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BULLETIN 74

THE STRATIGRAPHY AND STRUCTURAL DEVELOPMENT OF THE SALINA BASIN OF KANSAS

By

WALLACE LEE, CONSTANCE LEATHEROCK, and THEODORE BOTINELLY

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CONTENTS

ILLUSTRATIONS

TABLES

THE STRATIGRAPHY AND STRUCTURAL DEVELOPMENT OF THE SALINA BASIN OF KANSAS

ABSTRACT

This report describes the stratigraphy and structural history of the Salina basin in Kansas and adjoining areas. The stratigraphic descriptions are based on a microscopic examination of samples from wells.

The rocks of the basin range in age from Pre-Cambrian to Quaternary but many hiatuses make the record incomplete.

Stratigraphy.—The Pre-Cambrian rocks consist of red granite or granitic gneiss.

The Upper Cambrian Series is represented by the Lamotte sandstone, Bonneterre dolomite, and Eminence dolomite. The Lamotte sandstone is absent in most parts of the Salina basin but at one point it reaches a thickness of 80 feet. The Lamotte grades upward into the noncherty glauconitic Bonneterre dolomite, which has a thickness of more than 180 feet at some places. The cherty Eminence dolomite is bounded at the base and top by unconformities. It has been recognized only in McPherson County where it has a thickness of 35 feet.

The Lower Ordovician Series is represented in central Kansas by the Van Buren formation, Gasconade, Roubidoux, Jefferson City, and Cotter dolomites, and St. Peter sandstone. The Van Buren dolomite is cherty and at the base contains the Gunter sandstone member. The Van Buren and overlying Gasconade dolomite, which are inseparable in this area, have a thickness of 50 feet in southern McPherson County; strata of this combined unit thicken southward but disappear northward. The Roubidoux dolomite is widely distributed in Kansas but is absent on the crest of the Southeast Nebraska arch and parts of the Central Kansas uplift. The dolomite rests unconformably on rocks ranging from Pre-Cambrian granite to the Gasconade dolomite. In the Salina basin the Roubidoux comprises sandy dolomite having a maximum thickness of 247 feet; it lacks sandstone zones such as characterize this formation in Missouri. The undivided Jefferson City-Cotter sequence, which overlies the Roubidoux, is commonly present. Its maximum known thickness is 410 feet in Rice County. The St. Peter sandstone, 10 to 90 feet thick, rests unconformably on all the older rocks. It is divisible into three members.

The Middle and Upper Ordovician rocks of the Salina basin consist of the Platteville formation, Kimmswick dolomite, and Maquoketa shale, each bounded by obscure disconformities. The Platteville and St. Peter beds are equivalent to part of the Simpson group of Oklahoma, the Kimmswick corresponds to part of the Viola limestone of Oklahoma, and the Maquoketa equals the Sylvan shale of Oklahoma. The Platteville consists

of shale, sandy clay, sand, and dolomite; a persistent dolomite at the base is a reliable datum bed. The Platteville thickens toward northeastern Kansas, ranging from a featheredge in McPherson and Marion Counties to 60 feet in Pottawatomie County. The Kimmswick dolomite consists of alternating beds of cherty and noncherty dolomite and some limestone in which three zones are recognizable. It thickens toward the northeast from 20 feet in Harvey County to 310 feet in Washington County. The Maquoketa shale consists of gray silty dolomitic shale and locally very cherty dolomite at the top. Insoluble residues of the shale reveal conspicuous dolomolds. The thickness of the Maquoketa, except in parts of Osborne and Smith Counties where it is absent, ranges irregularly from 40 to 155 feet. The variations in thickness are due mainly to pre-Silurian erosion.

The Silurian rocks consist mainly of coarsely sucrose and granular dolomite which is divisible into five zones, of which the lower three are correlated with the Chimneyhill limestone of Oklahoma. The Silurian increases in thickness toward the northeast from 117 feet in Dickinson County to 270 feet in Marshall County.

The Devonian rocks contain two recognizable zones and consist mainly of dolomite but limestone is present in the southwestern part of the area where the Devonian is thin. Sparsely distributed sand occurs in the lower part of the sequence and sandy dolomite commonly marks the base. Thickness of these rocks is variable, owing to pre-Chattanooga erosion, but it increases irregularly northeastward from a featheredge in the southern part of the area to 215 feet in Nemaha County. An important unconformity, comparable to that at the base of the St. Peter sandstone, separates the Devonian rocks from older formations.

Between the Devonian dolomites and Mississippian limestones, sandstone and shale of uncertain age comprise the Misener sandstone, Chattanooga shale, and Boice shale. They are separated from older rocks by an angular unconformity that extends over a broad region. The Misener is a discontinuous unit composed of sandstone or sandy shale. The Chattanooga consists mainly of gray finely micaceous shale containing sparely distributed spores but dark shale, in its lower part bears many spores. Impure silty or clayey dolomite and limestone occur locally in the middle part of the Chattanooga.

The shale thickens irregularly northeastward from 100 to more than 200 feet, but pre-Chattanooga valleys in McPherson County contain as much as 250 feet of beds belonging to this formation. The Boice shale, which overlies the Chattanooga unconformably, occurs in the northeastern part of the Salina basin area. The basal deposits are red and generally are characterized by ferruginous oölites, but the upper part resembles the Chattanooga.

The Mississippian limestones of the Salina basin consist of many units: an upper member of the Sedalia dolomite and the Gilmore City limestone, of Kinderhookian age; the St. Joe, Reeds Spring, Burlington, and Keokuk limestones, of Osagian age; and the "Warsaw" and Spergen limestones of

Meramecian age. The Mississippian limestones in central Kansas are now confined to synclinal areas but originally they were more widespread. The upper formations probably extended northward beyond the Salina basin and westward across the Central Kansas uplift.

The Kinderhookian rocks in the Salina basin belong to the upper part of the series. They occur principally in the northern two-thirds of the area, but outliers occur as far south as Sedgwick County. The upper member of the Sedalia dolomite is a brownish noncherty sucrose dolomite, rarely more than 15 feet thick, that lies disconformably on the Chattanooga shale. The Gilmore City limestone, unconformably above the Sedalia, consists of soft noncherty granular limestone containing some oölitic zones. The thickness of the Gilmore City increases toward the north and reaches a maximum of 62 feet in Mitchell County.

The St. Joe, Reeds Spring, and Burlington limestones overlap northward upon a beveled surface of Kinderhookian rocks. The St. Joe limestone is noncherty or slightly cherty argillaceous dark-gray limestone which is 40 feet thick in Harvey County. It is overlain conformably by the Reeds Spring limestone, characterized by abundant semitranslucent bluish-gray to gray chert. This unit is 100 feet thick in Harvey County and overlaps beyond the St. Joe to the east, west, and north, where a tongue extends into Ottawa County. The Reeds Spring limestone is conformably overlain by the undifferentiated Burlington and Keokuk limestones, which comprise two zones separated by an unconformity. The lower zone, partly or wholly of Burlington age, is characterized by white blocky opaque chert; the upper zone, partly or wholly of Keokuk age, is characterized by rough, pitted, and porous chert and includes siliceous material resembling tripoli. The Burlington-Keokuk sequence is 170 feet thick in Harvey County but it thins irregularly northward to 100 feet in Republic County.

The "Warsaw" limestone consists mainly of limestone containing much microfossiliferous chert. Its thickness varies greatly on account of the relief of the pre-"Warsaw" erosion surface; the limestone is 95 feet thick in Harvey County and 35 feet thick in Ottawa County. The Spergen limestone, which succeeds the Warsaw limestone with seeming conformity, consists mainly of noncherty or sparsely cherty granular limestone. The small amounts of chert generally include semitranslucent salmon-colored or pink chalcedony or small amounts of microfossiliferous chert like that in the Warsaw.

The thickness of the Mississippian rocks as a whole is related in large measure 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 youngest Mississsppian formations were removed by pre-Pennsylvanian erosion.

The rocks of Pennsylvanian and Permian age consist of numerous alternating sequences of limestones, marine and nonmarine shales, and sandstone. Each sequence was deposited during a cycle that included an advance and retreat of the sea.

The Cherokee shale, of Desmoinesian age, consists mainly of alternating shale and sandstone interstratified with coal and thin limestones. The Cherokee is about 300 feet thick in the center of the Salina basin but is absent through 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 which are not sharply differentiated in the subsurface. The group is probably about 100 feet thick in the Salina basin.

Missourian rocks, comprising the lower part of the Upper Pennsylvanian Series, are separated from Desmoinesian formations by an unconformity that is marked by channeling and a faunal change. Of Missourian age are the Pleasanton, Kansas City, Lansing, and Pedee groups. The Pleasanton group is not clearly distinguishable in the logs of all wells; its thickness seems to be less than 25 feet at most places. The Kansas City and Lansing groups have an average aggregate thickness of about 350 feet in the Salina basin, and consist dominantly of limestone with alternating beds of shale, which clearly reveal the cyclical deposition of the rocks. The Pedee group is probably not represented in the Salina basin area.

Virgilian rocks, which comprise the upper part of the Upper Pennsylvanian Series, include the Douglas, Shawnee, and Wabaunsee groups. An important unconformity separates the Virgilian from underlying beds. The Douglas group consists largely of shale and sandstone with one or more thin interbedded limestones. In the central part of the Salina basin, it is about 175 feet thick but it is thinner toward the margins of the basin. The Shawnee group consists of four formations of limestone that alternate with three formations of shale. The thickness of the group is 360 feet in the center of the Salina basin. The Wabaunsee group, which consists dominantly of shale interbedded with many relatively thin limestones, ranges in thickness from 200 to 400 feet, owing to an unconformity at its top.

The Wolfcampian Series, of Early Permian age, rests on an uneven surface of Pennsylvanian rocks in which deep channels were cut and subsequently filled with sand. The relations of the beds adjacent to the unconformity indicate regional tilting of the beds below it prior to the beginning of Permian sedimentation. Three groups called Admire, Council Grove, and Chase, are recognized in the Wolfcampian Series. The Admire group consists of shale and sandstone interstratified with thin limestones and ranges in thickness from 100 to 250 feet. The Council Grove group attains a thickness of 375 feet in the Salina basin and consists of well-developed limestones, in part argillaceous, interstratified with shales which become increasingly red and variegated toward the top. The Chase group ranges in thickness from 340 to 375 feet and is similar lithologically to the upper part of the Council Grove group but it includes two persistently cherty limestones, the Wreford and the Barneston, both of which are useful datum beds in subsurface stratigraphy.

The Sumner and Nippewalla groups constitute the Leonardian Series. The Sumner group is composed of the Ninnescah shale, which is mostly red, the Stone Corral dolomite, which includes some gypsum, and the Wellington formation which consists mainly of gray shale and gypsum and includes the Hutchinson salt member. The Sumner group has a thickness of 500 to 750 feet. The only part of the Nippewalla group present in the Salina basin is red shale which lies at the base of the group. Higher Permian rocks were eroded prior to Cretaceous time.

The rocks of Cretaceous age have an aggregate thickness of more than 1,000 feet on the western border of the Salina basin area and 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 approached by preparation of thickness maps and stratigraphic cross sections. The interpretation of structural movements from thickness maps is based on the concept that if a sequence of rocks is deposited on a flat surface and then warped before a younger horizontal surface is developed, variations in the thickness of the rocks between the two surfaces reveal the amount and place of the deformation.

Five periods of folding are distinguished (1) Upper Cambrian and Lower Ordovician dolomites lying below the St. Peter sandstone were deformed before the deposition of the St. Peter sandstone. The structural movement revealed by the thickness map of this sequence (Pl. 1) resulted from many minor movements that occurred at different times prior to the deposition of the St. Peter sandstone. The movements involved a subsidence of a deep basin in central Missouri in which more than 2,000 feet of dolomites are preserved. During the same epoch, a south-trending positive area, termed the Southeast Nebraska arch, was developed in southeastern Nebraska and northeastern Kansas. On the crest of this arch, the St. Peter rests on Pre-Cambrian granite and on the flanks it rests on the beveled edges of the Late Cambrian and Early Ordovician formations. In central Kansas, a parallel syncline is revealed by the thickness map.

(2) Another period of folding extended from St. Peter time to the beginning of deposition of the Mississippian limestone and may have continued through Kinderhookian time. During this period the structural deformation was a complete reversal of that preceding St. Peter time, for now the Ozark uplift rose from the deepest part of the previously subsiding area in southern Missouri and the previously rising Southeast Nebraska arch became the site of the gradually subsiding North Kansas basin. Events that were contemporaneous with the subsidence of the North Kansas basin and the rise of the Ozarks were the development of the Chautauqua arch and the Central Kansas uplift on the south and west. Although the development of these features was more or less continuous and oc-

curred during periods of sedimentation, a considerable part of the folding took place during the hiatuses preceding the deposition of the Devonian rocks and preceding the deposition of the Chattanooga shale. The unconformities that are expressions of these hiatuses show beveling of previously deposited formations and thus show the development of structural elements. The subsidence of the North Kansas basin by the end of Chattanooga time (Pl. 7) was not less than 1,200 feet and may have been several hundred feet greater.

(3) A third period of folding began at least as early as the beginning of Mississippian time, culminated after Mississippian deposition, and continued with diminished movement through Pennsylvanian into Permian time. The principal structural feature developed in Kansas was the Nemaha anticline, trending slightly east of north, which was flanked by the Salina basin on the west and the Forest City basin on the east. The Salina basin was a synclinal area which trended northwest and paralleled the northern flank of the Central Kansas uplift. Secondary anticlines, paralleling both the Nemaha anticline and the Salina basin syncline were also developed. The Central Kansas uplift, which had been a positive area since St. Peter time, continued to develop; the Chautauqua arch remained quiescent at the end of Mississippian time although parallel minor anticlinal movements continued along its trend into Pennsylvanian time. It was later crossed at right angles by the Cherokee synclinal basin; a rising surface in southeastern Nebraska cut eastward across the deepest part of the North Kansas basin.

The pre-Pennsylvanian movement of the Nemaha anticline were distinctly anticlinal with steeper dips on its east side than on the west. Early Pennsylvanian movements steepened the east dip, and in many places developed a structural escarpment. At the same time, the region to the west was raised, with only minor anticlinal movements on the crest of the anticline. The west limb became essentially a monoclinal slope broken by a series of secondary folds paralleling the escarpment. The gradual elevation of the western area did not permit the Pennsylvanian sea to inundate the Salina basin until long after it spread over the Forest City and Cherokee basins. Appreciable deformation of the Central Kansas uplift and the Salina basin, as recorded by 50-foot thickness lines, ceased after Wolfcampian time or a little earlier. This is shown by the formation of the Hutchinson salt basin across the end of the Central Kansas uplift in mid-Permian time. The continued growth of many local and secondary anticlines paralleling both the Nemaha anticline and the Central Kansas uplift is, however, recorded in rocks even younger than the Wolfcampian.

During the cyclical deposition of most of the Pennsylvanian and Early Permian rocks, the floor of the Salina basin area stood close to sea level. The limestone beds have a relatively even thickness but the shales thicken with considerable regularity southeastward toward the Ouachita basin. Eastern Kansas lay on the margin of a much larger structural feature centering in the Ouachita basin in which Pennsylvanian rocks older than Marmaton accumulated to a thickness of 18,000 to 20,000 feet. Compared to the deformation of the Ouachita basin, the structural features developed in Kansas, although important, are insignificant.

(4) A fourth period of deformation occurred after Permian time and before Cretaceous time. It involved the development of a broad synclinal basin in southwestern Kansas which gave the Permian and Pennsylvanian rocks of eastern Kansas a southwesterly dip.

(5) A fifth period of deformation occurred after the deposition of the Cretaceous rocks. As a result of this deformation these rocks were tilted toward the northeast in western Kansas and toward the north and northwest in central Kansas and were raised 1,500 to 2,000 feet above sea level in the Salina basin.

Each change in the pattern of structural movement altered the attitude of earlier anticlines as well as earlier regional structure. Changes in the direction of dip shifted the position of the crests of low anticlines in some cases and destroyed the closure in others. In consequence, the exposed crests of low anticlines in the younger rocks do not, in all cases, 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 influenced the migration and distribution of fluids in the rocks. Each structural movement, particularly those involving changes of dip, caused readjustments in the distribution of connate waters. The movements of nascent gas and oil were affected, and in some cases, earlier accumulations of oil and gas were probably lost.

The maps show the areas in which well-known zones of production will not be found 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 anticlinal conditions are present in northern Lincoln County. Also, northeasterly and northwesterly trending folds are probably 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 investigation of the stratigraphy and structural development of the Salina basin was carried on during the period from September 1943, to June 1946, under a cooperative agreement between the State Geological Survey of Kansas and the U.S. Geological Survey.

The area studied (Fig. 1) includes not only the Salina basin but also parts of the adjacent Nemaha anticline and Central Kansas uplift. The axis of the Salina basin, which was an area of post-Mississippian structural subsidence, extends northwest and southeast from Saline County, Kansas. Most of the Salina basin lies in Kansas, but in the earlier stages of its development the synclinal warping extended into southern Nebraska.

The report follows in general the plan of a previously published report on the Forest City basin (Lee, 1943). 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 data upon which the report is based were derived entirely from the cuttings and logs of wells. The criteria by which most of the formations are identified were determined from the outcrops of the formations in many areas distant from the Salina basin.

Most of the several thousand wells that have been drilled in the Salina basin are in the developed southern and southwestern parts. The wells are more widely scattered in the northern part of the basin. Sets of samples from more than 300 wells drilled by both rotary and cable tools were examined microscopically. The accurate detail thus secured was augmented by a considerable number of sample logs which were prepared by company geologists. All available electric logs and drillers logs in which the datum beds could be identified were used in the preparation of the accompanying map that shows the thicknesses of different parts of the sequence of the sedimentary rocks. Considerably more than 2,000 well logs were studied and correlated and the logs of many hundred more wells were examined. Some 1,600 logs of wells, most of which are in the southern part of the basin, were selected from a file of several thousand for use in the study of the Pennsylvanian and Permian rocks.

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

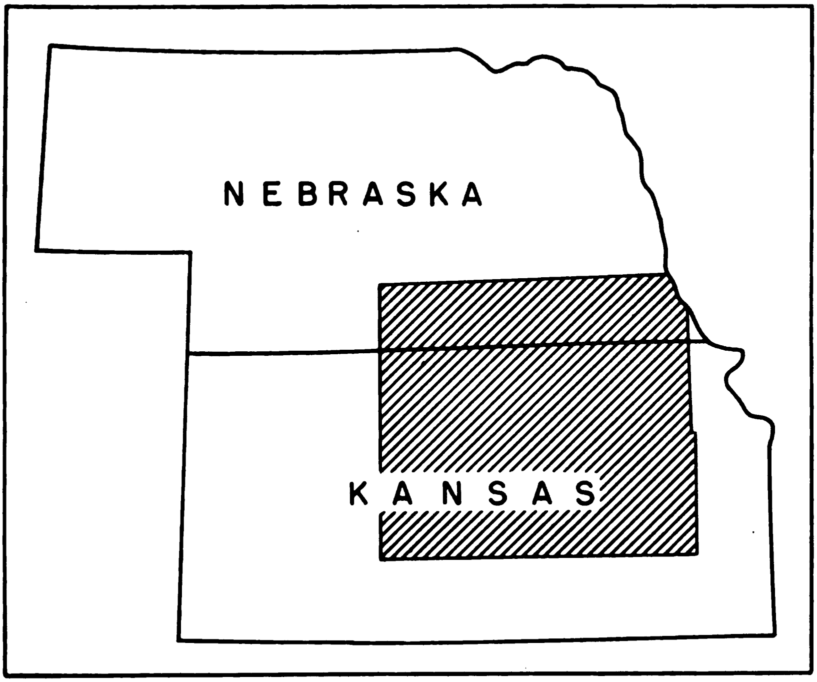


Fig. 1.—Map of Kansas showing the area covered by this report.

Some sets of rotary samples were found to be so badly contaminated that critical points could not be determined. Also, in some sets of rotary samples many contacts were determined with doubtful accuracy. These contacts include (1) the limits of soft beds of sandstone, such as the St. Peter sandstone, (2) the base of some limestones such as the Hertha limestone where the Pleasanton shale is thin, and (3) the base of the Devonian rocks. Relatively few drillers logs of rotary wells contributed essential information unless they were accompanied by determination of datum beds by company geologists.

Drillers logs showing abnormal thicknesses were discarded unless they were supported by the logs of other wells in the same vicinity. Sample logs showing unusual thicknesses or other features have generally been plotted although it is recognized that they also are subject to differences of interpretation and to inaccuracies of sampling, recording, and depth.

In consequence of the varying degrees of accuracy of the data, the maps that show the thicknesses of the different parts of the rock sequence of the Salina basin have been prepared with lines spaced at 50-foot intervals. Intervals of 25 feet or less would doubtless bring out many local structural features, particularly in oil fields where local deformation probably accompanied regional deformation throughout Pennsylvanian and Permian time. In densely drilled areas only one or two wells in a land section were used because the object of the investigation was the study of regional and not local deformation.

The major structural features of eastern and central Kansas are shown in Figure 2. Some of them were developed contemporaneously, but others were developed at different times. 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, a structural basin parallel and to the west, and a somewhat vaguely located arch still farther west. Later 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 basin. The most prominent of the principal 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 Central Kansas uplift. Also, a number of secondary folds parallel to the Nemaha anticline were formed. The only movements of the Chautauqua arch after Chattanooga time that can be recognized by 50-foot thickness lines were confined to several minor northwesterly trending folds and the broad Bourbon arch that separated the Forest City and Cherokee basins during early Pennsylvanian deposition.

The Salina basin was first defined by John S. Barwick (1928, p. 179) as "The pre-Pennsylvanian syncline bounded on the east by the Nemaha granite ridge, on the southwest by the Barton arch, 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 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 John L. Rich (1933) as the North Kansas basin. The Salina basin had no separate existence until the uplifting of the Nemaha anticline destroyed 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.

Terminology

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

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 materials in insoluble residues. Dolomolds may occur singly or be so numerous that they form a porous or spongy texture.

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

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

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

Hackly texture is applied to broken quartz without crystalline faces.

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

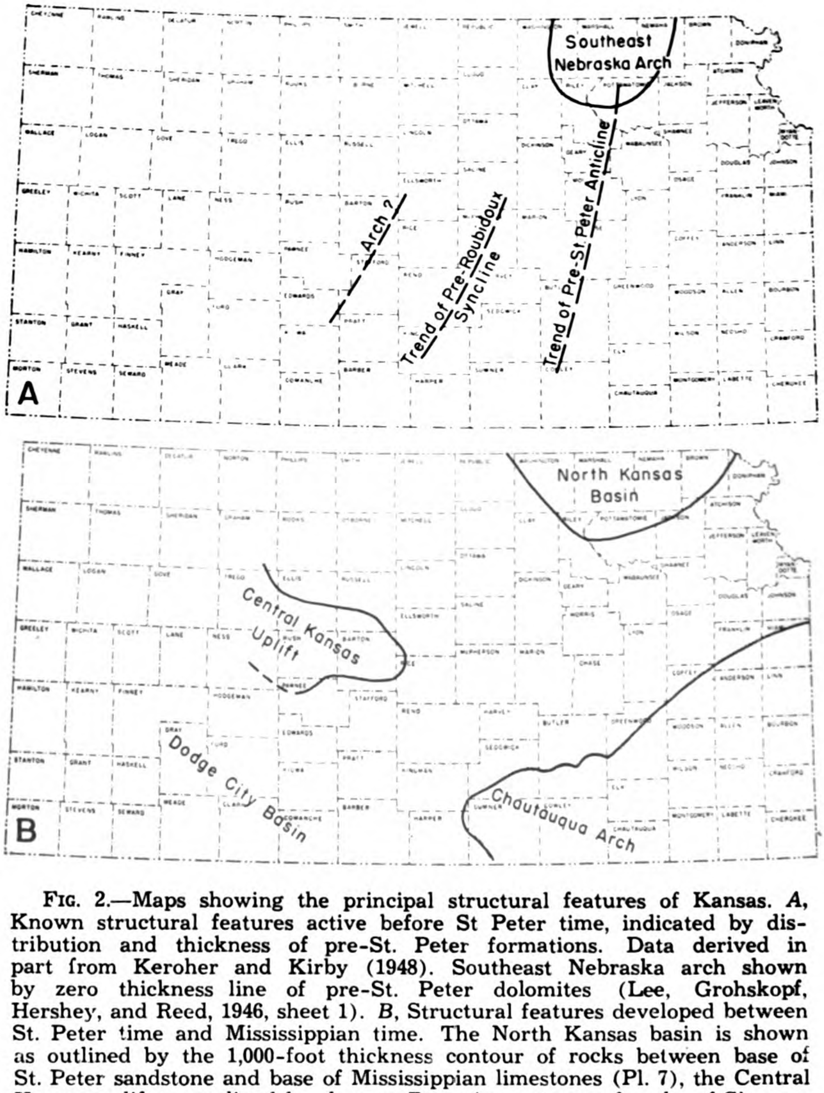
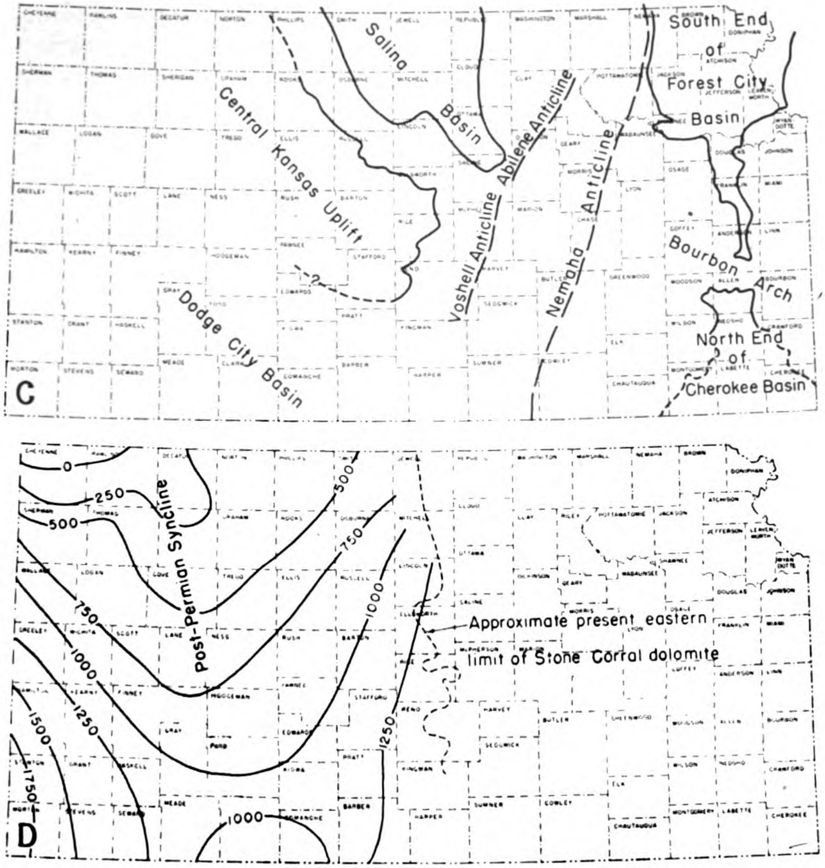


FIG. 2.—Maps showing the principal structural features of Kansas. *A*, Known structural features active before St Peter time, indicated by distribution and thickness of pre-St. Peter formations. Data derived in part from Keroher and Kirby (1948). Southeast Nebraska arch shown by zero thickness line of pre-St. Peter dolomites (Lee, Grohskopf, Hershey, and Reed, 1946, sheet 1). *B*, Structural features developed between St. Peter time and Mississippian time. The North Kansas basin is shown as outlined by the 1,000-foot thickness contour of rocks between base of St. Peter sandstone and base of Mississippian limestones (Pl. 7), the Central Kansas uplift as outlined by the pre-Devonian outcrop of rocks of Simpson age (Pl. 5), and the Chautauqua arch by the pre-Chattanooga outcrop of



the St. Peter sandstone (in part after McClellan, 1930). ***C*****, Structural features that were developed between the end of Mississippian time and early Permian time. The Salina basin is shown as outlined by the 300-foot thickness contour of pre-Hertha Pennsylvanian rocks (Pl. 9), the Central Kansas uplift as outlined by the 50-foot thickness contour (Pl. 9), the Forest City and Cherokee basins as outlined by the 750-foot thickness line of the pre-Hertha Pennsylvanian rocks (Lee, Grohskopf, Hershey, and Reed, 1946, sheet 6).** ***D*****, Generalized present attitude of the top of the Stone Corral dolomite in the post-Permian and pre-Cretaceous synclinal basin. The contour interval is 250 feet. Since the deposition of the Cretaceous rocks, structural movements have raised the basin, tilted the Cretaceous toward the northeast, and in other ways have modified their original attitude.**

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

Porous texture is used for 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. In some rocks crinoidal limestones are semigranular.

