Stratigraphy and Structural Development of the Salina Basin Area

By

WALLACE LEE

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BULLETIN 121

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By Wallace Lee

ABSTRACT

This report describes the stratigraphy and structural history of the Salina basin in Kansas and adjoining areas. The stratigraphic descriptions are based on microscopic examination of samples from wells. The rocks of the area range in age from Precambrian to Quaternary, but many hiatuses make the record incomplete.

Stratigraphy.—The Precambrian rocks consist of red granite or granitic gneiss.

The Upper Cambrian Series is represented by the Lamotte sandstone and the Bonneterre dolomite. The Lamotte sandstone is essentially the equivalent of the Reagan sandstone of Oklahoma. The Lamotte is absent in parts of the Salina basin area but is locally as much as 60 feet thick. It grades upward into noncherty slightly sandy glauconitic Bonneterre dolomite, which reaches a thickness of about 200 feet.

The Lower Ordovician Series is represented in central Kansas only by the Roubidoux, Jefferson City, and Cotter formations and the St. Peter sandstone. The Roubidoux, which overlies the Bonneterre unconformably, is widely distributed but is absent on the crest of the Southeast Nebraska arch and parts of the Central Kansas uplift. In the Salina basin the Roubidoux consists of sandy and slightly cherty dolomite averaging about 140 feet thick. The undivided Jefferson City—Cotter sequence, which is composed of cherty and sandy dolomite, thin beds of sandstone, and shale, has a thickness of about 300 feet. The St. Peter sandstone, which is a part of the Simpson group, is mainly friable sandstone of rounded and subrounded grains but includes some green shale. It is unconformable on all the older rocks. Where the overlying rocks are conformable on the St. Peter its thickness ranges from 12 to 80 feet.

The Middle and Upper Ordovician rocks of the Salina basin are the Platteville formation, the Viola limestone (Kimmswick limestone of Missouri), and the Maquoketa shale (Sylvan shale of Oklahoma). The Platteville and the St. Peter are partial correlatives of the Simpson group of Oklahoma. The Platteville consists of limestone and shale, and thickens northeastward from a featheredge to more than 100 feet at the Nebraska border. The Viola, which consists of dolomite and limestone banded with spicular chert, has a thickness of 295 feet near the Nebraska line but thins southward. The Maquoketa consists of silty dolomitic shale, parts of which grade locally into cherty shale and argillaceous and cherty dolomite. It is disconformable on the Viola, and its thickness ranges from 30 to 143 feet.

Silurian rocks consist mainly of coarsely sucrose and granular dolomite, divisible into five zones. The basal dolomites are generally oölitic. Thickness of the Silurian rocks ranges from a featheredge in the south, where the Silurian was beveled by pre-Devonian erosion, to 445 feet near the Nebraska border.

Devonian rocks are composed mainly of dolomite, but in the southwestern part of the area limestone is included. In Lyons County, the Devonian rocks thicken in a valley eroded in the pre-Devonian outcrop of the Maquoketa shale. The Devonian overlaps southward across the truncated margins of Silurian to upper Arbuckle beds, but hills as much as 80 feet high stood above the general level of the surface. In most areas, the upper surface of the Devonian rocks was beveled by pre-Chattanooga erosion, but in McPherson County and adjoining counties broad open valleys about 150 feet deep dissected the Devonian rocks and cut into older formations. Because of the unconformities at the top and bottom of the Devonian, its thickness is irregular, increasing from a featheredge at its margin in the southern part of the area to 213 feet in the north.

The Chattanooga shale and the Boice shale, which lie between Devonian and Mississippian limestones, are of uncertain age. The Chattanooga includes the basal Misener sandstone, a sandy shale in most areas. It filled the McPherson and tributary valleys, where its thickness locally exceeds 250 feet. In the tributary valley in Reno and Rice Counties the Chattanooga shale includes a lentil of slightly argillaceous gray limestone having a maximum thickness of 80 feet. Except where it filled such valleys, the Chattanooga overlies a beveled surface and toward the south overlaps in succession upon Devonian to Arbuckle rocks. East of the Nemaha anticline its thickness increases from 50 feet in the southwestern corner of the area to more than 250 feet in the northeastern corner. The Boice shale, which unconformably overlies the Chattanooga, is of variable thickness. Its base is characterized by red shale or ferruginous oölites.

The Mississippian limestones of the Salina basin consist, in ascending order, of the upper member of the Sedalia dolomite and the Gilmore City limestone of Kinderhookian age; the St. Joe, Reeds Springs, Burlington, and Keokuk limestones of Osagian age; and the "Warsaw" and Spergen limestones of Meramecian age. Most of these formations are separated from each other by disconformities. Because of post-Mississippian erosion the Mississippian formations in north-central Kansas are confined to the Salina basin, although most of them were originally more widespread.

The thickness of the Mississippian rocks as a whole is closely related to structural features. In the deepest part of the Salina basin these rocks are 350 feet thick, but on the margin of the basin, as well as on the crests of local anticlines, the uppermost Mississippian formations were beveled or removed by pre-Pennsylvanian erosion.

The rocks of Pennsylvanian and Permian age consist of numerous cyclothems, alternating sequences of limestone, marine and nonmarine shales, and sandstone. Each sequence was deposited during a depositional cycle that included an advance and retreat of the sea. If a period of emergence was long, the deposits of the previous cycle of deposition were locally dissected and in certain areas completely removed.

The Cherokee shale, of Desmoinesian Pennsylvanian age, consists mainly of alternating beds of shale and sandstone interstratified with coal and thin limestone. The limestones are discontinuous, either because of local deposition or intercyclical erosion. The Cherokee is about 240 feet thick in the center of the Salina basin but is absent because of nondeposition on the Central Kansas uplift and the northern end of the Nemaha anticline. The Marmaton group, the next higher unit, consists of alternating limestone and shale formations, which are not sharply differentiated from each other in the subsurface. The group is about 130 feet thick in the Salina basin.

Missourian rocks, constituting the lower part of the Upper Pennsylvanian, are separated from Desmoinesian formations by an unconformity that is marked by channeling and a faunal change. Missourian rocks are represented in the Salina basin by the Pleasanton, Kansas City, and Lansing groups. The Pleasanton consists of less than 25 feet of shale. The Kansas City and Lansing groups are chiefly limestone and interbedded shale deposited in cyclical succession. The combined thickness of these two groups is 285 feet in the deepest part of the Salina basin. In some areas, the cyclical oscillation raised the rocks enough above sea level for long enough time for erosion to develop considerable topographic relief. Most such broad open valleys and minor depressions of the surface were filled and leveled off by the initial clastic deposits of the succeeding cycle.

The Virgilian rocks, which are separated from the Missourian by an important unconformity, consist of the Douglas, Shawnee, and Wabaunsee groups. In the Salina basin the Douglas group consists of shale less than 25 feet thick. The Shawnee group resembles the Kansas City and Lansing groups in the cyclical deposition of limestone and shale beds. In the Salina basin, which at this time had become a structural embayment, the thickness of the Shawnee group is 244 feet in the northern part, increasing toward the southeast. The Wabaunsee group consists mainly of shale with many thin interbedded limestone beds. In some parts of Kansas, it has a wide range of thickness because of local channeling during the hiatus between the deposition of Pennsylvanian and deposition of Permian rocks, but no indication of channeling was recognized in the Salina basin area, where the Wabaunsee is about 350 feet thick.

The Wolfcampian Series, at the base of the Permian, consists of the Admire, Council Grove, and Chase groups. The contact of the Permian and Pennsylvanian rocks in the Salina basin area seems to be a mature erosional surface. The Admire lithologically resembles the underlying Wabaunsee group and is about 90 feet thick. The Council Grove group consists of alternating limestone and shale formations in about equal proportions. Much of the shale is red, and much of the limestone is impure and shaly. The group is about 300 feet thick. The Chase consists of about equal proportions of shale and more or less cherty limestone. It is 250 feet thick.

The Leonardian Series, which overlies the Wolfcampian, consists of the Sumner and Nippewalla groups. The Sumner group includes the Wellington shale, which consists mainly of gray shale interstratified with beds and laminae of anhydrite, and the Hutchinson salt member near the middle of the formation; the Ninnescah red sandy shale; and the Stone Corral dolomite and anhydrite. The salt member is present only in the southwestern part of the area. The salt beds become plastic under pressure and tend to flow toward anticlinal areas. The local thickening of the salt exaggerates the structural relief of anticlines in beds above the salt. The thickness of the Sumner group varies sharply with the thickness of the salt. The Sumner group is represented only in the western counties of the area, where its average thickness is about 650 feet in areas not underlain by salt. The thickness increases to more than 1,200 feet in the southern part of the area, where both salt and shale beds thicken.

Rocks of Cretaceous age have an aggregate thickness of more than 1,000 feet on the western border of the Salina basin area. They include the Cheyenne sandstone and Kiowa shale of the Comanchean Series, and the Dakota formation, Graneros shale, Greenhorn limestone, Carlile shale, and Niobrara chalk of the Gulfian Series.

The Tertiary and Quaternary Systems are represented by alluvial deposits in ancient valleys and on high-level benches. In the northeastern part of the area, glacial till and loess occur in upland areas. These deposits are more than 150 feet thick at some places and in large areas conceal the underlying consolidated rocks of Cretaceous, Permian, and earlier age.

Structural development.—Study of the structural development of the Salina basin and adjacent areas has been carried on by preparation of thickness maps and stratigraphic cross sections.

Five periods of regional warpings are distinguished.

(1) Arbuckle dolomites were deformed and beveled by erosion before the deposition of the overlying St. Peter sandstone. A synclinal basin, in which Arbuckle rocks more than 2,000 feet thick were deposited, was developed in central and eastern Missouri. This basin was flanked on the west by the Southeast Nebraska arch, an anticline that was beveled to Precambrian granite before the deposition of the St. Peter sandstone. A broad syncline trending northwest across a part of the area that later became the Central Kansas uplift was contemporaneously developed southwest of the Southeast Nebraska arch.

(2) A conflicting pattern of regional warping that developed between St. Peter and Mississippian time transformed the Ozark basin into the Ozark uplift, and the Southeast Nebraska arch into the North Kansas basin, which subsided 1,200 feet in the area mapped. The Chautauqua arch and the initial movements of the Central Kansas uplift and the Hugoton embayment were contemporary structural developments.

(3) A third period of deformation began early in Mississippian time, culminated at the end of Mississippian time, and continued with decreasing emphasis until middle Permian time. The most conspicuous structural feature of this period was the Nemaha anticline, which divided the older North Kansas basin, giving rise to the Forest City basin on the east and the Salina basin on the west. The Central Kansas uplift and the Hugoton embayment attained their maximum development during this period. Arching of the Central Kansas uplift ceased with the downwarping of the salt basin in Wellington time. The Chautauqua arch became inactive before Mississippian time.

(4) The records of subsequent structural events in eastern Kansas have been lost by erosion of significant formations. Surviving formations in western and central Kansas indicate that after Wellington time, when arching of the Central Kansas uplift ceased, the areas in which the Central Kansas uplift and the Salina basin had previously been developed were tilted toward the Hugoton embayment, greatly extending its northeastern limb.

(5) Details of post-Cretaceous deformation are obscure in eastern Kansas. Isopachous and structure maps in western Kansas reveal pre-Cretaceous and post-Cretaceous deformation, which tilted that region northward and northwestward toward the Denver basin (Lee and Merriam, 1954). In eastern Kansas the composite of these movements is expressed in the Salina basin by the northwestward tilting of surviving areas of the Dakota in the Salina basin and the general northwestward dip of the underlying Permian and Pennsylvanian rocks.

Each change in the pattern of structural movement altered the attitude of pre-existing anticlines as well as other regional structural features. Changes in the direction of dip shifted the position of the crest of some low anticlines and destroyed the closure in others. In consequence, the exposed crests of low anticlines in the younger rocks do not necessarily reveal accurately the position and configuration of those anticlines in older more steeply dipping rocks.

The repeated changes in the pattern of deformation and the repeated re-elevation and beveling of the formations must have influenced the migration and distribution of fluids in the rocks. Each structural movement, particularly those involving changes in the direction of dip, caused readjustments in the distribution of connate water. The movements of nascent gas and oil must also have been affected, and probably some earlier accumulations of oil and gas were dispersed up dip.

The maps show the areas in which well-known zones of production are absent, owing to erosion or to nondeposition. The areas in which potentially productive zones wedge out beneath beveled surfaces are at least theoretically favorable to the development of stratigraphic traps.

Available data from the thickness maps of this report suggest that northeasterly and northwesterly trending folds may be concealed by or only weakly revealed in the Cretaceous and Upper Permian rocks in the central and northern parts of the Salina basin.

INTRODUCTION

The original report on the Salina basin was prepared during the period from September 1943 to June 1946 by Wallace Lee with the collaboration of Constance Leatherock and Theodore Botinelly, under a cooperative agreement between the Geological Survey of Kansas and the U. S. Geological Survey. By 1950 so many new wells had been drilled in the area that it became desirable to revise the original report, again under a cooperative agreement between State and Federal Surveys. The new data proved to be so voluminous, however, that it has been necessary to reexamine all phases of the original report and to prepare new maps and many new cross sections. The completion of the work in 1953 to 1955 has been carried on by the State Survey without Federal cooperation.

The work of Leatherock and Botinelly for the original report has been invaluable in the revision, but the examination and coordination of data from new wells, several times as numerous as were formerly available, have been carried on by the present author. All data available to June 15, 1955, have been incorporated in the revised report (Fig. 1).

It is probable that even before the publication of this bulletin, new wells will provide increased information at many points. The project was designed primarily as a study of regional deformation and, except locally, the data do not warrant isopachous lines drawn

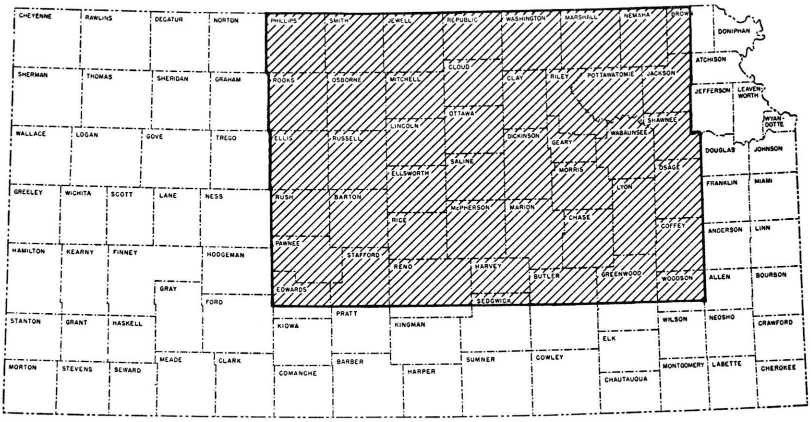


FIG. 1.—Map of Kansas showing area covered by this report.

at intervals less than 50 feet. Closer contouring based on accurate records would reveal much of interest in the growth of local anticlines, but such detail was not the object of this report. New data will ultimately reveal desirable information in the northern parts of the Salina basin, where few wells have been drilled.

The report follows the plan of the earlier report on the Salina basin (Lee, Leatherock, and Botinelly, 1948). The analysis of the complex regional stratigraphy and structure with which the report is primarily concerned will be useful in guiding future drilling, not only in this area but also in bordering areas where the relations of overlap and regional structure are similar and have an important bearing on the accumulation of oil. Local structural features, to which oil company geologists give special attention, have not in general been the subject of study in the present investigation.

The Salina basin was first defined by Barwick (1928, p. 179) as "The pre-Pennsylvanian syncline bounded on the east by the Nemaha granite ridge [now Nemaha anticline], on the southwest by the Barton arch [now Central Kansas uplift] and on the south by the saddle between the Chautauqua arch and the Barton arch. The basin continues northward into Nebraska where its exact termination is not known." The Barton arch, a name suggested by Barwick, is now more generally known as the Central Kansas uplift, and since 1926 (Ley, 1926) the Nemaha granite ridge has been recognized as a post-Mississippian beveled anticline.

The Salina basin lies on the margin of an earlier structural basin referred to by Rich (1933) as the North Kansas basin. The Salina basin had no separate existence until the uplifting of the Nemaha anticline divided the North Kansas basin and developed the Salina basin on the west and the Forest City basin on the east. These basins were at first structural basins revealed by the beveling of Pre-Pennsylvanian rocks. During Pennsylvanian time they were subsiding areas in which Pennsylvanian deposits accumulated in greater thickness than on the margins.

Most of the Salina basin lies in Kansas, but synclinal warping extended northwest into Nebraska, and the northeastern flank of the basin extends north into Nebraska along the west side of the Nemaha anticline. No attempt has been made in this report to study the Nebraska portion of the Salina basin and adjoining structural features.

The data upon which the report is based were derived from sample logs of wells prepared in the Geological Survey of Kansas, sample logs of the Kansas Sample Log Service, electric logs, drillers logs by unidentified geologists, and old drillers logs of cable-tool wells. The last have been used with caution in areas where no other data are available.

Many old drillers logs could not be used, owing to inaccurate logging or obvious unrecorded corrections of depth. The logs of many early wells generally designate as sand all cherty beds, water-bearing beds, and coarsely sucrose dolomites. Through a comparison of these old logs with recent electric and sample logs, it has been possible to identify essential datum beds in many logs that were previously discarded.

The data are of unequal value, on account of the character of samples available, inaccuracies in measuring depths, unequal lag of samples from rotary wells, and other factors. Electric logs are most dependable and old drillers logs least so. Some logs in all categories had to be rejected for obvious errors. There is almost an embarrassment of wells in the southern part of the area, but in parts of the Salina basin the wells are widely scattered.

The criteria by which most of the formations have been identified were determined at identified outcrops, many of which are distant from the Salina basin. Facies changes in the subsurface have been determined by comparison of samples and insoluble residue in successive wells. Table 1 lists the outstanding physical characteristics of cuttings and insoluble residues as seen under the microscope.

Logs of more than 4,300 wells have been studied in the preparation of this report. Samples from nearly 1,000 wells were examined in whole or in part by Lee and his coworkers Leatherock and

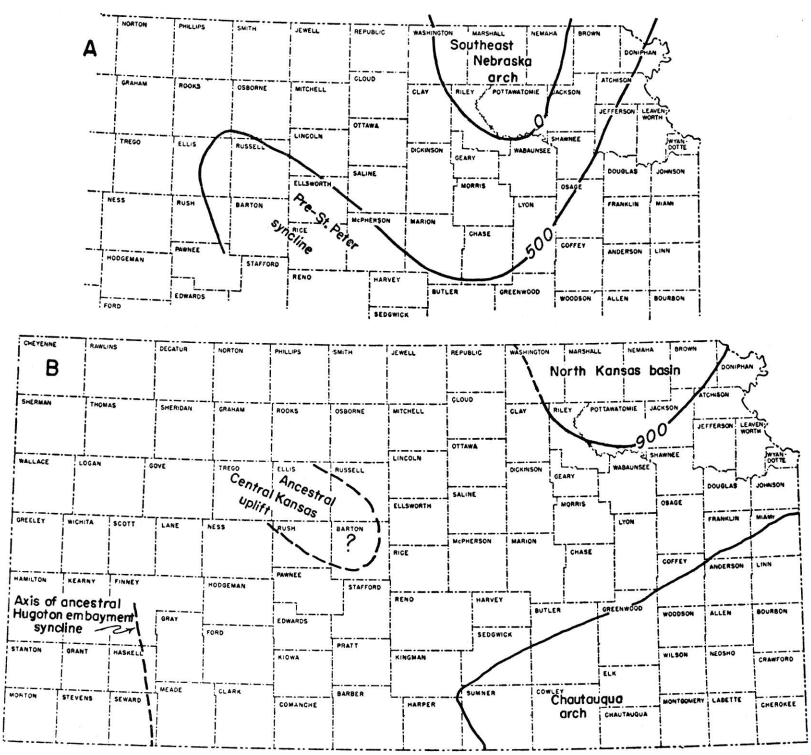
TABLE 1.—*Sequence of pre-Pennsylvanian formations encountered in the Salina basin, their range of thickness, and distinctive physical characteristics of well cuttings under the microscope.*

System	Series	Correlatives	Formations and members	Approximate thickness, feet	Distinctive physical characteristics (Detailed descriptions will be found in the text)
Mississippian	Meramecian		Spergen limestone	0–99	Noncherty or sparsely cherty granular limestone at top and silty dolomite at base. The small insoluble residues, rarely more than 5 percent, are characterized by salmon-colored chalcedonic chert. May include traces of microfossiliferous chert. Granular limestones may contain sparsely distributed *Endothyra*.
			"Warsaw" limestone	0–80	Chert, opaque, partly gray and partly dark, characteristically packed with silicified broken micro-organisms and spicules. Chert constitutes 10 to 50 percent of samples.
	Osagian		Undivided Keokuk and Burlington limestones	0–110	Upper zone: Chert, white, rough, pitted, and porous. Cotton rock in some samples. Residues include soft spongy particles resembling tripoli. Includes, also, in some zones microfossiliferous organisms similar to those in chert of the "Warsaw" limestone but embedded in chalcedony.
				0–155	Lower zone: Chert, abundant, mainly white, opaque, microscopically massive, breaking in smoothish blocky chips. Hackly quartz present in samples and drusy quartz common in insoluble residues.
		Rocks of Fern Glen age	Reeds Spring limestone	0–120	Chert, bluish to bluish gray or gray, translucent to semitranslucent, breaking in sharp-edged chips and splintery fragments.
			St. Joe limestone	0–40	Noncherty or sparsely cherty, dark-gray to gray, argillaceous limestone of earthy or finely crystalline texture.
	Kinderhookian		Gilmore City limestone	0–62	Oölitic limestone in part, with soft chalky matrix; not oölitic throughout. Nonoölitic limestone is granular. Residues negligible.
			Upper member of Sedalia dolomite	0–20	Buff to brown, locally gray, noncherty or sparsely cherty sucrose dolomite.
Mississippian or Devonian	Kinderhookian or Late Devonian		Boice shale	0–110	Red and brown ironstone oölite, and red shale at base.
			Chattanooga shale	0–255	Gray to black, generally silty, finely micaceous shale. Pyrite common. Spores disseminated throughout but abundant near base. Includes thin beds of argillaceous sucrose dolomite and locally toward the west a thick lentil of argillaceous limestone.
Devonian	Late		Undifferentiated dolomite of Devonian age; includes Cooper dolomite	0–200	Contains, in lower zone, coarse rounded sand grains thinly disseminated in dolomite or limestone but generally abundant at base.

Silurian	Niagaran and Alexandrian		Undifferentiated rocks of Silurian age; includes Chimneyhill dolomite	0–315	In ascending order: First zone, characterized by oölitic dolomite; Second zone, characterized by white chert; Third zone, characterized by small silty insoluble residues containing rare specimens of *Ammodiscus* and other foraminifera and glauconite, locally streaked with red or pink dolomite or limestone; Fourth zone, characterized in the upper part by insoluble residues of drusy and hackly quartz and the quartz crystals in the northeastern part of the area and by dolocastic and spongy chert in the southern and western parts of the area. Contains much variegated semiopaque to semitranslucent chert in marginal areas in northwestern part of area.
Ordovician	Late	Sylvan shale of Oklahoma	Maquoketa shale	0–155	Gray and greenish-gray silty and nonsilty dolomitic shale. Locally includes cherty dolomite yielding large insoluble residues of very dolocastic semitranslucent chert. Insoluble residues of shale are, generally, dolocastic in contrast to Chattanooga shale.
	Middle	Part of Viola limestone of Oklahoma	Viola limestone	0–310	Chert with embedded black or dark tubular microorganisms; buff chert enclosing densely matted silicified microorganisms. Alternate zones sparsely cherty.
		Rocks of Simpson age in Oklahoma	Platteville formation	0–95	Sublithographic limestone, dolomite, and sandstone interbedded with green shale; a persistent bed of sucrose dolomite at the base, little or no chert.
			St. Peter sandstone	0–90	Coarse rounded to subangular sand interbedded with green shale.
	Early	Rocks of Arbuckle age in Oklahoma	Undivided Cotter dolomite and Jefferson City dolomite	0–400*	Upper part, abundant chert of variable character, much oölitic chert; oölites commonly brown or translucent in light-colored matrix; lower part, less cherty, oölitic chert, predominantly white and in lesser volume. Tripoli-like chert increasingly common in insoluble residues toward the base.
			Roubidoux dolomite	0–247	Sand less abundant than in Missouri. Generally, sandy dolomite in Kansas. Sand in most Kansas areas fine grained. Includes minor amounts of chert, in part oölitic.
			Gasconade dolomite	0–50	Present in eastern Kansas but not in central Kansas.
Cambrian	Late		Eminence dolomite	0–35	Present in eastern Kansas but not in central Kansas.
			Bonneterre dolomite	0–183	Noncherty argillaceous dolomite with glauconite. In central Kansas includes disseminated sand but is not argillaceous.
		Lamotte sandstone in Missouri	Reagan sandstone	0–80	Coarse angular to rounded poorly sorted sand.
Precambrian			Precambrian rocks		Arkose, granite, and quartzite.

Botinelly. Use was made of 885 logs of the Kansas Sample Log Service, a large proportion of which are of wells on the Central Kansas uplift, and 445 electric logs were used especially for Pennsylvanian data. Tops of formations reported by unidentified geologists in more than 2,000 drillers logs were checked in the preparation of the thickness maps, although not all were used. In addition, 13,000 drillers logs of various degrees of accuracy were plotted to determine the pre-Pennsylvanian areal geology of the Central Kansas uplift.

On the maps that show the thickness of the different parts of the rock sequence in the Salina basin, the lines indicating equal thickness are spaced at 50-foot intervals. Differences in the degree of accuracy of the data precluded use of a smaller interval, although intervals of 25 feet or less would doubtless bring out many local structural features, particularly in oil fields, where local deformation accompanied regional deformation throughout Pennsylvanian and Permian time. Furthermore, the object of the investigation was the study of regional rather than local deformation. For this



same reason only one or two wells in a land section were used in densely drilled areas.

The major structural features of eastern and central Kansas are shown in Figure 2. Not all were developed contemporaneously. The structural features that were formed before the deposition of rocks of Simpson age are shown in Figure 2A. These are the Southeast Nebraska arch and a structural basin to the southwest. Some major structural features (Fig. 2B) were formed between St. Peter time and early Mississippian time. They include the Chautauqua arch, the Central Kansas uplift, and the North Kansas

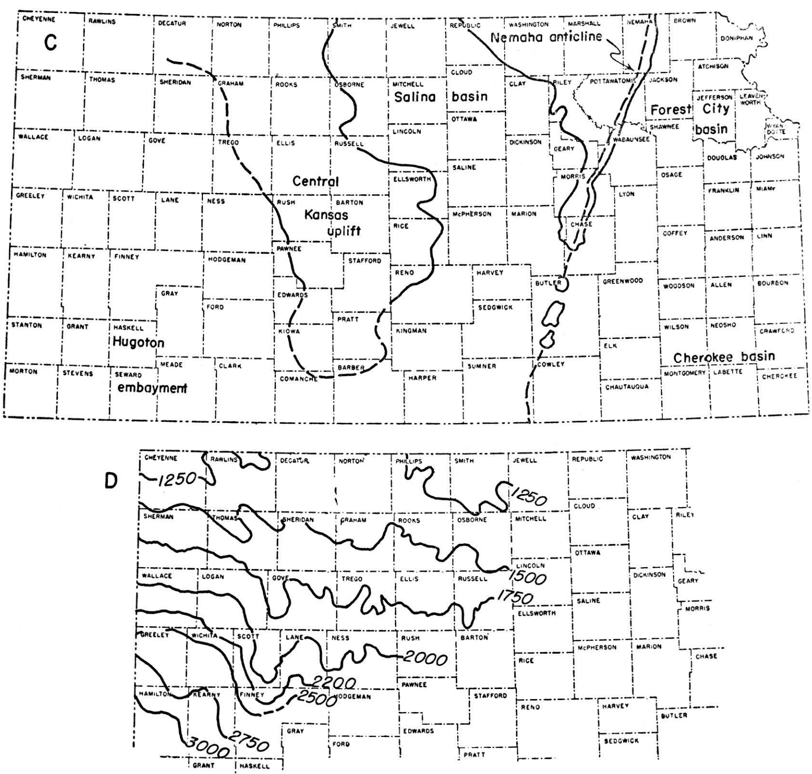


FIG. 2.—Maps showing principal structural features of Kansas. **A.** Pre-Simpson structure represented by 500-foot thickness lines of Arbuckle dolomite and Reagan sandstone. **B.** Structural deformation from Arbuckle through Chattanooga time: (a) North Kansas basin outlined by 900-foot isopach, (b) Chautauqua arch, outlined by margin of Simpson rocks, (c) trend of Hugoton embayment (after Maher and Collins, 1949, sheet 1). **C.** Pattern of structural deformation from Chattanooga to middle Permian time, outlined by margin of Mississippian rocks. **D.** Post-Dakota deformation shown by 250-foot structure contours on the Dakota formation (after Lee and Merriam, 1954, pl. 2).

basin. The most prominent of the regional structural features formed between the end of Mississippian time and Middle Permian time (Fig. 2C) are the Nemaha anticline, the Forest City and Cherokee basins, the Salina basin, and the enlarged Central Kansas uplift. Several secondary folds parallel to the Nemaha anticline were also formed then. Figure 2D shows the present north dip of the Dakota formation, resulting from post-Cretaceous structural movement, which also reduced but did not reverse the south plunge of the Mississippian and older rocks in the Hugoton structural embayment.

TERMINOLOGY

The meanings intended for certain descriptive terms used in this report are listed below.

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

Dolomold (Ireland, 1947) is a term for the impression left by a dolomite crystal removed from chert or other material in insoluble residues. Dolomolds may occur singly or so abundantly that they form a porous or spongy texture.

Drusy texture is a term applied to deposits of crystalline quartz formed in microscopic cavities.

Even-textured rock has a homogeneous character and is microscopically fine grained or dense.

Grainy texture denotes 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. With change in the character of the matrix, rocks having this texture grade into sucrose dolomite or silty limestone.

Hackly texture is a term applied to broken quartz without crystal faces.

Matted texture as applied to chert indicates closely packed fragments of silicified microfossils and sponge spicules cemented in a siliceous matrix.

Mottled is applied to parti-colored chert in patches without sharp margins; it is microscopic, but much coarser than *stippled.*

Porous texture denotes aggregates of quartz, chert, or other materials in which the intervening individual cavities are microscopic.

Semigranular texture is applied to coarsely crystalline grains, principally fossil fragments, in a microcrystalline matrix. Some crinoidal limestone is semigranular.

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

Stippled indicates a dotted pattern on a smoothly broken chert surface. It results from complete replacement by silica of rocks having grainy texture. The originally sharp outline of the replaced impurities in some zones is blurred, so the replaced particles show a cloudy margin.

Streaked texture indicates imperfectly replaced or subsequently modified matted chert containing microfossils. Outlines of the microfossil constituents are thus blurred.

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

ACKNOWLEDGMENTS

The most important contributions to this report were made by the Kansas Geological Society, whose foresighted officers acting through the Well Log Bureau have collected and made available the priceless collections of well logs, samples, and electric logs now on file in Wichita and Lawrence. Sample logs of the Kansas Sample Log Service, many of which were checked for detail, have been used freely. A good many samples of wells drilled before the establishment of the Well Log Bureau are in the files of the Geological Survey of Kansas. Data of various kinds were contributed to the original report by nearly every oil company in Wichita and Tulsa, and were acknowledged in the original report.

Sample logs by Constance Nieschmidt (nee Leatherock) and Theodore Botinelly prepared for the original bulletin have been invaluable in preparing the revision. Cross sections X-X′ and Y-Y′ (Pl. 11 and 12) by Botinelly are reproduced without alteration.

The writer also acknowledges helpful comment by Earl McCracken and Robert F. Walters, to whom the chapter on the Arbuckle rocks was submitted. Neither, however, approved or disapproved the theory advanced.

STRATIGRAPHY

The exposed rocks in the Salina basin and those that have been penetrated in wells range in age from Precambrian to Quaternary. The sequence of the pre-Pennsylvanian rocks in the Salina basin is shown in Table 1. This table also shows the range of thickness of the pre-Pennsylvanian rocks, and the characteristics by which the several formations are recognized in well cuttings. Every one of the pre-Pennsylvanian formations is absent in some part of the area. Most of the formations were deposited originally throughout the area, but many of them were later removed in whole or in part from certain areas during recurrent periods of emergence and erosion. Some of the formations, however, were deposited only locally and never extended across the area. In consequence the complete columnar section is not represented at any point in the Salina basin area or even at any place in Kansas.

The sequence of formations of Pennsylvanian, Permian, and Cretaceous age is given in the chapters dealing with stratigraphy of these systems. The age classification and nomenclature used in the report accord with the usage of the State Geological Survey of Kansas.

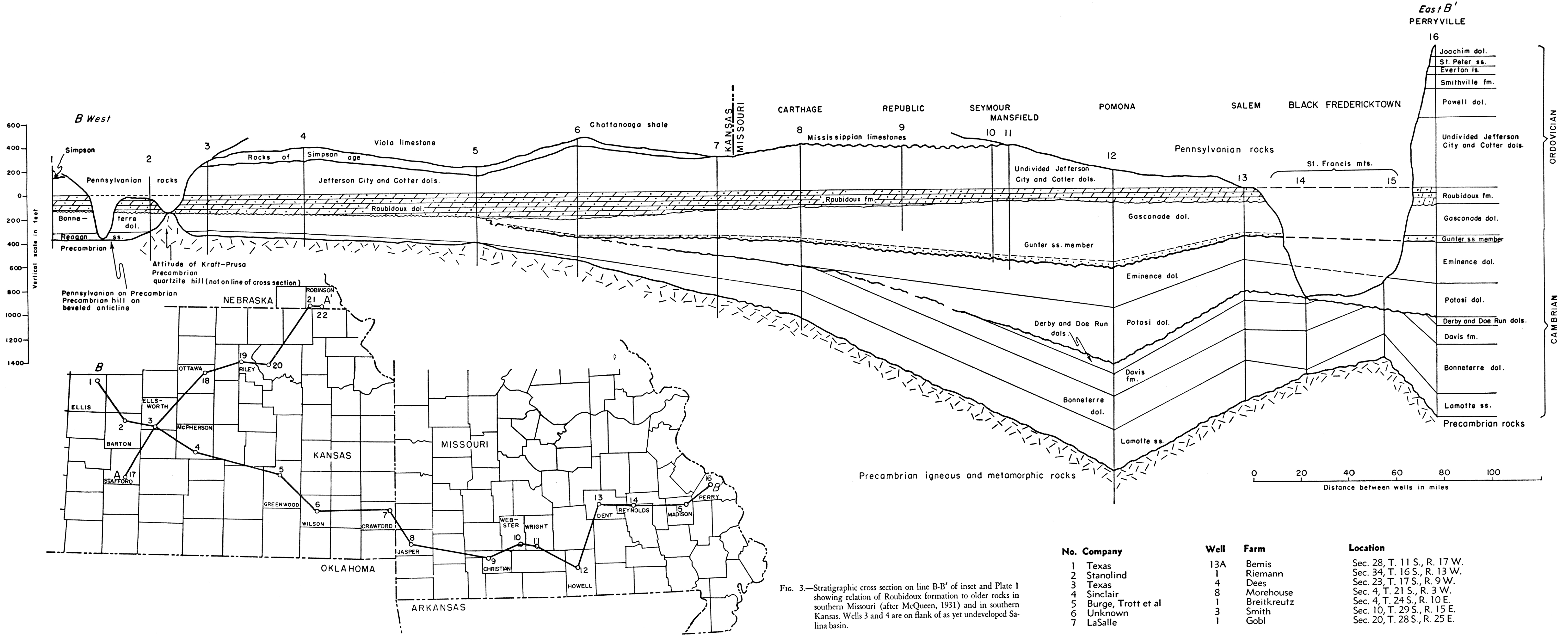
The accompanying thickness maps show the approximate present distribution and thickness of formations and groups of formations that were affected by similar structural development. The maps show, also, the areas from which various formations that were once present have been eroded. The cross section accompanying each map is designed to show the relation of each formation or sequence to the overlying and underlying rocks.

PRECAMBRIAN ROCKS

The oldest rocks known in the Middle West consist of various types of igneous and volcanic rocks and altered sedimentary rocks that are generally classified collectively as Precambrian. They are nearly everywhere covered by younger deposits but come to the surface in the Arbuckle and Wichita Mountains of Oklahoma, in the St. Francois Mountains of southeastern Missouri, in southeastern South Dakota and adjoining parts of Iowa and Minnesota, in the Black Hills of South Dakota and Wyoming, and in Colorado. In the Salina basin, which is roughly central to these outcrops, the Precambrian rocks lie deep beneath sedimentary rocks that include representatives of nearly all ages from Cambrian to Recent.

The Precambrian rocks of the subsurface in Kansas resemble more closely those exposed in Oklahoma and Missouri than those in the other areas mentioned. Landes (1927), who studied the samples of Precambrian rocks from deep wells in Kansas and adjoining states, found that these rocks consist mainly of granite or granite gneiss and schist, although other intrusive igneous rocks and metamorphosed sediments have been penetrated in some wells.

The surface of the Precambrian rocks dips away from the granitic cores of the mountain areas, and reaches a depth of several thousand feet below the surface in the adjoining structural basins. In some areas, the sedimentary rocks deposited on the Precambrian surface were later elevated above sea level, and their removal by erosion laid bare areas of ancient crystalline rocks. Such a series of events occurred in Kansas at the end of Mississippian time on parts of the Nemaha anticline and in places on



No.	Company	Well	Farm	Location
1	Texas	13A	Bemis	Sec. 28, T. 11 S., R. 17 W.
2	Stanolind	1	Riemann	Sec. 34, T. 16 S., R. 13 W.
3	Texas	4	Dees	Sec. 23, T. 17 S., R. 9 W.
4	Sinclair	8	Morehouse	Sec. 4, T. 21 S., R. 3 W.
5	Burge, Trott et al	1	Breitkreutz	Sec. 4, T. 24 S., R. 10 E.
6	Unknown	3	Smith	Sec. 10, T. 29 S., R. 15 E.
7	LaSalle	1	Gobl	Sec. 20, T. 28 S., R. 25 E.

Fig. 3.—Stratigraphic cross section on line B-B' of inset and Plate 1 showing relation of Roubidoux formation to older rocks in southern Missouri (after McQueen, 1931) and in southern Kansas. Wells 3 and 4 are on flank of as yet undeveloped Salina basin.

the Central Kansas uplift. These areas, however, later sank below sea level and were buried by Pennsylvanian sediments. Although the Kansas region has since been re-elevated, the Precambrian rocks have not been raised high enough nor has erosion cut deep enough to bring them to the surface again.

ROCKS OF LATE CAMBRIAN AND EARLY ORDOVICIAN AGE

The Arbuckle Group

The thick sequence of dolomites of Late Cambrian and Early Ordovician age that lies between Precambrian and Simpson rocks in southeastern Oklahoma was named the Arbuckle limestone by Taff in 1902 (U. S. Geol. Survey Folio 79) from exposures in the Arbuckle Mountains. The corresponding sequence in the Ozark region of southern Missouri was long known as the "Cambro-Ordovician". In 1932, Ulrich restricted the Arbuckle limestone as a formation by excluding from it the basal Honey Creek limestone, which he correlated with the Davis formation of southeastern Missouri, thus excluding also the older Bonneterre dolomite. The original Arbuckle limestone of Oklahoma and the corresponding "Cambro-Ordovician" rocks of Missouri have been divided into mappable formations, and it is now convenient to regard them collectively as the Arbuckle group. The Honey Creek limestone as a part of the original Arbuckle as well as its correlative, the Davis formation of Missouri, and the underlying Bonneterre are currently regarded as formations included in the Arbuckle group.

The outcropping formations into which the "Cambro-Ordovician" or Arbuckle group has been divided in Missouri were differentiated in the subsurface by McQueen (1931) in his pioneer work on insoluble residues. By the criteria thus established, McQueen traced the Arbuckle formations from the outcrops in Missouri to the border of Kansas.

The correlation of the formations in Kansas with those in Missouri is complicated by the fact that some of the formations in Missouri wedge out toward the west as shown in the cross section B-B′ of Figure 3, the Missouri part of which is based on the work of McQueen. Owing to facies changes, some of the criteria are less distinctive in Kansas than in type areas in Missouri. Although many of the deep wells in eastern Kansas have been drilled with cable tools, the samples and the insoluble residues do not uniformly reveal satisfactory criteria for correlation because many of the samples were drilled to dust. Samples from wells drilled with rotary tools are generally contaminated by recirculated cuttings, which reduce the reliability of the insoluble residues, on which McQueen's correlations are based. Although the approach is somewhat tedious, and not particularly accurate as to depth, the writer has found that insoluble residues of selected particles from rotary samples reveal the first appearances of such distinctive features as embedded sand, spongy and drusy quartz, chalcedony and tripoli, flocculent silica, and dolomolds in chert and tripoli, which are not directly perceived in untreated specimens.

Table 2 shows in descending sequence the Arbuckle formations represented in Missouri, after McCracken (1955), and in eastern Kansas.

TABLE 2.—*Formations of Arbuckle age in Missouri and in eastern Kansas*

Missouri *	Eastern Kansas
St. Peter sandstone	Rocks of Simpson age
Arbuckle group	
Early Ordovician	
Smithville formation *	Absent
Powell dolomite	Absent
Cotter dolomite	Undifferentiated Cotter and
Jefferson City dolomite	Jefferson City dolomites
Roubidoux formation	Roubidoux dolomite
Gasconade dolomite	Gasconade dolomite †
Late Cambrian	
Eminence dolomite	Eminence dolomite †
Potosi dolomite	Absent ‡
Derby and Doe Run dolomites	Absent ‡
Davis formation	Absent ‡
Bonneterre dolomite	Bonneterre dolomite
Pre-Arbuckle	
Lamotte sandstone	Lamotte (Reagan) sandstone

* McQueen, 1931, pl. 12.
† Present in eastern counties of Kansas but absent in the Salina basin area.
‡ May be present in eastern Kansas (oral communication from Earl McCracken). Absent in the Salina basin area.

ROCKS OF LATE CAMBRIAN AGE

REAGAN (LAMOTTE) SANDSTONE

The Reagan sandstone overlies the Precambrian rocks of Oklahoma and in this respect corresponds to the Lamotte sandstone of Missouri. Both represent a clastic sandy deposit at the base of the Arbuckle group but are not necessarily correlative inasmuch as, in the outcrops, the Reagan underlies the Honey Creek, correlated by Ulrich with the Davis formation of Missouri, and the Lamotte underlies the older Bonneterre dolomite. Both are basal Upper Cambrian clastic deposits. The basal sandstone of the Central Kansas uplift underlies the Bonneterre dolomite but is commonly called Reagan. Like the Lamotte sandstone of Missouri the basal sediments are generally arkose and grade upward through angular and subangular sandstone into sandy dolomite in the base of the Bonneterre. In central Kansas the arkose is generally referred to as "granite wash," and in some wells its contact with weathered granite in place is obscure. The top of "granite wash" at its contact with the relatively pure overlying sandstone is a more satisfactory datum than the top of the unaltered Precambrian igneous rocks. The contact of the Lamotte or Reagan with the Bonneterre is placed at the point where dolomite predominates over sand.

In southeastern Missouri the Lamotte has a maximum thickness of 350 feet and thins westward to about 100 feet as the Kansas border is approached. In eastern Kansas it becomes irregularly thinner and in some places is only a few feet thick. It is absent from areas that were topographically high at the time of its deposition. It is also absent from the crest of the Southeast Nebraska arch (from which it was eroded preceding the deposition of the Simpson in that area) and also from parts of the Central Kansas uplift (from which it was removed by pre-Pennsylvanian erosion).

Bonneterre Dolomite

The Bonneterre dolomites of Missouri are typically dark and noncherty, in part interbedded with green shale. The insoluble residues of samples from the top of the formation are generally dark-gray or chocolate-colored dolomoldic clay sponge. They grade downward through spongy aggregates of silt and fine sand into angular and subangular coarse sand at the bottom. Dolomolds in green shale are common in eastern Missouri but not in western Missouri. Glauconite, which is characteristic of the Bonneterre, occurs as fine to coarse granules in the dolomite and in the spongy insoluble residues.

The Bonneterre and the underlying Reagan were widely distributed upon the Precambrian plain except in areas where hills rose above the level of Bonneterre deposition. Such hills are distributed erratically in northeastern Oklahoma, in southeastern Kansas, and on the Central Kansas uplift, where Precambrian quartzite hills in the Kraft-Prusa and adjacent fields in Barton and Ellsworth

Counties were studied by Walters (1946). Walters effectively described the Precambrian surface, the quartzite hills that rose 225 feet above the plain, and the Arbuckle rocks that overlapped upon their flanks. These hills were originally covered by upper Arbuckle rocks and a long sequence of still younger formations, but after the arching of the Central Kansas uplift that preceded Pennsylvanian deposition, the covering rocks were worn away by erosion and the crests of some of the hills were reexposed.

Among other Precambrian hills capped by Pennsylvanian rocks is one reached by a well in sec. 1, T. 21 S., R. 15 W., reported by the Kansas Sample Log Service. The log of this well reports Pennsylvanian rocks overlying arkose or weathered granite although a nearby well in sec. 31, T. 20 S., R. 14 W., less than a mile distant encountered a normal sequence of Viola, Simpson, and Arbuckle rocks. The Arbuckle in a well about 6 miles west is about 500 feet thick. If the samples from the well in sec. 1 are reliable they indicate that a hill at least 500 feet high rose above the Precambrian plain at this point.

Another Precambrian hill composed of red granite was penetrated by a well in sec. 1, T. 24 S., R. 16 W. Both Lamotte and Bonneterre are missing, but a minimum of 330 feet of younger Arbuckle rocks was eventually deposited across its crest.

The Missouri characteristics of the Bonneterre prevail in southeastern Kansas. Toward the northwest as the areas of the Salina basin and Central Kansas uplift (neither as yet a structural feature) are approached, the fine argillaceous impurities of the lower part give way to fine to medium angular and subangular embedded sand, in some samples amounting to only 1 to 5 percent. Embedded glauconite, especially in Phillips, Rooks, Osborne, and Mitchell Counties, identifies these rocks as Bonneterre. Glauconitic dolomite occurs also on the western flank of the Southeast Nebraska arch.

Glauconitic sandy Arbuckle dolomite is preserved in synclinal areas on the Central Kansas uplift notably in sec. 12, T. 11 S., R. 18 W.; sec. 29, T. 11 S., R 17 W.; sec. 5, T. 12 S., R. 17 W.; sec. 32, T. 16 S., R. 14 W.; and sec. 34, T. 16 S., R. 13 W., not far from the Precambrian quartzite hills of the Kraft-Prusa fields. Although not everywhere conspicuously glauconitic, these slightly sandy dolomites at the base of the Arbuckle group seem to be a lateral facies of the more finely clastic (argillaceous and silty) Bonneterre of southeastern Kansas.

The Texas Company No. 4 Dees well, in the SE SE NW sec. 23, T. 17 S., R. 9 W., for example, penetrated the Jefferson City—Cotter sequence at a depth of 3200 feet and was drilling in sandy dolomite of probably Roubidoux age at 3435 feet. The actual top of the Roubidoux established by McCracken (1955, p. 53) is slightly higher. Insoluble residues reveal sandy chert at 3455 feet. The Roubidoux continues from this point to 3595 feet, for the insoluble residues of the finely drilled samples consist of 6 to 10 percent mixed chert and sand. The insoluble residues of samples below this point to 3682 feet consist of 2 to 8 percent sand with no chert. Although not seen in the residues, traces of embedded fine particles of glauconite are included in all the untreated dolomite samples from 3610 to 3680 feet. The noncherty beds from 3595 feet to the top of the Lamotte sandstone at 3733 feet are therefore correlated with the similar, more obviously glauconitic Bonneterre dolomites of other wells in the vicinity of the Kraft-Prusa field.

The distinguishing characteristics of rocks that are believed to represent the Bonneterre, in and adjacent to what is now the Salina basin, are absence of chert and presence of minor amounts of medium to fine embedded sand and embedded glauconite, which in some wells occurs in very fine particles very thinly disseminated. Insoluble residues from the Continental No. 1 Boland well in sec. 13, T. 25 S., R. 13 W., farther south include relatively abundant glauconite accompanying and embedded in material that seems to be silicified gray shale.

The Bonneterre, like the Lamotte, was originally deposited on the crest of the Southeast Nebraska arch, from which it was eroded before the deposition of the St. Peter sandstone, and over the Central Kansas uplift, from parts of which it was removed before the deposition of the Pennsylvanian rocks.

