however, another black shale about the middle of the Bronson which is called the Stark shale. The Winterset limestone member of the Dennis limestone at the top of the Bronson group is characterized by the occurrence of small amounts of dark to black chert near its top.

The redefined Kansas City group extends from the base of the Fontana shale to the top of the Bonner Springs shale with frequent cyclical alternation of other shales and limestone beds. The Lansing group, as restricted by Moore (1936), extends from the base of the Plattsburg limestone immediately overlying the

Bonner Springs shale to the top of the Stanton limestone, of which the topmost member is the Little Kaw limestone. In some outcrops the deep erosion that marks the base of the Virgilian series has cut so deeply that the entire Pedee shale group as well as the upper beds of the Stanton have been eroded.

In the subsurface the Bronson, Kansas City, and Lansing groups of the Missourian series closely resemble their features as revealed in outcrops. There is considerable diversity in the thickness of individual limestone and shale members in different parts of the area, and even in adjacent wells, because of the repeated unconformities between the cycles of deposition. In some places certain beds were reduced in thickness or entirely removed by erosion leaving a surface of low relief upon which the succeeding beds were deposited. In some instances the irregularities of the low topography were leveled off by the initial deposits of the succeeding cycle; in others, the first sediments failed to fill the inequalities of the surface left by erosion so that flatness of the sea bottom was not restored until several thin beds of shale and limestone had been deposited. In consequence, as is well shown by comparison of carefully kept logs of nearby wells, there is a lack of parallelism between individual beds. The aggregate thickness of the three groups, however, is in most places singularly uniform, although there is considerable variation in the thickness of individual formations and members.

A map showing the combined thickness of the Bronson, Kansas City, and Lansing groups is presented in figure 17B. The thickness ranges from 300 to 400 feet, being greatest toward the south. Some allowance has been made for the Little Kaw limestone where it appears to have been eroded from the top of the Stanton. Corrections of 15 to 20 feet for this reason have been made in the logs of some wells.

No very striking unconformity marks the contact of the Bronson with the Bourbon. If disconformity exists, it is probably no greater than many cyclical unconformities within the Bronson. The Lansing is essentially conformable beneath the overlying Pedee shale group, but in many places the entire Pedee group and a part of the Stanton limestone at the top of the Lansing group were eroded before the deposition of the Virgilian rocks.

Pedee group

The strata overlying the Stanton limestone up to the disconformable rocks of the Virgilian series constitute the Pedee group. These rocks consist of the Weston shale and the Iatan limestone which survives only locally near the top of the Pedee group. The Iatan crops out north of Leavenworth, but toward the south and in the Kansas river valley the Iatan limestone and part or all of the Weston shale were eroded in pre-Virgilian time.

No effort has been made to distinguish the Weston shale and the Iatan limestone in the logs from the shale and limestone of the Douglas group at the base of the Virgilian series because better datum beds occur both above the Douglas and below the Pedee. A well-defined sandstone of irregular occurrence that may represent the base of the Virgilian series is present in some wells in the shale overlying the Stanton limestone. Moore (1936, pp. 140, 141), reports a maximum thickness of 140 feet for the Weston shale and 22 feet for the Iatan in outcrops.

The Pedee group overlies the Stanton limestone without pronounced disconformity. An unconformity with pronounced relief separates it from the overlying Virgilian series. The extent of this relief, not less than 200 feet, is indicated by the erosion of the entire thickness (about 160 feet) of Pedee rocks and the upper members of the Stanton limestone which has been eroded locally to a depth of 10 feet or more.

VIRGILIAN SERIES

Douglas group

This group is the lowest division of the Virgilian series (Moore, 1936, p. 145). It consists of two parts, the Stranger formation below and the Lawrence shale above. The Stranger formation, of which the Tonganoxie sandstone is the basal member, was deposited upon the dissected surface of the Missourian series. The Stranger formation grades upward without marked interruption of sedimentation into sandy shale. A thin coal (Sibley) and a thin widely distributed limestone (Westphalia) occur in the upper part of the Stranger formation. The Haskell limestone near the top of the formation is only 2 or 3 feet thick, but it was deposited over a very broad area. The Robbins shale overlies the Haskell limestone. It was locally eroded before deposition of the Lawrence shale.

The Lawrence shale was deposited after a period of exposure and erosion that left the surface of the Stranger formation deeply channeled. The Robbins shale and the Haskell and Westphalia limestones were cut out in some places. The channels were filled with the Ireland sand which grades up into the lower part of the sandy Lawrence shale. A thin limestone and several thin beds of coal are known in the upper part. The Douglas group crops out in northeastern Kansas in a belt extending southwest from Leavenworth through Lawrence.

No effort has been made to distinguish the members of this group in the subsurface. The intervals, complicated as they are by unconformities, are variable. The Haskell limestone appears to be present in most wells, but it may be confused with the Westphalia and both may be misidentified with the Iatan which, where present, occurs at about the same interval above the Stanton limestone. The Haskell limestone, although widely deposited, is not a very good datum bed because its stratigraphic intervals below the Oread and above the Lansing are not constant. It appears to have been deposited upon an imperfectly leveled surface. The sandstones of the Douglas group are particularly variable inasmuch as they were deposited upon a deeply eroded and locally channeled surface. The sandstone bodies in the Lawrence shale grade laterally into sandy shale and have no lithologic continuity.

There is no regularity in the thickness of the Douglas group. The interval from the top of the Stanton to the base of the overlying Oread limestone shown in figure 18A is a rough measure of its thickness, which ranges from less than 100 feet to more than 300 feet. The thinning is toward the north and toward the axis of the Nemaha anticline.

The Douglas group is included in the Virgilian series because of the pronounced unconformity already mentioned at the base of that group. No pronounced irregularity has been noted between the Douglas group and the overlying Oread limestone at the base of the Shawnee group. The beds are assumed to be essentially conformable, although cyclical exposure probably occurred at or near the contact.

Shawnee group

The Shawnee group consists of four prominent limestone formations (Oread limestone, Lecompton limestone, Deer Creek limestone, and Topeka limestone, named in ascending order) separated by prominent shale formations (the Kanwaka shale above the Oread, the Tecumseh shale above the Lecompton, and the Calhoun shale above the Deer Creek). This group crops out in a belt extending southwest from eastern Doniphan county through central Coffey county. The limestones form fairly well-developed eastward-facing escarpments. No great change takes place in the character of this group of beds in the subsurface except that toward the north and west the shale formations between the limestones become thinner so that there is a considerable thinning of the group as a whole.

The Shawnee group thins northward from about 350 feet in the deeper parts of the basin in Douglas county to less than 250 feet west of the Nemaha anticline, as shown by the thickness map (fig. 18B).

No pronounced unconformities occur at either the bottom or the top of the Shawnee group, although there is no reason to doubt that there were frequent periods of cyclical emergence at the beginning and at the end as well as during the deposition of the Shawnee group.

Wabaunsee group

The Wabaunsee group includes the youngest rocks of Pennsylvanian age. It consists of shales, sandy shales, and thin beds of sandstone interstratified with a number of limestone beds. Although the limestones are neither very hard nor very thick, they are more conspicuous in the outcrops than might be expected because of their relatively lesser resistance to erosion and the monotony of the associated shales. The most prominent of these limestones, named in ascending order, are: Howard limestone, Burlingame limestone, Emporia limestone, Tarkio limestone, and Dover limestone.

The Wabaunsee group crops out in a narrow belt extending from eastern Brown county southwest through western Coffey county. It is exposed also on the crest of the Nemaha anticline north of Kansas river where the younger rocks, originally present above it, have been stripped away by erosion.

No great part of the area under discussion is underlain by the Wabaunsee group. It occupies a narrow belt of the Nemaha anticline that has been avoided, almost superstitiously by oil operators, because of its synclinal structure. There are in consequence few wells that penetrate the Wabaunsee rocks in this area.

Not enough wells have been drilled through the Wabaunsee to determine the variations of its thickness in this area. Inasmuch as its upper surface was deeply eroded before the deposition of the overlying rocks, it is certain that these variations will be great and unpredictable. Moore (1936, p. 201) reports its thickness to be reduced from 500 feet to a possible 375 feet where it is most deeply channeled. Like other Pennsylvanian groups in northeastern Kansas, the Wabaunsee group thins toward the north.

The Wabaunsee group is essentially conformable above the Topeka limestone at the top of the Shawnee group. Its top is the unconformable surface between the Pennsylvanian and Permian with a topographic relief of at least 80 feet and possibly 125 feet.

Rocks of Permian Age

The Permian rocks of Kansas have been reclassified to conform with the recommendations in the report of the Permian Committee of the American Association of Petroleum Geologists (C. W. Tomlinson et al., 1940), and divided by Moore (1940, p. 42) for the State Geological Survey of Kansas into the following series and groups, in descending order:

- Guadalupian series
    - Quartermaster group
    - Whitehorse group
- Leonardian series
    - Nippewalla group
    - Sumner group
- Wolfcampian series
    - Chase group
    - Council Grove group
    - Admire group

Only the Wolfcampian series is represented in the outcrops in the Forest City basin.

WOLFCAMPIAN SERIES

Detailed descriptions of the outcrops of strata of the Wolfcampian series in Riley and Geary counties have been published by Jewett (1941a). The rocks included under this term were formerly known in Kansas as the Big Blue series, but since their correlation with the standard section established in Texas the term Big Blue has been abandoned by the State Geological Survey of Kansas. Under the new classification the Sumner group, formerly included in the Big Blue, has been excluded from the Wolfcampian and added to the overlying Leonardian series. The western counties of the Forest City basin are underlain by the Admire and Council Grove groups which constitute the lower part of the Wolfcampian series. These rocks, concealed in many places by glacial deposits, occupy broad belts trending east of north on both sides of the Nemaha anticline in northeastern Kansas. Older rocks of Wabaunsee age come to the surface on the crest of the Nemaha anticline in this part of Kansas. Only small areas east of the Nemaha anticline are underlain by the Chase group.

Admire group

North of Kansas river, the Admire group crops out in two southwesterly trending belts separated by the Wabaunsee which is exposed between them on the crest of the Nemaha anticline. These belts merge south of Wabaunsee county. The Admire group consists chiefly of shale, much of which is red. The shale is interstratified with a number of limestones, named, in ascending order, Aspinwall, Falls City, Five Points, and others which are thinner and less prominent than those in the overlying Council Grove group. The lowest rocks of the Admire group were deposited in channels, possibly 125 feet deep, eroded in the Pennsylvanian rocks. The channel deposits consist mainly of deposits known as the Indian Cave sandstone. The Admire group without the channel deposits has a thickness of only about 100 feet. It is overlain by the Council Grove group without obvious disconformity.

Council Grove group

This group of rocks consists principally of shale with a number of resistant but thin limestone beds, the Americus, Neva, Cottonwood, Funston, and others. Much of the shale is red or green. The lowest member is the Americus limestone. The highest member is the Speiser shale which underlies the conspicuous Wreford limestone at the base of the Chase group.

The Council Grove group north of Kansas river underlies the surface in the syncline east of the Nemaha anticline. It crops out again on the west side of the anticline. South of Kansas river these two belts of outcrops come together and the Council Grove takes its place in the parallel bands in which successive groups crop out across the state.

According to sections measured by Jewett (1941a, pl. 6) in outcrops in Riley county, the Council Grove group has a thickness of 300 feet. This group overlies the Admire group and underlies the Chase group with essential conformity.

Chase group

The Chase group is composed of cherty limestones alternating with shale. The lowest member of the group is the Wreford limestone; the highest is the Herington limestone. Only the lowest Chase rocks occur in the Forest City basin north of Kansas river where they have been preserved locally in a synclinal area in northeastern Nemaha county. The lower part of the Chase group occurs in a narrow belt at the surface of the Flint hills on the western border of the Forest City basin.

Permian rocks younger than the Chase group are not now found in the Forest City basin, although eastern Kansas was undoubtedly covered at one time by many hundreds of feet of upper Permian rocks.

Rocks of Quaternary Age

PLEISTOCENE SERIES

Glacial till.—No rocks of Mesozoic age are known to occur now in or adjacent to the Forest City basin area of northeastern Kansas, but it is probable that Cretaceous rocks at one time extended far into the basin. Deposits of Tertiary age, consisting dominantly of chert gravels, have been reported (Todd, 1920; Frye, 1941, p. 246) at some localities overlying the bedrock and overlain by Pleistocene glacial till. The stratified rocks of Pennsylvanian and Permian age in the northern counties of the Forest City basin were covered by unconsolidated glacial debris in Pleistocene time. At least part of the area was covered by both the Nebraskan and Kansan glaciers (Frye, 1941, pp. 146, 147), so the original thickness of these deposits is not known. The Kansan ice sheet advanced approximately to the present valley of Kansas river, and glacial deposits formerly covered all of eastern Kansas north of this line (Schoewe, 1930). The glacial deposits have been eroded from much of the area since the retreat of the ice, especially in the major valleys and their tributaries. Deposits of Pleistocene age attain a maximum thickness of more than 100 feet and conceal the stratified rocks in large areas of the upland surface between the valleys.