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

Stippled indicates a dotted pattern on a smoothly broken chert surface due to the complete replacement by silica of rocks having grainy texture. The sharp outline of the replaced impurities in some zones is blurred and gives a cloudy margin to the replaced particles.

Streaked texture indicates the microfossiliferous content of matted chert that is imperfectly replaced or subsequently modified resulting in blurred outlines of the microfossiliferous constituents.

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

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The work was directed by Wallace Lee who is responsible for the interpretation of the structural development of the area. The microscopic examination, lithologic descriptions, and correlation of the pre-Pennsylvanian samples are the work of Constance Leatherock who also prepared the thickness maps, cross sections, and the columnar section of Table 1. Theodore Botinelly examined the Pennsylvanian and Permian samples of numerous wells, correlated the post-Mississippian sections of well logs, and prepared thickness maps of the Pennsylvanian and Permian rocks and cross section X-X′ and Y-Y′. Other geologists who worked briefly on the Pennsylvanian and Permian rocks at the beginning of the project were Harold L. Williams, formerly of the State Geological Survey, Clifford N. Holmes, who was transferred to another Geological Survey project, Merald E. Rhoades, who entered the Navy, and Warren Grunert, who joined the Army and was killed in parachute operations in Holland in 1944.

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

System	Series	Correlatives	Formations and members	Approximate thickness in 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 micro-fossiliferous chert. Granular limestones may contain sparsely distributed ***Endothyra.***
			"Warsaw" limestone	0-80	Chert, opaque, partly gray and partly dark, characteristically packed with silicified broken microorganisms. 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 micro-fossiliferous organisms similar to those in chert of the "Warsaw" limestone but replaced by chalcedony or quartz.
				0-155	Lower zone. Chert, abundant, mainly white, opaque, microscopically massive, breaking in smoothish blocky crumbs. 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 semi-translucent, breaking in sharp-edged crumbs 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 some argillaceous sucrose dolomite and locally toward the west a zone of argillaceous limestone.
Devonian	Late		Undifferentiated dolomite of Devonian age; Includes Cooper dolomite	0-200	Contains, in lower zone, imbedded coarse rounded sand grains thinly disseminated in dolomite or limestone but generally abundant at base. Upper zone includes chert at base. Not sandy.

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 fine quartz crystals in the northeastern part of the area and by dolocastic and spongy chert in the southern and western parts of the 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	Kimmswick limestone	0-310	Chert with imbedded 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	Limestone, dolomite, and sandstone interbedded with green shale; a persistent bed of sucrose dolomite at the base, little or no chert.
	Early		St. Peter sandstone	0-90	Coarse rounded to subangular sand interbedded with green shale.
		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, commonly, with secondary enlargement.
			Undivided Gasconade dolomite and Van Buren formation	0-50[*]	Chert abundant. In upper part, chert is dense, gray to dark to dark bluish. In lower part, chert is dense, white to quartzose, grading downward to white dolocastic chert. Gunter sandstone or sandy dolomite member at base.
Cambrian	Late		Eminence dolomite	0-35[*]	Chert, vitreous to quartzose, light bluish gray, characterized in insoluble residues by lace-like structure due to the abundance of fine dolocasts.
			Bonneterre dolomite	0-183[*]	Noncherty dolomite with abundant glauconite.
			Lamotte sandstone	0-80	Coarse angular to rounded poorly sorted sand.
Pre-Cambrian			Pre-Cambrian rocks		Arkose; granite.

The nomenclature and classification follow the usage of the State Geological Survey of Kansas.

[*] (Keroher and Kirby, 1948)

STRATIGRAPHY

The exposed rocks in the Salina basin and those that have been penetrated in wells range in age from Pre-Cambrian 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 the cuttings of wells. 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, no columnar section showing the sequence of formations is representative of the basin as a whole.

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

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.

Pre-Cambrian Rocks

The oldest rocks known in the Middle West consist of various types of igneous and volcanic rocks and altered sedimentary rocks which are generally classified collectively as Pre-Cambrian. 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 Pre-Cambrian rocks lie deep beneath a variable thickness of sedimentary rocks that include representatives of nearly all ages from Cambrian to Recent.

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

The surface of the Pre-Cambrian rocks dips away from the granitic cores of the mountain areas, and reaches depths of several thousand feet below the surface in the adjoining structural basins. In some areas, the sedimentary rocks deposited on the Pre-Cambrian surface were 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 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 Pre-Cambrian rocks of that State have not been raised high enough nor has erosion cut deep enough to bring them to the surface.

Rocks of Late Cambrian and Early Ordovician Age

The entire sequence of dolomites of Late Cambrian and Early Ordovician age in Kansas was formerly called the Arbuckle limestone, a name derived from exposures of these rocks in the Arbuckle Mountains of Oklahoma. In Missouri, they were known as the Cambro-Ordovician. These rocks are also known to some oil men as the "siliceous lime." The Arbuckle limestone of Oklahoma and the corresponding Cambrian and Ordovician rocks of Missouri have now been subdivided into many formations. The formational units in Missouri were first differentiated by the Missouri Geological Survey and identified in the subsurface by McQueen (1931) in his pioneer work on insoluble residues. Keroher and Kirby (1948) and others, using the Missouri terms, have extended the identification of these formations into and throughout Kansas.

TABLE 2.—*Late Cambrian formations in Kansas and Missouri*

Missouri	Eastern Kansas
Proctor dolomite	Absent
Eminence dolomite	Eminence dolomite
Potosi dolomite	Absent
Derby and Doe Run dolomites	Absent
Davis formation	Absent
Bonneterre dolomite	Bonneterre dolomite
Lamotte sandstone	Lamotte sandstone

ROCKS OF LATE CAMBRIAN AGE

The Cambrian System is represented in Missouri and Kansas only by rocks of Late Cambrian age. Table 2 shows, in descending order, the sequence of these rocks. Several of the formations present in Missouri wedge out and do not extend into Kansas.

Inasmuch as the oldest Cambrian rocks in Missouri and Kansas belong to the upper part of the system, long exposure and erosion of the land surface must have preceded deposition of the first Cambrian sediments. The Pre-Cambrian surface was reduced to a relatively level plain and the Lamotte sandstone and the overlying Bonneterre dolomite were widely deposited on it. Broad regional topographic relief on the Pre-Cambrian surface, however, is suggested by excessive thickening of the Lamotte sandstone in some areas in Missouri and its absence beneath the Bonneterre dolomite in parts of Kansas.

LAMOTTE SANDSTONE

McQueen (1931) described the Lamotte sandstone as yellow to white sandstone having fine to coarse subangular and rounded grains. It is generally arkosic at the base and in consequence the exact contact between arkosic sand and weathered granite is difficult to determine from cuttings of some wells. The Lamotte sandstone is transitional upward into sandy dolomite at the base of the Bonneterre dolomite.

The Lamotte sandstone has a maximum thickness of 350 feet in southeastern Missouri but thins westward to the Kansas-Missouri line where it has an average thickness of about 100 feet. According to Keroher and Kirby (1948) it continues to thin westward and wedges out east of the Salina basin. They report a thickness of only 6 feet in a well in Wabaunsee County, and report the absence of the Lamotte in a well in Greenwood County where the Bonneterre dolomite rests on granite. The Lamotte is present, however, beneath the Bonneterre in two wells in a synclinal area in McPherson County; in one of these wells (sec. 4, T. 21 S., R. 3 W.) Keroher and Kirby (1948) report 80 feet of Lamotte sandstone, and in the other (sec. 9, T. 17 S., R. 3 W.) Leatherock found approximately 70 feet of this sandstone. Farther west it is absent in an anticlinal area in which the Roubidoux dolomite overlies granite. Northward, the Lamotte is locally absent beneath the Bonneterre but in sec. 22, T. 5 N., R. 1 W. in Nebraska, the Lamotte, overlain by the Bonneterre, is more than 65 feet thick.

Where the Lamotte is absent in broad areas in central Kansas, including part of the area of the Salina basin, the Pre-Cambrian rocks are overlain by the Roubidoux dolomite of Early Ordovician age (cross sections A-A′, Pl. 1; B-B′, Fig. 8). The stratigraphic relations of these rocks suggest that the Lamotte sandstone had originally a broader distribution but was eroded from these areas in pre-Roubidoux time.

BONNETERRE DOLOMITE

The Bonneterre dolomite, which crops out in southeastern Missouri, is present in the subsurface throughout Missouri and most of Kansas but is absent in a considerable area in central Kansas, including part of the Salina basin.

McQueen (1931) describes the Bonneterre as consisting of finely to coarsely crystalline dolomite and magnesian limestone with almost no chert. The dolomite is light colored to brown; it contains disseminated sand and interbedded green and brown shales. Characteristic features are abundant glauconite and the dolomoldic pitting of the shale in the insoluble residues. The Bonneterre in Kansas is similar to the Bonneterre in Missouri, but shale is a less common constituent in the Salina basin than in many localities.

The maximum reported thickness of the Bonneterre in Missouri is 440 feet. Keroher and Kirby (1948) report a thickness of 112 feet in Wilson County in southeastern Kansas and 90 feet in Shawnee County in northeastern Kansas. The Bonneterre is absent on the crest of the Southeast Nebraska arch where, together with younger formations, it was eroded preceding the deposition of the St. Peter sandstone (Lee, 1943, p. 102). It is thin or absent on the southern extension of this arch (Fig. 2A) but thickens again westward where, in sec. 4, T. 21 S., R. 3 W., McPherson County, Keroher and Kirby (1948) found 183 feet of Bonneterre. Leatherock found 170 feet of Bonneterre in a well in northern McPherson County in sec. 9, T. 17 S., R. 3 W. In the Kansas area directly north of McPherson County, no wells have reached the Bonneterre but it is present in southern Nebraska where E. C. Reed (personal communication) of the Nebraska Geological Survey reports Bonneterre dolomite, from 17 to 70 feet thick, in wells within 30 miles of the Kansas-Nebraska line as far west as R. 13 W. Leatherock determined a thickness of 44 feet in a well in sec. 1, T. 1 S., R. 2 E., Washington County, Kansas. The Bonneterre is absent on the arch west of McPherson County where the Roubidoux dolomite overlies granite, but Keroher and Kirby (1948) found the Bonneterre to be generally present farther west in Kansas.

As shown in cross section B-B′ (well 8, Fig. 8) the Eminence dolomite in western Missouri overlaps unconformably upon the Bonneterre. Farther west in Wilson County, Kansas (well 6, Fig. 8), the Bonneterre is unconformably overlain by undivided Van Buren and Gasconade dolomites. In well 5B, Greenwood County, and at other points, it is overlain unconformably by the Roubidoux dolomite. The significance of these unconformities is discussed later in the chapters dealing with structure. It seems probable that the Bonneterre was originally deposited across central Kansas but, like the Lamotte, was eroded from parts of the area as a result of later emergence and exposure.

EMINENCE DOLOMITE

The Eminence dolomite is present throughout most of Missouri but Keroher and Kirby (1948) found it in only limited areas in eastern and western Kansas. It is absent so far as known in the Salina basin except in the deep well in sec. 4, T. 21 S., R. 3 W., McPherson County.

As described by McQueen (1931), the Eminence is a cherty dolomite recognized by large percentages of insoluble residues which consist, in large part, of chert that is so pitted with dolomoldic cavities that it is almost lacelike. The chert, mainly of vitreous luster, is bluish to white. Many fragments are coated with crystalline quartz.

The Eminence has a known thickness of 320 feet in southeastern Missouri but, like other Cambrian formations, it thins westward into Kansas. It is reported by Keroher and Kirby (1948) to have a thickness of 175 feet in Douglas County and 172 feet in Crawford County, but to the west and south it wedges out or is beveled by the Van Buren formation. It has not been recognized in deep wells in Wilson, Greenwood, or Pottawatomie Counties. It is present in limited areas in western Kansas, but the only well on the map of the Salina basin (Pl. 1) in which the Eminence was recognized by Keroher and Kirby (1948) is in sec. 4, T. 21 S., R. 3 W. (well 4B, Fig. 8) in the pre-Roubidoux synclinal basin in McPherson County where it has a thickness of 35 feet.

The Eminence dolomite rests unconformably on the Bonneterre dolomite in Kansas. The magnitude of this stratigraphic break is measured by the absence in Kansas of the Davis formation, the Derby and Doe Run dolomites, and the Potosi dolomite, all of which occur in ascending sequence above the Bonneterre in southeastern Missouri (cross section B-B′, Fig. 8, McQueen, 1931). The Eminence lies unconformably below the undifferentiated Van Buren-Gasconade sequence. The noncherty Proctor dolomite, 225 feet thick, which intervenes between the Eminence and Van Buren in southeastern Missouri, is not recognized in Kansas. The Eminence is overlain in Kansas by the Gunter sandstone member of the Van Buren formation.

Rocks of Early Ordovician Age

The Lower Ordovician formations in Missouri and in Kansas are shown in descending order in Table 3.

VAN BUREN-GASCONADE SEQUENCE

The dolomites lying between the top of the Gunter sandstone member of the Van Buren formation and the Roubidoux sandstone were originally known as Gasconade dolomite. Ulrich (Mc-

TABLE 3.—*Formations of Early Ordovician age in Kansas and Missouri*

Missouri	Kansas
St. Peter sandstone	St. Peter sandstone (equivalent to part of Simpson group of Oklahoma)
Smithville formation (McQueen, 1931, Pl. 12)	Absent
Powell dolomite	Absent
Cotter dolomite Jefferson City dolomite	Undifferentiated Cotter and Jefferson City dolomites
Roubidoux formation	Roubidoux dolomite
Gasconade dolomite Van Buren formation	Undifferentiated Gasconade dolomite and Van Buren formation

Queen, 1931, p. 18), on the basis of paleontology, later restricted the term Gasconade to the upper part and named the lower part, including the Gunter sandstone, the Van Buren formation. McQueen (1931, p. 18) has differentiated the formations lithologically by insoluble residues. They crop out widely on the valley slopes of streams traversing the northern flanks of the Ozark uplift. The formations are difficult to separate, however, in the subsurface in areas far removed from the outcrop, and in Kansas were designated by Keroher and Kirby (1948) as the Van Buren-Gasconade sequence. This sequence was recognized in the subsurface by Keroher and Kirby only in eastern and southeastern Kansas. It is not known to occur north of McPherson County nor west of Wabaunsee County. It is absent in northern Greenwood County (well 5B, cross section B-B′, Fig. 8) where it seems to have been beveled by pre-Roubidoux erosion.

Except for the Gunter sandstone member, the Gasconade and the Van Buren formations consist of cherty dolomite. The cherts of the Van Buren dolomite in the central Ozarks, as described by McQueen (1931), are white, drusy, porcelainlike, and in part oölitic. The chert of the Gasconade dolomite is reported to be bluish gray, blue, or even bluish black and predominantly vitreous and quartzose. The Gunter sandstone at the base of the Van Buren is composed of fine- to medium-grained subangular to rounded, and frosted sand grains. In some wells in Kansas it is a sandy dolomite.

The Van Buren and Gasconade in the Ozark region of Missouri have a combined thickness of about 400 feet. They are much thinner in eastern and southeastern Kansas. According to Keroher and Kirby (1948), they are 100 feet thick in Osage County, 14 feet thick in Wabaunsee County, 228 feet thick in Wilson County, 115 feet thick in Sedgwick County, and 50 feet thick in southern McPherson County.

The unconformity at the base of the Van Buren in Kansas is substantiated by the westward thinning of the underlying Eminence dolomite and by the absence of the Proctor dolomite which in southeastern Missouri directly underlies the Van Buren. Keroher and Kirby (1948) show that the Gunter sandstone in southeastern Kansas overlaps westward beyond the edge of the Eminence dolomite and rests progressively in this direction on the Bonneterre dolomite and the Pre-Cambrian rocks. The contact of the Gasconade dolomite with the overlying Roubidoux dolomite is probably unconformable, although the relations shown in cross section B-B′ (Fig. 8) might be interpreted as an overlap of the Roubidoux onto a pre-Van Buren topographic high.

ROUBIDOUX DOLOMITE

The Roubidoux formation underlies the surface of much of the upland areas of the central part of the Ozark Plateau of Missouri where it is composed of thick beds of sandstone alternating with cherty dolomite. Keroher and Kirby (1948) found the Roubidoux represented in most places in Kansas by sandy dolomite without interbedded sandstone. It is therefore referred to as Roubidoux dolomite in Kansas. The Roubidoux is generally present throughout Kansas but on the crest of the Southeast Nebraska arch it was eroded prior to the deposition of the St. Peter sandstone (cross section A-A′, Pl. 1) and on the Central Kansas uplift it was removed by erosion preceding the deposition of Pennsylvanian rocks.

Sand constitutes from 5 to 80 percent of the insoluble residues of well cuttings but in many samples the sand is so disseminated in the dolomite that the sandy character of the dolomite is not determined without recourse to insoluble residues. The dolomites are cherty. Keroher and Kirby (1948) report that the residues include quartzose and cherty oölites. Traces of bright-green shale are reported in the well cuttings.

The Roubidoux is relatively regular in thickness. Keroher and Kirby (1948) report thicknesses of 175 to 200 feet in southeastern Kansas and 350 feet in some places in western Kansas. In the Salina basin its thickness ranges from 154 to 247 feet.

In Missouri the Roubidoux rests unconformably on the Gasconade (Lee, 1913, p. 33, figs. 3, 4), although the unconformity is obscure. In Kansas, Keroher and Kirby (1948) found that the Roubidoux overlies the Van Buren-Gasconade sequence in eastern and southeastern Kansas; that toward the west it overlaps from these rocks upon Bonneterre dolomite; and that still farther west in parts of the Salina basin it rests on Pre-Cambrian rocks. West of the Salina basin (Pl. 1) Keroher and Kirby (1948) show the Roubidoux overlying the Bonneterre dolomite.

The relation of the Roubidoux to the overlying Jefferson City is uncertain. It is regarded as unconformable in Missouri by McQueen (1931) but Cullison (1944, p. 23) is uncertain. Inasmuch as no consistent boundary has been drawn between these formations in the multitudinous outcrops in Missouri it seems probable that the unconformity separating them is no greater than the many sedimentary interruptions within both formations and that the two formations are in effect conformable.

JEFFERSON CITY AND COTTER DOLOMITES

All the rocks in Missouri between the St. Peter sandstone and the Roubidoux formation were originally called Jefferson City dolomite. Through the paleontological work of Ulrich and others, parts of the original formation were cut off to form the Cotter and younger formations. The Cotter and the restricted Jefferson City were differentiated in the subsurface in Missouri by McQueen (1931) on the basis of insoluble residues. The difficulty of separating these formations by this means in wells in areas distant from the outcrops has resulted in the practice of referring to these rocks as undifferentiated Cotter and Jefferson City dolomites. Cullison (1944), whose approach to the problem was based on both lithologic and paleontologic studies, redefined the Jefferson City of McQueen and raised it to the rank of a group, consisting of two formations, the Rich Fountain formation below and the Theodosia formation above. The Theodosia includes a part of the rocks previously included in the Cotter dolomite.

In Kansas, the undivided Jefferson City and Cotter dolomites were everywhere truncated by erosion so that the original thickness has been materially reduced. According to Keroher and Kirby (1948), this sequence wedges out toward the north in Rooks, Osborne, Mitchell, Cloud, and Clay Counties. It thickens with some regularity toward the south to more than 600 feet near the Kansas-Oklahoma line in Cowley County. A thickness of 360 feet is reported in the well in sec. 4, T. 21 S., R. 3 W. in southern McPherson County. This well was drilled near the pre-Pennsylvanian trace of a thrust fault developed after Mississippian time on the west flank of the Voshell anticline (Bunte and Fortier, 1941, fig. 5). The thickness of the sequence is exceptional for the locality and the well was thus probably drilled through the fault.

In sample logs, the contact of the Jefferson City dolomite with the Roubidoux dolomite is placed by Keroher and Kirby (1948) at the first appearance of sand in the cuttings and residues. Probably no important unconformity occurs at this contact. Throughout most of the Salina basin, the St. Peter sandstone overlies unconformably the Jefferson City-Cotter sequence. The magnitude of this unconformity in Kansas is attested by the absence of the Powell, Smithville, Black Rock, and Everton formations of Arkansas. The Jefferson City-Cotter rocks were raised and thinned by erosion on the Chautauqua arch in pre-Devonian time and again prior to Chattanooga time. They were eroded from parts of the Nemaha anticline and from much of the Central Kansas uplift preceding Pennsylvanian deposition. In consequence the Jefferson City-Cotter sequence in different areas lies unconformably below rocks of many different ages ranging from the St. Peter sandstone of Ordovician age to beds of Pennsylvanian age.

ST. PETER SANDSTONE

The St. Peter sandstone of Early Ordovician age, which crops out in northern Missouri, and the Platteville formation of Middle Ordovician age, as restricted by Kay (1935, p. 288) in outcrops in Iowa, occupy the stratigraphic position of the Simpson group of Oklahoma, but they represent only a part of the Simpson group, which in some places is more than 1,500 feet thick.

In the Salina basin, the St. Peter sandstone consists of three zones (Leatherock, 1945, p. 10). The upper and lower zones consist of sandstone characterized by rounded and frosted sand grains. The middle zone which is of variable lithology consists of (a) green clay shale containing sand grains, (b) interbedded sandstone and shale, or (c) sandstone consisting of finer and less rounded sand grains than those in the upper and lower zones. The middle zone is also characterized locally by disseminated grains of glauconite. Red and brown shale and red and brown ironstone oölites are also found in the middle zone where it overlaps upon rocks older than the St. Peter. This seems to be the red zone described by Dake (1921, pp. 68, 85, 128) at the base of the St. Peter sandstone in certain wells in Minnesota and Illinois and in some exposures in Missouri, and is the middle zone in other areas of these states (Dake, 1921, pp. 24, 86, 99).

The thickness of the upper zone ranges from 15 to 45 feet, the middle zone from 10 to 30 feet, and the lower zone from 15 to 50 feet. Where only one sand zone composed of rounded grains is present, it is impossible to determine from the cuttings whether this sandstone represents the upper or lower zone.

The St. Peter sandstone has an irregular thickness, ranging from 10 to 90 feet; however, greater thicknesses are known in some places. The sandstone is notably thin in wells in Smith and Jewell Counties where it is 10 to 13 feet thick and in Riley and Pottawatomie Counties where it is 10 to 15 feet thick. Both these areas lie on the margin of the North Kansas basin where more or less continuous upward movements may have taken place during St. Peter time. The variations in the thickness of the St. Peter, however, are probably due mainly to erosional irregularities of the beveled surface upon which the St. Peter was deposited or to deposition in sink holes as in the Kasper No. 1 James well in sec. 8, T. 13 S., R. 25 E. in Johnson County where it is 403 feet thick. There were also slight local structural movements at the end of St. Peter deposition and an erosional unconformity preceded the deposition of the overlying Platteville rocks (Leatherock, 1945, pp. 11-12). Regional unconformity between the Platteville and the St. Peter is revealed by the presence in southeastern Missouri and southern Illinois of a thick sequence of formations which are not present in Kansas (Lee, 1943, p. 32).

Rocks of Middle and Late Ordovician Age

The following Ordovician formations above the St. Peter sandstone, listed in descending order, are recognized in the Salina basin.

- Late Ordovician
  - Maquoketa shale (equivalent to Sylvan shale of Oklahoma)
- Middle Ordovician
  - Kimmswick limestone (equivalent to part of the Viola limestone of Oklahoma)
  - Platteville formation (equivalent to part of the Simpson group of Oklahoma)

The North Kansas basin was the dominant structural feature under development between the deposition of the St. Peter sandstone and the Mississippian limestones. The variations in thickness and lithology of the rocks deposited during this time interval were closely related to the subsidence of this basin. Frequent references are made, therefore, to the central and marginal areas of the North Kansas basin in discussing the lithology of this sequence of rocks. The Salina basin, which did not come into existence until after Mississippian time, was formed on the southwestern flank of the North Kansas basin. All references to the Salina basin prior to the end of Mississippian time are therefore geographical and refer to the area in which the Salina basin was later developed and not to the Salina basin as a structural feature.

PLATTEVILLE FORMATION

The upper part of the sequence of Simpson age in the Salina basin has been correlated by Leatherock (1945, pp. 12-14) with the Platteville formation of Iowa. In northeastern Kansas, the Platteville consists of a variable sequence of green clay shale and minor amounts of interbedded limestone, dolomite, and sandstone, but the basal member is a persistent bed of dolomite. This dolomite is composed mainly of sucrose or granular dolomite but some wells reveal local variations of interbedded earthy limestone of lithographic texture. In some wells disseminated rounded grains of sand occur in parts of the dolomite, and interbedded green clay shale has also been noted. The thickness of the basal dolomite in the area of the Salina basin ranges from 5 to 35 feet.