McQueen (1931, pl. 1) reports a thickness of 440 feet of Bonneterre in southeastern Missouri. It thins gradually westward, and along the southwestern border of Missouri it is less than 200 feet thick. It continues westward into the Salina basin, where its thickness is 135 to 150 feet. Figure 3 shows gradual convergence, in Missouri, of the Bonneterre and Roubidoux formations, which continues into the Salina basin, where the two formations seem to be in contact. Westward from the central Ozarks the Bonneterre is successively unconformable beneath the Eminence, the Gasconade, and the Roubidoux. In the Salina basin the thickness of the Bonneterre is ordinarily about 150 feet, but in some places pre-Roubidoux erosion reduced the thickness to less than 100 feet. In the Sinclair No. 8 Moorehouse well (sec. 4, T. 21 S., R. 3 W.), after correction for about 300 feet of duplication by reverse faulting, the Bonneterre, which is repeated, has a thickness of about 155 feet. Its contact with the Roubidoux in this well is obscure, partly on account of faulting and partly because of the fineness of the samples.

Eminence Dolomite

In central Missouri, the insoluble residues of the Eminence dolomite consist mainly of abundant chert with lacelike dolomolds and thin drusy walls. In eastern Kansas near the Missouri border, very little chert (rarely more than a trace) occurs in the Eminence. The interlocking dolomite crystals are separated by white interstitial films of tripoli. This material is conspicuous in samples but yields only traces of tripolitic flakes and flocculent silica in the insoluble residues. Some of the firmer siliceous flakes reveal fine drusy faces or pittings but form no coherent residues. Both of these types of residue seem to represent the fading out of the very siliceous material characterizing residues from the type locality.

McQueen reports more than 320 feet of Eminence in well 12 (Fig. 3) in south-central Missouri. In well 8 near Carthage, Missouri, he reports 200 feet of Eminence overlying Bonneterre. In well 7, rocks assigned to the Eminence are 160 feet thick and, in the absence of the Potosi, unconformably overlie the Bonneterre and unconformably underlie the Gunter sandstone at the base of the Gasconade formation. In well 6 the Eminence is missing.

McCracken (1955, p. 48) notes that the unconformity previously postulated at the base of the Potosi cannot be supported. From the data now available, it seems possible, as shown in the cross section (Fig. 3), that the Potosi is conformable on the Derby-Doe Run in the subsiding basin in southern Missouri but that the overlying Eminence may overlap unconformably on the underlying Bonneterre toward the west. Current studies of the pre-Roubidoux formations in Missouri by McCracken may result in revision of the published data and modification of the relations suggested by the cross section.

ROCKS OF EARLY ORDOVICIAN AGE

Gasconade Dolomite

Insoluble residues characteristic of the Gasconade dolomite of Missouri are obtained from the cuttings of a few wells in eastern Kansas near the Missouri line. In wells 6 and 7 of the cross section (Fig. 3) both the coarsely dolomoldic chert distinctive of the lower Gasconade dolomite and the Gunter sandstone member at its base represented by sandy dolomite are well developed. Like the Eminence the Gasconade wedges out before it reaches the area under study. In well 7 the Gasconade overlies the Eminence as in McQueen's well 8 at Carthage, Missouri. In well 6 it unconformably overlaps upon the Bonneterre. It seems to be unrepresented in well 5, but the samples from this zone were reduced to dust in drilling and the evidence is inconclusive. If present it is thin. Insoluble residues characteristic of the Gasconade were not recognized in wells farther northwest, and this formation is probably missing in the Salina basin area.

In southern Missouri in well 12 of the cross section (Fig. 3) McQueen reports about 550 feet of Gasconade. In Kansas in well 7, the LaSalle No. 1 Gobl well in sec. 20, T. 28 S., R. 25 E., it is 215 feet thick, and in well 6, the No. 3 Marian Smith well in sec. 10, T. 29 S., R. 15 E., it is 171 feet thick.

Roubidoux Formation

Nearly everywhere in Missouri the Roubidoux includes conspicuous beds of sandstone, which give the formation its distinctive character in outcrops. In Kansas, the sandstone beds are represented by sandy dolomite in which the embedded sand rarely exceeds 25 percent of the sample. The lower part of the formation is generally more sandy than the upper part. The chert that accompanies the sandy dolomite is varied and in part oölitic. The oölites occur in gray translucent chert and brown quartzose chert as well as in opaque chert. Some of the cherts are sandy, a feature that is characteristic of the Roubidoux. Tripolitic flakes are common in insoluble residues. The chert in many samples is roughly proportionate to the amount of sand.

As the areas of the Central Kansas uplift and the Salina basin are approached, the sand and chert content of the insoluble residues diminishes. In wells 1 and 2 of the cross section (Fig. 3) the insoluble residues are almost negligible. The presence of chert accompanying sand in the insoluble residues is somewhat arbitrarily regarded as distinguishing the Roubidoux from the underlying noncherty, otherwise somewhat similar Bonneterre dolomite, in wells in which the Bonneterre is not conspicuously glauconitic. In the absence of chert and absence of glauconite the contact has been placed arbitrarily where the white dolomite of the Roubidoux is in contact with gray dolomite of assumed Bonneterre age. The top of the Roubidoux is placed at the point below which cherty samples and residues reveal a continuous descending sequence of sand embedded in dolomite or chert. The overlying Jefferson City includes sandy dolomite at irregular intervals, but the Roubidoux dolomite is uniformly sandy. The brown quartzose oölite that caps the Roubidoux, described by McCracken (1955, p. 55), is not represented in the residues of all the wells in the area. It is probable that it occurs no more than 15 or 20 feet above the highest sandy dolomite of the Roubidoux.

The Roubidoux is unconformable on the Gasconade in Missouri and overlaps upon the Bonneterre in southeastern and central Kansas. Its thickness ranges from 100 to 190 feet in southwestern Missouri (McCracken, 1952, p. 63) as a result of inequalities of the underlying surface. It is probably equally variable in eastern Kansas, where it averages about 150 feet.

Jefferson City and Cotter Dolomites

No attempt has been made to separate the Jefferson City and the Cotter dolomites in the deep wells of the area, from which there are few satisfactory sets of samples. As established by McCracken (1955, p. 55), the base of the Jefferson City is at the contact of the brown quartzose oölitic chert at the top of the Roubidoux with a smooth tan finely oölitic chert at the base of the Jefferson City. McCracken places the base of the Cotter directly above a zone of large free brown oölites and oölitic chert at the top of the Jefferson City. Both the Jefferson City and the Cotter include sandy dolomite and thin beds of sandstone, and both include oölitic cherts distinctive enough to differentiate them in good samples.

The Jefferson City is essentially conformable above the Roubidoux and in Kansas the Jefferson City—Cotter sequence is unconformable below rocks of Simpson age. In some areas the Jefferson City—Cotter sequence was subsequently exposed to erosion. On the Chautauqua arch the sequence was exposed to pre-Chattanooga erosion, and in a small area in the southeast corner of the state, to pre-Mississippian erosion. These formations were pretty generally removed from the crest of the Central Kansas uplift by pre-Pennsylvanian erosion, and on the flanks their truncated outcrops were capped by Pennsylvanian rocks. The sequence was eroded from the crest of the Southeast Nebraska arch by pre-Simpson erosion, but in the Salina basin and adjoining areas Simpson rocks were deposited across the beveled surface of the Jefferson City—Cotter sequence (cross section A-A′, pl. 1).

In southwest Missouri the Jefferson City thins irregularly northward from 190 feet to 110 feet (McCracken, 1952, p. 63). The Jefferson City—Cotter sequence in the pre-Simpson synclinal area in Reno County, Kansas, is 300 to 400 feet thick and, like the Jefferson City alone in southwestern Missouri, thins northward beneath the Simpson and thickens southward into Oklahoma.

St. Peter Sandstone (Simpson Group)

The rocks in the Salina basin area that occupy the stratigraphic interval of the Simpson group of Oklahoma, between the Arbuckle and the Viola, consist of the St. Peter sandstone and its correlatives, and the overlying Platteville, as restricted by Kay at outcrops in eastern Iowa (1935, p. 288). The Simpson rocks of Kansas represent only a part of the Simpson of Oklahoma, which in southern Oklahoma is more than 1,500 feet thick.

The St. Peter sandstone, which is of Early Ordovician age, is separated from the Platteville (Middle Ordovician) by an obscure but important unconformity. The contact is placed somewhat arbitrarily at the base of a bed of dolomite of widespread distribution. In the subsurface, McQueen and Greene (1938, pl. 6 and 7) have traced the St. Peter sandstone and the Decorah shale of Missouri, a correlative of part of the Platteville of Iowa (Kay, 1935), from outcrops in eastern Missouri to northwestern Missouri. Leatherock (1945, p. 10) has carried the subsurface correlation into the Salina basin. In northern Missouri and northeastern Kansas the St. Peter consists almost entirely of soft white coarse to medium-grained sandstone. A considerable proportion of the grains are well rounded and frosted. Much of the recovered sand is weakly cemented by silica. In some wells drilled in northeastern Kansas traces of green shale are found in samples from the middle part of the formation; inasmuch as most of the wells in this area have been drilled with cable tools, it is probable that the shale is even more abundant than is indicated by the samples.

Leatherock (1945, p. 10) noted three zones in the St. Peter, an upper and a lower sandstone member and a middle member of variable lithology composed mainly of sandy green shale or fine-grained sandstone. The middle member is locally glauconitic, and in some places where it overlaps upon the Arbuckle it is colored red and brown and includes embedded ironstone pellets. A shaly zone was reported by Dake (1921, p. 24, 86, 99) in wells in Minnesota, Illinois, and Missouri, and an overlapping red zone was reported by him at the base of the St. Peter in wells and outcrops in the same areas (p. 68, 85, 128). The threefold division of the St. Peter is not everywhere clear, for the sandstone of the upper and lower members toward the southwest includes interbedded shale and, in a few wells, thin beds of limestone or dolomite. The thickness and lithology of the middle member also vary. In the central parts of the Salina basin area, a shaly middle member is generally recognizable, but in some wells it lies directly below the capping dolomite; it is presumed that the upper member was removed during pre-Platteville erosion. Where the middle member overlaps upon the Arbuckle it is presumed that the lower zone was not deposited on account of topographic relief of the eroded surface of the Arbuckle. As a result of these relations the middle member, where it can be recognized, occurs at irregular intervals within the St. Peter.

The predominantly sandy character of the St. Peter prevails westward to Washington and Clay Counties and southward to Geary and Shawnee Counties. Beyond this area the St. Peter sandstone is broken by green shale, and in some wells, as in T. 10 S., R. 13 W., and T. 10 S., R. 12 W., the St. Peter is represented almost entirely by sandy shale. Toward the south discontinuous beds of sandy limestone or dolomite are locally interstratified with sandstone and shale. The limestone is generally soft and mealy. The dolomite is brown and sandy. Cherty dolomite occurs in T. 22 S., R. 9 W., and in T. 21 S., R. 8 W., and in some other places toward the south but is not widespread.

Leatherock (1945, pl. 1) found the St. Peter beneath the basal dolomite of the Platteville to be only 10 to 15 feet thick in some wells in Jewell, Smith, Riley, and Pottawatomie Counties. It becomes irregularly thicker toward the south and is more than 100 feet thick in a few wells in southeastern Reno County, where the Platteville is commonly missing. Wells in Jefferson and Atchison Counties have penetrated as much as 80 feet of unbroken sandstone, but a well in Brown County found only 12 feet. In general, the correlative of the St. Peter thins toward the west and, as in Smith and Jewell Counties, its thickness diminishes to 15 feet or less in the southwestern corner of the area. Outside the area, a few wells have penetrated an excessive thickness of St. Peter sand, believed to have accumulated in sink holes in the Arbuckle surface (Lee, Grohskopf, Reed, and Hershey, 1946, sheet 1). Despite the fact that the St. Peter was deposited upon an eroded surface and is overlain unconformably by the Platteville, it is everywhere present in this and adjoining areas except where removed from areas of uplift by post-Platteville erosion. The extraordinary continuity of the

St. Peter under these circumstances implies only minor topographic relief on both the Arbuckle surface and on the pre-Platteville surface. Its thickness in this area beneath the basal dolomite of the Platteville ranges from 10 feet to slightly more than 100 feet, but it is only rarely less than 50 or as much as 100 feet.

ROCKS OF MIDDLE AND LATE ORDOVICIAN AGE

Platteville Formation (Simpson Group)

The upper part of the sequence of Simpson age has been correlated with the Platteville formation of Iowa by Leatherock (1945, p. 12-14). The Platteville in northeastern Kansas consists of green clay shale, dolomite, sandstone, earthy to granular limestone, and sublithographic limestone, locally interbedded with dolomite. The basal member of the formation is a persistent and widespread bed of sucrose or granular dolomite, which is interstratified in some wells with thin earthy limestone and in others with interbedded green shale. Rounded sand grains are generally thinly disseminated in the basal dolomite. The thickness of the basal dolomite ranges from less than 5 feet, around the margin of the North Kansas basin, to about 35 feet near the center.

The upper part of the Platteville is extremely variable. Like the basal dolomite, it thickens toward the center of the North Kansas basin. In the extreme southeastern corner of Nebraska, the extreme northwestern corner of Missouri, and the extreme northeastern corner of Kansas it is 70 to 79 feet thick and consists mainly of coarse granular and earthy limestone interbedded with green shale, minor amounts of red shale, sandstone, and dolomite (Leatherock, 1945, pl. 1). On the west side of the basin, in sec. 22, T. 5 N., R. 1 W., in Nebraska the upper part of the Platteville, 60 feet thick, is mainly green shale. The upper Platteville in these areas is younger than any part of the Platteville in the Salina basin. In the thinner parts of the Platteville farther south, green shale also predominates, but sandstone and thin beds of generally sandy limestone and dolomite are irregularly interbedded.

The diverse lithology of the upper beds of the Platteville is illustrated by the following observations. In the Coronado Oil Company No. 1 Parks well in sec. 16, T. 10 S., R. 8 E., Pottawatomie County, and in the Turner et al No. 1 Umscheid well in sec. 32, T. 8 S., R. 9 E., Riley County, the basal dolomite bed is overlain directly by a bed of sandstone 15 to 20 feet thick. South and west of these wells the sandstone changes laterally to sandy shale excepting about 5 feet of sandstone at the base. Toward the northwest green shale occupies the stratigraphic position of the sandstone.

The Platteville is 104 feet thick in Richardson County, Nebraska, 85 feet thick in T. 5 N., R. 1 W., in Nebraska, and 100 feet thick in northern Brown County, Kansas. All these areas are in the deeper part of the North Kansas basin. On the southwestern flank of this basin, the Platteville thins irregularly toward the margin. It is 60 feet thick in Pottawatomie County and 20 to 30 feet thick in southern Dickinson and Saline Counties. It is thin or absent on the margin of the North Kansas basin southwest of Marion and Harvey Counties and west of central Smith and Osborne Counties. Representatives of the Platteville on the margin of the North Kansas basin consist of 5 to 10 feet of brown, densely crystalline basal dolomite (less commonly mealy limestone) with embedded rounded sand grains.

The Platteville rests unconformably on the St. Peter sandstone. This unconformity is recognized in the subsurface of Kansas by the fact that the persistent dolomite at the base of the Platteville overlies different members of the St. Peter in different areas. The unconformity is expressed regionally by the absence in Kansas of formations that occur between the St. Peter and the Platteville in southeastern Missouri, where the Plattin limestone, the Stones River limestone, the Joachim dolomite, and the Dutchtown formation have an aggregate thickness of about 900 feet (Weller and McQueen, 1939). These formations are separated from one another by unconformities and were deposited in a subsiding basin while eastern Kansas and northwestern Missouri remained intermittently at or near sea level.

The Platteville is unconformably overlain by the Kimmswick limestone of Missouri, a representative of the Viola limestone of Oklahoma. This unconformity is expressed in the North Kansas basin by irregularity in thickness of the Platteville. In the deeper part of the basin, the Viola (Kimmswick) overlies deposits of late Platteville age. Toward the southwestern margin of the basin in Kansas it progressively overlaps upon the basal dolomite member of the Platteville or upon the St. Peter sandstone (Leatherock, 1945, cross sections A-A′ and B-B′, pl. 1). The contact of the Viola with the Platteville or with older Simpson rocks is indicated by the first appearance of sandy dolomite, sandy limestone, or green shale below the Viola.

Viola (Kimmswick) Limestone and Dolomite

The Viola limestone of Kansas, like its correlative the Kimmswick limestone of Missouri, is a partial equivalent of the Viola limestone of the type locality in Oklahoma. It comprises the sequence of limestone and dolomite between rocks of Simpson age and the Maquoketa shale, and is separated from both by minor unconformities. The Kimmswick is correlated with a part of the Galena limestone of Illinois, which crops out northwestward as far as southeastern Minnesota. In northern Illinois the Galena as a group is subdivided in ascending order into the Prosser limestone, the Stewartville dolomite, and the Dubuque formation. In the area of outcrop, these formations are distinguished by their fossil assemblages, but in the subsurface in areas far removed from the outcrop they cannot be differentiated with confidence, although Condra and Reed (1943, p. 69) tentatively identified the Prosser—Stewartville sequence in the subsurface of southeastern Nebraska. The Kimmswick has been traced in the subsurface from the outcrop in northeastern Missouri to northwestern Missouri (McQueen and Greene, 1938) and into northeastern Kansas, where it is correlated with the attenuated Viola traced northward in the subsurface from Oklahoma outcrops. It is probable that only the lower part of the Prosser is represented in the Salina basin, for the formation thins southward from the Prosser—Stewartville area in Nebraska.

In the subsurface of central Kansas the Viola limestone consists of interbedded limestone and dolomite, much of which is conspicuously cherty. The formation is characterized by the absence of argillaceous impurities, in which it differs from the carbonate rocks of the Maquoketa.

The limestone and dolomite are generally coarse to medium crystalline. The dolomite is in part densely crystalline, but is inclined to be vuggy and granular, especially at the top of the Viola. In the central part of the North Kansas basin the Viola is composed almost entirely of dolomite. On the southwest flank of the North Kansas basin, in the central part of the area mapped, the formation is composed of interstratified limestone and calcareous dolomite, but south of the Central Kansas uplift it is nearly all limestone.

The chert and some of the limestone and dolomite enclose sparsely disseminated or crowded particles of spicules and disintegrated graptolites in the form of black flakes, tubes, flecks, and dust, a feature which is found also in some of the chert of the overlying Maquoketa shale. The finer inclusions have been replaced by pyrite in some samples. Some of the Viola chert displays the cloudy outlines of other fossil fragments. The Viola chert as represented in well cuttings is buff, brown, or gray. The fracture ranges from smooth to rough, and the texture from massive to grainy. The Viola chert from wells in western Reno County and southern Stafford County south of the Central Kansas uplift is gray or white, opaque to subopaque, and the characteristic graptolite flecks are less abundant.

Although good datum beds characterized by chert occur locally, the Viola sequence does not lend itself to accurate regional zoning. A comparison of sample logs reveals more or less persistent cherty zones, but their character and the intervals between them, as observed in well cuttings, vary from well to well. Chert occurs sporadically between the more persistent cherty zones in some localities but is absent in others. In wells 10 to 20 miles apart, the siliceous constituents of beds at the same horizon seem to be unequally distributed, unequally segregated into chert, or absent.

No.	Company	Well	Farm	Location
1	Carlock	1	Basore	Sec. 25, T. 25 S., R. 2 W.
2	Derby	1	Webster	Sec. 15, T. 24 S., R. 2 W.
3	Continental	2	Meyer	Sec. 19, T. 21 S., R. 1 W.
4	Cling	1	Bitikafer	Sec. 2, T. 20 S., R. 1 W.
5	Simmons et al	1	Bishop	Sec. 15, T. 18 S., R. 1 W.
6	Phil-Han	1	Currie	Sec. 10, T. 15 S., R. 1 W.
7	Bay	1	Rockhold	Sec. 20, T. 13 S., R. 1 W.
8	Babcock	1	Copeman	Sec. 7, T. 10 S., R. 2 W.
9	Carter	1	Strat. Test	Sec. 16, T. 7 S., R. 2 W.
10	Phillips	1	Helms	Sec. 20, T. 4 S., R. 2 E.
11	Gulf	1	Baker	Sec. 1, T. 1 S., R. 2 E.

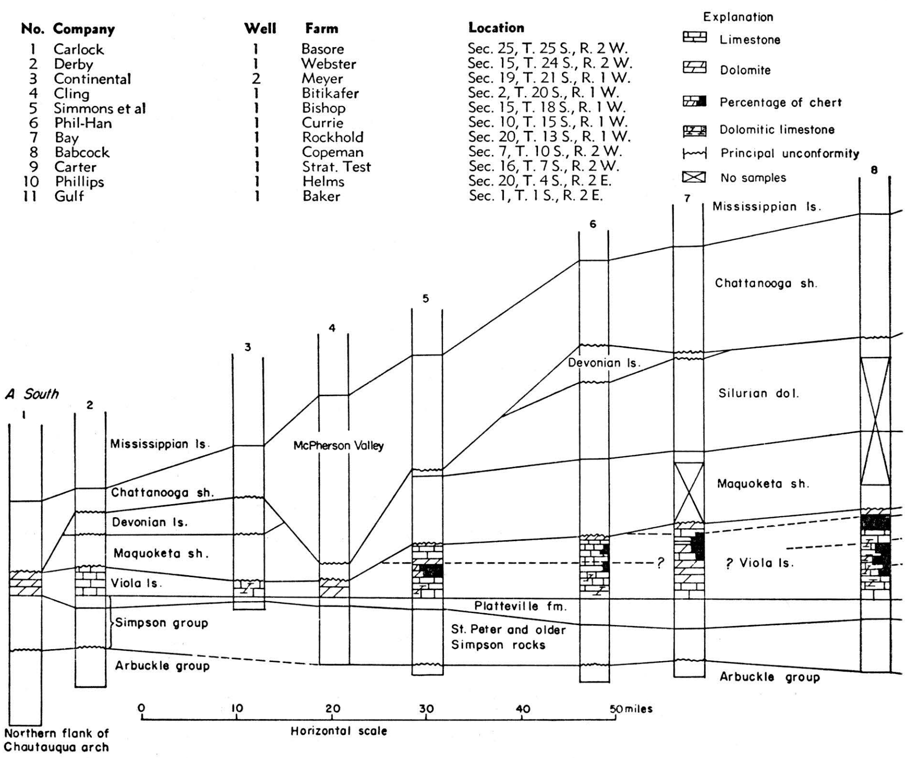
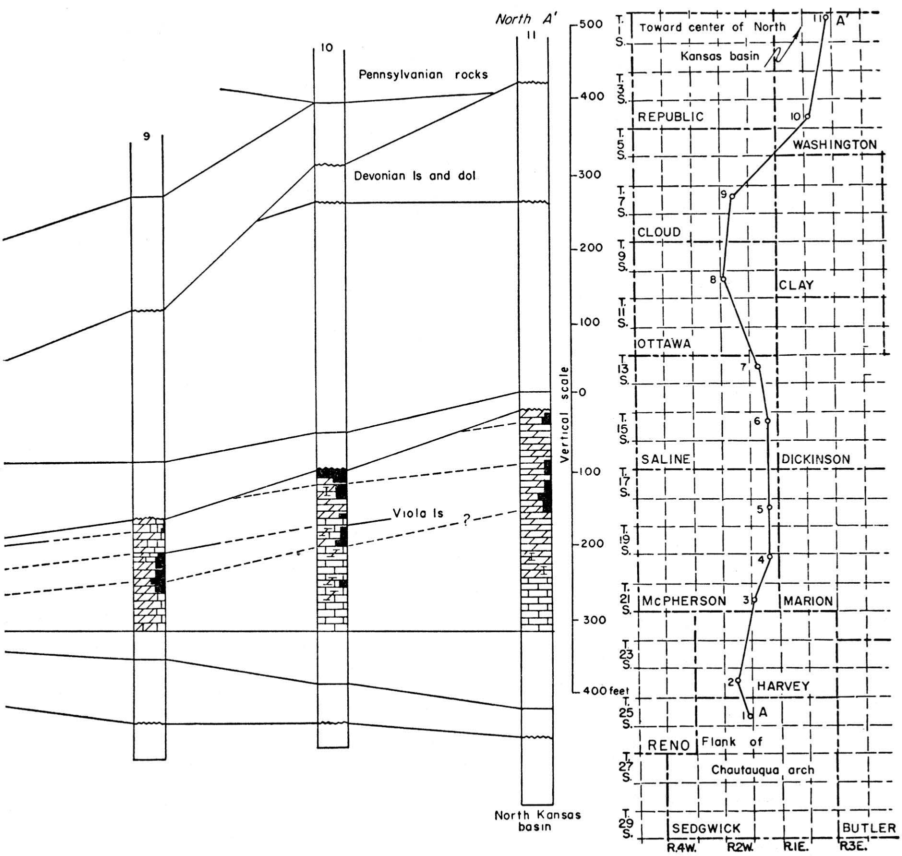


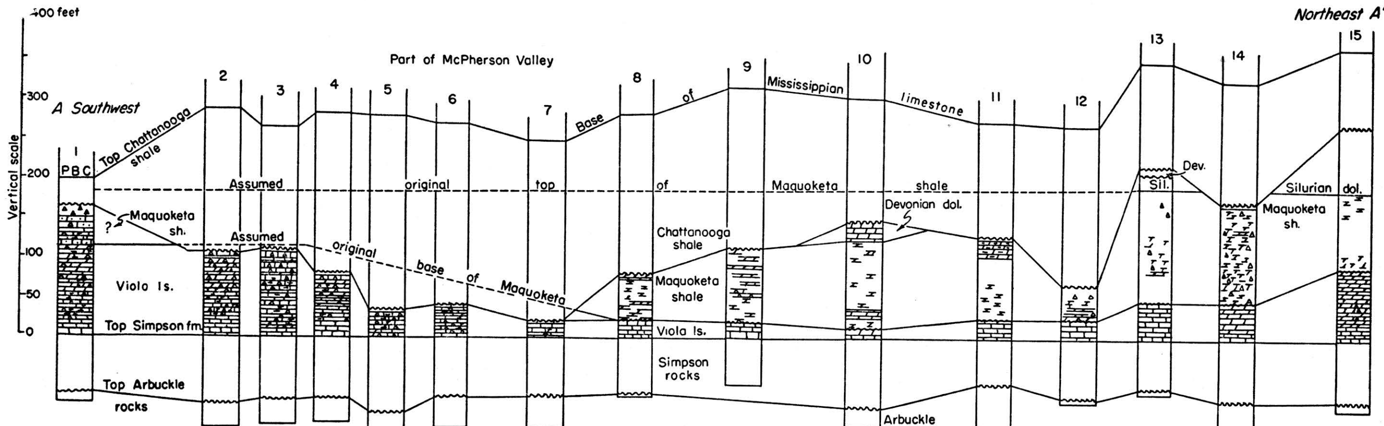
FIG. 4.—Cross section A-A′ from south to north showing (a) irregular distribution of chert in Viola limestone, and (b) northerly thickening of pre-Devonian formations.

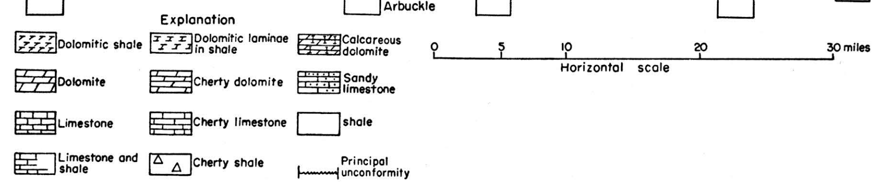
As a consequence the cherty beds do not provide very satisfactory data for zoning over broad areas although some have wide distribution.

Figure 4 is a cross section from Sedgwick County north to Washington County, which shows the quantitative distribution of chert in the Viola based on percentage logs by Constance Leatherock. The correlation of the cherty zones by the writer is admittedly speculative, but the cross section illustrates the difficulties involved in using the cherty zones as datum beds.

The lack of continuity in the presence and position of cherty dolomite suggests intraformational disconformities, but no definite interruption of the sequence is determinable. The changes from dolomite to limestone and from limestone to dolomite and the dissimilarities in the chert content at apparently the same horizon in wells only a few miles apart are regarded as the result of facies variations.







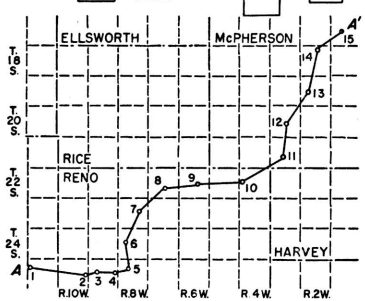
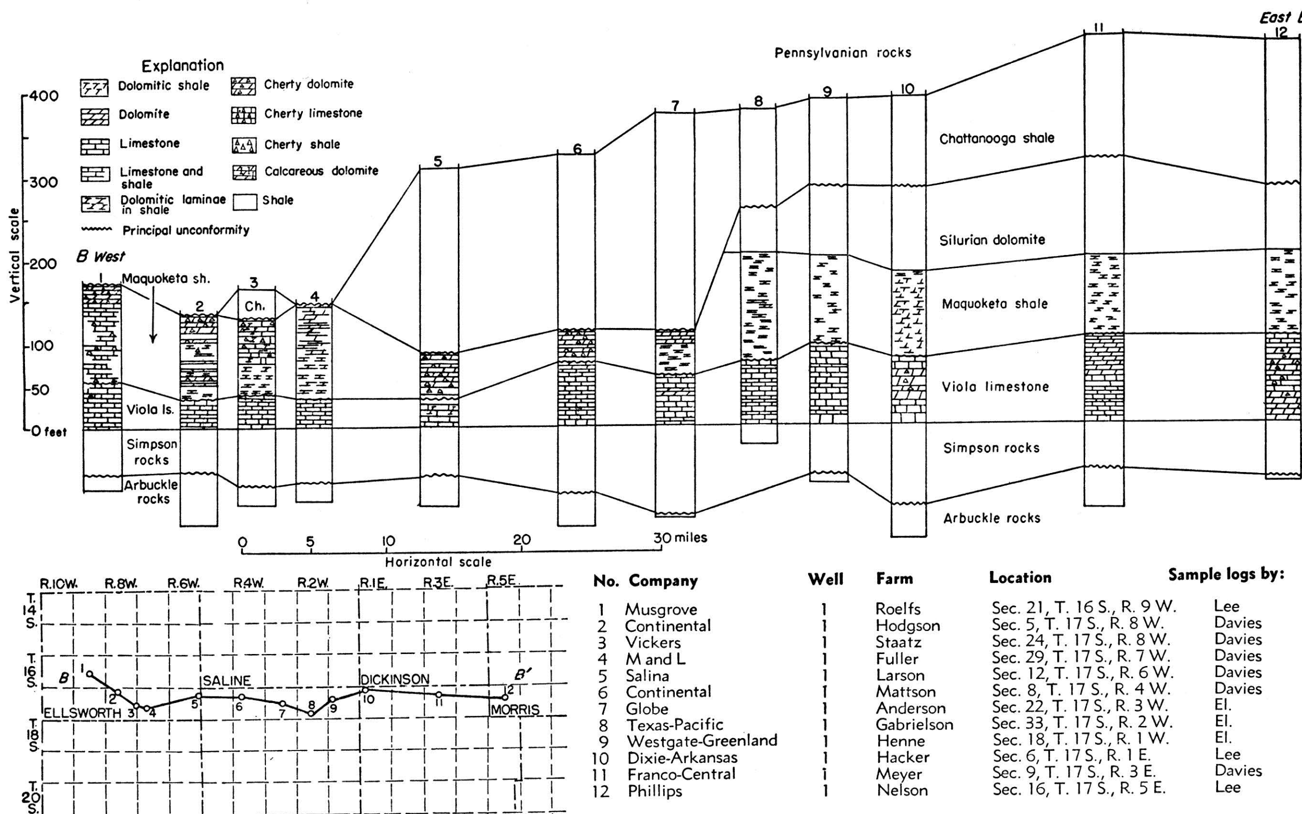


Fig. 5.—Cross section A-A' from southeastern Stafford County to northeastern McPherson County showing (a) unconformities at base of Maquoketa shale, at base of Devonian limestone, and at base of Chattanooga shale; (b) facies variations of Maquoketa shale, and (c) transition to impure cherty and sandy limestone in well 1. Well 13 shows outlier of Silurian oolitic dolomite capped by Devonian sandy dolomite.

No.	Company	Well	Farm	Location	Sample logs by:
1	Aylward et al	1	Newell	Sec. 6, T. 25 S., R. 11 W.	Lee
2	Mid-Plains	1	Hays	Sec. 24, T. 25 S., R. 10 W.	Davies
3	Skiles	1	Wright	Sec. 17, T. 25 S., R. 9 W.	Davies
4	Texas	1	Moore	Sec. 13, T. 25 S., R. 9 W.	Electric Log
5	Melland	1	Miller	Sec. 8, T. 25 S., R. 8 W.	Davies
6	Lotus	1	Fesler	Sec. 17, T. 24 S., R. 8 W.	Lee
7	Atlantic	1	Short	Sec. 14, T. 23 S., R. 8 W.	Davies
8	Deal	1	Detter	Sec. 28, T. 22 S., R. 7 W.	Lee
9	Penguin	1	Phillips	Sec. 23, T. 22 S., R. 6 W.	Davies
10	Glickman	1	Ediger	Sec. 18, T. 22 S., R. 4 W.	Davies
11	Gled-Shell	1	Sperling	Sec. 28, T. 21 S., R. 3 W.	Lee
12	Westgate-Greenland	1	Roberson	Sec. 22, T. 20 S., R. 3 W.	Lee
13	Aladdin	1	Johnson	Sec. 20, T. 19 S., R. 2 W.	Lee
14	Barbara & Beardmore	1	Klinkerman	Sec. 36, T. 18 S., R. 2 W.	Davies
15	Williams	1	Tolle	Sec. 21, T. 17 S., R. 1 W.	Lee



No.	Company	Well	Farm	Location	Sample logs by:
1	Musgrove	1	Roelfs	Sec. 21, T. 16 S., R. 9 W.	Lee
2	Continental	1	Hodgson	Sec. 5, T. 17 S., R. 8 W.	Davies
3	Vickers	1	Staatz	Sec. 24, T. 17 S., R. 8 W.	Davies
4	M and L	1	Fuller	Sec. 29, T. 17 S., R. 7 W.	Davies
5	Salina	1	Larson	Sec. 12, T. 17 S., R. 6 W.	Davies
6	Continental	1	Mattson	Sec. 8, T. 17 S., R. 4 W.	Davies
7	Globe	1	Anderson	Sec. 22, T. 17 S., R. 3 W.	El.
8	Texas-Pacific	1	Gabrielson	Sec. 33, T. 17 S., R. 2 W.	El.
9	Westgate-Greenland	1	Henne	Sec. 18, T. 17 S., R. 1 W.	El.
10	Dixie-Arkansas	1	Hacker	Sec. 6, T. 17 S., R. 1 E.	Lee
11	Franco-Central	1	Meyer	Sec. 9, T. 17 S., R. 3 E.	Davies
12	Phillips	1	Nelson	Sec. 16, T. 17 S., R. 5 E.	Lee

FIG. 6.—Cross section B-B′ from Ellsworth County east to Morris County showing (*a*) unconformity at the base of the Maquoketa shale, and (*b*) lateral transition of shale to cherty shale, cherty dolomite, impure cherty limestone, and marl.

South of T. 12 S., a zone of coarsely crystalline noncherty limestone mottled by shapeless dark-gray to black organic stains is conspicuous at the base of the formation in both sample and electric logs. In a few wells in the southern part of the area, this zone consists of similarly mottled coarsely crystalline dolomite or dolomitic limestone. In some wells in the southern part of the area the limestone has a mealy matrix in which coarser granules are embedded. This phase of the lower zone locally includes well-rounded semitranslucent grains of crystalline limestone that are optically so similar to rounded quartz sand that they can be distinguished as limestone grains only by hardness or acid tests. The calcite grains so closely resemble the quartz sand in similar rocks at the top of the Simpson that in some wells of record the enclosing rock has been erroneously logged as sandy limestone. Northward from T. 12 S., as the center of the North Kansas basin is approached the basal zone is interstratified with and grades into dolomite. The mottled basal limestone is, however, represented in sec. 1, T. 1 S., R. 2 E.

The unconformity between the Viola dolomite and the Maquoketa shale is illustrated graphically by the cross sections of Figures 5, 6, 7, and 8. The eroded character of the Viola surface is also indicated by the occurrence in some wells of a clastic deposit at the base of the Maquoketa. This clastic bed is thin and includes fine granules of limestone and dolomite embedded in characteristic Maquoketa shale. Although probably overlooked in the examination of the cuttings from many other wells, it was recognized in the following wells:

Ingling No. 1 Anderson	sec. 10, T. 16 S., R. 2 W.
McBride et al No. 2 Tolle	sec. 21, T. 17 S., R. 1 W.
Lowell No. 1 Greenwood	sec. 28, T. 18 S., R. 1 W.
Texas-Pacific No. 1 Peterson	sec. 17, T. 18 S., R. 2 W.
Deep Rock No. 1 Miller	sec. 27, T. 18 S., R. 2 W.
Dickey No. 1 Reusser	sec. 26, T. 21 S., R. 2 W.
Westgate-Greenland No. 1 Hegerty	sec. 36, T. 22 S., R. 5 W.
Appleman No. 1 McManus	sec. 29, T. 15 S., R. 6 W.

In the northeastern corner of the area the lower zone of the Viola, which includes both limestone and dolomite, is 35 to 50 feet thick. The thickness decreases irregularly to less than 20 feet in the south, where in many places the Viola is overlain unconformably by Maquoketa shale or by Chattanooga shale.

The Viola limestone, as a whole, reaches a maximum known thickness of 295 feet in well 11, Figure 4, in sec. 1, T. 1 S., R. 2 E., Washington County, Kansas, and it is 272 feet thick on the Kansas-Nebraska line in sec. 31, T. 1 N., R. 1 E., Jefferson County, Nebraska.

It thins as a whole with some irregularity toward the southwestern margin of the North Kansas basin. In T. 24 S., R. 2 W., Harvey County, Figure 4, where only the basal limestone member of the Viola has survived, its total thickness is only 40 feet.

Pre-Maquoketa erosion reduced the thickness of the Viola, and in many wells it is represented only by a part of the basal zone of coarsely crystalline limestone. Less than 15 feet of lower Viola survives in parts of Reno, Harvey, and Butler Counties. In parts of Marion, McPherson, and Reno Counties pre-Chattanooga erosion removed the Maquoketa cover and reexposed the Viola. In the Wakefield No. 1 Goering well in sec. 14, T. 25 S., R. 6 W., both the Viola and Maquoketa were removed and the Chattanooga overlies the Simpson.

As shown in the coss section of Plate 2, pre-Maquoketa erosion roughly beveled the Viola. The rude beveling that thinned the Viola toward the south suggests that at least a part of the regional subsidence of the North Kansas basin occurred before Maquoketa time.

Westward, the thickness of the Viola increases abruptly to 115 feet in the Aylward et al No. 1 Newell well in sec. 6, T. 25 S., R. 11 W., in Stafford County (well 1, cross section A-A′ of Fig. 5), on the west side of the Maquoketa erosional basin and west of the deeper part of the pre-Chattanooga valley.

A thickness of 175 feet of Viola has been reported toward the west in the Musgrove No. 1 Roelfs well in sec. 21, T. 16 S., R. 9 W., (well 1, cross section B-B′, Fig. 6). The lower 60 feet is coarse crystalline limestone typical of the basal zone of the Viola. The upper 115 feet of this sequence, except the uppermost 25 feet of cherty dolomite, consists of mealy siliceous and cherty limestone, argillaceous chalk, and marl yielding argillaceous insoluble residues. Despite the calcareous nature of the sequence, unusual in the Maquoketa, the writer regards the upper 115 feet as Maquoketa on account of the argillaceous character of most of the cuttings as shown also in well 1, cross section B-B′, Figure 6.

Pre-Chattanooga erosion very generally cut below the contact of the Maquoketa with the Viola on the western margin of the pre-Maquoketa erosion basin, as shown in cross section A-A′ of Figure 5. The contact of the Viola and Maquoketa seems to have survived, however, in a few areas as in sec. 6, T. 25 S., R. 11 W. (well 1, cross section A-A′, Fig. 5), where the Viola increases fairly abruptly to more than 100 feet. The Viola continues to thicken westward into the Hugoton embayment, where Maher and Collins (1949, sheet 1) report more than 200 feet of Viola beneath Mississippian limestone.

In the Hugoton embayment, southwest of the Central Kansas uplift, the normal sequence of Maquoketa, Silurian, Devonian, and Chattanooga rocks between the Viola and the Mississippian is missing. It must be assumed that, at some time after Viola deposition, the region of the Hugoton embayment was a positive and rising area. It was either too high to receive sediments between Viola and Mississippian time or the formations were deposited, raised, and eroded during one or more of the periods of erosional truncation so clearly exhibited in eastern Kansas. In any case a greater thickness of Viola limestone must originally have been deposited in the Hugoton embayment than is now preserved.

In the Salina basin area, the wide distribution of the basal limestone member indicates the absence of important erosional relief at the contact of the Viola with the underlying Simpson rocks.

Porosity in the Viola, as indicated by microscopic cavities and loosely interlocked grains of granular and sucrose dolomite, is confined to the upper 5 to 50 feet. Where the upper beds are especially cherty, the porosity occurs mainly in the dolomite or cherty dolomite beneath the zone of maximum chert concentration.

Maquoketa Shale

The Maquoketa shale, the youngest of the Ordovician formations in northeastern Kansas, is named for outcrops on Maquoketa River in northeastern Iowa and is exposed in adjoining areas of Illinois, Wisconsin, and Minnesota, and in southeastern Missouri and southern Illinois. The Maquoketa is widespread in the subsurface and extends westward in Kansas at least to the Central Kansas uplift. Southward its equivalent, the Sylvan shale, occurs throughout most of eastern Oklahoma.

The character of the Maquoketa shale in northeastern Kansas is variable and in different areas the Maquoketa is composed of one or more of the following rocks: argillaceous shale, dolomitic shale, silty shale, and dolomitic silty shale, argillaceous dolomite, and cherty and siliceous dolomite. No limestone or calcareous shale has been observed in the Maquoketa except toward the west in well 1 of cross section A-A′, Figure 5, and in wells 1 and 3 of cross section B-B′, Figure 6.

The shales of the Maquoketa range from dark gray and greenish

No.	Company	Well	Farm	Location	Sample logs by:
1	Texas	1	Pauls	Sec. 25, T. 21 S., R. 5 W.	Lee
2	Westgate-Greenland	1	Roberson	Sec. 22, T. 20 S., R. 3 W.	Lee
3	Aladdin	1	Johnson	Sec. 20, T. 19 S., R. 2 W.	Lee
4	Simmons et al	1	Bishop	Sec. 15, T. 18 S., R. 1 W.	Leatherock
5	White Eagle	1	Ucker	Sec. 24, T. 17 S., R 2 E.	Lee
6	Lincoln	1	Breckbill	Sec. 24, T. 16 S., R. 5 E.	Davies
7	Frank et al	1	Nelson	Sec 6, T. 15 S., R. 7 E.	Lee
8	Continental	1	Falk	Sec. 23, T. 13 S., R. 8 E.	Davies
9	Empire	1	Schwalm	Sec. 19, T. 12 S., R. 11 E.	Lee
10	Continental	1	Berridge	Sec. 8, T. 9 S., R. 17 E.	Lee
11	Carter	4	Strat. Test	Sec. 24, T. 4 S., R. 16 E.	Leatherock
12	Ohio	1	Lamparter	Sec. 3, T 2 S., R. 14 E.	Lee

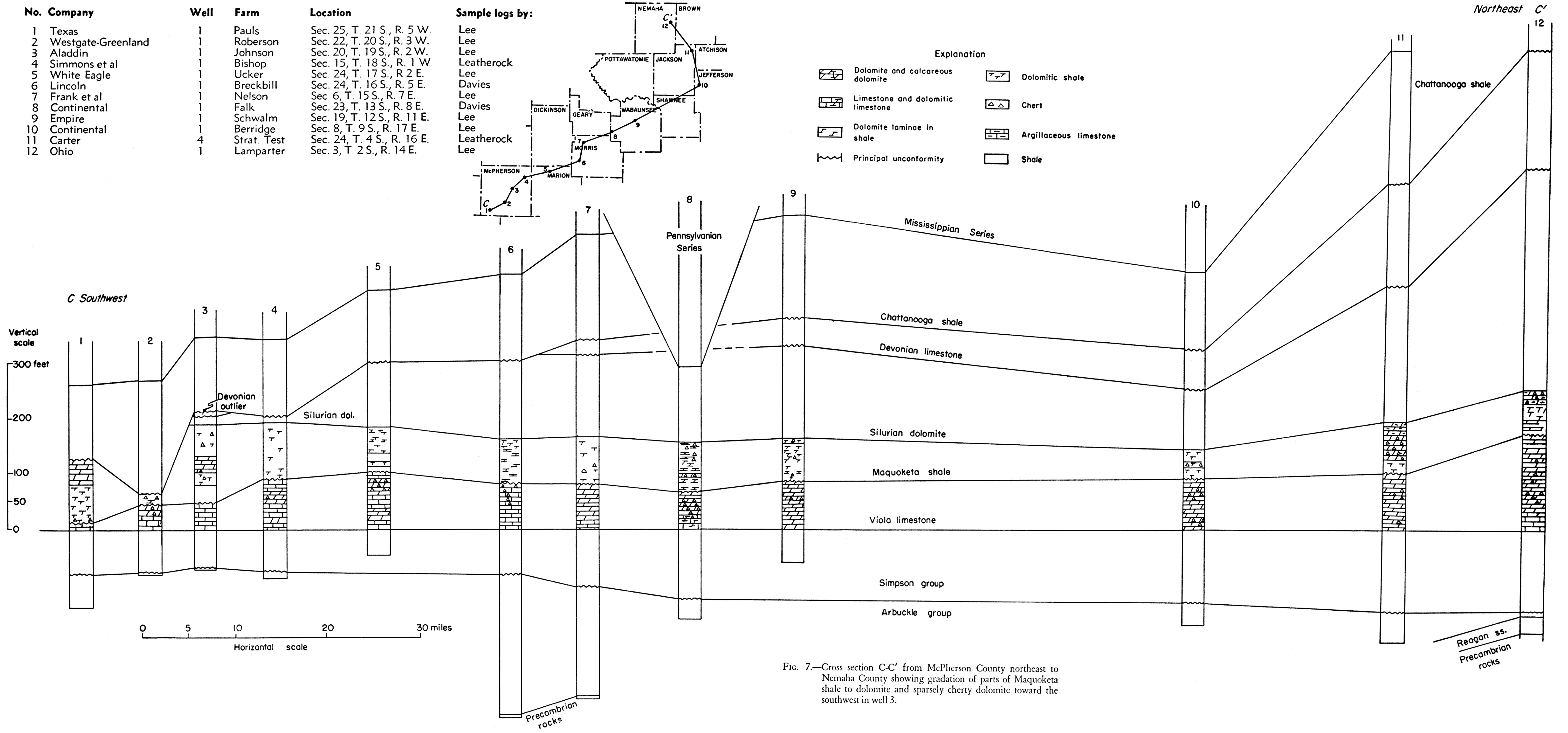


Fig. 7.—Cross section C-C′ from McPherson County northeast to Nemaha County showing gradation of parts of Maquoketa shale to dolomite and sparsely cherty dolomite toward the southwest in well 3.

gray to dark green. Most of the shales are dolomitic. Some are silty, siliceous, and cherty. Insoluble residues, especially from samples of wells toward the northeast, display molds of free dolomite crystals in spongy coherent silt or silica. Toward the southwest fine dolomite molds pit the chert. The most common type of shale is dolomitic and includes more or less thinly disseminated fine crystals or interlaminated argillaceous grainy dolomite. The Maquoketa includes fine subangular sand in T. 2 S., R. 13 W., and similar fine sand grains are embedded in limestone in the Aylward et al No. 1 Newell well in sec. 6, T. 25 S., R. 11 W. Some of the shales, particularly toward the southern part of the area, include fine dark particles of what seem to be disintegrated graptolites.

The Maquoketa dolomite is gray to dark gray, grainy, composed of fine crystals set in an argillaceous or silty matrix. The impure dolomite of the Maquoketa contrasts sharply with the clean sucrose or coarsely crystalline dolomite of the Viola.

The chert is similar to that in the Viola. It is gray and opaque, bluish gray semiopaque, or chalcedonic, and encloses silicified fine fragments of microfossils and spicules. Like that of the Viola, the Maquoketa chert is in many places flecked and peppered with dark fragments of disintegrated graptolites. Some of the semiopaque gray chert is massive or laced with white spicules. Some of the siliceous beds are dolomitic and some in T. 25 S., R. 11 W., and T. 16 S., R. 9 W., are calcareous.