Alluvium.—The valley flats of the major valleys are underlain by deposits of alluvium. These deposits have in large part been deposited since the retreat of the ice, but the development of the major valleys may have been initiated before the advance of the Kansan ice sheet.

STRUCTURAL DEVELOPMENT OF THE FOREST CITY BASIN AND ADJACENT AREAS

Deformational forces have affected the rocks of northeastern Kansas in different ways. These forces have greatly modified the original attitude of all the rocks and have expressed themselves from time to time in structural domes and basins, in synclines and anticlines, and in faults and regional tilting. At times, as during the Cambrian and early Ordovician and during the Pennsylvanian, the strata were deformed almost as soon as deposited. In some regions, the earliest dips given to the rocks were for a long time progressively increased in the same general direction. At a later time these original dips were reversed in direction by a change in the pattern of structural deformation, giving some areas dips at variance with those previously imposed so that the net result of the structural movements has not been the same in all parts of the area.

The Use of Isopachous Maps to Determine Structural Deformation

If a formation of uniform character were deposited upon a perfectly flat surface and subsequently folded and exposed to erosion for a period long enough to be reduced to a perfect peneplain, the rocks would be thin on anticlines and thick in synclines, and the thickness of the formation as expressed by an isopachous map would reflect clearly the amount and location of all structural movements. Similarly, if the originally level surface upon which sediments were accumulating was deformed concurrently with the sedimentation and if the accumulating deposits attained a flat upper surface at the end of the period of sedimentation, the isopachous map would reflect the amount and position of the deformation that took place during the interval. Such theoretical conditions, of course, are never completely fulfilled, but in a general way and within limits much may be learned regarding the regional structure from the thickness of the rocks where the top and bottom of any unit were originally essentially horizontal.

A number of factors, including compaction, interfere with the accuracy of the determination of structural deformation by means of thickness maps. Inasmuch as sediments are thicker in synclinal areas, where compaction is greatest, the thickness map would indicate less deformation in such areas than actually occurred. It is necessary to assume that the unit affected by compaction possessed a uniform lithologic character and that post-depositional compaction would be the same for each unit of thickness in all parts of the area under consideration. This is essentially true of all the pre-Pennsylvanian rocks of Kansas which consist mainly of limestone, dolomite, and sand in which there was probably very little additional compaction after the initial consolidation. The pre-Pennsylvanian shale deposits no doubt were subjected to greater post-depositional compaction than were the limestones and sandstones, but as they are generally of uniform character their compaction was also uniform in proportion to thickness.

The Pennsylvanian rocks of Kansas consist mainly of irregular and variable beds of shale, sandy shale, and sand, but they include some limestone of more or less uniform character. Considerable thicknesses of shale are generally recorded in the logs of wells, but examination of cuttings reveals that a large part of the shales is very sandy and thus perhaps not subject to much more compaction than the sandstone beds. Individual beds vary widely in character from place to place and many overlying and underlying beds also show great variability. The amount of local compaction in one bed of a variable zone is generally compensated by the local differences in other beds. In any case, it is probable that compaction after deposition was relatively slight in comparison to the initial compaction that took place shortly after the deposition of individual beds. There was, of course, greater compaction of shale units than of limestones after the formation of the upper limiting surface. Compaction of shale over massive sandstone bodies induces pseudostructural features in the overlying rocks, but the effect of this phenomenon may be largely eliminated by the use of thick contour intervals on isopachous maps for the study of regional structure.

It is necessary to assume also that the datum beds bounding a stratigraphic unit under consideration were originally horizontal. Where sedimentation in a structural basin fails to keep pace with gradual submergence, there will be convergence between datum beds and the deposits may be laid down initially with low dips toward the deeper part of the basin. Such deposits will tend to change in lithologic character in deeper water. Where, on the contrary, sedimentation keeps pace with the flooding of the region, the original attitude of individual beds will be essentially horizontal. Deposits filling a basin contemporaneously with its subsidence are characterized by (a) the presence of thin lithologic units deposited over wide areas without much change in character; (b) evidence of frequent emergence, such as many minor unconformities, intraformational breccias, and sun cracks; and (c) evidence of shallow water, such as ripple marks and deposits of coal and other shallow-water beds. The interior basin, of which northeastern Kansas forms a part, exhibits sediments of this type throughout the Paleozoic from Lower Cambrian to Permian. None of the stratigraphic units are thick, and most of the formations furnish internal evidence of deposition in shallow seas.

Not all the stratigraphic units, however, are equally useful as horizontal datum beds. The initial clastic deposits upon a dissected surface of an unconformity are of irregular thickness, and individual beds deposited upon such a surface are likely to be marked by deviations from the horizontal. Beds that were probably deposited upon a hummocky surface, reflecting vaguely the incompletely filled valleys of erosional surfaces below, include some of the limestone members of the Lansing, Kansas City, and Bronson groups, the Haskell limestone, and the Burlingame limestone, all of Pennsylvanian age. On the other hand, beds that represent horizons which originally closely approached the horizontal include the Hertha limestone and other persistent limestones and thin black shales which show wide distribution and regularity of relation to overlying and underlying beds. Some deposits, such as the basal conglomerate of the Pennsylvanian, were never horizontal. Although this conglomerate forms a continuous sheet, it was deposited as the sea advanced upon an eroded and structurally deformed surface and in consequence it differs in age in different areas.

That a land surface can be completely worn down to sea level by erosion is, of course, only a concept. All thoroughly eroded surfaces possess some relief, owing to the low divides between broad, shallow valleys and to residual hills composed of rock especially resistant to erosion. In spite of these irregularities, however, any region that has been tilted and then thoroughly beveled by erosion may be thought of as having an approximately horizontal surface. Where an area gradually subsides below sea level, the beveling of its surface by wave action produces an even closer approach to a plane surface, although, there also, some masses of resistant rock may remain above the general level. If the warping that subsequently deformed a maturely eroded surface greatly exceeds in magnitude the topographic relief of the surface, an approximate, though imperfect, expression of the deformation will be revealed by an isopachous map showing the thickness of a unit or sequence whose base is an eroded surface and whose top is a horizontal plane of deposition.

In the following discussion of structural movements in the Forest City basin and adjacent areas, no claim is made for the mathematical accuracy of the deformation revealed by the isopachous maps. The maps, however, reveal much information regarding the location and trend of structural movements during certain periods of the geological history of the area and, to some degree, their relative importance.

Regional Deformation Between the Beginning of Cambrian Time and the End of St. Peter Time

The structural deformation that took place during the Lower Ordovician and Upper Cambrian is reflected by the changes in thickness of the sequence of rocks between the pre-Cambrian granite and the top of the St. Peter sandstone. The top of the Lamotte sandstone would have been preferable to the top of the pre-Cambrian granite as the lower datum for this sequence because the Lamotte apparently had leveled off many of the inequalities of that surface; however, the fact that the granite has been logged in many old wells in which the Lamotte sandstone was not recorded requires the use of the top of the granite. The top of the St. Peter sandstone was chosen for the top of the sequence because it has always been carefully noted in drillers' logs. Also, the St. Peter is a widely distributed formation and is relatively thin, averaging less than 75 feet in northeastern Kansas. Although the St. Peter sandstone may represent a transgressive deposit, it is thought that within the geographical area of the map (fig. 9) its top was essentially a horizontal surface which serves as a satisfactory reference datum within the limits mapped and the 100-foot thickness interval used. The area of the thickness map is limited on the south by the Chautauqua arch in southeastern Kansas, from which the St. Peter sandstone was removed during pre-Devonian base-leveling. The St. Peter was also removed from some localities on the crest of the Nemaha anticline during post-Mississippian peneplanation.

Most of the deep wells in northeastern Kansas were drilled before it was common practice to save samples. Consequently, most of the data used in determining the top of the St. Peter are from drillers' logs. The top of the granite in most of the wells was determined by examination of samples at the time the wells were drilled. The widespread distribution of the Bonneterre dolomite and the Lamotte sandstone (figs. 4 and 5) indicates that the original relief of the granite surface was generally low.

The thickness map of the sequence of rocks between the top of the St. Peter and the top of the pre-Cambrian (fig. 9) indicates roughly the amount of deformation that occurred during the corresponding time of deposition, except for a possible slight initial dip or for irregularities at the top of the St. Peter and on the surface of the granite. By the beginning of St. Peter time, the surface of the pre-Cambrian rocks had risen in a broad uplift whose highest parts in Kansas appear to have been in Marshall or Washington counties. Because its surface probably rose to even higher altitudes in Nebraska, it is here named the Southeast Nebraska uplift. Within the area of figure 9, the top of the pre-Cambrian at the close of St. Peter time had attained a total structural relief of nearly 900 feet. The structural relief was more than 2,000 feet above the deepest part of the Ozark basin in Missouri. The top of the granite sloped southward from the crest of the uplift into a deep structural basin in southern Oklahoma where the pre-St. Peter sedimentary rocks have a thickness of more than 7,000 feet.

These structural movements are the first known to have deformed the sedimentary rocks of northeastern Kansas. The character of the deformation in eastern Kansas and Missouri is shown by the thickness map of the interval from the top of the Roubidoux to the top of the Lamotte sandstone (fig. 10). The Ozark basin and the Southeast Nebraska uplift appear to have been structurally complementary so that as the basin subsided the uplift rose.

Some of the structural development indicated by the thickness maps (figs. 9 and 10) took place during the frequently interrupted deposition of the early dolomites. However, inasmuch as the St. Peter sandstone is unconformably in contact with all of the older formations, a considerable part of the deformation must have occurred in the time interval represented by the unconformity at its base (fig. 5).

If the section prepared by McQueen (1931, pl. 12) across the central part of the Ozarks in southern Missouri is correlated on the Roubidoux sandstone (fig. 4), it is evident that the western part of the Ozark region was a broad subsiding synclinal basin throughout the Upper Cambrian and Lower Ordovician in which the various formations become thinner and converge toward the west. Another cross section by McQueen (1931, pl. 10) from south to north near the Kansas border shows a slight convergence of the formations below the Roubidoux toward the north, although the lower formations at one place appear either to have been deposited unconformably upon a granite hill or to be in contact with an intrusion.

The present study, as well as earlier studies by Missouri geologists, reveals a series of structural cycles whose center of subsidence lay within the Ozark basin (see figs. 4, 5, and 10). The Lamotte sandstone, which was deposited on the irregularities of the pre-Cambrian surface, leveled off to a considerable extent the inequalities of that surface, although there were some localities in which hills survived. The wide distribution of the overlying Bonneterre dolomite indicates that it was laid down upon a low and essentially flat surface, for it is now found overlying the Lamotte not only in the deepest part of the Ozark basin but also on the upper flanks of the Southeast Nebraska uplift. A remnant of the Bonneterre seems to be present on this uplift in the Turner No. 1 Umschied well, in sec. 32, T. 8 S., R. 9 E. (fig. 5), and in other wells in the surrounding territory.

A cycle beginning with the Lamotte sandstone and closing with erosion of the Doe Run dolomite was the first of several similar cycles. In, this cycle the Lamotte, Bonneterre, Davis, Derby, and Doe Run formations were deposited in conformable sequence. After the deposition of the Doe Run, the marginal deposits were warped upward very gently, the sea withdrew, and the exposed rocks were eroded to what seems to have been essentially a peneplain. The Doe Run and Derby dolomites, if they had ever been deposited in western Missouri and eastern Kansas, were eroded from the western margin of the basin.

At the beginning of the second cycle, the land surface was warped downward restoring the embayment in which the Potosi dolomite was deposited upon the beveled edges of all the older formations. The Eminence dolomite, which conformably overlies the Potosi, extended north and west beyond the Potosi dolomite and overlapped unconformably upon the eroded surface of the Bonneterre dolomite in eastern Kansas. The Proctor dolomite was then deposited upon the Eminence dolomite, but it, together with part of the Eminence, was removed from the margin of the basin during the ensuing re-elevation and peneplanation.

The third cycle may be regarded as extending from Gunter time to the close of Gasconade time, though a break took place between Van Buren and Gasconade time. The sequence of events from the beginning of Roubidoux time to the end of Smithville time is not recorded in western Missouri or northeastern Kansas. After Gasconade time, the Ozark basin appears to have sustained less warping and less beveling of marginal areas and a considerable extension of areas of deposition.