The variable 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 with about 5 feet of sandstone at the base. Toward the northwest the sandstone grades into green shale.

The Platteville thickens toward the northeast into the deeper part of the North Kansas basin in southeastern Nebraska where the upper part of the Platteville is composed mainly of coarsely granular and earthy limestone and sucrose dolomite interbedded with minor amounts of green clay shale, thin sandstone, and rarely some red shale. The upper part of these limestones and dolomites is probably younger than any part of the Platteville in the Salina basin. In the deeper part of the North Kansas basin the predominant dolomite and limestone of the lower part of the Platteville seem to interfinger with the shales, sandy shales, and sand on the margin of the basin.

The subdivision of the Platteville limestone in the outcrops in Iowa and Illinois is dependent largely on paleontologic criteria which are not available in samples from the subsurface. The lithologic variations observed in the Salina basin are the expression of advance and retreat of the shoreline of the North Kansas basin which caused intraformational disconformities at least on the margin of the basin.

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 somewhat irregularly toward the margin. It is 60 feet thick in Pottawatomie County, 20 to 30 feet thick in Dickinson and Saline Counties, and wedges out on the margin of the basin in parts of Marion and McPherson Counties on the southwest and in Douglas County on the south.

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 zones of the St. Peter in different areas. The unconformity is expressed regionally by the absence in Kansas of the Stones River limestone, the Joachim dolomite, and the Dutchtown formation of the Missouri section which have an aggregate thickness in southeastern Missouri 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 at or about sea level.

The Platteville is unconformably overlain by the Kimmswick limestone of Missouri. This unconformity is expressed in the North Kansas basin by the irregular thickness of the Platteville and by the fact that in the deeper part of the basin, the Kimmswick overlies younger deposits of Platteville age, and toward the southwestern margin of the basin in Kansas progressively overlaps the basal dolomite member and the St. Peter sandstone (cross sections A-A′, Pls. 2 and 4; Leatherock, 1945, pl. 1).

KIMMSWICK LIMESTONE

The Kimmswick limestone, which is named for outcrops in southeastern Missouri, is widely distributed in the surface and subsurface in the Mississippi Valley. It is equivalent to at least part of the Viola limestone of Oklahoma and is equivalent also to part of the Galena limestone, which extends northward to Minnesota. In northern Illinois and Iowa, the Galena is treated as a group and is subdivided, in ascending order, into the Prosser limestone, Stewartville dolomite, and Dubuque formation, mainly by fossils. Inasmuch as stratigraphic units can be recognized in the subsurface only by their lithological characteristics as revealed in the cuttings from wells, these lithologically similar formations cannot be differentiated with confidence in places far removed from outcrops. In parts of Nebraska where rocks of Galena age are thicker than in Kansas, the Nebraska geologists have tentatively identified the formations recognized in Iowa. It seems probable that in northeastern Kansas only the Prosser limestone is represented. The Missouri name for these rocks is used in this report because the Kimmswick limestone of that state has been traced in the subsurface across northern Missouri to the border of northeastern Kansas by McQueen and Greene (1938) and because this unit in Kansas more closely resembles the Kimmswick of Missouri than the Viola of Oklahoma.

The Decorah shale of Iowa, which comprises the Ion and Guttenburg members, lies between the Platteville formation and the Galena limestone. These members have not been identified in Kansas. If they are present as shaly or sandy beds, they are included in the Platteville in the thickness maps, and if represented by a calcareous phase, they are included in the basal Kimmswick. Their combined thickness in outcrops is reported at only about 30 feet (Kay, 1928, p. 16), but in view of the overlap and unconformity at the base of the Kimmswick, the Decorah may not be represented in Kansas. In southeastern Nebraska and northeastern Kansas, the Kimmswick is conveniently divided into four zones of alternating cherty and noncherty or sparsely cherty dolomite. Some limestone is interstratified with the dolomite in central Kansas toward the southwestern margin of the North Kansas basin.

The Kimmswick limestone, as a whole, reaches a maximum known thickness of 310 feet in sec. 1, T. 1 S., R. 2 E., Washington County, Kansas. It is 272 feet thick on the Kansas-Nebraska line in sec. 31, T. 1 N., R. 1 E., Jefferson County, Nebraska (well 10, Pl. 2). It thins as a whole with considerable regularity toward the southwestern margin of the North Kansas basin. In T. 24 S., R. 2 W., Harvey County (well 1, Pl. 2), where only the second of the four zones of the Kimmswick has survived, its total thickness is only 20 feet.

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

The unconformity between the Platteville and the Kimmswick is revealed mainly by the variable thickness of the underlying Platteville (Leatherock, 1945, Pl. 1). This unconformity seems to be of minor importance in Kansas but the regular beveling of the Platteville indicates an exceptionally well-developed flat surface. The upper surface of the Kimmswick is separated from the overlying Maquoketa by a marked unconformity indicated by the progressive overlap of the Maquoketa from the fourth zone of the Kimmswick in southeastern Nebraska upon the third and second zones on the southwestern flank of the North Kansas basin. It is probable that the younger formations of Trenton age, the Dubuque and Stewartville, which have been tentatively recognized in the deeper part of the North Kansas basin in Nebraska (Condra and Reed, 1943, pp. 68-69) were laid down throughout the northern midcontinent region but that almost the whole of this sequence was eroded from the southwestern flank of the basin before the deposition of the Maquoketa shale.

The four zones of the Kimmswick limestone are described below in ascending order of age.

First zone.—The first zone extends from the top of the Platteville to the top of a thin cherty bed that separates it from the second zone. In the deeper part of the North Kansas basin, where the deposits are thickest, the first zone consists almost entirely of dolomite, but toward the southwestern margin of the basin this zone is composed of interbedded granular dolomite and earthy limestone. The upper 10 to 20 feet contains sparsely disseminated coarse rounded grains of sand.

The cherty bed at the top of the first zone is 10 to 15 feet thick and includes 2 to 10 percent chert. The chert is buff to brownish buff and is characterized by matted texture owing to the silicification of vast numbers of broken micro-organisms and spicules that accumulated in the original sediments. The first zone is 45 feet thick in the Ebke No. 1 Mathies well in sec. 22, T. 5 N., R. 1 W., Nebraska, near the center of the North Kansas basin, but becomes thinner toward the south and southwest and wedges out in Harvey County as shown in well 1 of cross section A-A′, Plate 2. On the southwestern margin of the North Kansas basin, it is overlapped by the second zone.

Second zone.—Toward the north, the second zone consists of sucrose and granular dolomite and chert but, toward the south and west, the dolomite is interbedded with earthy and granular limestone. On the southwestern margin of the North Kansas basin (cross section A-A′, Pl. 2) where the second zone overlaps the first and rests on either the Platteville or the St. Peter, coarse rounded grains of sand are sparsely disseminated in the basal

10 to 15 feet. The disseminated sand in the lower part of this zone continues basinward above the first zone but does not reach so far northward into the basin as the sand in the first zone.

The upper and middle parts of the second zone are very cherty. The chert is in part gray or buff and microscopically massive. Much of the chert, however, is characterized by traces of imbedded fragments of spicular and tubelike micro-organisms either black or of dark shades which are in contrast with the lighter-colored matrix. Part of the filling of the black tubular fragments is pyrite but part is siliceous. This type of chert with its black and dark flecks is characteristic of the second and third zones of the Kimmswick in the Salina basin.

In the northeastern part of the area shown on Plate 2, the cherts of the second zone occur in two well-defined beds which are separated by a noncherty bed as shown in well 11 of the cross section. This sequence was described by Lee (1943, pp. 38-39) in northeastern Kansas and by McQueen and Greene (1938, pp. 40-42) in northwestern Missouri as the middle zone of the Kimmswick. Toward the west, in the area of the Salina basin, however, the lower chert bed of this middle zone fades out and cannot be used to mark the base of the middle zone. The second zone of this report, in consequence, is extended down to the top of the matted chert bed of the first zone and thus includes noncherty beds that were considered to be below the middle zone of previous reports. The chert in the cherty beds of the second zone amounts to 20 to 80 percent of the samples. Where both chert beds are present the upper one is 10 to 35 feet thick and the lower 5 to 35 feet thick. They are separated by 45 to 65 feet of noncherty dolomite. The noncherty bed at the base of the second zone is 25 to 60 feet thick.

The second zone reaches a maximum known thickness of 153 feet in the Mathies well in T. 5 N., R. 1 W., Nebraska (well 11, Pl. 2). It thins somewhat irregularly toward the southwestern margin of the North Kansas basin and, as shown in cross section A-A′ (Pl. 2), is 55 feet thick in T. 18 S., R. 1 W. (well 26) in the area in which it is overlain by the third zone.

Third zone.—The carbonate rocks of the third zone, as in the other zones, consist of granular dolomite to the north. South of T. 4 S., R. 2 E. (well 8, Pl. 2) earthy and granular limestone is interstratified with granular and sucrose dolomite. The chert, which is present in its upper part, is more variable in lithologic character than the chert in the first and second zones and comprises 20 to 100 percent of the samples. The chert in the third zone, like that in the second, is characterized by dark and black flecks but it includes also much opaque and grainy chert, for the most part white and gray. Toward the deeper part of the North Kansas basin, other types of chert occur in this zone, such as curdled chert, chert with matted texture, similar to but less distinctive than that in the first zone, and in some wells soft white chert resembling tripoli. The cherty phase at the top of the third zone occurs only where the zone is relatively thick. The cherty beds are from 10 to 35 feet thick and increase irregularly in thickness toward the center of the North Kansas basin. Toward the margin of the basin, the cherty beds were removed by beveling and in this direction the lower noncherty beds are capped by the Maquoketa shale as shown in Plate 2.

The maximum known thickness of the third zone is 101 feet in T. 1 N., R. 1 E., Jefferson County, Nebraska (well 10, Pl. 2). Toward the south, as shown in the cross section, the third zone thins irregularly to thicknesses ranging from 45 to 15 feet. In T. 21 S., R. 1 W. (well 24) it is overlapped by the Maquoketa shale which is there in contact with the second zone. The third zone, which was probably originally deposited throughout a broader area, is in consequence now absent on the margin of the North Kansas basin.

Fourth zone.—A fourth and higher zone—consisting mainly of dolomite and minor amounts of chert—is recognized above the third zone in the central area of the North Kansas basin in Nebraska, but this zone is not present in the Salina basin.

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 also 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, and southward its equivalent, the Sylvan shale, occurs throughout most of eastern Oklahoma. In Iowa, the Maquoketa was subdivided by Calvin (1906) into the following formations listed in ascending order: Elgin limestone, Clermont shale, Fort Atkinson limestone, and Brainerd shale, but these subdivisions have not been identified in north-central Kansas.

The Maquoketa shale in north-central Kansas is composed of very silty dolomite or dolomitic silt and silty dolomitic shale. In some areas beds of very cherty dolomite occur near the top of the formation and in others the shale is argillaceous and only slightly dolomitic. Silty dolomite predominates in the northern part of the Salina basin and toward the center of the North Kansas basin. In the southern part of the Salina basin, the dolomite facies grades laterally through dolomitic silty shale to nonsilty only slightly dolomitic shale.

In T. 5 N., R. 1 W., Nebraska (well 11, Pl. 2) the Maquoketa is 105 feet thick and consists of silty dolomite with minor amounts of interbedded silty shale. Farther south in the Wolf Creek Oil Company No. 1 Brenizer well, sec. 35, T. 12 S., R. 2 E., the Maquoketa is 95 feet thick but, except for the upper 10 feet of silty dolomite, it consists of dolomitic shale. In the Auto-Ordnance Corporation No. 1 Ruch well in sec. 25, T. 13 S., R. 2 W., however, the Maquoketa, 100 feet thick, is composed entirely of shale. In the northern and northeastern parts of the area shown in Plate 2, the rocks of the upper 10 to 20 feet of the dolomite facies are interbedded with gray chalcedonic chert and silty shale. The chalcedonic chert is found only in areas where the Maquoketa is of less than the average thickness and has not been observed where the dolomitic phase of the Maquoketa is thick or where the Maquoketa consists mainly of shale. These facts suggest that the cherty beds are the result of cementation of especially silty dolomite under conditions of erosion and weathering (Fig. 3A). The upper 28 feet of the Maquoketa (total thickness 78 feet) in the Transcontinental No. 1 Acker well in sec. 1, T. 12 S., R. 4 E. consists of indurated highly silty shale resembling gray opaque chert, which is interbedded with gray chalcedonic chert. This indurated shale may be the result of weathering of very silty dolomite and silty shale.

The shale varies considerably in color. It is generally green and light gray in the upper part and medium to dark gray in the lower part. In some wells, however, the shale is greenish gray throughout. Glauconite is uncommon but occurs sparingly in wells in the northern part of the area. It was noted throughout the upper 49 feet of shale in the Boyle Grossman Drilling Company No. 1 Bonham well in sec. 31, T. 1 N., R. 1 E., Nebraska.

The insoluble residues of the dolomitic facies of the Maquoketa consist of 5 to 15 percent of silt and silty sponge. Probably considerable silt was lost in the washing of the residues. The insoluble residues of the shales approach 100 percent and generally include one-half to 2 percent silt. The insoluble residues of the shale from all parts of the formation are nearly everywhere dolomoldic. The cherty zones yield large residues of dolomoldic chert. Some geologists have referred dolomitic rocks at the top of the Maquoketa to the overlying Silurian but the dolomite in this position is distinguished from the Silurian by the silt or by the dolomoldic chert of the insoluble residues.

The Maquoketa shale does not thicken toward the central part of the North Kansas basin, like the Platteville and Kimmswick below and the Silurian and Devonian rocks above, although it may once have done so. The thickness of the Maquoketa, where it is overlain by Silurian rocks, ranges irregularly from 155 feet in the Appleman Oil Company No. 1 McManus well in sec. 29, T. 15 S., R. 6 W., Ellsworth County, to 40 feet in the Gulf Oil Corporation No. 1 Baker well in sec. 1, T. 1 S., R. 2 E., Washington County.

The Maquoketa is thin in a belt extending northward from Marion County where it is 80 feet thick in the White Eagle Oil and Refining Company No. 1 Ucker well in sec. 24, T. 17 S., R. 2 E., and 40 feet thick in the well in Washington County mentioned above. East of this belt its thickness increases to 110 feet in sec. 6, T. 15 S., R. 7 E. and toward the west to 155 in Ellsworth County in the Appleman Oil Company No. 1 McManus well. In the McManus well, part of the increase seems to be at the expense of the underlying Kimmswick. The trend of the belt of thinning corresponds roughly to the trend of a belt of thick Silurian rocks above and thus suggests a pre-Silurian erosional basin.

Although it is probable that there was some topographic relief on the pre-Maquoketa surface of the Kimmswick, the relations of the thickness of the Maquoketa and the Silurian strongly suggest that most of the variations in thickness of the Maquoketa are due to topographic relief on its upper surface. The Maquoketa is absent in wells in southwestern Smith County and northwestern Osborne County (Pl. 4), where the Silurian rocks overlapped the eroded surface of the Maquoketa onto the Kimmswick. The unconformity between the Maquoketa and the overlying Silurian rocks is revealed also in the Arab Petroleum Company No. 1 Ogle well in sec. 9, T. 1 N., R. 14 E. in Nebraska. In this well, the Maquoketa is thinner than is common for this locality and is separated from the Silurian dolomites by a 12-foot zone of red shale in which ferruginous oölites are imbedded. Du Bois (1945, p. 13), who noted topographic relief at the top of the Maquoketa in Illinois, reports similar ferruginous oölites between the Maquoketa and the Silurian limestones of Illinois, Iowa, and Wisconsin, but they are uncommon in areas adjacent to Kansas.

In north-central Kansas, the topographic relief on the pre-Silurian surface over a broad area may have reached 100 feet, but within the area of one or two townships, the relief in few places exceeded 25 feet.

The area in which the Maquoketa was deposited was originally more extensive than the area now underlain by it in northeastern and central Kansas. Pre-Silurian erosion removed the Maquoketa from parts of Osborne and Mitchell Counties; pre-Devonian erosion beveled the Silurian, Maquoketa, and older rocks on the southwestern and southeastern borders of the North Kansas basin (Pl. 4; Lee, Grohskopf, Reed, and Hershey, 1946, sheet 2); pre-Chattanooga erosion cut a valley in McPherson and adjoining counties and removed the Maquoketa from part of the area (Pl. 5); and pre-Pennsylvanian erosion removed it from the crest of the northern end of the Nemaha anticline (Pl. 8).

Rocks of Silurian Age

The limestones and dolomites lying between the Maquoketa shale and the Chattanooga shale are conveniently referred to as Hunton formation or group by oil operators and many geologists. Study of this sequence has revealed that it consists of rocks of Silurian and Devonian age. Unconformities at the bottom and top of both the Silurian and Devonian have so modified 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 limestone and dolomite 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, 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, 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. In Oklahoma, the Brassfield equivalent 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, pp. 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 are widely distributed in the subsurface. It was probably originally deposited throughout the region from the outcrops in the Mississippi Valley across the Ozarks to western Kansas and western Oklahoma. Upwarping and erosion have removed all the Silurian rocks from the crests of anticlinal structures in Kansas such as the Chautauqua arch, the Nemaha anticline, and the Central Kansas uplift, and from comparable structural features in adjoining states.

The Silurian rocks lie unconformably on the Maquoketa except in parts of Smith and Osborne Counties where they overlap upon the Kimmswick (Pl. 4), but without determinable angular unconformity. The Devonian is separated from the Silurian by an important unconformity, which not only beveled the Silurian but also all the underlying formations down to the Lower Ordovician dolomites. Pre-Devonian erosion left hills of Silurian dolomite in two areas in Dickinson County. The Devonian rocks probably covered these hills but they were re-exposed by pre-Chattanooga erosion.

In the Salina basin, the Silurian rocks consist chiefly of dolomite but include some limestones. They are conveniently separated into five zones on the basis of physical character, siliceous residues, and foraminiferal remains. The overall thickness of the Silurian rocks in northeastern Kansas ranges from a featheredge to 435 feet in the Lamparter well (well 14, Pl. 3), but their thickness is even greater at places in southeastern Nebraska. The maximum thickness observed in the Salina basin is 315 feet in the Arkansas Fuel Oil Company No. 1 Martin well in sec. 24, T. 8 S., R. 4 E.

Erosion and weathering of the surface of the Silurian rocks in pre-Devonian time probably developed porosity at and near the surface of the exposed rocks. For the most part, the degree of porosity in limestones and dolomites can only be inferred from the abundance of microscopic cavities in the cuttings but small interstitial openings are present in many rocks away from the larger openings. Unfortunately the more important larger pores are not clearly revealed by the cuttings except occasionally when sizable rock fragments are recovered in cores or by chance specimens recovered in drilling. The cavities developed in the Silurian rocks seem to have been rather generally filled and re-cemented later by the circulation of calcareous waters from the overlying Devonian limestone, although in many localities the openings were not completely sealed. In parts of the area the Silurian rocks were re-exposed by pre-Chattanooga erosion and, as the Chattanooga shale is generally not calcareous, the porosity developed in pre-Chattanooga time survived in most places. The tops of the first and second zones where these underlie the Chattanooga shale are generally porous.

Porosity is not confined to the top of the Silurian. In the first zone interstitial openings occur between the oölites in many wells. Throughout the third zone interstitial porosity is general in the deeper part of the North Kansas basin but is less common toward the margin. Porosity of this kind occurs also in the fourth zone to depths of 10 to 60 feet below its contact with the Devonian. It occurs in the middle of the fourth zone in the B. B. Blair No. 1 Cox well in sec. 10, T. 4 S., R. 7 E. and in the basal 15 feet of the zone in the Derby No. 1 Neimoller well in sec. 19, T. 10 S., R. 3 E. The upper 5 feet of the fourth zone is porous in the Ohio Oil

Company No. 1 Lamparter well in sec. 3, T. 2 S., R. 14 E. where the fourth zone is overlain by a thick section of the fifth zone.

Oil stains and flecks and stringers of asphalt occur 120 feet below the top of the Silurian in 5 feet of porous dolomite below cherty limestone at the top of the second zone in the Auto-Ordnance Corporation-Helmerich and Payne No. 1 Gekler well in sec. 20, T. 12 S., R. 2 W. Oil stains were also noted 25 feet below the top of the Silurian in 5 feet of dolomite below the chert of the fourth zone in the E. S. Adkins No. 1 Weis well in sec. 32, T. 14 S., R. 2 W.

The five zones into which the Silurian rocks have been divided are described below in ascending order.

First zone.—The first zone immediately overlies the Maquoketa shale and extends upward to the top of rocks enclosing dolomitized oölites. It corresponds to the oölitic zone of the report on the Forest City basin in Kansas (Lee, 1943, p. 46). It is composed of crystalline and sucrose dolomite throughout and is characterized by dolomitized oölites which occur in variable amount in different wells and in different parts of the zone, but some parts of the zone have few or none. The oölites are roughly spherical grains composed of sucrose dolomite. The surface of the oölites is rough and in some samples the oölites resemble granular cuttings of soft sucrose dolomite that have become rounded in drilling. Many of the oölites are broken. Some samples from rotary wells expose the oölites touching one another in cross section. The interstitial cavities between the oölites are angular, with concave walls and in some samples these cavities indirectly reveal the oölitic nature of the rock. The concentric banding usual in oölites has been destroyed by recrystallization.

The amount of insoluble residues of the first zone is very small in most wells and consists generally of particles of clear hackly quartz but in the following wells, in all of which this zone is relatively thin (5 to 30 feet), small amounts of oölitic chert were noted: 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 general, the first zone becomes thinner toward the southwestern margin of the North Kansas basin but there are local areas in the deeper part of the basin also where it is thin. In the B. B. Blair No. 1 Cox well in sec. 10, T. 4 S., R. 7 E., the first zone is 7 feet thick and in the Carter No. 1 Stratigraphic test in sec. 16, T. 7 S., R. 2 W., it is 10 feet thick. In well 3 of Plate 3 and in other parts of the marginal areas of the basin, it wedges out locally and is overlapped by the second zone. The variation in the thickness and in the abundance of the oölites in the rocks of this zone is probably due to topographic relief on the surface of the Maquoketa. The first zone is absent in some areas but where present ranges from 5 to 65 feet in thickness.

Second zone.—The second zone, which is characterized by white chert, extends from the top of the oölitic dolomite to the top of the cherty dolomite. It is the equivalent of the white chert zone described in the adjacent Forest City basin in Kansas. It consists mainly of crystalline dolomite throughout the deeper parts of the North Kansas basin but toward the southwestern margin it is interbedded with increasingly larger proportions of coarse semigranular limestone and earthy limestone, but does not at any place lose all the dolomite. The volume of the white opaque chert in the samples ranges from 5 to 20 percent. Where the second zone is thick the chert occurs in greatest abundance in the upper two-thirds of the zone but where the zone is thin the cherty phase lies on the first zone. The noncherty dolomite beds at the base of the second zone are similar to the dolomite in the underlying oölitic zone except for the absence of oölites. It is possible therefore that this material represents a part of the first zone in which oölites were not developed. The second zone nearly everywhere overlies the oölitic zone but in the Nathan-Jones et al. No. 1 Robertson well in sec. 27, T. 14 S., R. 2 W. (well 3, Pl. 3) and in some other wells near the margin, the second zone, in the absence of the oölitic beds, is in contact with the Maquoketa shale. Anhydrite was noted in minor amounts in the Forest City basin to the east (Lee, 1943, p. 46) but none was detected in the cuttings from the Salina basin. The second zone is the most regular in thickness of the several zones of the Silurian, and for this reason and because its distribution is co-extensive with the Silurian as a whole, its top was used as the datum for correlating the Silurian in the cross sections of Plate 3. Its observed thickness ranges from 27 to 45 feet.

Third zone.—The third zone extends from the top of the cherty dolomite of the second zone to the base of a well-developed siliceous zone above. This zone includes the foraminiferal zone described in the Forest City basin report. The foraminiferal zone of that area has no well-defined upper limit and in the Salina basin the third zone is extended upward to the most definite datum, the base of the siliceous rocks of the fourth zone.

The third zone, like so many other units deposited in the North Kansas basin, consists entirely of dolomite in the central part of the basin but is increasingly interstratified with limestone toward the southwestern margin. The dolomite of the third zone is generally sucrose in contrast to the adjacent zones above and below, which are generally granular. The lower 5 to 35 feet of this zone includes, in some wells, minor amounts of interbedded pink and reddish dolomite, pink and red earthy limestone, and white coarsely granular limestones with imbedded pink grains.

Chert is conspicuously absent in the third zone but the residues reveal small amounts of silt rarely exceeding 1 to 2 percent but some samples include as much as 5 or 6 percent of silt with traces of hackly and drusy quartz. The lower part of the zone is characterized by the presence of Foraminifera of species resembling *Lituotuba* and *Ammodiscus* described by Ireland (1939) from the Silurian of Oklahoma. The Foraminifera are diffusely distributed in the dolomite and are rarely recognizable in the untreated samples except as tubular fragments on the face of cuttings. The residues from 5-gram samples from the foraminiferal rocks rarely yield more than 5 or 6 specimens and some contain none. The demonstrable thickness of the foraminiferal bed is 95 feet in the Coronado No. 1 Parks well in sec. 16, T. 10 S., R. 8 E. Elsewhere, Foraminifera have rarely been noted more than 40 feet above the base. The lower part of the third zone is marked by the presence of imbedded grains of glauconite.

The third zone is 165 feet thick in the Ohio Oil Company No. 1 Lamparter well in sec. 3, T. 2 S., R. 14 E. near the center of the North Kansas basin. The thickness decreases with considerable regularity toward the margin of the basin as shown on Plate 3. It is only 55 feet thick in well 4 of the cross section.

Fourth zone.—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, including both quartzose and cherty materials, are extremely variable in character and volume. The quartzose residues consist of quartz crystals, hackly quartz, drusy quartz, siliceous sponge, and silt. The cherty residues of this zone include grainy opaque chert, semiopaque chert, soft white opaque chert resembling tripoli, and in certain areas much varicolored chalcedonic chert.

The quartzose residues which predominate in the basinward areas range in volume from traces to 10 percent, and the quartz crystals are confined to the upper 5 to 40 feet. These materials, particularly the quartz crystals when present, identify the fourth zone in the basinward areas. Toward the margin of the basin the quartzose residues diminish in volume and disappear and the residues become increasingly cherty. Near the western margin of the basin, samples from the fourth zone consist almost entirely of chert much of which is chalcedonic, as in the Carter Oil Company No. 8 Stratigraphic test in sec. 21, T. 11 S., R. 8 W. where the zone is 65 feet thick and in the Dickey Oil Company No. 1 Eckart well in sec. 24, T. 11 S., R. 7 W. where the zone is 75 feet thick.