Cross section C-C′ of Figure 7, from McPherson County to Nemaha County, shows the variations in the lithology of the Maquoketa and the relation of the Maquoketa to the eroded surface of the Viola. The occurrence of chert in silty dolomitic Maquoketa shale in wells 10, 11, and 12 in Jefferson, Brown, and Nemaha Counties is of interest because of the common occurrence of similar chert in wells farther southwest in Saline and McPherson Counties. Examination of samples and residues from well 11 reveals that the Maquoketa shale, which is 93 feet thick, consists, in descending order, of 28 feet of argillaceous dolomite with traces of flecked chert; 40 feet of silty and siliceous dolomite with 10 to 20 percent of insoluble residues consisting of variegated dense and spongy dolomitic chert or cemented silt; and at the base 25 feet of argillaceous shale in which fine dolomite crystals are thinly disseminated. In well 10 the Maquoketa consists of 50 feet of dolomitic shale, containing a 12-foot zone near the middle that yields insoluble residues of spongy and chalcedonic chert. Southwestward from well 10 on the line of the cross section, the Maquoketa consists of greenish-gray shale interbedded or interlaminated with dolomitic shale as far as well 4. In well 3 the Maquoketa thickens to 142 feet. The upper 55 feet is dark-green shale with traces of

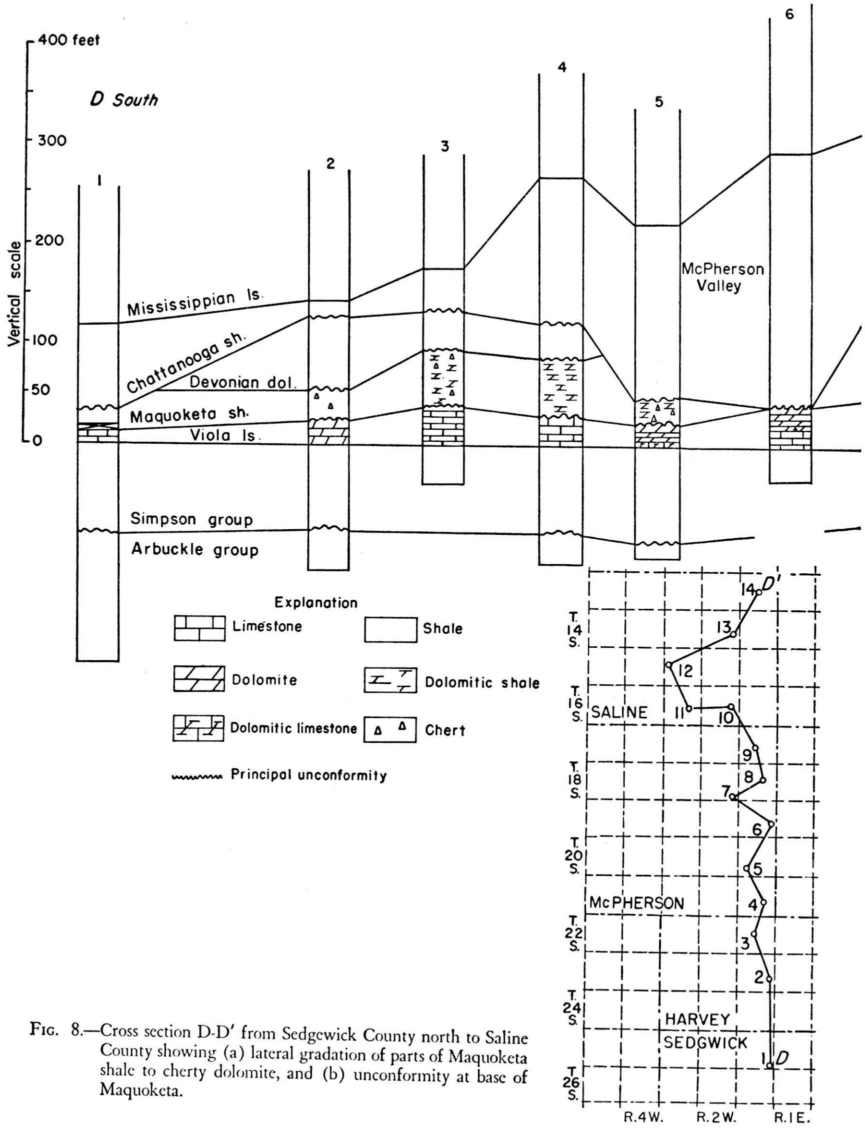
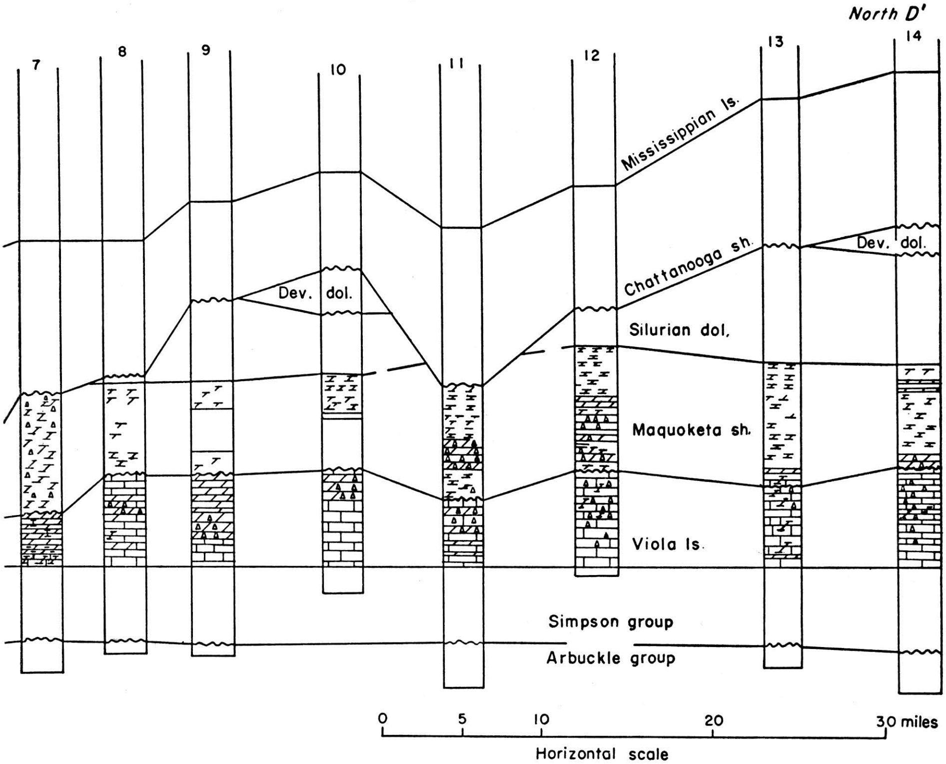


FIG. 8.—Cross section D-D′ from Sedgewick County north to Saline County showing (a) lateral gradation of parts of Maquoketa shale to cherty dolomite, and (b) unconformity at base of Maquoketa.

flecked chert underlain by 52 feet of silty and argillaceous grainy gray dolomite with traces of similar chert, and 35 feet of dark-green shale.

Cross section B-B′, Figure 6, from Ellsworth County to Morris



No.	Company	Well	Farm	Location	Sample logs by:
1	Aladdin	1	Smyser	Sec. 36, T. 25 S., R. 1 W.	Lee
2	West Kansas	1	Moorehead	Sec. 24, T. 23 S., R. 1 W.	Lee
3	Mid-Plains	1	Dunkelberger	Sec. 16, T. 22 S., R. 1 W.	Lee
4	Penguin	1	Regier	Sec. 23, T. 21 S., R. 1 W.	Davies
5	Hartman	1	John	Sec. 29, T. 20 S., R. 1 W.	Davies
6	Darby	1	Brucker	Sec. 24, T. 19 S., R. 1 W.	Lee
7	Barbara & Beardmore	1	Klinkerman	Sec. 36, T. 18 S., R. 2 W.	Davies
8	Simmons et al	1	Bishop	Sec. 15, T. 18 S., R. 1 W.	Leatherock
9	McBride et al	2	Tolle	Sec. 21, T. 17 S., R. 1 W.	Lee
10	Lario	1	Fulton	Sec. 14, T. 16 S., R. 2 W.	Lee
11	National Assoc.	1	Nelson	Sec. 22, T. 16 S., R. 3 W.	Lee
12	Shields	1	Swanson	Sec. 18, T. 15 S., R. 3 W	Davies
13	Berry and Fick	1	Hoeffner	Sec. 23, T. 14 S., R. 2 W.	Davies
14	Jones & Shelburne	1	Markley	Sec. 16, T. 13 S., R. 1 W.	Davies

County, shows the transition of the lower part of the Maquoketa from dolomitic shale to cherty dolomite in wells 5 and 6 in northern McPherson County. In wells 1 and 3 the formation consists chiefly of very cherty chalky limestone and marl, in part dolomitic, but irregularly interbedded with calcareous shale and grainy dolomitic shale.

Cross section D-D′ of Figure 8, from Sedgwick County to Saline County, again shows the transition from Maquoketa dolomitic shale to cherty dolomite in western Saline County, and the progressive substitution of the Viola by the Maquoketa from north to south. It also shows roughly the truncation of the Maquoketa and Silurian rocks by pre-Devonian erosion and the local removal of the Devonian and Maquoketa in the McPherson valley eroded during the hiatus that preceded the deposition of the Chattanooga shale. An example of abrupt transition is shown in well 12 of cross section D-D′, Figure 8, in which the lower 53 feet consists of cherty argillaceous dolomite interbedded with dolomitic shale, but the upper 50 feet is noncherty dolomitic shale. The variability of the Maquoketa sequence is illustrated also by the change between this well and the Appleman No. 1 McManus well in sec. 29, T. 15 S., R. 6 W., only 16 miles away, in which the Maquoketa samples represent 140 feet of argillaceous and dolomitic shale containing only traces of gray argillaceous and silty dolomite and limestone in the lower 50 feet.

Cross section A-A′, Figure 5, from McPherson County to Stafford County, shows the thickening of the Maquoketa at the expense of the Viola, the elimination of the Maquoketa from wells 2 to 7 by pre-Chattanooga erosion, and the presumed reappearance of the Maquoketa in Stafford County in well 1 as argillaceous, cherty or siliceous chalky limestone with embedded fine sand and silt and yielding insoluble residues of tripolitic silica.

In well 1, 50 feet of pure, cherty, chalky limestone and calcareous chert seems to represent the Maquoketa. Insoluble residues of the base and middle of the Maquoketa in this well yield fine subangular sand embedded in limestone and spongy chert. The presence of sand may be an indication of approach to a shore line.

Fine subangular sand also occurs below very dark gray extremely pyritiferous shale between the Silurian and the Viola in the Mid-Kansas No. 1 Borgan well in sec. 4, T. 2 S., R. 13 W. The Maquoketa is only 30 feet thick in this well and seems to represent a pinch-out or marginal deposit on the flank of a mild initial stage of the Central Kansas uplift.

The thickness of the Maquoketa where it is normally overlain by the Silurian and not cut off by later unconformities ranges from 30 feet to 142 feet. It is 30 feet thick in the Mid-Kansas No. 1 Borgan well in sec. 4, T. 2 S., R. 13 W., and in the Murfin No. 1 Wessling well in sec. 35, T. 6 S., R. 7 W., where it displays the normal character of greenish-gray dolomitic shale. In the northern part of the area it is generally less than 65 feet thick, although locally, as in wells in T. 4 S., R. 15 and 16 W., it thickens to about 95 feet. The thickness increases irregularly toward the south and southwest, and in Saline and McPherson Counties it averages somewhat more than 100 feet, ranging from 80 feet in sec. 24, T. 17 S., R. 2 W., to 142 feet beneath a Silurian outlier in sec. 20, T. 19 S., R. 2 W. The irregularities in thickness are due in large part to topographic relief of the eroded surface of the underlying Viola as illustrated in the cross sections, Figures 6, 7, and 8.

The Maquoketa has not been reported southwest of the Central Kansas uplift. The increase in the proportion of carbonates in the most western wells in which the Maquoketa is recognized suggests that westward it may become indistinguishable from the Viola. On the other hand the relations suggested in cross section A-A′, Figure 5, and the sandy beds at the base of the Maquoketa in well 1 suggest that the Maquoketa overlapped on topographically high Viola that remained above the level of Maquoketa deposition near the margin of the Maquoketa basin.

There is some reason to suspect that an inconspicuous disconformity separates the Maquoketa from the Silurian. This supposition is based on the variable position of the oölitic dolomite zone of the Silurian, which in some places is 30 feet or more above the Maquoketa and in others is in contact with it. This theory is supported by discrepancies in the thickness of the Maquoketa in nearby wells in which the thickness of the Viola is uniform. The topographic relief in any case is low and negligible.

ROCKS OF SILURIAN AGE

The limestone and dolomite lying between the Maquoketa shale and the Chattanooga shale are conveniently referred to as the Hunton formation or group by oil operators and petroleum geologists. Study of this sequence has revealed that it includes both rocks of Silurian age and rocks of Devonian age. Unconformities at the bottom and top of the Devonian part have so restricted the distribution of the separate parts of the Hunton in Kansas and Oklahoma that either the Silurian or Devonian beds may be present alone or in combination with parts of the other. The term Hunton has thus become ambiguous except in the sense that it includes all the carbonate rocks between the Maquoketa and Chattanooga shales.

Silurian rocks crop out at intervals from the Arbuckle Mountains in Oklahoma through central Arkansas, thence northward around the Ozark uplift to southeastern Missouri, thence to northeastern Iowa and parts of adjoining states. These rocks include the Alexandrian Series of Savage (1908) at the base of the Silurian, consisting in ascending order of the Cape Girardeau limestone, Edgewood limestone, and Brassfield or Sexton Creek limestone. In some areas outside Kansas, rocks of Alexandrian age are overlain by the Bainbridge limestone or its correlatives of the next younger Niagaran Series. The oldest of the Silurian rocks in Oklahoma is the Chimneyhill limestone, which includes equivalents of the Noix oölite member of the Edgewood limestone and the Brassfield limestone of Missouri and Illinois. In Oklahoma, the Chimneyhill is overlain by the Henryhouse shale, which is believed by some geologists to represent the Bainbridge of the Mississippi Valley. Some of the Silurian rocks of north-central Kansas are correlated with the Chimneyhill of Oklahoma (Lee, 1945, p. 44-45). Younger Silurian rocks may be represented in parts of northeastern Kansas, but they have not been differentiated.

The Chimneyhill limestone and its correlatives and the overlying Silurian rocks are widely distributed in the subsurface. They were probably originally deposited throughout the region from the outcrops in the Mississippi Valley across the Ozarks and at least to central Kansas and central Oklahoma. Upwarping and erosion have removed all the Silurian rocks from the central Ozarks and from the crests of anticlinal structures in Kansas, including the Chautauqua arch, the Nemaha anticline, and the Central Kansas uplift. In outcrops in southeastern Missouri and southern Illinois, unconformities have been recognized at the base of the Edgewood limestone, of Brassfield age, and at the base of the Bainbridge.

There are several recognizable zones in the Silurian sequence of Kansas. They have well-defined limits in some wells, but their separation in others is vague and unsatisfactory. These may be described in ascending order as the oölitic zone, the white chert zone, the foraminiferal zone, a siliceous and cherty zone, and a noncherty zone of alternating dolomite and limestone. These zones are clearly defined in areas near the center of the basin, but toward the margin lithologic diversity makes zoning difficult or impossible.

The first or oölitic zone, which overlies the Maquoketa, is everywhere composed of sucrose or fine-grained dolomite characterized by dolomitized oölites. The oölites are composed of sucrose dolomite, and their surfaces are roughened by minute crystals of dolomite. In some samples the oölites are touching, without matrix. In others they are embedded in the matrix, which in some places displays voids left by the removal of fossil fragments. In some wells the oölites resemble grains of soft dolomite worn to roundish surfaces in drilling. The abundance of the oölite is variable, and the variation in thickness of the zone may be due either to poor preservation of the oölites or to their irregular distribution. In the absence of recognizable oölites, the zone is generally represented by the sucrose dolomite typical of this zone. Small amounts of oölitic white chert were noted in this zone in the following wells: the B. B. Blair No. 1 Cox well in sec. 10, T. 4 S., R. 7 E., the Wolf Creek Oil Company No. 1 Brenizer well in sec. 35, T. 12 S., R. 2 E., the Bay Petroleum Corporation No. 1 Rockhold well in sec. 20, T. 13 S., R. 1 W., and the Hutchinson No. 1 Ehrmann well in sec. 15, T. 18 S., R. 1 E. In the W. A. Haney No. 1 Faidley well in sec. 27, T. 10 S., R. 1 W., the centers of the oölities and some of the openings have been filled with chalcedony, leaving fragments that superficially resemble rounded grains of quartz sand. The thickness of the Silurian in this well is nearly twice that in the nearest wells in adjoining townships, although the thickness of the other pre-Pennsylvanian formations is normal. This fact, the unusual chalcedonic replacements, and the presence of excessive amounts of quartz and siliceous dolomite in the middle part of the Silurian suggest the possibility that this well was drilled through a fault in the Silurian. The oölitic zone is missing in parts of Cloud and Mitchell Counties and in scattered wells elsewhere, especially toward the southern margin of the North Kansas basin. It is not represented in samples from a cable tool well in the NW corner SW¼ sec. 27, T. 14 S., R. 2 W., nor in samples from a well in the NW corner sec. 30 of the same township. It is, however, well developed in 12 other wells in this township, a relationship that suggests that its seeming absence may be due to poor samples rather than nondeposition.

The insoluble residues of samples from this zone generally constitute less than 2 percent by volume and consist of fine particles of hackly and drusy quartz and silt. The zone is correlated with the Noix oölite member of the Edgewood limestone of northeastern Missouri, which was correlated by Ulrich (1930, p. 73) with the basal beds of the Chimneyhill of Oklahoma.

Except for local areas in which it is absent, the oölitic zone is coextensive with the Silurian. It reaches its greatest thickness of 60 feet in the northern part of the area in the Phillips No. 1 Helms well in sec. 20, T. 4 S., R. 2 E.; it is only 7 feet thick in the Blair No. 1 Cox well in sec. 10, T. 4 S., R. 7 E., and 10 feet thick in the Carter No. 1 stratigraphic test in sec. 16, T. 7 S., R. 2 W. The zone thins irregularly toward the south, where it is commonly less than 5 feet thick or absent.

The second or white chert zone normally overlies the oölitic zone, but it was not developed in some areas. The zone consists mainly of medium to coarse crystalline dolomite that generally includes only minor amounts of white opaque chert or dense tripolitic white chert. In the Phillips No. 1 Helms well in sec. 20, T. 4 S., R. 2 E., where the Silurian is especially cherty, 35 feet of coarsely granular dolomite containing 10 to 40 percent white opaque chert overlies the oölitic zone. The cherty zone diminishes in thickness toward the south and is missing or noncherty in many wells. The zone is 15 feet thick in the Turner No. 1 Umsheid well in sec. 32, T. 8 S., R. 9 E., and in the Lashelle No. 1 Umsheid well in sec. 16, T. 9 S., R. 9 E. In the Wolf Creek No. 1 Brenizer well in sec. 35, T. 12 S., R. 2 E., it is only 5 feet thick. Only traces of white chert occur directly above the oölitic beds in some of the wells in Saline and Dickinson Counties. Chert seems to be absent farther south.

The third zone, which includes foraminifera, extends upward from the cherty dolomite to the base of a well-developed siliceous dolomite. Toward the center of the North Kansas basin this zone consists entirely of dolomite, but like other deposits in the basin it becomes increasingly interstratified with limestone toward the margin. The dolomite in the lower part of the zone is dense to sucrose and of fine texture, but the upper beds are coarsely crystalline and coarsely vuggy, many voids resulting from the solution of fossil fragments. The limestones in areas marginal to the North Kansas basin are semigranular, mealy, or sublithographic. The lower limestone beds contain embedded grains of dolomite. In some wells, as in the Arab No. 1 Ogle well in sec. 9, T. 1 N., R. 14 E., in Nebraska, the lower beds of this zone include pink and red dolomite, and in Dickinson County and adjoining areas the beds are red and argillaceous. In the Arab No. 1 Ogle well, the two lower zones are absent or not identified and the foraminiferal zone seems to be in contact with the Maquoketa.

Where the sequence is normal, the fine-grained dolomites of the third zone and their limestone correlatives on the margin of the North Kansas basin are characterized by the presence of diffusely distributed foraminifera of species resembling *Ammodiscus* and *Lituotuba* present in the Silurian of Oklahoma but unreported from the Devonian (Ireland, 1939). Similar foraminifera have been reported from the Brassfield limestone of the Mississippi valley, with which this zone is correlated. The insoluble residues from 5-gram samples (usually less than 2 percent) rarely yield as many as 6 specimens, and some contain none. These foraminifera occur at a depth of 1,530 feet, 90 feet above the white chert zone in the Coronado No. 1 Parks well (a cable tool well) in sec. 16, T. 10 S., R. 8 E., but foraminifera are only infrequently found more than 40 feet above the zone of white chert. On the southern margin of the North Kansas basin, where the dolomite beds are interstratified with limestone, *Ammodiscus* has been found in limestone as well as in dolomite. It occurs in pink limestone directly below semiopaque chalcedonic chert 75 feet above the oölitic zone in the Auto-Ordnance No. 1 Gawith well in sec. 27, T. 11 S., R. 5 W., at a depth of 3,620 to 3,625 feet. It occurs also in semigranular limestone directly above the oölitic zone in the Auto-Ordnance No. 1 Ruch well in sec. 25, T. 13 S., R. 2 W., and in the same position in earthy semigranular limestone in the Northern Ordnance No. 1 Warner well in sec. 10, T. 15 S., R. 3 W., and in wells in sec. 30, T. 15 S., R. 2 W., and in sec. 17, T. 15 S., R. 1 W.

The zone is generally noncherty, but in the Phillips No. 1 Helms well in sec. 20, T. 4 S., R. 2 E., dolomite at the depth of this zone, but possibly not its correlative, includes 10 to 40 percent chert. The chert in the lower part is mottled and spicular and that in the upper part massive, vitreous, and varicolored. It may be that the varicolored cherty dolomite in this well and in wells farther west, in place of the normal noncherty dolomite, indicates a mid-Silurian disconformity rather than a facies variation. In most wells in Cloud and Mitchell Counties in which the oölitic zone has been identified, the oölitic zone is overlain by a sequence of limestone and dolomite and massive semiopaque vitreous chert of shades of gray and yellow to pink and red, unlike the lithology of the third zone in most areas but resembling the less vivid vitreous cherts in the Phillips No. 1 Helms well described above.

The third zone is 165 feet thick in the Ohio No. 1 Lamparter well in sec. 3, T. 2 S., R. 14 E., near the center of the North Kansas basin. Its thickness decreases somewhat irregularly toward the south to 55 feet in the Bay Petroleum Company No. 1 Rockhold well in sec. 20, T. 13 S., R. 1 W., and 40 to 60 feet in wells in T. 14 S., R. 2 W. Westward in Cloud and Mitchell Counties, rocks assigned to the third zone consist of an irregular relatively thin sequence of varicolored (red, pink, lemon yellow to gray) dolomite and limestone. The upper part of this sequence is extremely siliceous and contains a large amount of varicolored semiopaque massive chert.

The fourth zone is composed mainly of dolomite but includes minor amounts of interbedded limestone toward the southwest in the usual gradation from central to marginal areas of the North Kansas basin. This zone is siliceous, but the insoluble residues, which include both quartzose and cherty materials, are extremely variable in character and in volume, ranging from a trace to 10 percent. The insoluble residues include quartz crystals, hackly quartz, drusy quartz, spongy silica, and silt. The cherty residues of this zone include grainy opaque chert, semiopaque chert, and soft white opaque chert resembling tripoli. The quartz crystals are confined to the upper 5 to 40 feet of this zone, and where present identify the fourth zone in the basin areas. Toward the margin of the basin the quartzose residues diminish in volume and disappear, and the residues become increasingly cherty. The fourth zone is normally 65 to 75 feet thick in basinward areas, but toward the south and west it was removed by pre-Devonian erosion.

The fifth zone consists of interbedded limestone and dolomite, whose insoluble residues are of negligible volume. It attains a maximum known thickness of 140 feet in the Ohio Oil Company No. 1 Lamparter well in sec. 3, T. 2 S., R. 14 E., (well 14, Pl. 3), but it is absent toward the south and west on account of pre-Devonian erosion.

Toward the southwestern margin of the North Kansas basin, the entire Silurian sequence grades into coarsely crystalline white limestone as much as 40 feet thick overlain by cherty dolomite as much as 80 feet thick. The chert is varicolored, vitreous, and semitranslucent. These rocks are correlated with the Silurian because of the similarity of the chert to that of zone 3 in the Phillips No. 1 Helms well in sec. 20, T. 4 S., R. 2 E., and because sandy Devonian limestone overlies these cherty beds in the Livermore No. 1 Froelich well in sec. 30, T. 5 S., R. 10 W., and in other wells in the vicinity.

In Kansas the Silurian rocks overlie the Maquoketa shale in seeming conformity, but differences in the interval from the top of the oölitic zone to the top of the Maquoketa suggest a slight disconformity between them. The Silurian is separated from the overlying Devonian rocks by an important unconformity (cross section C-C′, Fig. 7), caused by erosion that beveled older rocks as far down as the Arbuckle. This surface was an imperfect plain in central Kansas. Topographic relief of 80 feet or more is revealed by variations in the thickness of the Silurian beneath its contact with the Devonian in Ottawa and Dickinson Counties. Lesser relief occurs in other areas.

Plate 2 shows the present distribution of the Silurian rocks. They were originally deposited throughout the area, but during repeated periods of uplift and erosion were worn away from certain areas. As shown in cross section A-A′ of Plate 2 and Figure 4, the Devonian rests on progressively thinner remnants of the Silurian toward the south. The Silurian where it is overlain by the Devonian is 445 feet thick in the Ohio No. 1 Lamparter well in sec. 3, T. 2 S., R. 14 E. Its thickness diminishes to 16 feet on an outlier capped by Devonian in the Aladdin No. 1 Johnson well in sec. 20, T. 19 S., R. 2 W. (well 3, Fig. 7). Farther south the Silurian is missing where the Devonian overlaps upon the Maquoketa shale. Pre-Mississippian erosion removed the Silurian from flank areas of the Central Kansas uplift, where its thickness had already been reduced by pre-Devonian erosion. The Silurian was removed from the highest parts of the Nemaha anticline by pre-Pennsylvanian erosion.

ROCKS OF DEVONIAN AGE

The outcrops of Devonian rocks nearest to the Salina Basin are situated in central Missouri, where Devonian formations of no great thickness appear at the surface in separated outcrops. Branson (1944, p. 131, 151) recognized and named the formations of Middle Devonian age in northern Missouri, each of which is bounded by disconformities. These formations, in ascending order, are Cooper limestone, Ashland limestone, and Callaway limestone. The Upper Devonian is represented by the Snyder Creek shale, which lies disconformably on the Callaway in outcrops but is not represented in northeastern Kansas. The Cooper limestone of the outcrops consists mainly of bluish-gray lithographic limestone. It is nearly everywhere characterized by basal beds of sandstone, calcareous sand, or sandy limestone.

Rocks of Cooper age, consisting of lithographic and sublithographic limestone, have been traced in the subsurface westward from the outcrops into northeastern Kansas. West of the Nemaha anticline, from the crest of which the Devonian rocks were later eroded, the Devonian has been identified by its basal sandy beds as far west as T. 6 S., R. 1 W. West of this point the basal sandy beds have not been recognized except in a thin outlier in T. 5 S., R. 10 and 11 W. The Devonian rocks of the Salina basin area are divided conveniently into upper and lower zones by a bed of cherty or siliceous dolomite at the top of the lower zone. The formations above the Cooper limestone have not been differentiated in the subsurface.

The *lower zone* of the Devonian rocks includes a sandy bed at the base and in most areas a cherty bed at the top. In the central part of the North Kansas basin the lower zone consists of dolomite of sucrose texture. In many areas nearer the margin of the basin the dolomite is interstratified with limestone, but in Harvey County and adjoining areas south of the pre-Chattanooga valley the Devonian consists of grainy, finely crystalline dolomite capped by cherty dolomite. Insoluble residues reveal that the grainy character of the dolomite in this area is due to the presence of very fine subrounded to subangular sand. Embedded medium-grained sand typical of the Devonian in other wells of the area identify this dolomite as Devonian. In the Phil-Han Oil Company No. 1 Currie well in sec. 10, T. 15 S., R. 1 W., the lower 40 feet of the lower zone consists of semigranular limestone interbedded with thin sheets of sucrose dolomite. The sandy bed at the base of the lower zone is generally dolomitic but in a few wells toward the southern margin of the North Kansas basin the sandy bed is a limestone. The embedded sand grains are of medium size, and mainly rounded and frosted. They constitute a trace to 40 percent of the volume of the sample. In some wells sand is thinly disseminated throughout most of the lower zone. In the Scow Bros. et al No. 1 Gates well, in sec. 16, T. 9 S., R. 4 E., 20 feet of dolomitic sandstone containing some green clay shale directly underlies the cherty bed. Considerable sand, as much as 20 percent of the samples, occurs in a bed 40 to 60 feet above the base of the Devonian in the McLaughlin No. 1 Allen well in sec. 32, T. 8 S., R. 16 E., and various amounts of sand also are found several feet above the basal sandy bed in some other wells.

The cherty dolomite at the top of the lower zone is 10 to 35 feet thick, and the chert content in the insoluble residues ranges from 10 to 80 percent of the samples. Part of the chert is gray and opaque and its texture is massive to grainy and spicular. Part is white and soft and resembles tripoli. The thickness of the lower zone ranges from 105 feet in the Ohio Oil Company No. 1 Lamparter well in sec. 3, T. 2 S., R. 14 E., to 30 feet or less on the southern margin of the North Kansas basin, where the Devonian rocks were beveled by pre-Chattanooga erosion.

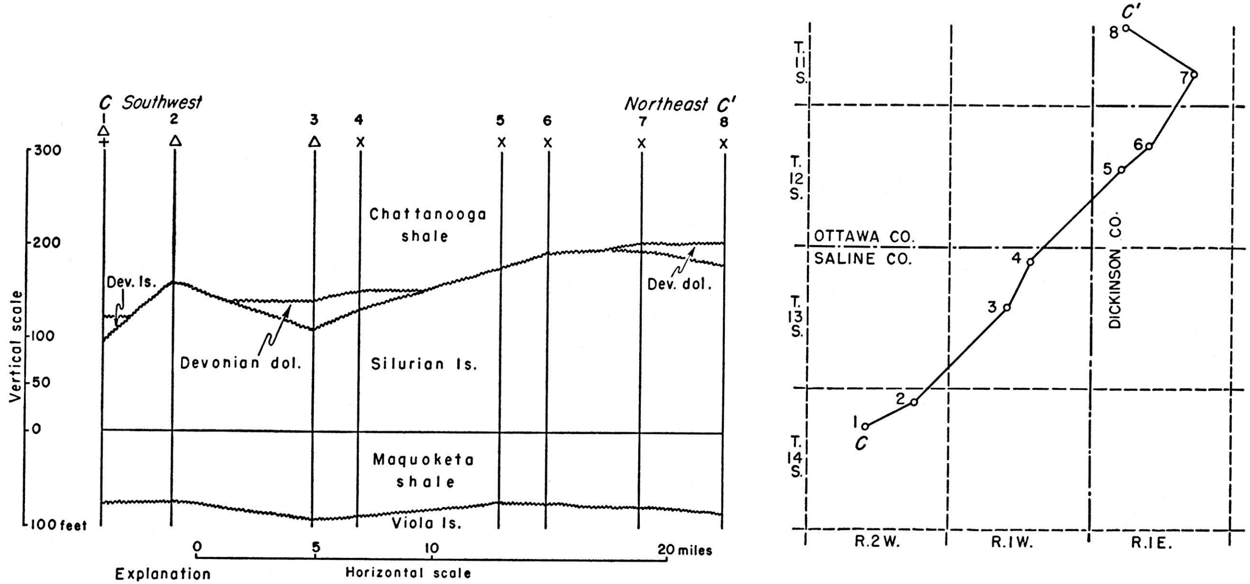
The increase in thickness of the lower zone toward the center of the North Kansas basin seems to be the result of the differential subsidence of the basin during the deposition of the lower zone of the Devonian.

The *upper zone* consists of the Devonian rocks above the persistent white chert beds. It was reduced to its present thickness by post-Devonian erosion. It is 100 feet thick and lies at a depth of 2,185 to 2,285 feet in the Gulf No. 1 Baker well in sec. 1, T. 1 S., R. 2 E. It is 55 feet thick and lies at a depth of 1,650 to 1,705 feet in the Davon No. 1 Schaefer well in sec. 20, T. 1 S., R. 6 E., but it is only 10 feet thick and at a depth of 2,237 to 2,247 feet in the Phillips No. 1 Helms well in sec. 20, T. 4 S., R. 2 E. The upper zone is absent farther south as a result of post-Devonian erosion. In the Gulf-Baker well the upper zone is composed of limestone interbedded with dolomite and in the Davon-Schaefer well it consists of red, brown, and gray limestone. Elsewhere it is composed of various types of dolomite, but in some wells the dolomite is interstratified with thin limestone beds. The upper zone provides no useful datum beds, and except locally it is doubtful whether the persistent white chert bed at the top of the lower zone is a reliable datum, on account of the variation in its thickness.

Most of the Devonian rocks, whether limestone or dolomite, are dense. Even on the eroded pre-Chattanooga surface they do not ordinarily develop porosity. Where the original texture of the exposed rocks is favorable, however, porosity has developed, as in the upper 40 feet of the Devonian in the Arkansas Fuel Company No. 1 Martin well in sec. 24, T. 8 S., R. 4 E.

Porosity occurs also in a local sandstone directly below the cherty dolomite beds in the Scow Bros. No. 1 Gates well in sec. 16, T. 9 S., R. 4 E., and in the sandy slightly dolomitic member near the base of the Devonian dolomite in the same well. Porosity occurs also in many wells where the basal beds consist of very sandy dolomite or a dolomitic sand as in the Leeward Petroleum Corporation No. 1 Knight well in sec. 23, T. 13 S., R. 3 E.

The Devonian dolomite and limestone in eastern Kansas, in the area of the map, have a maximum thickness of 213 feet in the Ohio Oil Company No. 1 Lamparter well in sec. 3, T. 2 S., R. 14 E. They are considerably thicker in southeastern Nebraska and become irregularly thinner toward the southern margin of the North Kansas



Explanation
+ Electric logs
X Sample logs
Δ Logs of Kansas Sample Log Service
〰 Principal unconformities

No.	Company	Well	Farm	Location
1	Anschutz	1	Rosener	Sec. 9, T. 14 S., R. 2 W.
2	Atlantic	1	Hoeffner	Sec. 2, T. 14 S., R. 2 W.
3	Jones & Shelburne	1	Markley	Sec. 16, T. 13 S., R. 1 W.
4	Valley Oil	1	Herrington	Sec. 3, T. 13 S., R. 1 W.
5	Stanolind	1	Equitable Life	Sec. 17, T. 12 S., R. 1 E.
6	Goens & Morgan	1	Whitehair	Sec. 9, T. 12 S., R. 1 E.
7	Phillips	1	Dickenson	Sec. 26, T. 11 S., R. 1 E.
8	Wolf Creek	1	Mustard	Sec. 17, T. 11 S., R. 1 E.

FIG. 9.—Cross section C-C', in Saline and Dickinson Counties, on inset and on Plate 3, showing pre-Devonian hills of Silurian dolomite reexposed by pre-Chattanooga erosion.

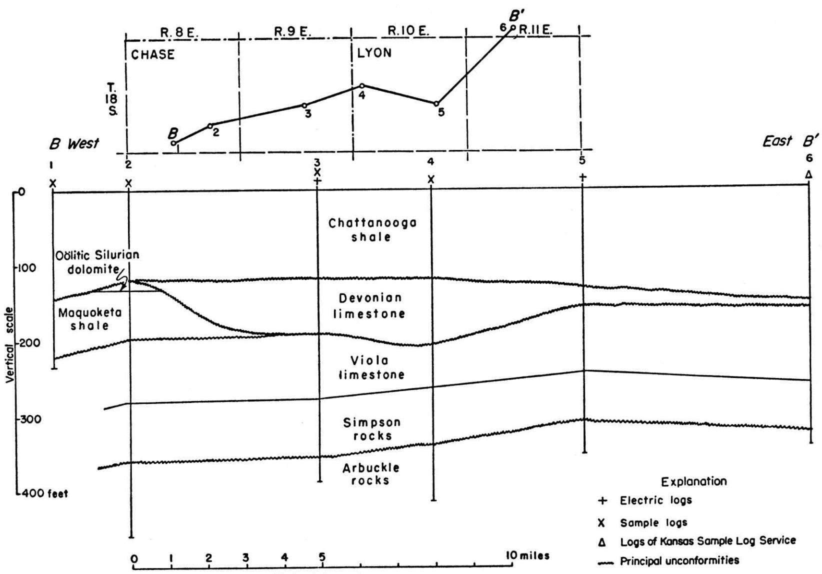
basin. They are 75 feet thick in the Veeder Supply and Development Company No. 1 Gravenstine well in sec. 21, T. 8 S., R. 6 E., but were cut out by erosion of a pre-Chattanooga valley in Marion and McPherson Counties. In the Devonian area in Harvey County, south of the valley, the Devonian rocks range in thickness from a maximum of 83 feet in the McPherson Oil Company No. 1 Ruth well in sec. 14, T. 23 S., R. 2 W., to a featheredge on the eroded margin still farther south.

After the deposition of the Silurian rocks the region was raised above sea level during active development of the Chautauqua arch. Erosion reduced the surface to a rolling plain of moderate topographic relief that truncated the tilted Silurian and older formations. Closely spaced wells in southeastern Ottawa County and northwestern Dickinson County reveal pre-Devonian hills of Silurian dolomite no longer covered by Devonian rocks. Cross section C-C′ of Figure 9 (cross section C-C′ of Pl. 3) across two of these hills shows topographic relief exceeding 50 feet. In northeastern Chase County and west-central Lyon County a relatively narrow valley about 50 feet deep was eroded along the pre-Devonian outcrop of the Maquoketa shale, as shown in cross section B-B′ of Figure 10 and the line B-B′ of Plate 3. This valley narrows the outcrop of the Maquoketa shale on the pre-Devonian areal map and is indicated on Plate 3 by the great thickness of the Devonian. The upper surface of the Devonian was more nearly peneplained than the pre-Devonian surface except in Marion and McPherson Counties, where a broad deep valley was eroded before the deposition of the Chattanooga shale.

Disregarding the extremes of thickness caused by local hills on the pre-Devonian surface and the removal of the Devonian by erosion in the pre-Chattanooga valley, it is evident that the Devonian limestones progressively overlie the previously beveled surface of older rocks from the center toward the margin of the North Kansas basin on the flank of the Chautauqua arch. The Devonian overlies 398 feet of Silurian in the Davon No. 1 Schaefer well in sec. 20, T. 1 S., R. 6 E., 315 feet of Silurian in the Arkansas Fuel Company No. 1 Martin well in sec. 24, T. 8 S., R. 4 E., 290 feet in the Payrock No. 1 Johnson well in sec. 9, T. 12 S., R. 6 E., and 150 feet in the Youker No. 1 Larsen well in sec. 16, T. 16 S., R. 3 E., just north of the pre-Chattanooga valley in Marion County. The Devonian originally overlapped from the Silurian onto the Maquoketa, but the line of overlap was in the main cut out by the erosion of the pre-Chattanooga valley.

South of the valley the Devonian rests on the eroded surface of the Maquoketa in such wells as the Panhandle Eastern Pipe Line Company No. 1 Waltner well in sec. 36, T. 21 S., R. 3 W., where 75 feet of Maquoketa intervene between the Devonian and the Viola. In the Tidewater No. 1 Heyman well in sec. 33, T. 23 S., R. 5 E., and in nearby wells, the Devonian rests on 35 feet of coarsely crystalline dolomite of the lower part of the Viola. In the Phillips No. 1 Guilfoyle well in sec. 18, T. 25 S., R. 8 E., the Devonian overlaps upon the Simpson. East of the area of the map, the Devonian in some localities overlies the Arbuckle.

Although the surface of the Silurian was roughly truncated by pre-Devonian erosion, considerable relief survived the erosional processes in certain areas. The most conspicuous relief is manifest in southeastern Ottawa County and adjoining parts of Dickinson County. In sec. 15, T. 11 S., R. 1 W., Chattanooga shale overlies 160 feet of Silurian rocks, but in sec. 28, T. 10 S., R. 2 W., 6 miles



No.	Company	Well	Farm	Location
1	Marland	1	Altemus	Sec. 33, T. 18 S., R. 8 E.
2	Aladdin	1	Altemus	Sec. 26, T. 18 S., R. 8 E.
3	Landon and Stanolind	1	Leith	Sec. 22, T. 18 S., R. 9 E.
4	Inland	1	Diggs	Sec. 18, T. 18 S., R. 10 E.
5	Huber et al	1	Ball	Sec. 23, T. 18 S., R. 10 E.
6	Brack	1	Davidson	Sec. 33, T. 17 S., R. 11 E.

FIG. 10.—Cross section from east to west across pre-Devonian valley in Chase and Lyon Counties, along line B-B′ on inset and Plates 2 and 3.

distant, 50 feet of sandy Devonian dolomite overlies only 100 feet of Silurian. In sec. 20, T. 12 S., R. 2 W., 12 feet of sandy dolomite caps 158 feet of Silurian, but in a well in sec. 16, T. 13 S., R. 1 W., 8 miles distant, Devonian rocks overlie only 109 feet of Silurian. Samples from a well in sec. 19, T. 13 S., R. 3 W., reveal 57 feet of Devonian sandy limestone overlying only 80 feet of Silurian. Inasmuch as other wells in this township penetrated 100 to 137 feet of Silurian capped by Chattanooga shale, the Silurian must have been thicker in Devonian time than now. Similar evidence indicates pre-Devonian topographic relief in the eastern part of T. 14 S., R. 2 W., and in adjacent areas.

Devonian rocks are not represented in the samples from the Page and Gurley No. 1 Bonham well in sec. 31, T. 1 N., R. 1 E., in Nebraska just north of the Kansas border, where some thickness of Devonian might have been anticipated, but no samples are available for 200 feet above the Silurian.

A sequence 58 feet thick tentatively identified as Devonian rocks because of traces of fine sandstone at the base has been reported from the Wakefield No. 1 Stockton well in sec. 26, T. 2 S., R. 15 W. The fine sand at the base of the sequence in this well more clearly resembles the coarse silt in the disconformable Maquoketa shale in a nearby well in sec. 5, T. 3 S., R. 11 W., than the sand residues usual at the base of the Devonian. This and the fact that oölitic dolomite is present 20 feet above the base of the sequence makes it more reasonable to refer these rocks to the Maquoketa than to the Devonian.

Plate 3 shows the thickness of the Devonian rocks and the pre-Chattanooga areal geology. Inliers of thick Silurian rocks in parts of Ottawa, Dickinson, and Saline Counties reveal pre-Devonian eminences from which the Devonian cover was removed by pre-Chattanooga erosion. The pre-Chattanooga valley is indicated by outcrops of Silurian, Maquoketa, and Viola on the valley slopes.

It is interesting to note that aside from the channel (Fig. 10) following the Maquoketa outcrop in Chase and Lyon Counties, the Devonian is thickest in a belt closely paralleling and just east of the Nemaha anticline. Although fewer wells are available, the data seem to indicate a belt of thin Devonian rocks farther east. The structural relations revealed by wells in this area suggest a syncline and an anticline and give support to the concept that the stresses that ultimately produced the Nemaha anticline were already causing deformation at the end of Devonian time.

Distribution of. Devonian rocks.—There is some difference of opinion as to the position of the base of the Devonian or even as to the presence of the Devonian west of T. 6 S., R. 1 W., and north of the pre-Chattanooga valley in McPherson County. In this area basal sandy rocks are absent in the "Hunton" in most wells. The "Hunton" sequence in this area consists of very cherty and argillaceous limestone and dolomite, which are regarded by some geologists as of Devonian age. Their relation to the Devonian seems to be revealed by comparison of two wells in Cloud County; the Bells-Wells No. 1 Le Blanc well in sec. 35, T. 6 S., R. 1 W., and the Stanolind Oil Company No. 1 Campbell well in sec. 26, T. 6 S., R. 2 W., only 6 miles distant.

The Devonian in the Le Blanc well in T. 6 S., R. 1. W., consists of 60 feet of lithographic and sublithographic gray limestone overlying 170 feet of Silurian. Embedded medium and coarse sand grains are disseminated throughout most of the sequence and are more abundant toward the base, where the samples include calcareous sandstone. Insoluble residues of the lithographic and sublithographic limestones yield no chert or flocculent or other siliceous residues except the sand.

The corresponding zone in the Campbell well 6 miles distant is also 60 feet thick, but consists of varicolored mealy or chalky or semigranular limestone accompanied by 5 to 65 percent massive varicolored subopaque to semitranslucent vitreous chert. The residues from the limestone include flocculent silica and traces of dusty quartz particles but no sand or silt.

The contrast in the lithology of these beds does not in itself preclude essential continuity, for abrupt lateral transition in relatively short distance is not unknown. However, the "Hunton" rocks in all the wells for which samples are available in the area west of T. 6 S., R. 1 W., and northwest of McPherson County display chert similar to that in the Campbell well. No embedded sand grains have been observed in any of the "Hunton" rocks in this area except in T. 5 S., R. 10 and 11 W., where sandy limestone occurs above the varicolored vitreous chert, and in the following outliers: (1) in sec. 26, T. 8 S., R. 10 W., where 12 feet of Devonian sandy limestone overlies Maquoketa shale, (2) in sec. 29, T. 15 S., R. 6 W., where 5 feet of sandy limestone overlies 20 feet of Silurian oölitic dolomite, (3) in sec. 4, T. 16 S., R. 4 W., where 18 feet of sandy Devonian dolomite overlies Maquoketa shale, and (4) in sec. 20, T. 19 S., R. 2 W., where 8 feet of sandy dolomite overlies 16 feet of Silurian oölitic dolomite shown in well 9 of cross section

A-A′ of Plate 3. On the other hand, sandy dolomite or sandy limestone occurs at the base of the Devonian in nearly all the wells east of R. 1 W.

Toward the south the Silurian consists almost entirely of vuggy, medium to coarsely crystalline dolomite almost devoid of chert, but many wells toward the center of the North Kansas basin include considerable amounts of chert in the Silurian. The nearest of these wells is the Phillips No. 1 Helms well in sec. 20, T. 4 S., R. 2 W., in which cherty beds were first penetrated at a depth of 2,410 feet, 112 feet below the Devonian and 195 feet above the base of the Silurian. These cherts are in part semiopaque bluish-gray and buff-gray vitreous chert similar to the more strikingly varicolored vitreous chert in the Campbell well and occur at about the same interval above the base of the Silurian. Similar cream-color, gray, and bluish-gray vitreous chert occurs also in the Silurian in the Gulf No. 1 Baker well in sec. 1, T. 1 S., R. 2 E., at a depth of 2,331 to 2,360 feet. No chert of this type has been observed anywhere in authentic Devonian rocks. In the Phillips No. 1 Helms and other wells the Devonian cherts are white, opaque, and in part spicular, microfossiliferous, and grainy. Such cherts do not occur in the Campbell well and have not been recognized west of T. 6 S., R. 2 W.

The writer believes that the discrepancy in lithology between beds to the east of R. 1 W., represented by the lithology of the Devonian in the Le Blanc well, and beds to the west characterized by the cherts of the Campbell well, believed to be Silurian, is the result of topographic relief of the pre-Devonian surface. The surface west of T. 6 S., R. 1 W., seems to have remained too high to receive the earliest Devonian deposits except as noted in T. 5 S., R. 10 and 11 W. It is probable that these areas were eventually submerged in the Devonian sea, but that the Devonian rocks in these areas were removed by pre-Chattanooga erosion except locally where Devonian rocks survived as outliers. This conclusion is supported by the abundant evidence of topographic relief at the contact of the Silurian and Devonian rocks in nearby areas already cited.

ROCKS OF DEVONIAN OR MISSISSIPPIAN AGE

Chattanooga Shale

In eastern Kansas a sequence of black and gray shales of undetermined age separates limestones definitely of Mississipian age from limestones and dolomites definitely of Devonian age. A black shale in southwestern Missouri, earlier called Eureka shale and

Noel shale, was correlated with the Chattanooga shale by Adams and Ulrich (1905), and was subsequently correlated with the Grassy Creek shale of northeastern Missouri by Branson (1944, p. 159). The Chattanooga shale thickens to the north and west from the outcrops in southwestern Missouri.

Johnston (1934, p. 15), in describing the stratigraphy of the Hollow pool of Harvey County, Kansas, described this shale sequence between the "Mississippi limestone" and the top of the "Silurian-Devonian group" as interrupted by Chouteau limestone, and for this reason he placed the upper part of the shale in the Kinderhookian Series. These correlations are based upon the discovery of Kinderhookian fossils in a dolomite core * taken from the McBride No. 4 Abraham Schmidt well in the NE cor. NE¼ sec. 30, T. 22 S., R. 3 W., Harvey County. It seems probable, however, that the fossiliferous material was not in place when cored, that the dolomite of the sample represents rocks knocked from the base of the Mississippian limestone above the shale when the casing was run, and that, after cementation, it was this material at the bottom of the hole below the pipe that was cored. This conclusion is based on the following considerations: (1) the presence of cavings below the cement is revealed by the fact that the first cuttings below the cement include fragments of opaque white chert of the Burlington-Keokuk type not known in the Kinderhookian, and also traces of the Kinderhookian Gilmore City oölitic limestone commonly found in wells in this area directly above the Sedalia and above the Chattanooga; (2) dolomite lithologically identical with the fossiliferous cores overlies the shale sequence in other parts of Harvey County and in McPherson County (Fig. 12A); (3) dolomite of this character has not been found within the shale sequence in Harvey and adjoining counties, where many clean samples from wells drilled by cable tools have been examined; (4) the occurrence of Kinderhookian dolomite within the shale sequence is incompatible with the regional relations and distribution of the Kinderhookian rocks as described in a subsequent section of this report.