These cycles were probably more involved than is expressed in the simplified outline above. Two factors affected the areas of erosion and deposition. One factor involved changes in shore line due to rise and fall of the sea that were not accompanied by local structural movements. The other involved shore-line changes due to deformation of the basin with only incidental changes in sea level. The character of the pre-St. Peter rocks indicates that they were deposited in shallow water. Frequent brief intervals of emergence occurred, so that both the gradual expansion of the sea and the gradual emergence of marginal land areas were probably the composite result of small local deformatory movements, on the one hand, and of many large and small oscillatory changes of sea level, on the other. There were, therefore, secondary and many even less important cycles within the major cycles. The secondary interruptions to sedimentation are

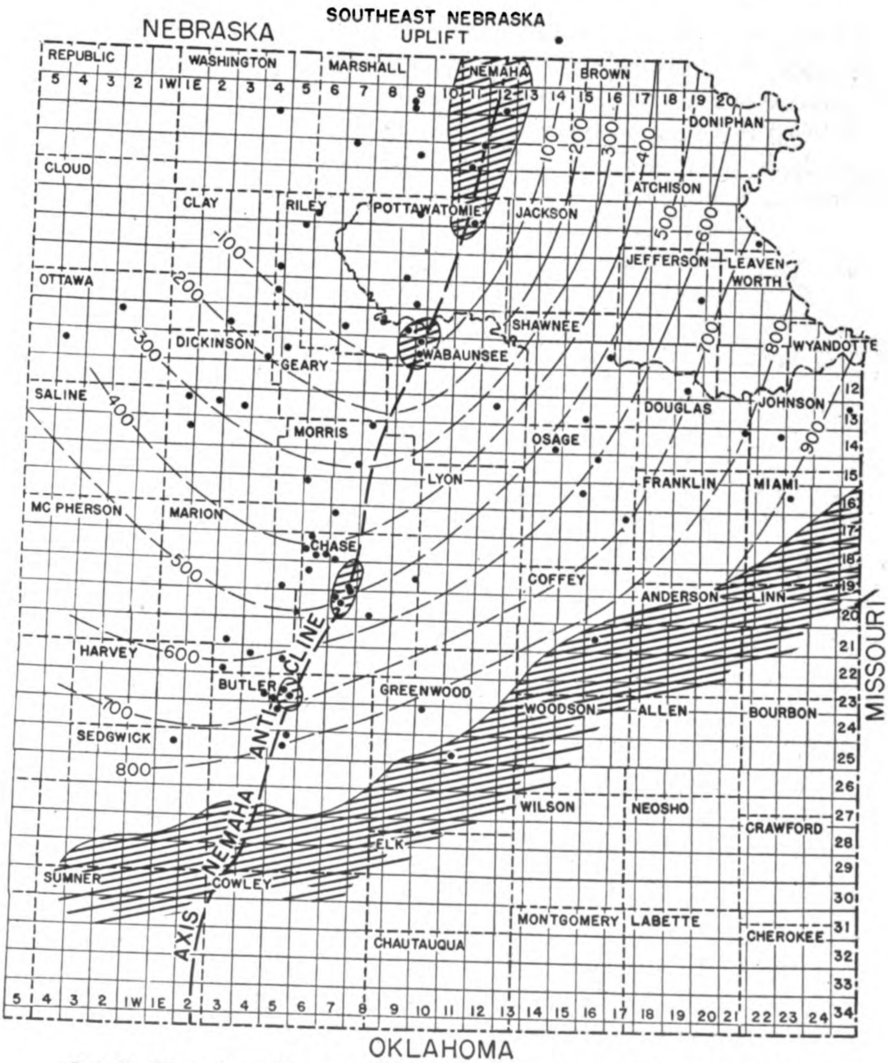


FIG. 9. Map of northeastern Kansas showing thickness of rocks between the top of the pre-Cambrian and the top of the St. Peter sandstone.

Isopachous lines connecting points of equal thickness are drawn at intervals of 100 feet. Diagonal pattern indicates areas from which St. Peter sandstone has been eroded. Dots show location of wells used as source of data.

probably represented by such unconformities as those between the Gasconade dolomite and the Van Buren formation and between the Jefferson City dolomite and the Roubidoux formation. Cycles of less importance are indicated by ripple marks and sun cracks or may even have occurred without any obvious stratigraphic expression. The widespread deposition of the Roubidoux sandstone may be explained by assuming that the hiatus at the base of this sandstone represents simply a retreat and readvance of the sea without local warping of the basin. This type of cycle appears to have been more prevalent during the early Ordovician when the areas of deposition were greatly extended than during the late Cambrian.

With these concepts in mind, it seems reasonable to conclude that the Cotter, Powell, and Smithville formations which are missing in Kansas were originally widely deposited but probably of greater thickness in the center of the Ozark basin. Like the Davis, Derby, and Doe Run formations, their thin marginal deposits were probably removed from the shores of the basin after the final re-elevation and peneplanation of the margin of the basin that preceded St. Peter deposition. Only those pre-St. Peter formations (such as the Bonneterre, Eminence, and Gasconade dolomites) that were deposited in greatest thickness on the flank of the basin in northeastern Kansas during the maximum expansion of the Ozark sea survived the subsequent periods of exposure and erosion.

The size and configuration of the Southeast Nebraska uplift on the northwest side of the Ozark basin are as yet undetermined, but it appears to have been commensurate in size with the Ozark basin of the same period. Its configuration in Kansas is roughly suggested in figure 9, which shows the surface of the pre-Cambrian at the close of St. Peter time. By St. Peter time all the earlier sediments had acquired a regional dip toward the south or southeast. The amount of dip increases with the depth below the St. Peter. At the end of St. Peter deposition, the Lamotte sandstone had an average dip in northeastern Kansas of 9 feet per mile toward the southeast.

Regional Deformation from the End of St. Peter Time to the End of Maquoketa Time

The amount and the direction of deformation that took place

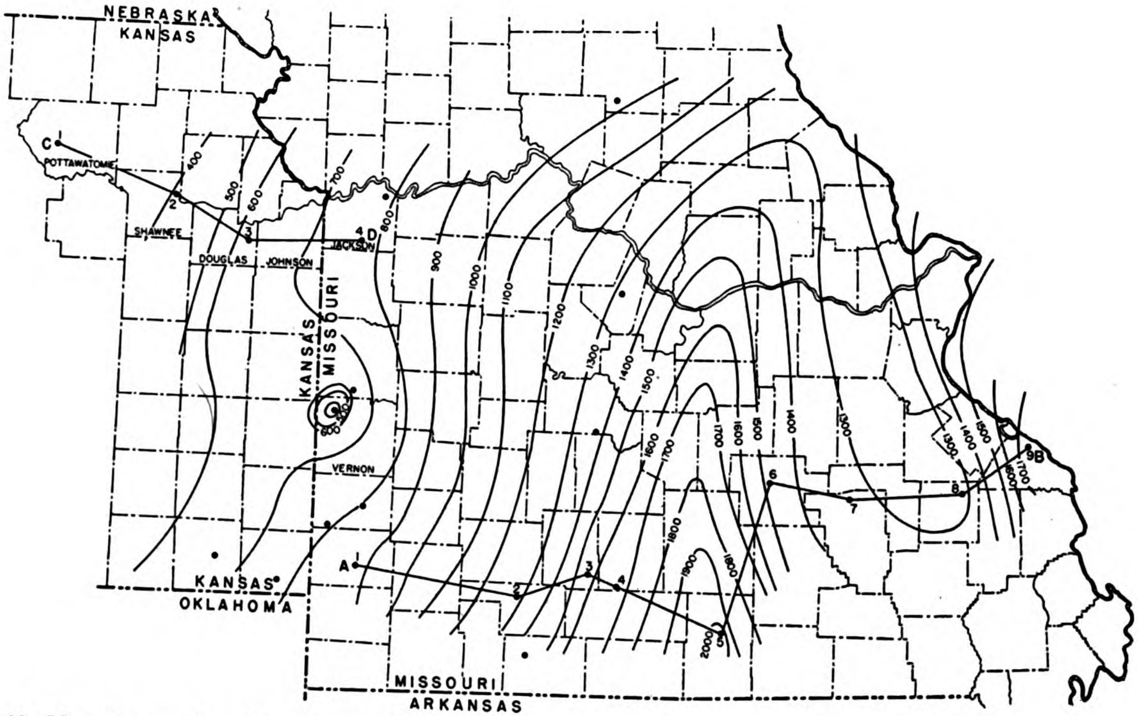


Fig. 10. Map of a portion of Missouri and eastern Kansas showing thickness of rocks between the top of the Lamotte sandstone and the top of the Roubidoux formation. Data in Missouri from McQueen (1931) and in eastern Kansas from samples of wells examined by R. P. Keroher. The thin section in Vernon county, Missouri, may be due either to an igneous intrusion, an unreduced pre-Cambrian ridge, or a local structure that was active until the deposition of the Gunter sandstone member of the Van Buren formation, which in this area is reported to overlie granite.

Isopachous lines connecting points of equal thickness are drawn at intervals of 100 feet. Dots show locations of wells used as source data. Lines A-B and C-D indicate locations of cross sections shown in figures 4 and 5.

between St. Peter and Maquoketa times are indicated by the thickness of the sediments deposited during this interval, although the top and bottom of the section have been preserved in a relatively small area. The thickness map of this interval (fig. 11) indicates that the St. Peter sandstone in northeastern Kansas was tilted slightly west of north toward a basin whose central area lay north of the Kansas-Nebraska border. This basin was called the North Kansas basin by Rich (1933, p. 796), but it is probable that its deepest part was in Nebraska and that it may be only a part of a larger basin flanking the Ozark area on the north. By the end of Maquoketa time this structural movement had given the top of the St. Peter sandstone a dip toward the northwest of about 5 feet per mile.

The subsidence in this direction and the accompanying tilt in the basement rocks must have been connected with the development of the Chautauqua arch, for the trend of the thickness contours is approximately parallel to the strike of the rocks on the northern flank of the Chautauqua arch. Another indication of the same relation is the slower decrease in thickness as the crest of the Chautauqua arch is approached. Luther H. White (1928, p. 21) reports that the pre-Sylvan (pre-Maquoketa) rocks on the south flank of the Chautauqua arch in Oklahoma also become thicker as the distance south from the Chautauqua arch increases.

The initial movements of the Chautauqua arch thus probably began after St. Peter time but before the end of Maquoketa time. During this time interval there were several interruptions in sedimentation in northeastern Kansas. One of these occurred between the deposition of the St. Peter sandstone and the Decorah shale, during which several hundred feet of rocks were deposited in southeastern Missouri. Another unconformity that occurred during the interval represented by the thickness map is revealed in the Mississippi valley. In that region the Fernvale limestone, tentatively identified in the Forest City basin below the Maquoketa, is reported by Ulrich (1939, p. 107) to overlap beds ranging in age from lower Ordovician to Trenton. It is probable that much of the deformation revealed by the thickness map in this area occurred during the time represented by these unconformities.

The identification of pre-Decorah rocks of possible Plattin age in the deeper parts of the North Kansas basin implies that the North Kansas basin was subsiding and the Chautauqua arch had

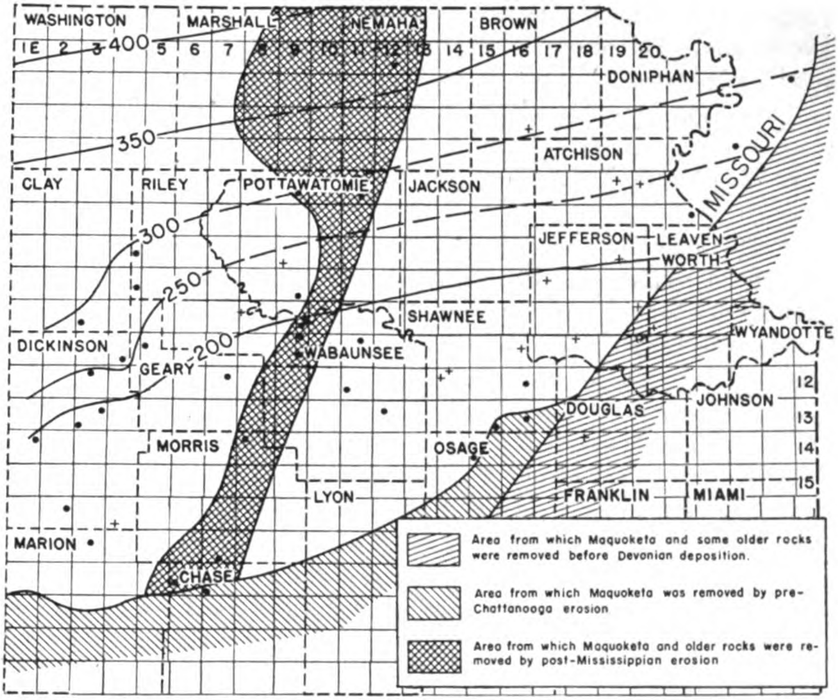


FIG. 11. Map of northeastern Kansas showing the thickness of rocks between the top of the St. Peter sandstone and the top of the Maquoketa shale. Isopachous lines connecting points of equal thickness are drawn at intervals of 50 feet. Plus signs show locations of wells from which samples were examined. Dots show locations of wells for which data were taken from drillers logs.

begun to rise early in the time interval represented by the thickness map. The occurrence of post-Kimmswick rocks in the deeper part of the basin tentatively referred to the Fernvale would indicate that the same structural movements were going on at least to the beginning of Maquoketa time.

REGIONAL DEFORMATION FROM THE END OF MAQUOKETA TIME TO PRE-CHATTANOOGA PENEPLANATION

The continued development of the North Kansas basin during Silurian and Devonian time is indicated by the thickness of these rocks above the Maquoketa shale. The peneplain at the base of the Chattanooga shale was very well developed. Although some drainage is recognizable upon its eroded surface (Lee, 1940, p. 27) the beveled outcrops of all the older formations had extremely low relief. The area that may be contoured is restricted to areas in which both the base of the Chattanooga and the top of the Maquoketa have been preserved from erosion, although in some border areas where only the base of the Maquoketa has been preserved an estimate has been made of the position of its original top.