The fourth zone maintains a regular thickness of 65 to 75 feet. Toward the south and west, however, it has been beveled by pre-Devonian erosion and in some places is cut out in the pre-Chattanooga valley of Marion and McPherson Counties.

Fifth zone.—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 thinner or absent toward the south and west on account of pre-Devonian beveling.

Rocks of Devonian Age

The outcrops of Devonian rocks nearest to the Salina Basin are in central Missouri where the oldest are of Middle Devonian age (Branson, 1923, pp. 19-47; 1941). Although the Devonian formations appear at the surface in separated outcrops of small thickness, Branson (1944, pp. 131, 151) has determined the following sequence of formations of Middle Devonian age in northern Missouri in ascending order: Cooper limestone, Ashland limestone, and Callaway limestone. These formations are separated from one another by disconformities. The Upper Devonian is represented by the Snyder Creek shale, which lies disconformably on the Callaway in outcrops.

The Cooper limestone of the outcrops consists mainly of bluish-gray lithographic limestone, is sparingly fossiliferous, and encloses sparsely disseminated rounded and frosted grains of sand. The base of the Cooper is nearly everywhere characterized by a bed of sandstone, calcareous sand, or sandy limestone which is useful in determining the base of the Devonian in the subsurface. The Ashland and Callaway limestones are granular and more fossiliferous than the Cooper and only the basal bed of the Cooper just described can be differentiated in the subsurface. The Snyder Creek shale, which is represented only locally at the surface, has not been identified with certainty in the subsurface far from the outcrop.

The lithographic limestone of the Cooper with its basal sandy bed has been traced in the subsurface westward from the outcrops to Douglas and Jefferson Counties in northeastern Kansas. Farther north, in the deeper parts of the North Kansas basin, the Cooper limestone and the overlying undifferentiated limestones of probable Callaway age become dolomitic by lateral gradation into, and interfingering with, dolomite beds and thus lose the lithology of the outcrops except that the basal bed is nearly everywhere sandy or includes disseminated grains of rounded or frosted sand. In the deeper parts of the North Kansas basin, the rocks of unquestioned Devonian age, including the basal sandy beds of the Cooper, are dominantly dolomitic but in the southwestern part of the North Kansas basin, which later became the Salina basin, limestone correlated with the Cooper occurs alone or interbedded with dolomite. The Devonian rocks of the Salina basin are divided conveniently into upper and lower zones by a bed of cherty or siliceous dolomite in the top of the lower zone.

The Devonian dolomites and limestones in eastern Kansas, including both the lower and upper zones, have a maximum thickness of 215 feet in the Ohio Oil Company No. 1 Lamparter well (well 14, Pl. 5) although they become considerably thicker in parts of southeastern Nebraska. They are 155 feet thick in the

Veeder Supply and Development Company No. 1 Gravenstine well in sec. 21, T. 8 S., R. 6 E. They thin toward the southwest where they are absent in a deep pre-Chattanooga valley in Marion and McPherson Counties. The Devonian has a thickness of 30 feet in the Gled No. 1 "B" Franz well (well 2, cross section A-A′, Pl. 5) and is generally erratic in thickness or absent toward the southwest on account of pre-Chattanooga topography. It is worthy of comment that, in a number of wells (wells 2, 3, 24, and 28, cross section A-A′, Pl. 5), the uppermost Devonian rock is the cherty bed at the top of the lower zone which seems to have offered enough resistance to prevent the erosion of this zone in certain areas.

Pre-Devonian erosion beveled all the rocks from the Jefferson City to the Silurian and reduced the surface of the North Kansas basin to a plain of low relief but the stratigraphic relations of the older rocks to the Devonian were obscured in some areas by post-Devonian erosion. Plate 4 shows the restoration of the pre-Devonian outcrops as they appeared before they were altered by pre-Chattanooga and pre-Pennsylvanian erosion.

Pre-Chattanooga erosion in the North Kansas basin again beveled the rocks, this time from the Jefferson City to the Devonian. Erosion also cut a broad deep valley below the beveled surface in Marion and McPherson Counties and left an outlier of Devonian rocks in Harvey County. Plate 5 shows the areal geology of the pre-Chattanooga surface. Inliers of Silurian rocks in Dickinson County represent pre-Devonian hills, originally covered by Devonian rocks but re-exposed by pre-Chattanooga erosion. Post-Mississippian erosion again beveled the region and in some places, as shown on Plate 8, re-exposed the Chattanooga shale and removed or reduced the thickness of the Devonian.

It might be expected that the eroded surface of the Devonian dolomite underlying the unconformable Chattanooga shale or the Pennsylvanian rocks would have developed and preserved a porous zone of weathering. However, many beds of Devonian dolomite are extremely dense and this density except in some parts of the section has prevented the development of porosity in the zone of weathering. Porosity was noted in the upper 40 feet in the Arkansas Fuel Company No. 1 Martin well in sec. 24, T. 8 S., R. 4 E.; in the 10 feet remaining after pre-Chattanooga erosion in the Auto Ordnance Corporation-Helmerich and Payne

No. 1 Gekler well in sec. 20, T. 12 S., R. 2 W.; and in the thin remnant remaining in the Helmerich and Payne No. 1 Verhage well in sec. 2, T. 7 S., R. 11 W. in which the Devonian dolomite is overlain by Mississippian limestone. Pin point porosity occurs throughout a 30-foot bed of sucrose dolomite, 37 feet below the top of the Devonian dolomite, in the Turner et al. No. 1 Umscheid well in sec. 32, T. 8 S., R. 9 E. Porosity occurs also in the local sandstone immediately underlying the cherty dolomite member of the lower zone 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, where water was reported. Porosity occurs also in many wells where the basal sandy bed is a 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.

Lower zone.—The lower zone of the Devonian rocks includes a sandy bed at the base and extends upward to the top of a sequence of cherty beds. In the central part of the North Kansas basin, the lower zone consists of dolomite of sucrose texture, but toward the southwestern margin of the North Kansas basin, as toward the southeastern margin, some limestone is interbedded with the dolomite. In the Phil-Han Oil Company No. 1 Currie well in sec. 10, T. 15 S., R. 1 W., the lower 40 feet of this zone consists of semigranular limestone interbedded with thin sheets of sucrose dolomite. The sandy bed at the base of the lower zone is dolomitic except in a few wells toward the southwestern margin of the North Kansas basin, as in the Currie well in which the sandy bed is calcareous. The imbedded sand grains are rounded and frosted and constitute from a trace to 40 percent of the volume of the sample. Occasional disseminated grains of similar sand occur erratically throughout most of the lower zone. In some places the rocks immediately below the cherty dolomite bed at the top of the lower zone are conspicuously sandy, as in the Scow Bros. et al. No. 1 Gates well, in sec. 16, T. 9 S., R. 4 E., where 20 feet of dolomitic sandstone with some green clay shale immediately underlies the cherty bed. Considerable sand, up to 20 percent of the sample, 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 sand also occurs in some other wells in varying amounts well above the basal sandy bed.

The bed at the top of the lower zone is cherty dolomite, 10 to 35 feet thick, in which insoluble residues form 10 to 80 percent of the samples. Part of the chert is gray and opaque with textures varying from massive to grainy and part is white and soft and resembles tripoli. The cherty bed in the Turner et al. No. 1 Umscheid well, sec. 32, T. 8 S., R. 9 E., is 15 feet thick. Insoluble residues from the upper 5 feet consist of grainy quartzose chert; from the middle 5 feet, of opaque chert flecked with grainy quartzose chert; and from the lower 5 feet, of opaque chert. The position of the cherty bed above the base of the Devonian and the absence of imbedded sand grains above the chert suggest that it correlates with the quartzose zone of the Forest City basin area to the east (Lee, 1943, pp. 55-56). 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 removed by pre-Chattanooga erosion.

Upper zone.—The upper zone of the Devonian occurs only in the deeper parts of the North Kansas basin where it was preserved from pre-Chattanooga erosion. It was recognized in the Gulf Oil Corporation No. 1 Baker well in sec. 1, T. 1 S., R. 2 E. where it is 100 feet thick and in the Turner et al. No. 1 Umscheid well in sec. 32, T. 8 S., R. 9 E. where it is 107 feet thick. It has not been observed in the cuttings of wells to the south and west but is generally present to the northeast of these two wells. In the Gulf No. 1 Baker well the upper zone is composed of limestone interbedded with dolomite but in the Turner No. 1 Umscheid well it is composed of dolomite interbedded with minor amounts of pale-green shale in the lower 35 feet of the zone. The presence of this shale, although it is not definitely correlated with the Snyder Creek shale of Missouri or the Independence shale of eastern Iowa, suggests that the beds above the cherty dolomite of the lower zone may be of Late Devonian age. Condra and Reed (1943, p. 62) correlate similar greenish shale of irregular distribution in the subsurface of southeastern Nebraska with the Independence shale. Northeastward from the Baker and Umscheid wells, the upper zone consists mainly of dolomite but thin beds of limestone are interbedded with the dolomite in some places. It varies in thickness owing to the unconformity at its top. The minimum known thickness of this zone is 100 feet in the

Baker well. It is 110 feet thick in the Ohio No. 1 Lamparter well in sec. 3, T. 2 S., R 14 E. The maximum thickness, 215 feet, is in the Isaacs et al. No. 1 Magor well in sec 15, T. 5 N., R. 15 E. in southeastern Nebraska.

Rocks of Devonian or Mississippian Age

In eastern Kansas a sequence of black and gray shales of Devonian or Mississippian age separates limestones definitely of Mississippian age from limestones and dolomites definitely of Devonian age. A black shale in southwestern Missouri, earlier called Eureka shale and Noel shale, was renamed the Chattanooga shale by Adams and Ulrich (1905) and it has been 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[1] taken from the McBride No. 4 Abraham Schmidt well in the NE cor. NE¼ sec. 30, T. 22 S., R. 3 W. in Harvey County. It seems probable, however, that the fossiliferous material was not in place when cored, that the dolomite of the sample represents pieces 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

[1] The core was taken below 79 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 and that 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 reveal black shale with spores typical of the basal Chattanooga *above* the Misener. Devonian limestone was encountered at 3,449 or 3,450 feet. The fossiliferous samples from 3,438 to 3,440 feet, lent by Sinclair Prairie Oil Company, were examined in 1946 by L. R. Laudon and R. C. Moore of the Kansas Geological Survey, who agree on the Kinderhookian age of the fossils.

that the first cuttings below the cement include fragments of opaque white chert of the Burlington-Keokuk type not known in the Kinderhookian, and traces of the Kinderhookian Gilmore City oölitic limestone commonly found in wells in this area immediately above the Sedalia and above the Chattanooga; (2) dolomite lithologically identical with the fossiliferous cores occurs immediately above the shale sequence in parts of Harvey and McPherson Counties (Fig. 5A); (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 by the authors; (4) the occurrence of Kinderhookian dolomite within the shale sequence is incompatible with the regional relations and distribution of the Kinderhookian limestone as described in a subsequent section of this report.

Near the Missouri-Nebraska line, the Chattanooga shale in some wells is overlain by red and pink shales locally interstratified with green shale. In some wells the red shales include concentrations of red oölites or fine ironstone pellets. These shales and the underlying oölitic bed 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) has proposed the name Boice shale for this formation.

CHATTANOOGA SHALE

At the outcrops in southwestern Missouri and in the subsurface of the adjacent parts of southeastern Kansas, the Chattanooga ranges in thickness from a featheredge to 30 feet and consists of black fissile shale, slightly silty and finely micaceous with conspicuous amounts of pyrite. The shale contains plant spores which are especially abundant in the lower part. Toward the north and west (Lee, 1940, pp. 21-23; cross section B-B′, Pl. 5) the shale thickens and becomes lighter in color. The basal beds, however, are nearly everywhere dark colored, if not black, and include abundant spores. In northeastern and north-central Kansas the color of the shales is generally gray or gray green but interstratified darker shales occur in some places above the base. With increasing thickness the Chattanooga becomes locally dolomitic in some zones and in some areas includes beds of impure dolomite. In the Appleman Oil Company No. 1 McManus well in sec. 29, T. 15 S., R. 6 W., a bed of finely sucrose silty dolomite 15 feet thick, lying 35 feet above the base of the shale, contains spores typical of the Chattanooga. Spores in the dolomitic beds of the Chattanooga have also been observed in other wells. In the Salina basin the shales are finely micaceous but less silty and more argillaceous than to the south and east. Gray earthy limestone has been observed locally in the middle part of the shale section in the Calikan Producing Company and I. T. I. O. No. 1A Fair well in sec. 4, T. 22 S., R. 8 W. in Harvey County and in another well in sec. 8 of the same township. This limestone is believed to be a lentil within the Chattanooga shale. It occurs 100 feet below the top of the Chattanooga and in an area in which the Chattanooga shale is exceptionally thick. Figure 3A shows the distribution of this lentil which wedges out to the northeast and south and is cut off on the west by post-Mississippian beveling.

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 lies below the black spore-bearing shale, except in the Hollow pool in T. 22 S., R. 3 W. in Harvey County where cores from wells reveal a bed, 1 or more feet thick, of gray or black slate with large numbers of *Lingula* below the Misener sand.

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 the St. Peter 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, Salina, and Harvey Counties, the Misener forms a bed of sandstone rarely more than 2 feet thick but in some localities much thicker. In Rice County a number of wells have encountered the Misener sand with thicknesses of 10 to more than 35 feet. It is 11 feet thick in a well in sec. 24, T. 11 S., R. 7 W. in Lincoln County and 5 feet thick in a well in sec. 35, T. 8 S., R. 9 W. in 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. The thickness displays considerable irregularity on account of the unconformity at the base of the Chattanooga and the several periods of exposure of its top during which the original thickness was reduced by erosion.

In eastern and southeastern Kansas the thickness of the Chattanooga increases toward the north with great regularity. If local topographic relief of any magnitude had existed on either the underlying surface or at the top, the thickness of the Chattanooga would have reflected the irregularities of either surface. Inasmuch as local irregularities in thickness are negligible in these areas, both the top and bottom of the Chattanooga must have been surfaces of exceptional smoothness. In northeastern Kansas the Chattanooga shale overlies limestones and dolomites of Devonian age. Toward the south it transgresses upon a smoothly leveled surface and rests in succession on rocks ranging in age from Devonian to Early Ordovician.

In the Salina basin the pre-Chattanooga surface was dissected by a broad open valley with a topographic relief of more than 200 feet. In T. 23 S., R. 2 W., in Harvey County on a pre-Chattanooga high, the Chattanooga shale has a maximum thickness of 20 feet. 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 and the shale successively overlies progressively older rocks from Devonian dolomite to Kimmswick dolomite. Farther north, the Chattanooga thins and overlaps onto the same formations in reverse order. The stratigraphic and structural relations indicate the development of a deep pre-Chattanooga valley whose approximate configuration is shown by the thickness map of the Chattanooga shale (Pl. 6) and by the areal map of the pre-Chattanooga surface (Pl. 5). Earlier investigations (Lee, 1940, pls. 3 and 4) seemed to indicate that this

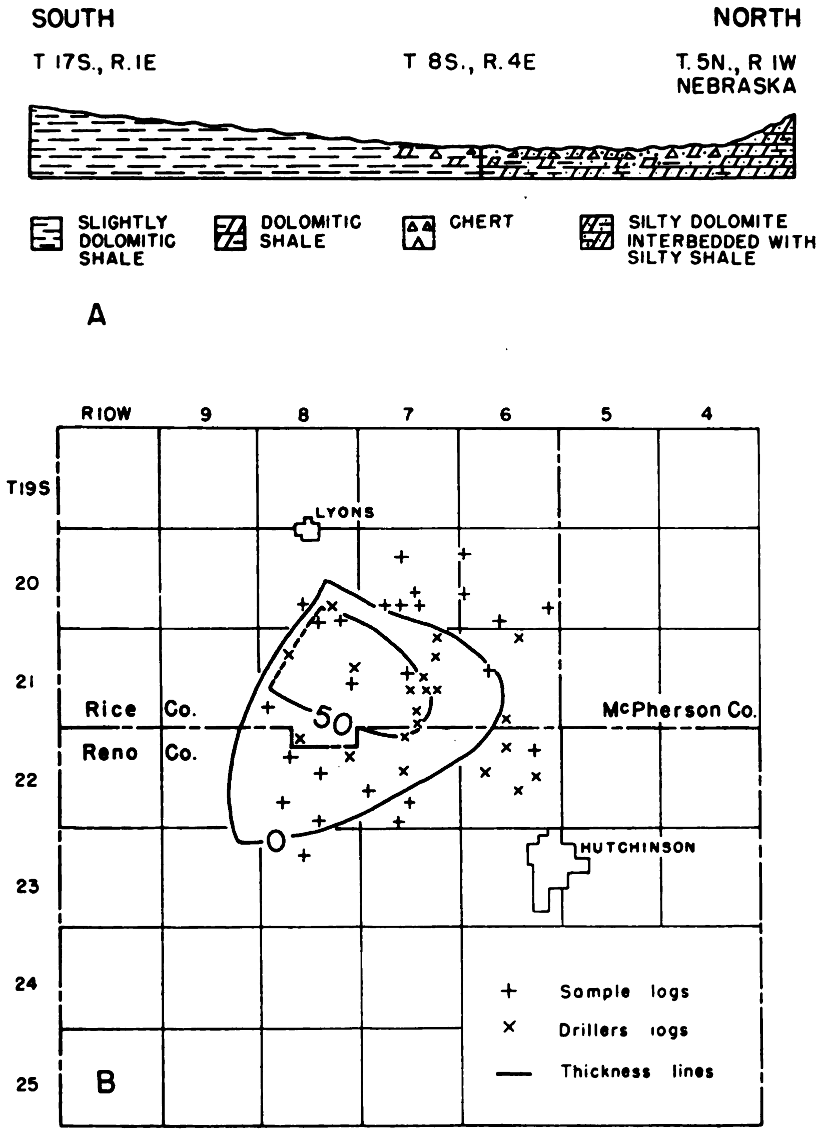

FIG. 3.—*A*, Diagrammatic cross section showing the distribution of chert in Maquoketa shale in areas once subjected to weathering and erosion. *B*, Map showing the area in Rice and Reno Counties underlain by the earthy limestone lentil of the Chattanooga shale.

valley drained northeastward across the later beveled Nemaha anticline into southeastern Nebraska where the Chattanooga and Boice shales, together, are thickest. The thickening of the shales in that area, however, is not accompanied by a corresponding thinning of the underlying Devonian limestones as would be the case if a channel had been cut in that area. The configuration of the valley as revealed by the areal geology of Plate 5 makes it seem more likely that the valley drained westward or northwestward.

After the deposition of the Chattanooga shale, the surface was re-elevated and was probably subjected to minor warping. Considerable areas to the west were stripped of Chattanooga shale at this time, for outliers of Chattanooga shale are reported in the subsurface as far west as Ness County (Lee, 1940, p. 25). 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 is thin where the Boice is thick and increases in thickness where the Boice is thin. The range in the thickness of the Chattanooga shale from 120 to 258 feet is a measure, though imperfect, of the topographic relief of the pre-Boice surface.

With resubmergence of the eroded surface the higher areas of the Chattanooga surface were reduced by wave and tidal action. At the same time the eroded material of the weathered surface was washed into topographically low areas where the surface was aggraded by reworked Chattanooga shale. The shale thus formed in these low areas is the Boice shale.

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. The following considerations lead to the conclusion that this interval is of greater importance than has hitherto been recognized. (1) The Boice shale in parts of the Forest City basin intervenes between the Chattanooga shale and the Chouteau. (2) In northeastern Missouri, the Louisiana limestone and the Hannibal shale intervene between the Chattanooga (Grassy Creek) and the Chouteau. (3) In Smith County, Kansas, where the Chouteau and the lower member of the Sedalia are missing.

the upper member of the Sedalia overlaps from the Boice shale onto the Chattanooga shale and locally overlaps onto rocks of pre-Chattanooga age.

The Chattanooga must have been removed from parts of Smith, Osborne, and Jewell Counties before the deposition of the upper Sedalia (Pl. 6), for in this area upper Sedalia rocks overlap from the Chattanooga onto rocks of pre-Chattanooga age. The exposure of this area seems to have begun prior to Boice deposition and extended through Chouteau and lower Sedalia time.

South of McPherson County, except for outliers of upper Sedalia and Gilmore City rocks, the Kinderhookian Series is absent. In this area the Chattanooga is generally overlain by the St. Joe limestone of the Osagian Series. In some areas 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 older Osagian rocks onto the Chattanooga shale (Fig. 5B).

There is, therefore, a hiatus between the Chattanooga shale and the Boice shale that in some areas extended to late Sedalia time and in others to early Osagian or even to Burlington time, during which the Chattanooga must have been exposed and presumably subjected to erosion. The elevation above sea level and the erosion, however, are believed to have been slight, for the thinning of the Chattanooga in the areas of overlap is not substantial.

The final unconformity affecting the thickness of the Chattanooga developed in post-Mississippian time when the Nemaha anticline was folded and the Central Kansas uplift and the Ozarks were re-elevated. The erosion of these 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 was essentially a peneplain. The Chattanooga shale cropped out on this surface in a belt encircling the area of older rocks (Pl. 8).

Outliers of Chattanooga shale, such as the one in T. 17 S., R. 8 W. in Ellsworth County (Pl. 6) which are overlain by Pennsylvania rocks were presumably isolated during post-Mississippian exposure.

In consequence of the complex relations described, the Chattanooga rests unconformably on rocks ranging from Devonian to Early Ordovician age and is overlain by the Boice shale, by Mississippian limestones from the Chouteau to the Burlington, and by rocks of Pennsylvanian age.

BOICE SHALE

The Boice shale is best known from wells in southeastern Nebraska where it was named by Reed (1946) for the No. 1 Boice well drilled with cable tools by the Pawnee Royalty Company in sec. 18, T. 1 N., R. 16 E., Richardson County, Nebraska, from which an excellent set of samples is preserved in the files of the Nebraska Geological Survey. The section of the Boice shale as reported by Reed from the above-named well is given in Table 4.

A section of rocks in Holt County, Missouri, here referred by the writer to the Boice shale, was reported by McQueen and Greene (1938, p. 176) and is given in Table 5. The rocks were designated by Mary Hundhausen of the Missouri Geological Survey as "Kinderhook undifferentiated."

TABLE 4.—*Section of Boice shale in the 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 feet	
Shale, dark greenish gray with some pyritic and carbonaceous zones; calcareous with black "Sporangites" in lower 10 feet; interbedded with gray dolomitic siltsone and silty argillaceous dolomite	19 feet	
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 feet	
Chattanooga shale		204
Devonian dolomite		

TABLE 5.—*Section of the Boice shale in the 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		43
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	6	
Mississippian or Devonian rocks		
Chattanooga shale		83

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 oölite is 90 feet and the Chattanooga 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. 11, 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 oölitic member which is 5 to 25 feet thick. In these counties red shale without oölites, from 20 to 40 feet thick, which occurs in some wells at the top of the Chattanooga 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. Such a well occurs in Dickinson County in sec. 11, T. 13 S., R. 1 E. where red and green shales 10 feet thick underlie the oölitic member of the Boice.

Except where the Boice shale contains red and oölitic beds it is singularly like the Chattanooga shale from which the major part of the sediments for the Boice is believed to have been derived. In Nemaha and Brown Counties, Kansas, where considerable thicknesses of green and gray shale overlie 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 more argillaceous 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.

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 the Misener sand.

The Boice shale is unconformable on the Chattanooga and seemingly conformable below the Chouteau 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.

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 reduced by erosion. As a result, the sequence of Mississippian formations is nowhere complete and formations are missing from the top, middle, or bottom of the columnar section in different localities. 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.

Limestones and dolomites predominate in the Mississippian rocks of the Middle West. The Mississippian of Kansas consists entirely of limestones and dolomites, 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.

The Mississippian formations represented in the Salina basin are listed in Table 6 in descending order.

TABLE 6.—*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 in 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, relatively pure semigranular limestone, which is essentially equivalent to the Compton limestone of outcrops of southwestern Missouri; (2) a middle unit, an impure sucrose gray to buff dolomite having large amounts of uniquely charac-

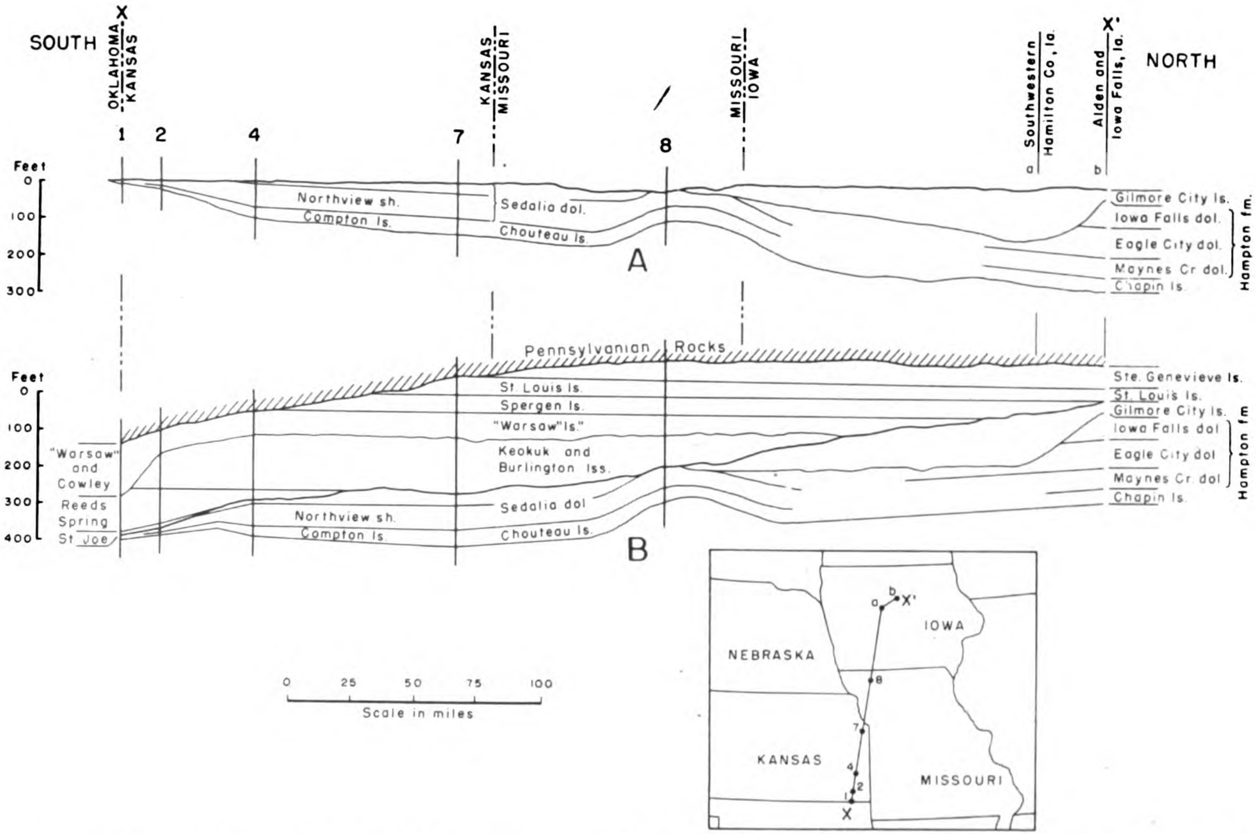

Fig. 4.—Diagrammatic cross sections from southeastern Kansas to central Iowa showing structural relations of Kinderhookian to younger Mississippian limestones. Cross section A shows the attitude of the Kinderhookian rocks on the line X-X′ at the beginning of Osagian time. Central Iowa had been a subsiding basin in which sediments of Kinderhookian rocks accumulated more thickly than in southeastern Kansas. Slight elevation and beveling probably ended Kinderhookian deposition. Cross section B shows the attitude of Mississippian formations at the end of Meramecian time on the same line. The surface of the beveled Kinderhookian rocks was progressively lowered toward the south during Osagian and Meramecian time. All the formations from St. Joe to St. Louis overlapped in turn, northward upon the surface of the Kinderhookian rocks.

teristic 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 he thus restricted the Chouteau to the lower unit. The upper unit of the sequence in the subsurface for a time was considered 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 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 as shown in Figure 5. Thin outliers occur south of Saline County.