* The core was taken below 78 feet of shale and above 7 or 8 feet of black shale crowded with spores typical of the basal Chattanooga. Casing in this well was set and cemented at 3,431 feet, 71 feet below the top of the shale. The sample from a depth of 3,436 feet, taken after the casing was cemented, consisted entirely of cement and a few fragments of dark shale. A cored sample was taken between the depths of 3,438 and 3,442 feet. The sample representing the first 2 feet consisted of fossiliferous dolomite interlaminated with dense limestone. The sample representing the second 2 feet, not seen by the writer, is described as sand and sandy shale reported as "Misener sand". Drill cuttings below 3,442 feet consist of black shale containing spores typical of the basal Chattanooga *above* the Misener. Devonian limestone was encountered at 3,449 or 3,450 feet. The fossiliferous dolomite core from 3,438 to 3,440 feet, lent by Sinclair Prairie Oil Company, was examined in 1946 by L. R. Laudon and R. C. Moore of the Kansas Geological Survey, who agree on the Kinderhookian age of the embedded fossils.

The use of the term "Kinderhook shale" for Chattanooga shale has become standard usage among oil geologists, however inappropriate, but, like the term "Nemaha mountains" or "Nemaha granite ridge" for Nemaha anticline, is, unfortunately, not likely to be discarded.

At the outcrops in southwestern Missouri and in the subsurface of adjacent parts of Kansas, the Chattanooga shale ranges in thickness from a featheredge to 30 feet and consists of black fissile shale, slightly silty and finely micaceous, containing conspicuous amounts of pyrite. North and northwest of the outcrops the formation becomes much thicker and is lighter in color except the basal beds, which are generally dark or black. In northeastern Kansas the color of the shale is generally gray or gray green, but in some places the upper beds are interstratified with darker shale. In the Salina basin the shale is finely micaceous, less silty and more argillaceous than to the south and east. The basal darker shales generally include abundant spores, but spores are embedded only sparingly throughout the upper beds of the Chattanooga.

With increasing thickness the Chattanooga becomes in part dolomitic locally and in some areas includes beds of impure sucrose dolomite. In the Appleman No. 1 McManus well in sec. 29, T. 15 S., R. 6 W., spores occur in impure silty dolomite 50 feet below the top and 35 feet above the base of the Chattanooga. Spores are embedded in sucrose dolomite in the Globe No. 1 Ostlind well in sec. 8, T. 19 S., R. 3 W., at a depth of 3,438 feet, 50 feet below the top of the Chattanooga, and in many other wells in thin beds of dolomite as well as in the shale.

The Misener sand at the base of the Chattanooga shale is of erratic distribution. In the central part of the Salina basin, it is generally represented only by rounded sand grains disseminated in shale at the base of the Chattanooga. Where the Misener is a sandstone, it includes many rounded grains like those in the Simpson sandstone, from which it was probably derived. It lies below the black spore-bearing shale. In the Hollow pool in T. 22 S., R. 3 W., Harvey County, cores from below the Misener sand reveal a bed, 1 or more feet thick, of gray or black slate containing numerous specimens of *Lingula*.

The thickness of the Misener sand is greatest in wells in the deeper parts of the pre-Chattanooga valleys, where the Chattanooga shale is thick, and on the flanks of the Central Kansas uplift. The development of the sandstone facies, although by no means general, seems to bear a relation to the proximity of pre-Chattanooga outcrops of Simpson sandstone on the Central Kansas uplift and to pre-Chattanooga outcrops of the basal sandy beds of the Devonian.

In many wells in Marion, McPherson, Saline, and Harvey Counties, the Misener forms a bed of sandstone less than 2 feet thick in most places but in some localities much thicker. In Rice County several wells have penetrated 10 to more than 35 feet of Misener sand. It is 11 feet thick in a well in sec. 24, T. 11 S., R. 7 W., Lincoln County, and 5 feet thick in a well in sec. 35, T. 8 S., R. 9 W., Mitchell County.

In many wells north of Dickinson County and in some wells as far south as Marion County red or pink beds lie above the Chattanooga shale. They are interpreted in part as remnants of a weathered zone developed during the exposure that preceded the deposition of the Boice shale and in part as weathered material reworked to form the basal deposits of the Boice shale.

The thickness of the Chattanooga ranges from a featheredge to at least 263 feet. This considerable variation results from the unconformity at the base of the Chattanooga and from the several periods of exposure of the top during which the original thickness of the Chattanooga was reduced by erosion.

In Edwards and Pawnee Counties, where Maquoketa, Silurian, and Devonian rocks are absent southwest of the Central Kansas uplift, the rocks between the Mississippian and the Viola differ from the Chattanooga ("Kinderhook" of oil fields) shale in eastern Kansas areas. The rocks in these counties consist of greenish-gray and rusty-brown shale interstratified with sandy shale and streaks and beds of sandstone in the upper part as well as at the base. No black shale and no spores are reported. Dolomite, locally cherty, as much as 45 feet thick occurs in the middle of the formation in some wells on the flank of the Central Kansas uplift.

The lithology of these rocks is so strikingly different from the Chattanooga farther east as to suggest a Mississippian basal clastic deposit rather than Chattanooga. The cross section from Meade County to Smith County (Lee, 1953, fig. 2) shows that low arching of the Central Kansas uplift had already begun before Mississippian time. The formations normally deposited—Devonian, Silurian, Maquoketa, and part of the Viola—if they were ever present, were removed from this flanking area as well as from the crest. During the hiatus it seems probable that the exposed surface was dissected. Loose debris, sand, shale, and, in protected areas, dolomite might accumulate as a Mississippian basal clastic. Weathered Viola chert occurs at the base of this sequence in many wells, a phenomenon curiously rare or absent below the Misener sandstone. It is probable that these mixed clastics are a marginal facies of the Chattanooga or a local facies of the Boice shale to be described later.

In eastern and southeastern Kansas the thickness of the Chattanooga increases toward the north with some irregularity, but the local irregularities as represented by 50-foot isopachs are inconspicuous.

McPherson Valley.—In McPherson and Marion Counties, the pre-Chattanooga surface was dissected by a broad open valley having a topographic relief of more than 200 feet (Pl. 4). In T. 23 S., R. 2 W., south of the valley in Harvey County, on a pre-Chattanooga hill, the Chattanooga shale has a local thickness of less than 5 feet (well 3 of cross section A-A′ of Pl. 4) and overlies Devonian limestone. From this area it thickens in all directions. In McPherson and Marion Counties, in a distance of less than 25 miles, the thickness increases to more than 200 feet in the valley area, and the shale successively overlies increasingly older rocks from Devonian dolomite to Kimmswick dolomite. Farther north, the Chattanooga becomes thinner again and overlaps upon the same formations in reverse order. Both stratigraphic and structural relations indicate the development of a deep pre-Chattanooga valley, which may be called the McPherson Valley, the approximate configuration of which is shown by the thickness map of the Chattanooga shale (Pl. 4) and by the areal map of the pre-Chattanooga surface (Pl. 3). The pre-Chattanooga exposure of Silurian rocks in Lyon County (Pl. 3) suggests that the west-trending McPherson Valley headed in that county. A tributary entered the main valley from the south in western McPherson County (Lee, 1940, pl. 4). The river probably drained toward the north or northwest in an area in which it cannot now be traced because the original thickness of the Chattanooga was reduced by pre-Pennsylvanian erosion. The closure of the 250-foot isopach in the southwestern corner of Saline County is the result of the erosion of the original top of the Chattanooga and does not represent the topography of the pre-Chattanooga valley in that area.

Chattanooga limestone lentil.—In parts of McPherson, Rice, and Reno Counties, the Chattanooga deposits of the valley include a bed of limestone 100 to 110 feet below the base of the overlying Mississippian limestones. This limestone is gray and for the most part mealy or chalky and slightly argillaceous. It is capped in many wells by 5 to 10 feet of argillaceous sucrose dolomite. In some wells 5 to 10 feet of sublithographic limestone occurs at the base. Spores that are characteristic of the Chattanooga have been found not only in the dolomite capping the limestone but also in the upper part of the limestone in the Sharon No. 1 Leatherman well in sec. 35, T. 21 S., R. 9 W., as well as in the shale below and above the limestone. The thickness of the limestone ranges from a featheredge on the margin of the lentil to more than 80 feet in T. 21 S., R. 7 W.

The shaded area of Figure 11 shows the distribution and generalized thickness of the Chattanooga limestone and its relation to the pre-Chattanooga valleys. Except in T. 21 S., R. 7 and 8 W., where it is thin, the limestone is confined to the western side of the tributary that joins the McPherson Valley from the south. On the west the limestone overlaps upon the western slope of the valley as shown in cross section B-B′, but the western margin of the valley was uptilted and beveled before Pennsylvanian time; therefore the original border of the limestone has been lost to erosion.

On the east the limestone is underlain by shale, which is 125 feet thick in well 5, cross section A-A′ of Figure 11, but is commonly 50 to 60 feet thick. In cross section A-A′ the shale is shown wedging out to the east. In cross section B-B′ the limestone is shown interfingering with shale, but it may wedge out abruptly. The abruptness of the transition from limestone to shale is illustrated by two wells in sec. 34, T. 22 S., R. 8 W., for which both samples and electric logs are available. The shale in the well in the northeast corner of the section includes 25 feet of chalky limestone 105 feet below the top, but in the southwest corner of the same section, one mile distant, where the thickness of the Chattanooga is the same, neither samples nor electric logs reveal the presence of any limestone.

It might be expected that the Chattanooga limestone would be deposited in the deeper parts of the McPherson Valley where compaction of the shale might have provided a basin for marine invasion and the accumulation of limestone. Equally deep parts of the valley in other areas, however, were filled with shale without limestone. The peculiar isolation of this mid-Chattanooga limestone and its eccentric position mainly on the west side of the valley may, perhaps, be explained as the result of temporary shielding of the limestone area from clastic sediments by the building

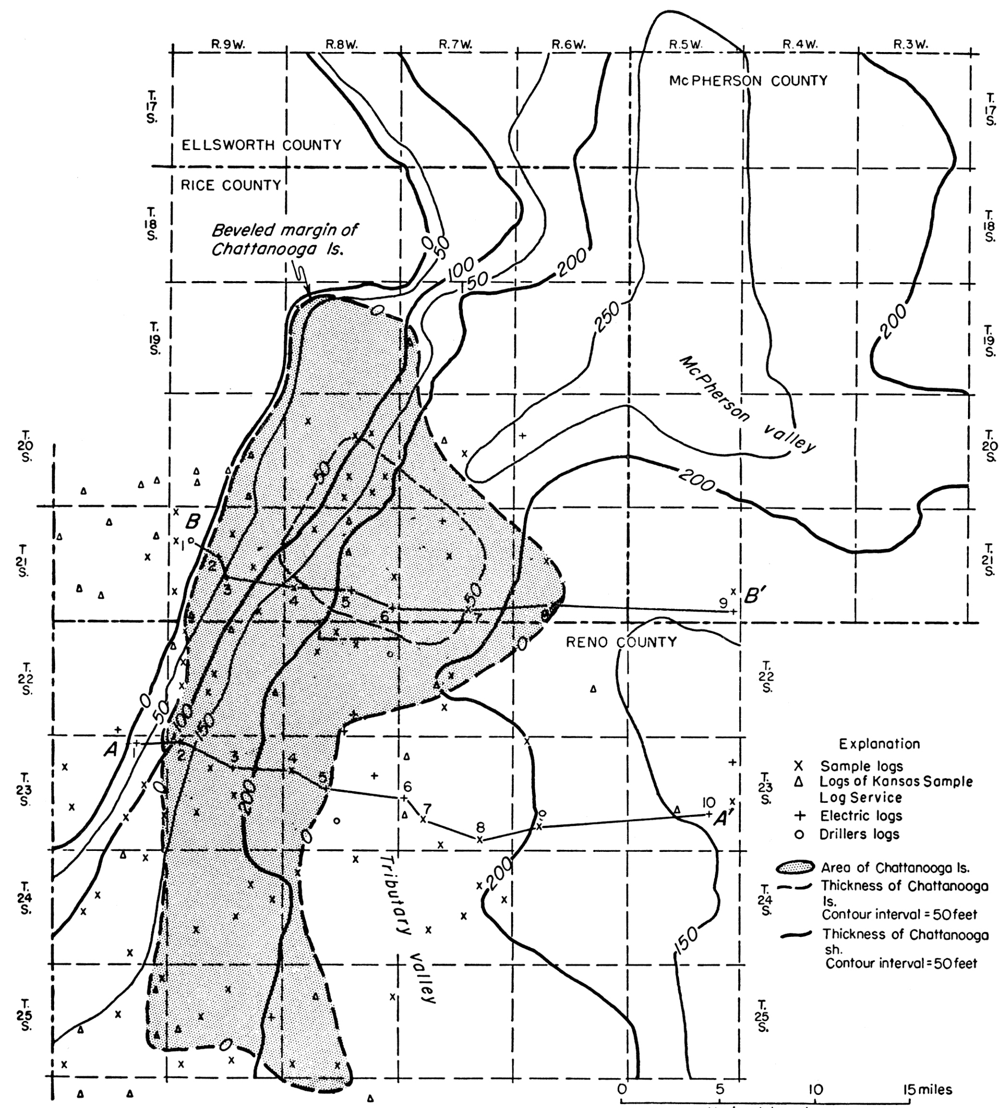
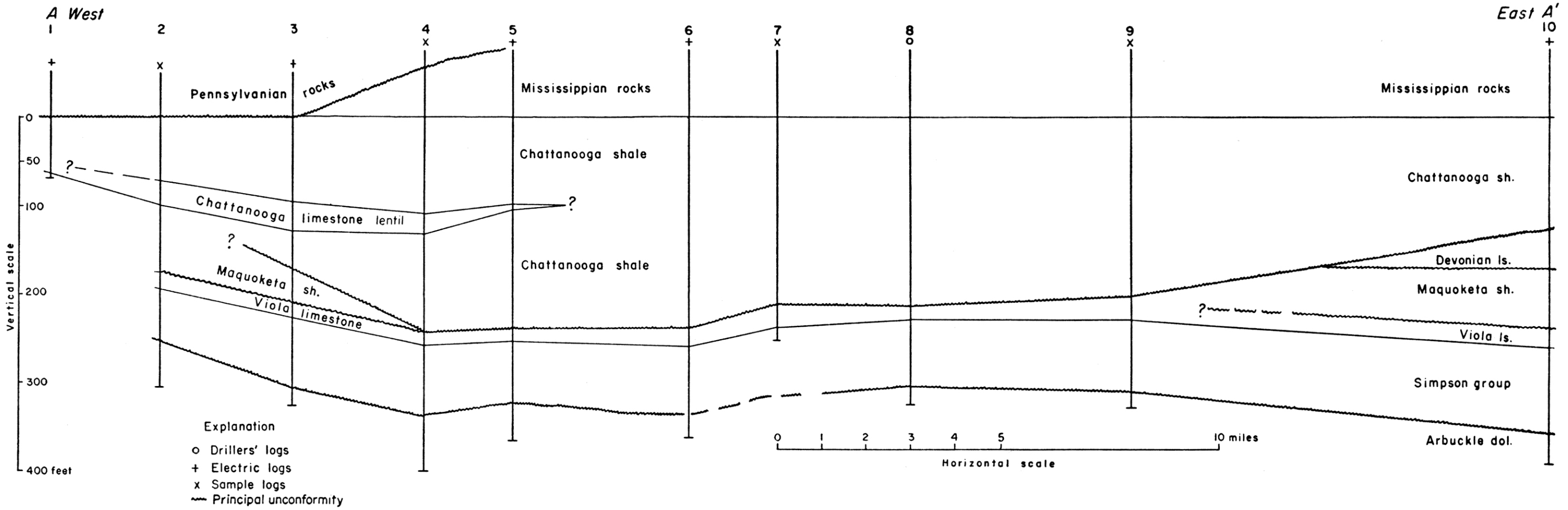
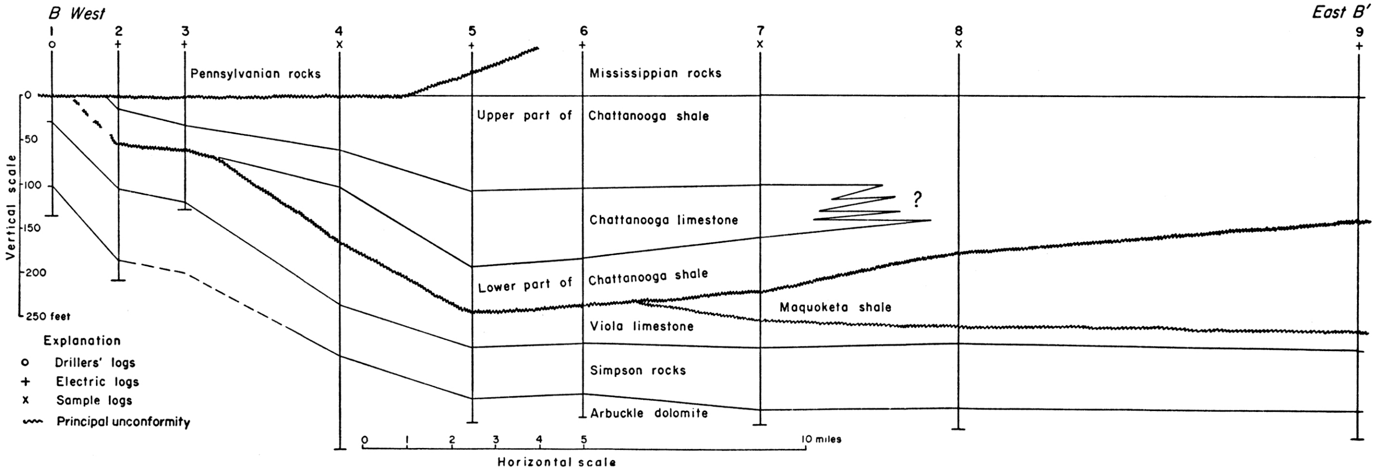


Fig. 11.—Areal distribution and cross sections of Chattanooga limestone lentil. A. Map showing thickness of Chattanooga limestone lentil. B. Cross section A-A′ of map A. C. Cross section B-B′ of map A.



No.	Company	Well	Farm	Location (Section A-A′)
1	Lion	3	Phillips	Sec. 2, T. 23 S., R. 10 W.
2	Thomas et al	1	Greenwood Heirs	Sec. 6, T. 23 S., R. 9 W.
3	Helmerich & Payne	1	Geist	Sec. 10, T. 23 S., R. 9 W.
4	Helmerich & Payne	1	Roy	Sec. 7, T. 23 S., R. 8 W.
5	Iron	1	Ramsey	Sec. 16, T. 23 S., R. 8 W.
6	Atlantic	1	Paige	Sec. 19, T. 23 S., R. 7 W.
7	Lario	1	Russell	Sec. 29, T. 23 S., R. 7 W.
8	Mid-Kansas	1	Nisley	Sec. 35, T. 23 S., R. 7 W.
9	Kessler & Thier	1	Bigger	Sec. 29, T. 23 S., R. 6 W.
10	Snowden	1A	Swanson	Sec. 26, T. 23 S., R. 5 W.

No.	Company	Well	Farm	Location (Section B-B′)
1	Davisson	1	Stout	Sec. 8, T. 21 S., R. 9 W.
2	Phillips	1	Ruie	Sec. 16, T. 21 S., R. 9 W.
3	Parker et al	1	Small	Sec. 22, T. 21 S., R. 9 W.
4	Detrick	1	Fitzpatrick	Sec. 30, T. 21 S., R. 8 W.
5	Manning & Martin	1	Mathes	Sec. 27, T. 21 S., R. 8 W.
6	Helmerich & Payne	1	Russ	Sec. 36, T. 21 S., R. 8 W.
7	Braden & McClure	1	Trotter	Sec. 34, T. 21 S., R. 7 W.
8	Atlantic	1	Thorp	Sec. 33, T. 21 S., R. 6 W.
9	Carey	1	Freisen	Sec. 36, T. 21 S., R. 5 W.



up of a shale delta at the mouth of the tributary to the McPherson Valley as the valleys were being filled.

The thickness of the Chattanooga shale as a whole ranges from a featheredge, in southeastern Kansas and in areas that have been uptilted and beveled, to more than 250 feet in the deep parts of the McPherson Valley and in the North Kansas basin in Nemaha County. The thickness displays considerable variation as a result of contemporaneous warping and the erosional unconformities at its base and top. The Chattanooga normally thickens toward the subsiding North Kansas basin. In northeastern Kansas, where the Chattanooga is thickest, it overlies limestone and dolomite of Devonian age. Toward the south in eastern Kansas it progressively transgresses upon the truncated outcrops of Silurian, Maquoketa, Viola, Simpson, and Arbuckle (pre-Chattanooga areal geology, Pl. 3). In central Kansas the regularity of its northward thickening is broken by the filling of the pre-Chattanooga valleys and the more irregular topography. Aside from the effect of the topographic relief of the McPherson Valley, the Chattanooga thickens northward toward the North Kansas basin.

After the deposition of the Chattanooga shale, the surface was re-elevated and was probably subjected to minor warping.

Near the Missouri-Nebraska line the normal sequence of Chattanooga shale in most wells is followed at different stratigraphic levels by gray-green shale interstratified with red and pink shale. In some wells the red shale includes concentrations of red oölites or fine ironstone pellets. These shale and ferruginous oölitic beds are not known to crop out anywhere at the surface. They are particularly well developed in the subsurface of southeastern Nebraska, where they were penetrated in many wells during the development of the Falls City oil field, but they occur also in adjoining parts of Missouri and Kansas and in southwestern Iowa. Reed (1946) proposed the name Boice shale for this formation.

Pre-Boice erosion of the Chattanooga shale is revealed in northeastern Kansas by the relations of the Chattanooga and Boice shales. In Nemaha and Brown Counties, Kansas, where the combined thickness of the shales varies little, the Chattanooga thins where the Boice thickens and increases in thickness where the Boice is thin. The range in the thickness of the Chattanooga shale in this area from 120 to 258 feet is an imperfect indication of the topographic relief of the pre-Boice surface. Considerable areas to the west were probably stripped of Chattanooga shale at this time.

With resubmergence of the eroded surface, the higher areas of the Chattanooga shale were reduced by wave and tidal action, and the weathered and eroded material was washed into the low areas, which were aggraded to a common level with the beveled Chattanooga. The redeposited material constitutes the Boice shale.

The lower Kinderhook limestones, which normally succeed the Chattanooga shale in Missouri and northeastern Kansas, are missing west of the Nemaha anticline; the Gilmore City of late Kinderhookian age (Laudon, 1931) and possibly the upper beds of the Sedalia overlap upon pre-Chattanooga formations in parts of Smith, Osborne, and Jewell Counties. The Chattanooga must have been eroded from these areas before the deposition of the Kinderhookian limestones, for in this area Gilmore City and upper Sedalia rocks, really of Kinderhookian age, overlap from the Chattanooga onto Devonian and older rocks. The exposure of this area may have begun before Boice time and extended through early Kinderhookian time.

The smooth horizontal contact of the Chattanooga shale with the Chouteau limestone and its correlatives throughout large areas in eastern Kansas, northern Missouri, and parts of Iowa gives the illusion of conformable relations between these formations. However, the fact that the Boice shale intervenes between the Chattanooga and the Chouteau in parts of the Forest City basin, and the fact that younger formations overlie the Chattanooga farther afield lead to the conclusion that a hiatus of some importance intervenes, although thinning of the Chattanooga in areas of overlap seems not to have been great.

The final unconformity that modified the thickness of the Chattanooga developed in post-Mississippian time when the Nemaha anticline was raised and the Central Kansas uplift and the Ozarks were re-elevated. The erosion of these uplifted anticlinal areas removed the Mississippian limestones from their crests and beveled the Chattanooga and older rocks on their flanks, thus reducing the surface to what must have been essentially a peneplain. The Chattanooga shale cropped out on this surface in a belt encircling the area of older rocks (Pl. 4). South of McPherson County the Chattanooga is generally overlain by the St. Joe limestone of the Osagian Series, although there are some outliers of upper Sedalia and Gilmore City rocks. On the western flank of the Nemaha anticline and the eastern flank of the Central Kansas uplift, the Reeds Spring and the Burlington limestones overlap from St. Joe limestone upon Chattanooga shale (Fig. 12B).

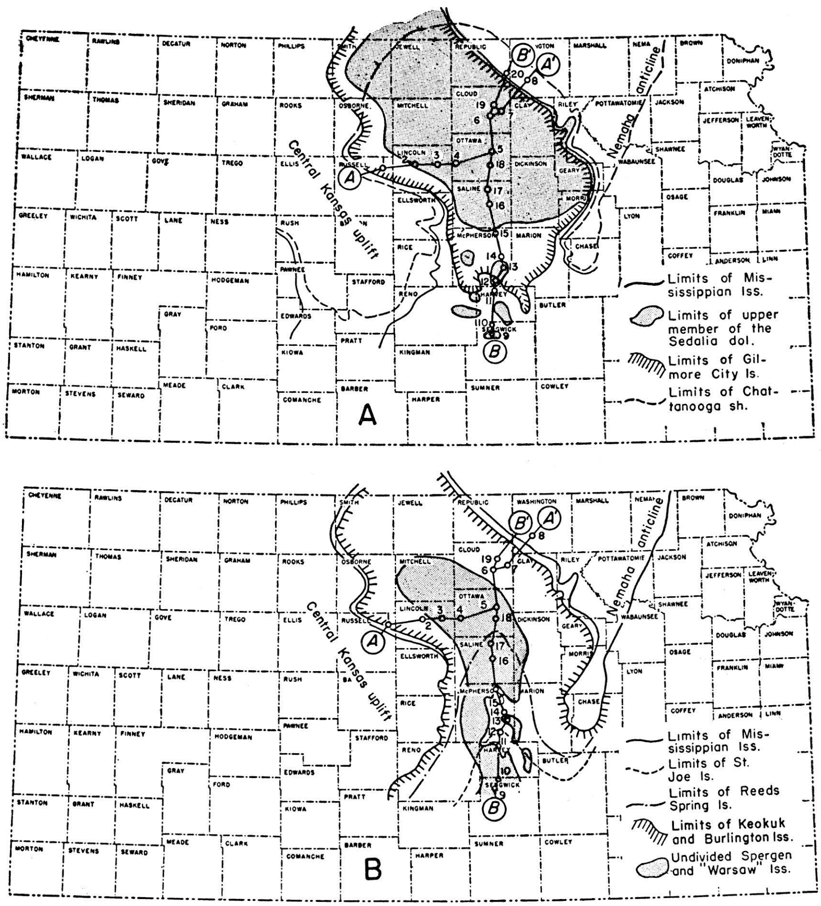


FIG. 12.—Maps showing the approximate distribution of the Mississippian formations in the Salina basin area. **A.** Distribution of upper member of Sedalia limestone and Gilmore City limestone of Kinderhookian age. **B.** Distribution of St. Joe, Reeds Spring, and Burlington—Koekuk limestone sequence of Osagian age and Spergan-"Warsaw" limestone sequence of Meramecian age. Line A-A′ shows trend of cross section A-A′ of Plate 6. Line B-B′ shows trend of cross section B-B′ of Figure 13.

In consequence of the complex relations described, the Chattanooga rests unconformably on rocks ranging from Devonian to early Ordovician age and is overlain in certain areas by the Boice shale, by Mississippian limestones from the Chouteau to the Burlington, and by rocks of Pennsylvanian age. The unconformity above the Chattanooga shale is first recorded at its contact with the Boice shale. It is uncertain whether these unconformities express a prolonged hiatus with gradual overlap of younger formations upon the

Chattanooga or a series of minor unconformities during which rocks deposited between Boice and Burlington time were successively removed in marginal areas during succeeding periods of exposure. The latter seems more likely.

Boice Shale

The Boice shale is best known from wells in southeastern Nebraska, where it was named by Reed (1946) for the Pawnee Royalty Company No. 1 Boice well in sec. 18, T. 1 N., R. 16 E., Richardson County, Nebraska. A set of cable tool samples from this well is preserved in the files of the Nebraska Geological Survey. The section of the Boice shale as reported by Reed is given in Table 3.

TABLE 3.—*Section of Boice shale and Chattanooga shale in Pawnee Royalty Company No. 1 Boice cable tool well in sec. 18, T. 1 N., R. 16 E., Richardson County, Nebraska (Reed, 1946)*

		Thickness, feet
Mississippian System		
Kinderhookian Series		
Chouteau limestone and Sedalia dolomite		69
Boice shale		31
Siltstone and sandstone, medium dark gray to brownish, calcareous, in part pyritic	2	
Shale, dark greenish gray with some pyritic and carbonaceous zones; calcareous with black "Sporangites" in lower 10 feet; interbedded with gray dolomitic siltstone and silty argillaceous dolomite	19	
Hematite, in flattened discoidal oölites or concretions ranging from 0.2 mm to 1.5 mm in diameter, in part embedded in rouge-red shale	10	
Mississippian or Devonian		
Chattanooga shale		204
Devonian dolomite		

A section of rocks in Holt County, Missouri, here referred by the writer to the Boice shale (Table 4), was described by McQueen and Greene (1938, p. 176). At that time, the rocks were designated as "Kinderhook undifferentiated" by Mary Hundhausen of the Missouri Geological Survey.

The Boice shale consists of gray-green shale, in part carbonaceous, interbedded with gray dolomitic shale. The basal beds consist of oölitic limonite and hematite beds or red shale. Except where the Boice shale contains red and ferruginous oölitic beds, it is singularly like the Chattanooga shale from which the major part of the sediments of the Boice is believed to have been

TABLE 4.—*Section of Boice shale and Chattanooga shale in Forest City No. 1 Davis cored well in sec. 4, T. 59 N., R. 38 W., Holt County, Missouri*

		Thickness, feet
Mississippian limestone and dolomite		331
Boice shale		43½
Shale, gray to green; containing specks and streaks of carbonaceous material	5	
Dolomite, gray, argillaceous	4	
Shale, green and gray with plant remains	24	
Limonite, oölite, oölites are brown, flattened, and oblong	4	
Shale, gray and red	2½	
Hematite oölite, flattened discoidal oölites cemented with calcium carbonate	3½	
Hematite, dark red, shaly	½	
Mississippian or Devonian rocks		
Chattanooga shale		83

derived. In Nemaha and Brown Counties, Kansas, where a considerable thickness of green and gray shale overlies the red oölitic beds, the Boice shale is finely micaceous, resembles the upper part of the Chattanooga, and includes thinly disseminated spores. The Boice shale is less silty and more dolomitic than the Chattanooga shale, but the lithologic differences are not sufficiently striking to distinguish the formations in the absence of the oölitic zone or the basal red beds.

The Boice shale so far as known is confined to southeastern Nebraska, southwestern Iowa, northwestern Missouri, and northeastern Kansas. In the Forest City basin in Kansas the Boice thins sharply southward from central Brown and Nemaha Counties. Red shale at the top of the Chattanooga, probably in part of Boice age, occurs in northeastern Wabaunsee County. In the Salina basin ferruginous oölites extend south to Saline and Dickinson Counties, and red shale without oölites to northeastern Marion County. Westward the oölitic bed extends to the border of the Central Kansas uplift, where in sec. 35, T. 8 S., R. 9 W., 25 feet of ferruginous oölitic beds overlie the Chattanooga, which is here represented only by 5 feet of sand of probable Misener age.

In Kansas, in the Ohio Oil Company No. 1 Lamparter well in sec. 3, T. 2 S., R. 14 E., the thickness of shale above the base of the hematite oölite at the base of the Boice is 90 feet, and the underlying Chattanooga shale is 135 feet thick. In sec. 15, T. 2 S., R. 16 E., the Boice shale is 110 feet thick, and the Chattanooga is 125 feet thick. In sec. 12, T. 4 S., R. 14 E., the Boice shale is only 14 feet thick, and the underlying Chattanooga is 258 feet thick.

In scattered wells in Clay, Mitchell, Dickinson, and Saline Counties the Boice shale, where present, is represented only by the red oölitic member, which is 5 to 25 feet thick. In these counties red shale without oölites, 20 to 40 feet thick, at the top of the shale sequence in some wells, may be of Boice age, but some of the zones of red shale, especially where they are mixed with green shale, may be weathered Chattanooga shale in place. A well in sec. 11, T. 13 S., R. 1 E., Dickinson County, where red and green shales 10 feet thick underlie the oölitic member of the Boice, is one sample of the second condition.

The Boice shale is unconformable on the Chattanooga and seemingly conformable below the Chouteau of Moore (1928) in the area centering around the corners of Nebraska, Kansas, and Missouri. In the northern part of the Salina basin the oölitic bed, where present, is unconformably overlain by the upper member of the Sedalia dolomite. The Boice shale, although not specifically correlated with the Hannibal shale of Missouri, occupies the same stratigraphic position.

ROCKS OF MISSISSIPPIAN AGE

Mississippian rocks are widely distributed in the Mississippi Valley both at the surface and in the subsurface. Some of the formations were deposited only in certain regions, and the areal extent of others was restricted by erosion. As a result the sequence of Mississippian formations in Kansas is nowhere complete and in different localities formations are missing from the top, middle, or bottom of the columnar section. Some of the breaks in the formational sequence are true disconformities, but some were accompanied by obscure warping of so low an order that angular unconformity can be determined only by regional studies of the distribution and thickness of single formations and their relations to underlying and overlying units.

Limestone and dolomite predominate in the Mississippian rocks of the Middle West. The Mississippian of Kansas consists entirely of limestone and dolomite, except for the Northview shale, a local facies of the lower Sedalia dolomite in southeastern Kansas, and some shaly beds in the St. Joe of south-central Kansas. The Boice shale in the northeastern corner of Kansas may be of Mississippian age. Shale partings of negligible thickness have been reported between limestone beds in some formations.

The Mississippian formations represented in the Salina basin are listed in Table 5 in descending order.

TABLE 5.—*Mississippian formations represented in the Salina basin*

Meramecian Series	
Spergen limestone	
"Warsaw" limestone	
	Unconformity
Osagian Series	
Burlington and Keokuk limestones, undifferentiated	
Upper zone	
	Unconformity
Lower zone	
Reeds Spring limestone	
St. Joe limestone	
	Unconformity
Kinderhookian Series	
Gilmore City limestone	
	Unconformity
Sedalia limestone (upper member only)	
	Unconformity
Rocks of Devonian or Mississippian age	
Boice shale	
	Unconformity
Chattanooga shale	

KINDERHOOKIAN SERIES

The Chouteau limestone was first described by Swallow (1855) at Chouteau Springs, Cooper County, Missouri. The outcrops nearest to the Salina basin are in Pettis County in north-central Missouri. At the outcrops and in the subsurface of northeastern Kansas, three units of the Chouteau limestone, as originally defined, are distinguished by lithologic criteria: (1) a basal unit of relatively pure semigranular limestone, which is essentially equivalent to the Compton limestone of outcrops in southwestern Missouri; (2) a middle unit, an impure sucrose gray to buff dolomite having large amounts of uniquely characteristic chert; and (3) an upper unit, a noncherty or sparsely cherty buff sucrose dolomite. In Miami, Linn, and Anderson Counties in eastern Kansas the middle unit grades southward into, and is at least a partial correlative of the Northview silty shale of southwestern Missouri and southeastern Kansas (Lee, 1940, p. 31).

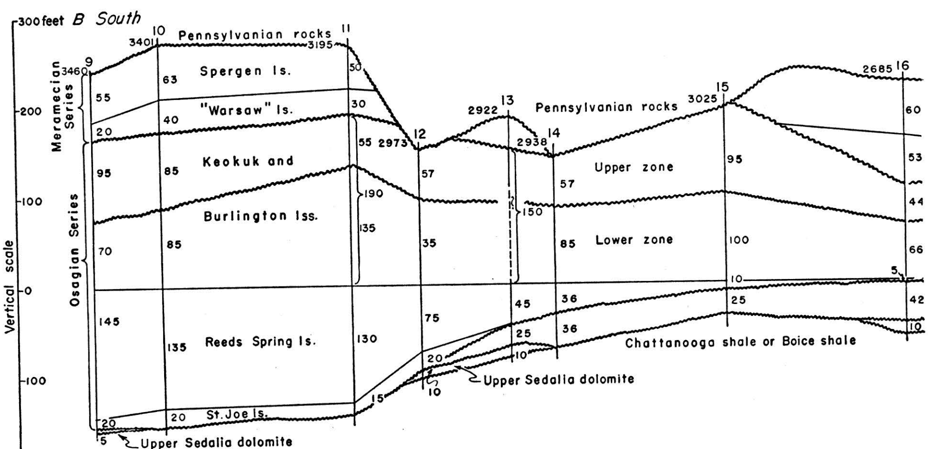
In 1928 Moore separated the upper and middle units from the originally defined Chouteau and applied to them the name Sedalia limestone, and restricted the term Chouteau to the lower unit. The upper unit of the sequence in the subsurface was considered for a time as the Sedalia by the Missouri Geological Survey, and this usage was followed by Lee in 1940.

In 1943 Lee (p. 67) described the Chouteau of Moore and the upper and lower members of the Sedalia limestone in the Forest City basin as three members of Swallow's original Chouteau. In the present report these terms are used to conform with the usage of the Kansas Geological Survey—namely, the application of Sedalia limestone to the upper and middle units of the original Chouteau and the restriction of Chouteau to the lower unit.

The Chouteau of Moore (1928) and both members of the Sedalia are well developed in the Forest City basin (Lee, 1943, p. 67), but only the upper member of the Sedalia has been recognized west of the Nemaha anticline.

Sedalia Dolomite

The upper member of the Sedalia consists of buff to brown, locally gray, sucrose dolomite. It is generally noncherty, but in some wells small amounts (less than 5 percent) of chert similar



No.	Company	Well	Farm	Location
9	Kayser et al	1	Stroot	Sec. 8, T. 26 S., R. 2 W.
10	Hawkins and Marshall	1	Mary Dick	Sec. 4, T. 25 S., R. 2 W.
11	Twin Dr. Co. et al	1	Ruth	Sec. 16, T. 22 S., R. 2 W.
12	McPherson Oil	1	Fisk	Sec. 15, T. 21 S., R. 2 W.
13	Regina Oil and Gas	1	Voght	Sec. 8, T. 20 S., R. 1 W.
14	Dieter et al	1	Sellars	Sec. 19, T. 19 S., R. 1 W.
15	McPherson Oil	1	Norling	Sec. 9, T. 17 S., R. 2 W.
16	Sampson-Deterick	1	Sudendorf	Sec. 30, T. 14 S., R. 2 W.
17	Central Kansas	1	Crawford	Sec. 26, T. 13 S., R. 3 W.
18	Auto-Ordnance et al	1	Geklar	Sec. 20, T. 12 S., R. 2 W.
5	Anderson et al	1	Ottawa State Bank	Sec. 28, T. 10 S., R. 2 W.
6	Carter	1	Strat. Test	Sec. 16, T. 7 S., R. 2 W.
19	Allen	1	Cleveland	Sec. 14, T. 6 S., R. 2 W.

to that in the lower member of the Sedalia have been noted in the insoluble residues. The upper member of the Sedalia extends westward to Smith County and southward across Saline County. Thin outliers occur south of Saline County as shown in Figure 12A.

Unconformities occur above and below the upper member in the Salina basin, but its more or less uniform thickness reveals that both its upper and lower surfaces were locally exceptionally smooth and regular. The upper member thins westward with extraordinary regularity from Johnson County, Kansas, where it is 30 feet thick and overlies the lower member of the Sedalia, to Smith County, 200 miles west, where it is less than 10 feet thick and overlies pre-Chattanooga rocks. In the Salina basin it is less than 15 feet thick except in a few wells, and in some of the outliers in McPherson and Harvey Counties it is represented by less than 5 feet of buff sucrose dolomite.

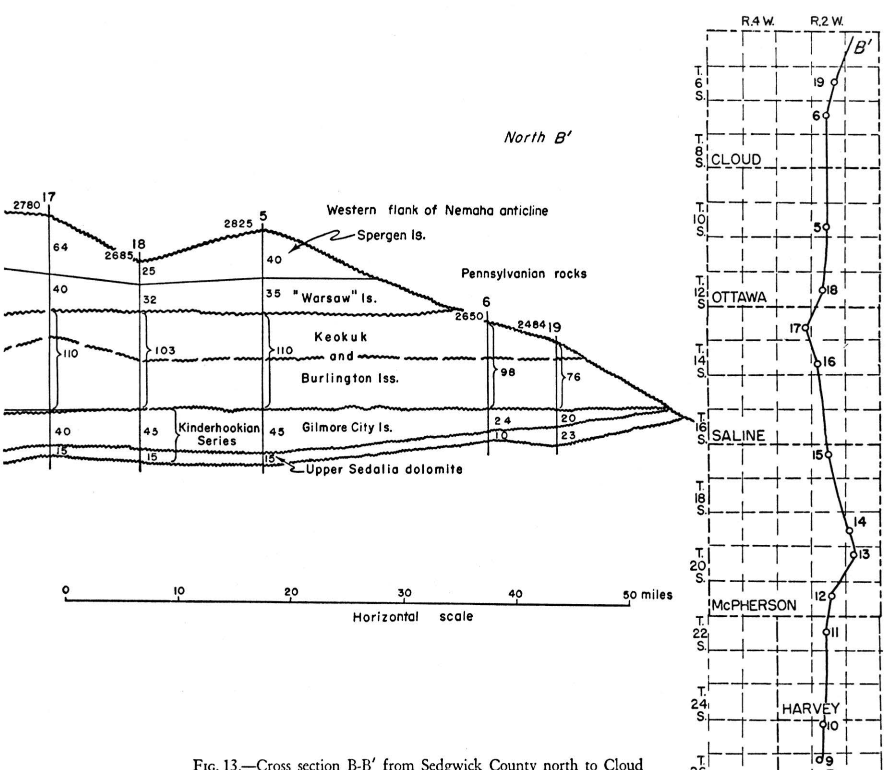


FIG. 13.—Cross section B-B′ from Sedgwick County north to Cloud County on line of inset, Plate 6, and Figure 12, showing southerly thinning of Kinderhookian limestones and overlap and thinning of Osagian and Meramecian formations toward the north.

The upper member of the Sedalia seems to be conformable upon the lower member in the Forest City basin. In the Salina basin, however, it overlaps uncomformably upon the Chattanooga shale or the Boice shale where that formation is present, and wedges out to the west on the Devonian.

In the Salina basin the upper member of the Sedalia is nearly everywhere overlain disconformably by the Gilmore City limestone. The disconformity is obscure, but it is revealed in several wells in the Forest City basin in which the upper member of the Sedalia is missing and the Gilmore City rests on the lower member of the Sedalia (Lee, 1943, p. 69). In McPherson and Marion Counties the Gilmore City rests on the Chattanooga shale where the upper member of the Sedalia is absent. In these counties some of the thin outliers of upper Sedalia dolomite are overlain by the St. Joe limestone, and locally in Reno County, the Reeds Spring limestone overlaps upon the upper Sedalia (Fig. 12B and cross section B-B′ of Fig. 13).

Gilmore City Limestone

The Gilmore City was first described by Laudon (1933) at outcrops in the vicinity of Gilmore City in central Iowa. At the outcrops the Gilmore City is mainly pure white to gray oölitic limestone. Laudon reports that it is "usually bedded with green shale" and that minor amounts of blue dolomite occur at definite horizons. The Gilmore City limestone in the subsurface, distribution of which in the Salina basin is shown in Figure 12A, is similar to that of the outcrops, but it is not oölitic throughout and is not dolomitic. It is 62 feet thick in the Seidhoff et al No. 1 Greif well in sec. 16, T. 8 S., R. 10 W., but may be thicker toward the north. Its thickness decreases somewhat irregularly toward the southeast; it wedges out in southern McPherson County and parts of Harvey County.

The Gilmore City in the Salina basin is a relatively pure noncherty or very slightly cherty granular limestone composed of worn fragments of finely broken fossils, with or without oölites, embedded in a cryptocrystalline matrix. The matrix is firm in samples from some zones but so chalky in others that except for the fossiliferous granules the cuttings from cable tool wells are generally reduced to calcareous mud and lost in washing. The oölitic limestone is generally gray or white, but shades of dark gray, yellowish brown, and buff are not uncommon, and in one well the color is pink.

Fragments of green argillaceous shale are minor constituents of some samples.

The most outstanding characteristic of the Gilmore City limestone is the oölitic limestone. The oölites are irregularly distributed vertically, and the oölitic beds are discontinued horizontally. Oölites are commonly encountered 25 to 35 feet above the base of the Gilmore City, but oölitic beds occur erratically higher and lower in the formation. The oölites are of various sizes and some of them are irregular in shape. Most are gray but some are dark, nearly black. Some of the oölites have black centers and some have alternating light and dark crusts. The oölites generally have the same color as the matrix.

The insoluble residues of the Gilmore City are so small in amount as to be almost negligible. Chert particles derived from younger rocks in the wells occur in the insoluble residues of some samples, but there are also traces of indigenous vitreous chert. The characteristic residues consist of loose aggregates of very fine quartz crystals and thin finely drusy crusts and microscopic mammillary and columnar flakes of chalcedony. Traces of spherical crusts from partly silicified oölites are occasionally found. Residues from wells in Saline County and northward are generally pale lemon yellow, but elsewhere they are colorless.

Where the Gilmore City is thin and not oölitic it is distinguished from the St. Joe by the darker color and argillaceous character of the St. Joe. Although the lower part of the Reeds Spring in some areas is a semigranular limestone not unlike the Gilmore City, the Reeds Spring contains translucent chert, but the Gilmore City does not.

At places along its southern margin, the Gilmore City rests unconformably on Chattanooga shale or on outliers of the upper member of the Sedalia dolomite. The Gilmore City is separated by a pronounced unconformity from the overlying Osagian rocks. In a few wells in Harvey County, as in the McBride Inc. No. 1 Friesen well in sec. 20, T. 22 S., R. 3 W., in northwestern Harvey County, a thin bed of nonoölitic Gilmore City limestone is overlain by dull dark earthy St. Joe limestone, which elsewhere overlies the upper member of the Sedalia or the Chattanooga shale. Farther north the Gilmore City is overlain by the Reeds Spring dolomite, and still farther north by the lower zone of the Burlington—Keokuk limestone sequence (Fig. 12A, 12B).

Osagian Series

Osagian rocks are widely distributed in the Mississippi Valley and are represented in the subsurface in the Salina basin. As originally used by Williams (1891), the term Osage included only the Burlington and Keokuk limestones of southeastern Iowa. The term was later expanded to include the underlying Fern Glen limestone of eastern Missouri. Some geologists include the overlying Warsaw limestone in the Osagian, but on account of the pronounced unconformity at the base of the southern Kansas "Warsaw" the writer places it in the Meramecian.

The Fern Glen is represented in southwestern Missouri by the Reeds Spring limestone above and the St. Joe limestone below, both of which change their lithologic character in the subsurface toward the west. In outcrops in southwestern Missouri and in the subsurface of southeastern Kansas the St. Joe limestone consists of noncherty or very sparsely cherty semigranular fossiliferous limestone. Toward the west, in southern Kansas, the St. Joe thickens and some zones become argillaceous. In the area south of the Salina basin it includes beds of calcareous green and red shale and some reddish granular limestone.

At outcrops in southwestern Missouri the Reeds Spring consists of dolomite interbedded with vitreous dark to almost black chert, opaque in hand specimens but semitranslucent in small chips. In the subsurface of southeastern Kansas the chert cuttings from wells are dark to brownish and semitranslucent. Farther west in southern Kansas the dolomite changes gradually to semigranular limestone containing various amounts of semitranslucent to translucent bluish-gray and colorless chalcedonic chert. The correlatives of both the St. Joe and Reeds Spring thin and wedge out toward the north, both east and west of the Nemaha anticline. Neither is present on the crest of the anticline (Fig. 12B). The Reeds Spring limestone overlaps northward beyond the margin of the St. Joe, and in turn it is overlapped by the more widely distributed Burlington.

St. Joe Limestone

In the area just south of the Salina basin, in Sedgwick County, the St. Joe limestone is 75 to 100 feet thick and consists of interlayered beds of noncherty semigranular limestone, argillaceous limestone, and calcareous shale. Toward the north this sequence of beds becomes thinner and more argillaceous and on the southern border of Harvey County consists of dark argillaceous limestone, in part earthy textured and in part dark, impure, dull, and finely crystalline. In Harvey County the St. Joe ranges in thickness from 10 to 40 feet. It thins out irregularly northward in the basin that lies between the Central Kansas uplift and the Nemaha anticline, as shown on Figure 12B. The variation in thickness is due chiefly to the unconformity at its base. The distinction between St. Joe and Reeds Spring in most parts of southeastern Kansas is based on the absence of chert in the St. Joe cuttings and presence of chert in the Reeds Spring cuttings. Consequently, the separation is arbitrary and the selected contact somewhat variable in position. In Harvey County the argillaceous character and the dark color of the St. Joe provide additional criteria for their differentiation.