The thickness map of this interval (fig. 12) indicates a continued subsidence of the North Kansas basin. The trend of the thickness lines is approximately northeast and conforms more closely to the border of the Ozark uplift than to the Chautauqua arch. The total subsidence of the basin in Kansas during this interval was at least 700 feet, and in Nebraska it was even greater. The average increase in thickness representing deformation is approximately 8 feet per mile to the northwest.

This deformation occurred mainly during two distinct movements marked by angular unconformities, although some subsidence was going on during the intervening periods of sedimentation. The first interval occurred after the deposition of the Silurian of the region. It is obvious from an inspection of the cross sections (fig. 7) that after the deposition of the Silurian rocks the surface was tilted toward the northwest and eroded. The rocks were beveled although the surface may not have reached an advanced stage of peneplanation. Some idea of the amount of erosion that took place can be gained from the fragmentary thickness map of the Silurian (fig. 13). Several hundred feet of Silurian strata may have been eroded toward the southeast. Probably more Silurian rocks were removed from the area contoured than remain.

The other period of tilting and beveling occurred after the deposition of the Devonian. The thickness of the Devonian strata indicates that more than 300 feet of Devonian rocks were eroded from the margin of the basin. Luther H. White (1928, p. 21) has indicated that in northeastern Oklahoma the interval from the top of the Sylvan (Maquoketa) shale to the base of the Chattanooga shale increases similarly away from the Chautauqua arch on its south side. In that area the thinning is due to tilting into a basin to the south and the elevation and subsequent erosion of the Chautauqua arch. It is probable that during this period some local structural movements occurred, but the information from

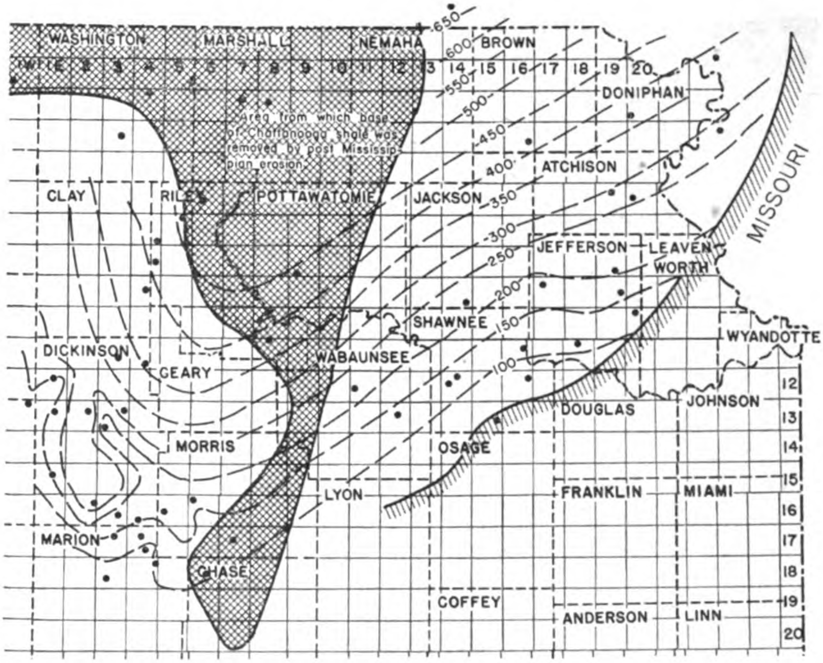


FIG. 12. Map of northeastern Kansas showing thickness of rocks between top of Maquoketa shale and the base of the Chattanooga shale.

Isopachous lines connecting points of equal thickness are drawn at intervals of 50 feet. Dots show locations of wells used as source of data. Diagonal lines show margin of area from which Maquoketa shale was removed by pre-Devonian and pre-Chattanooga erosion. Checkered area indicates area from which base of Chattanooga shale was removed by post-Mississippian erosion.

Kansas is inadequate for proof. There is evidence in the Dawson pool, T. 1 N., R. 14 E. in Nebraska, that local deformation occurred between the deposition of the Maquoketa and Silurian rocks for in the Arab No. 1 Ogle well of that pool the foraminiferal zone of the Silurian, normally more than 50 feet above the Maquoketa, is in contact with the weathered and eroded surface of the Maquoketa shale.

Regional Deformation Indicated by the Thickness of the Chattanooga Shale

The continued subsidence of the North Kansas basin through Chattanooga time is indicated by the pattern of the thickness lines of the Chattanooga, as shown by Lee (1940, p. 28) and by figure

14 in which changes of the thickness lines involving local detail have been made from recently acquired data.

Comparison of this thickness map with maps showing the thickness of the St. Peter-Maquoketa sequence and the thickness of the Maquoketa-Chattanooga sequence reveals a progressive change in the strike of the thickness lines on the southeastern side of the North Kansas basin. During the interval from St. Peter to Maquoketa, the strike was east-northeast; from Maquoketa to pre-Chattanooga peneplanation the strike turned to northeast, and during the Chattanooga to north-northeast. This change in direction of strike indicates a gradually southward shift of that part of the North Kansas basin toward which the margin was being tilted and may be related to strains antecedent to the Nemaha anticline. The subsidence of the North Kansas basin during the deposition of the Chattanooga shale was the last movement affecting this basin before the first recognizable movement of the Nemaha anticline, although east of the anticline sinking of the basin continued until the deposition of the Chouteau limestone of Kinderhookian age.

Irregularities in the thickness of the Chattanooga shale in Dickinson county have been interpreted as expressing drainage lines on the pre-Chattanooga peneplain. It is interesting to note that compensating thinning occurs in the Devonian rocks in the same areas as shown in figure 12, thus confirming the conclusion of measurable relief on the pre-Chattanooga surface. To avoid the use of the imperfectly peneplaned pre-Chattanooga surface, a thickness map showing the interval between the top of the Maquoketa and the top of the Chattanooga was prepared (fig. 15). In this map the irregularities caused by the imperfections of the pre-Chattanooga peneplain in figures 12 and 14 have been eliminated. During the deposition of the rocks represented by figures 11 and 15 the North Kansas basin presents a record of intermittent subsidence.

The North Kansas basin and its complementary positive areas, the Chautauqua arch and the Ozark uplift, dominated the structural history of northeastern Kansas from the end of St. Peter time at least until the end of Chattanooga time. It thus provides an interesting example of the reversal of this type of structural movement. The central Ozark region had been a negative and sinking area and southeastern Nebraska had been a positive or

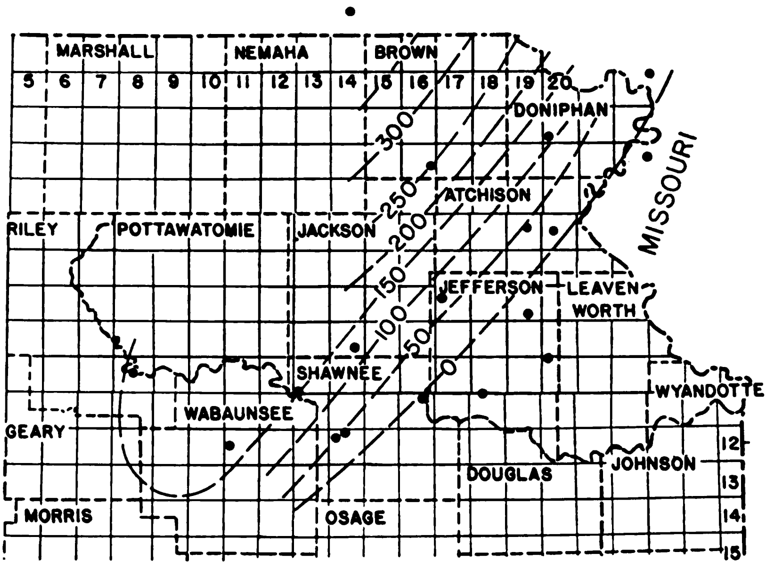


FIG. 13. Map of northeastern Kansas showing the thickness of rocks of Silurian age. The Silurian rocks were originally widely distributed in Kansas and Missouri, then were tilted and beveled by pre-Devonian erosion. The contact between Silurian and Devonian rocks cannot be sharply differentiated northwest of the 150-foot thickness line. The thickness of 150 feet in Riley county is tentative, but the pattern indicated is in harmony with the geologic history shown in figures 12 and 15. Southeast of the line of zero thickness, the Silurian was removed by pre-Devonian erosion.

Isopachous lines connecting points of equal thickness are drawn at intervals of 50 feet. Dots show locations of wells from which samples were examined.

rising area from the deposition of Bonneterre limestone to St. Peter time. From St. Peter time to the end of Chattanooga deposition (possibly through the deposition of the Chouteau limestone) the Chautauqua arch and probably the Ozark area were positive and rising areas and southeastern Nebraska a negative and subsiding area. The structural deformation during both periods was only a few feet per mile and was more in the nature of a ground swell than of directional folding. The regional aggregate of the differentially distributed epeirogenetic movements involved in the subsidence of the Ozark basin in Missouri, however, amounted to about 2,000 feet of structural relief; the subsidence of the North Kansas basin was not less than 1,400 feet.

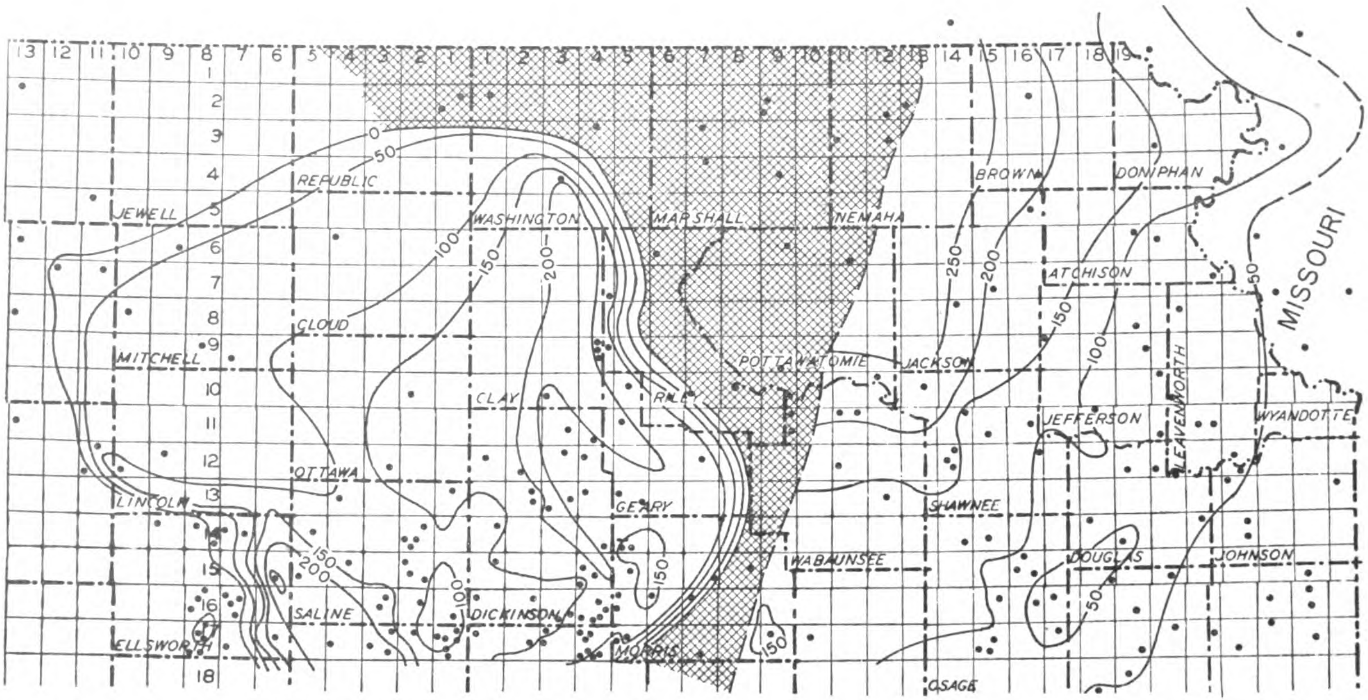


FIG. 14. Map of northeastern Kansas showing the thickness of the Chattanooga shale. The thickening of the Chattanooga shale toward the north indicates that the sinking of the North Kansas basin continued into Chattanooga time. The irregularities in the smoothness of the contours seem to be the expression of topographic relief upon the pre-Chattanooga peneplain (see fig. 12). In Dickinson county the thickness map of the Chattanooga and the underlying rocks is detailed enough to show thinning of the underlying rocks where the Chattanooga is thickest.

Checkered pattern shows area from which Chattanooga shale was removed by post-Mississippian erosion. Isopachous lines connecting points of equal thickness are drawn at 50-foot intervals. Dots show locations of wells used as source data.

Early Mississippian Deformation

The earlier part of the post-Devonian structural history of eastern Kansas is revealed by the distribution of the Mississippian formations. Initial movements of the Nemaha anticline are suggested as early as the Kinderhookian by the distribution of the lower two members of the Chouteau limestone which are confined to the area east of the Nemaha anticline. The thin upper member of the Chouteau, once doubtfully referred to the Sedalia (Lee, 1940, p. 37), extends west across the axis of the fold. The Chouteau east of the axis thickens northward into the eastern half of the North Kansas basin. This is interpreted to mean that during the deposition of the Chouteau limestone the North Kansas basin was still active, although initial folding had already begun on the Nemaha anticline.