Unconformities occur above and below the upper member in the Salina basin but its thickness reveals that both its upper and lower surfaces were 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-

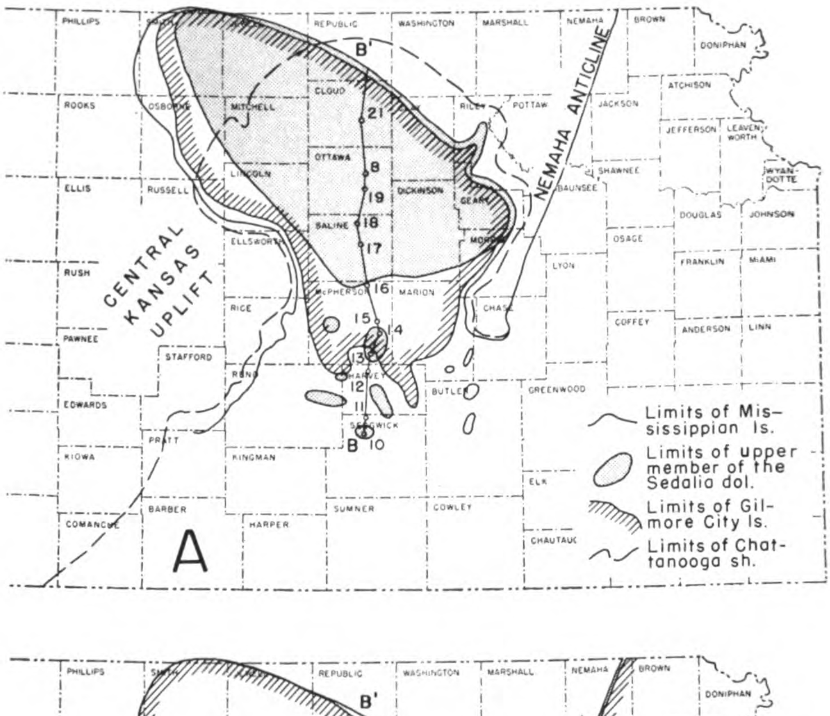

FIG. 5.—Maps showing the approximate distribution of the Mississippian formations in the Salina basin area. *A*, the distribution of the Chattanooga shale and those Kinderhookian rocks that are represented in the Salina basin. The Kinderhookian rocks, originally more widely distributed, have been eroded from the southern part of the area. *B*, the approximate distribution of Osagian and Meramecian formations. The Osagian formations

Chattanooga rocks. In the Salina basin it is rarely more than 15 feet thick and in some of the outliers in McPherson and Harvey Counties it is represented by less than 5 feet of buff sucrose dolomite.

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 unconformably onto 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 overlain disconformably nearly everywhere by the Gilmore City limestone. The disconformity is obscure but it is revealed in a number of wells in the Forest City basin in which the Gilmore City rests on the lower member of the Sedalia (Lee, 1943, p. 69) and in cross section A of Figure 4. In McPherson and Marion Counties the Gilmore City rests on the Chattanooga shale. 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 onto the upper Seladia (Fig. 5).

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 a 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, the subsurface distribution of which in the Salina basin is shown in Figure 5, 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. The thickness decreases somewhat irregularly toward the southeast where it wedges out in southern McPherson County and parts of Harvey County.

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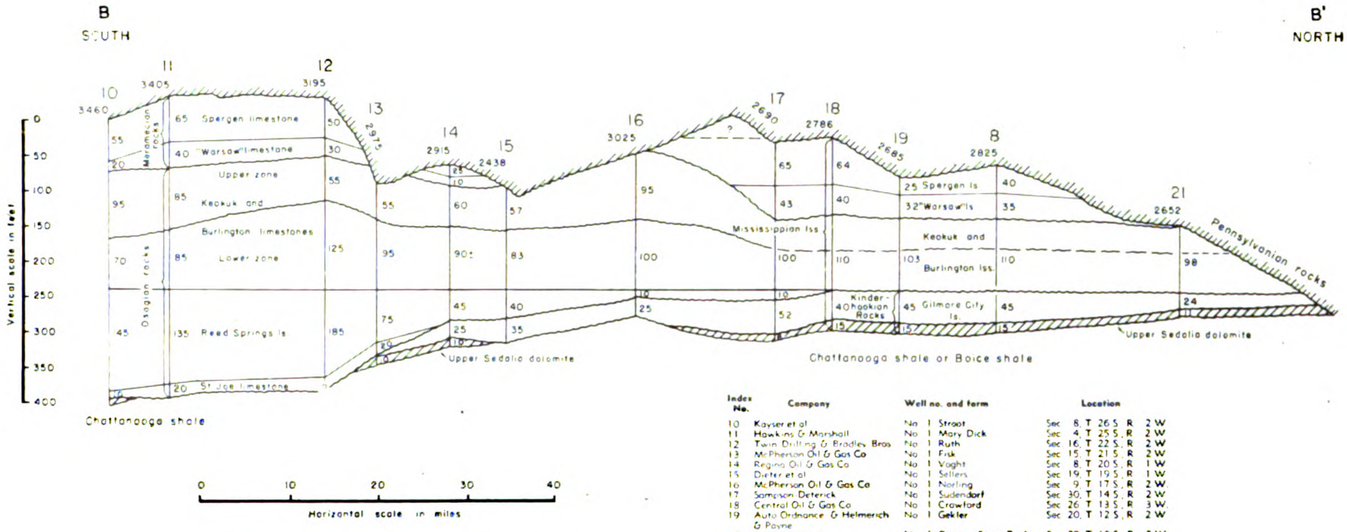
overlapped in turn upon the Kinderhookian surface. The distribution of the St. Joe and Reeds Spring limestones reveals the development of synclinal movements west of the Nemaha anticline in early Mississippian time. The distribution of the "Warsaw" and Spergen limestones, once general throughout the region, was restricted to synclinal areas by beveling at the close of Mississippian time.



Index No.	Company	Well no. and farm	Location
10	Kayser et al	No 1 Straot	Sec 8, T 26 S, R 2 W
11	Hawkins & Marshall	No 1 Mary Dick	Sec 4, T 25 S, R 2 W
12	Twin Drilling & Bradley Bros	No 1 Ruth	Sec 16, T 22 S, R 2 W
13	McPherson Oil & Gas Co	No 1 Fisk	Sec 15, T 21 S, R 2 W
14	Regina Oil & Gas Co	No 1 Voght	Sec 8, T 20 S, R 1 W
15	Dieter et al	No 1 Sellers	Sec 19, T 19 S, R 1 W
16	McPherson Oil & Gas Co	No 1 Norling	Sec 9, T 17 S, R 2 W
17	Sampson Deterick	No 1 Sudendorf	Sec 30, T 14 S, R 2 W
18	Central Oil & Gas Co	No 1 Crawford	Sec 26, T 13 S, R 3 W
19	Auto Ordnance & Helmerich & Payne	No 1 Gekler	Sec 20, T 12 S, R 2 W
8	Anderson et al	No 1 Ottawa State Bank	Sec 28, T 10 S, R 2 W
21	Carter Oil Co	No 1 Strat Test	Sec 16, T 7 S, R 2 W

FIG. 6.—Stratigraphic cross section from south to north on the line B-B′ of Figure 5 and Plate 8 showing overlap of Osagian rocks on the Kinderhookian surface. Figures at left of wells at top show depth in feet below the surface. Figures at right of wells show thickness of lithologic units. The wells are correlated on the base of the Burlington. The upper member of the Sedalia dolomite was eroded from parts of the area but outliers occur toward the south. The St. Joe, Reeds Spring, and Burlington in conformable sequence overlap in turn upon the surface of the Kinderhookian. Unconformities occur at the base of the upper member of the Sedalia, Gilmore City, Keokuk, and "Warsaw."

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, imbedded 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 color of 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 discontinuous 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 variable in size and some of them are irregular in shape. They are commonly gray in color but some are dark to 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 traces of indigenous vitreous chert. The characteristic residues consist of loose aggregates of very fine quartz crystals, thin finely drusy crusts and microscopic mammilary and columnar flakes of chalcedony. Traces of spherical crusts from partly silicified oölites are occasionally found. In Saline County and to the north the residues are generally pale lemon yellow but elsewhere they are colorless.

Where the Gilmore City is thin and nonoölitic it is distinguished from the St. Joe by the dark 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 which is absent in the Gilmore City.

At places along its southern margin, the Gilmore City rests unconformably on the 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. 5).

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 writers place 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 with variable 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. 5). 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 immediately south of the Salina basin in Sedgwick County, the St. Joe limestone consists of alternating beds of non-cherty semigranular limestone, argillaceous limestone, and calcareous shale, from 75 to 100 feet thick. Toward the north this sequence of beds becomes thinner and more argillaceous and on the 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 between the Central Kansas uplift and the Nemaha anticline as shown on Figure 6. The variable thickness is due largely to the unconformity at its base. The separation of the St. Joe from the Reeds Spring in most parts of southeastern Kansas is based on the absence of chert in the St. Joe cuttings and their presence 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 Reno and Harvey Counties, the St. Joe is in contact in different localities with the underlying Gilmore City, the upper member of the Sedalia, or the Chattanooga shale with 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 immediately overlies Chattanooga shale. The St. Joe limestone seems to be conformable below the Reeds Spring limestone, although in Harvey County a marked lithologic break at the top of the dark earthy limestone of the St. Joe marks the contact with the Reeds Spring. The contact between the two limestones is transitional in southeastern Kansas.

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. Conspicuous amounts of chert occur throughout most of the formation; at some places 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 of 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 occur with 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 5. 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. 5) 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 rarely exceeds 20 feet (Fig. 6).

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 onto 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 eroded surface at the base of the Reeds Spring in areas where it overlaps beyond the St. Joe account for some of the irregularities 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, pp. 143, 207) and Moore, Fowler, and Lyden (1939, p. 9) report 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 in the subsurface of Kansas between the lower and upper zones of the Burlington-Keokuk sequence and has tentatively correlated them, respectively, with the Burlington limestone and the Keokuk limestone. The variable position of the contact between the two 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 limestones and dolomites but are differentiated by the character of the chert.

Lower zone.—The lower zone is characterized by opaque chert of microscopically massive 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 with 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 limestones, 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 microorganisms 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 relations to the upper zone and its locally obscure contact with the Reeds Spring. It is thickest in Harvey County where several wells found it to be more than 150 feet thick. It is 155 feet thick in the Rosenthal and Madison No. 1 Masters well in sec. 24, T. 23 S., R. 3 W. but toward the 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 although variable is commonly less than 50 feet.

Upper zone.—Most of the chert of the upper zone is white, rough, and pitted, and breaks into 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 microorganisms with glassy or translucent chalcedony. The cherts of the upper zone include varying 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 leaves soft tripolitic crumbs of "cotton rock" which constitute a considerable proportion of the volume of the insoluble residues. Insoluble residues of dolomitic beds leave also dolomoldic chert. The contact between limestones with blocky opaque gray chert of the lower zone and limestones 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, it has a local thickness of as much as 110 feet 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 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[1] 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 which followed the post-Mississippian deformation.

[1] 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.

Meramecian time was preceded by an elevation of Kansas above sea level and 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 their base, 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, pp. 66-78). On the northern margin of the erosional basin this formation consists of silty and dolomitic gray and black shale in areas near the shore line 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 varies 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 sediments graded upward into the semi-granular limestone of the "Warsaw." The "Warsaw" limestone generally contains much chert. The Spergen limestone overlies the "Warsaw" with seeming conformity in eastern Kansas. It is interstratified with sucrose dolomite. In some places in northeastern Kansas where the Spergen consists largely of dolomite it is locally interstratified with granular limestone lentils. Patient examination of these granular limestones generally reveals the presence of thinly disseminated specimens of the foraminifer *Endothyra*. Insoluble residue of the dolomitic beds reveal much silt and spongy masses of spicules. The St. Louis limestone overlies the Spergen in northeastern and southwestern Kansas. The St. Louis limestone includes some granular limestone and is locally oölitic but its distinctive characteristic is lithographic limestone. If it is separated from the Spergen by disconformity, the contact is a surface of low relief. The Ste. Genevieve limestone in northeastern Kansas includes noncherty oölitic beds and noncherty granular limestone. The basal limestone beds enclose disseminated coarse silt and fine angular sand. It is oölitic in western Kansas.

"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 fossils. The chert is variable in amount and rarely reaches 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 the "Warsaw" is in the Kinney-Coastal Oil Company No. 1 Beil well in sec. 23, T. 14 S., R. 5 W. where it is 80 feet thick. 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 16 and 17 of Figure 6. The great variations 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 been deposited on higher parts of this surface. Some wells, in which the "Warsaw" is missing, reveal Spergen limestone directly overlying the Keokuk.

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. 5). 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 slighty waxy luster. In some localities the limestone is interstratified in the upper part with noncherty sucrose dolomite. The basal member, however, is generally dolomitic and silty. In wells in Ts. 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. However, 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. 8). 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 onto the Keokuk. In the Salina basin surviving remnants of the Spergen are everywhere unconformable beneath rocks of Pennsylvanian age.

Rocks of Pennsylvanian Age

The Pennsylvanian rocks of Kansas are divided into the following series, listed in descending order: Virgilian, Missourian, and Desmoinesian.

Major unconformities that resulted from widespread erosion and that display well-developed topographic features separate the series but there are innumerable minor unconformities within the groups and formations. The Pennsylvanian rocks of the central and eastern United States were deposited in very shallow and exceedingly fluctuating seas. Studies by Weller (1930) in Illinois, by Moore (1936), and others have demonstrated that the deposition of the Pennsylvanian rocks in Kansas and other states was cyclical and that the sequence of rocks may be divided into cyclothems representing deposits made during a single period of submergence. These cycles of deposition were the result of changes of sea level but differential regional deformation and in places differential local structural deformation accompanied many if not most of the cycles. Throughout the greater part of Pennsylvanian time the surface upon which each successive sheet of sediment was deposited was so nearly level that a lowering of the sea level of only a few feet resulted in the emergence of very large areas and a slight rise caused flooding of equally broad areas.

During the periods of emergence the degree and character of erosion were dependent upon the height of the surface above sea level and the length of time that elapsed before resubmergence. As the sea readvanced upon the land, the first deposits were derived from the dissected surface of the land itself and were mainly silty shales and sandstones in which the remains of plant fossils were generally incorporated. Without discussing in detail the sequence of distinctive deposits that characterize a completed cyclothem (Moore, 1936, pp. 34-35), it may be stated that the initial deposits were followed by marine shales and by fossiliferous limestones as the water deepened and sources of sediment became more distant. During the completion of the cycle when the sea gradually became more shallow, similar sediments were repeated in reverse order and were concluded with a deposit of shale or sandstone. Local sources of clastic material were no longer available at the end of the cycle, so the material of the final phase of the cyclothem must have been derived from distant land areas and deposited in the shallowing sea by tides, waves, and currents.

The normal sequence of deposits of a cyclothem was often modified by local conditions, especially near the borders of the basin. Where clastic material from adjacent rapidly rising land areas was abundant, limestone deposition was inhibited in the offshore areas and the character of the cyclothems was altered. Toward land areas, therefore, limestones interfinger with shale and sand or grade laterally (in many places abruptly) into impure limestone, fossiliferous shale, and nonfossiliferous shale and sand. Near rising land, the abundance of clastic material that was being carried into the adjacent subsiding basin kept the surface of the basin almost continuously above sea level by the deposition of low alluvial fans reaching at times far into the basin.

All imaginable variations of cyclic deposition are probably represented in the interior basin of which the Salina basin formed a part. The variants include height of the surface and length of time of emergence, rapidity of advance and retreat of the sea, and depth and length of time of submergence. Although most cyclothems were completed, some were incomplete and a new cycle set in by readvance of the sea before the surface was exposed. At the end of some cyclothems emergence was brief and there was little or no erosion. In many cases, however, exposure continued long enough to develop channels. Sometimes there was little or no dissection of the divides between the channels but sometimes mature topography of low relief developed. The several series of the Pennsylvanian System were separated by long periods of exposure during which the surface was deeply and maturely dissected. Also, channels more than 100 feet deep are known between the Pennsylvanian and Permian Systems.

As pointed out by Moore (1929, p. 479), many of the limestone and shale beds, although only a few feet thick, were evenly distributed across thousands of square miles. On the other hand there are many local and regional variations in thickness and distribution. Many of these deviations from regularity may be attributed to the effects of erosion between cycles of deposition. Where erosion cut down through part or all the deposits of the preceding cycle, the initial shale deposits of a new cycle occupy the position of the eroded parts of the deposits of the preceding cyclothem.

If mature dissection occurred during the emergent phase of a cycle, and if subsidence at the beginning of the new cycle was so rapid that the initial shale deposits failed to level off the topographic relief, the middle or limestone phase of the new cycle might be deposited on a rolling or hummocky surface. The interval between the very persistent Haskell limestone and well-marked datum beds above and below shows so much local variation as to suggest that this limestone was deposited on such an uneven surface.

Some variations in thickness, however, seem to be the result of minor local warping of the surface during deposition of one or more cyclothems. It seems necessary to postulate local anticlinal warping of the surface during the period of deposition where all the phases of a single cyclothem or of several succeeding cyclothems are represented but are thinner in many places than the regional average. Local synclinal warping is similarly expressed by thickening of the cyclic phases. These relatively local differential structural movements in some cases affected the thickness of one or more cyclothems but generally were not perpetuated later. Cross sections along the outcrops of the Marmaton formations in southeastern Kansas by Jewett (1945) illustrate this phenomenon. In general, these movements resulted in greater local variations in the thickness of the formations than those due to erosion during intercyclical exposure. Even the most pronounced localized structural movements, however, were secondary to, and superimposed upon, the less striking but regionally greater movement of the sedimentary basin as a whole which in Kansas is reflected by the northerly and westerly thinning of the Pennsylvanian rocks and the southerly thickening toward the Ouachita basin. There were, however, differential structural movements of a subregional character, such as those resulting in the Central Kansas uplift, the Nemaha anticline, the Salina basin, and the Cherokee and Forest City basins that continued throughout Pennsylvanian time. These structural features will be discussed later in chapters on the regional structure.

DESMOINESIAN SERIES

The Desmoinesian Series has been divided into the Marmaton group above and the Cherokee shale below.

Cherokee Shale

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 folding followed much the same pattern as at the end of Mississippian time but there was some modification of earlier folds and some structural features were not revived. When Pennsylvanian sedimentation began in Kansas the region east of the Nemaha anticline was already lower than the region to the west, and in consequence, the sea advancing from the south entered the Forest City and Cherokee basins east of the anticline before it submerged the Salina basin on the west. When the Pennsylvanian sea reached eastern Kansas, it is probable that the structural divide separating the Salina and Forest City basins was low and would have been covered at an earlier date if it had not continued to rise. The Pennsylvanian sea reached the Salina basin from the south during Cherokee time. The Burns dome on the crest of the Nemaha anticline in T. 23 S., R. 5 E. in northern Butler County was, however, not covered until the end of Cherokee time (Kellett, 1932). In southeastern Nebraska, the crest of the Nemaha anticline was not submerged until middle Kansas City time when the Drum limestone overlapped onto the crest of the fold (E. C. Reed, personal communication). The gradually rising crest of the anticline thus formed a southwesterly projecting peninsula of shrinking proportions that separated the Forest City and Salina basins at least until the close of Cherokee time. The greatest thickness of Cherokee rocks in the Forest City basin is 790 feet but the maximum known thickness of the Cherokee in the Salina basin is only 230 feet.

The Cherokee shale has not been divided into formations, although many beds—coal, sandstone, and limestone—which are widely distributed have been named (Moore, Frye, and Jewett, 1944, pp. 197-200). The Cherokee rocks in the outcrops in eastern Kansas and in the subsurface east of the Nemaha anticline in the Forest City and Cherokee basins consist mainly of clastic rocks. Light and dark shales predominate but there is much sandstone and sandy micaceous shale. A few thin limestones are present in some localities but the Ardmore limestone member, 65 to 135 feet below the top of the Cherokee, is the only limestone of general distribution. There are many coal seams but only a few are thick enough to mine.

The Cherokee rocks in the Salina basin consist mainly of gray silty shale interstratified with red shale. In the center of the basin two zones of red shale can be roughly correlated with each other. 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 which 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 streaks of limestone are reported in some wells but on account of discontinuity or the lack of detail in the logs they cannot be traced from well to well. One limestone of some persistence, 135 to 145 feet below the top of the Cherokee in the center of the basin, is tentatively correlated with the Ardmore limestone.

The sandstone and coal beds, so characteristic of the Cherokee shale at the outcrops in southeastern Kansas, are not represented in the Salina basin. Streaks of black shale probably representing coal beds of the Cherokee basin are recognized in the samples of some wells.

The Pennsylvanian basal conglomerate is well developed in most wells. 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 occurrence of chert-bearing basal conglomerate is much more common in the Salina basin where most of the underlying rocks are cherty limestones than in the Forest City basin where the widely exposed sparsely cherty or noncherty limestones of Spergen, St. Louis, and Ste. Genevieve ages provided little material for a basal conglomerate.

In drillers logs and in many sample logs it is impossible to differentiate the Pennsylvanian basal cherty conglomerate from Mississippian chert that had been weathered in place. Currents and wave action 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 (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 in which chert is consistently reported as sand, beds of "sand" in the position of the basal conglomerate have been assumed to represent chert in some wells. The elimination of these doubtful beds from the Cherokee and their inclusion in the Mississippian may have introduced some minor errors in the thickness maps.

The Cherokee shale is absent on the north end of the Nemaha anticline. It is 10 feet thick in sec. 32, T. 8 S., R. 9 E. and gradually increases in thickness toward the south although it is absent at places on structural and topographic highs. It is 55 feet thick in sec. 34, T. 17 S., R. 7 E. Along the axis of the Nemaha anticline, the thickness of the Cherokee varies with the height of the structural crest and with the topographic relief which was greater along the anticline than elsewhere.

The thickness of the Cherokee increases rapidly east of the Nemaha anticline and its thickness in eastern Morris County only a few miles to the east of the crest exceeds 300 feet (Bass, 1936, pl. 1). On the northeastern flank of the Salina basin in sec. 10, T. 7 S., R. 4 E. the Cherokee is only 30 feet thick, but increases in thickness irregularly toward the center of the basin where, in sec. 2, T. 7 S., R. 11 W. near the deepest part of the basin it has a thickness of 230 feet. It thins southwestward from the center of the basin and wedges out on the pre-Pennsylvanian surface of the Central Kansas uplift.

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 which are named in Table 7 in descending order have been differentiated in outcrops in southeastern Kansas (Jewett, 1945). The range and average thickness of each in southeastern Kansas has been reported by

Table 7.—*Sequence and thickness of formations of the Marmaton group*

	Range in thickness in outcrops in southeastern Kansas, in feet	Average thickness in outcrops in southeastern Kansas, in feet	Subsurface thickness in southeastern Nebraska, in feet
Marmaton group			
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			

Moore, Frye, and Jewett (1944). The thicknesses in southeastern Nebraska are reported by Condra and Reed (1943).

The formations of the Marmaton group that are referred to as limestones in the outcrops actually consist of conspicuous groupings of limestones which alternate with shale beds of varying thickness. The details of stratification in the subsurface can rarely be determined from drillers or sample logs because in the subsurface toward the northwest the shale beds become thinner than in the outcrop, and all the limestone members, which are not very hard, are seldom recorded. The upper limestone members of some formations were eroded during emergent phases of cyclothems shortly after deposition and some wedge out. The upper formations of the Marmaton down to the Bandera shale were removed from broad areas by pre-Missourian erosion, so that even in the outcrops the Marmaton sequence is not everywhere complete.

In the Salina basin the Marmaton group can be described only as a sequence of shale and thin limestones. The more persistent and thicker Fort Scott limestone at its base can generally be recognized. The sandstone members that provide reservoirs for oil and gas in the Forest City and Cherokee basins (the "Peru sand" of the Labette shale, the sandstone of the Bandera shale, and the "Wayside sand" of the Nowata shale) which are present only intermittently in eastern Kansas, are not represented at all in the Salina basin.

The formations composed dominantly of limestone include black shale and one or more streaks of coal. Some thin beds of red shale are interstratified with the limestones but they lack stratigraphic continuity and are of no help in identifying the several limestones. The upper members of the Altamont, Pawnee, and Fort Scott limestones in outcrops contain fusulines in abundance. The fusulines are the only features likely to be of assistance in differentiating the Marmaton formations in cuttings from wells, although the Fort Scott is generally recognized by its greater thickness and the Pawnee limestone by its brown color. It is probable that only the lower part of the Marmaton is represented in the Salina basin.

The Marmaton group is commonly about 200 feet thick in the Cherokee and Forest City basins but, so far as can be determined from the samples, the Marmaton in the Salina basin has a maximum thickness of only 130 to 140 feet. It thins markedly on the crest of the Nemaha anticline and probably to a lesser degree in other structurally positive areas. On the crest of the anticline in T. 17 S., R. 7 E. it ranges in thickness from 30 to 50 feet. In T. 9 S., R. 9 E. it is 45 feet thick. On the northern flank of the Salina basin in sec. 1, T. 1 S., R. 2 E. it is 65 feet thick. On the southwestern side of the Salina basin it becomes gradually thinner and individual formations overlap on the pre-Pennsylvanian surface of the rising Central Kansas uplift.