In different localities in Reno and Harvey Counties the St. Joe is in contact with the underlying Gilmore City, the upper member of the Sedalia, or the Chattanooga shale, on all of which it is unconformable. Thus, in the McBride No. 1 Friesen well in sec. 20, T. 22 S., R. 3 W., 5 feet of dark dense St. Joe limestone overlies 25 feet of Gilmore City; in the Boyle Grossman Drilling Company No. 1 Moulds well in sec. 7, T. 24 S., R. 1 W., 25 feet of St. Joe limestone overlies 5 feet of upper Sedalia dolomite; in the Garland et al No. 1 Cox well, in sec. 27, T. 24 S., R. 1 W., 30 feet of St. Joe overlies Chattanooga shale. The contact between St. Joe and Reeds Spring limestones is transitional in southeastern Kansas. In the Salina basin, it seems to be conformable, although in Harvey County a marked lithologic break at the top of the dark earthy limestone of the St. Joe commonly marks the contact with the Reeds Spring.

Reeds Spring Limestone

In the part of Kansas south of the Salina basin the Reeds Spring limestone, of late Fern Glen age, is composed mainly of semigranular limestone, but it includes some interbedded dolomite and some slightly argillaceous limestone. Chert is conspicuous throughout most of the formation; at some places, however, zones near the base are only sparsely cherty. The distinguishing feature of the Reeds Spring is the translucent and semitranslucent character of the chert. The color of the chert is variable. Shades of blue and bluish gray predominate. Some zones are yellowish and some are dark and brown, like the chert in the outcrops in southwestern Missouri and northeastern Oklahoma. Some of the chert is colorless in thin chips. In drill cuttings the chert is generally represented by smooth splinters and blocky fragments with sharp flinty edges. In some zones minor amounts of opaque blocky chert with rough surfaces accompany the semitranslucent chert. The contact of the Reeds Spring with the Burlington is determined by the change from the dominantly semitranslucent splintery chert of the Reeds Spring to the dominantly opaque and semiopaque blocky chert of the Burlington.

The distribution of the Reeds Spring in the Salina basin is shown in Figure 12 B. In this basin the Reeds Spring overlaps the St. Joe limestone and thins to a wedge toward the north, east, and west. It is thickest on the southern margin of the mapped area (Fig. 12 B) in northern Sedgwick County and southern Harvey County, where it is 100 to 120 feet thick. In the area where it overlaps beyond the St. Joe limestone its thickness is materially reduced. In central McPherson County its thickness ranges from 30 to 60 feet, but in central Saline County its thickness in very few places exceeds 20 feet (Fig. 13). Its presence north of Saline County is doubtful.

The Reeds Spring is conformable above the St. Joe limestone, but in the absence of the St. Joe it is unconformable on the older rocks upon which it overlaps. It overlies the Chattanooga shale in parts of Reno County and in much of Butler County. It overlies thin outliers of the upper member of the Sedalia at a few places in Reno County, but toward the north, in the absence of the St. Joe, the Reeds Spring overlaps upon the Gilmore City.

The contact of the Reeds Spring with the overlying lower zone of the Burlington—Keokuk sequence is transitional. The lack of a clear-cut lithologic contact between them, and the irregularity of the eroded surface at the base of the Reeds Spring where it overlaps beyond the St. Joe account for some of the variations in its thickness.

Burlington and Keokuk Limestones

Burlington and Keokuk limestones are widely distributed in the Mississippi Valley both at the surface and in the subsurface, but without the aid of fossils their differentiation in the subsurface of the Salina basin is unsatisfactory. Moore (1928, p. 143, 207) and Moore, Fowler, and Lyden (1939, p. 9) reported a hiatus between the Burlington and the Keokuk in outcrops in southwestern Missouri. In the Joplin district Moore found the Burlington limestone absent and the Keokuk lying disconformably on the Reeds Spring limestone. Laudon (1939, p. 329) reports the same relations throughout northeastern Oklahoma. Lee (1940, p. 58) has described lithologic differences between the lower and upper zones of the Burlington—Keokuk sequence in the subsurface of Kansas and tentatively correlated the zones, respectively, with the Burlington limestone and the Keokuk limestone. The variable position of the contact between the two lithologic zones supports the conclusion that the upper zone lies unconformably on the lower. Where the Burlington is absent in the Joplin area, only rocks of the upper zone are present. In other areas both lithologic phases occur with erratic variations in thickness. The lower zone, which is transitional with the underlying Reeds Spring, is at least partly of Burlington age and the upper zone at least partly of Keokuk age. Both zones consist of cherty limestone and dolomite but they are differentiated by the character of the chert.

Lower zone of the Burlington—Keokuk sequence.—The lower zone is characterized by opaque chert of microscopically dense texture, which appears in well cuttings as blocky fragments with more or less tabular surfaces. The sequence of beds characterized by typical white opaque chert is interrupted in some wells by zones rarely more than 5 feet thick containing semitranslucent chert of the Reeds Spring type. A minor amount of rough nondescript chert is present in many samples; some chert, commonly associated with sucrose dolomite or dolomitic limestone, shows a grainy or stippled pattern on the smoothly broken surface; some of the chert breaks with rough and pitted surfaces. Traces of sparsely distributed micro-organisms and spicules appear on the broken faces of some chert fragments in the upper part of the lower zone. Insoluble residues of samples from the lower zone reveal quartz crystals, drusy quartz, and hackly quartz. Insoluble residues from some dolomitic beds include dolomoldic chert.

The lower zone varies in thickness from place to place by reason of its unconformable relation to the upper zone and its locally obscure contact with the Reeds Spring. It is thickest in Harvey County, where several wells penetrated more than 150 feet. It is 155 feet thick in the Rosenthal and Madison No. 1 Masters well in sec. 24, T. 23 S., R. 3 W., but farther north it is commonly 75 to 120 feet thick, although locally it is thinner. In areas where it overlaps beyond the Reeds Spring its thickness is commonly less than 50 feet.

Upper zone of the Burlington—Keokuk sequence.—Most of the chert of the upper zone is white, rough, and pitted, and breaks to subangular fragments. Although other types of chert occur in the upper part of the zone, they are uncommon in the lower part. Microfossiliferous chert similar to that in the "Warsaw" occurs in some areas in the middle or upper part of the upper zone, but it is distinguished from "Warsaw" chert by the replacement of the micro-organisms with glassy or translucent chalcedony. The cherts of the upper zone include various amounts of siliceous aggregates resembling tripoli, which are sometimes referred to as "cotton rock". Some of the "cotton rock" is firm but some is soft. The greater part of the limestone and dolomite of the lower zone is siliceous and when treated with acid yields soft tripolitic crumbs of "cotton rock" that constitute a considerable proportion of the volume of the insoluble residues. Insoluble residues of dolomitic beds contain also dolomoldic chert. The contact between limestone with blocky opaque gray chert of the lower zone and limestone with subangular, rough, pitted, and tripolitic white chert of the upper zone is generally sharply marked.

In southeastern Kansas, where the Burlington limestone is absent, an oölitic bed (probably the Short Creek oölite) occurs high above the base of the Keokuk limestone. On the southern margin of the Salina basin, where the upper zone of the Keokuk—Burlington sequence is underlain by the lower zone, the oölitic bed lies at or near the base of the upper zone. The oölitic bed was not observed in the more northerly wells in the Salina basin.

The upper zone, which is bounded both above and below by disconformities, varies greatly in thickness. In Harvey County and northern Butler County its thickness is as much as 110 feet locally, although thicknesses of 70 to 80 feet are more common. It is less than 70 feet thick in most areas north of Harvey County and is absent in some wells on the margin of the Salina basin, where it was removed by pre-Pennsylvanian erosion. In general, the upper zone, like the lower zone, is thinner toward the north than toward the south, and their combined thickness where they are overlain by the "Warsaw" is also less.

The upper zone is separated by unconformity from the overlying Meramecian formations. In the Salina basin the upper surface of the upper zone was one of moderate relief, but farther south, near the Oklahoma border, the Keokuk and older rocks were deeply eroded.

Meramecian Series

Rocks of Meramecian age are present in widely separated areas in the Mississippi Valley. In Kansas they consist in descending order of the Ste. Genevieve, St. Louis, Spergen, and "Warsaw" limestones* and the Cowley formation. The sequence from the "Warsaw" limestone to the Ste. Genevieve limestone occurs in the subsurface of the deeper parts of the Forest City basin and on the southwestern flank of the Central Kansas uplift in western Kansas. The "Warsaw" and Spergen limestones are preserved in the central part of the Salina basin and in other synclinal areas. All the formations of Meramecian age except the Cowley were probably deposited throughout Kansas but were removed from anticlinal areas by the erosion that followed the post-Mississippian deformation.

Meramecian time was preceded by an elevation of Kansas above sea level, as a result of which the Keokuk and earlier Mississippian rocks were deeply eroded in southern Kansas, where in some valley areas erosion cut through the Chattanooga shale and exposed pre-Chattanooga rocks. The relations of the early Meramecian deposits to the Keokuk in the Salina basin reveal a dissected surface at the base of the Meramecian, although the relief is less pronounced than in southern Kansas. The first deposit of Meramecian age in southern Kansas during the resubmergence of the region was the Cowley formation (Lee, 1940, p. 66-78). In areas near the shore line on the northern margin of the eroded basin, this formation consists of silty and dolomitic gray and black shale, but basinward, in southern Kansas and northern Oklahoma, it becomes less argillaceous and more dolomitic. The Cowley is commonly very cherty, although the chert content differs greatly in different areas. The chert is characterized by crowded masses of micro-organisms, but this characteristic is less well developed in northern Oklahoma. As the advancing sea spread out over the less deeply eroded surface of the upland toward the north, the argillaceous and silty Cowley sediments graded upward into the "Warsaw" semigranular limestone. The Spergen limestone overlies the "Warsaw" with seeming conformity in eastern Kansas and is followed by St. Louis and Ste. Genevieve limestones. Neither of the latter formations has been recognized in the Salina basin. It is probable that they were formerly deposited but were removed by pre-Pennsylvanian erosion.

"Warsaw" Limestone

The "Warsaw" limestone in the Salina basin consists mainly of semigranular cherty limestone, although some sucrose dolomite occurs as the matrix cementing crystalline fragments of broken

* Rocks called Warsaw by Lee in the manuscript of this report are judged to be wholly younger than the type Warsaw, which carries a characteristic Osagian fauna and, as confirmed by recent field studies of Laudon, must be classed as upper Osagian—not lower Meramecian. Accordingly, Lee's Warsaw has been changed editorially to "Warsaw".—R. C. Moore. (Footnote, Lee, 1948)

fossils. The chert is variable in amount but rarely constitutes as much as 40 percent of the volume of samples. It is typically lighter colored than the chert of the Cowley formation, and although the silicified organic remains are revealed in dark patterns against a gray matrix in some fragments, much of the microfossiliferous chert is entirely gray and the microfossiliferous character is less noticeable. The silicified fossils of the "Warsaw" chert are commonly coarser than those in the Cowley.

The maximum observed thickness of 80 feet of "Warsaw" is in the Kinney—Coastal Oil Company No. 1 Beil well in sec. 23, T. 14 S., R. 5 W. This thickness is exceptional. The "Warsaw" is commonly less than 50 feet thick, and it wedges out locally on the flanks of topographically high areas of the pre-"Warsaw" surface as shown between wells 15 and 16 of Figure 13. The great differences in thickness are due to the unconformities at the top and bottom. The oldest beds of the "Warsaw" seem to have been deposited in deeply eroded areas of the Keokuk surface, and the later beds of the "Warsaw" seem to have overlapped on higher parts of this surface.

The "Warsaw" limestone and the overlying Spergen limestone survived post-Mississippian erosion only in the deeper parts of the Salina basin. They are present in the syncline between the Voshell anticline and the Central Kansas uplift, in synclinal areas east and west of the Halstead and Graber pools, and in the structural basin west of the Valley Center anticline (Fig. 12B). On the flanks of these synclines, the "Warsaw" was beveled by pre-Pennsylvanian erosion and covered by Pennsylvanian rocks.

Spergen Limestone

The Spergen limestone is less widely distributed than the "Warsaw" in the structural basins and synclinal areas of the Salina basin. It is composed mainly of noncherty yellowish granular limestone with a slightly waxy luster. In some localities the limestone is interstratified in the upper part with noncherty sucrose dolomite. Patient examination of the granular limestones generally reveals the presence of thinly disseminated specimens of the foraminifer *Endothyra*. Insoluble residues of the dolomitic beds reveal much silt and "spongy" masses of sponge spicules. The basal member is generally dolomitic and silty. In wells in T. 20 and 21 S., R. 4 W., the basal dolomite is 15 to 20 feet thick and includes exceptionally large amounts of semitranslucent chalcedonic chert, which in this area amounts to 10 to 20 percent of the samples. This dolomitic member is of variable thickness and is less silty and less cherty farther north.

The Spergen is less than 40 feet thick in most wells in which it has been encountered. In the Auto Ordnance—Darby No. 1 Gawith well in sec. 27, T. 11 S., R. 5 W., a thickness of 99 feet was drilled (well 5, cross section A-A', Pl. 6), and in the absence of lithographic limestone by which the St. Louis limestone is commonly recognized, the entire thickness of this unusually thick limestone is referred somewhat doubtfully to the Spergen.

The Spergen normally succeeds the "Warsaw" but where the "Warsaw" is absent it may overlap upon the Keokuk. In the Salina basin surviving remnants of the Spergen are everywhere unconformable beneath rocks of Pennsylvanian age.

ROCKS OF PENNSYLVANIAN AGE

Desmoinesian Series

The Desmoinesian Series of Kansas was formerly divided into the Marmaton group above and the Cherokee group below. Representatives of the Geological Surveys of Iowa, Nebraska, Kansas, Missouri, and Oklahoma* have agreed to divide the Cherokee into two groups, the Cabaniss group above and the Krebs group below, on the basis of exhaustive paleontologic and stratigraphic studies of the outcrops. The Krebs group is capped by the Seville limestone, and the Cabaniss group extends upward to the base of the Fort Scott.†

Cherokee Group

Unfortunately, the sequence of Desmoinesian rocks below the Marmaton contains no beds of sufficient continuity to be identified with confidence in either well samples or electric logs, with the possible exception of the Verdigris (formerly "Ardmore") limestone in the middle of the Cabaniss subgroup. It is necessary, therefore, in spite of the paleontologic and diastrophic separation of the Krebs and Cabaniss subgroups in the outcrops, to continue the use of the term Cherokee group in subsurface studies.

The beveled surface that resulted from the erosion of the warped and folded Mississippian rocks was subjected to renewed folding before the Pennsylvanian sea reached Kansas. The rejuvenated

* Searight and others, 1953, Classification of Desmoinesian (Pennsylvanian) of northern Midcontinent, Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2747-2749.

† At a conference, Oct. 17, 1955, attended by representatives of the State Geological Surveys of Kansas, Nebraska, Oklahoma, and Missouri and the United States Geological Survey, the Krebs and Cabaniss groups were relegated to the status of subgroups and the Cherokee was restored to group status at the discretion of any state.

folding followed much the same pattern as the folding at the end of Mississippian time, but there was some modification of earlier folds; some structural features were not revived, and some new features were introduced.

When Pennsylvanian sedimentation began in Kansas, movement of the Nemaha anticline had been revived, and the region to the east was already lower than the region to the west. In consequence, the sea advancing from the south in both basins entered the Cherokee and Forest City basins on the east before it submerged the Salina basin on the west. The Nemaha anticline rose by differential movements contemporaneously with the deepening of the basins. The Burns dome on the crest of the Nemaha anticline was not submerged until the end of Cherokee time (Kellett, 1932). In southeastern Nebraska the crest of the Nemaha anticline was not covered until middle Kansas City time, when the Drum limestone overlapped upon the pre-Pennsylvanian surface. (E. C. Reed, personal communication.) The gradually rising crest of the anticline, seldom very high above the adjoining basins, thus formed a southwesterly projecting peninsula of shrinking proportions until long after Cherokee time.

East of the Nemaha anticline, in the outcrops of southeastern Kansas and in the subsurface, the Cherokee group consists mainly of clastics. Light and dark shales predominate, but there is much sandstone and micaceous sandy shale. There are many coal seams and associated clay beds in cyclical succession, but only a few of the coals are thick enough to mine and some are discontinuous. Thin limestone beds were also deposited in cyclical succession, but erosion at the end of each cycle of deposition left only separated remnants with the exception of the Verdigris, which is generally recognizable in the resistivity curves of electric logs in the Cherokee and Forest City basins. It lies about 90 feet below the base of the Marmaton group. The Seville limestone, capping the Krebs subgroup and about 200 feet below the base of the Marmaton, is doubtfully identified in a few electric logs, but only in the southeastern corner of the area.

The Forest City basin was separated from the Cherokee basin by the Bourbon arch in early Cherokee time. Until the Bourbon arch was submerged the deposits in the Forest City basin consisted mainly of black shale, accompanied by some arkosic material derived from Precambrian granite exposed in a small area on the crest of the Nemaha anticline.

The shoestring sands of the Teeters and Sallyard trends in northern Greenwood County in the southeastern corner of the area are offshore bars of seas that intermittently advanced into the Cherokee basin (Bass, 1936.) The tops of these buried sand bars lie at depths of 190 to 225 feet below the base of the Marmaton group. Other shoestring sands, which seemingly accumulated in intercyclical erosion channels, occur locally at unpredictable depths. Interbedded sheet sands and irregularly disposed lenticular bodies of sand are also present.

In the Salina basin the sandstone and coal beds so characteristic of the Cherokee in outcrops in southeastern Kansas are not represented. Seams of black shale probably correlative with coal beds in the Cherokee basin are recognized in the samples of some wells. The rocks consist mainly of gray silty shale interstratified with red shale. Toward the margin of the basin, where the Cherokee overlapped upon the differentially rising surface of the Central Kansas uplift, several relatively thin beds of red shale that do not extend far into the basin are commonly present. Each of these beds probably records a nearshore phase of a depositional cycle during which the normal marine phase was inhibited by outwash from the adjacent land areas. Some thin beds of limestone are reported in some wells, but on account of discontinuity or poor representation in the logs they cannot be traced from well to well.

The Pennsylvanian basal conglomerate is well developed in most wells in the Salina basin. It reaches a thickness of 20 to 30 feet in many places but is not present everywhere. Extreme thicknesses exceeding 50 feet have been drilled. The cherty basal conglomerate is much more common in the Salina basin, where most of the underlying rocks are cherty limestone, than in the Forest City basin, where the widely exposed sparsely cherty or noncherty limestone of Spergen, St. Louis, and Ste. Genevieve ages provided little material for a cherty conglomerate.

In drillers logs and in many sample logs it is impossible to differentiate the Pennsylvanian basal cherty conglomerate from Mississippian chert that weathered in place. Wave action and currents during gradual submergence tend to remove residual debris from topographic crests and redistribute it in channels and basins. The top of the basal conglomerate, therefore, presents a more nearly level surface and consequently a more useful surface in the study of structural deformation than the actual, more irregular surface of the Mississippian. The thickness of the Mississippian and the thickness of the lower Pennsylvanian rocks have therefore been measured from the top of the chert-bearing beds or coarse clastic (basal Pennsylvanian) rather than the top of the true Mississippian surface. This procedure, although not stratigraphically accurate, has the advantage of consistent application, and it is to be understood that references to the thickness of the lower Pennsylvanian rocks exclude the cherty basal Pennsylvanian conglomerate.

In the drillers logs of old wells chert is consistently reported as sand. Beds of "sand" in the position of the basal conglomerate have been assumed to represent chert in some old well logs. The elimination of these doubtful beds from the Cherokee and their inclusion in the Mississippian may have introduced minor errors in the thickness maps where dependence on old drillers logs has been necessary.

East of the Nemaha anticline the Cherokee is 490 feet thick in T. 21 S., R. 16 E., at the northern end of the Cherokee basin; it thins to 385 feet on the Bourbon arch in sec. 23, T. 18 S., R. 10 E., and thickens again to 820 feet in the deepest part of the Forest City basin in sec. 33, T. 1 S., R. 16 E.

In the deepest part of the Salina basin, in sec. 34, T. 2 S., R. 11 W., the Cherokee is only 240 feet thick, but in T. 18 S., R. 4 W., on the saddle separating the Salina basin from the Sedgwick basin it is 105 to 115 feet thick. It is missing on the crest of the Nemaha anticline north of T. 8 S., is 10 feet thick in sec. 32, T. 8 S., R. 9 E., and increases in thickness irregularly southward along the crest to 45 feet in sec. 23, T. 17 S., R. 7 E., and to 70 feet in sec. 30, T. 25 S., R. 5 E., but it is missing on structural and topographic highs.

The Cherokee is separated from the Mississippian limestones by a marked unconformity, but it is essentially conformable with the overlying Marmaton group.

Marmaton Group

The formations of the Marmaton group, named in Table 6 in descending order, have been differentiated and described in outcrops in southeastern Kansas (Jewett, 1945). The range and average thickness of each in southeastern Kansas have been reported by Moore and others (1944, 1951). The thicknesses in southeastern Nebraska are reported by Condra and Reed (1943).

The Marmaton group consists of a sequence of limestone and shale formations. The limestone formations are interstratified with shale members, and the shale formations include some sandstone and, locally, thin limestone beds. In the outcrops black shale

TABLE 6.—*Sequence and thickness of formations of the Marmaton group*

	Range in thickness in outcrops in southeastern Kansas, feet	Average thickness in outcrops in southeastern Kansas, feet	Subsurface thickness in southeastern Nebraska, feet
Marmaton group			
Holdenville (Memorial) shale	0–30	10	missing
Lenapah limestone	1–18	12	missing
Nowata shale	3–30	18	10
Altamont limestone	6–25	19	20
Bandera shale	20–50	35	55
Pawnee limestone	15–60	30	19
Labette shale	30–100	50	25
Fort Scott limestone	24–35	33	36
Total		207	165
Cherokee group			

and thin coal beds occur in all formations below the Altamont. Some thin beds of red shale are interbedded in the limestone formations in the subsurface, but the red shales lack continuity over broad areas and probably represent weathering during intercyclical exposure.

The sequence of formations can rarely be determined accurately from drillers logs or sample logs of rotary wells, but are generally revealed in electric logs. From the outcrops in southeastern Kansas the shale beds thin toward the north and west in the subsurface. Intercyclical erosion locally modified the thickness of the limestone formations. In outcrops in northeastern Kansas and in the subsurface on the margins of the Salina basin, pre-Missourian erosion removed the Lenapah and associated shale formations. In the subsurface the sequence of Marmaton formations is generally complete except for the local absence of the Lenapah limestone. All of the formations extend in outcrops into northern Oklahoma.

In the central part of the Salina basin the electric log of the Carter No. 5 Exploration well in sec. 5, T. 5 S., R. 10 W., reveals the following sequence:

Top of Marmaton group at a depth of	3028 feet
Holdenville shale	missing
Lenapah limestone	22 feet
Nowata shale	15 feet
Altamont limestone	15 feet
Bandera shale	10 feet
Pawnee limestone	20 feet
Labette shale	20 feet
Fort Scott limestone	25 feet
Total	127 feet

The place normally occupied by Holdenville shale is probably taken by 28 feet of Pleasanton shale. The sandstone members of the Marmaton shale formations that provide reservoirs for oil and gas in the Forest City and Cherokee basins (the "Peru sand" of the Labette shale, the sandstone in the Bandera shale, and the "Wayside sand" of the Nowata shale), and which are discontinuous in eastern Kansas, are not represented west of the Nemaha anticline in the Salina basin area. The sandstone beds of the Bandera shale formation locally become so calcareous as to be indistinguishable from limestone in electric logs, and in some areas probably grade into limestone. The electric logs reveal discontinuous limestone lentils or calcareous zones in the shale formations of the Marmaton to the confusion of local correlations. The Holdenville shale (formerly Memorial shale) is indistinguishable from the Pleasanton shale unless the latter includes at its base a recognizable sandstone formation. Where the sequence between the Lenapah and the base of the Kansas City group is thin, the Holdenville shale has probably been removed by pre-Missourian erosion.

The thickness of the Marmaton group differs from place to place and in general is responsive to contemporary regional structural movements. East of the Nemaha anticline the succession from the top of the Lenapah to the base of the Fort Scott thins toward the north from 210 feet in sec. 30, T. 29 S., R. 8 E., to 155 feet in sec. 21, T. 7 S., R. 13 E. In the Salina basin, in sec. 5, T. 5 S., R. 10 W., the sequence including the four limestone formations is 127 feet thick. It becomes thinner on the contemporaneously rising flanks of the basin where it overlaps upon the pre-Pennsylvanian rocks. In sec. 10, T. 4 S., R. 7 E., the upper 35 feet of the Marmaton overlaps upon 35 feet of Pennsylvanian basal conglomerate on the west flank of the Nemaha anticline.

The Marmaton is thinner on the crest of the Nemaha anticline than in the adjoining basins, and like the Cherokee it thickens southward along the crest from 70 feet in sec. 6, T. 11 S., R. 10 E., to 155 feet in sec. 14, T. 20 S., R. 7 E. The data reveal that there was general but locally irregular thinning from south to north in the basins as well as along the crest of the Nemaha anticline.

Missourian Series

The Missourian Series is separated from the Desmoinesian Series by an unconformity and by a faunal break. The unconformity was marked by erosion of the upper Marmaton beds and by the development of channels, which were later filled by sandstone deposits.

The subordination of the Bronson rocks by which they were reclassified as a subgroup of the Kansas City group was agreed upon at a four-state nomenclature conference of the state geologists of Kansas, Nebraska, Iowa, and Missouri held in Lawrence May 5, 1947. The term Bourbon shale was abandoned in favor of the older equivalent term, Pleasanton group.

The Missourian Series has been divided into the following groups, listed in descending order: Pedee, Lansing, Kansas City (Zarah, Linn, and Bronson subgroups), and Pleasanton.

Pleasanton Group

Four formations of the Pleasanton group, named in descending order in Table 7, have been differentiated in outcrops in southeastern Kansas. The average thicknesses of the formations in eastern Kansas have been reported by Moore and others (1944, 1951).

TABLE 7.—*Sequence and thickness of formations of the Pleasanton group*

	Average thickness in eastern Kansas, feet
Pleasanton group	
Knobtown sandstone and shale	30
Unnamed shale	60
Checkerboard limestone (southeastern Kansas only)	2
Hepler sandstone	10
Total	102

The Hepler sandstone was deposited in channels and basins eroded in the upper formations of the Marmaton group. On account of the unconformity, the Hepler sandstone and the overlying shale are of variable thickness and character in eastern Kansas. The positon of the Knobtown sandstone of Linn and Bourbon Counties is occupied farther south by thin beds of dense blue limestone alternating with thin beds of black shale (Moore, Frye, and Jewett, 1944, p. 195). Sandstone has been traced westward by well samples to the crest of the Nemaha anticline in T. 18 S., R. 5 E. on the line of cross section X-X′ (well 44, Pl. 11). Westward from this point red shale and gray silty shale, in part finely micaceous, occupy its stratigraphic position. Some black shales and dark shales are locally interbedded with lighter-colored shales. The red shales were probably deposited during submergence after periods of weathering and exposure.

In the Salina basin the Pleasanton shale cannot be separated from the Holdenville shale, although it is probable that its initial deposit was the red shale observed in the samples of many wells. The Holdenville—Pleasanton beds are 20 to 40 feet thick in McPherson County, and in the deepest part of the Salina basin are 15 to 40 feet thick. The sequence is 20 feet thick on the northeastern side of the Salina basin in sec. 1, T. 1 S., R. 2 E., and even less on the southwestern side, where it wedges out in overlap upon the pre-Pennsylvanian surface on the Central Kansas uplift.

On the crest of the Nemaha anticline the Pleasanton is thin or absent. The thickness of the Pleasanton group, although controlled locally by movements of such structural features as the Nemaha anticline, the Salina basin, and the Central Kansas uplift, increases regionally toward the southeast and shows a definite relation to the regional deformation of the Ouachita basin.

Kansas City and Lansing Groups

The Kansas City and Lansing groups, which consist of alternating shale and limestone, were deposited in sequence above the Pleasanton group with cyclical interruptions. The cyclical periods of exposure, during which minor channeling and erosion occurred, were not infrequent, and each exposure reduced in some degree the thickness of the deposits of the preceding cyclothem. The initial clastic deposit of the following cyclothem, for the most part shale, leveled off the surface in most areas before the limestones of the new cycle were deposited.

The Kansas City and Lansing groups are composed dominantly of limestone formations. In the outcrops of southern Kansas some of the limestone formations grade into or interfinger with contemporaneously deposited shale and sandstone. Some of the limestone beds, however, have been traced into Oklahoma. Many of the formations are convenient lithologic groupings of beds without regard to the cyclothems involved. The cyclothems are commonly separated from each other by obscure disconformities within the shale formations (Moore and others, 1951, p. 92-93).

Most of the formations referred to as limestones include shale members of various thicknesses, some of which have characteristics recognizable in outcrops throughout extraordinarily broad areas. In the outcrops the limestone beds display faunal, lithologic, and weathering characteristics by which they are commonly recognized. Most of the distinctive features of color, weathering, jointing, faunal content, and texture, however, cannot be determined in cuttings taken from wells. The identification of formations in sample logs is in consequence dependent upon the sequence of limestone beds and upon the thickness of shale between them, confirmed by fusulines, oölites, and cherts of some limestones, and by the regular occurrence of black, red, olive-colored, and sandy shale units having the rank of members and formations. Unfortunately none of these characteristics can be relied upon with certainty over very broad areas. Both oölites and chert are variable. Algal limestones include oölites in some areas but not in others. Chert is a more or less constant constituent of some limestones in certain areas but is unrecognizable or absent in other areas from beds ordinarily cherty; on the other hand, chert has been found in almost all the limestones at some place in the subsurface. Fusulines are widely distributed but because of their abundance are not very useful as lithologic features, and in samples from rotary wells they have only slight usefulness, because of uncertainty of the source.

Electric logs provide an invaluable means of correlation, but in some areas the orderly sequence of formations is so interrupted by intercyclical erosion that correlation of some limestones from well to well is difficult, especially west of the Nemaha anticline where the intercyclical shales are thin.

Kansas City Group

The formations of the Kansas City group listed in descending order in Table 8 have been differentiated in their outcrops in eastern Kansas. Detailed descriptions of the formations and their thickness in the outcrops have been reported by Moore and others (1944, 1951) in Kansas, and by Condra and Reed (1943) in southeastern Nebraska.

Samples from the subsurface lack the visible characteristics that distinguish the weathered outcrops; therefore the formations appear as a somewhat monotonous alternation of limestone and shale; the principal characteristics shown by the subsurface samples are the thickness and order of deposition. In most of the area the shales are considerably thinner than in the outcrops, a fact that increases the difficulty of separating the limestone formations in sample logs.

The Kansas City and Lansing formations as represented in sample logs of wells west of the Nemaha anticline seem to consist almost entirely of limestone, but electric logs reveal thin shale beds representing the shale formations and members of the outcrops. Many of the limestone members seem thicker in the subsurface than in outcrops, owing perhaps to the representation in electric logs of

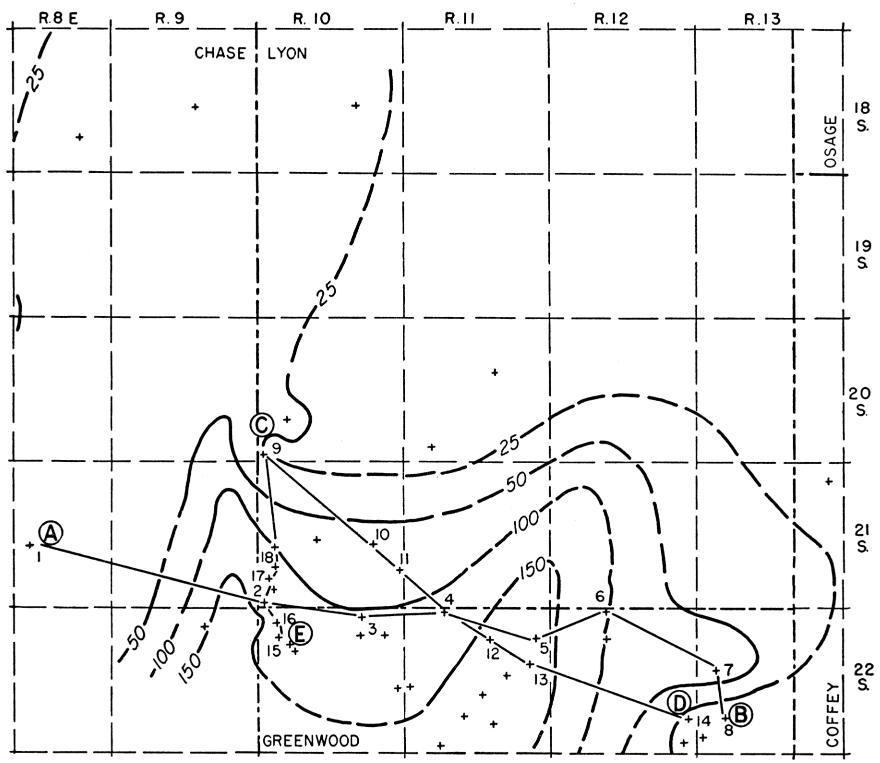
TABLE 8.—*Sequence and thickness of formations of the Kansas City group*

	Range of thickness in outcrops in southeastern Kansas, feet	Average thickness in outcrops in eastern Kansas, feet	Thickness in southeastern Nebraska, feet
Kansas City group			
Zarah subgroup			
Bonner Springs shale	0–60	20	6–8
Wyandotte limestone	0–75	50	30–44
Lane shale	15–105	50	17–18
Linn subgroup			
Iola limestone	0–30	12	3–12
Chanute shale	12–165	75	14–16
Drum limestone	0–60	9	8–9
Cherryvale shale			
Quivira shale member	3–11	7	6–14
Westerville limestone member	1–16	8	17–18
Wea shale member	15–35	25	
Block limestone member	3–8	4	14–30
Fontana shale member	5–25	15	
Bronson subgroup			
Dennis limestone	2–60	40	21
Galesburg shale	3–75	35	8
Swope limestone	0–35	23	22
Ladore shale	2–50	20	5
Hertha limestone	0–30	16	5
Total		409	203

the calcareous shales of the weathered outcrops as dense argillaceous limestones.

The Hertha limestone at the base of the Kansas City group is easily recognized in the electric logs of wells in the Cherokee and Forest City basins from its occurrence directly above the long shale sequence of the Holdenville shale and the Pleasanton group. It is absent from some wells on the crest of the Nemaha anticline, but it reappears farther west. In electric logs in the Salina basin and on the flanks of the Central Kansas uplift where the Pleasanton is thin, it is difficult to distinguish the basal formation of the Kansas City group from the limestones and calcareous shales at the top of the Marmaton group. It is probably absent from much of the Salina basin where the Swope limestone seems to be the basal formation.

In many wells red shale in the Pleasanton group is locally a guide in identifying the Hertha, but on the flanks of the Central Kansas uplift red shale occurs also above the Hertha as outwash from pre-Pennsylvanian rocks exposed on the broad crest of the Central Kansas uplift. In doubtful areas, the Hertha can be most confidently identified in electric logs by carrying the contact step by step



No.	Company	Well	Farm	Location	
1	Aladdin	1	Noller	Sec. 21, T. 21 S., R. 8 E.	Cross-section A – B
2	Ohio	W23"0"J	Atyeo	Sec. 31, T. 21 S., R. 10 E.	
3	Ace Oil	1	Mackey	Sec. 2, T. 22 S., R. 10 E.	
4	White & Ellis	2	Curry	Sec. 5, T. 22 S., R. 11 E.	
5	Cities Service	36	Madison Unit A	Sec. 12, T. 22 S., R. 11 E.	
6	Sunray	W17	Fankhauser	Sec. 4, T. 22 S., R. 12 E.	
7	Stewart Oil Co.	2	Levi Ott	Sec. 18, T. 22 S., R. 13 E.	
8	White & Ellis	1	Winzler	Sec. 29, T. 22 S., R. 13 E.	
9	Gough Davis	1	Farmer Bell	Sec. 31, T. 20 S., R. 10 E.	Cross-section C – D
10	McNab	1	Bobbinger	Sec. 23, T. 21 S., R. 10 E.	
11	Mendenhall	1	Citizens Bank	Sec. 25, T. 21 S., R. 10 E.	
4	White & Ellis	2	Curry	Sec. 5, T. 22 S., R. 11 E.	
12	Cities Service	2	Yearout	Sec. 10, T. 22 S., R. 11 E.	
13	Stewart Oil Co.	1	Brown	Sec. 13, T. 22 S., R. 11 E.	
14	Cities Service	56	Schwab	Sec. 25, T. 22 S., R. 12 E.	
15	Moss	9	Pixley	Sec. 7, T. 22 S., R. 10 E.	Cross-section C – E
16	Cities Service	6	Atyeo C	Sec. 6, T. 22 S., R. 10 E.	
2	Ohio	W23"0"	Atyeo	Sec. 31, T. 21 S., R. 10 E.	
17	Ohio	16	Atyeo	Sec. 30, T. 21 S., R. 10 E.	
18	Stewart Oil Co.	1	Lowe	Sec. 30, T. 21 S., R. 10 E.	
9	Gough Davis	1	Farmer Bell	Sec. 31, T. 20 S., R. 10 E.	

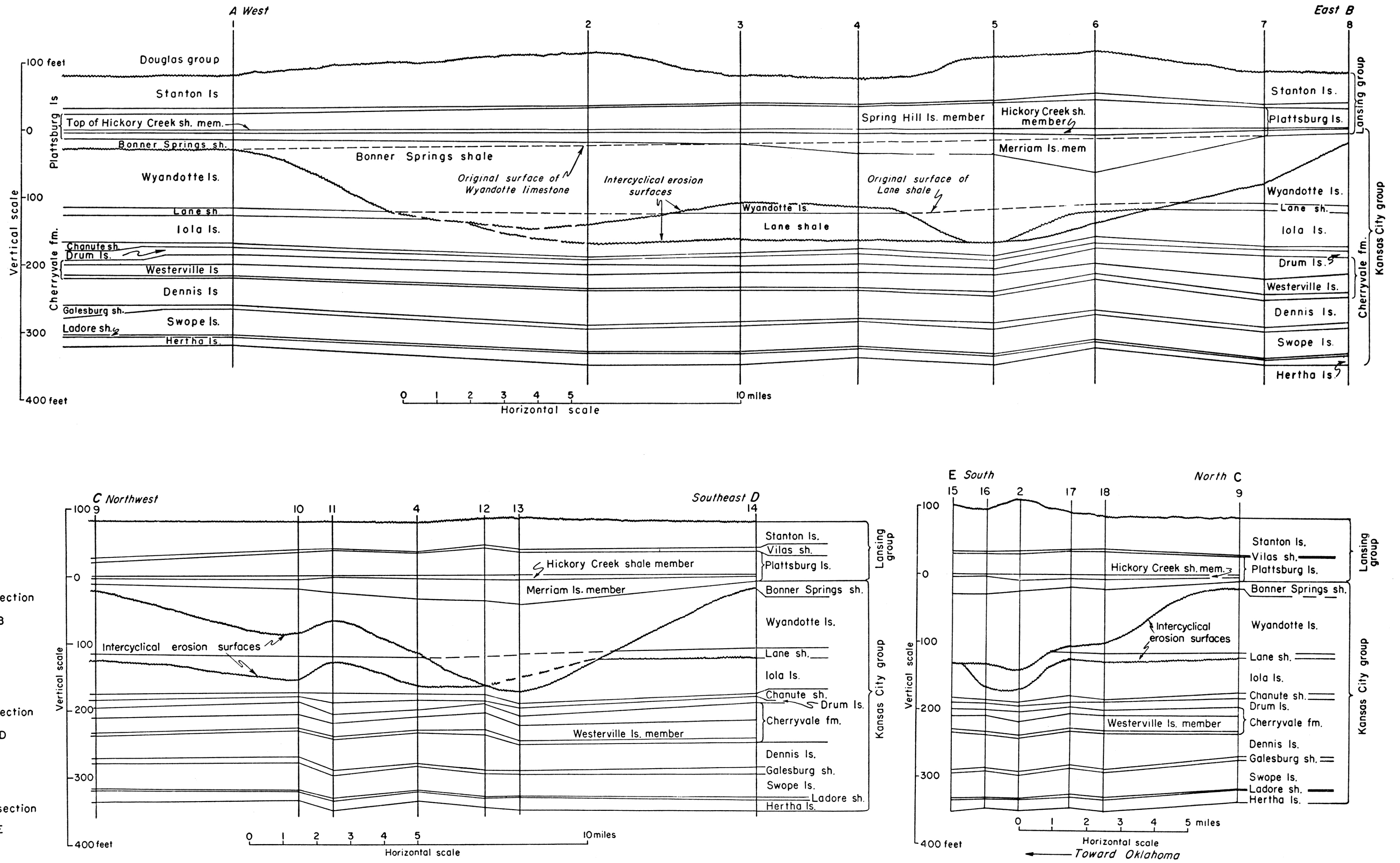


FIG. 14.—Map of parts of Chase, Lyon, and Greenwood Counties and cross sections showing pre-Bonner Springs erosion and pre-Lane erosion by data from electric logs. Map shows topographic relief of pre-Bonner Springs surface by 50-foot and 25-foot contours. Cross sections of Lansing and Kansas City groups of Missourian Series on lines A-B, C-D, and C-E show topographic relief of pre-Bonner Springs and pre-Lane surfaces. Correlation on the top of Hickory Creek shale member of Plattsburg limestone.

westward from areas in which it is clearly revealed and cross checking with electric logs to the north and south.

The Swope and Dennis limestone formations are confidently recognized once the base of the Kansas City is established, but the overlying Winterset, Drum, Iola, and Wyandotte limestones are likely to have been affected by intercyclical erosion. The Drum and Westerville limestone members of the Cherryvale formation are considerably thicker in the subsurface than in the outcrops, and in most of the area constitute almost the whole of the Cherryvale. The Block limestone, if represented, forms a part of the Westerville limestone member.

Intercyclical erosion.—The relation of the Lane and Bonner Springs shale formations to the underlying formations is illustrated graphically by the cross sections based on electric logs shown in Figure 14. A cycle of deposition was completed after the deposition of the Iola limestone (Moore and others, 1951, p. 92). The region was elevated, dissection set in, and erosion removed part or all of the Iola in broad open valleys to a depth of 40 feet, as shown by wells 3 and 4 of cross section A-B and well 4 of cross section C-D (Fig. 14).

The first deposits of the next cyclothem, the Lane shale, tended to level off the dissected surface, and after filling the eroded basins overlapped upon the undissected or partly dissected upland areas, where shale was deposited to a depth of 5 to 15 feet.

After the deposition of the Wyandotte limestone the region was again raised above sea level. At this time, the elevation was high enough and the exposure was long enough to develop topographic relief of considerable magnitude and to carve out valleys at least 175 feet deep (well 13 of cross section C-D, Fig. 14).

As the region again settled below sea level, the first clastic deposits of the next cycle again filled the eroded areas and distributed shale to a depth of 5 to 30 feet across the upland areas. At well 6, and to a lesser degree in wells 4 and 5, the filling of a tributary, valley by shale was incomplete. As a result, the limestone members of the overlying Plattsburg limestone accumulated to abnormal thickness. It seems probable that the surface of the basin at this point was not completely leveled until the deposition of the Vilas shale, for correlation on the Vilas shale eliminates the apparent anticline at the base of the Hertha limestone.

The inset map (Fig. 14) is based entirely on the interpretation of available electric logs and is designed to show by 50-foot contours the approximate topography of the pre-Bonner Springs surface.

The wells of the cross section and map are correlated on the Hickory Creek shale member of the Plattsburg limestone, the first post-Bonner Springs datum that is approximately level in this area.

South of the area of the inset map the Wyandotte, Iola, and even older limestones were generally eroded. Toward the northeast electric logs reveal local pre-Bonner Springs valleys of less relief. Minor increases in thickness of shale members at the expense of the underlying limestone occur in the Wyandotte and in the Chanute formation. The cross sections of Figure 14 show also the irregular surface of the Stanton limestone as a result of post-Lansing erosion.

In the center of the Salina basin in sec. 5, T. 5 S., R. 10 W., the electric log of the Carter Exploration well reveals the following sequence of the Kansas City group:

	Thickness, feet	Thickness, feet
Kansas City group		
Bonner Springs shale	5	
Wyandotte limestone	50	
Lane shale	15	
Iola limestone	55	
Cherryvale shale (mainly Westerville limestone)	65	
Dennis limestone	25	
Galesburg shale	5	
Swope limestone	15	
Pleasanton shale		28
Total	235	28

The lower formations of the Kansas City group overlapped upon the flank of the contemporaneously rising Central Kansas uplift and Nemaha anticline. Parts of the uplift received no Kansas City limestones older than Winterset, and parts none older than Drum.

The shale formations of the Kansas City, not only in the area of the cross section but also throughout the area, are much thinner than in the outcrops farther east, except under conditions of deep intercyclical erosion. Variations in the thickness of limestones are no doubt due in part to the vagaries of deposition in a vast area, possibly in part to local reefs, and in part to accumulation in depressed areas of the bottom as suggested by cross section C-D. Thinning of limestones where accompanied by increased thickness of overlying shale, however, as at the base of the Vilas shale, at the base of the Island Creek shale member of the Wyandotte, and in the Cherryvale formation, is attributed to intercyclical erosion.

Intercyclical erosion is not commonly noted in the outcrops, partly because so many of the erosion surfaces that were developed between cyclothems were cut in the midst of a shale section and partly because the first deposits of relatively few cycles of deposition were composed of sand or coarse clastics.

Like the other Pennsylvanian groups, the Kansas City group thins northward. It is 350 feet thick in the Ellis No. 3 Barngrover well in sec. 7, T. 23 S., R. 15 E., in the northern end of the Cherokee basin, and 260 feet thick in the Carter No. 4 Exploration well in sec. 24, T. 4 S., R. 16 E. West of the Nemaha anticline it thins from 325 feet in the Anschutz No. 1 Schrag well in sec. 27, T. 19 S., R. 4 W., on the saddle between the Salina basin and the Sedgwick embayment, to 235 feet in the Carter No. 5 Exploration well in sec. 5, T. 5 S., R. 10 W., in the deepest part of the Salina basin.

Lansing Group

The formations of the Lansing group are listed in descending order in Table 9. Detailed descriptions of the formations and their

TABLE 9.—*Sequence and thickness of formations of the Lansing group*

	Range of thickness in eastern Kansas, feet	Average thickness in eastern Kansas, feet	Average thickness in southeastern Nebraska, feet
Lansing group			
Stanton limestone	10–90	42	32
Vilas shale	15–90	20	11
Plattsburg limestone	0–100	23	10
Total		85	53

thickness in outcrops in eastern Kansas have been reported by Moore and others (1944, 1951) and in southeastern Nebraska by Condra and Reed (1943).

Both the Stanton and the Plattsburg have been traced in outcrops into southern Kansas. They were deposited throughout the Salina basin area and can be recognized in the electric logs although their thicknesses vary considerably. The Plattsburg in outcrops consists of two limestone members, the Spring Hill above and the Merriam below, separated by the Hickory Creek shale member. These members are represented in all the electric logs. The Spring Hill limestone is commonly less than 10 feet thick and in many places is less than 5 feet thick. In some areas the thickness of the Plattsburg increases locally to more than 50 feet, as in well 6 of cross section A-B of Figure 14, where the Spring Hill limestone member increases from less than 20 feet to more than 40 feet. The Hickory Creek shale maintains a more or less uniform thickness of 5 to 10 feet, although it is scarcely recognizable in a few electric logs.

The Plattsburg in the outcrops generally includes oölitic beds, but oölitic limestone is not present in the Salina basin. The black Hickory Creek shale member, distinct in the outcrops of the Plattsburg, is recognized in the samples of some wells in the Salina basin.

The Vilas shale contains sandy beds and some sandstone in outcrops along Kansas River, but westward in the subsurface the Vilas is thin and contains no sand, although it is locally silty. Red shale is present in the Vilas in some wells. In the Salina basin the thickness of the Vilas does not exceed 10 feet and is generally much less, although it increases locally at the expense of the Plattsburg.

The Stanton limestone formation consists of five members, three limestone beds interstratified with two shale members, of fairly regular thickness and distribution, except the upper limestone member. Neither chert nor oölite is reported from the outcrops, although the lowest limestone member is siliceous. In the subsurface of the Salina basin, however, the Stanton is generally either cherty or oölitic, but neither chert nor oölite has been recognized in every well. The lower shale member of the Stanton, the black fissile Eudora shale, is a good datum in eastern Kansas, both in the outcrops and in the subsurface. In the Salina basin it has been identified in the samples of some wells. The South Bend limestone member at the top of the formation is of exceptionally variable thickness in many places, owing to an unconformity at the end of Missourian time. The accompanying erosion thinned or removed the South Bend limestone in many localities, but at very few places cut into the older members at the base of the formation. In parts of the area, notably in Dickinson and Marion Counties, the South Bend limestone, ordinarily less than 10 feet thick, is 20 to 30 feet thick where not eroded, and the underlying Rock Creek shale, elsewhere less than 5 feet thick except in a few places, is locally 20 feet thick.