Slight folding in Osagian time along the trend of the Nemaha anticline is indicated by the distribution of limestones of Fern Glen age in synclinal areas both east and west of the Nemaha anticline and by the absence of these formations beneath the Burlington in intervening areas on its crest and flank. At the time of deposition of the Short Creek oölite near the close of the Keokuk, there was a greater interval from the Short Creek oölite to the Chattanooga shale east of the Nemaha anticline than west of it, again suggesting Osagian subsidence east of the Nemaha fold. During Osagian and Meramecian time there appears to have been a gradual tilt of all of eastern Kansas toward the south, for most of the formations younger than Kinderhookian thin toward the north.

The Nemaha Anticline

The minor and obscure structural movements just described as having occurred during the deposition of the Mississippian rocks gave way to a pronounced change in the pattern of structural movement at the end of Mississippian sedimentation. The principal phenomenon was the development of the Nemaha anticline, which extended from southeastern Nebraska to central Oklahoma with a trend slightly west of south. Secondary and subsidiary parallel folds such as the Voshell anticline were also developed.

After the first stage of folding of the Nemaha anticline the region was peneplaned. The thickness of the rocks from the top of the Chattanooga to the peneplaned surface (fig. 16) reveals the approximate structural deformation that had occurred prior to peneplanation. The dip on the east flank of the anticline, although not uniform in different parts of the area, averaged about 5 feet per mile to the east.

At the close of peneplanation the area west of the Nemaha anticline was raised above the area on the east probably with faulting with the formation of an eastward-facing escarpment several hundred feet high rising above a basin (the Forest City basin) formed by the subsidence of the peneplain east of the anticline. The nature of the escarpment formed on the east side of the Nemaha anticline has long been a subject of debate. There can be little doubt that the displacement in some places was produced by faulting, but it seems possible that in many places it was the result of sharp monoclinal dip.

Before 1914 geological concepts of the structure and stratigraphy of northeastern Kansas were based on interpretations of surface outcrops in Missouri and Kansas and on the study of occasional logs of wells of no great depth drilled for oil, gas, or water. From the available information, it was generally believed that, although unconformities were known to occur in the pre-Pennsylvanian rocks of Missouri, the older rocks and the pre-Cambrian surface dipped more or less regularly beneath the Pennsylvanian strata westward from the Ozark region into a deep but somewhat vaguely localized basin east of the Rocky mountains. Oil wells in eastern Kansas up to that time were not drilled below the Pennsylvanian rocks and yielded no data contrary to the accepted theory.

When granite was reported at 958 feet in an oil test near Zeandale in Riley county, Kansas, in 1914, it aroused much interest among geologists. Granite had been reported earlier at even shallower depths in wells drilled for water in southeastern Nebraska and northeastern Kansas, but, as no samples had been saved, the reports had generally not been credited. Another well near Zeandale and two wells near Elmdale, Chase county, were drilled into granite within a few months after the Zeandale well and confirmed the original discovery. The belief that granite would be found only at much greater depths was so firmly held, however, that some geologists refused to accept the discoveries, and a number of interesting and ingenious reasons were suggested

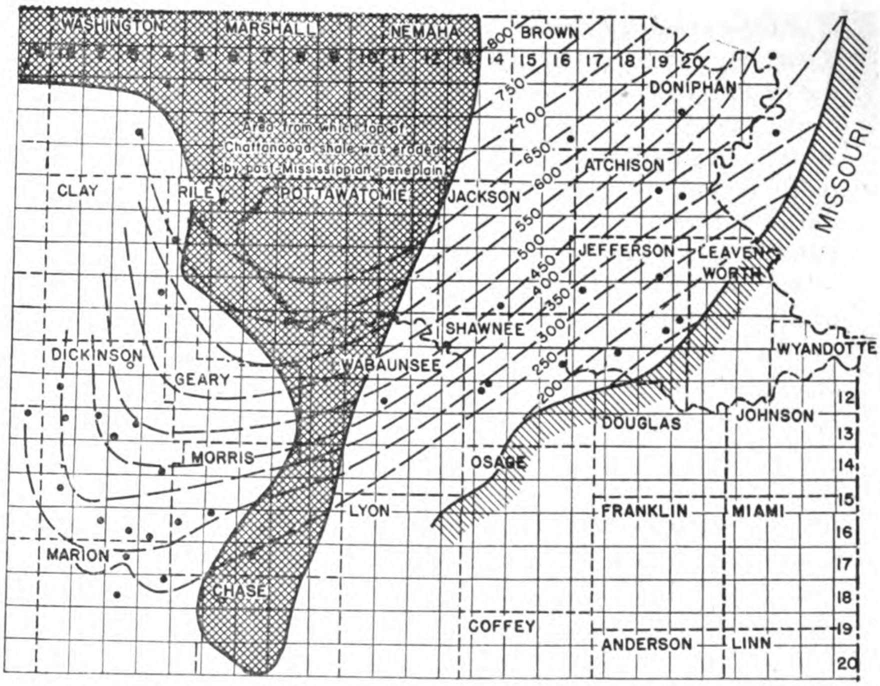


FIG. 15. Map of northeastern Kansas showing thickness of rocks between the top of the Maquoketa shale and the top of the Chattanooga shale. Checkered pattern shows area from which top of Chattanooga shale was removed by post-Mississippian erosion. Diagonal lines show margin of area from which top of Maquoketa shale was removed by pre-Devonian and pre-Chattanooga erosion. Isopachous lines connecting points of equal thickness are drawn at intervals of 50 feet. Dots show locations of wells used as source data.

for discrediting the evidence (Haworth, 1915). Since that time the understanding of the structure and stratigraphy of the region has greatly increased as a result of the large number of deep wells that have been drilled in the search for oil and gas.

It was at once recognized that the wells with granite at shallow depths were aligned with a series of surface anticlines and that in northern Kansas, where the first discoveries were made, the Pennsylvanian rocks were unconformable upon the granite. It was also correctly surmised that the granite was pre-Cambrian in age. It was at first assumed that a range of pre-Cambrian mountains had existed in northeastern Kansas and that its higher peaks had kept above the level of sedimentation until early Pennsylvanian time.

As the number of granite wells increased, modifications of this theory appeared. Taylor (1917, p. 118) expressed the view that the granite was a part of an ancient land mass with jagged peaks projecting above the general level of the region, but, noting the absence of clastic rocks in the Mississippian, he concluded that there might have been "rather intense though local deformation during the latter part of the Mississippian or the early part of the Pennsylvanian period . . . followed by rapid truncation of the folds." Moore and Haynes (1917, pp. 167,169) presented a more detailed discussion, and stated that the phenomena observed clearly indicate "an uplifted ridge [which they named the "Nemaha Granite Mountains" from Nemaha county where the deformation of the surface rocks is most pronounced] forming an essential part of the crystalline basement . . ." and that the relations indicate "a rather pronounced though local deformation in central Kansas in late Mississippian or early Pennsylvanian time, followed by rapid erosion which removed all of the sediments covering at least the top of the granite." They also wrote, "the absence of [sedimentary] rocks older than the Pennsylvanian . . . may be accounted for by the supposition . . . that they have been deposited as in neighboring areas but have been removed by subsequent erosion."

Sidney Powers (1917, p. 150) thought that the evidence suggested "that in the beginning of Pennsylvanian time, they [the Nemaha mountains] presented an appearance similar to that of the Wichita mountains at the beginning of Permian time . . . The mountain system must have been formed in the Cambrian, the lower Paleozoic [pre-Silurian], or in the Mississippian." In 1920 A. E. Fath who had studied the granite ridge (as it was then generally known) in Butler county, concluded that "the granite ridge did not come into existence until post-Boone time [middle Mississippian] . . . and that the ridge was elevated during the widespread erosion between the Mississippian and Pennsylvanian epochs."

In 1920, Eliot Blackwelder (1920, p. 92) had suggested that gravitational compaction of sediments over crests of hills on the trend of the "buried ridge" could explain the observed relation between the local structure of the Pennsylvanian strata and the supposed granite knobs. This theory, elaborated by Sidney Powers (1925) and others, was applied to the Nemaha anticline and other midcontinent structural features, and dominated the thought on the subject until 1926 when the accumulated data from deeper drilling caused a readjustment of the concepts.

In January 1926, Henry Ley (1926, p. 96) in a brief communication in the Bulletin of the American Association of Petroleum Geologists, published his conclusions that the granite ridge was a "southward pitching anticlinal fold" and that "south of Chase county, the Pennsylvanian beds rest on the 'siliceous' lime." He stated also that

> In late Mississippian or early Pennsylvanian time, the entire region emerged, and the granite ridge was elevated a thousand feet or more above the surrounding country. In the long interval before the advance of the Pennsylvanian seas, erosion stripped the Mississippian and even older rocks from the axis of the ridge. The ridge was thus reduced practically to the base-level of the surrounding country which at no time appears to have had an altitude more than 50 to 100 feet above sea level.

This brief and concise statement appears to have been favorably received and generally accepted by geologists. Two months after the publication of this communication the same ideas slightly modified were presented by R. C. Moore (1926, fig. 2) in a series of block diagrams prepared to illustrate an article on another subject.

In 1930, Hugh W. McClellan (1930, p. 1553) in an article on the distribution of pre-Mississippian rocks, stated that he had found no conclusive evidence of post-Devonian movement in faults on the east side of the Nemaha ridge. He interpreted the evidence to mean "that the granite ridge did not exist at that time." Later McClellan (1940, p. 20) restated that he had "never been able to find any proof of its existence before the post-Mississippian folding."

In 1931 Rich (1931, p. 1437) expressed the same ideas as McClellan (1930) and pointed out the post-peneplain development of the Cherokee basin. He also noted that north of El Dorado the granite ridge "seems not to have been covered until late Cherokee or the beginning of Marmaton time." In 1934, Tomlinson (1934, p. 571) refers to the Nemaha mountains as "a truncated anticline in pre-Pennsylvanian rocks." This conclusion is now firmly established.

Deformation of the Post-Mississippian Peneplain

The regional relief of the pre-Pennsylvanian surface measured from the Ft. Scott limestone, which amounts to several hundred feet, is due chiefly to faulting on the east flank of the Nemaha anticline and to deformation of the post-Mississippian peneplain, although there were later slow increments of folding throughout the Pennsylvanian and there is no doubt that in some places there was erosional relief of the pre-Cherokee surface (Lee, 1939). This conclusion rests on the following observations. (1) The Mississippian limestones on the downthrow side of the sharp displacement along the east side of the Nemaha anticline are beveled in the same way that the same rocks are beveled on the elevated west side of the anticline. (2) A greater thickness of the Cherokee shale occurs on the east side of the Nemaha anticline than on the west side, and the crest of the beveled anticline in most places was not covered until Marmaton time or later. (3) The topographic high points of the pre-Pennsylvanian surface are on beveled Mississippian limestones and are also beneath anticlines where the Pennsylvanian and Permian rocks are thin.

The Nemaha anticline cuts the North Kansas basin into two structural basins which have had a slightly different history. The Salina basin revealed by the thickening of the Mississippian limestones below the post-Mississippian peneplain (Lee, 1939) lies west of the Nemaha anticline and was slightly rejuvenated during the post-peneplain re-elevation. The corresponding structural basin east of the Nemaha anticline follows the Missouri river in northeastern Kansas and contains a thick sequence of Mississippian limestones including the Ste. Genevieve limestone at the top (fig. 16). The Salina basin and its counterpart east of the Nemaha anticline were both beveled pre-peneplain synclines.