MISSOURIAN SERIES

The Missourian Series is separated from the Desmoinesian Series by an unconformity and by a faunal break. The unconformity was accompanied by erosion of the upper Marmaton beds and by the development of channels later filled by sandstone deposits. The subordination of the Bronson rocks to 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 8, have been differentiated in outcrops in southeastern Kansas. The average thicknesses of the formations have been reported by Moore, Frye, and Jewett (1944).

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

	Average thickness in eastern Kansas, in 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 Knobtown sandstone of Linn and Bourbon Counties is replaced toward the south by thin beds of dense blue limestone alternating with thin beds of black shale (Moore, Frye, and Jewett, 1944, p. 195). Sandstone can be traced westward across the Nemaha anticline on the line of cross section X-X′ (Pl. 13) to T. 5 E. (well 44). Westward from this point it is replaced by red shale and gray silty shale in part finely micaceous. 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.

The thickness of the Pleasanton group is controlled in part by the erosional relief at its base, but in large part also by regional warping of the pre-Pleasanton surface. The Pleasanton thins northward from an average thickness of about 100 feet in areas of outcrop in eastern Kansas to 18 feet in southeastern Nebraska where until the recent reclassification it was regarded as the basal formation of the Bronson group (Condra and Reed, 1943, p. 53). The Pleasanton group is 60 feet thick in central Chase County and continues to thin westward to McPherson County where it is 20 to 40 feet thick. In the center of the Salina basin it increases to a thickness of 50 or 60 feet; on the northeastern flank of the Salina basin in sec. 10, T. 4 S., R. 7 E., it thins to 20 feet; and in sec. 1, T. 1 S., R. 2 E. to 25 feet. It thins also on the southwestern flank of the Salina basin where it overlaps upon the pre-Pennsylvanian surface of the rising Central Kansas uplift. On the crest of the Nemaha anticline it is thin or absent. The thickness of the Pleasanton group, although controlled locally by movements such 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 thick limestone, were deposited in sequence above the Pleasanton group with only cyclical interruptions. The cyclical periods of exposure, during which minor channeling and erosion occurred, were not infrequent and each exposure reduced in varying degree the thickness of the limestone and shale members of the preceding cyclothem. The loss of limestones by dissection was in general compensated by an increase in thickness of initial shale deposits of the succeeding cycle. The net result of such cyclical erosion and filling tended to restore the level surface of the vast basin before the limestones of the new cyclothem were deposited.

The Kansas City and Lansing groups are composed dominantly of limestone in Kansas but southward the formations and members composed of shale become thicker and the limestone beds in general grade into contemporaneously deposited shale and sandstone. Some of the limestones extend into northern Oklahoma, others fade out in southern Kansas. Many of the formations are convenient lithological groupings of beds without regard to the cyclothems involved.

Most of the formations referred to as limestones include shale members of varying thicknesses, some of which have characteristics recognizable in outcrops throughout extraordinarily broad areas. In the outcrops the limestones display faunal, lithological, and weathering characteristics by which they are commonly recognized. Most of the distinctive features of color, weathering, jointing, and faunal content and texture, however, cannot be determined in the cuttings taken from wells. The identification of formations is in consequence dependent upon the sequence of limestone beds and upon the thickness of shale between them, confirmed by the 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 fail to do so in others. Chert is a more or less constant constituent of some limestones in certain areas but chert is absent from ordinarily cherty beds in many wells and on the other hand, has been found in nearly all the limestones at some place in the subsurface. Fusulines are widely distributed but because of their frequency, are not very useful as lithologic features. A report on the zoning of fusulines in the Pennsylvanian and Permian rocks in Kansas, in preparation by M. L. Thompson, will provide an important means of identifying many formations. The detailed sequence of the members, many of which are thin, is seldom fully revealed by well cuttings or by the most careful logs, but the thickness and position of the group as a whole can generally be determined from good sets of well samples in areas where the shale units that are formations are well developed. In parts of the Salina basin, however, such shale units are so thin that even the groups are doubtfully differentiated in some wells.

Kansas City Group

The several formations of the Kansas City group listed in descending order in Table 9 have been differentiated in outcrops in southeastern Kansas. The range and average thickness at outcrops of each formation have been reported by Moore, Frye, and Jewett (1944, pp. 187-193). The thicknesses of the formations in

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

	Range of thickness in outcrops in southeastern Kansas, in feet	Average thickness in eastern Kansas outcrops, in feet	Thickness in southeastern Nebraska, in 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 mbr.	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
Total thickness in Salina basin, 255 feet			

southeastern Nebraska have been reported by Condra and Reed (1943, pp. 51-53).

Bronson subgroup.—The lower member of the Hertha is partly algal in the outcrops and it becomes oölitic in places in the subsurface in the Salina basin.

The Swope limestone is commonly oölitic in outcrops but not everywhere oölitic in the subsurface. The Hushpuckney black fissile shale member in the lower part of the Swope is generally recognized in the samples and is useful in identifying the Swope limestone.

The Dennis limestone also includes a useful black fissile shale (Stark shale member). The upper member of the Dennis, the Winterset limestone, is cherty and oölitic in outcrops. The chert is widespread but is not everywhere recognized in the subsurface. The oölitic facies of the Winterset is not dependable in the subsurface.

It will be noted that the thickness of the shale units that are formations in the table decreases toward the north more rapidly than that of the limestones. The average thickness of the formations of the Bronson subgroup that are mainly limestone is 79 feet in outcrops in eastern Kansas and 61 feet in southeastern Nebraska. Part of the thinning of the formations that are mainly limestone is probably due to the thinning of the shale members within the predominantly limestone formations. In the same areas the thickness of the shales of formation rank decreases from 55 feet to 13 feet. The average thickness of the Bronson subgroup as a whole in Kansas outcrops is 134 feet. The average thickness of the Bronson in seven wells in the subsurface on the line of cross section X-X′ (Pl. 13) is approximately 100 feet. The decrease in thickness toward the northwest is almost entirely due to loss of shale.

Linn and Zarah subgroups.—The nomenclature conference of state geologists May 5, 1947, restored to accepted usage in Kansas the term Cherryvale shale as the designation of a formation to include the Quivira shale, Westerville limestone, Wea shale, Block limestone, and Fontana shale as members.

The Block limestone has not been identified in outcrops south of Linn County and it thins northward. In southeastern Nebraska, a limestone 7 inches thick in the base of the Cherryvale shale may represent the Block, if the Fontana is absent. The Block is either absent or indistinguishable in the Salina basin where the Wea and Fontana shales in some places unite.

The Westerville limestone is cherty and oölitic in outcrops. The chert is not conspicuous in the Salina basin and the oölite is not well developed. The Westerville seems to be somewhat thicker in some wells than in outcrops, but it is not clearly distinguishable throughout the Salina basin.

The Quivira shale in the outcrop includes black shale which may occur also in the subsurface of the Salina basin.

The Drum limestone is oölitic in outcrops but oölites are not common in it in the Salina basin.

The Chanute shale was identified by Betty Kellet (1932) as far west as McPherson and Rice Counties but it has not been identified farther west and has not been recognized in the Salina basin, where, if present, it forms a thin parting between the Drum and the Iola.

The Iola limestone in outcrops includes the black fissile Muncie Creek shale member, a good datum in the subsurface.

The Lane shale, although thin, is a persistent formation and is recognized in many but not all wells in the Salina basin.

The upper member of the Wyandotte limestone is oölitic in the outcrops. It is also generally oölitic in the subsurface, but is not everywhere recognized in logs. The lower part of the Wyandotte includes the black fissile Quindaro shale member which is recognized in some wells.

The Bonner Springs shale, although much reduced in thickness, is recognized in most of the wells of the Salina basin. The thickness and distribution of the Bonner Springs shale illustrate the effects of the erosion that sometimes occurred between cyclothems. The Kellett cross section (1932) shows that westward from Woodson County the thickness of the Bonner Springs shale increases at the expense of the underlying rocks.

A comparison of the thickness of the formations of the Linn and Zarah subgroups in different areas shows that the total average thickness of formations composed mainly of limestones in the outcrops of east-central Kansas decreases northward toward southeastern Nebraska from 81 feet to 64 feet and the shales that are formations decrease from 190 feet to 71 feet. The total average thickness of the two subgroups in outcrops in east-central Kansas is 275 feet and in the Salina basin only 155 feet. The exact amount of decrease of the thickness of the shale cannot be determined from the sample logs but it is plain that much if not all the decrease to the northwest is due to thinning and wedging out of shale. The sample logs in the Salina basin seem to consist almost entirely of limestone but Schlumberger logs reveal the presence of many shale beds not recognized from the samples. The thickness of the Kansas City group as a whole decreases from an average of 409 feet in eastern Kansas outcrops to 203 feet in southeastern Nebraska.

Lansing Group

The sequence of formations of the Lansing group, listed in descending order in Table 10, has been established in outcrops in eastern Kansas. The range and average thickness at outcrops are reported by Moore, Frye, and Jewett (1944, pp. 186-187). Thicknesses in southeastern Nebraska are reported by Condra and Reed (1943, pp. 50-51).

Southward along the outcrops the Plattsburg limestone thins and disappears near the Oklahoma border bringing the Vilas shale in contact with the Bonner Springs shale, so that in southeastern Kansas near the Oklahoma border almost the entire section from the base of the Stanton to the top of the Drum limestone is shale. The Stanton limestone is more persistent than the Plattsburg and continues southward across Kansas but near the Oklahoma line it interfingers with shale and becomes difficult to trace (Moore, 1936, fig. 4A, p. 36; Moore, Frye, and Jewett, 1944, p. 186). The Stanton and the Plattsburg extend westward into the Salina basin with unbroken continuity.

The Plattsburg in the outcrops is generally oölitic but is not consistently oölitic in the subsurface of the Salina basin. On the

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

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

other hand, chert is not conspicuous at the outcrops but is generally present in the Plattsburg in the Salina basin. The black Hickory Creek shale member in the outcrops of the Plattsburg is recognized in some wells in the Salina basin.

The Vilas shale contains sandy beds and some sandstone in outcrops along the 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. The Vilas shale occurs locally in McPherson County and in structurally subsiding areas in the center of the basin, but it is generally absent or obscure in the subsurface of the Salina basin.

The Stanton limestone in outcrops is a sequence of three limestone alternating with two shale members. Neither chert nor oölites are reported in 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 is present in all wells. 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.

In northeastern and southeastern Kansas the Lansing group is commonly overlain conformably by the Weston shale of the Pedee group, but later erosion, which in many places removed the Weston and the upper members of the Stanton, introduced local irregularities in the thickness of the Stanton. The Weston shale is probably absent in the Salina basin. Irregularities in the thickness of the Stanton, where the Weston shale has been eroded, are probably due mainly to the post-Pedee unconformity. In some places in the Salina basin as in the White Eagle No. 1 Ucker well, sec. 12, T. 17 S., R. 2 E. (well 43, cross section X-X′, Pl. 13), a limestone bed younger than the Stanton of near-by areas occurs at the top of the Lansing. Because of topographic relief so general on its upper surface, the top of the Stanton, although easily recognized, is not a dependable datum for close contouring.

As in other groups of the Missourian Series, the Lansing group thins northward from an average of 85 feet in outcrops in eastern Kansas to an average of 53 feet in southeastern Nebraska. Part of the thinning occurs in the Vilas shale and in shale members of the Plattsburg but part of the thinning occurs also in the limestone members of both the Plattsburg and the Stanton. No thinning of the Lansing group as a whole is noted in the Salina basin where the average thickness is about 95 feet.

Pedee Group

The formations of the Pedee group recognized in outcrops in northeastern and southeastern Kansas are listed in descending sequence in Table 11. The range of thickness of the formations in Kansas is reported by Moore, Frye and Jewett (1944). The range of thickness in southeastern Nebraska is reported by Condra and Reed (1943).

TABLE 11.—*Sequence and thickness of formations of the Pedee group*

	Range of thickness in outcrops in eastern Kansas, in feet	Range of thickness in southeastern Nebraska, in 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 in contrast to the generally yellowish sandy shale of the overlying unconformable 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 occurrence of the Iatan limestone is even more restricted. It has not been recognized 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 in wells 44, 45, and 46 of cross section X-X′ (Pl. 13) by the shale below the sandstone of the Douglas group but in any case 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 very deeply into it. 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 with regional subsidence toward the southeast as indicated by a westward and northward convergence of the interval between the Stanton limestone and the base of the Oread limestone. No perceptible thinning of this interval occurs, however, on the axis of the Nemaha anticline on the line of cross section X-X′ of Plate 13.

Douglas Group

The formations of the Douglas group, represented in outcrops in eastern Kansas, are listed in descending order in Table 12. The range of thickness in outcrops in eastern Kansas is reported by Moore, Frye, and Jewett (1944); in southeastern Nebraska by Condra and Reed (1943).

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

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

The Stranger formation in the outcrops consists of yellowish-gray shale and sandstone with one or two limestone members in the upper part. The thickest areas of the Stranger formation occur 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 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 above is so variable that it seems to have been deposited on an uneven surface. The Haskell limestone, in consequence, is unsuitable for detailed contouring.

Outcrops of the Lawrence shale consist chiefly of blue-gray and yellowish shale with a thin discontinuous limestone member (Amazonia limestone) near the top and the tan-colored Ireland sandstone member of irregular thickness and distribution at its base. An unconformity of considerable erosional relief occurs between the Stranger formation and the Lawrence shale. The thickest deposits of Ireland sandstone lie in deeply eroded areas of the Stranger formation and, in some places, the base of the Ireland lies below the Haskell limestone. 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 after all other parts of the Lawrence shale have wedged out. It seems to be the initial deposit of a cyclothem below the Oread limestone, the first formation of the Shawnee group.

Westward the Douglas group becomes progressively thinner. The Tonganoxie sandstone thins out in the region east of the Nemaha anticline. In the Salina basin the Tonganoxie sandstone is seldom encountered. In McPherson and Marion Counties on the southeastern margin of the Salina basin the Ireland sandstone is more than 150 feet thick and makes up the greater part of the Lawrence shale (Kellett, 1932). The Ireland sandstone thins westward and is represented in the Salina basin by lenticular sandstone bodies.

The Douglas group combined with remnants of the Weston shale thins northwestward from 270 feet in sec. 31, T. 20 S., R. 10 E. (well 46, cross section X-X′, Pl. 13) to 225 feet in sec. 15, T. 20 S., R. 7 E (well 45) on the crest of the Nemaha anticline. It is 200 feet thick in sec. 23, T. 18 S., R. 5 E. (well 44) and thins gradually northwestward to 45 feet in well 38 at the northwestern end of the cross section. The regularity in the westward thinning of the Douglas-Pedee sequence on and across the crest of the Nemaha anticline implies that little or no local movement of the Nemaha anticline took place during Douglas-Pedee time.

Shawnee Group

The formations of the Shawnee group are listed in Table 13 in descending sequence. The thicknesses of the formations at outcrops in eastern Kansas are reported by Moore, Frye, and Jewett (1944, pp. 177-182). The thicknesses in southeastern Nebraska are reported by Condra and Reed (1943, pp. 46-49).

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

Well samples of the limestones present no distinguishing lithologic characteristics. Each limestone of formation rank includes one or more algal members, some of which are oölitic in outcrops, although oölites are uncommon in the subsurface. Also, each limestone of formation 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 point in the subsurface. All the limestones include one or several members containing fusulines but the range of the species is not yet well enough known to identify specific formations.

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 as T. 1 W. Farther west none of the

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

	Range of thickness in outcrops in eastern Kansas, in feet	Average thickness in outcrops in eastern Kansas, in feet	Thickness in outcrops in southeastern Nebraska, in feet
Shawnee group			
Topeka limestone	33-55	35	27-40
Calhoun shale	10-60	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	40-150	80	7-37
Oread limestone	52-100	70	47-54
Total		324	Aver. 212

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 recognizable shale units it is difficult or impossible to differentiate the limestones.

A comparison of the average thicknesses of the formations of limestone and shale of the Shawnee group in outcrops in eastern Kansas and southeastern Nebraska (Table 13) 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 60 feet thick. The outcrops of both are thinner north and south of this area (Moore, Frye, and Jewett, 1944, pp. 178-179). Probably the thickening of these shales in the same general area is due to more or less local and temporary synclinal warping of the strata prior to the deposition of the shales. The general northward thinning of the Shawnee group as a whole is the result of thinning of the shales of the group and only in minor degree to the thinning of the limestones.

The overall thickness of the Shawnee group in the subsurface also decreases gradually from southeast to northwest. It is 370 feet thick east of the Nemaha anticline in well 46 of cross section X-X′ (Pl. 13); 335 feet in well 18; and 200 feet in well 38. No material thinning of the Shawnee occurs on the crest of the Nemaha anticline in well 45, from which it is concluded that this structural feature was quiescent at this locality during Shawnee time.

Wabaunsee Group

The formations of the Wabaunsee group, listed in Table 14 in descending sequence, have been differentiated in the outcrops in eastern Kansas and southeastern Nebraska. The thicknesses in Kansas are reported by Moore, Frye, and Jewett (1944, pp. 172-176) and those in southeastern Nebraska by Condra and Reed (1943, pp. 41-46).

The Wabaunsee group comprises a sequence of alternating limestones and shales. Most of the limestones are relatively thin

TABLE 14—*Sequence and thickness of the formations of the Wabaunsee group*

	Range of thickness in outcrops in eastern Kansas, in feet	Average thickness in outcrops in eastern Kansas in feet	Range of thickness in southeastern Nebraska, in 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. 343

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, these limestones are less than 10 feet thick. Few of the other limestones exceed 5 feet in thickness and in many places do not exceed 2 or 3 feet in thickness.

The total average thickness of all the limestones of the Wabaunsee group, in the outcrops in Kansas, including the shale members of formations comprised mainly of limestones, is only 104 feet or about 20 percent of the average total thickness of the group. In outcrops, the shale units of formation rank include, without exception, 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. The cuttings of coal beds, because they float away, are seldom recognized in washed samples. Thin discontinuous limestones are not uncommon in the shales of formation rank, and in some wells, thin limestones that probably appear as unnamed calcareous marine shale in outcrops toward the source of clastic sediments are noted. On the other hand, some limestones reported in drillers logs are probably indurated shales. Some of the widely distributed limestones are only occasionally recognized and reported in logs because they are thin and argillaceous. As a result there is considerable confusion and uncertainty in the identification of individual formations in the logs of many wells that penetrate the Wabaunsee group.

The Howard limestone is generally recognized in logs as a prominent limestone about 50 feet above the top of the Topeka limestone. In the subsurface, the Happy Hollow limestone is generally noted but the Rulo limestone seems to be lenticular and erratic in distribution. The coal or black shale that occurs between the Happy Hollow and Rulo limestones in outcrops has been noted in the subsurface in some wells. In some areas in the subsurface a streak of red shale occurs between them and is useful in local correlations.

The Burlingame limestone seems to be missing in many wells in the Salina basin. The Wakarusa, Reading, and Elmont limestones, in areas where the intervening shales become thin, draw closer together and in some logs are recorded as a single limestone. A red shale between the Reading and the Wakarusa is helpful in some areas in identifying these limestones.

The Tarkio limestone is 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 and well developed in the Salina basin. Westward in the subsurface the interval between the Dover and the Tarkio becomes markedly thinner.

The formations of the Wabaunsee group that lie above the Dover limestone were in many places eroded during the hiatus between the deposition of Pennsylvanian and Permian rocks. Most of the formations designated as limestones above the Dover in the outcrops are thin or are in reality sequences of thin limestones separated by shale members. Inasmuch as they display no marked lithologic peculiarities, they are doubtfully identified in the subsurface.

The thickness of the Wabaunsee group ranges from 420 feet to 210 feet. Much of the variation in thickness is due to the unconformity at its top, into which erosion cut channels as much as 120 feet deep in some places. Harned and Chelikowsky (1945) report the relief of the pre-Permian surface to be 250 feet in Pottawatomie County, Kansas, where Permian beds, lying on an irregular surface, rest on Pennsylvanian beds as much as 150 feet below the Dover limestone. In well 46 of cross section X-X′ (Pl. 13) east of the Nemaha anticline, the thickness of the Wabaunsee below the Brownville limestone is 390 feet. In well 45, the same interval measures 380 feet. It is concluded, therefore, that little or no movement of the Nemaha anticline occurred at the location of this well during Wabaunsee time. In well 44 where some Pennsylvanian beds above the Brownville were preserved from erosion, the thickness of the Wabaunsee is 420 feet, but in well 42 where erosion cut below the Tarkio the thickness is only 210 feet.

The amount of northeastward convergence across the Salina basin during Wabaunsee time is difficult to determine because of the erosion of the upper part of the Wabaunsee, but there is definite convergence of the limestones in this direction. The average thickness of the Wabaunsee group from the Brownville limestone to the Topeka limestone at outcrops in eastern Kansas is 514 feet. A composite section of the same sequence, 390 feet thick, was measured in southeastern Nebraska by Condra and Reed (1943). Measurements of the Wabaunsee from the base of the Brownville to the top of the Topeka in the eastern part of the Salina basin average about 385 feet. The pattern of relative subsidence toward the southeast therefore continued through Wabaunsee time.

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 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 15 have been differentiated in outcrops in eastern Kansas. The thicknesses at outcrops in eastern Kansas are reported by Moore, Frye, and Jewett (1944, pp. 168-170); those in southeastern Nebraska by Condra and Reed (1943, pp. 36-37).

The Admire group, exclusive of the basal sandstone, is dominantly shale, some of which is sandy. The limestone beds, although persistent, are thin and without unique lithologic features that aid in their identification 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. In the subsurface, the details of topography of the surface between the Pennsylvanian and the Permian are less clearly re-

TABLE 15.—*Sequence and thicknesses of the formations of the Admrie group*

	Range of thickness in Kansas outcrops, in feet	Average thickness in Kansas outcrops, in feet	Range of thickness in southeastern Nebraska, in 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

vealed and give the impression of a mature erosional surface. Except in steep-sided channels the basal beds of the Towle consist mainly of sandy or silty shale. Toward the northwest, thin limestones or indurated shales occur in the Towle shale in the subsurface.

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 interval 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 interval is the basis for the conclusion that regional deformation continued in the same general pattern during the hiatus represented by the interval, as during Pennsylvanian time when areas toward the north and west were continually tilted by differential movements toward the southeast.

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

The part of the Admire group above the base of the Aspinwall limestone varies in thickness. It is 90 feet thick to the east of and on the crest of the Nemaha anticline, thickens gradually to 140 feet in the synclinal area of the Salina basin, and thins again northwestward. Abnormal thickening toward the northwest occurs in the upper shale member of the Hamlin shale and also in the West Branch shale. Toward the northwest, the interval between the Falls City-Five Point limestone sequence and the top of the Admire thins, and toward the southeast the same interval increases.

Council Grove Group

The following formations of the Council Grove group, listed in descending order in Table 16, have been differentiated in outcrops in Kansas. The thicknesses at outcrops in Kansas are from Moore, Frye, and Jewett (1944, pp. 165-168). Those for Nebraska are from Condra and Reed (1943, pp. 33-36).

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

	Range of thickness in Kansas outcrops, in feet	Average thickness in Kansas outcrops, in feet	Average thickness in southeastern Nebraska, in 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 the 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 limestones interstratified with shale members. These limestones are more clearly recognized in the samples of some wells than in others.

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 that the Foraker stands out prominently in the subsurface of the Salina basin from other formations in which the fusulines are a less conspicuous feature. The Foraker becomes more calcareous southward and the middle member as well as the upper and lower members is limestone in outcrops in southern Kansas and in Oklahoma. This relation contrasts with the limestones in the Pennsylvanian, which toward the south commonly become argillaceous or interfinger with clastic sediments.

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 of southern Kansas. In the outcrops it thins slightly toward the north. Although recognized in the subsurface, the limits of the Red Eagle limestone are generally not clearly defined in sample logs.

The Grenola limestone can be identified in most sample logs. The upper member, the Neva limestone, is clearly recognized, 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 in spite of 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 Beattie and Bader limestones, as represented in drillers and sample logs, are indistinct in many wells probably because they, together with the thin intervening Stearns shale, contain as much shale and impure limestone as pure limestone. The Cottonwood limestone member of the Beattie limestone, which immediately overlies the Eskridge shale, is nearly always recognized.

The Easly Creek shale consists mainly of red and gray shales. 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.

The Speiser shale consists of shales and streaks 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. The thickness of the group is 290 feet just west of the Nemaha anticline. It thickens to 340 feet in the Salina basin and continues northwest without thinning.

Chase Group

The formations of the Chase group, listed in descending order in Table 17, have been differentiated in outcrops in Kansas. The thicknesses of these formations at the outcrops are reported by Moore, Frye, and Jewett (1944, pp. 160-168). Those in Nebraska are reported by Condra and Reed (1943, pp. 31-33).

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

The Wreford limestone consists of two limestone beds separated by a shale bed. Because both are consistently cherty in outcrops and in the subsurface, the Wreford is an excellent datum bed.

The Matfield shale is varicolored. It includes the Kinney limestone member consisting of interstratified shale and thin limestone beds, one or another of which is commonly overlooked in drilling and not accurately represented in sample logs.

TABLE 17.—*Sequence and thickness of the formations of the Chase group*

	Range of thickness in Kansas outcrops, in feet	Average thickness in Kansas outcrops, in feet	Average thickness in southeastern Nebraska, in 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 Barneston limestone includes the Florence limestone member at the base and the Fort Riley limestone member at the top separated by a gray calcareous shale member generally not differentiated in logs. 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 practically 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 chert-bearing beds, the Florence and the Wreford, are valuable markers in a sequence of limestones and shales whose identification might otherwise remain obscure.

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. Unlike the Pennsylvanian limestones, the shale member of the Winfield thins or grades into limestone toward the south and in southern Kansas the Winfield consists of a single bed of limestone. 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 in color with red predominating.

The Nolans limestone consists of two thin limestones at the base, generally not recognized in logs, and the more prominent and thicker Herington limestone at the top. The intervening shale member is calcareous and includes some limestone in southern Kansas outcrops. The Nolans limestone thickens toward the northwest and grades into dolomite. The limestones become dolomitic toward the west.

The limestones and shales of the Chase group, as represented in the subsurface in well logs, are somewhat more variable in thickness 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 average thickness of 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 well 43 of cross section X-X′ (Pl. 13) in northern McPherson County is 360 feet. In well 38 in Phillips County the thickness is only 290 feet. The Chase group as a whole thus thins toward the northwest like the older Permian and Pennsylvanian groups but the southward increase in the proportion of limestone in some formations is a new feature in the sedimentation of the region.

LEONARDIAN SERIES

The Leonardian Series is divided into the following groups listed in descending sequence; Nippewalla and Sumner.