These variations increase the thickness of the Stanton, the upper formation of the Lansing group, from a normal 20 to 30 feet to as much as 75 feet where post-Missourian erosion has not thinned the upper beds. Cross section A-B of Figure 14 shows abnormal depositional thickening of the Stanton as well as thinning due to erosion.

Erosion of the upper part of the Stanton brought about much topographic relief locally. In such areas the top of the Lansing cannot be regarded as a trustworthy datum for detailed contouring, although it is a convenient reference point.

The regularity and consistent expression of the Lansing formation contrasts strikingly to the irregular distribution and thickness of the underlying Wyandotte and Iola limestones. Like other groups, the Lansing thins northward and westward. Where all members are present east of the Nemaha anticline the thickness of the Lansing decreases from 135 feet in the Ohio No. 23 Atyeo D well in sec. 31, T. 21 S., R. 10 E., to 70 feet in Carter No. 4 Exploration well in sec. 24, T. 4 S., R. 16 E. West of the Nemaha anticline the same sequence thins northward from 50 feet in the Anschutz No. 1 Schrag well in sec. 27, T. 19 S., R. 4 W., to 40 feet in the Carter No. 5 Exploration well in sec. 5, T. 5 S., R. 10 W., in the central part of the Salina basin.

Pedee Group

The formations of the Pedee group recognized in outcrops in northeastern and southeastern Kansas are listed in descending order in Table 10. The thickness and character of the formation in Kansas have been reported by Moore and others (1944, 1951) and in Nebraska by Condra and Reed (1943).

TABLE 10.—*Sequence and thickness of formations of the Pedee group*

	Range of thickness in outcrops in eastern Kansas, feet	Range of thickness in southeastern Nebraska, feet
Pedee group		
Iatan limestone	0–22	0–9
Weston shale	0–200	0–50

The Weston shale, which overlies the Stanton limestone in probable conformity, consists of dark-bluish to bluish-gray shale that contrasts with the generally yellowish sandy shale of the unconformably overlying Douglas group. At least 200 feet of Weston shale occurs at outcrops in southeastern Kansas and about 100 feet in northeastern Kansas, but in Douglas and Leavenworth Counties and elsewhere the Weston shale was eroded during the hiatus between the Missourian and Virgilian Series. The distribution of the Iatan limestone is even more restricted. It has not been identified in the subsurface far from its outcrops in northeastern and southeastern Kansas.

The Weston shale is reported in the subsurface of Woodson and Greenwood Counties by Kellett (1932). It may be represented as shown in wells 44, 45, and 46 of cross section X-X′ (Pl. 11) by the shale below the Tonganoxie sandstone of the Douglas group. It thins westward from the outcrops and is probably absent throughout the Salina basin.

During the hiatus between the Missourian and Virgilian Series there was widespread and deep erosion, which in many areas exposed the Stanton limestone without, however, cutting much below the South Bend limestone member at its top. The regional topographic relief of the pre-Virgilian surface between southeastern Kansas, where 200 feet of Pedee rocks survived, and areas in which the Stanton was exposed was not less than 200 feet.

Virgilian Series

The Virgilian Series is divided into the following groups, listed in descending sequence: Wabaunsee, Shawnee, and Douglas.

The hiatus that separates the Missourian and Virgilian rocks was accompanied by low regional warping and regional subsidence toward the southeast, as indicated by a westward and northward convergence of the Stanton limestone and the base of the Oread limestone.

Douglas Group

The formations of the Douglas group, represented in outcrops in eastern Kansas, are listed in descending order in Table 11.

Table 11.—*Sequence and thickness of formations of the Douglas group*

	Range of thickness in eastern Kansas, feet	Range of thickness in southeastern Nebraska, feet
Douglas group		
Lawrence shale	40–175	19–42
Stranger formation	40–220	17–24

The range of thickness in outcrops in eastern Kansas is reported by Moore and others (1944, 1951) and in southeastern Nebraska by Condra and Reed (1943).

The Stranger formation in the outcrops consists of yellowish-gray shale and sandstone and includes one or two limestone members in the upper part. The Stranger formation is thickest in places where the Pedee was deeply eroded or entirely removed. The lower part includes the Tonganoxie sandstone member, which is irregular in distribution and character. The Tonganoxie sandstone is absent in some places and in others has a thickness of as much as 90 feet. The Haskell limestone member, in the upper part of the Stranger formation above the Tonganoxie sandstone, is in places as much as 10 feet thick, but it is generally thinner. The Haskell limestone is very persistent, but the interval between this limestone and the base of the Shawnee group above is so variable that the Haskell seems to have been deposited on an uneven surface. The Haskell limestone, in consequence, is an untrustworthy datum for detailed contouring.

In outcrops the Lawrence shale consists chiefly of blue-gray and yellowish shale, but it includes a thin discontinuous limestone member (Amazonia limestone) near the top and the tan Ireland sandstone member, of irregular thickness and distribution, at its base. An unconformity of considerable erosional relief separates the Stranger formation and the Lawrence shale. The thickest deposits of Ireland sandstone lie in deeply eroded areas of the Stranger formation; in some places the base of the Ireland reaches below the Haskell limestone and is even in contact with the Tonganoxie. A very persistent bed of red shale near the top of the Lawrence shale is widely distributed in outcrops in eastern Kansas and southeastern Nebraska. In the subsurface it extends into western Kansas, where it persists although all other parts of the Lawrence shale have wedged out. It seems to be the first deposit of a cyclothem that includes the basal members of the Oread limestone, the first formation of the Shawnee group.

The Tonganoxie sandstone occurs mainly in the Forest City basin area east of the Nemaha anticline and fingers out on the margin of the basin. It is doubtful whether it is represented in the Salina basin. In McPherson and Marion Counties the greater part of the Stranger formation is made up of Ireland sandstone, which is locally more than 150 feet thick (Kellett, 1932). The Ireland sandstone thins out toward the northwest. In the Salina basin, sandstone beds are uncommon in the Douglas group north of Saline County.

On the western flank of the Nemaha anticline as far south as Riley County two to five limestone beds 5 to 20 feet thick are interstratified with Douglas shale, which in this area is 75 to 90 feet thick. The most persistent of these limestones lies near the base of the Douglas group 5 to 20 feet above the South Bend limestone member of the Stanton formation. It is revealed by electric logs throughout much of the Salina basin, where it is 10 to 20 feet thick, but it has not been reported in outcrops. It might plausibly be regarded as a part of the Lansing group except that the top of the Lansing has been placed at the top of the Stanton.

The Douglas group, combined with remnants of the Pedee Weston shale, thins northwestward from 275 feet in the K & E

Drilling Company No. 2 Mohr well in sec. 29, T. 20 S., R. 10 E., to 5 feet in the Texas Company No. 1 Armstrong well in sec. 2, T. 5 S., R. 18 W.

Deformation along the east flank of the Nemaha anticline is revealed by the abrupt thinning of the sequence between the top of the Stanton and the base of the Oread limestone. In a distance of 2½ miles the sequence decreases from 185 feet in the Amerada No. 1 Elizabeth Enlow well in sec. 4, T. 11 S., R. 10 E., to 150 feet in the Amerada No. 1 Mertz well in sec. 6, T. 11 S., R. 10 E., near the crest of the anticline. West of the crest the section continues to decrease to 120 feet in T. 10 S., R. 9 and 8 E. In the deepest part of the Salina basin, still farther west in T. 2 S., R. 11 W., the section is only 10 feet thick. The data seem to indicate that there was uplift west of the east flank of the Nemaha anticline but little or no arching of the crest, and at the same time a regional tilt toward the southeast, hence less shale deposition on the rising area toward the northwest.

Shawnee Group

The formations of the Shawnee group are listed in Table 12 in descending sequence. The thicknesses of the formations at outcrops in eastern Kansas are reported by Moore, Frye, and Jewett (1944, p. 177-182) and Moore and others (1951). The thicknesses in southeastern Nebraska are reported by Condra and Reed (1943, p. 46-49).

TABLE 12.—*Sequence and thickness of formations of the Shawnee group*

	Range of thickness in outcrops in eastern Kansas, feet	Average thickness in outcrops in eastern Kansas, feet	Thickness in outcrops in southeastern Nebraska, feet
Shawnee group			
Topeka limestone	33–55	35	27–40
Calhoun shale	10–45	30	2½
Deer Creek limestone	20–80	40	29–32
Tecumseh shale	65–12	35	32–50
Lecompton limestone	30–50	34	30–36
Kanwaka shale	40–15	80	7–37
Oread limestone	52–100	70	47–54
Total		324	Aver. 212

The formations referred to as limestones are convenient groupings of limestone beds separated by thin shales without regard to division into cyclothems. The formations, all of which have been traced in outcrops across the state from Nebraska to Oklahoma, vary considerably in thickness. The thicknesses of the individual limestone and shale members of the formations also differ from place to place, and abnormally thin limestones in local areas are generally overlain by thick shales.

Samples of the limestones from wells do not present any distinguishing lithologic characteristics. Each limestone of formational rank includes one or more algal members, some of which are oölitic in outcrops, but oölites are infrequently recognized in the well samples. Also, each limestone of formational rank includes a bed of black shale. Parts of the Oread and Topeka limestones are cherty in the outcrops, but all the limestones are cherty at some points in the subsurface. All the limestone formations include one or several members containing fusulines.

All the shale units that are formations include sandstone and sandy shale at the outcrops. In the subsurface, sandstones and sandy shale occur intermittently in the Calhoun, Tecumseh, and Kanwaka shales as far west at T. 1 W. Farther west none of the shale units of formation rank is more than 10 feet thick, and in some wells they cannot be recognized in the samples, although thin shale beds are revealed by electric logs. In the absence of conspicuous shale units, it is difficult to identify, in the subsurface, the limestone formations defined at the outcrops.

In electric logs, the Oread limestone formation at the base of the Shawnee is one of the most distinctive and most easily identified Pennsylvanian formations. Although the Oread includes all or parts of 4 cyclothems (Moore and others, 1951, p. 7 C), all the members of the Oread are represented throughout the area.

The black fissile Heebner shale member, near the middle of the formation, is the most distinctive datum in the Pennsylvanian system. Its thickness ranges from less than 1 foot to more than 10 feet. It is underlain by the thin Leavenworth limestone, the Snyderville shale, and the Toronto limestone members. In places, especially toward the west, the Snyderville, ordinarily 10 to 15 feet thick, attains a thickness of 50 feet or more. Where the underlying Douglas shale is thin and the Snyderville is thick, the Toronto limestone has occasionally been misidentified as Haskell limestone. The thick Plattsmouth limestone overlies the Heebner. The Heumador shale and the Kereford limestone overlie the Plattsmouth; the Kereford varies considerably in thickness, probably as a result of intercyclical erosion.

The Clay Creek limestone member of the Kanwaka shale formation is an argillaceous limestone 5 feet thick in outcrops. It seems to increase in thickness in the subsurface, where in some wells, either by the increasingly calcareous character of the shale or by thickening of the limestone, it constitutes the greater part of the Kanwaka.

The Lecompton limestone formation appears in electric logs as a somewhat variable sequence of thin limestone and shale members dominated by the Beil and Avoca limestone members.

The Deer Creek limestone formation is most conspicuously represented by the Ozawkie and Ervine Creek limestones.

The Calhoun shale formation, which overlies the Deer Creek, thins toward the west, where the Deer Creek closely approaches the Topeka limestone formation.

The Topeka limestone formation consists of a sequence of six limestone members alternating with shale members. The thin upper limestone members are not everywhere distinguishable in electric logs, owing partly to erosion of the top of the Topeka or to nondeposition of the thin upper limestones toward the west. The two lower limestone members, the Curzon and Hartford members, are each 10 to 15 feet thick and are represented in nearly all electric logs. As a matter of expediency, the top of the Curzon limestone has been used as a datum, although some of the younger members of the formation are represented in many areas.

A comparison of the average thicknesses of the formations of the Shawnee group in outcrops in eastern Kansas and southeastern Nebraska (Table 12) reveals that with two exceptions all the formations thin northward, although the limestones thin much less than the shales. The Tecumseh and Calhoun shales are the exceptions to northward thinning. The maximum thickness of both these shales is reported in outcrops in the Kansas River valley, where the Tecumseh is 65 feet thick and the Calhoun is 45 feet thick. The outcrops of both are thinner north and south of this area (Moore, Frye, and Jewett, 1944, p. 178-179). In view of the not uncommon intercyclical erosion, which locally reduced the thickness of exposed limestones, it seems not unlikely that such unusual local increases in the thickness of clastic deposits are the result of leveling off of topographic relief at the beginning of a new cycle of sedimentation. The local thickening of shale formations may, however, be due to local synclinal warping or possibly to uneven sedimentation.

Like the Douglas, the Shawnee group thins on the crest of the Nemaha anticline. It is 400 feet thick in the Amerada No. 1 Elizabeth Enlow well in sec. 4, T. 11 S., R. 10 E., in the syncline to the east of the anticline; it is 310 feet thick in the Amerada No. 1 Mertz well in sec. 6, T. 11 S., R. 10 E., 2½ miles farther west near the crest of the anticline; and 280 feet thick in the Parker Oil Company No. 1 Bardwell well in sec. 26, T. 10 S., R. 9 E., near Zeandale. Westward into the Salina basin its thickness ranges from 270 to 290 feet. These thicknesses seem to indicate that, as during the deformation in Douglas time, the region east of the Nemaha anticline was subsiding faster than the region to the west but that there was no arching of the anticline.

There is overall thickening of the Shawnee group toward the southeast irrespective of differences resulting from local structural movements. The Shawnee group is 255 feet thick in sec. 15, T. 13 S., R. 17 W., on the crest of the Central Kansas uplift; it is 244 feet thick in sec. 10, T. 5 S., R. 10 W., but thickens to 305 feet in sec. 27, T. 19 S., R. 4 W., on the saddle between the Salina basin and the Sedgwick embayment; and it is 375 feet thick in sec. 31, T. 23 S., R. 10 E., on the western flank of the Cherokee basin.

The southeastward thickening of the Shawnee group is due mainly to the thickening of the shale deposits and only in minor degree to thickening of the limestones.

Wabaunsee Group

The formations of the Wabaunsee group, listed in Table 13 in descending sequence, have been differentiated in the outcrops in eastern Kansas and southeastern Nebraska. The thicknesses in Kansas are reported by Moore and others (1944, 1951) and those in southeastern Nebraska by Condra and Reed (1943).

The Wabaunsee group comprises a sequence of alternating limestones and shales. Most of the limestones are relatively thin but nearly all extend in outcrops from southeastern Nebraska to Oklahoma. On the outcrop, the Howard limestone in places is 30 feet thick, the Wakarusa reaches 18 feet, the Reading 15 feet, and the Dover 20 feet. In most places, however, the thicknesses of these limestones do not exceed 5 feet and in many places 2 or 3 feet.

The sum of the average thicknesses of all limestones of the Wabaunsee group, in the outcrops in Kansas, including the shale members of formations composed mainly of limestones, is only 104 feet, or about 20 percent of the total of the group. In outcrops, many of the shale units include sandy shales, and many include beds of sandstone. Streaks of coal, some of which are thick enough to have been mined near the outcrop, occur in nearly all the shales,

TABLE 13.—*Sequence and thickness of formations * of the Wabaunsee group*

	Range of thickness in outcrops in eastern Kansas, feet	Average thickness in outcrops in eastern Kansas, feet	Range of thickness in southeastern Nebraska, feet
Wabaunsee group			
Brownville limestone	2–8	5	2
Pony Creek shale	5–20	14	5
Caneyville limestone	21	21	11–13
French Creek shale	30	30	8
Jim Creek limestone	¼–2	1	1
Friedrich shale	15	15	41–44
Grandhaven limestone	10	10	
Dry shale	5–20	15	14
Dover limestone	2–20	10	2–5
Langdon shale	5–50	30	not reported
Maple Hill limestone	1–5	3	15
Wamego shale	6–25	17	not reported
Tarkio limestone	0–10	6	3–7
Willard shale	30–66	40	28–30
Elmont limestone	1–15	5	2–4
Harveyville shale	1–25	10	12–20
Reading limestone	2–15	6	3–5
Auburn shale	20–70	50	14–30
Wakarusa limestone	2–18	8	3–6
Soldier Creek shale	12–18	15	12–14
Burlingame limestone	4–16	9	20
Silver Lake shale	25	25	10–12
Rulo limestone	2	2	1–2
Cedarvale shale	25	25	19–20
Happy Hollow limestone	1–8	4	6–8
White Cloud shale	30–80	50	80
Howard limestone	8–30	13	3–7
Severy shale	75	75	22–29
Total		514	Aver. 369

* At a conference Oct. 17, 1955, attended by representatives of the State Geological Surveys of Kansas, Nebraska, Oklahoma, and Missouri and the United States Geological Survey, the thin stratigraphic units of the Wabaunsee group above the Howard limestone, heretofore listed as formations, were reduced to the rank of members and grouped in formations to which new names, not yet officially announced, are to be applied.

but coal is seldom recognized in washed samples from the subsurface. Thin discontinuous limestones are not uncommon in the shales, and thin limestones that probably appear as unnamed calcareous marine shale in outcrops are noted in the subsurface in some wells. On the other hand, some limestones reported in drillers logs are probably indurated shales. Some of the widely distributed limestones of the outcrops are only occasionally recognized and reported in sample logs, because they are thin and argillaceous. As a result there is considerable confusion and uncertainty in the identification of individual formations in both sample and drillers logs of many wells that penetrate the Wabaunsee group.

The electric logs reveal, more or less clearly, most of the thin named limestone units of the outcrops, but their multiplicity and the variations in the thickness of the intervening shale beds is a source of confusion. Some units seem to wedge out or to have been irregularly deposited, but where beds are represented only at random in electric logs, their absence is probably due to intercyclical erosion.

The Howard limestone, which is 20 feet thick in the Cherokee basin but in very few places elsewhere exceeds 10 feet, is present throughout the area. It is clearly identified in most electric logs as two limestone members, separated by a thin shale, but in some areas one of the limestone members is missing. The interval between the Topeka and the Howard is 85 feet in T. 20 S., R. 8 E., in the Cherokee basin but only 20 feet on the crest of the Central Kansas uplift.

The Happy Hollow limestone varies in thickness. Its distance above the Howard decreases westward. The Rulo limestone, above the Happy Hollow, is erratic in distribution and generally missing. The coal or black shale seen in outcrops of the Cedarville shale, between the Happy Hollow and the Rulo limestones, has also been noted in the samples from some wells. A red bed in the shale between these limestones is useful in local correlations of sample logs.

As the intervening shales become thinner toward the north and west, the thin limestones of the upper part of the Wabaunsee tend to fall into groups. The Burlingame and the Wakarusa approach each other, but they are missing in many wells in the Salina basin. Similarly the Elmont and Reading limestones draw closer together. A red shale between the Reading and the Wakarusa limestone has been helpful in identifying these limestones in sample logs.

The Grandhaven, Dover, Maple Hill, and Tarkio limestones appear as a group in some areas, although one or more of the limestones is missing in many wells. Samples of the Tarkio limestone are characterized by an abundance of exceptionally large fusulines. The Maple Hill limestone is thin and doubtfully present in the Salina basin. The Dover limestone, on the other hand, is persistent.

The limestones of the Wabaunsee group above the Dover are thin and where present are identified mainly by the intervals between them. A thin limestone that is present in most electric logs at a suitable interval above the Dover limestone is tentatively identified as the Brownville. Beds of sandstone and sandy shale are discontinuously interbedded in nearly all of the shale formations of the Wabaunsee.

The relation of the Wabaunsee group at the top of the Pennsylvanian System to the overlying Admire group at the base of the Permian System is obscure in the subsurface. The lower beds of the Admire, like the upper beds of the Wabaunsee, consist of sandy shale, sandstone, and thin interstratified limestone beds, none of which can be satisfactorily identified in the subsurface in either sample or electric logs. In outcrops in Lyon County, O'Connor (1953, p. 8-23) reported a complete sequence of upper Pennsylvanian and lower Permian rocks without encountering the pronounced disconformity represented by the Indian Creek sandstone, which was deposited in valleys eroded to a depth of 120 feet. These channels occur at several places in outcrops in Nebraska and eastern Kansas (Moore and others, 1951, p. 52). Harned and Chelikowsky (1945) report erosion of 250 feet of Wabaunsee rocks.

Most of the electric logs examined display a more or less normal sequence of upper Wabaunsee formations culminating in the Brownville limestone similar to the sequence of formations seen in outcrops in Lyon County. A few wells in T. 12 S., R. 2 W., and adjoining townships reveal a sequence of sandstone and sandy shale extending down to the horizon of the Dover limestone without limestone breaks.

The inference drawn from these observations is that at the end of Wabaunsee time the region was elevated high enough above sea level to allow the trenching of valleys possibly as much as 250 feet deep. Erosion, however, did not continue long enough to bring about the general dissection of the surface. As was the case of pre-Bonner Springs and other intercyclical exposures, the returning sea filled the eroded valleys with clastic sediments—at this time sand—and overflowed upon the only slightly dissected upland areas upon which the succeeding deposits of a new cycle of sedimentation were deposited.

It seems probable that in places the Brownville was still covered by Pennsylvanian shales upon which early Permian sediments of similar character were deposited. The thickness of the Wabaunsee rocks is in this sense indeterminate, but it can be approximated by using the top of the Brownville as a datum.

The average thickness of the Wabaunsee group in outcrops in the basin area of eastern Kansas is 514 feet. A composite section of the same sequence measured in southeastern Nebraska by Condra and Reed (1943) indicates a northward thinning of the Wabaunsee to 369 feet. In the subsurface in the Cherokee basin in sec. 30, T. 20 S., R. 10 E., the Wabaunsee is 485 feet thick. West of the Nemaha anticline on the divide between the Salina basin and the

Sedgwick embayment, in sec. 27, T. 19 S., R. 4 W., the Wabaunsee is 465 feet thick. It thins northward across the Salina basin to 360 feet in sec. 34, T. 2 S., R. 11 W., and in sec. 5, T. 5 S., R. 10 W. Northwestward on the crest of the Central Kansas uplift its thickness decreases from 355 feet in sec. 23, T. 15 S., R. 12 W., to 315 feet in sec. 6, T. 7 S., R. 20 W., where the Wabaunsee beds above the Dover seem to have been eroded during the hiatus preceding the Permian. The thickness in general decreases toward the northwest but is modified by local structural features and locally by pre-Permian erosion.

ROCKS OF PERMIAN AGE

The Permian rocks of Kansas are divided into the following series listed in descending order: Guadalupian, Leonardian, and Wolfcampian.

Permian rocks are separated from the Pennsylvanian by a low angular unconformity and an erosional surface of high relief in some areas. They are separated from the overlying Cretaceous by an angular unconformity representing a long hiatus, during which hundreds of feet of Permian rocks were eroded.

Wolfcampian Series

The Wolfcampian Series is divided into the following groups listed in descending sequence: Chase, Council Grove, and Admire.

Admire Group

The formations of the Admire group, listed in descending order in Table 14, have been differentiated in outcrops in eastern Kansas. The thicknesses at outcrops in eastern Kansas are reported by Moore and others (1944, 1951); those in southeastern Nebraska by Condra and Reed (1943, p. 36-37).

TABLE 14.—*Sequence and thickness of formations of the Admire group*

	Range of thickness in Kansas outcrops, feet	Average thickness in Kansas outcrops, feet	Range of thickness in southeastern Nebraska, feet
Admire group			
Hamlin shale	50	50	48–50
Five Point limestone	1–5	3	1–5
West Branch shale	10–30	20	30
Falls City limestone	3–10	7	9
Hawxby shale	12–40	30	10–12
Aspinwall limestone	1–8	5	1–3
Towle shale	15–135	30	10–50
Total		145	Aver. 134

The Admire group, exclusive of the basal sandstone, consists dominantly of shale, some of which is sandy. The limestone beds, although persistent, are thin and lack unique lithologic features that might identify them in the subsurface.

The Towle shale includes the Indian Cave sandstone member, which fills deep channels cut in the surface of the Pennsylvanian rocks during the hiatus between deposition of the Wabaunsee and Admire groups. Channels filled with Indian Cave sandstone 120 feet thick are exposed in outcrops. The sandstone is reported (Harned and Chelikowsky, 1945) to be in contact with the Auburn shale below the Reading limestone in Pottawatomie County, which fact would indicate a local depth of erosion of about 250 feet. In the subsurface the details of topography of the pre-Permian surface are not clearly revealed and give the impression of a surface only slightly dissected. Except in steep-sided channels filled with sand the basal beds of the Towle consist mainly of sandy or silty shale.

The Aspinwall limestone is the first persistent limestone above the base of the Admire. On account of the unconformity at the base of the Admire, the thickness of the Permian below the Aspinwall varies greatly. Comparison of the sequence from the Aspinwall to datum beds such as the Dover and Tarkio limestones, in the Wabaunsee below the unconformity, reveals a decrease in thickness toward the west or northwest. The regular thinning of this succession is the basis for the conclusion that regional deformation continued during the hiatus, in the same general pattern as during Pennsylvanian time, when the area was tilted by differential movements toward the southeast.

The Falls City and Five Point limestones, together with a lenticular limestone locally recognized in the intervening West Branch shale, appear in logs of wells in the Salina basin as a limestone sequence in which the shale partings are generally determinable only in electric logs.

That part of the Admire group above the Aspinwall limestone averages about 115 feet in thickness in outcrops in eastern Kansas, about 100 feet in southeastern Nebraska, and 90 feet in the Salina basin and on the Central Kansas uplift.

Council Grove Group

The formations of the Council Grove group, listed in descending order in Table 15, have been differentiated in outcrops in Kansas. The thicknesses at outcrops in Kansas are from Moore, Frye, and Jewett (1944, p. 165-168). Those for Nebraska are from Condra and Reed (1943, p. 33-36).

TABLE 15.—*Sequence and thickness of formations of the Council Grove group*

	Range of thickness in Kansas outcrops, feet	Average thickness in Kansas outcrops, feet	Average thickness in southeastern Nebraska, feet
Council Grove group			
Speiser shale	18–35	25	19
Funston limestone	5–11	8	8
Blue Rapids shale	16–25	20	22
Crouse limestone	10–13	12	11
Easly Creek shale	15	15	14
Bader limestone	18–25	23	24
Stearns shale	8–20	14	17
Beattie limestone	15–20	18	18
Eskridge shale	37	37	50
Grenola limestone	38	38	33
Roca shale	20	20	23
Red Eagle limestone	18–20	19	11
Johnson shale	16–25	20	19
Foraker limestone	50	50	46
Total		319	315

The alternation of well-defined limestones and shales of the Council Grove group is in sharp contrast to that of thin limestones and dominant shales of the Admire group. The group consists of equal proportions of shale, a large part of which is red, and of limestone, much of which is impure and shaly. There is seldom any doubt as to the identity and position of the Foraker and Grenola limestones or the Eskridge and Speiser shales. The limits of some of the intervening beds are obscure, partly because some of the limestones are soft and argillaceous and some of the shales are calcareous, and partly because such formations as the Funston, Crouse, Bader, and Beattie limestones consist of relatively thin limestone beds interstratified with shale members. The formations are more clearly identified in electric logs than in samples.

The Foraker limestone, at the base of the Council Grove group, consists of two more or less prominent limestone members separated by a calcareous shale containing fusulines in such abundance as to distinguish the Foraker from other formations, in which fusulines are less conspicuous. In electric logs the upper member is more prominent. The Foraker becomes more calcareous southward, and in the outcrops in southern Kansas and Oklahoma the middle shale member also becomes limestone. This formation contrasts with the limestones of the Pennsylvanian, most of which become argillaceous or interfinger with shale toward the south.

The Red Eagle limestone, like the Foraker, consists of upper and lower limestone members separated by a shale member and, like the Foraker, becomes a single limestone ledge in the outcrops in southern Kansas. In the outcrops it thins slightly toward the north. Although the Red Eagle is recognized in the subsurface, its limits are generally not clearly defined in sample logs, although well marked in electric logs.

The Grenola limestone can be identified in most sample logs. The upper member, the Neva limestone, is clearly defined, but the lower member, the Burr limestone, which is interstratified with shale, is obscure.

The Eskridge consists mainly of red shale, although it includes some gray shale. In some localities in the subsurface the shale is interstratified with calcareous beds. The Eskridge is consistently reported in all drillers logs and is easily recognized in sample logs. It is the most reliable datum bed in the lower Permian despite the fact that the Roca, Stearns, Easly Creek, and Speiser shales also include red shale. None of these shales is so consistently thick or so consistently red as the Eskridge. The Eskridge displays a characteristic pattern in electric logs.

The Beattie and Bader limestones, as represented in drillers logs, sample logs, and electric logs, are indistinct in many wells, probably because these formations and the intervening Stearns shale contain as much shale and impure limestone as pure limestone. However, the Cottonwood limestone, which includes numerous slender fusulines, overlies the Eskridge shale and is nearly always manifest.

The Easly Creek shale consists mainly of red and gray shale. It includes some gypsum near the base. This is the first appearance in the Permian of evaporites, which constitute a large proportion of the deposits of the upper part of the Permian.

Neither the Crouse limestone nor the Funston limestone is consistently recognized in sample logs, probably because they include much impure limestone and calcareous shale, but they are recognizable in most electric logs.

The Speiser shale consists of shale and thin beds of limestone. The lower part includes much red shale. It is generally revealed in logs as a red shale below the conspicuously cherty Wreford limestone of the Chase group.

The thickness of the Council Grove group is singularly constant. It averages about 319 feet in the outcrops in eastern Kansas and 315 feet in southeastern Nebraska. It is 290 feet in wells just west of the Nemaha anticline, 310 to 320 feet in the Salina basin, and 320 feet on the Central Kansas uplift, in T. 7 S., R. 20 W.

Chase Group

The formations of the Chase group, listed in descending order in Table 16, have been differentiated in outcrops in Kansas. The thicknesses of these formations at the outcrops are reported by Moore and others (1944, 1951). Those in Nebraska are reported by Condra and Reed (1943).

TABLE 16.—*Sequence and thickness of formations of the Chase group*

	Range of thickness in Kansas outcrops, feet	Average thickness in Kansas outcrops, feet	Average thickness in southeastern Nebraska, feet
Chase group			
Nolans limestone	22–40	34	28
Odell shale	20–40	30	34
Winfield limestone	28	28	21
Doyle shale	80	80	59
Barneston limestone	80–90	84	60
Matfield shale	60–90	78	62
Wreford limestone	30–40	35	30
Total		369	294

The Chase group consists of a sequence of alternating beds of thick limestone and shale. The limestones constitute approximately 50 percent of this group in outcrops. Northward into southeastern Nebraska the proportion of shale and limestone remains approximately the same, although both limestones and shales become thinner.

All the limestone formations of the Chase are cherty, especially the Wreford and the Florence limestone member at the base of the Barneston.

The Wreford limestone consists of two limestone beds separated by a shale bed. Because both limestone beds are consistently cherty in outcrops and in the subsurface, the Wreford is an excellent datum bed, although the formation is not everywhere conspicuous in electric logs.

The Matfield shale is varicolored. It includes the Kinney limestone member consisting of interstratified shale and thin limestone beds commonly represented only in electric logs.

The Barneston limestone includes the Florence limestone member at the base and the Fort Riley limestone member at the top separated by a thin gray calcareous shale member. The Florence limestone member is conspicuously cherty both at outcrops and in the subsurface. Careful search of samples from the Fort Riley or the Florence member almost always reveals fusulines, many of which in the Florence member are silicified. The Fort Riley limestone is noncherty and contains the youngest fusulines known in Kansas. The two conspicuously cherty beds, the Florence and the Wreford, are valuable markers in a sequence of limestone and shales whose identification might otherwise remain obscure. In electric logs the Barneston displays a characteristic pattern. For this reason its base has been used as a datum in drawing thickness maps; its top and the Nolans and Winfield are obscure in some areas. The expression of the Barneston in electric logs from wells on parts of the Central Kansas uplift is weak.

The Doyle shale is variegated and in part calcareous. The Towanda limestone member of the Doyle occurs 20 to 30 feet above its base. Fossils are rare in the outcrops. In the subsurface toward the northwest the Towanda becomes dolomitic and in Phillips County consists entirely of anhydrite.

The Winfield limestone in outcrops in northern Kansas consists of upper and lower limestone members separated by shale. Toward the northwest it becomes dolomitic. The lower member of the Winfield is cherty in outcrops, but chert is not present in all wells in the subsurface.

The Odell shale, like the other shales of the Chase group, is variegated, red predominating.

The Nolans limestone consists of two thin limestone beds at the base, generally recognized only in electric logs, and the more prominent and thicker Herington limestone at the top. The intervening shale member is calcareous and includes some limestone in outcrops in southern Kansas. The Nolans limestones thicken toward the northwest and grade into dolomite.

The limestones and shales of the Chase group seem to be somewhat more variable in thickness in the subsurface, as represented in well logs, than in outcrops. This is probably due more to imperfections in the logs and samples than to sharp fluctuations in the thickness of the formations, although these also may occur. Red shales are not uncommon in the upper Pennsylvanian, but they are increasingly prominent in the Council Grove group and make up a still larger proportion of the shales of the Chase group. Toward the northwest the limestones above the Barneston grade into dolomite, and some anhydrite begins to appear with the dolomite.

The total of the average thicknesses of formations in the Chase group in outcrops in Kansas is 369 feet. The average thickness of the Chase in southeastern Nebraska is 294 feet. The overall thickness of the Chase in northern McPherson County is 360 feet. In the Salina basin the Chase is 250 feet thick and on the crest of the Central Kansas uplift it is 240 feet thick. The Chase group thins toward the northwest in the familiar pattern of the Pennsylvanian and older Permian groups. There seems to have been little or no accentuation of the Salina basin or Central Kansas uplift in Chase time. The southward increase in limestone components contrasts with the tendency toward increase in shale in the older rocks.

Leonardian Series

The Leonardian Series is divided into the Nippewalla group above and the Sumner group below.

Sumner Group

The following formations of the Sumner group, listed in descending order, have been differentiated by the Kansas Geological Survey in outcrops in east-central Kansas (Moore and others, 1944, 1951): Stone Corral dolomite, Ninnescah shale, and Wellington formation.

Other groupings of these rocks have been made. Norton (1939) placed the Ninnescah and Stone Corral at the base of the redbed sequence of the "Cimarron Series" described by Cragin (1896). The base of the Wellington was at one time placed at the Hollenberg limestone member of the Wellington, about 50 feet above the Herington limestone member of the Nolans limestone, which is now listed as the uppermost formation of the Chase group.

The Sumner group comprises a sequence of beds of evaporite and shale containing a few local, more or less discontinuous thin limestone beds of variable character. The upper part consists mainly of shale, and the lower part in central Kansas consists chiefly of shale, anhydrite, and salt.

Wellington formation.—A detailed study of the outcrops of the Wellington formation in south-central Kansas was made by Ver Wiebe (1937), who traced several beds of limestone in the outcrops. The Hollenberg is the only one of these limestones recognized with confidence in the subsurface of the Salina basin, but others may be present. In the subsurface, Ver Wiebe distinguished five zones, based on lithologic changes, which he correlated with the outcrops. These five zones in descending order are: "upper gray beds", "red beds", "middle gray beds", "salt beds", and "anhydrite beds". These zones are all recognizable in the subsurface in the Salina basin.

The accurate separation of these units is rendered difficult by the transitional contacts between some of the units. The base of the Wellington at the top of the Nolans limestone is a definite datum, but the contact of the anhydrite beds with the overlying salt beds is transitional. The contact of the "salt beds" with the "middle gray beds", which, like the salt bed, include much anhydrite, is also transitional. Even the color distinctions of the three upper units are elusive because over broad areas toward the west some of the "middle gray beds" seem to grade into the increasingly thick "red beds" zone.

Thick beds of salt in the Hutchinson salt member are revealed by gamma ray logs and inferentially by comparison in electric logs. It is probable that mixtures of salt and anhydrite as well as alternating thin beds of salt and anhydrite are expressed as anhydrite in electric logs. The contact of the "upper gray beds" of the Wellington with the red shales of the Ninnescah is abrupt and definite in sample logs but is not apparent in electric logs.

It is convenient to divide the Wellington formation into three members: The "anhydrite beds" of Ver Wiebe at the bottom, the "salt beds" or Hutchinson salt member in the middle, and an unnamed member at the top comprising the "middle gray beds", "red beds", and "upper gray beds" of Ver Wiebe's classification.

The "anhydrite beds" at the base of the Wellington (known also as the Pearl shale) consist of a sequence of gray shale alternating with anhydrite beds. In the Salina basin it includes the Hollenberg limestone member, 20 to 40 feet above the base, and the overlying beds of shale and anhydrite 130 to 150 feet thick. Toward the west anhydrite predominates. The Hollenberg limestone of the central area of the Salina basin becomes irregularly dolomitic toward the west and probably grades northwestward into one of the anhydrite beds of this zone. Some varicolored shale occurs in this zone below the Hollenberg.

The Hutchinson salt member, the "salt beds" of Ver Wiebe, is an evaporite zone consisting of salt (halite) interstratified with beds and laminae of anhydrite and probably coprecipitated mixtures of both. The salt beds are thickest in Russell, Ellsworth, Rice, and Reno Counties, and they thin somewhat irregularly toward the margin of the basin where, together with the anhydrite, they interfinger with shale washed into the basin from the low border areas. The "salt zone" becomes thinner in southern Kansas and extends into northern Oklahoma. It should normally crop out in a belt trending south from Osage and Saline Counties, but the salt and most of the associated anhydrite beds have been dissolved by surface waters for a distance of 20 to 30 miles down dip. In the areas of outcrops, the removal of the salt has allowed the overlying cover of insoluble rocks to slump in a zone of irregular dips and confused bedding.

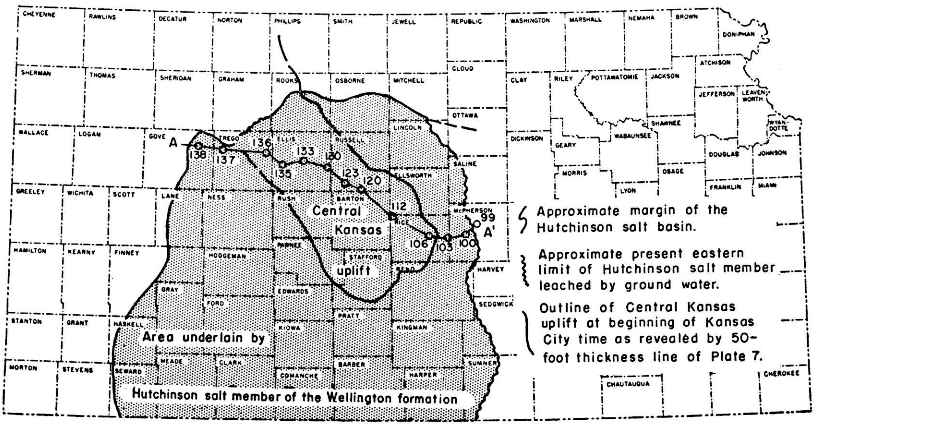


FIG. 15.—Map showing (*a*) approximate area underlain by Hutchinson salt member of Wellington formation in Kansas in relation to Central Kansas uplift as outlined by 50-foot thickness line of pre-Kansas City Pennsylvanian rocks, and (*b*) trend of cross section A-A′ of Figure 16.

Figure 15 shows the approximate limits of the salt basin, after Bass (1926), modified by the addition of more recent data from Norton (1939), the Gulf Oil Corporation, and Botinelly (1948). The cross section (Fig. 16) after Kellett (1932) shows that the combined thickness of Wellington rocks above and below the salt sequence (exclusive of the Hutchinson salt member) is essentially constant whatever the thickness of the salt. The salt basin thus must have been formed by downwarping of the area after the deposition of Ver Wiebe's "anhydrite beds" and ceased to develop after the deposition of the salt. Inasmuch as the thickest salt beds, and therefore the area of greatest downwarping, overlie, in part, the crest of the previously rising Central Kansas uplift, as shown in Figure 15, it is clear that arching of the uplift was interrupted at this time, if not earlier, by the downwarping of the salt basin. There seems to be no evidence to indicate later arching of the Central Kansas uplift as such, although local parallel secondary anticlines were developed in the area later.

The cross section (Fig. 16) shows the lenticular character of the salt sequence and the attitude of the salt and overlying beds at

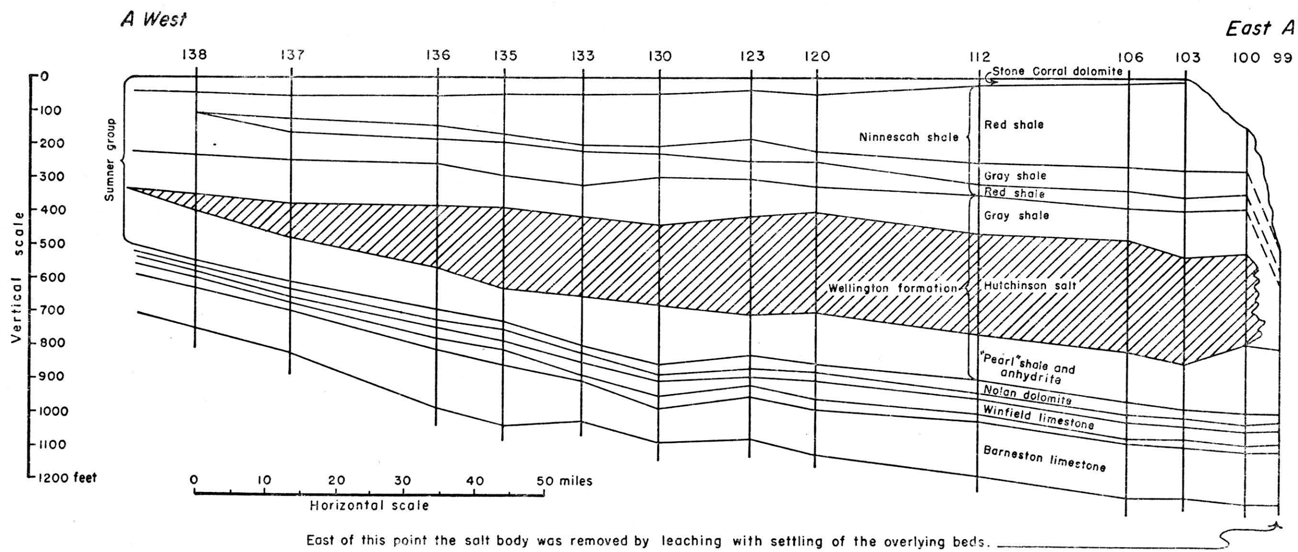


FIG. 16.—Cross section, west to east, of Sumner group, Leonardian Series, on line A-A′ of Figure 15, showing lenticular character of Hutchinson salt member of Wellington shale (after Kellett, 1932). Salt at eastern end of cross section has been dissolved down dip from outcrop area. Well numbers correspond to those of the original cross section by Kellett (1932).

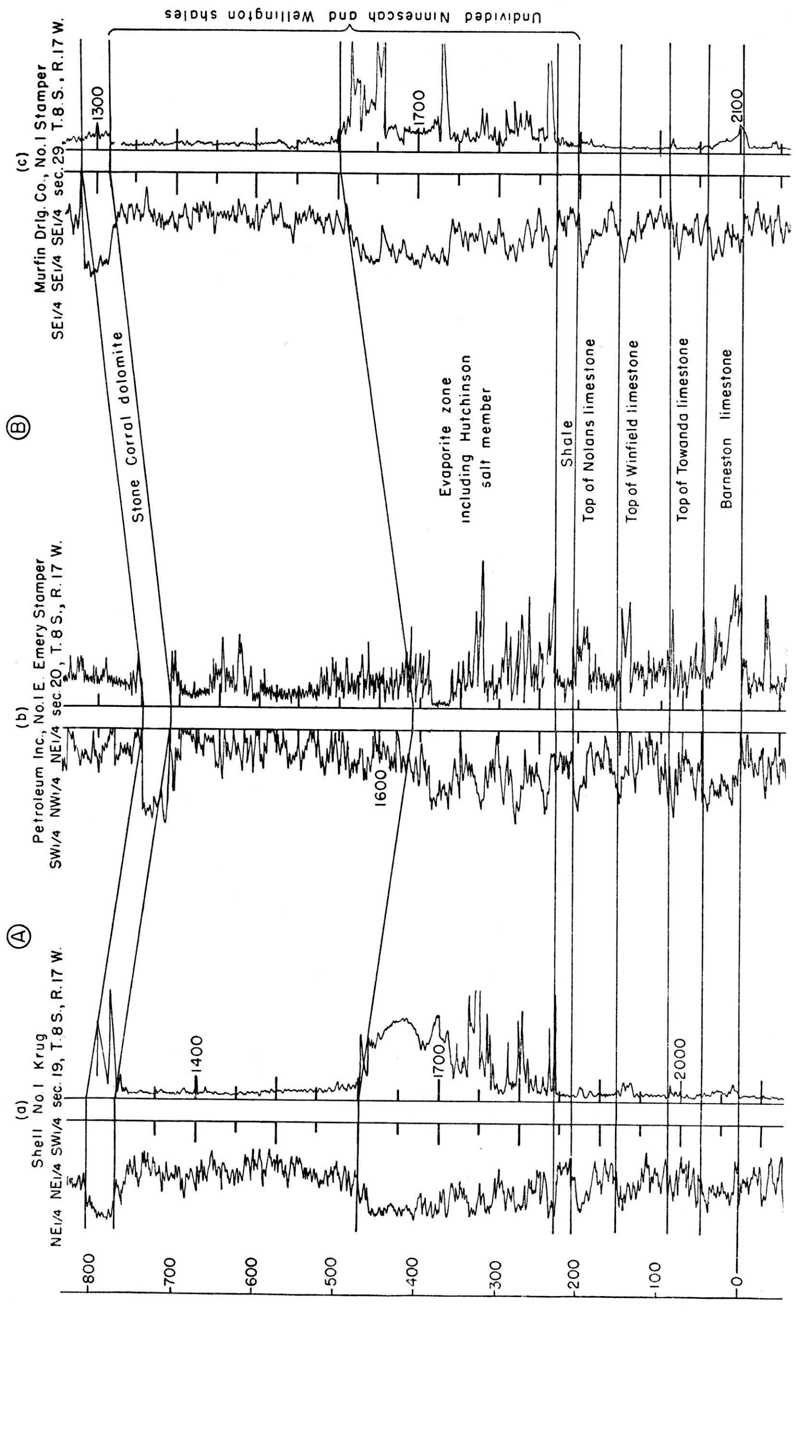
the end of Sumner time along the line of the Kellett cross section (1932), which traverses the central part of the salt lens. Inasmuch as the unleached salt areas show no definite thinning toward the southeast, it seems probable that at least half the original salt body has been lost by erosion and leaching.

The outcrops of the upper member of the Wellington are unsatisfactory on account of their disturbed subsidence into the zone of salt solution. The alternation of gray and red shales, which is only vaguely revealed by samples from rotary wells, is well displayed in samples from cable tools wells.

Ver Wiebe's "middle gray beds" unit at the base of the upper member consists mainly of gray shale interbedded with anhydrite, especially near the base. It normally overlies the Hutchinson salt, but outside the salt area this unit cannot be clearly separated from the anhydrite beds of the Pearl shale, although it includes much less anhydrite and some streaks of red shale. It some wells salt molds occur in anhydrite cuttings from above the salt member. The thickness of the "middle gray beds" unit approximates 110 feet in T. 18 S., R. 10 W.

The "red beds" unit of Ver Wiebe consists of red shale but little or no anhydrite. In T. 18 S., R. 10 W., it is 40 feet thick. The "upper gray beds" unit consists mainly of soft gray clay and blue shale; it includes less anhydrite than the base of the member. The thin Milan limestone seen on the outcrops at the top of this member has not been identified in the subsurface. The thickness in T. 18 S., R. 10 W., is 60 feet. The upper member of the Wellington thins toward the north and west, and the thicknesses of the three characteristic units likewise thin from 110 feet, 40 feet, and 60 feet, respectively, in T. 18 S., R. 10 W., to 40 feet, 10 feet, and 45 feet in T. 8 S., R. 18 W., as reported in drillers logs of wells drilled with cable tools. The separation of upper Wellington shales from the overlying Ninnescah shale is impracticable in electric logs.