On the contrary, the Forest City basin and the contemporaneous Cherokee basin farther south were topographic basins formed by sharp displacement on the east flank of the Nemaha anticline and by the warping of the peneplaned surface at the top of the Mississippian rocks. The deepest part of the Forest City basin, as shown in figure 7, was about 50 miles west of the earlier beveled syncline developed east of the Nemaha anticline contemporaneously with the Salina basin. This eastern beveled syncline is not known to have been further deformed at the time of the re-elevation of the region to the west and cannot be regarded as

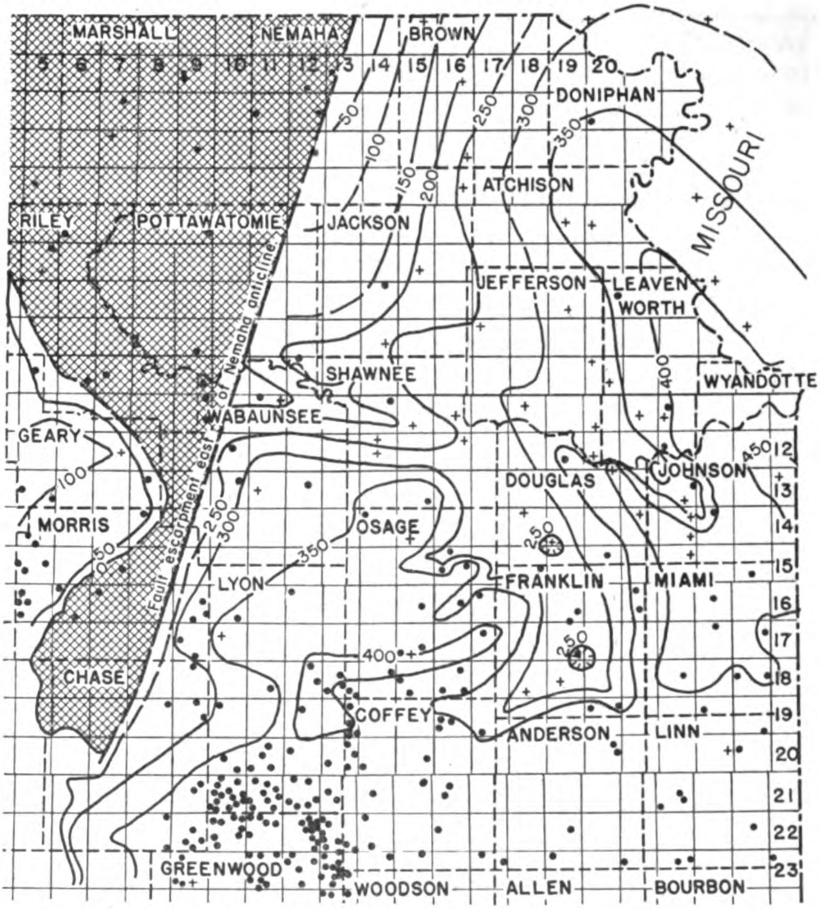


Fig. 16. **Map of northeastern Kansas showing thickness of limestones of Mississippian age.**

Isopachous lines connecting points of equal thickness are drawn at intervals of 50 feet. Checkered pattern shows area from which Mississippian limestones were removed by post-Mississippian erosion. Crosses show locations of wells from which samples have been examined. Dots show locations of wells from which only logs are available.

the initial movement of the Forest City basin. Neither the Forest City basin nor the Cherokee basin, both of which were topographic features, came into existence until after the development of the peneplain.

Renewal of deformation during the deposition of the Cherokee is indicated by the position of an unnamed dark crinoidal limestone in the Cherokee shale. This limestone is 265 feet above the base of the Cherokee in the deepest part of the Forest City basin in Nemaha county, 210 feet above the base in the Forest City well on its eastern flank, an average of 60 feet above the base in the McLouth field, and 90 feet above the base in Franklin county. Local minor folding also was going on during Pennsylvanian time, as is shown by all the local anticlines in the McLouth field which reveal increasing amounts of deformation with depth.

Detailed maps showing the thickness of the Cherokee shale reveal dendritic drainage patterns on the pre-Pennsylvanian surface. Where the lower Cherokee rocks are thick in the McLouth field, limestones as low as undivided Burlington and Keokuk have been found at the top of the Mississippian. On the other hand, the broad anticlinal area of the McLouth field is in general underlain by Spergen limestone. The relations indicate that the McLouth area lies upon a broad flat northward-trending pre-Cherokee anticline whose crest at the top of the Mississippian is now about 300 feet above the bottom of the Forest City Basin. Pre-Pennsylvanian drainage of this surface channeled the flanks of the anticline but did not completely destroy the fundamental relation of the thin Mississippian and thin lower Pennsylvanian rocks on the crest of the anticline.

The relation of the eroded surface of the Mississippian to the Hertha limestone and to the Chattanooga shale in two wells in northern Douglas county is shown in figure 19. The increase in the thickness of the Pennsylvanian rocks in the Wise well to compensate for the thinning of the Mississippian and the fact that the thick Pennsylvanian section overlies undivided Burlington and Keokuk limestone and that the thin Pennsylvanian overlies the St. Louis limestone is interpreted as the result of pre-Pennsylvanian erosional relief. Other similar but less striking instances have been noted. The relation between the Schiltz No. 3 Davis well, in sec. 33, T. 18 S., R. 18 E., and the Hollet No. 1 Koontz well, in sec. 21, T. 18 S., R. 19 E., shows that both deformation and erosion took place after post-Mississippian peneplanation. Although it is true that the Mississippian limestones were thinned on the crest of anticlines by peneplanation, there is evidence to indicate that there was also some local pre-Pennsylvanian erosion which developed entrenched drainage lines in this part of Kansas. The thinning of the Mississippian rocks in northeastern Kansas is, upper beds of the Mississippian are absent, it is obvious that erosion has occurred. On the other hand, where the thickness interval shows regularity of thinning or thickening in broad areas, it is probable that structural deformation is involved.

Interpretation of the structural significance of the thickness map is doubtful in many areas in northeastern Kansas, particularly where few samples are available for examination. Erosion of the top of the Mississippian is clearly demonstrable on the flanks of the McLouth arch, in the belt between Lawrence and DeSoto, T. 12 S., Rs. 20 and 21 E., and in Douglas and Franklin counties. Erosion is probably responsible for many of the other local eccentricities of thickness shown. It appears certain that the McLouth arch, the area of thinning that extends from southeastern Jefferson county into southern Doniphan county, is of structural origin, although the surface of the Mississippian on its top and flanks was affected by erosion before being covered. A pronounced valley trending northwest was cut in the surface in T. 9 S., R. 19 E. cutting off an area to the southwest that is probably not a part of the McLouth arch but an outlier of St. Louis limestone. The trough in the northern part of T. 9 S., R. 20 E. is the result of structure and erosion. It is uncertain as yet whether the well-developed valley in T. 12 S., Rs. 20 and 21 E. has cut across this arch or lies south of it. It is uncertain also whether the thin areas in the thickness map in western Osage, southern Wabaunsee, and northwestern Shawnee counties represent primarily structural or erosional elements.

The abrupt thinning of the lower Pennsylvanian rocks from more than 1,000 feet in Nemaha county to about 100 feet in Pottawatomie county, just west of the crest of the Nemaha anticline, indicates a profound displacement on the east flank of the anticline. This displacement was formed by a fault or a sharp monoclinal fold and was a prominent east-facing escarpment. It is worthy of comment that the McLouth arch, the deepest part of the Forest City basin, and the Nemaha anticline and the associated escarpment have approximately the same trend.

The thickness variations of the three limestone groups of the Missourian series (Bronson, Kansas City, and Lansing) combined are shown in figure 17B. Little structural movement of a regional character is indicated during the time interval represented by the deposition of these rocks. There is a gradual thinning of the detherefore, a less reliable criterion of anticlinal structure than it is in central Kansas. The thickness of the overlying lower Pennsylvanian rocks and the particular formation encountered at the top of the Mississippian must also be taken into account in determining the relation of the thickness of the Mississippian to structure.

The three areas in which Mississippian limestones are thin in southern Douglas county and in central Franklin county (Lee, 1940, pl. 1) are areas in which the Cherokee rocks are thick (figs. 17 and 18). In the light of information now available, the thinning of the Mississippian in these places is interpreted as due to pre-Pennsylvanian erosion of the Mississippian surface. A slow and gentle growth of most of the post-Mississippian local structural features continued through the Pennsylvanian and probably into the Permian. Most of the local structural features are parallel to the Nemaha anticline and it is presumed that these folds accompanied development of that anticline.

Regional Deformation During the Pennsylvanian

The thickness of the sequence of rocks between the top of the Mississippian and the base of the Hertha limestone includes the Cherokee shale and the Marmaton and the Bourbon groups (see figs. 17 and 18). Unlike most other sequences for which thickness maps have been prepared, this sequence is bounded below by a peneplaned surface modified by deformation and erosion. The upper limit of the sequence was essentially horizontal. The thickness maps (figs. 17 and 18), therefore, indicate the nature and magnitude of the structural movements that took place between development of the post-Mississippian peneplain and the deposition of the Hertha. The indicated magnitude of these structural movements is only an approximation because there was local erosion of the peneplain before submergence. Discrimination between structural relief and erosional relief, two factors that control the thickness, cannot be made with any confidence from logs of single wells. In the McLouth field and adjoining areas, where samples from about 150 wells have been examined, the distinction between erosional and structural variations can be made with confidence in some localities. Where there is an abrupt increase in the interval from the lowest datum bed in the Cherokee to the top of the Mississippian and where in the same place the posits toward the north from about 400 feet near Emporia to about 300 feet near the Nebraska line. This is interpreted as the result of a gentle regional tilting toward the south. There is a slight, although vague, thinning in the uplifted area west of the Nemaha anticline and a slight thickening in the Forest City basin area, which by this time had become merely a northern extension of the Cherokee sea. These changes in thickness, though low, probably indicate slight movement both along the Nemaha escarpment and in the basin to the east.

The thickness of the rocks from the top of the Stanton limestone to the base of the Oread limestone is shown in figure 18A. This interval includes the shale deposits of the Pedee and Douglas groups. The time interval represented by the deposition of these rocks is augmented by unconformities within these groups and by the unconformity that separates the Missourian and Virgilian series. The map shows a gradual convergence of the limiting surfaces toward the west from more than 350 feet in the syncline in southwestern Douglas county to 50 feet in Riley county. There is local thickening in the synclinal extensions of the Cherokee basin. The thickness map is interpreted as indicating a revival of synclinal folding which was greater toward the south than toward the north, but with little or no activity of either the Nemaha anticline or the eastward-facing escarpment.

The thickness map of the Shawnee group (fig. 18B) shows only moderate changes in thickness east of the Nemaha anticline, but abrupt thinning from more than 350 feet east of the escarpment to less than 250 feet on the crest. The thickness relations suggest that during Shawnee time the synclinal flexing of the Cherokee basin declined but that movement along the escarpment was revived.

Post-Pennsylvanian Structural Movements

The cross section of Kansas prepared by Betty Kellett (1932) shows pre-Cretaceous westward tilting and also truncation of Permian rocks by Lower Cretaceous rocks. Therefore, much of the westerly dip that characterizes the surface rocks of the present day took place prior to the deposition of the Lower Cretaceous rocks of Kansas. The Cretaceous rocks were deposited at or below sea level but have been raised several thousand feet to their present position without much tilting or regional deformation.

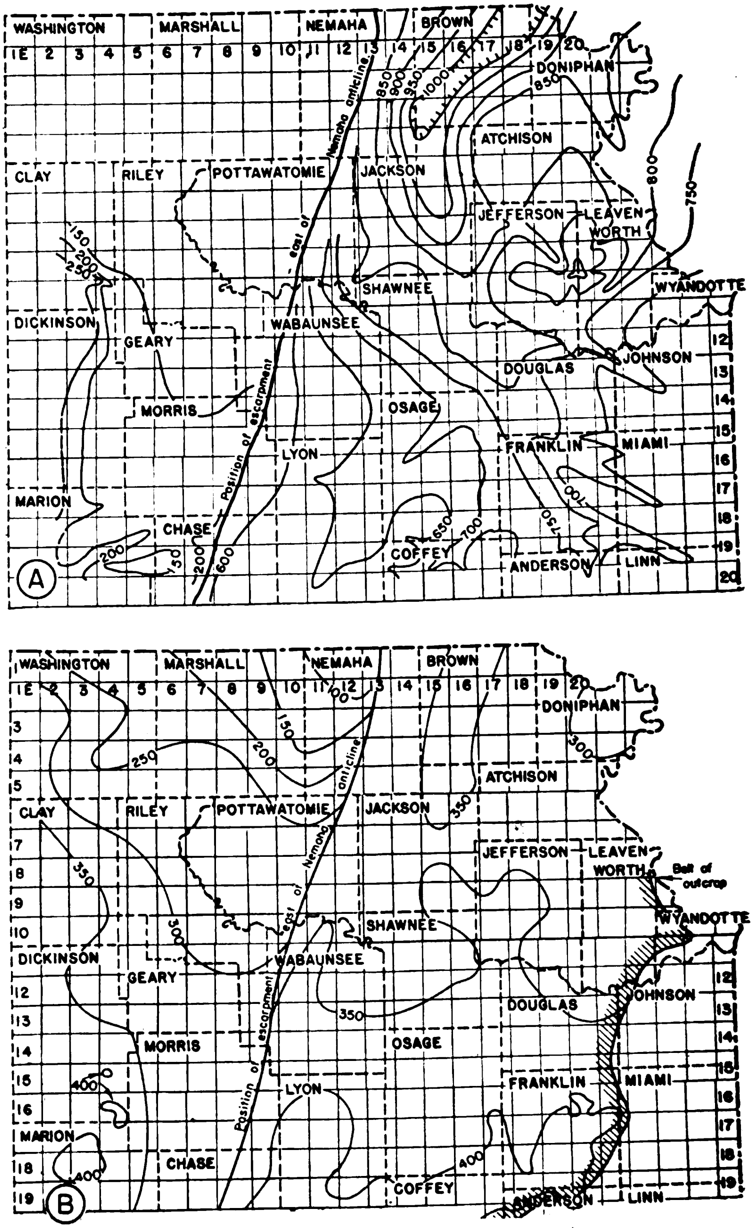


Fig. 17. Maps of northeastern Kansas showing thickness of (A) rocks of Cherokee, Marmaton, and Bourbon age, and (B) rocks of Bronson, Kansas City, and Lansing age. Isopachous lines connecting points of equal thickness are drawn at intervals of 50 feet.