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, Frye, and Jewett, 1944): Stone Corral dolomite, Ninnescah shale, and Wellington formation.

Other groupings of these rocks have been made. Norton (1939) places the Ninnescah and Stone Corral in the redbed sequence at the base 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, some 50 feet above the Herington limestone member of the Nolans limestone.

The Sumner group comprises a sequence of evaporites and shale with a few local more or less discontinuous thin limestones of variable character. The upper part consists mainly of shale and the lower part in central Kansas consists largely of shale, anhydrite, and salt.

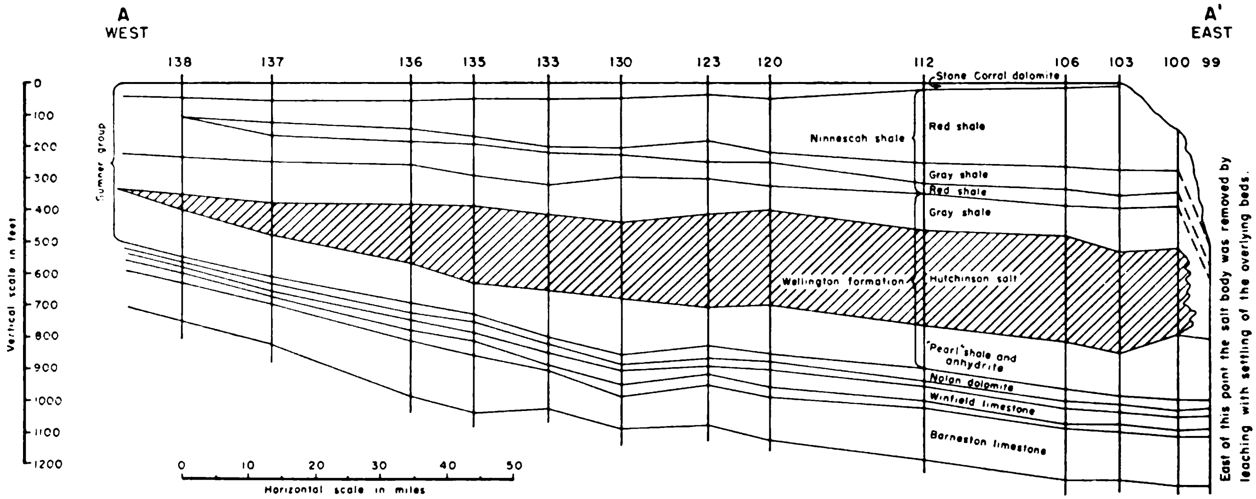
Wellington formation.—A detailed study of the Wellington formation in south-central Kansas was made by Ver Wiebe (1937) who traced the beds of limestone in the outcrops. The Hollenberg is the only one of these limestones recognized with confidence in the subsurface of the Salina basin but others may 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 of the Salina basin.

The "anhydrite zone" at the base of the Wellington (known also as the Pearl shale) comprises a sequence of gray shales 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 east these beds consist mainly of gray shale but 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 "salt zone," known as the Hutchinson salt member, consists mainly of salt interstratified with thin beds and laminae of anhydrite and shale partings of no great thickness. Thicker shale beds are interbedded with the salt near the base and near the top. The salt zone is thickest in Russell, Ellsworth, Rice, and Reno Counties and thins somewhat irregularly to a featheredge toward the north and west. It thins toward the south in Kansas and extends into northern Oklahoma. Eastward, the salt and most of the associated anhydrite have been dissolved by surface waters for a distance of 20 to 30 miles down dip from the belt in which it should normally outcrop. The removal of the salt has allowed the overlying deposits to slump into a zone of steep dips and confused bedding.

The combined thicknesses of the parts of the Wellington above and below the salt lentil are essentially the same as outside the area of salt deposition. The salt therefore accumulated in a basin formed by the downwarping of the nearly flat surface of the "anhydrite zone."

Figure 7 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 to 1942, and Botinelly.


A
WEST
A'
EAST
138
137
136
135
133
130
123
120
112
106
103
100
99
Stone Corral dolomite
Red shale
Ninnescah shale
Gray shale
Red shale
Gray shale
Wellington formation
Hutchinson salt
"Pearl" shale and anhydrite
Nolan dolomite
Winfield limestone
Barneston limestone
Sumner group
East of this point the salt body was removed by leaching with settling of the overlying beds.
Vertical scale in feet
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Horizontal scale in miles
0
10
20
30
40
50

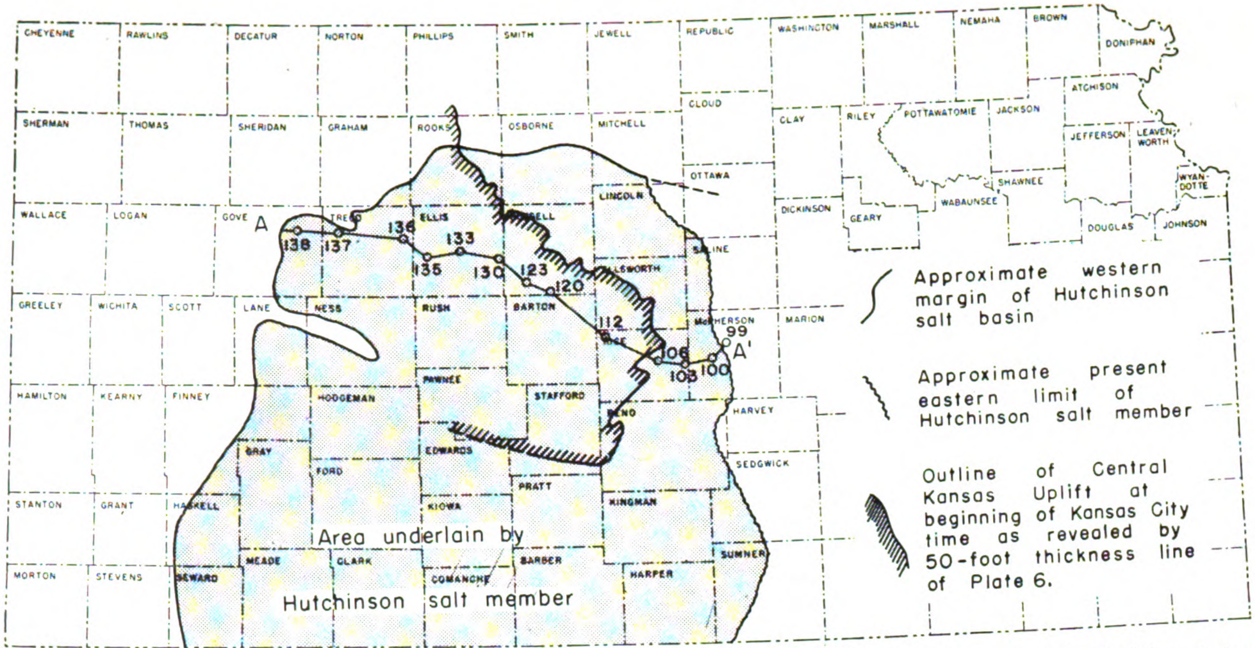


FIG. 7.—Stratigraphic cross section of the Sumner group of the Permian (after Kellet, 1932) on line A-A′ of insert showing eastward thickening of the Hutchinson salt member of the Wellington formation and an inset showing the salt basin crossing the Central Kansas uplift. The wells are correlated on the top of the Stone Corral dolomite. The numbers of the wells are the same as those used on the original Kellett cross section. The cross section reveals that the salt lens originally extended a considerable but undeterminable distance to the east or southeast. The Central Kansas uplift which had been a positive and rising area since St. Peter time, was a subsiding area during this interval. The present attitude of the salt in the Salina basin is shown on cross sections X-X′ and Y-Y′ (Pls. 13 and 14) and on the original Kellett cross section.

The cross section (Fig. 7) shows the lenticular character of the salt sequence and the attitude of the salt and overlying beds at the end of Wellington 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 east, it seems probable that at least half the original salt body has been lost by erosion and leaching. The "middle gray beds" of Ver Wiebe, which occur normally above the salt, include much less anhydrite and more thin red shales than the "anhydrite zone" below the salt. In the absence of the salt the middle gray beds cannot be clearly distinguished from the anhydrite beds.

The "red beds" zone is known mainly from wells although Ver Wiebe reports outcrops in southern Kansas where the shale beds thicken appreciably southward. In the Salina basin the thickness of the red beds zone averages about 50 feet. The thickness increases irregularly to more than 100 feet toward the west and northwest.

The "upper gray beds" consist largely of soft gray clays but blue shales are common. Ver Wiebe reports a thickness of 75 feet for these beds in south-central Kansas but in the Salina basin their thickness ranges from 30 to 60 feet. Westward these beds become thicker or grade into the increasingly thick red beds zone. The thin Milan limestone at the top of the Wellington in outcrops was not recognized in the subsurface.

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 impure limestones and calcareous sand. It thins rapidly northward from 425 feet near the Kansas-Oklahoma line to 280 feet 50 miles farther north. None of the datum beds recognized in southern Kansas has been identified in the subsurface of the Salina basin where the Ninnescah, although it locally includes some red sandstone, consists in most areas almost entirely of red partly silty shale. The thickness of the Ninnescah in the Salina basin decreases somewhat irregularly toward the north from about 300 feet in east-central Rice County to 65 feet in southeastern Smith County. Westward it thickens irregularly from 65 feet in Smith County to 200 feet in south-central Phillips County and 140 feet in Norton County (Norton, 1939).

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). It varies in character from place to place along the outcrops and in the subsurface. In some places dolomite predominates. At others it is interstratisfied with thin shale members and anhydrite and in some places it consists of anhydrite alone. The formation is 30 to 50 feet thick in Pratt, Stafford, and Rice Counties. Southeastward in Kingman County it thins to 10 feet and in northern Oklahoma it grades gradually into clastic sediments.

In the Salina basin the thickness ranges from 10 to 50 feet without notable trends of thickening in any direction. Where the Stone Corral is thin it consists almost entirely of anhydrite. Norton (1939) concluded that the Stone Corral is conformable on the underlying Ninnescah but suggests 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 the outcrops the Harper sandstone is divided into the Chickaskia and Kingman sandstone members, both of which consist chiefly of red sandstone broken by thin beds of red shale and white sandstone. 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 may be due in large part to the fact that grains of disintegrated sandstone are frequently 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 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 lie on the beveled edges of the Permian rocks. The formations of Permian age younger than Harper sandstone and all rocks of Triassic and Jurassic age are absent. Probably the uppermost Permian rocks of southwestern Kansas extended throughout this part of Kansas and were later eroded. Deposits of Triassic and Jurassic age, themselves separated by unconformities, are recognizable in western Kansas. If they extended eastward into the Salina basin, they were completely removed later.

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 as shown by the Kellett cross section (1932) was more than 300 feet.

The Niobrara chalk and older Cretaceous rocks are exposed on the western border of the Salina basin. Eastward they and the upper formations of the Cretaceous were removed by erosion shale interbedded with lenticular bodies of thin white siltstone and sandstone. Locally the sandstone lentils are as much as 20 feet thick. Shell fragments and carbonaceous material are com-

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

Detailed studies of the Cretaceous rocks in central Kansas have been made in recent years by several geologists of the State Geological Survey. Plummer and Romary (1942) examined 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 above 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. They 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 surface of the Permian east of Russell County.

The Kiowa shale consists of gray to black thinly laminated shale interbedded with lenticular bodies of thin white siltstone and sandstone. Locally the sandstone lentils are as much as 20 feet thick. Shell fragments and carbonaceous material are common. The sandstones are slightly glauconitic, generally micaceous, and less coarse in grain than the sands of 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.

GULFIAN SERIES

Colorado Group

The Dakota formation is composed dominantly of varicolored clay. It includes some siltstone but very little shale. Fine- and coarse-grained sandstones are frequent but discontinuous. They are mainly channel deposits and only a few can be traced from place to place. In spite of 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 onto the Permian. The thickness of the Dakota in Russell County ranges from 213 feet to 300 feet.

The Graneros shale in Russell County consists of dark-gray to brownish-black noncalcareous shale interbedded with thin beds of glauconitic fine-grained sandstone. It is distinguished from the overlying Greenhorn limestone by the absence in the Graneros shale of calcareous material and the foraminifer *Globigerina* 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 separated 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 feet to 215 feet thick, is made up largely 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 frequent partings of bentonite up to 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. The contacts are so indefinite in some wells that the Cretaceous sequence cannot be subdivided.

Rocks of Tertiary and Quaternary Age

Tertiary deposits of continental origin occur in many localities in central Kansas. The Emma Creek formation of Pliocene and early Pleistocene age, which consists of alluvial deposits of sand, silt, and clay, is found in thicknesses up to 180 feet in parts of McPherson 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 up to 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 mantle extensive upland areas throughout the region. High-level terraces of different ages occur on the borders of 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 the 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 development of a younger flat horizontal surface, the variations in thickness of the rocks between the two surfaces will reveal the amount and place of the deformation.

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 alter the overall deformation, which is the total amount of deformation between the development of the reference planes.

The accuracy with which the thickness maps record the structural movements is dependent upon the completeness with 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 recognized by the thinning of beds of one sequence accompanied by a compensating greater 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 the thickness lines combined with detailed stratigraphic studies reveal in some cases local topographic features on the eroded surfaces (Lee and Payne, 1944, p. 105 and fig. 14).

Beveling of stratified rocks is recognized by the thinning and wedging out of successive units immediately 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 is assumed that the surface at the locality was either progressively arched during deposition 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.

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 Pre-Cambrian surface and the base of the St. Peter sandstone. The second affected the rocks between the St. Peter sandstone and the base of the Mississippian and possibly also the Kinderhookian rocks. The third, which produced the Nemaha anticline and the Salina basin, affected the Mississippian, Pennsylvanian, and Permian rocks. The third period of folding began in Mississippian time 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-St. Peter Folding

The thickness of the rocks between the Pre-Cambrian surface and the base of the St. Peter sandstone is shown in Plate 1 by lines drawn at 100-foot contour intervals. A relatively level Pre-Cambrian surface is indicated by the wide distribution of the Bonneterre dolomite which is underlain in most areas by the Lamotte sandstone, but low topographic relief in Missouri, Iowa, and eastern Kansas is revealed by local variations in the thickness of the Lamotte and in its absence of the Bonneterre.

That hills of considerable height remained on the Pre-Cambrian surface is suggested by the record of a well in Vernon County, Missouri, where the Gunter sandstone member of the Van Buren formation directly overlies Pre-Cambrian rocks (McQueen, 1931, pl. 10). The relations of the Gunter to the Pre-Cambrian at that place, however, could have resulted from pre-Gunter and pre-Eminence uplift, exposure, and erosion.

The surface on which the St. Peter was deposited is known from outcrops in northern Missouri where it was trenched by shallow channels. Wells in that part of Missouri and in eastern Kansas have revealed local thicknesses of the St. Peter sandstone as great as 403 feet (Lee, Grohskopf, Reed, and Hershey, 1946, sheet 1). These thicknesses, when compared with the regular thickness of the sandstone, rarely less than 50 feet or more than 100 feet, indicate that the surface was probably affected by sink holes.

Although the surface on which the St. Peter was deposited beveled all the rock formations extending downward from the Jefferson City-Cotter sequence to Pre-Cambrian granite, it seems to have been reduced to a plain which had low topographic relief and local sink holes. That a subsiding basin, the Ozark basin, prior to St. Peter time extended from south-central Missouri northward into eastern Iowa is indicated by maps showing the thickness of the rocks between the top of the Roubidoux and the Pre-Cambrian in southern Missouri (Lee, 1943, fig. 10), and between the base of the St. Peter and the Pre-Cambrian in northern Missouri (Lee, Grohskopf, Reed, and Hershey, 1946, sheet 1). Also, at that time a broad beveled southward plunging arch, the Southeast Nebraska arch, extended from southeastern Nebraska southward across Kansas more or less parallel to the contemporaneous Ozark basin.

Cross section B-B′ (Fig. 8, Pl. 1) across the southern extension of the Southeast Nebraska arch between wells 4B and 6 reveals the Roubidoux dolomite resting directly on the Pre-Cambrian as the result of beveling or overlap of pre-Roubidoux rocks. Also, the Roubidoux overlies Pre-Cambrian rocks in a broad ill-defined area extending roughly northeast from wells 2 and 3. In McPherson County a pre-Roubidoux syncline is suggested by a deep well (No. 4) in which Keroher and Kirby (1948) found some 360 feet of pre-Roubidoux sediments. The trend of this syncline toward the northeast, shown on Plate 1, is vaguely indicated by a well in sec. 9, T. 17 S., R. 3 W., in which Miss Leatherock identified 170 feet of Bonneterre dolomite. The syncline becomes less prominent toward the northeast but is indicated by the thickening of the Bonneterre dolomite between wells 29 and 30 of cross section A-A′ (Pl. 1).

The interpretation of these structural features is based on the assumption that the sequence of pre-Roubidoux formations, as recognized in western Missouri, was deposited in eastern Kansas and was deformed and beveled before Roubidoux time. Possibly there were Cambrian hills that were not covered by sediments until Roubidoux time but this does not seem to be supported by the present relations of the Roubidoux to the Bonneterre, Eminence, Van Buren, and Gasconade formations in well 4B (Fig. 8) in McPherson County.

The well in McPherson County (well 4B, cross section B-B′, Sinclair No. 8 Morehouse, sec. 4, T. 21 S., R. 3 W.) penetrated a seeming abnormal thickness, 360 feet, of the Jefferson City and Cotter dolomites, which seems to be due to possible repetition by a pre-Pennsylvanian thrust fault (Bunte and Fortier, 1941, p. 114, fig. 5) whose trace passes near the well. Possibly the thickness of Jefferson City and Cotter dolomites has been increased as much as 150 feet by repetition along the fault. This seeming duplication has been taken into account in preparing cross section B-B′ and the thickness map. The fault is believed not to have affected the thickness of the pre-Jefferson City formations.

Cross section A-A′ (Pl. 1) reveals beveling of the Bonneterre dolomite on the flank of the Southeast Nebraska arch and overlap of the Roubidoux formation onto the Bonneterre, and suggests that the Bonneterre and the Roubidoux were removed from the crest of the arch immediately prior to St. Peter time. Although structural movement was more or less continuous throughout Arbuckle deposition, there seems to have been two periods of especially active deformation in eastern Kansas. The first period of special activity preceded the deposition of the Roubidoux which was deposited upon the beveled surface of the older rocks (Fig. 8) which had been arched on axes trending slightly east of north. The second period preceded the deposition of the St. Peter sandstone. This movement is especially well revealed on the crest of the Southeast Nebraska arch (cross section A-A′, Pl. 1) which shows the overlap of the St. Peter on Pre-Cambrian rocks as well as the overlap of the Roubidoux on the Bonneterre.

Development of the 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 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 beveled strata previously warped and re-elevated.

DEFORMATION OF ROCKS OF SIMPSON AGE

Rocks of Simpson age in the Salina basin consist of the St. Peter sandstone below and the Platteville formation above (Leatherock, 1945). The St. Peter sandstone lies unconformably on the earlier Ordovician and Upper Cambrian rocks, and unconformably also below the Platteville. Local variations in the thickness of the St. Peter owing to erosional relief equal or exceed its regional variations in some localities. In consequence, no conclusions concerning structural movements that were developed during its deposition can be drawn from its thickness.

The important unconformity between the St. Peter sandstone and the Platteville is expressed by the absence in Kansas of several thick formations cropping out in this interval in southeastern Missouri. In northeastern Kansas and in the Salina basin the contact between the two formations seems to have been unusually even over a broad area. The basal dolomite member of the Platteville rests on the upper member of the St. Peter in some places and on the middle member in others (Leatherock, 1945, p. 13) irrespective of the thickness of the dolomite member. The dissected surface of the St. Peter was reduced to an exceptionally perfect plain, presumably by tidal and wave action of the Platteville sea. The fact that different parts of the St. Peter underlie the base of the Platteville in different areas suggests that there was local deformation during the hiatus between the St. Peter and Platteville. The data are, however, inadequate to permit an analysis of these movements.

The Platteville is too thin and too irregular in thickness for structural deformation to be revealed by a thickness map. It is unconformable with the overlying Kimmswick as well as with the underlying St. Peter. Toward the south and southwest, the Kimmswick overlaps beyond the Platteville and is in contact with the St. Peter (well 1, cross section A-A′, Pl. 2; well 25, cross section A-A′, Pl. 4). The minor irregularities of the upper contact of the Platteville are probably the result of low topographic relief of the Platteville surface. The formation, as shown in the cross section of Plate 4, thickens toward the center of the North Kansas basin and the initial subsidence responsible for this thickening was contemporaneous with the deposition of the Platteville or took place during the hiatus between Platteville and Kimmswick times. The thickness map and the cross section (Pl. 2) reveal that subsidence of the North Kansas basin and the contemporaneous elevation of the Chautauqua arch and the Central Kansas uplift began before the deposition of the Kimmswick. A suggestion that the deformation was initiated even before the end of Platteville time is offered by cross section A-A′ of Plate 4.

DEFORMATION OF THE KIMMSWICK-MAQUOKETA SEQUENCE

The three zones of the Kimmswick limestone form a conformable sequence, and each thickens more or less regularly into the

North Kansas basin as shown in cross section A-A′ (Pl. 2). The wedging out of the first zone toward the south and the overlap of the second zone upon the Platteville and locally upon the St. Peter, suggest that the pre-Kimmswick surface was gently warped prior to the deposition of the first zone and that this zone was deposited only in the deeper parts of the basin. With continued subsidence the second zone overlapped beyond the previously unsubmerged margin of the basin.

The thickening of the second zone toward the north implies subsidence in this direction contemporaneous with its deposition, but it may be due wholly to subsidence and beveling during the hiatus between the Kimmswick and the overlying Maquoketa shale, for the Maquoketa overlaps from the third zone onto the second zone (Pl. 2) on the flank of the Central Kansas uplift. The deformation of the third zone probably occurred both during deposition and during the pre-Maquoketa hiatus.

DEFORMATION OF THE MAQUOKETA-SILURIAN SEQUENCE

Plate 4 shows the thickness of the Simpson, Kimmswick, Maquoketa, and Silurian rocks. Because the upper and lower surfaces of this sequence are known to have been exceptionally smooth and level (Lee, Grohskopf, Reed, and Hershey, 1946, sheet 2), its thickness, which increases regularly into the North Kansas basin, is regarded as a reliable measure of the character of the structural movements that occurred between pre-St. Peter and pre-Devonian beveling.

In order to determine if either the upper or lower surface of the Maquoketa was smooth enough to be used for the preparation of thickness maps that signify structural movement, Plates 2 and 3 were drawn for comparison with Plate 4. Plate 2 shows the combined thicknesses of the Kimmswick dolomite and the Maquoketa shale and Plate 3 shows the combined thicknesses of the Maquoketa shale and Silurian dolomite. Although the thickness of the Kimmswick and Maquoketa increases toward the center of the North Kansas basin, the configuration of the thickness lines (Pl. 2) deviates widely from the pattern of the lines of Plate 4. It is inferred that the significance of the thickness lines of Plate 2 in determining deformation is materially modified by the unconformity at the top of the Maquoketa shale, and that

Plate 2 thus does not portray the details of structural movement although a general subsidence of the North Kansas basin is indicated.

The thickness lines of Plate 3, although not as closely spaced, conform approximately to the thickness lines of Plate 4. This similarity implies that the deformation shown by the thickness lines of Plate 3 adequately represents the increment of folding from the base of the Maquoketa to the pre-Devonian surface, and that the base of the Maquoketa, although having some relief, was a relatively more level surface than its top.

The cross section of Plate 3 shows that the thickness of the first zone of the Silurian tends to increase where the Maquoketa is thin and to decrease where the Maquoketa is thick. The areal geology of Plate 4 shows that pre-Silurian erosion cut deep enough to remove the Maquoketa shale in parts of Smith and Osborne Counties. Some erosional relief at the base of the Maquoketa as well as at the top is suggested in well 24 of cross section A-A′ (Pl. 3), where the Kimmswick thickens at the expense of the Maquoketa.

Because of the pronounced unconformity at the base of the Silurian and the regularity in thickness of its second zone, the cross section of Plate 3 has been correlated on the base of this zone. The cross section shows that northeasterly subsidence occurred during the deposition of the third zone and that little or none occurred during the deposition of the fourth zone.

At the end of Silurian time the whole region was elevated above sea, probably by a series of differential vertical and deformational movements. During the ensuing erosion the surface was reduced to a nearly flat plain although in some areas there were low hills (Pl. 5; and Lee, Grohskopf, Reed, and Hershey, 1946, sheets 2 and 3, Chariton County, Mo.). All the rocks down to the Lower Ordovician dolomites were beveled on the flanks of the Chautauqua arch and the Central Kansas uplift (Pl. 4). On the line of the cross section of Plate 3 pre-Devonian erosion beveled the Silurian from the fifth zone to the fourth zone, but on the cross section of Plate 4 the Devonian overlaps onto the Maquoketa shale also. Cross section A-A′ of Plate 3 shows that the subsidence of the North Kansas basin was not less than 400 feet between the beginning of Maquoketa time and the beveling of the pre-Devonian surface.

OVERALL DEFORMATION BETWEEN THE BASE OF THE ST. PETER AND THE BASE OF THE DEVONIAN

Plate 4, which shows the thickness of rocks from the base of the St. Peter sandstone to the base of the Devonian rocks, indicates the subsidence of the North Kansas basin up to the time of pre-Devonian beveling. On the northern flank of the Chautauqua arch, which was developed during the deposition of this sequence, pre-Devonian erosion beveled rocks ranging in age from Silurian to Jefferson City (Lee, Grohskopf, Reed, and Hershey, 1946, sheet 2).

The thickness maps and cross sections of Plates 2, 3, and 4 reveal that there was no perceptible deformation in northeastern Kansas during the deposition of the St. Peter sandstone but that gradual subsidence of the North Kansas basin occurred during Platteville, Kimmswick, and Silurian times and continued intermittently until the beveling of the pre-Devonian surface. The pre-Devonian subsidence of the North Kansas basin was about 800 feet.

DEFORMATION OF THE DEVONIAN ROCKS

After Devonian time and probably in part during the Devonian, the North Kansas basin was again warped downward. Subsequently the whole region was eroded to a plain that rivaled the pre-Devonian surface in its smoothness.

Plate 5 shows the thickness of the Devonian rocks and also the pre-Chattanooga areal geology. Inliers of Silurian rocks shown on the map in Dickinson County indicate that the pre-Devonian surface possesses some topographic relief in that area.