Salt Flow.—Correlation of electric logs reveals that the thickness of the evaporite zone including the Hutchinson salt member varies sharply from place to place, as illustrated by the electric logs reproduced in Figure 17. Detailed comparison of these electric logs of wells in the southwest quarter of T. 8 S., R. 17 W., (Fig. 18A) in Rooks County shows that between well *b* in the SW NW NE sec. 20, and well *a* in the NW NW SW sec. 19, a distance of 1¼ miles (line A of Fig. 18A), the thickness of the evaporite


(a) Shell No. 1 Krug NE1/4 NE1/4 SW1/4 sec. 19, T. 8 S., R. 17 W.
(b) Petroleum Inc., No. 1 E. Emery Stamper SW1/4 NW1/4 NE1/4 sec. 20, T. 8 S., R. 17 W.
(c) Murfin Drlg. Co., No. 1 Stamper SE1/4 SE1/4 SE1/4 sec. 29, T. 8 S., R. 17 W.
A
B
Undivided Ninnescah and Wellington shales
Stone Corral dolomite
Evaporite zone including Hutchinson salt member
Shale
Top of Nolans limestone
Top of Winfield limestone
Top of Towanda limestone
Barneston limestone
1300
1400
1600
1700
1700
2000
2100
800
700
600
500
400
300
200
100
0

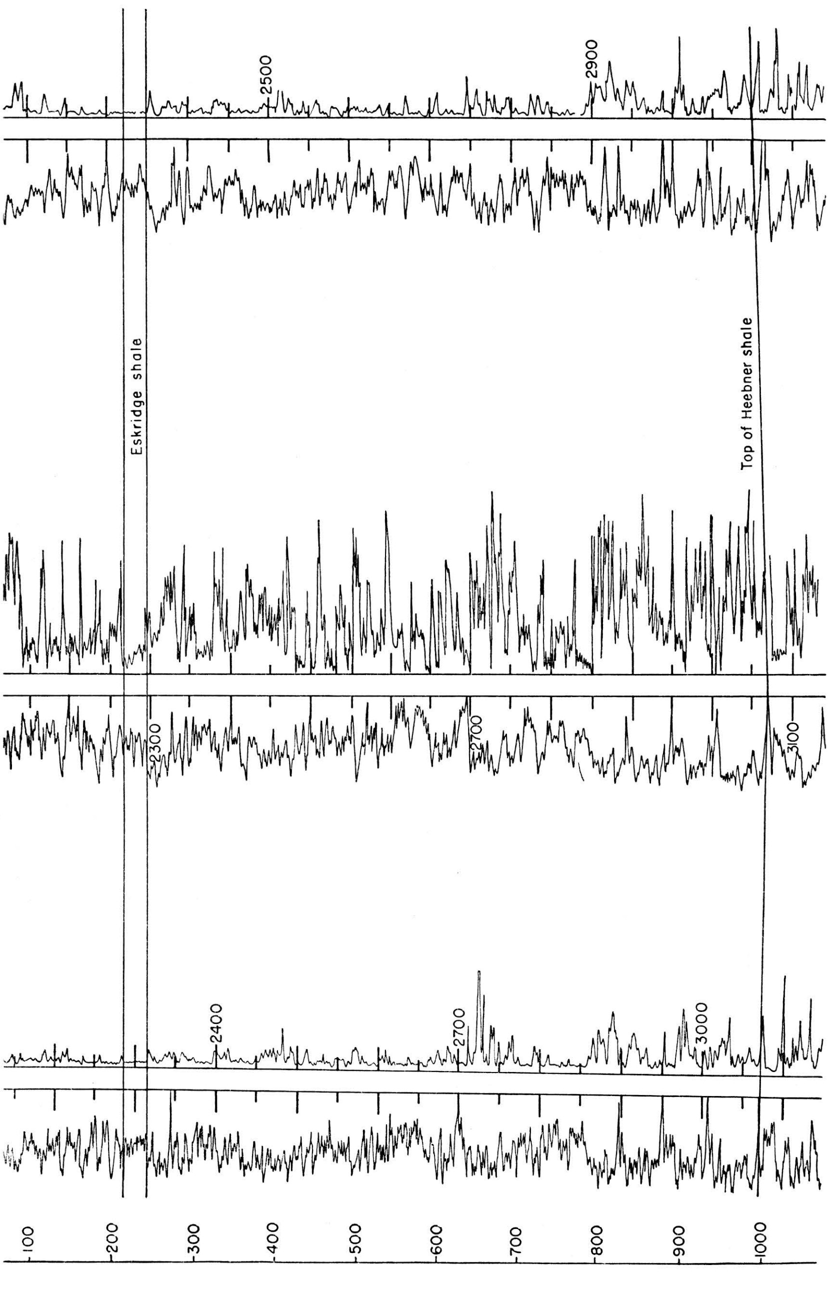
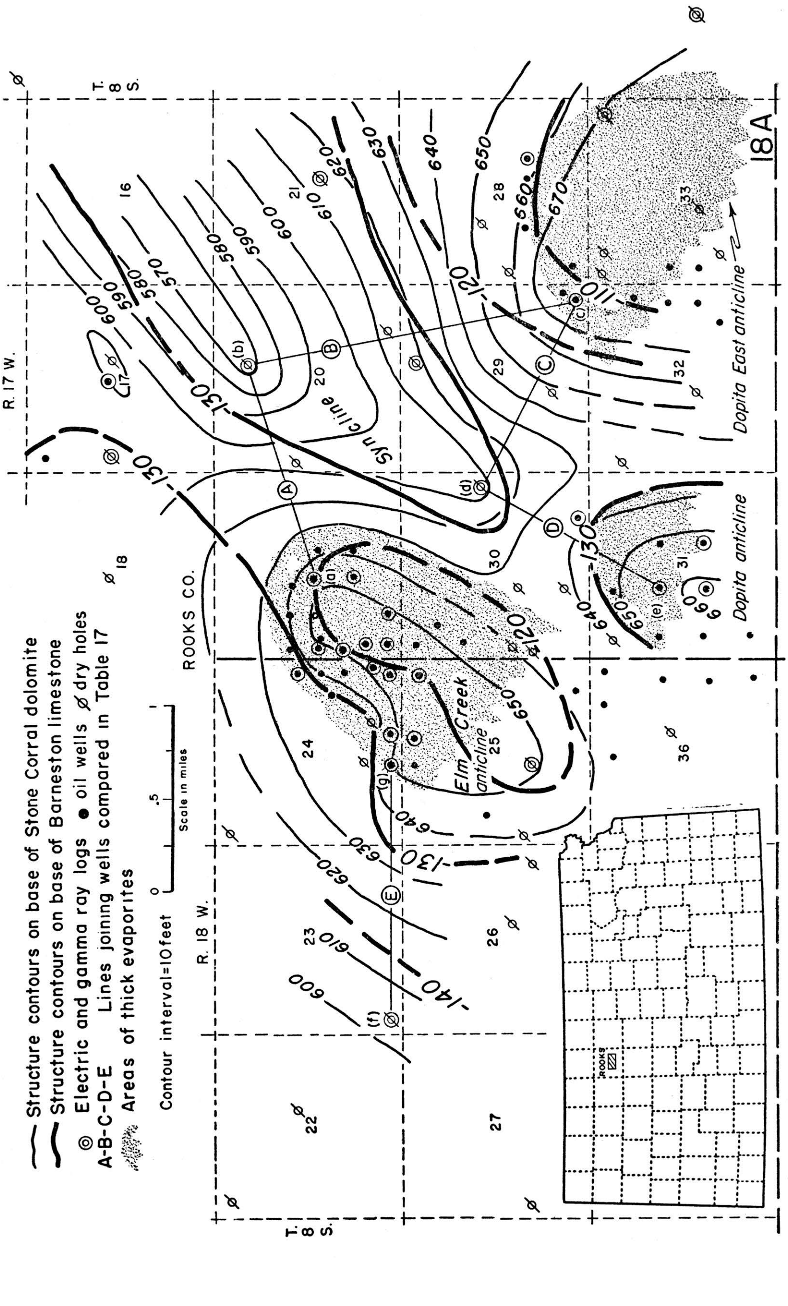


FIG. 17.—Correlation of electric logs (*a*), (*b*), and (*c*) of Figure 18 showing abrupt thickening of evaporite zone including Hutchinson salt member of Wellington formation.


Structure contours on base of Stone Corral dolomite
Structure contours on base of Barneston limestone
Electric and gamma ray logs ● oil wells ⌀ dry holes
A-B-C-D-E Lines joining wells compared in Table 17
Areas of thick evaporites
Contour interval=10 feet
Scale in miles
0 .5 1
ROOKS CO.
R. 17 W.
R. 18 W.
T. 8 S.
Syncline
Elm Creek anticline
Dopita anticline
Dopita East anticline
ROOKS
18A

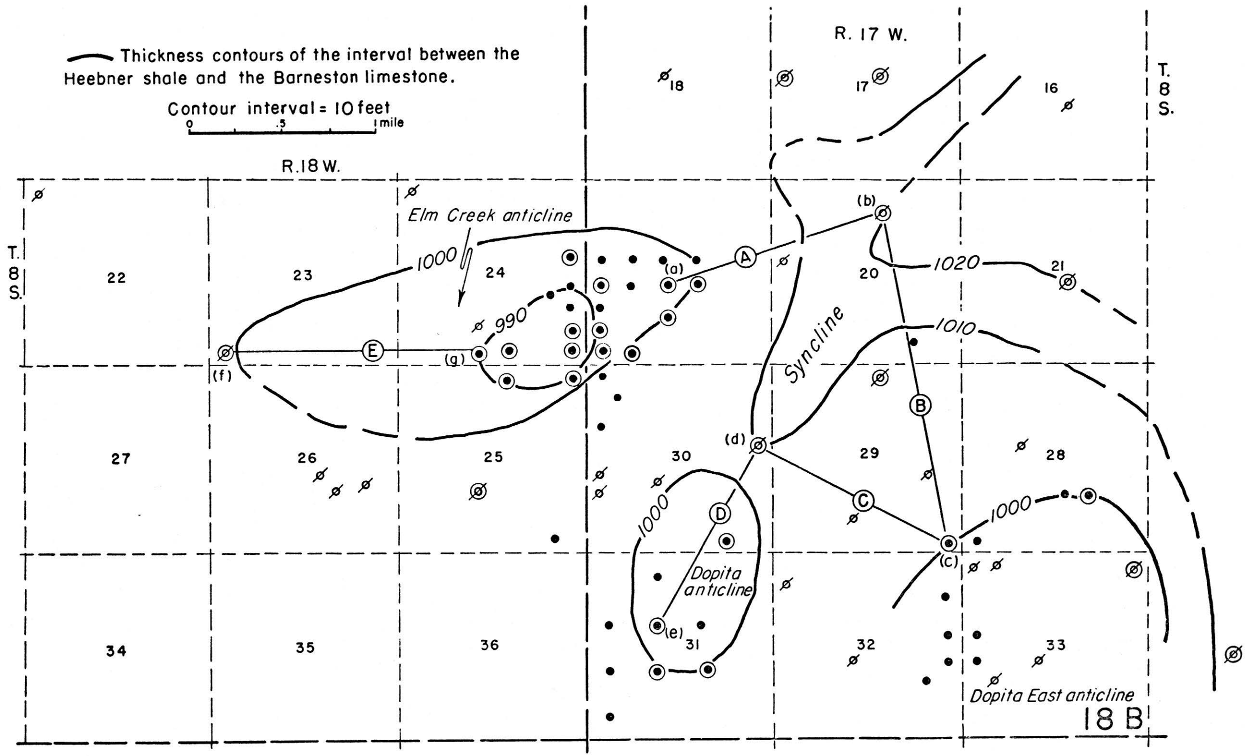


FIG. 18.—Maps of parts of T. 8 S., R. 17 and 18 W., Rooks County, showing structure. **A.** Shows (*a*) present structure of base of Stone Corral dolomite by 10-foot structure contours, (*b*) structure of base of Barneston limestone by 10-foot structure contours, and (*c*) areas of thick evaporites. **B.** Shows structure of Heebner shale in same area in Barneston time by 10-foot isopachous lines of interval between Heebner shale and Barneston limestone. The structure was similar to the structures in **A** but of lower relief.

zone increases 58 feet; between well *b* in the SW NW NE sec. 20 and well *c* in the SE¼ sec. 29, a distance of 1¾ miles (line B), the thickness of the evaporite zone increases 88 feet. Similar variations between other wells are indicated in Table 17.

It was at first conjectured that the downwarping of the evaporite basin produced local depressed areas in which abnormally thick evaporites accumulated. Closer study showed that the areas of thick evaporites are anticlinal areas.

Figure 18A shows the structure of the base of the Stone Corral dolomite, the structure of the base of the Barneston, and areas of thickened evaporites. The map is based entirely on electric logs, but producing wells and dry holes in the area are also shown. This figure shows the close association of thick evaporites with anticlinal structure. Table 17 shows the relation of the thickening of the salt zone to the structure of the Stone Corral and Barneston on the lines A, B, C, D, and E of Figure 18A. It will be noted that the difference between the structural relief of the Stone Corral and Barneston equals the increase in thickness of the salt zone.

The Barneston limestone and the Heebner shale are dependable datum beds throughout vast areas in Kansas. A thickness map of the interval between them reveals with considerable accuracy the deformation of the Heebner shale at the beginning of Barneston time. Figure 18B is a thickness map of this interval based on the same electric logs that were used in Figure 18A. The map shows structural features similar to those of the Barneston and Stone Corral but of lower structural relief. It indicates that the anticlinal movements revealed by the structure map of the Barneston were already taking form before Barneston time.

The interval from the base of the Barneston to the base of the evaporites is almost uniform in this area, and the thickness of the shale between the top of the evaporites and the Stone Corral is equally constant, irrespective of the thickness of the evaporite as shown in Figure 17. It is clear from Table 17 that the difference between the structure of the Barneston limestone and the structure of the Stone Corral dolomite is due entirely to the thickening of evaporites in structurally high areas.

The concept of abnormal accumulation of salt in local depressions requires the unlikely condition that the areas in T. 8 S., R. 17 W., which were already slightly anticlinal in Barneston time, became synclinal during the deposition of the salt and that later the same

TABLE 17.—*Variations in thickness of evaporite zone between wells shown in Fig. 18A, and relation of thickness to structural relief of Stone Corral.*

Line	Between wells	Distance, miles	Structural relief of Stone Corral	Structural relief of Barneston	Difference in structural relief	Increase in thickness of evaporite zone	Structural relief of Heebner shale in Barneston time (Fig. 18B)
A	b—a	1¼	75 feet	17 feet	58 feet	58 feet	17 feet
B	b—c	1¾	112 feet	24 feet	88 feet	88 feet	20 feet
C	d—c	1⅛	71 feet	26 feet	45 feet	45 feet	10 feet
D	d—e	1⅛	48 feet	23 feet	25 feet	25 feet	15 feet
E	f—g	1⅜	44 feet	28 feet	16 feet	16 feet	10 feet

areas became again anticlinal. It seems more likely that the thickening of the salt beds and associated anhydrite is the result of the movement of the plastic evaporites toward yielding anticlinal areas.

The uniformity of the thickness of the shale interval between the Stone Corral and the evaporite zone leads to the conclusion that the folding that induced the salt flow did not take place until after the deposition of the Stone Corral dolomite and probably not until after Permian time. The thinning of the Heebner—Barneston sequence indicates that minor movement on the anticlines shown in Figure 18A began before Barneston time and that the ultimate post-Permian movements that caused the readjustment of the salt in this area were a revival of earlier minor folds. It is probable, however, that anticlines newly initiated after Permian time would induce similar exaggerated structure above the salt in the same way.

Although anticlines at the horizon of the Stone Corral are a valid indication of structure in the older rocks, they are not an accurate measure of the structural relief to be expected in formations below the Hutchinson salt beds. The intrusion of salt on anticlines in the area of salt deposition such as the Elm Creek anticline of Figure 18A exaggerates the structural relief of the pre-Wellington formation from which oil is produced in this area.

Because of its tendency to adjust to local structural stresses, the Hutchinson salt member is probably similarly variable in thickness in other areas of salt deposition as yet not studied. The thickness of the Hutchinson salt member ranges regionally from a thin edge at the margin of the basin to more than 500 feet in parts of Russell County and more than 400 feet in Edwards County.

Ninnescah shale.—The Ninnescah shale was named by Norton (1939) and described from outcrops in Kingman and Reno Counties as consisting predominantly of red shale with minor amounts of gray shale and thin beds of impure limestone and calcareous sand. None of the datum beds recognized in southern Kansas has been identified in the subsurface of the Salina basin, where the Ninnescah, although it includes some red sandstone, consists in most areas almost entirely of red, partly silty shale.

The thickness of the Ninnescah shale as reported in logs of wells drilled by cable tools decreases somewhat irregularly toward the north from about 300 feet in east-central Rice County to 200 feet in southeastern Smith County in the Salina basin. It seems to thicken westward to about 265 feet in Phillips County.

Stone Corral dolomite.—This formation of dolomite and anhydrite is the youngest deposit of the Sumner group. It was formerly known as the Cimarron anhydrite, but was more appropriately named by Norton (1939) for an enclosure and fort built of this rock where the Santa Fe Trail crossed Little Arkansas River. It varies in lithology from place to place along the outcrops and in the subsurface. In some places dolomite predominates. At others the Stone Corral is interstratified with thin shale members and anhydrite, and in some places it consists of anhydrite alone. In view of the lack of lithologic continuity it would be more appropriate to designate the sequence as the Stone Corral formation rather than the approved term Stone Corral dolomite. The formation is 30 to 50 feet thick in Pratt, Stafford, and Rice Counties. Southeastward in Kingman County it thins to 10 feet, but it shows no consistent trends of thinning in any direction within the area mapped except toward the north in Smith County, where its expression in electric logs is weak or missing. Where the Stone Corral is thin it consists almost entirely of anhydrite. From outcrop studies, Norton (1939) concluded that the Stone Corral is conformable on the underlying Ninnescah, but suggested that there may be a minor unconformity at its top.

Nippewalla Group

The following formations of the Nippewalla group, in descending sequence, have been differentiated in outcrops in southern Kansas: Dog Creek shale, Blaine formation, Flowerpot shale, Cedar Hills sandstone, Salt Plain formation, and Harper sandstone.

All the formations of this group above the Harper sandstone, as well as the entire overlying Guadalupian Series, were eroded from the Salina basin during the hiatus preceding Cretaceous deposition.

In outcrops the Harper sandstone is divided into the Chikaskia and Kingman sandstone members, both of which consist chiefly of red sandstone broken by thin beds of red shale. Subsurface cross sections published by Norton (1939) show that the sandstone members, so prominent in the outcrops, are less conspicuous and more irregular in the subsurface. This seeming change may be due in large part to the fact that grains of disintegrated sandstone are so generally lost in the cuttings from rotary wells. In the subsurface of the western part of the Salina basin the Stone Corral is overlain by red shale, sandy shale, and sandy micaceous shale. The sandstone members of the Harper sandstone, although they may be present, cannot be differentiated in the cuttings of the wells examined. Rocks classified as of Harper age have a thickness of 300 feet in sec. 13, T. 5 S., R. 18 W. These rocks may include some undifferentiated red shales in the base of the Salt Plain formation. Eastward the sandy shales of the Harper are truncated and are overlain by Cretaceous rocks.

ROCKS OF CRETACEOUS AGE

The following Cretaceous rocks, listed in descending sequence, have been differentiated in outcrops in central and western Kansas:

- Cretaceous System
  - Gulfian Series
    - Montana group
      - Pierre shale
    - Colorado group
      - Niobrara chalk
      - Carlile shale
      - Greenhorn limestone
      - Graneros shale
      - Dakota formation
  - Comanchean Series
    - Kiowa shale
    - Cheyenne sandstone

The Cretaceous rocks overlie the truncated outcrops of the Permian rocks. Permian formations younger than the Harper sandstone, and all rocks of Triassic and Jurassic age are absent in the area under discussion. The younger Permian rocks of southwestern Kansas must have spread across this part of Kansas but were later eroded. Triassic rocks, separated from the Permian by unconformities, were also deposited in the area but now reach only to the western margin of Phillips County and the northwestern corner of Rooks County (Lee and Merriam, 1954.)

The land surface across which the Cretaceous sea advanced had a mature relief sloping at a low angle toward the west. The local relief of this surface within a single county was at least 50 feet. The regional relief referred to a Cretaceous datum increases more than 300 feet from west to east as shown by the Kellett cross section (1932). Cretaceous rocks are 567 feet thick in sec. 13, T. 11 S., R. 17 W., in Ellis County, but increase to more than 1000 feet on the western border of the map.

The Niobrara chalk and older Cretaceous rocks are exposed on the western border of the Salina basin. Eastward these rocks and the younger formations of the Cretaceous were removed by erosion; only the Dakota sandstone extends as far east as Washington County.

Detailed studies of the Cretaceous rocks in central Kansas have been made by several geologists of the State Geological Survey.

Plummer and Romary (1942) examined outcrops of the Dakota formation from Ellsworth County northeast to Washington County by means of open cuts for the purpose of studying the clays. Frye and Brazil (1943) studied the Cretaceous section in outcrops and in test holes drilled in Ellis and Russell Counties in connection with ground-water studies. Swineford and Williams (1945) examined cuttings from many test wells in Russell County in the study of salt-water disposal problems. These reports, all of which deal with the Cretaceous within or bordering the Salina basin, have been drawn upon for descriptions of the subsurface character and thickness of the Cretaceous formations.

Comanchean Series

The Cheyenne sandstone is the basal deposit of the Cretaceous throughout most of western Kansas. It is reported to overlie the Morrison shale of Jurassic age in Norton County by Norton (1939) and in Gove County by Kellett (1932), but east of these areas the Cheyenne rests on the Permian. The Cheyenne sandstone consists predominantly of buff to light-gray sandstone with small amounts of shale and siltstone. These clastic materials were derived in large part from exposed Permian rocks, reworked by wave action of the eastwardly advancing sea. Their characteristics in Russell County (Swineford and Williams, 1945, p. 130) and probably elsewhere vary with the character of the rocks exposed on the underlying surface and in bordering areas. The sediments are characterized by relatively coarse sand, absence of shell fragments, and absence of mica in the coarser facies. The Cheyenne has a thickness of 200 feet in Ellis County. In Russell County, it ranges in thickness from a featheredge, where it overlaps upon topographic highs, to 62 feet. It wedges out on the pre-Cretaceous surface east of Russell County.

The Kiowa shale consists of gray to black thinly laminated shale, interbedded with thin lenticular bodies of white siltstone and sandstone. Locally the sandstone lentils are as much as 20 feet thick. Shell fragments and carbonaceous material are common. The sandstone bodies are slightly glauconitic, generally micaceous, and less coarse in grain than the sand in the overlying Dakota. The thickness of the Kiowa in Russell County ranges from 50 to 100 feet. The thinner deposits overlie hills of the Permian surface. The Kiowa overlaps the Cheyenne and thins out toward the east. It is absent in outcrops north of Ottawa County.

5—4029

Gulfian Series

Colorado Group

The Dakota formation is composed dominantly of varicolored clay. It includes some siltstone, but very little shale. Fine-grained and coarse-grained sandstones are numerous but discontinuous. The sandstones are mainly channel deposits, and only a few can be traced from place to place. Despite their prominence in outcrops, the sandstones constitute only a minor element in the Dakota sequence. Siderite in concretions and pellets is abundant. Hematite, limonite, and carbonaceous material of various kinds are common. Lateral variation of all lithologic types is pronounced. Plummer and Romary (1942) report that the sediments are nonmarine and were seemingly deposited near sea level under conditions somewhat analogous to present conditions in the lower Mississippi delta. Careful measurements by Plummer and Romary (1942, fig. 4) at intervals from Ellis County northeast to Washington County reveal thicknesses of 270 feet in southern Ottawa County, where the Dakota overlies the Kiowa shale, and 190 feet in Washington County, where the Dakota overlaps upon the Permian. The thickness of the Dakota in Russell County ranges from 213 to 300 feet.

The Graneros shale in Russell County consists of dark-gray to brownish-black noncalcareous shale interbedded with thin beds of fine-grained glauconitic sandstone. It is distinguished from the overlying Greenhorn limestone by the absence in the Graneros shale of calcareous material and the foraminifers *Globigerina* common in the Greenhorn, and by the presence of sheets of sandstone and siltstone. It is distinguished from the underlying Dakota by the occurrence of glauconite and pyrite in the Graneros, and by the absence of kaolin and siderite (Swineford and Williams, 1945). The thickness of the Graneros shale in Russell County ranges from 14 to 40 feet.

The Greenhorn limestone in Russell County consists of alternating beds of limestone and chalky shale. The upper limestone beds are chalky and not readily separated lithologically from the overlying Carlile shale. The lower beds are crystalline. Shell fragments and *Globigerina* are common in the cuttings. Some bentonite occurs in the lower part of the formation. The Greenhorn limestone is 85 to 110 feet thick in Ellis and Russell Counties.

The Carlile shale is divided into three dissimilar lithologic units. The lower third, the Fairport chalky shale member, about 100 feet thick, consists of thin beds of chalky limestone distinguished with difficulty from the similar upper beds of the Greenhorn limestone.

Most of the upper two-thirds of the Carlile (the Blue Hill shale member, 175 to 215 feet thick) is made up of gray-black fissile shale. At the top lies a sandstone member, the Codell sandstone, a few inches to 20 feet thick. Bass (1926a) reports that the Carlile shale in Ellis County is approximately 300 feet thick.

The Niobrara chalk is a thick sequence of alternating chalk and marl. The lower member, the Fort Hays limestone, averages about 55 feet in thickness and includes chalky limestone somewhat harder than the overlying rocks. The upper member, the Smoky Hill limestone, ranges from 450 to 700 feet in thickness. It consists mainly of chalk and marl interstratified with thin beds of chalky shale and numerous partings of bentonite as much as 6 inches thick. The total thickness of the Niobrara is 500 to 750 feet in the subsurface of Logan and Wallace Counties, where it is overlain by the Pierre shale. Only the lower part of the Niobrara is represented on the western border of the Salina basin, where its thickness is less than 300 feet.

The condition of available rotary samples of the Cretaceous on the western margin of the Salina basin does not permit accurate determination of the contacts of the various Cretaceous formations.

ROCKS OF TERTIARY AND QUATERNARY AGE

Tertiary and Quaternary deposits of continental origin occur in many localities in central Kansas. Rocks of Pliocene and early Pleistocene age, consisting of alluvial deposits of sand, silt, and clay, are as much as 180 feet thick in parts of McPherson County and adjacent counties (Moore, Frye, and Jewett, 1944, p. 148).

Quaternary deposits of Pleistocene and Recent age are also present in central Kansas. Sand, gravel, silt, and clay as much as 150 feet thick occur in places in McPherson and Republic Counties and fill pre-glacial or early Pleistocene valleys. Glacial till mantles the uplands in the northeastern part of the Salina basin. Loess deposits cover extensive upland areas throughout the region. High-level terraces of different ages border ancient and recent valleys.

STRUCTURAL DEVELOPMENT OF THE SALINA BASIN

The structural development of the Salina basin has been studied by means of a series of maps that represent the thickness of individual formations and of sequences of formations in and adjacent to the basin.

The interpretation of structural movements from thickness maps is based on the following concept: if a sequence of rocks is deposited on an originally flat surface, and if this sequence of rocks is warped and folded before the later development of a second flat horizontal surface, the variations in thickness of the rocks between the two surfaces will reveal the amount and place of the deformation (Lee, 1954) that had taken place when the second surface was still undisturbed.

The deformation of the first surface may precede or follow the deposition of the overlying rocks or occur during the deposition of the sequence. The presence of a marked unconformity or disconformity within the sequence will not confuse the objective, which is the determination of the total amount of deformation between the development of the first and second reference planes, *provided the pattern of deformation remains unchanged.*

The accuracy with which the thickness maps record the structural movements is dependent upon the degree to which the surfaces above and below the sequence approach base level, whether by deposition or erosion. A depositional surface generally presents a nearly perfect horizontal datum plane. Most of the eroded surfaces of the area have little topographic relief, and thus resemble peneplains. The topographic relief of most of the surfaces utilized in preparing the thickness maps is negligible in comparison with the regional variations of thickness that are due to structural movement.

The topographic relief of some surfaces, however, introduces erratic configuration of the thickness lines. Valleys on imperfectly beveled surfaces are generally recognizable on account of thinning of beds of one sequence accompanied by a compensating increase in thickness of the overlying beds. On the other hand, hills are revealed by local thickening of the lower sequence accompanied by a compensating thinning of the overlying formation. Minor structural and topographic features are generally not revealed by 50-foot thickness lines. In oil fields where many wells have been drilled, the local structural features are commonly expressed by thickness lines drawn at small intervals, and in some fields the study of thickness lines combined with detailed stratigraphic studies reveals local topographic features on the eroded surfaces (Lee and Payne, 1944, p. 105, fig. 14).

Beveling of stratified rocks is recognized by the thinning and wedging out of successive units directly below an unconformity.

A progressive development of anticlinal features is indicated by the localized thinning of two or more consecutive units in the same area. In such an area, it must be assumed that the surface at the locality was either progressively arched during the deposition of several units or that exposure and erosion caused thinning of the consecutive units in the same place. The latter, although not impossible, is unlikely. Similarly, progressive synclinal movement is indicated by the localized thickening of two or more consecutive units in the same locality.

In the Salina basin area, three principal periods of folding of distinctly different character are revealed by the thickness maps and two others are revealed by structure maps. The first period of folding affected the rocks lying between the Precambrian surface and the base of the St. Peter sandstone. The second occurred during the deposition of the rocks between the St. Peter sandstone and the base of the Mississippian. The third period of folding began early in Mississippian time, developed maximum intensity between the end of Mississippian time and the beginning of Pennsylvanian deposition, and continued with decreasing structural vigor through most of the Permian. The fourth occurred between Permian and Cretaceous times, and the fifth between Cretaceous time and the present.

PRE-SIMPSON FOLDING

The thickness of rocks between the Precambrian surface and the base of the St. Peter sandstone is shown in Plate 1 by lines drawn at 100-foot intervals of thickness. A relatively level Precambrian surface is indicated by the wide distribution of the Bonneterre dolomite, which is underlain in most areas by the Lamotte sandstone. Precambrian hills of considerable height have been revealed in several places by drilling. McQueen (1931, pl. 10) reports Gunter sandstone overlying a Precambrian hill in Vernon County, Missouri, a relationship that implies an elevation of about 600 feet above the general Precambrian surface. Similar hills have been found by drilling in northeastern Oklahoma (Ireland, 1955), southeastern Kansas, and on the Central Kansas uplift (Walters, 1946). The thickness of the Arbuckle above such hills has been ignored in drawing the thickness maps, and only those wells that have penetrated the Bonneterre have been utilized.

The upper surface of the Arbuckle, upon which the St. Peter sandstone was deposited, is exposed in parts of northern Missouri, where it was drained by shallow channels. Inasmuch as the thickness of the St. Peter in wells of the area is rarely less than 50 feet or as much as 100 feet, the topographic relief of the surface was relatively low. Scattered wells in northwestern Missouri and northeastern Kansas, however, have revealed local thicknesses of St. Peter sandstone as great as 403 feet (Lee, Grohskopf, Reed, and Hershey, 1946, sheet 1). These exceptional increases in the thickness of the St. Peter sandstone seem to indicate a material lowering of the ground-water level and the development of sink holes or possibly deep incised drainage valleys. In either case an uplift of the region of at least 400 feet is implied before subsidence and deposition of the St. Peter sandstone upon an otherwise truncated surface.

A map showing the thickness of the Arbuckle in northern Missouri and northeastern Kansas (Lee, Grohskopf, Reed, and Hershey, 1946, sheet 1) indicates a subsiding basin, the Ozark basin, extending northward from central Missouri into eastern Iowa, and a broad structural arch, the Southeast Nebraska arch, trending south from southeast Nebraska into eastern Kansas, more or less parallel to the contemporaneous Ozark basin.

In southern Missouri, where the St. Peter has been eroded, a thickness map of rocks between the top of the Roubidoux and the Precambrian (Lee, 1943, fig. 10) reveals that the Ozark basin was already an active structural feature before Roubidoux time.

Because of the scanty data, the configuration of the thickness lines on Plate 1 is of necessity only an approximation. The top of the Lamotte would have provided a more nearly horizontal datum, but this surface is not reported in old records, which log only the top of the Precambrian. The thickness map therefore records the structural deformation and in addition the local topographic relief of the Precambrian surface, which in places may have projected above the level of Lamotte deposition. Wells drilled into recognizable Precambrian hills and those in areas from which the overlying Simpson rocks were later eroded have been ignored in drawing thickness lines for the determination of regional structure. The small number of wells available and the distances between them eliminate local detail. The map, therefore, illustrates only in generalized form the regional deformation of the Precambrian plain at the beginning of Simpson time.

Similarly the cross sections, although based on examination of samples and insoluble residues in the Kansas area, do not pretend to depict the local irregularities of the formations, or hills or other topographic features, but only the regional relations of the stratigraphic sequence to the structural features revealed by the thickness maps.

Plate 1 shows the Southeast Nebraska arch, from parts of which the St. Peter or Simpson rocks were later eroded, and a flanking syncline extending northwest from Reno County to Rooks County. The data are inadequate to define the basin with complete accuracy, but the evidence from available wells in which the Simpson and Bonneterre are both present seems to indicate that the axis of the basin trended northwest into the area that later formed a part of the Central Kansas uplift. Enough evidence is available to indicate that the Central Kansas uplift, as such, was not yet a structural feature. The map suggests also that the south end of the Southeast Nebraska arch tended to flatten toward the south and merge with the southerly sloping monocline of Oklahoma.

Cross section A-A′ of Plate 1 extends across the synclinal area in Stafford and Rice Counties toward the crest of the Southeast Nebraska arch and shows the beveling of the Arbuckle formations before the deposition of the St. Peter sandstone or other Simpson rocks.

The wells of cross section B-B′ of Figure 3 are correlated on the top of the Roubidoux formation in the absence of the Simpson. The cross section extends across the Ozark basin of southern Missouri into southeastern Kansas, thence along the southern extension of the Southeast Nebraska arch to T. 11 S., R. 18 W., in the structural basin southwest of the arch.

The Missouri part of the cross section is based on McQueen's report (1931), the only available data. The overlap of the Roubidoux upon pre-Roubidoux rocks in eastern Kansas is based on the examination and interpretation by the writer of the somewhat inadequate samples and residues in the files of the State Geological Survey, as described in the section on stratigraphy.

The disappearance toward the west of the Davis, Derby and Doe Run, and Potosi is interpreted as overlap of the Eminence on the gradually rising surface of the Bonneterre, although other unconformities may exist. The Eminence in turn is overlapped by the Gasconade toward the west. Farther west, the Roubidoux overlaps the eroded surface of the Gasconade, and still further northwest it overlies the Bonneterre. The southern extension of the Southeast Nebraska arch is not reflected on the cross section for lack of a critically located well. The thickness map shows the arch to be considerably flattened on the line of the cross section.

Intermittent oscillatory movement was more or less continual throughout the deposition of the Arbuckle as is shown by the numerous indications of shallow water and minor exposure in outcrops of Arbuckle formations in the Ozarks. There seem to have been four principal movements of uplift and erosion represented by (a) the overlap of Eminence on Bonneterre in well 8 of cross section B-B′ of Figure 3; (b) the overlap of Gasconade from Eminence to Bonneterre in well 6; (c) the overlap of Roubidoux from Gasconade to Bonneterre in wells 6, 5, and 4; and (d) the final beveling of the whole sequence of Arbuckle formations and overlap by the Simpson as shown in cross section A-A′ of Plate 1. The uplifts and bevelings that preceded deposition of the Roubidoux and, later, of the Simpson seem to have been the most important.

DEVELOPMENT OF NORTH KANSAS BASIN

After St. Peter time a broad area in southeastern Nebraska and northeastern Kansas known as the North Kansas basin, which had previously been a positive area (the Southeast Nebraska arch), began a long period of differential subsidence. Also at this time the Ozark region of Missouri rose, and the Chautauqua arch and the Central Kansas uplift began their upward movement (Lee, 1943; Lee, Grohskopf, Reed, and Hershey, 1946).

The deformation of these structural features in post-St. Peter time was intermittent and occurred both during periods of sedimentation and during periods of emergence. In some areas the re-elevated surface was eroded without deformation; in others, surfaces of low relief truncated strata previously warped and re-elevated.

Deformation of Rocks of SIMPSON Age

Evidence of deformation between the deposition of the St. Peter and the Platteville is obscure in the Salina basin area. The area seems to have remained more or less static after the deposition of the St. Peter sandstone, for during the hiatus between the St. Peter and the Platteville several thick formations separated from one another by unconformities and aggregating about 900 feet in thickness were deposited in a subsiding basin in southeastern Missouri.

The Platteville is unconformable with both the underlying St.

Peter and the overlying Viola. Its thickness is therefore irregular, although neither surface shows pronounced topographic relief. The Platteville thickens northward as shown in cross section A-A' of Plate 2, which records the beginning of subsidence of the North Kansas basin.

The southward thickening of the Simpson in Oklahoma south of the Chautauqua arch implies major subsidence of that area.

Deformation of VIOLA—MAQUOKETA Sequence

Although a hiatus exists between the Simpson and the Viola, the wide distribution of the basal noncherty zone of the Viola indicates that the surface of the Simpson was one of very low relief. The upper surface of the Viola was broadly dissected by prè-Maquoketa erosion, as indicated by the cross sections of Figures 5, 6, 7, and 8. Despite the stronger erosion in the southwestern part of the area, the northerly increase in the thickness of the Viola is greater than the topographic relief of the pre-Maquoketa surface, as shown graphically in cross section A-A' of Plate 2. The effect of Maquoketa deposition was to level off the inequalities of the Viola surface and present an almost level surface to Silurian deposition. The thinning from north to south of the Viola—Maquoketa sequence is the measure of the subsidence of the North Kansas basin during the corresponding time interval. On the line of cross section A-A' of Figure 4 the subsidence was 165 feet greater at the site of well 11 than at well 5 in a distance of 105 miles.

Deformation of SILURIAN Rocks

The Silurian is essentially conformable with the Maquoketa. At the end of Silurian time, the whole region was elevated above sea level, probably by a series of differential and oscillatory movements accompanied by regional warping. During the ensuing erosion most of the surface was reduced to a nearly flat plain, but in some areas the surface was broken by broad hills as much as 80 feet high. As a result, as indicated in cross section A-A' of Plate 2, the thickness of the Silurian is not a mathematically accurate gage of the structural movements that occurred before deposition of the first beds of the Devonian. The consistent thickening of the Silurian rocks toward the center of the North Kansas basin (cross section A-A' of Pl. 2 and Fig. 4), however, clearly demonstrates that the North Kansas basin continued to subside either during the deposition of the Silurian, as seems probable from cross section A-A′ of Plate 3, or certainly preceding Devonian deposition, or both.

Cross section A-A′ of Plate 3 indicates that, from the first deposition of the Silurian rocks until the end of the pre-Devonian erosion, the North Kansas basin subsided about 350 feet more at the site of well 18 than at well 8. In the central part of the basin the subsidence was even greater.

Overall Deformation Between ARBUCKLE and DEVONIAN Rocks

Plate 2 shows the thickness of the interval between the base of the Simpson and the base of the Devonian, and also the pre-Devonian areal geology. On the pre-Devonian surface the Viola and Maquoketa rocks cropped out in broad belts flanking the Silurian. In sec. 12, T. 25 S., R. 5 E., the Devonian overlies the Simpson. This relation was probably general elsewhere in the southeast part of the area before the Devonian was removed by pre-Chattanooga erosion.

Deformation of DEVONIAN Rocks

The Devonian rocks are confined between unconformable surfaces of considerable relief. Plate 3 shows the thickness of the surviving Devonian limestone. Disregarding the obvious effect of the McPherson Valley in removing and thinning the Devonian in that area, it is obvious that the Devonian rocks follow, although irregularly, the pattern of thickening towards the North Kansas basin exhibited by the older formations. Again disregarding the McPherson Valley, it is evident (cross sections, Pl. 3, 4, and 5) that the northward thickening of the Devonian over broad areas exceeds the topographic relief.

During the deposition of the Devonian rocks on the post-Silurian truncated surface, the North Kansas basin continued to subside. After the deposition of Devonian limestone, the region was again raised, and although deeply eroded locally, the surface was again irregularly beveled by pre-Chattanooga erosion.

Deformation of CHATTANOOGA and BOICE Shales

Plate 4 shows the thickness of the combined Chattanooga and Boice shales. The thickness of this shale sequence in the Salina basin is more expressive of the topography of the pre-Chattanooga surface than of the structural developments. The pre-Chattanooga valley, which is revealed by the meanderings of the thickness lines in McPherson and Marion Counties and in the adjoining counties to the south and east, was eroded on the beveled surface of the Devonian rocks. The wedging out of the shales on the western, northern, and eastern margins of the shale area is, however, the result of beveling at the end of Mississippian time and is thus not related to structural movements or to the topography that developed between pre-Chattanooga erosion and the deposition of the Mississippian limestones.

Outside the pre-Chattanooga valley and the areas of westward and northward thinning of the shales, there is a gradual thickening toward the northeast in the direction of the deeper part of the North Kansas basin. This thickening is more significant when taken in connection with broader areas, including the Forest City basin (Lee, 1940, pl. 4; Lee, Grohskopf, Reed, and Hershey, 1946).

Overall Deformation Between Base of SIMPSON and Top of CHATTANOOGA

Plate 5 shows the thickness of rocks between the base of the St. Peter sandstone and the top of the Chattanooga—Boice shale sequence and reveals the deformation that took place during the corresponding time interval. The extent of this deformation represents the total of the separate increments of deformation indicated in Plates 2 to 4. The post-Devonian anticlinal arch in Harvey County, revealed by cross section B-B′ of Figure 19, is also clearly shown on Plate 5. Its northerly trend is approximately parallel to the Nemaha anticline. Plate 5 reveals also that the subsidence of the North Kansas basin amounted to at least 1300 feet below the flank of the Chautauqua arch within the area mapped. The total downwarping of the bottom of the North Kansas basin below the crest of the Chautauqua arch was considerably greater and may have reach 2000 feet during this interval.

DEVELOPMENT OF NEMAHA ANTICLINE AND SALINA BASIN

Deformation During MISSISSIPPIAN Time

As pointed out in the discussion of the stratigraphy of the Chattanooga—Boice shale sequence, the surface at its upper contact with Mississippian limestones was exceptionally level. The first deposits upon this surface were Kinderhookian limestones. In southeastern Kansas they consist of correlatives of the Chouteau and Sedalia limestones, both of which thicken northward from a featheredge

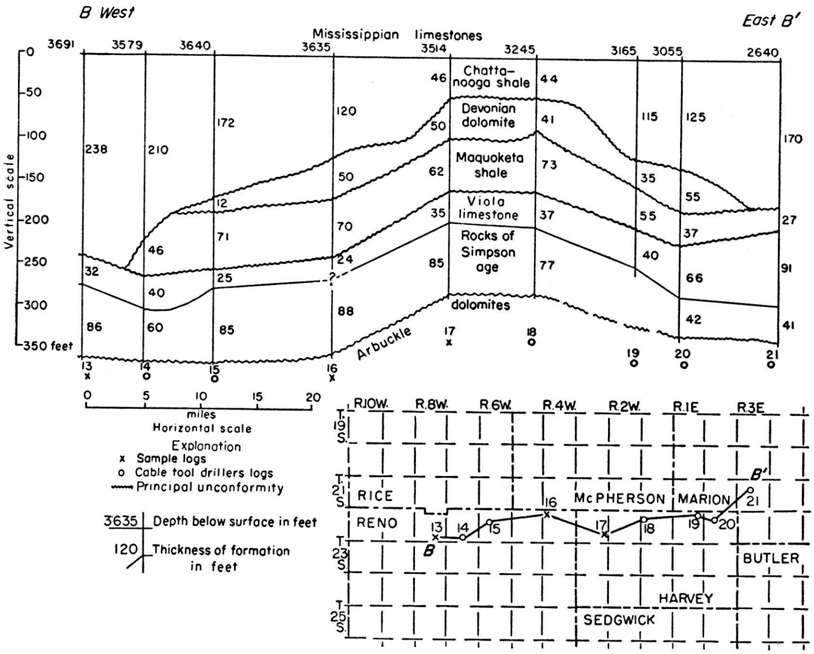


FIG. 19.—Cross section, west to east, across Reno and Harvey Counties, on line B-B′ of inset and Plate 5, showing pre-Chattanooga anticline at wells 17 and 18 (after Leatherock, 1948, fig. 9).

near the Kansas—Oklahoma border to 245 feet in central Iowa, where the Kinderhookian Hampton formation occupies a position corresponding to the Chouteau and Sedalia (Laudon, 1931).

The gradual northward thickening of the Kinderhookian formations from southeastern Kansas north to central Iowa, as shown in cross section A of Figure 20, reveals that during Kinderhookian time and at its close central Iowa was subsiding and southeastern Kansas was stationary or was being slightly elevated. At the end of Kinderhookian time the entire region was raised above sea level, and during a period of relative stability the formations were beveled as is illustrated diagrammatically in cross-section A of Figure 20. With the advent of Osagian time, the beveled surface seems to have been tilted southward, for the earliest Osagian deposit, the St. Joe limestone, wedges out northward. The later Osagian formations, the Reeds Spring, Burlington, and Keokuk limestones, and the Meramecian "Warsaw", Spergen, and St. Louis limestones overlap in succession northward on Kinderhookian limestones, as shown diagrammatically in cross section B of Figure 20. The differential

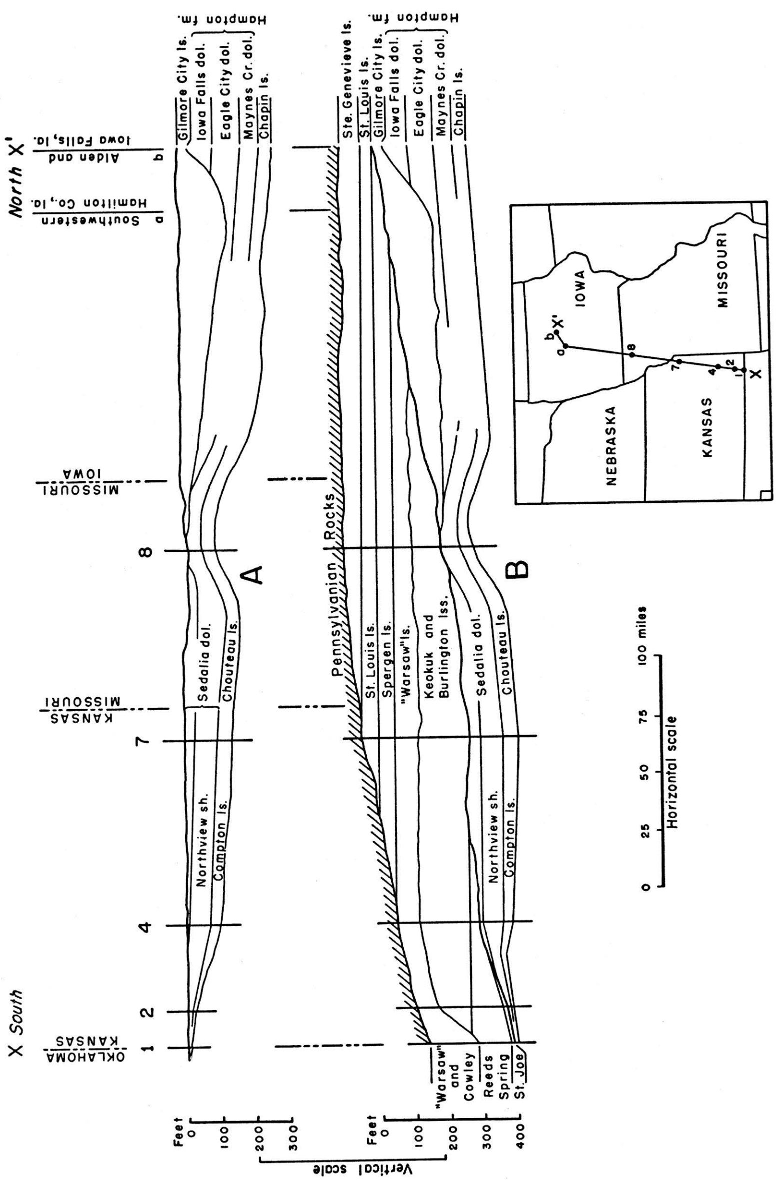


FIG. 20.—Diagrammatic cross sections from southeastern Kansas to central Iowa, showing northerly thickening of Kinderhookian limestones and northerly thinning and overlap of younger Mississippian formations. Compare with Figure 13.

tilting of the surface toward the south, which began before St. Joe time and must have been more or less continuous during the long period of overlap, kept the Kinderhookian rocks of Iowa above sea level. Although the surface probably was seldom raised much above sea level, some erosion of the Kinderhookian rocks of Iowa must have occurred during Osagian time. Figure 20 shows the structural relations of the Mississippian rocks east of the axis of the Nemaha anticline, in an area that was already beginning to subside in early Mississippian time.

Figure 13 shows the relation of Kinderhookian and younger Mississippian formations west of the Nemaha anticline in the Salina basin. The wells are correlated on the contact between the Reeds Spring and Burlington limestones. It will be noted that the only Kinderhookian limestones represented are the Gilmore City limestone and the upper member of the Sedalia dolomite. The absence of the lower member of the Sedalia and the restricted Chouteau of Moore (1928) (the Compton limestone of southwestern Missouri) is the result of movements before or during Kinderhookian time (not Chattanooga) that raised the area west of the Nemaha axis. This initial movement of the Nemaha anticline confined the older Kinderhookian limestones to the subsiding basin to the east.