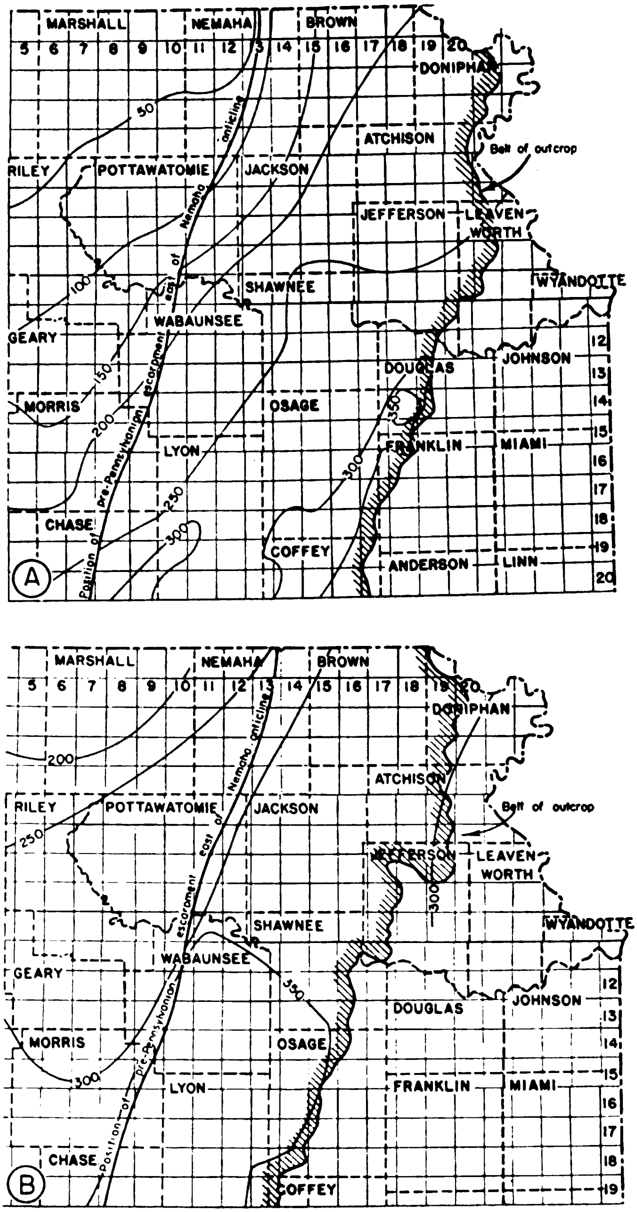


FIG. 18. Maps of northeastern Kansas showing thickness of (A) rocks between the top of the Lansing group and the base of the Shawnee group, and (B) rocks of Shawnee age. Isopachous lines connecting points of equal thickness are drawn at intervals of 50 feet.

The westward dip of the surface rocks of Pennsylvanian and Permian age of northeastern Kansas is now about 15 feet per mile. The eastern limit of the Permian sea is unknown, but there is good reason to believe that at least 2,000 feet of sediments at one time were deposited above the Lansing limestone in northeastern Kansas. Such a thickness must have carried the Permian rocks into the Mississippi valley where no trace of them survives.

STRUCTURAL DEVELOPMENT OF ANTICLINES

The direction and amount of regional dip, as already pointed out, have varied widely at different periods in the structural development of the region and at times in different places during a single period. From the relations of pre-Mississippian and post-Mississippian regional structure it is concluded (Lee, 1939, p. 32) that the Nemaha anticline and other northeasterly trending folds did not develop until the end of Mississippian time. These folds continued their growth by small increments of deformation during the deposition of Pennsylvanian and Permian rocks.

The relation between surface anticlines of low structural relief and deeper rocks in which the regional dips increase with depth is illustrated in figures 20 and 21. The effect of late deformation on rocks in which the cumulative regional dip has been mainly in the same direction as on the southeast side of the Forest City basin is illustrated in figure 20. The effect of surface folds on the deeper rocks where the regional dips have been at times in opposite directions is illustrated in figure 21. The structural features shown on all three figures are greatly exaggerated, for they are sketches that have not been drawn to scale. The principles involved in the formation of these structural features appear, as will be noted from the following discussion, to be applicable to the structural features of the Forest City basin.

Most of the anticlines mapped on the surface rocks of northeast Kansas are of low structural relief and have small easterly dips. In the oil and gas fields of the area that have been studied, however, the structural relief increases materially with depth. The increase in structural relief of most such anticlines in early Pennsylvanian and Mississippian rocks is great enough to result in easterly dips in depth in spite of the earlier low cumulative regional dips of 10 to 12 feet per mile to the west in the older rocks. Changes in the direction of regional dip at different times,

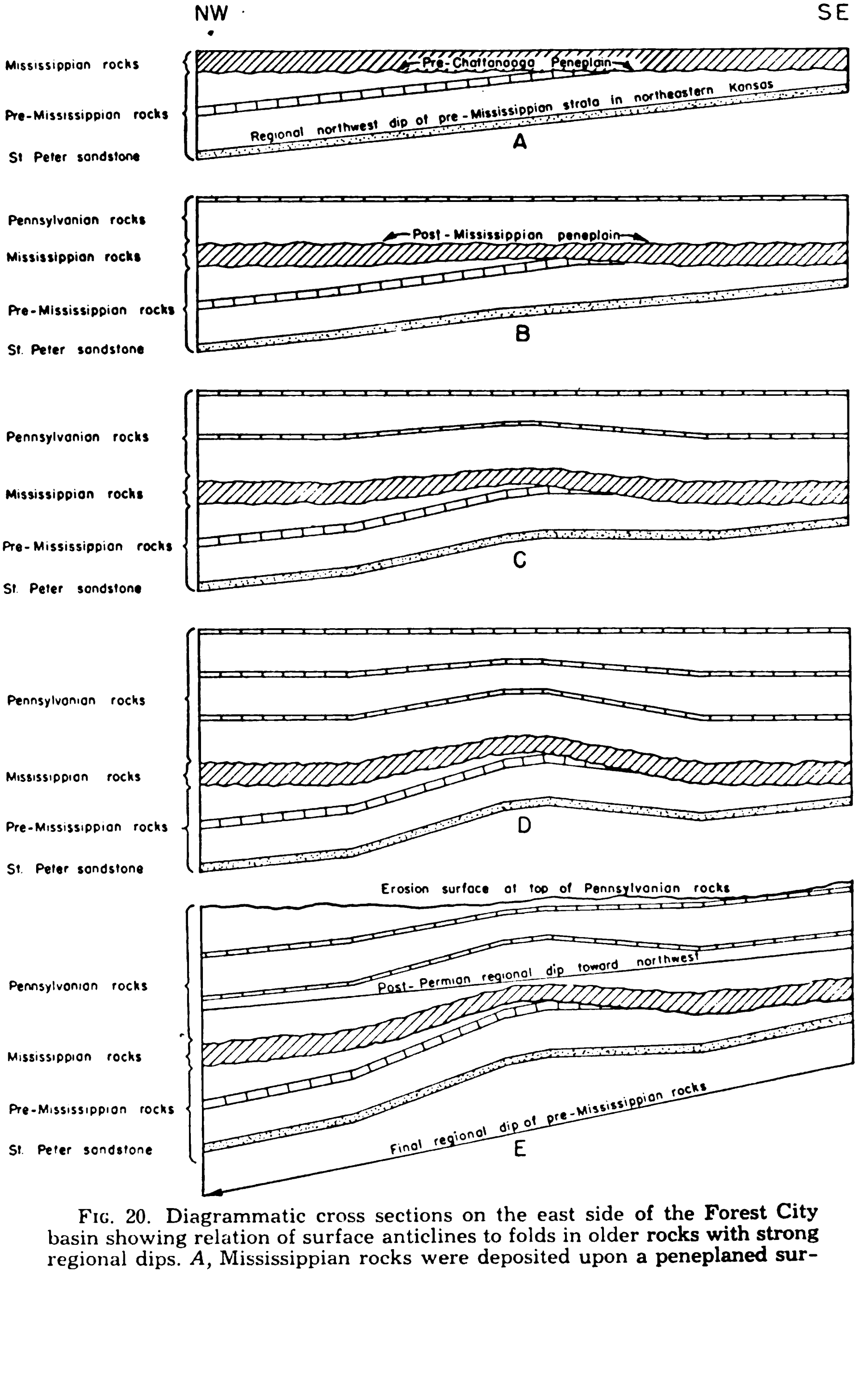


Fig. 20. Diagrammatic cross sections on the east side of the Forest City basin showing relation of surface anticlines to folds in older rocks with strong regional dips. *A*, Mississippian rocks were deposited upon a peneplaned sur-

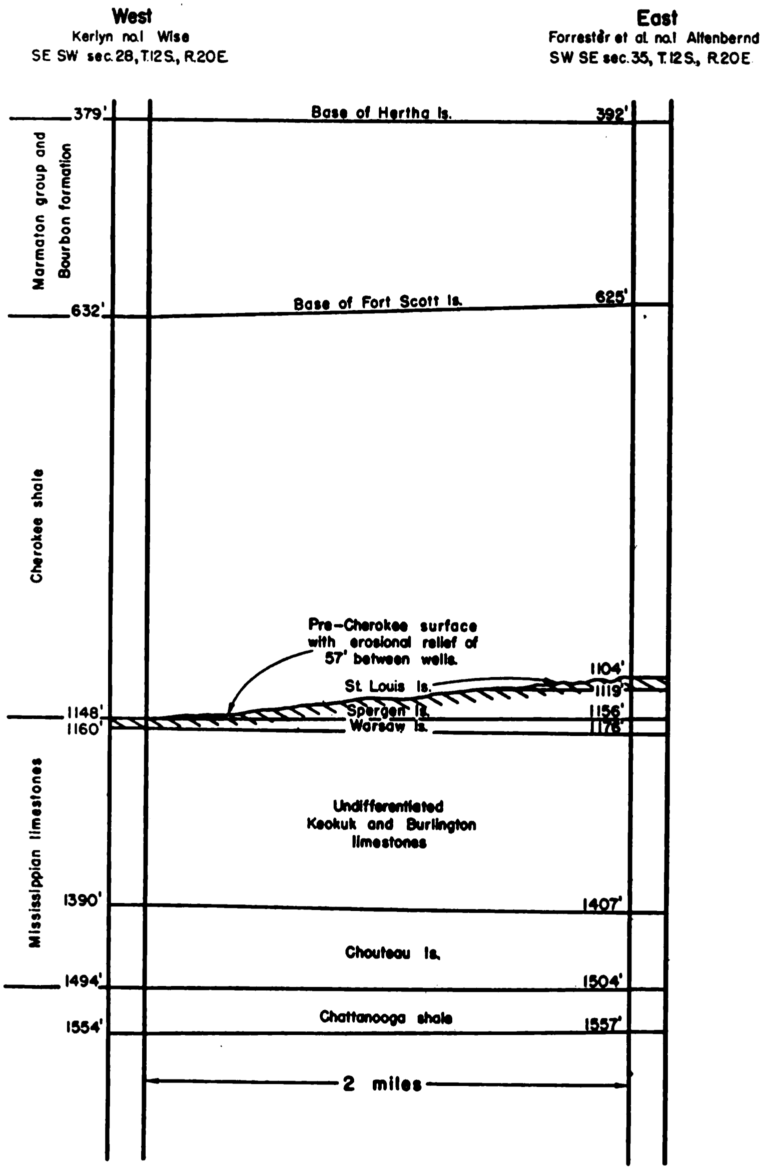


FIG. 19. Cross section between the Wise and Altenbernd wells in Douglas county, Kansas, showing erosional relief of 57 feet on top of Mississippian limestones. The wells are 2 miles apart. Both St. Louis and Spergen rocks were eroded at the Wise well.

Numbers at left of wells show depths below the surface.

however, may alter the amount of closure and the position of the crest in the older rocks.

Regional tilting of the region, such as occurred after the Pennsylvanian, reduces the amount of closure of the anticlines in the tilted rocks. Low anticlines in exposed rocks existing prior to the regional tilting may be reduced in this way to a bench or a structural nose, as illustrated in cross section, diagram E of figure 20 and in diagram D of figure 21. Where there is a considerable thickness of Pennsylvanian rocks below the surface, the amount of folding generally increases materially with depth, for these rocks were being progressively deformed during deposition. The regional dip may thus reduce the expression of a low anticline at the surface to a structural nose, but the increase in the amount of folding in depth will prevent loss of closure in the older Pennsylvanian rocks and in the Mississippian. On account of the increase of structural deformation with depth, a structural nose at the surface indicates the probability of a closed anticline below the surface and a low anticline may safely be expected to develop greater structural relief down to the Mississippian. In a low surface anticline, however, the regional dip may induce a shift in the position of the crest up dip from its position in the deeper rocks. These relations are well exemplified in the McLouth field.

Although there is an increase in structural relief in depth from middle and upper Pennsylvanian rocks down to the Mississippian, there is only slight increase in passing downward from basal Pennsylvanian rocks into the Mississippian. Thus the closure of weak anticlines mapped on lower Pennsylvanian rocks will probably be destroyed in the older rocks by the regional dip as shown on the St. Peter sandstone in diagram E of figure 20.

The average dip of the St. Peter sandstone on the eastern side of the Forest City basin is about 20 feet per mile toward the northwest (see fig. 22). The dip becomes less in the deeper parts of the

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face of northwestward dipping rocks. *B*, Post-Mississippian erosion on a low post-Mississippian fold followed by deposition of early Pennsylvanian rocks. Note structural closure in beds at base of Mississippian but lack of closure in underlying tilted formations. *C*, Increased folding during deposition of early Pennsylvanian rocks. Note lack of structural closure in the St. Peter sandstone. *D*, Further increase of folding during deposition of Pennsylvanian produces a limited area of closure in pre-Mississippian rocks. *E*, A regional northwestward tilting of the entire section in post-Permian time. Low folds in upper Pennsylvanian rocks are reduced to structural noses or terraces; closure of stronger folds in lower Pennsylvanian and Mississippian rocks is reduced in areal extent and closure in pre-Mississippian rocks is lost.

basin, and although the control for contouring is inadequate it appears probable that in a narrow belt on the east side of the Nemaha anticline the St. Peter has a dip toward the east. Comparative figures for the dip in feet per mile for the top of the St. Peter sandstone and for the base of the Hertha limestone between selected wells are shown in figure 22. It will be noted that dips at the top of the St. Peter on the southeastern side of the Forest City basin are two or more times as steep as the corresponding dips at the base of the Hertha and that in the deeper parts of the basin they are about the same.

On the east side of the basin only those surface anticlines that have southeasterly dips of more than 20 feet per mile or those whose dip in this direction increases in depth to more than 20 feet per mile may be expected to form anticlines in the St. Peter sandstone. The crest of folds that register as low anticlines in the St. Peter sandstone will be found to shift materially up dip. On the other hand, anticlines in the deepest part of the Forest City basin and on its narrow western side probably overlie anticlines in the St. Peter of commensurate size with those at the base of the Hertha limestone.

Northwestward trending folds.—The previous discussion applies to the northern or northeastward trending anticlines or other folds initiated contemporaneously with the Nemaha anticline at the end of Mississippian time. The age and relations of the northwestward trending folds are less well known.

Northwestward trending folds of regional character are represented in eastern Kansas by the Chautauqua arch, along which movement began shortly after deposition of the St. Peter sandstone. The Central Kansas uplift is a continuation of the Chautauqua arch and was probably initiated at the same time. Contemporaneous also is a syncline flanking the Central Kansas uplift on the north. This syncline constitutes one element of the subsequently formed Salina basin. Prior to the development of the Nemaha anticline this syncline appears to have continued to the southeast across the trend of the later formed Nemaha anticline, for the Nemaha anticline is interrupted by a saddle which is revealed by the thickness map of the Mississippian rocks (Lee, 1939, p. 32 and pl. 1) in continuation of the Salina syncline. Not enough deep wells have been drilled through the pre-Mississippian rocks in most areas to prove the early age of northwestward trending folds. It appears probable that the Bourbon arch, the northern flank of the Salina basin, and other less well defined northwestward trending structural features expressed in the Mississippian

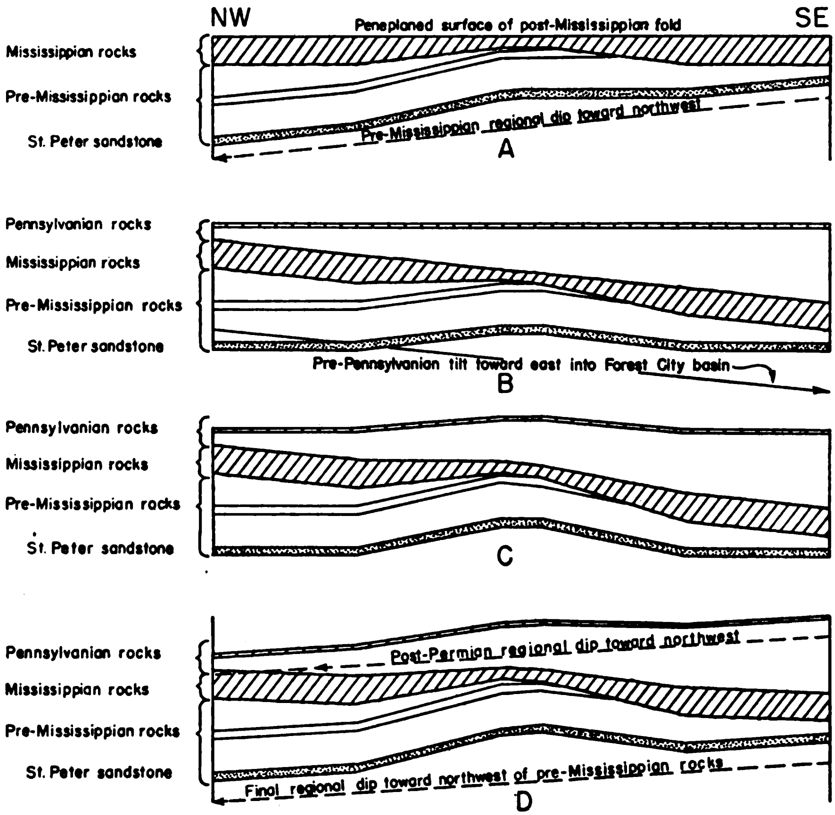

FIG. 21. Diagrammatic cross sections on the west side of the Forest City basin showing the relation of surface anticlines to folds in older rocks where regional tilting to the east is followed by folding and then regional tilting to the northwest. *A*, Peneplanation of a post-Mississippian fold. The folding is not strong enough to cause more than a monoclinal fold in northwestward-dipping pre-Mississippian rocks. *B*, Pre-Pennsylvanian tilting toward the east during the development of the Forest City basin. The eastward dip nearly destroys the structural closure at the base of the Mississippian, but the monoclinal fold becomes the east flank of an anticline. *C*, Increased folding during deposition of the Pennsylvanian produces an anticline in the Pennsylvanian rocks. The structural closure in the anticline at the base of the Mississippian is slightly increased and the position of the crest is shifted. Structural closure in pre-Mississippian rocks is increased also. *D*, Northwestward regional tilting of the entire section of rocks in post-Pennsylvanian time. Structural closure in Pennsylvanian rocks is reduced or destroyed but is increased at the base of the Mississippian. Closure in pre-Mississippian rocks is decreased but not lost.

and younger rocks are the result of renewed movement of structural features initiated contemporaneously with the Chautauqua arch. Local northwestward trending folds, such as the northwestward trending productive anticlines in Chautauqua, Elk, and Wilson counties revealed by thinning of the Mississippian formations and other similar folds elsewhere expressed in Mississippian and younger rocks, may also have been initiated prior to the Nemaha anticline and subsequently revived. The northwestward trending folds of low structural relief that have been mapped in the Pennsylvanian surface rocks of Miami, Johnson, and other counties of northeastern Kansas and in Missouri may also have had a pre-Mississippian history.

The structural relief of folds initiated in pre-Mississippian time may be expected to increase with depth below the Mississippian; and, other conditions being equal, adequately closed northwestward trending anticlines, if any exist in northeastern Kansas, would thus be more favorable for the occurrence of oil and gas in the deep zones than the northeastward trending anticlines.

STRATIGRAPHIC TRAPS

Any porous zone, whether it consists of a bed of sandstone or conglomerate or is produced by the weathering of limestone or dolomite, may theoretically constitute a reservoir rock if the conditions of porosity die out up the regional dip. Most of the pre-Pennsylvanian rocks of Kansas are limestones. Their deposition was many times interrupted by exposure, and weathering in varying degree resulted in the development of porosity. The exposure at times was brief but at others it was long enough to develop considerable relief. At times erosion proceeded to peneplanation. In most areas, however, limestone was deposited upon the weathered limestone surface, and the calcareous deposits appear to have recemented the superficial porous zones and also cemented the residual debris formed by weathering. For this reason most of the weathered zones beneath unconformities are not now conspicuously porous unless overlain by shale or sandstone. In the McLouth field, however, porosity has been preserved in a weathered dolomite zone of middle Mississippian age unconformably overlain by limestone. This zone of weathering yields oil in anticlinal areas; and, as the zone of porosity appears to have been nearly flat, deformation has affected it in the same way as deposits, such as sandstone, which were deposited with original porosity. Where weathered zones in limestone are overlain by shale or sand, as at the base of the Pennsylvanian rocks and at the base of the Chattanooga shale, or where solution zones occur at former groundwater levels below the top of the limestone, the openings in the limestone have in general not been closed by cementation. They thus provide reservoir rocks in the Devonian, Kimmswick (Viola), and Arbuckle limestones, all of which, though of varied productivity, have yielded oil under favorable structural conditions.

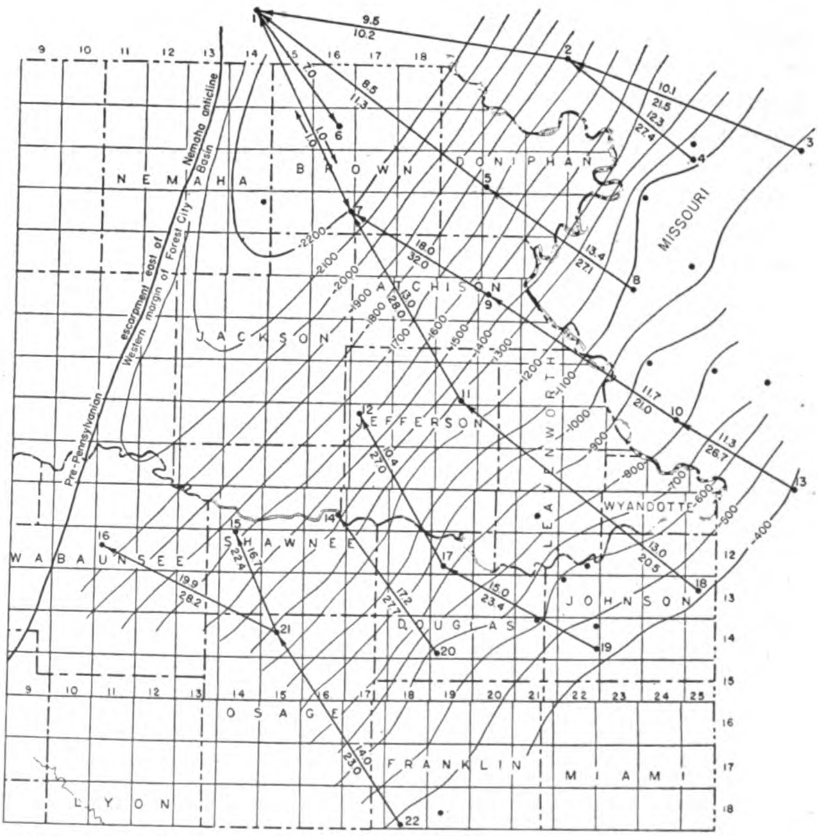

Fig. 22. Contour map of northeastern Kansas and adjacent areas showing the structure of the top of the St. Peter sandstone.

The average rate of dip of the base of the Hertha limestone is indicated by figures in feet per mile above the lines connecting the wells, and the dip of the top of the St. Peter sandstone by figures below the lines. The arrows indicate the direction of dip between wells. Altitudes of contours are in feet below sea level. Structure contour interval is 100 feet.

Experience has shown that oil has been trapped beneath anticlines in these porous zones in much the same way as in porous sedimentary rocks. There is no good reason why porous zones should not produce oil locally on monoclinal folds where porosity decreases up dip, but the occurrence of oil under such conditions seems unpredictable.

Conditions for the formation of stratigraphic traps might be expected at the beveled edges of sandstone beds where the rocks have been tilted and peneplaned. The beveling of the sandstone, however, involves also the beveling and weathering of the adjacent limestones. In consequence, although the beveled surface of the sandstone may be sealed above by shale, the weathered limestone on the peneplaned surface may form a porous zone continuous with the wedge end of the sandstone. The lateral continuity of porosity from the sandstone into the surface of the limestone in most places, therefore, may prevent the sealing of the sandstone necessary to the formation of a stratigraphic trap. The beveled edge of the St. Peter sandstone on the north flank of the Chautauqua arch is an example. Here the porosity of the weathered Ordovician rocks adjoining the St. Peter on the beveled surface probably leaves the way open for lateral escape. Under these conditions suitable folding, though not necessarily anticlinal, appears to be necessary to effect a trap.

The sandstone found at the base of the Devonian in northeastern Kansas may have been deposited in some places under conditions favorable to the formation of a stratigraphic trap. This sandstone was deposited at the unconformable contact of the Devonian limestone on the Silurian dolomite. Although the sandstone is calcareous in most places, it appears to be porous enough in some wells in Douglas, Johnson, and Jefferson counties to be a potential reservoir rock under favorable stratigraphic or structural conditions.

On the whole, conditions do not appear to be very favorable to the formation of stratigraphic traps along the beveled edges of pre-Chattanooga rocks without the addition of favorable structural conditions.

The lenticular character of sandstone beds in the lower Pennsylvanian is well known. Many oil and gas pools have been found in eastern Kansas in stratigraphic traps in the lower Pennsylvanian in lenticular bodies of sandstone, and in sandstone grading up into impervious shale.

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INDEX