As in the area east of the Nemaha axis, the Kinderhookian limestones thicken appreciably toward the north and wedge out toward the south, where outliers of the upper Sedalia member lie unconformably below the Gilmore City or below the St. Joe limestone, as shown in wells 10 and 12 of the cross section of Figure 13. Figure 13 shows that the Osagian formations in this area also thicken toward the south and unconformably overlap the Kinderhookian rocks toward the north. These phenomena reveal subsidence toward the north during Kinderhookian time and beveling at the end of Kinderhookian time, followed by a gradual rising of the surface toward the north during Osagian and Meramecian time in the same sequence of movements as that which affected the area east of the Nemaha anticline.

The distribution of the several formations of the Mississippian is shown in Figures 12A and 12B. The distribution of the St. Joe and Reeds Spring in Figure 12B indicates that these formations overlapped upon the flank of the incipient Nemaha anticline, which seems to have begun the separation of the Forest City and Salina basins as early as Osagian time. Of the Osagian formations, only the Burlington—Keokuk sequence extended across the Central Kansas uplift and the rising Nemaha anticline. The sequence was beveled by post-Mississippian erosion. The greater thickness of the Mississippian limestones below the Short Creek oölite member of the Keokuk (Lee, 1940, p. 63, pl. 6, cross section E-F′) east of the anticline than west of it also reveals displacement along the Nemaha axis before the deposition of the Short Creek oölite. There were thus at least two types of deformation going on contemporaneously during Mississippian time: (1) initial movements along the Nemaha anticline, whose maximum development occurred at the end of Mississippian deposition; and (2) progressive tilting of the region from south to north during Kinderhookian time and later tilting in the opposite direction.

Study of a cross section from Meade County to Smith County, Kansas, (Lee, 1953, fig. 2) suggests that minor development of the Central Kansas uplift occurred during or before Mississippian time but that the principal deformation occurred at the end.

Deformation at the End of MISSISSIPPIAN Time

Plate 6 shows the thickness of the Mississippian rocks and the areal geology at the beginning of Pennsylvanian deposition. The principal structural movements at the end of Mississippian time in this area affected the Nemaha anticline, the Central Kansas uplift, the Forest City basin, and the Salina basin.

The deformation of the Mississippian limestones was probably brought about by differential movements during which erosion of the gradually emerging surface kept pace with its elevation. In conformity with this concept, it is assumed that the rocks were beveled by submarine or subareal erosion as fast as they were elevated, that the surface was rarely much above sea level, and that minor beveling was going on intermittently during the whole period of elevation as well as at the end.

Before the invasion of the Pennsylvanian sea the beveled surface was re-elevated, deformed again by differential movement, and subjected to relatively brief and intermittent erosion. A broad shallow valley was eroded on the beveled surface of the Mississippian limestones in the Forest City basin during an early Pennsylvanian period of exposure. In consequence, the expression of structure by thickness lines in that area is modified by topographic relief (Lee, Grohskopf, Reed, and Hershey, 1946, sheets 5 and 6). This valley, which is mainly outside the area under consideration, is revealed by a local thickening of the Pennsylvanian rocks accompanied by a corresponding thinning of the upper Mississippian formations in the same locality.

In the Salina basin local shallow channels or possibly sink holes have been noted. Errors in interpretation of structure due to such topographic irregularities have been eliminated in some degree by including with the Mississippian sequence the cherty conglomerate at the base of the Pennsylvanian, for the top of the conglomerate, which consisted of reworked residual debris, was more nearly level than the eroded surface of the Mississippian. The use of this convention in mapping the thickness of the Mississippian introduces a difficulty as the border of the Mississippian is approached. In areas where the cherty Pennsylvanian basal conglomerate overlaps into areas underlain by rocks older than the Mississippian, its top loses its value as a Mississippian datum. Only those wells in which Mississippian limestone underlies the conglomerate are regarded as significant in estimating the degree of structural movement. The limit of the actual Mississippian is therefore vague where the differentiation of Mississippian residual chert from Pennsylvanian conglomerate becomes uncertain.

The Nemaha anticline is the most striking of the new structural features produced in eastern Kansas by post-Mississippian folding. It extends with varying structural relief from a point near Omaha, Nebraska, southwestward beyond Oklahoma City, Oklahoma. Throughout its length the eastern limb of the anticline is notably steeper than the western limb. The northern end of the anticline was raised so high that the erosional beveling in northeastern Kansas exposed Precambrian rocks on the crest and truncated the pre-Pennsylvanian rocks in parallel belts on its flanks. Toward the south, where the structural relief decreases, the Mississippian limestones were only partly eroded from its crest except at places of exceptional deformation.

The progressive development of the Nemaha anticline is illustrated in Figure 21, which includes a series of wells drilled by the Amerada Petroleum Corporation in T. 11 S., R. 10 E., at approximately one-mile intervals on the east limb of the anticline. Cross section A shows the arching of the pre-Pennsylvanian formations after post-Mississippian beveling; cross section B shows the deformation at the end of Lansing time, and cross section C the present deformation. The impulse to assume faulting on the east limb of the anticline is checked by redrafting cross section C as cross section D with equal vertical and horizontal scales.

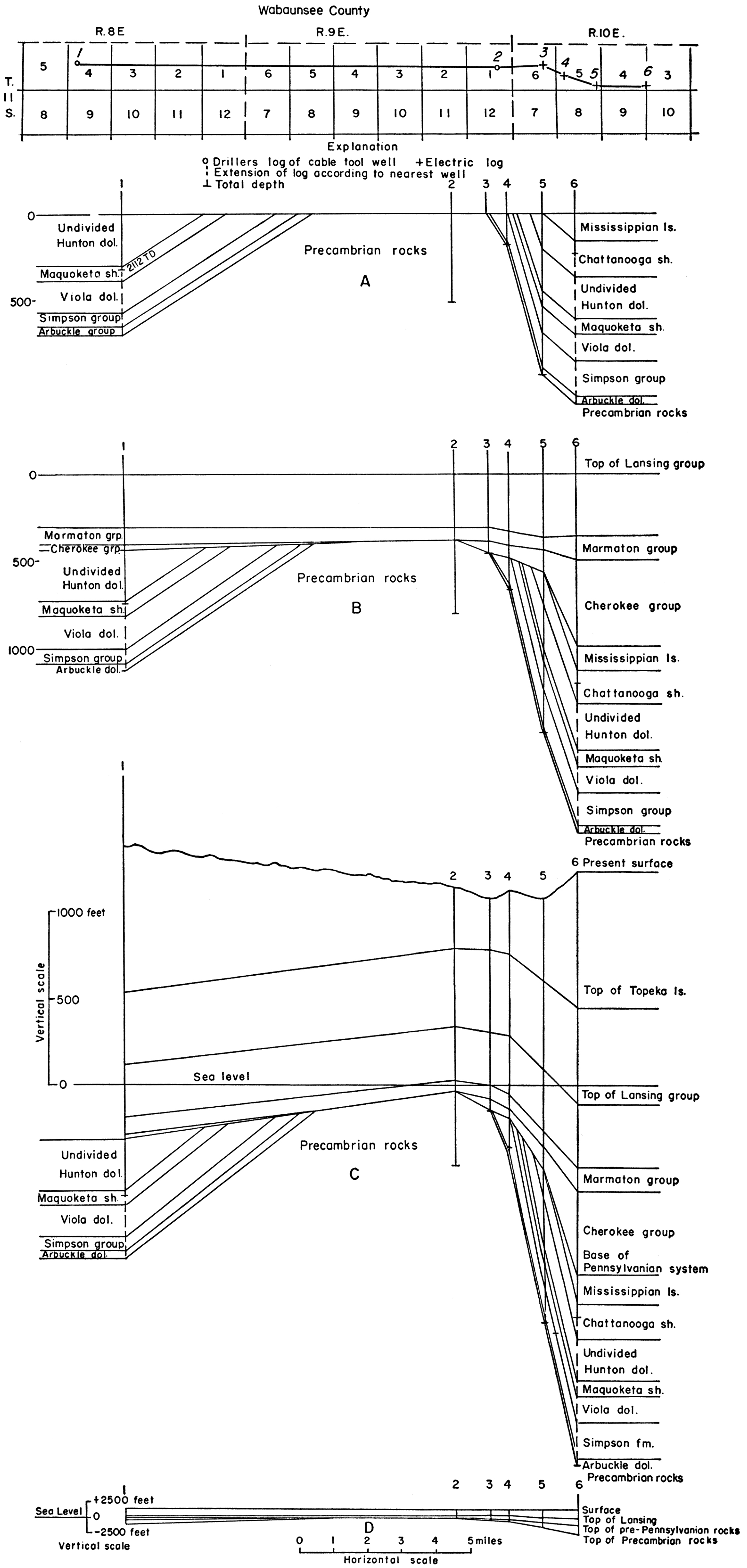


FIG. 21.—Diagrammatic cross sections in northern Wabaunsee County showing the progressive development of Nemaha anticline on line A-A′ of inset. **A.** Structure after erosional beveling of Mississippian limestones. **B.** Structure at end of Lansing time. **C.** Present structure including post-Cretaceous regional dip. **D.** Present structure drawn with the same vertical and horizontal scale.

The Central Kansas uplift, which is outlined on the areal map of Plate 6 by the beveled outcrops of Mississippian and older rocks, was already mildly developed in pre-Mississippian time (Lee, 1953, p. 20, fig. 2) but was vigorously rejuvenated at the end. The Chautauqua arch, which showed only slight movement at the close of Chattanooga time, remained quiescent, although feeble secondary movements parallel to its axis are shown locally by 50-foot thickness lines (Lee, 1939, pl. 1).

Many geologists have assumed that the northeasterly trending Forest City basin and the northwesterly trending Salina basin are the result of the intersection of the North Kansas basin by the Nemaha anticline. The Nemaha anticline strikes across the eastern side of the North Kansas basin (compare Pl. 5 and 6), but neither the Salina basin nor the Forest City basin bears a close relation to the North Kansas basin.

The Forest City basin parallels the Nemaha anticline and lies high on the southeast margin of the North Kansas basin between the Nemaha anticline and the northwestern flank of the contemporaneously re-elevated Ozark uplift (Lee, Grohskopf, Reed, and Hershey, 1946, sheet 5). The only feature common to the Forest City basin and to the North Kansas basin is their position on the northwestern flank of the Ozark uplift.

The axis of the southern part of the Salina basin is roughly parallel to the northeastern flank of the Central Kansas uplift, but its northeastern limb swings north around the broad northern end of the Nemaha anticline. The Salina basin lies between the Central Kansas uplift and the Nemaha anticline, both relatively new structural features, and it seems probable that a Salina basin would have been formed even had there been no North Kansas basin.

At the end of post-Mississippian beveling, 350 feet of Mississippian limestones survived in the deepest part of the Salina structural basin and 450 feet in the Forest City basin. These thicknesses do not, however, represent the total amount of deformation.

The Salina basin is bounded on the east by the Nemaha anticline, but where the syncline in the southern part of the Salina basin intercepts the Nemaha anticline in southeastern Chase County the continuity of the Nemaha axis is broken. The Salina basin syncline continues weakly to the southeast and fades out in central Greenwood County. The Central Kansas uplift confines the Salina basin on its southwestern side, but between the southeastern end of this uplift and the Nemaha anticline the Salina basin is confined by a broad low arch, shown between the 250-foot thickness lines (Pl. 6). This arch trends northwestward across central McPherson County, and is aligned with the northeastern flank of the Central Kansas uplift.

Northeast-trending folds were formed both east and west of the axis of the Nemaha anticline. The constricted area between the Central Kansas uplift and the Nemaha anticline contains more known northeasterly trending anticlines than any other area in Kansas, and most of them yield oil and gas. The Voshell anticline is the longest and most prominent of the anticlines in the constricted area, but it is cut off toward the north by the Salina basin.

The prominent Abilene anticline, on the northeast side of the Salina basin, is recognized in the surface rocks in Riley County and extends southward into Dickinson County. It resembles the Nemaha anticline in that the beds dip steeply on its southeastern side and very gently to the northwest. Not many subsurface data are available on the Abilene anticline, and the thickness lines have been drawn to conform to the scanty data and with the structure of the surface formations so far as known. The Abilene anticline seems to be interrupted on the south by the Salina basin syncline. Another anticline paralleling the Nemaha axis extends from T. 17 S., R. 3 W., to T. 13 S., R. 2 W., crossing the axis of the Salina basin.

Northwest-trending folds that parallel the Salina basin and the Central Kansas uplift are not clearly revealed by the Mississippian thickness lines of Plate 6. In Chautauqua and Elk Counties there is some indication of northwesterly trending folds (Lee, 1939, pl. 1). The exposure of Cambrian and Ordovician rocks in Ellsworth County on the pre-Pennsylvanian areal geology map (Pl. 6) suggests the probability of northwesterly trending folds on the northeastern flank of and paralleling the Salina basin in areas as yet inadequately explored. The major folds that trend northeast parallel to the Nemaha anticline and those that trend northwest parallel to the Central Kansas uplift, although they intersect nearly at right angles, seem to have developed contemporaneously, for the interruption of the Nemaha anticline resulting from the intersection by the Salina basin syncline in Chase and Marion Counties persisted into early Pennsylvanian time (Pl. 7).

Faulting.—A northeasterly trending post-Mississippian reverse fault, by which pre-Pennsylvanian rocks were displaced downward toward the west, was mapped in the subsurface by Bunte and

Fortier (1941, p. 114-115) on the west side of the Voshell anticline in T. 21, 22, and 23 S., R. 3 W. The fault is reported to have a maximum downward throw of about 400 feet on the west, but the displacement at the end of Mississippian time was less. In addition to the fault on the west flank of the Voshell anticline, a reverse fault with a down throw of 66 to 75 feet to the east has been described by Smith and Anders (1951, p. 43-47) on the east limb of the anticline of the Davis Ranch pool. Another reverse fault was drilled in the Davon No. 1 Swart well in sec. 26, T. 3 S., R. 13 E., on the east limb of the Nemaha anticline. The fault has a downward displacement to the east of at least 190 feet as measured by the repetition of the Maquoketa and Viola formations in the electric log.

Deformation During PENNSYLVANIAN and PERMIAN Time

The structural movements that occurred during Pennsylvanian and Permian time have been determined by comparison of thickness maps of four sequences of rocks. The upper and lower surfaces of each sequence were chosen at beds that were (1) originally essentially flat and horizontal, (2) commonly reported in drillers logs with reasonable accuracy, and (3) spaced at more or less regular intervals. The thickness of each sequence ranges from 750 to 1,000 feet, although there are wide variations in each sequence, owing to contemporaneous structural movements.

The five datum planes used are (1) the top of the Pennsylvanian basal cherty conglomerate, (2) the base of the Hertha limestone at the base of the Kansas City group, (3) the top of the Topeka limestone at the top of the Shawnee group, (4) the base of the Florence limestone member at the bottom of the Barneston limestone of the Chase group of the Permian, and (5) the top of the Stone Corral dolomite of the Sumner group of the Permian. The intervals, thicknesses of which are represented on Plates 7, 8, 9, and 10, are shown diagrammatically in Table 18.

The use of the top of the cherty conglomerate at the base of the Pennsylvanian results in some confusion where the Pennsylvanian overlaps upon the surface of pre-Mississippian rocks on the Central Kansas uplift. In such areas an extremely irregular line of zero thickness results. A part of the irregularity is due to erosional relief and to the occurrence of karst topography, as described by Walters (1946, p. 690-699). A part is due to the fact that where the basal conglomerate is represented by non-

TABLE 18.—*Skeletonized columnar section of Pennsylvanian and Permian rocks showing sequences whose thicknesses are represented on Plates 7, 8, 9, and 10.*

System	Series	Group	Formation	Sequence
Permian System	Leonardian Series	Nippewalla group	Harper ss.	
		Sumner group	Stone Corral dol.	The thickness of this sequence is shown on Plate 10.
	Wolfcampian Series	Chase group	Barneston ls.	
			Matfield sh.	The thickness of this sequence is shown on Plate 9.
		Council Grove group		
		Admire group		
Pennsylvanian System	Virgilian Series	Wabaunsee group	Severy sh.	
		Shawnee group	Topeka ls.	The thickness of this sequence is shown on Plate 8.
		Douglas group		
	Missourian Series	Pedee group		
		Lansing group		
		Kansas City group	Hertha ls.	
		Pleasanton group		The thickness of this sequence is shown on Plate 7.
	Desmoinesian Series	Marmaton group		
			Cherokee sh.	
			Basal Conglomerate	
Mississippian System				

cherty clastic deposits it has been included with the Pennsylvanian instead of with the Mississippian sequence. The configuration of the zero thickness line as shown on the Central Kansas uplift is therefore generalized.

Deformation Between Top of PENNSYLVANIAN BASAL CONGLOMERATE *and Base of* KANSAS CITY *Group*

Plate 7 shows the thickness of the pre-Kansas City Pennsylvanian rocks above the Pennsylvanian basal conglomerate. The structural movements revealed by the differences in thickness of the Mississippian limestone (Pl. 6) were generally revived during the deposition of the lower Pennsylvanian rocks, but there were some modifications in their character, particularly on the Nemaha anticline.

Before the advance of the Pennsylvanian sea into Kansas, the post-Mississippian beveled plain was warped and topographic basins developed east and west of the Nemaha anticline, the crest of which became a low barrier separating the basins. Subsidence of the Forest City basin to the east was continuously greater than in the Salina basin to the west and it was consequently invaded and received Pennsylvanian deposits before the Salina basin. Differential movements kept the crest of the Nemaha anticline above sea level until Marmaton time near the southern border of the Salina basin area and until middle Kansas City time in southeastern Nebraska. During much of this period a long narrow peninsula extended southward from Nebraska into the Pennsylvanian sea and formed a divide between the Forest City and Salina basins, but the surface was probably too low to warrant its designation as a ridge except in a structural sense.

In the deepest part of the Salina basin 400 feet of Pennsylvanian rocks had been deposited before Kansas City time, but in the deepest part of the Forest City basin pre-Kansas City rocks were 1,050 feet thick. The difference in the thickness of the deposits is the measure of the subsidence of the beveled Mississippian surface in the Forest City basin below that in the Salina basin.

Except for outstanding local structures such as the Burns dome and the Elmdale anticline, arching on the axis of the Nemaha anticline was too low to be expressed by 50-foot contours. The renewed activity during early Pennsylvanian time increased the structural displacement on the east flank, and tilted the upraised block slightly toward the west. Plate 7 shows a belt of thinning extending south from western Riley County to northwestern Butler County. This belt of thinning, which is west of the axis of folding, is not a structural feature but the result of the westward migration of the divide between the Salina and Forest City basins caused by erosion during the periods of exposure when the crest of the anticline was above sea level. The Central Kansas uplift also continued to develop and in Hertha time a considerable part of its area was land.

The thickness lines of Plate 7 show the renewed development of the Salina basin along the trend indicated by the greater thickness of the Mississippian limestones. The principal axis of the basin, which extended northwest from Ottawa and Saline Counties, remained the same, but the somewhat inadequate data available seem to indicate that the deepest part of the basin had moved about 60 miles northwest to Smith or Jewell County.

The divide in McPherson County that separated the Salina basin from the deeper Sedgwick basin toward the south on Plate 6 is only faintly shown by the thickness lines of Plate 7. The Salina basin interrupts the Nemaha anticline at the same place in Chase County as at the end of Mississippian time (Pl. 6.) The perpetuation of this feature seems to indicate the contemporaneous development of the two intersecting structural features throughout a long period of time. Structural movement during pre-Hertha Pennsylvanian time lowered the surface of the Mississippian limestones in the Salina basin about 450 feet below the crest of the Central Kansas uplift, where Mississippian rocks were removed.

Secondary northeasterly trending folds such as the Voshell anticline were less active than during the period ended by post-Mississippian beveling, and are revealed only locally by 50-foot thickness lines. The data are inadequate to determine the degree of activity of the Abilene anticline with accuracy, but some movement occurred. The extent of the activity of secondary northwesterly trending folds is not revealed by 50-foot thickness lines, but these folds were probably not inactive.

Deformation Between Base of KANSAS CITY *and Top of* SHAWNEE GROUP (*Top of* TOPEKA *limestone*)

Plate 8 shows the thickness of the Pennsylvanian rocks between the base of the Kansas City group, in most areas the base of the Hertha limestone, and the top of the Topeka limestone of the Shawnee group. The deformation indicated by the thickness of this sequence is similar to that revealed in Plates 6 and 7, but of declining intensity. During this time interval downward displacement on the east limb of the Nemaha anticline was only about 300 feet below the crest near the Nebraska—Kansas border and less than 100 feet near the southern border of the area. Continued development of the Burns dome in T. 23 S., R. 5 E., is revealed by a 50-foot thickness line partly encircling its crest, but only minor anticlinal movements, so far as known, affected other local structural features on the Nemaha anticline.

The Voshell anticline is only faintly expressed by 50-foot thickness lines and only in certain areas. Minor movements of less than 50 feet, however, were general along the trend. The available data from wells along the Abilene anticline suggest some activity of this structural feature.

Deformation of the Salina basin declined, and the structural basin of earlier times became a structural embayment. The low structural divide in McPherson County, which originally cut off the Salina basin from the subsiding Sedgwick basin to the south, had no expression during this period and probably became inactive even before the deposition of the Hertha limestone.

The thickness lines on the Central Kansas uplift form a broad bulge and here also reveal a decline of structural activity. The structural relief between the crest of the uplift and the deeper part of the Salina basin directly opposite was only about 200 feet.

Deformation Between TOPEKA *Limestone and* BARNESTON *Limestone*

Plate 9 shows the thickness of Pennsylvanian and Permian rocks between the Topeka limestone of Pennsylvanian age and the Barneston limestone of Permian age. The sequence transgresses the boundary between the Pennsylvanian and Permian Systems. A low angular unconformity is believed to separate these systems, and it would have been desirable to divide the sequence at or near the contact. Unfortunately a surface of considerable local relief occurs at the contact and, for several hundred feet both above and below the contact, the limestone formations are so thin and so infrequently identifiable in well logs that there is no suitable datum bed for dividing the sequence near the Permian-Pennsylvanian contact. The deformation indicated by the thickness map, therefore, includes movements of both late Pennslyvanian and early Permian age.

The thickness map of this sequence is in most respects similar to Plate 8, but less deformation is revealed, despite the fact that the average thickness of the sequence and probably the elapsed time is greater. Structural activity in the Salina basin continued to decline. The re-entrant shows a lower over-all structural gradient toward the southeast than during the older sequences, although in some areas the local gradient is steeper. The arching of the Central Kansas uplift had nearly ceased, and the thickness lines delineate it as a southeasterly plunging arch on a southeastwardly dipping monocline.

The deformation of the Voshell anticline is shown only at the northern end where a 50-foot contour touches the anticline. Some rejuvenation, however, is revealed at other places along the anticline by thinning that does not amount to the contour interval. Very little control is available on the Abilene anticline, but deformation is vaguely suggested by a few wells and by abrupt deformation of more than 50 feet on its east side in surface formations a short interval above the top of this sequence.

Most of the area in which the entire sequence survives lies west of the Nemaha anticline. The thickness lines therefore do not reveal the activity of this structural feature except toward the south. On the Burns dome the sequence is 55 feet thinner on the crest than on the eastern flank, and on the Eldorado anticline 40 feet thinner on the crest than on the eastern flank of the north end. It is probable that minor movements occurred at this time at other points along the crest of the Nemaha anticline. No abrupt thickening indicating a structural escarpment is evident directly east of either the Burns dome or the Eldorado anticline, but subsidence is shown by irregular thickening of the interval in some wells in the adjacent synclinal area to the east.

Deformation Between BARNESTON *Limestone and* STONE CORRAL *Dolomite*

Plate 10 shows the thickness of Permian rocks between the base of the Florence limestone member of the Barneston limestone and the top of the Stone Corral dolomite as determined mainly from electric logs. Because of salt flow, the original thickness of the sequence is obscured by the later thickening of the salt in local anticlinal areas and thinning in local synclines, the sum of which amounts in some areas to nearly 100 feet. To eliminate part of these imperfections, the contour interval has been increased to 100 feet, and local abnormalities that seem to result from salt flow have been suppressed. The thickness lines are therefore to be regarded as only roughly significant of regional structure. The Stone Corral was eroded from a large part of the Salina basin before the deposition of the Cretaceous rocks, and in consequence the full thickness of this sequence can be mapped only in the western part of the Salina basin area. The thickness lines show no movement of the Central Kansas uplift. Most of the Salina basin is outside the area of control, but the thickness lines in Osborne, Mitchell, and Lincoln Counties do not show the re-entrant that characterized the later stages of the development of the Salina basin as shown on Plate 9.

The cessation of structural activity on the Central Kansas uplift brought to an end a long period of regional arching. Its almost continuous development from St. Peter to early Permian time is recorded by thinning on its crest or beveling on its flank of nearly every mappable unit from Chattanooga to Barneston. Fifty-foot thickness lines of the interval from Chattanooga to Barneston (not shown) reveal no structural activity of the Central Kansas uplift after Barneston time, although minor movements on local northwesterly trending anticlines probably continued or were revived later. The Salina basin, which is first revealed by the thickening of the Mississippian limestones, continued its development with declining vigor into early Permian time and, like the Central Kansas uplift, became essentially inactive shortly after Barneston time.

A structural bench (Pl. 10), trending from Rush and Ellis Counties to Lincoln and Ellsworth Counties, breaks the regular southward increase in thickness of the Barneston—Stone Corral sequence. The wider spacing of the thickness contours in this area occurs where the Hutchinson salt member is thickest and is the expression of the downwarping that accompanied the development of the salt basin. The thickest salt, marking the greatest subsidence of the salt basin, overlies a part of the crest of the formerly active Central Kansas uplift (Fig. 15).

The structural deformation indicated on Plate 10 shows a regional tilt toward the south. It probably represents a composite of two regional movements; a continuation of southeasterly tilting toward the Ouachita basin until the formation of the salt basin, and a southwesterly tilting that followed the deposition of the salt, revealed a little later by the data of Figure 23A. A southwesterly dip imposed on a southeasterly dip produces a composite southerly dip.

RELATION OF PENNSYLVANIAN AND EARLY PERMIAN DEFORMATION IN KANSAS TO OUACHITA BASIN

During Pennsylvanian and early Permian time Kansas formed a part of a structural province comprising Illinois, Kansas, Missouri, Nebraska, Iowa, and parts of Oklahoma and Arkansas, which was dominated by the Ouachita basin of west-central Arkansas and southeastern Oklahoma. This basin extended from east to west and was flanked on the south by contemporaneously rising land. Miser (1934, p. 979) reports 18,000 to 20,000 feet of clastic Cherokee and older Pennsylvanian rocks in the Ouachita basin. This sequence includes 6000 feet of Stanley shale, which is reported by Hass (1951) as of Mississippian age. Compared with these deposits the maximum thickness of Cherokee rocks of approximately 800 feet in the Forest City basin and 200 feet in the Salina basin seems insignificant.

The Nemaha anticline and the Central Kansas and Ozark uplifts were structural features inherited from pre-Pennsylvanian time but they continued to develop in Pennsylvanian time. The Forest City basin and the Cherokee basin together represent an arm of the Ouachita basin that extended northward between the Ozark uplift and the Nemaha anticline. In a broad sense, particularly after Hertha time, the Salina basin, lying between the Central Kansas uplift and the Nemaha anticline, was also an arm of the Ouachita basin.

Attention has been called in the section on stratigraphy to the decrease in thickness of shale and clastic deposits toward the north and west and the relative regularity of the thicknesses of the limestone formations. All the Pennsylvanian series and groups in eastern Kansas thicken toward the Ouachita basin except where their thickness is modified by local deformation and intercyclical erosion. Most of the thickening occurs in the shale formations and in the shale members of formations in which limestone predominates. Table 19 shows the comparative thickness of limestones and clastic deposits in the wells shown in Figure 22.

Formations that are composed predominantly of limestone can generally be recognized in sample logs and in some drillers logs, but the precise thickness of interbedded shale cannot be determined. The thicknesses of shale and limestone shown in Table 19 were compiled by scaling the electric logs of the respective wells. In order to test the accuracy of the data, some of the electric logs were

TABLE 19.—*Comparative thickness, in feet, of limestone and clastic beds in groups of Upper Pennsylvanian and Lower Permian rocks in wells shown on Figure 22.*

Map no.	Well and location	County	Lansing and Kansas City groups		Douglas group, shale and sandstone	Shawnee group		Wabaunsee, Admire, Council Grove, and Chase groups to base of Barneston limestone		Total, base of Kansas City to base of Barneston limestone	
			Ls.	Clastic		Ls.	Clastic	Ls.	Clastic	Ls.	Clastic
1	E. S. Adkins No. 1 Dater, sec. 14, T. 24 S., R. 8 E.	Greenwood	207[a]	253	295	137	238	256	796	600	1582
2	Veeder Supply Co. No. 1 Borth, sec. 29, T. 19 S., R. 2 W.	McPherson	232	158	80	148	322	227	798	607	1358
3	Lion Oil Co. No. 2 Murray, sec. 18, T. 17 S., R. 10 W.	Ellsworth	197	93	110	165	110	247	623	609	936
4	Stanolind Oil and Gas Co. No. 1 Boxberger, sec. 10, T. 14 S., R. 14 W.	Russell	146[b]	106	23	183	82	259	561	588[b]	772
5	Harbar Drilling Co. No. 1 Coddlington, sec. 4, T. 10 S., R. 20 W.	Rooks	113[b]	77	10	156	124	213	552	482[b]	763
2	Veeder Supply Co. No. 1 Borth, sec. 29, T. 19 S., R. 2 W.	McPherson	232	158	80	148	322	227	798	607	1358
6	E. S. Adkins No. 1 Weis, sec. 32, T. 14 S., R. 2 W.	Saline	190	160[c]	175[c]	151	159	228	792	569	1286
7	D. W. McLaughlin No. 1 Gravenstine, sec. 21, T. 8 S., R. 6 E.	Riley	232	63	65	129	116	253	632	614	876

a. The Wyandotte and other Kansas City limestones were replaced by shale in this area.
b. Thinning of limestones is due in part to overlap of Kansas City upon the pre-Pennsylvanian surface and consequent nondeposition of lower Kansas City limestones.
c. Thickening of shales is due to deposition in subsiding Salina basin.

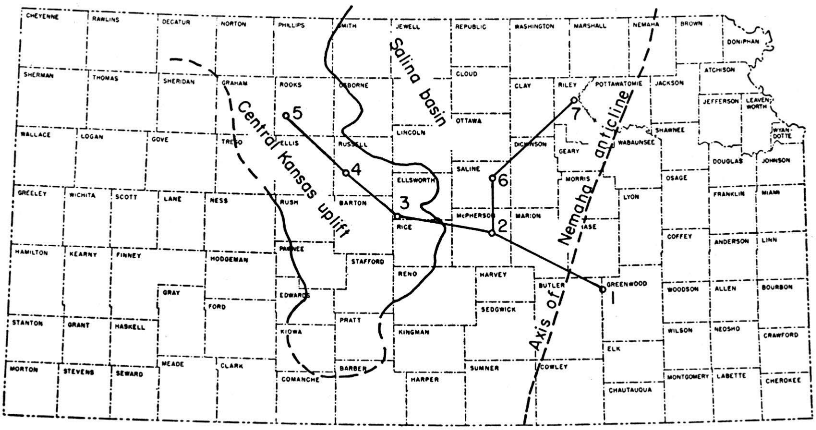


FIG. 22.—Map showing location of wells referred to in Table 19 and their relation to Pennsylvanian structural features.

scaled several times and the measurements compared. The several measurements were found to differ by less than 10 percent.

It will be noted that in general the thicknesses of the clastic beds in Table 19 decrease with the distance from the Ouachita basin and that the aggregate thickness of the limestones of each sequence is singularly constant in the different areas. Some of the deviations from regularity in the thickness of the limestones are caused by the difficulty of scaling the many thin limestones of the electric logs with consistent accuracy. Most of the differences in the thicknesses of the limestones and shales are due to the removal of some of the limestone beds during intercyclical erosion and their replacement by shale during the next cycle of deposition, as well as to local structural movement that caused deposition of greater or less thicknesses of shale in the areas affected, as on the Nemaha anticline.

In well 1 of Table 19 the Wyandotte and other limestones of the Kansas City group either were eroded during intercyclical erosion and their place occupied by shale or they graded into shales southeastward toward the source of sediments. In this area the thickness of limestone was thus decreased and that of the shale increased. The abnormal thickness of the shale in well 6, especially in the Douglas group, is probably due to the location of this well in the center of the differentially subsiding Salina basin syncline. In wells 4 and 5, the thinning of the limestones in the Lansing and Kansas City groups is due to overlap and nondeposition of the basal Kansas City rocks on the exposed surface of the Central Kansas uplift.

From the data in Table 19, as well as that included in the discussion of the Pennsylvanian stratigraphy, it seems probable that the limestones were deposited during quiescent periods of the cyclothems in a broad belt beyond the reach of clastic sediments from the southeast, and that in this belt they were deposited with little variation in thickness except toward land areas where they grade into or interfinger with clastics. The shales and sandstones, however, were deposited during periods of differential subsidence. They filled the subsiding basin with material that was worn from contemporaneously rising marginal land areas and distributed by tides and currents. The differential tilting of the border regions of Kansas and states farther east toward the Ouachita basin was the outstanding structural development in the Midcontinent region during Pennsylvanian and early Permian time. The Nemaha anticline and the contemporary structures that seem so prominent in eastern Kansas were scarcely more than ripples on the monoclinal dip into the Ouachita basin.

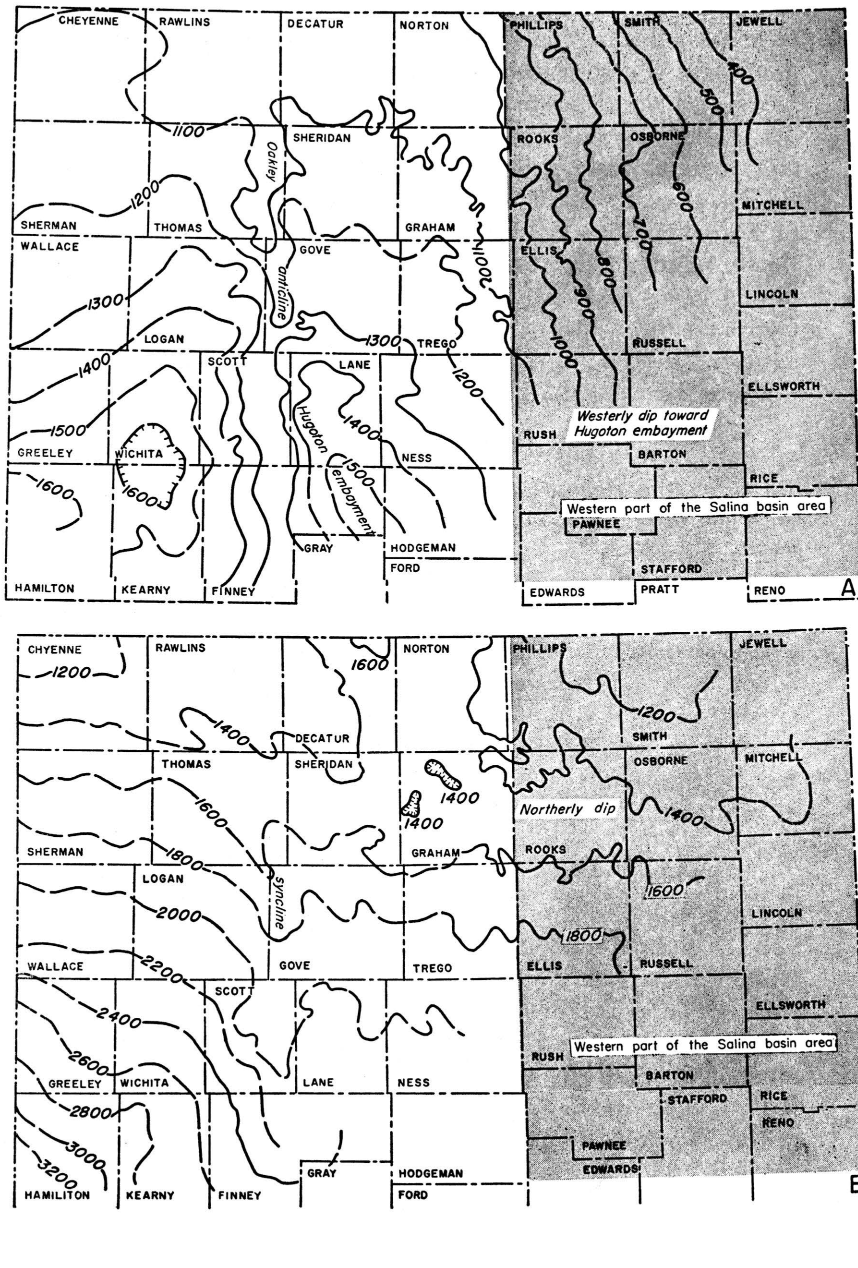
LATE PERMIAN DEFORMATION

During the deposition of the Mississippian, the Pennsylvanian, and the Permian to about Barneston time, southwestern Kansas was a subsiding basin (the Hugoton embayment of the Anadarko basin) on the southwest side of the Central Kansas uplift. It was the counterpart of the Salina basin to the northeast, but the Hugoton embayment was an area of much greater subsidence than the Salina basin. With the deposition of the Hutchinson salt beds, arching of the Central Kansas uplift ceased, but the areas of the Salina basin and Central Kansas uplift began to be tilted as a whole toward the southwest into the Hugoton embayment (Lee, 1953, fig. 2; Lee and Merriam, 1954).

POST-PERMIAN DEFORMATION

The details of deformation during the hiatus between the Permian and Cretaceous rocks of Kansas are only partly known. In northwestern Kansas the Permian is overlain unconformably by the Morrison formation of Jurassic age. During the hiatus that separates them, deposition and erosion of Triassic sediments occurred in other areas. The effect of these events on the structure of the Salina basin is quite unknown.

The Morrison formation, of Jurassic age, was deposited on the eroded surface of the Permian in an erosional and structural basin in Colorado. The deposits now reach eastward to the western border of Phillips County, but they must originally have extended farther east. The effect of pre-Morrison as well as Triassic deformation on the Salina basin area is problematical, for during the hiatus



that preceded Cretaceous deposition rocks of Jurassic age, if ever present, were eroded away. By the beginning of Cretaceous time the westerly inclined Permian rocks had been roughly truncated. The surface sloped gently westward with local relief of 50 feet or more.

Figure 23A (after Lee and Merriam, 1954, pl. 3) shows the pre-Dakota structure of the Stone Corral dolomite in western Kansas by 100-foot thickness lines of the sequence between these beds. The map records the deformation that had been imposed on the Stone Corral when the level surface of the Dakota was yet undisturbed.

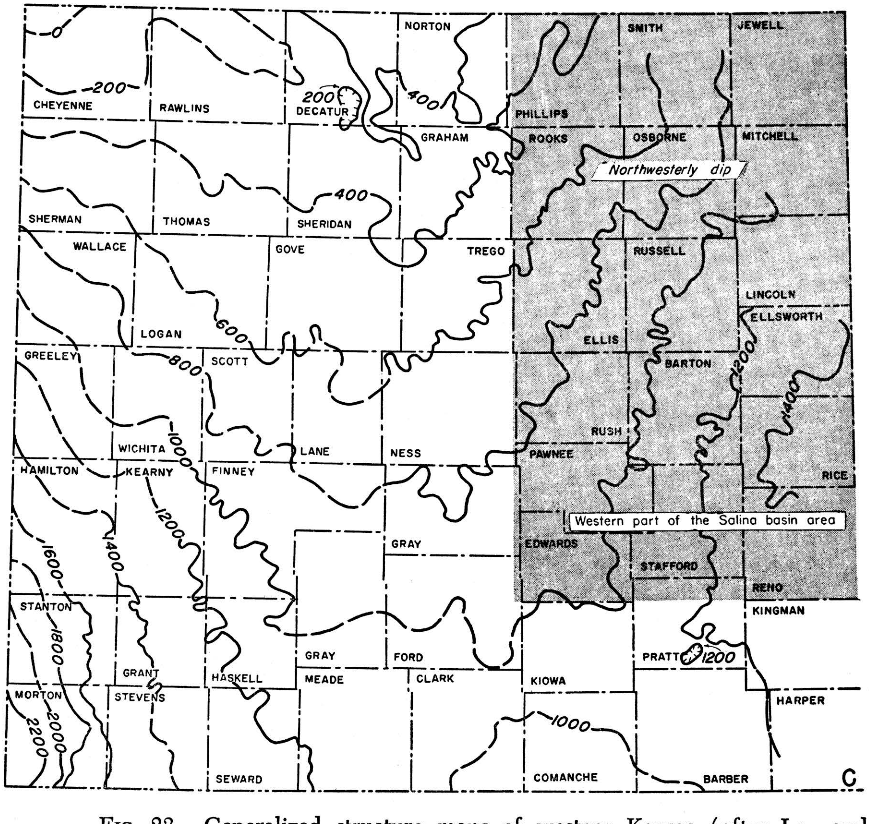


FIG. 23.—Generalized structure maps of western Kansas (after Lee and Merriam, 1954), showing late regional deformation of western Kansas. **A.** Shows by 100-foot thickness lines the southerly pitch of Hugoton embayment syncline at horizon of Stone Corral dolomite when Dakota formation was still undeformed (based on thickness of sequence between these beds). **B.** Shows by 200-foot contours the present structure of Dakota formation. Northerly post-Dakota dip was imposed on older rocks. **C.** Shows by 200-foot contours the present structure of Stone Corral dolomite as result of post-Dakota deformation.

This map shows the southerly plunging Hugoton embayment syncline flanked by a southerly trending local anticline. The structure is a composite of the deformation that modified the flat surface of the Stone Corral not only during late Permian time but also during Triassic, Jurassic, and pre-Dakota Cretaceous time. The synclinal warping was mainly a continuation of the movements that developed the Hugoton embayment. The effect of these movements on the Salina basin was to give the Stone Corral in that area a westerly inclination of 8 to 10 feet per mile.

POST-CRETACEOUS DEFORMATION

Figure 23B (after Lee and Merriam, 1954, pl. 2) shows the present structure of the Dakota sandstone in western Kansas by 200-foot contour lines. It is a composite of all the movements that have altered the essentially level surface of the Dakota during later Cretaceous time, during the Tertiary, and during the Quaternary.

Figure 23C shows the present structure of the Stone Corral dolomite by 200-foot contours. It represents the structure of the Stone Corral of Dakota time (Fig. 23A) modified by the post-Dakota structure (Fig. 23B). The result of these movements was to tilt the region northward toward basins in Nebraska. The northerly tilt reversed the pitch of the Hugoton embayment at the horizon of the Stone Corral (Fig. 23A) to the northerly pitch shown in Fig. 23C. In the deeper rocks, in which the structure of the Hugoton embayment was more pronounced, the northerly tilt reduced but did not destroy the southerly plunge.

Until Dakota time, the Stone Corral in the Salina basin and probably in other areas in northeastern Kansas seems to have been tilted westward on the eastern flank of the Hugoton embayment at the rate of 8 to 11 feet per mile (23A). The effect of post-Dakota deformation (8 to 10 feet per mile to the north, Fig. 23B) was to give the Stone Corral of the Salina basin area a dip of about 8 feet per mile toward the northwest (Fig. 23C).

Details of the post-Cretaceous structural history of the Salina basin are recorded in Kansas by a series of terrestrial deposits of Tertiary and Quaternary age laid down on the eroded surface of the older rocks and also by a series of dissected alluvial benches along the major streams as yet imperfectly related to regional structural movements. Among the latest post-Cretaceous movements is that resulting in the present elevation of the Cretaceous rocks.

Chalk beds approximately correlatives of the Smoky Hill chalk occur at river level in southeastern Missouri but at elevations of more than 2000 feet above sea level in Gove County and other areas in western Kansas.

Plates 11 and 12 show the present attitude of the rocks along the lines X-X′ and Y-Y′ of inset maps. The exaggerated vertical scale of these cross sections distorts the dip of the formations. The true rate of dip in feet per mile is shown by the insert diagrams.

RELATION OF STRUCTURAL DEVELOPMENT OF THE REGION TO ACCUMULATION OF OIL AND GAS

As has been shown in the preceding pages, the present attitude of the rocks of the Salina basin is the result of conflicting structural movements that occurred at several different times. The folding was brought about in the main by minor increments of deformation. Each new structural movement modified the previous structure by warping and tilting the rocks in the same or different directions. The closure of some anticlines of low relief was greatly reduced and in some folds the position of the crest in the surface rocks was shifted by later regional tilting (Lee and Payne, 1944, p. 70, fig. 12, p. 79). When the original dips of an anticline are less than a subsequently imposed regional dip, the anticline may be reduced to a structural nose in surface formations. In a somewhat similar way, an anticline in an upper sequence of rocks may overlie an unconformable sequence of rocks whose regional dip is too great to show closure (Lee, 1943, p. 128-133); this is one explanation of the so-called "loss of closure" in drilling into deeper rocks. Local thickening of salt beds by flow toward anticlinal areas also reduces the expected amount of closure in older rocks.

The movements of fluids in the rocks toward structural and stratigraphic traps must have been facilitated by the numerous structural adjustments by which both the local and regional structure were developed. These structural movements brought about many periods of exposure and erosion, and it is probable that with each re-elevation of the rocks above sea level the connate water escaped or was redistributed and that migration of nascent oil and gas was materially affected by the erosion of the rocks as well as by the intermittent changes of elevation. Thus any consideration of the time and manner of the accumulation of oil and gas and their subsequent adjustment in the positions in which they are now found must take into account the geologic history of the rocks in which they are trapped.

The accompanying maps show the areal distribution of the formations at different periods and indicate the areas from which well-known productive zones have been eroded and will not be found in drilling. The maps and the cross sections show also the belts of overlap and beveling along which conditions are favorable for stratigraphic traps if the beveled edges of the rocks are porous and structurally closed.

The structural deformation that occurred prior to St. Peter time was not accompanied, so far as known, by the accumulation of oil and gas. So few wells have been drilled through the pre-St. Peter sedimentary sequence, however, that local structures are completely unknown, and the regional structural features are revealed only in the most general way. Any local anticlines that may be present in the pre-St. Peter rocks may not correspond in location or character to the structural features of the younger rocks. The pre-St. Peter sedimentary rocks are productive of oil and gas on the Central Kansas uplift and in some places on the Chautauqua arch in Montgomery County and adjoining areas of southeastern Kansas. In these areas the anticlines in which the oil is found trend west and northwest at right angles to the structural axis of known pre-St. Peter features, and their development may have begun between St. Peter and Mississippian time, when a broad regional anticline extended west from the Ozarks as the Chautauqua arch and continued northwest to the area where initial movements of the Central Kansas uplift were developing.

Local structural features parallel to the Chautauqua arch are not known, however, to have been developed until the end of Mississippian time, when productive anticlines trending parallel to this fold were formed in Montgomery and adjacent counties (Lee, 1939, pl. 1). Minor anticlines are expressed by the thinning of Mississippian rocks. These folds are not strongly developed and, although there is no direct evidence, they are believed to represent the rejuvenation at the end of Mississippian time of folds originally formed during the development of the Chautauqua arch.

The Central Kansas uplift itself was only slightly developed before the end of Mississippian time, when the major uplift occurred. It reached its period of maximum deformation before Hertha time, and continued to develop with declining intensity through late Pennsylvanian and early Permian time until the downwarping of the salt basin. Most of the productive anticlines on the uplift trend northwest. The date of the first movements of the anticlines cannot now be determined, because the area was stripped of pre-Pennsylvanian rocks by successive periods of exposure and erosion. Such folds were probably being developed at the end of Mississippian time contemporaneously with the Salina basin.

During the development of the northwesterly trending Salina basin, the Nemaha anticline and other structural features trending east of north were initiated and continued to develop contemporaneously with the northwest-trending folds. Northeasterly trending folds are prominently revealed on the thickness map of the Mississippian, but only the most prominent anticlinal movements are revealed by 50-foot thickness lines after Hertha time. It is noteworthy that most of the oil from anticlines paralleling the Nemaha axis has been produced in the constricted area between the Central Kansas uplift and the Nemaha anticline.

Too few wells have been drilled in the Salina basin to permit any definite conclusions, but it seems probable that northwesterly trending anticlines will be found paralleling the Central Kansas uplift.

The central and northern part of the Salina basin have not been adequately tested. Only a few wells have been drilled on the Abilene anticline. A small amount of low-gravity oil in one well on the part of the anticline in Clay County (sec. 21, T. 9 S., R. 4 E.) shows that oil occurs on the northeastern side of the Salina basin. The offsets of this well, however, were all dry. In an effort to determine the subsurface structure of this anticline, the surface structure was recontoured, eliminating the post-Permian regional tilting. The structure as thus restored revealed a considerable shift in the position of the low crest on the axis of the present anticline.

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