The Devonian rocks are thickest in the central part of the North Kansas basin in southeastern Nebraska. Toward the margin of the basin they were beveled and completely removed from the major areas of uplift where older rocks also were beveled. The post-Devonian plain is well developed in most parts of eastern Kansas and in adjoining states, but deep valleys were cut in its surface toward the west. In northern Rice County a broad open valley trending northward in Reno County joins another trending westward across Marion and McPherson Counties. Thence, the drainage seems to have flowed northwest. In Marion and McPherson Counties, the valley cut through the Devonian, Silurian, and Maquoketa rocks and exposed the upper beds of the Kimmswick. An outlier of Devonian rocks was left south of the valley in Harvey and parts of adjoining counties as shown on Plate 5.

The thickness of the Devonian is significant of structural movement only where the original beveled surface lies beneath the Chattanooga and outside the pre-Chattanooga valley described above. In the area of control (Pl. 5) as thus limited the increase in the thickness of the Devonian rocks conforms to the pattern of thickness lines of Plate 4 and indicates continued subsidence of the North Kansas basin. The subsidence of the base of the Devonian in the North Kansas basin was at least 600 feet. The pre-Chattanooga areal geology shown on Plate 5 reveals that during Devonian time or at its close the Chautauqua arch became separated from the Central Kansas uplift.

Figure 9 shows a west-east section across the Devonian outlier on line B-B′ of Plate 5. It reveals pre-Chattanooga arching trending somewhat vaguely toward the north in T. 22 S., R. 2 W. in Harvey County. This fold is more clearly revealed by the thickness contours of Plate 7. Folding more or less parallel to the subsequently folded Nemaha anticline is indicated in the Forest City basin by similar thinning of the Devonian on the eastern border of Plate 5 and by Lee, Grohskopf, Reed, and Hershey (1946, sheet 3). These belts of thinning suggest that there was minor structural activity parallel to the Nemaha anticline before Chattanooga time, but there is no evidence that initial movements occurred on the anticline itself at that time.

DEFORMATION OF CHATTANOOGA AND BOICE SHALES

Plate 6 shows the combined thickness of the 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 of the period. The 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, was eroded on the beveled surface of the Devonian rocks. The wedging out of the shales on the western and northern margins of the shale area is, however, the result of beveling at the close of Mississippian time and is thus not related to structural movements that occurred between post-Devonian planation 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). The thickness lines of Plate 6 are dotted across areas from which the shales were removed by post-Mississippian erosion. The dotted lines extending northward from Republic and Washington Counties, Kansas, are intended to suggest the probable original thickness of the shales in that part of the area.

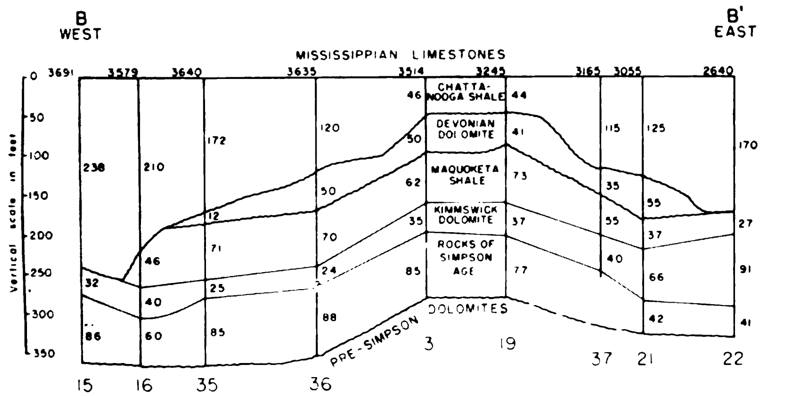
OVERALL DEFORMATION BETWEEN THE BASE OF THE ST. PETER SANDSTONE AND THE BASE OF THE MISSISSIPPIAN LIMESTONES

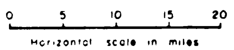
Plate 7 shows the thickness of rocks between the base of the St. Peter sandstone and the top of the Chattanooga-Boice shale sequence and it reveals the deformation that took place during the corresponding time interval. The extent of this deformation represents the total of the separate increments of deformation indicated in Plates 2 to 6. The post-Devonian anticlinal arch in Harvey County, revealed by cross section B-B′ of Figure 9, is clearly shown on Plate 7 as is its northerly trend approximately parallel to the Nemaha anticline. Plate 7 reveals also that the subsidence of the North Kansas basin was at least 1,400 feet below the flank of the Chautauqua arch and more than 1,000 feet below the pre-Mississippian flank of the Central Kansas uplift. The total downwarping of the North Kansas basin below the crests of these structural features was considerably greater and may have reached 2,000 feet.

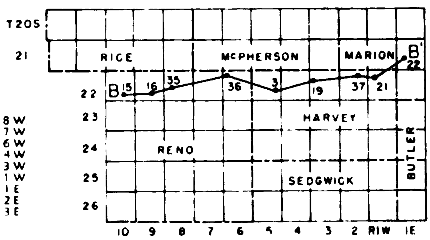
DEVELOPMENT OF THE NEMAHA ANTICLINE AND THE SALINA BASIN

DEFORMTION DURING MISSISSIPPIAN TIME

As pointed out in the discussion of the stratigraphy of the Chattanooga-Boice shale sequence, the surface at its upper contact was exceptionally level. The first deposits upon this surface were Kinderhookian limestones. In southeastern Kansas







Index No.	Company	Well no. and form	Location
15	Sterling Drlg Co	No 1 Osenbough	Sec 34, T 22 S, R 8 W
16	Derby Oil Co et al	No 1 Rainbow	Sec 33, T 22 S, R 7 W
35	H B Gorden	No 1 Fred Strickler	Sec 17, T 22 S, R 6 W
36	Braden & McClure	No 1 Williams	Sec 6, T 22 S, R 4 W
3	C L Carlock et al	No 1 Schrogg	Sec 25, T 22 S, R 3 W
19	Derby Oil Co	No 1 D B Jones	Sec 7, T 22 S, R 1 W
37	Helmerich & Payne	No 1 Schmidt	Sec 2, T 22 S, R 1 E
21	Saco Oil Co	No 1 Geo Guthrie	Sec 8, T 22 S, R 2 E
22	Fowler Bosinger et al	No 1 Janzen	Sec 9 T 21 S, R 3 E

Fig. 9.—Stratigraphic cross section across Reno and Harvey Counties on line B-B′ of Plate 5 showing anticline of probable pre-Chattanooga age. The anticline is not revealed on the Devonian thickness map on account of the pre-Chattanooga topography. It is clearly shown, however, by the thickness lines of Plate 7 which reveal also the trend of the fold.

they consist of the Chouteau and Sedalia limestones both of which thicken northward from a featheredge at 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 toward the north as shown in cross section A of Figure 4, reveals that during Kinderhookian time and at its close central Iowa was subsiding and southeastern Kansas was stationary or being slightly elevated. At the end of Kinderhookian time the region was raised above sea level and during a period of relative stability the formations were beveled as is illustrated on the cross-section in Figure 4. 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 Osagian formations, the Reeds Spring, Burlington, and Keokuk limestones, and the Meramecian "Warsaw," Spergen, and St. Louis limestones overlap in succession northward on Kinderhookian rocks, as shown diagrammatically in cross section B of Figure 4. The differential 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 was probably seldom raised much above sea level some erosion of the Kinderhookian rocks of Iowa must have occurred during Osagian time. Figure 4 shows the structural relations of the Mississippian rocks east of the Nemaha anticline which was already undergoing initial deformation in early Mississippian time.

Figure 6 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 only the upper member of the Sedalia is represented in this area. The absence of the lower member of the Sedalia and the Chouteau limestone is the result of pre-Chouteau elevation of the area west of the Nemaha axis which confined these deposits to a subsiding structural basin to the east.

West of the Nemaha anticline the Kinderhookian rocks thicken appreciably toward the north and wedge out toward the south where outliers of upper Sedalia rocks lie unconformably below the Gilmore City (Fig. 5) or below the St. Joe limestone as shown in wells 10 and 12 of the cross section of Figure 6. Figure 6 shows also that the Osagian formations 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 east of the Nemaha anticline.

The division of the basin in which the early Osagian rocks were being deposited by a northerly trending belt of land too high to be covered until Burlington time reveals that initial movements of the Nemaha anticline occurred prior to or during the deposition of the St. Joe and Reeds Spring (Fig. 5B). 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 reveals movement on the trend of 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 movement of the Nemaha anticline, the maximum development of which occurred at the end of Mississippian deposition; and (2) the progressive tilting of the region from south to north during Kinderhookian time and later tilting in the opposite direction. A third type of deformation that produced folds trending to the northwest is recognized in the post-Mississippian development of the Salina basin, but no evidence has been discovered that this type of deformation was active during the deposition of Mississippian rocks. Early Mississippian movements of this type seem probable inasmuch as regional folds trending in this direction had been active since St. Peter time and continued into the Pennsylvanian.

DEFORMATION AT THE END OF MISSISSIPPIAN TIME

Plate 8 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 included the formation of the Nemaha anticline, 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 the rocks were essentially beveled during the whole period of deformation as well as the end.

Before the invasion of the Pennsylvanian sea the beveled surface was re-elevated, deformed again, and subjected to relatively brief erosion. A broad valley was cut on the beveled surface of the Mississippian limestones in the Forest City basin and 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 is revealed by a local thickening of the Pennsylvanian rocks accompanied by a corresponding thinning of the upper Mississippian formations at 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 in the Salina basin 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, a residual debris, was more nearly level than the eroded surface of the Mississippian.

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 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 finally raised so high that the erosional beveling in northeastern Kansas exposed Pre-Cambrian rocks on the crest and truncated the overlying rocks in parallel bands 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 Central Kansas uplift, which is outlined on the areal map of Plate 8 by the beveled outcrops of Mississippian and older rocks, was vigorously rejuvenated at the end of Mississippian time, but 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. This concept is difficult to accept in the light of the relations shown by the thickness contours of the two basins and their relation to the Nemaha anticline. The Nemaha anticline strikes across the eastern side of the North Kansas basin (compare Pls. 7 and 8) and 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.

At the end of post-Mississippian beveling, 350 feet of Misssissippian 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 strikes northwest parallel to the northeastern flank of the Central Kansas uplift. It lies between this structural feature and a new broad contemporaneously developed area of uplift in southeastern Nebraska trending northwest from the northern end of the Nemaha anticline across the deepest part of the old North Kansas basin. The only feature common to the Salina basin and to the North Kansas basin is their position on the northeast flank of the Central Kansas uplift. It seems probable that a Salina basin would have been formed even had there been no North Kansas basin.

The Salina basin is bounded on the southeast by the Nemaha anticline but where the syncline which forms the Salina basin intercepts the 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 (Lee, 1939, Pl. 1). The Central Kansas uplift confines the Salina basin on its southwestern side but between the southeastern end of the uplift and the Nemaha anticline the Salina basin is confined by a broad low arch between the 250-foot thickness lines (Pl. 8). This arch trends northwestward across central McPherson County, and is alined with the flank of the Central Kansas uplift.

The folds that trend northeast parallel to the Nemaha anticline and those that trend northwest paralleling the Central Kansas uplift although they intersect nearly at right angles seem to have developed contemporaneously, for the interruption of the Nemaha anticline, at its intersection by the Salina basin syncline in Chase and Marion Counties, continued to develop in early Pennsylvanian time (Pl. 9).

Northeast-trending folds were formed both to the 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. A northeasterly trending post-Mississippian thrust fault in pre-Pennsylvanian rocks was mapped in the subsurface by Bunte and Fortier (1941) on the west side of the Voshell anticline.

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 with the scanty data and with the structure of the surface formations. The Abilene anticline is interrupted on the south by the Salina basin syncline.

The anticline on the southwestern limb of the Salina basin on which the Olsson pool (T. 16 S., R. 3 W.) lies, extends farther northeast into the Salina basin than the other anticlines. Available data from a single well, Northern Ordnance Inc. No. 1 Warner, sec. 10, T. 15 S., R. 3 W., suggest that this anticline may cross the Salina basin to its northeastern side.

Northwest-trending folds paralleling the Salina basin and the Central Kansas uplift are not clearly revealed by the Mississippian thickness lines of Plate 8. 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 areal geology map (Pl. 8) suggests northwesterly trending folds on the flank of and paralleling the Salina basin.

DEFORMATION DURING PENNSYLVANIAN AND PERMIAN TIME

The structural movements that occurred during Pennsylvanian and Permian time are based on the 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 due 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 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 described by Walters (1946, pp. 690-699). A part is due to the fact that where the basal conglomerate is represented by noncherty clastic deposits it has been included with the Pennsylvanian instead of with the Mississippian sequence. The irregular configuration of the zero thickness line as shown on the Central Kansas uplift cannot therefore be accepted as representing local structural movements although in some places it seems to do so.

DEFORMATION BETWEEN THE TOP OF THE PENNSYLVANIAN BASAL CONGLOMERATE AND THE HERTHA LIMESTONE

Plate 9 shows the thickness of the pre-Hertha Pennsylvanian rocks above the Pennsylvanian basal conglomerate. The structural movements revealed by the thickness of the Mississippian limestone (Pl. 8) 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, topographic basins developed east and west of the Nemaha anticline whose crest became a low barrier separating the basins. The Forest City basin to the east was deeper than the Salina basin to the west and was 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 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 but in the deepest part of the Forest City basin they were 1,050 feet thick. The difference in the thickness of the deposits is the measure of the vertical displacement of the Forest City basin below the Salina basin.

Except for such outstanding local structures as the Burns dome and the Elmdale and Eldorado anticlines, 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 displacement, partly by faulting on its east side, and tilted the upraised block toward the west. Plate 9 shows a belt of thinning west of the axis of folding extending south from western Riley County to northwestern Butler County. This belt of thinning is not a structural feature but the result of the westward migration of the divide between the Salina and Forest City basins during the long period of exposure when the crest of the anticline was kept above sea level by differential upward movements.

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 9 show the renewed development of the Salina basin along the same trend as indicated by the thickness of the Mississippian limestones. Plate 8 shows that the thickest section of Mississippian limestones lies in Saline County but Plate 9 shows that the thickest section of pre-Hertha Pennsylvanian rocks is in or near Jewell County and that the position of maximum deformation had thus moved some 60 miles northwest.

The divide in McPherson County that separated the Salina basin from the deeper structural basin toward the south on Plate 8 is only faintly shown by the thickness lines of Plate 9. The Salina basin interrupts the Nemaha anticline at the same place as at the end of Mississippian time (Pl. 8). The perpetuation of this feature probably indicates 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.

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 activity of the Abilene anticline although some movement probably occurred. Secondary northwesterly trending folds are not revealed by 50-foot thickness lines.

DEFORMATION BETWEEN THE HERTHA LIMESTONE AND THE TOPEKA LIMESTONE

Plate 10 shows the thickness of the Pennsylvanian rocks between the base of the Hertha limestone and the top of the Topeka limestone. The deformation indicated by the thickness of this sequence is similar to that revealed in Plates 8 and 9 but was of declining intensity. At this time 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 Plate 10. Continued development of the Burns dome is revealed by a 50-foot thickness line encircling its crest but only minor anticlinal movements, so far as known, occurred at other places.

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 area 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 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 less than 150 feet.

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 wells along the Abilene anticline suggest some activity of this structural feature.

DEFORMATION BETWEEN THE TOPEKA LIMESTONE AND THE BARNESTON LIMESTONE

Plate 11 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 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 identified in well logs that no suitable datum beds are available for dividing the sequence near the Permian-Pennsylvanian contact. The deformation indicated by the thickness map, therefore, includes movements of both late Pennsylvanian and early Permian age.

The thickness map of this sequence is in most respects similar to Plate 10 but less deformation is revealed in spite of the fact that the average thickness of the sequence is greater. Structural activity in the Salina basin again declined. The re-entrant shows a lower overall structural gradient toward the southeast than during the older sequence although in some areas the gradient is steeper. The arching of the Central Kansas uplift had nearly ceased and the thickness lines show 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 of less than the contour interval. Very little control is available on the Abilene anticline but deformation is suggested vaguely by a few wells and by abrupt deformation of more than 50 feet in surface formations on its east side 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. The sequence is 55 feet thinner on the crest than on the flanks of the Burns dome and is 40 feet thinner on the crest than on the flanks of the north end of the Eldorado anticline. 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 immediately east of either the Burns dome or the Eldorado anticline but subsidence, up to 40 feet, is shown by irregular thickening of the interval in a number of wells in the adjacent synclinal area to the east.

DEFORMATION BETWEEN THE BARNESTON LIMESTONE AND THE STONE CORRAL DOLOMITE

Plate 12 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. 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. The thickness lines reveal a regional tilt only a little east of south. They 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 11.

The cessation of structural activity on the Central Kansas uplift brought to an end a long period of anticlinal movement. Its almost continuous development from St. Peter to early Permian time is recorded by thinning on its flank or crest of nearly every mappable unit from Kimmswick to Barneston. The 50-foot thickness lines reveal no structural activity of the Central Kansas uplift after Barneston time although minor movements on local northwesterly trending anticlines probably continued through the Cretaceous. The Salina basin was 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 inactive after Barneston time.

A structural bench, trending from Rush and Ellis to Lincoln and Ellsworth Counties, breaks the regular southward increase in thickness of the Florence-Stone Corral sequence. The widening of the intervals between 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 the crest of the formerly active Central Kansas uplift (Fig. 7).

The southward thickening of the sequence below the Stone Corral dolomite is a change from the previously dominant southeasterly thickening of the older sequences. It suggests that the regional center of the synclinal movements may have moved westward from the Ouachita basin.

Relation of Pennsylvanian and Early Permian Deformation in Kansas to the Ouachita Basin

During Pennsylvanian and early Permian time Kansas formed a part of a structural province which comprised Illinois, Kansas, Missouri, Nebraska, Iowa, and parts of Oklahoma and Arkansas and 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 that 18,000 to 20,000 feet of clastic Pennsylvanian rocks of Cherokee and earlier age were deposited in the Ouachita basin. 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 seem 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 which 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 the 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 the formations in which limestone predominates. Table 18 shows the comparative thickness of limestones and clastic deposits in the wells shown in Figure 10.

Formations that are composed predominantly of limestone can generally be recognized in sample logs and in some drillers logs but the detailed thickness of interbedded shale cannot be determined with accuracy. The thicknesses of shale and limestone shown in Table 18 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 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 18 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 which caused the deposition of greater or less thicknesses of shale in the areas affected.

In well 1 of Table 18 the Wyandotte and other limestones of the Kansas City group were either eroded during intercyclical

TABLE 18.—*Comparative thickness, in feet, of limestone and clastic beds in groups of the Upper Pennsylvanian and Lower Permian rocks in wells shown on Figure 10*

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.	Clastics		Ls.	Clastics	Ls.	Clastics	Ls.	Clastics
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 & 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.

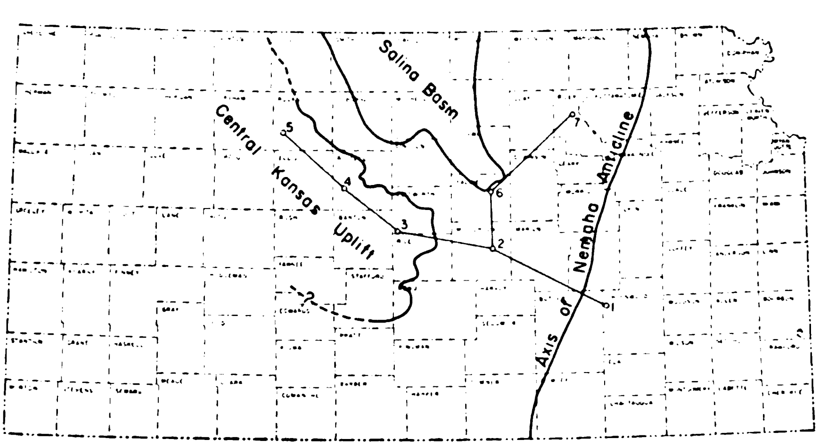


FIG. 10.—Map showing locations of wells referred to in Table 18 and their relation to Pennsylvanian structural features.

erosion and replaced by shale or graded into shales southeastward toward the source of sediments. In this area the thickness of limestone was thus decreased and 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 18, as well as 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, 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 toward the Ouachita basin was the outstanding structural development in the midcontinent region during Pennsylvanian and Permian times. 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.

Post-Permian Deformation

After Permian time a broad syncline developed in southwestern Kansas, and the whole region was raised, roughly beveled, and covered by rocks of Cretaceous age. The details of deformation during the hiatus between the Permian and the Cretaceous are now only partly known.

Late as well as early Permian rocks were laid down in the Salina basin, in eastern Kansas, and perhaps even in the Mississippi Valley, but they were completely removed from the region east of the Salina basin before Cretaceous time. Triassic rocks, 20 feet thick, have been tentatively identified on lithologic grounds in the subsurface of southwestern Kansas. They unconformably overlie the Permian and wedge out toward the east. Upper Jurassic rocks are represented in western Kansas by the Morrison formation which rests unconformably on the Triassic or the Permian and is unconformably overlain by Cretaceous rocks. Neither the Triassic nor the Jurassic rocks now extend into the Salina basin where the Cretaceous rocks overlap from the Morrison onto the Permian.

The post-Permian and pre-Cretaceous structural movements as they affected western Kansas and the Salina basin are shown by the generalized structure maps of Figure 11. Figure 11C shows the present attitude of the Stone Corral dolomite by 250-foot structure contours. Figure 11B shows the present attitude of the top of the Dakota formation (after Bass, 1926a, p. 85) by 250-foot structure contours. Figure 11A, which represents the structure of the Stone Corral dolomite before the deformation of the Dakota, shows a broad southwesterly plunging syncline whose axis lay some 40 to 50 miles west of the present syncline as shown in Figure 11C. The regional dip of the Stone Corral in the Salina basin was about 10 feet per mile toward the southwest.

The post-Dakota regional dip (Fig. 11B) is roughly 7 feet per mile, slightly east of north in Ellis County, and about 7 feet per mile toward the northwest in Republic County. The post-Dakota deformation tilted the syncline in western Kansas toward the north, shifted the position of the lowest part of the structural basin toward the east, and changed the dip of the Stone Corral and older Permian and Pennsylvanian rocks in the Salina basin from southwest to a somewhat variable dip of 6 to 10 feet per mile toward the northwest.

The present northwesterly dip of the Permian and Pennsylvanian rocks in the Salina basin and eastern Kansas is thus not the result of a single pre-Cretaceous structural movement but a composite of at least two separate and different structural components. The first, itself perhaps a composite movement, occurred mainly after Permian time and before Cretaceous time (Fig. 11A), and the second occurred mainly after Cretaceous time (Fig. 11B). The final structural movements raised Cretaceous rocks of Gulfian age to about 1,400 feet above sea level in the Salina basin.

Details of the post-Cretaceous structural history of the Salina basin are imperfectly 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.

Plates 13 and 14 show the present attitude of the rocks along the lines X-X′ and Y-Y′ of the thickness maps. The exaggerated vertical scale of these cross sections shows distorted dips. The true rate of dip in feet per mile is shown by the insert diagrams.

Relation of the Structural Development of the Region to the 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 structural movement at several different times. The folding which was thus brought about in the main by minor increments of deformation is expressed by the thickness of certain stratigraphic sequences. 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 cases 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 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, pp. 128-133); this is the explanation of the so-called "loss of closure" in drilling into deeper rocks.

The movements of fluids and gas 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 thus 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. However, so few wells have been drilled through the pre-St. Peter sedimentary sequence that any local structures are completely unknown, and the major 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 in southeastern Kansas. In these areas the anticlines in which the oil is found trend west and northwest at right angles to the structural axes of known pre-St. Peter folds and they may have been initiated between St. Peter and Mississippian time, when a broad regional anticline extended west from the

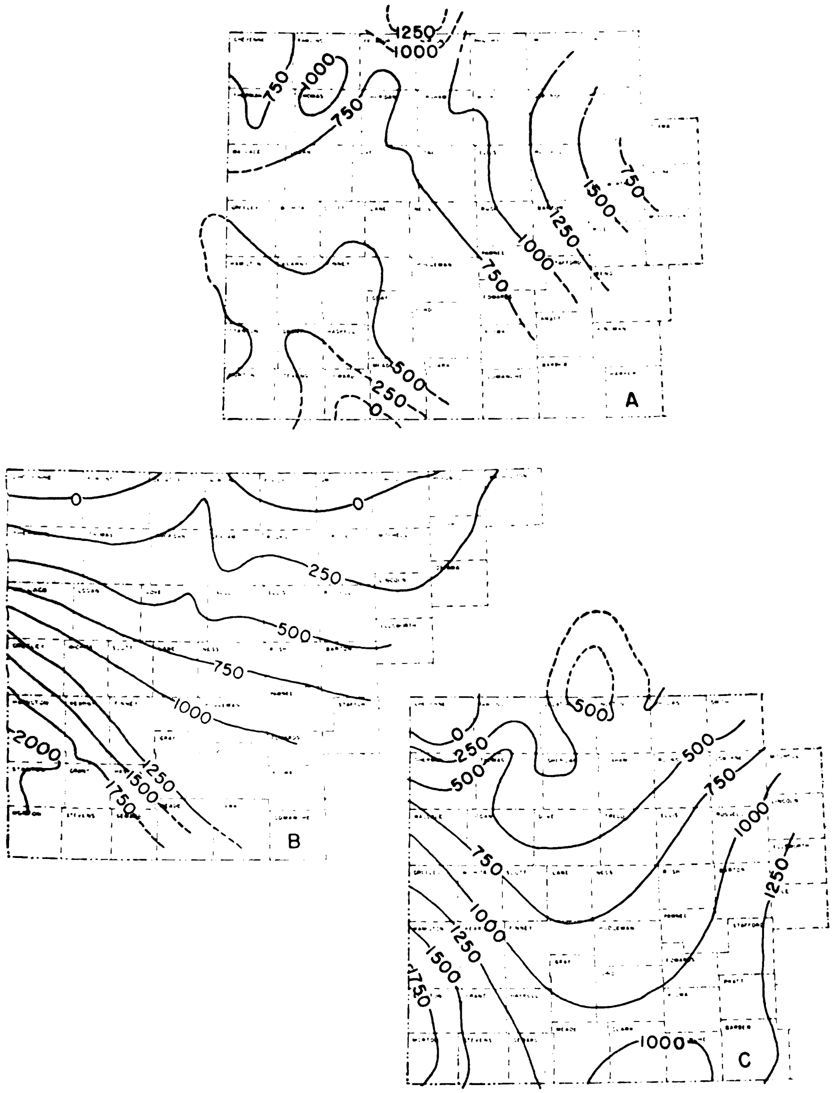


Fig. 11.—Generalized contour maps showing by 250-foot contours, *A*, the structure of the Stone Corral dolomite at the end of Dakota time, *B*, the present structure of the top of the Dakota formation, and *C*, the present structure of the Stone Corral dolomite.

Ozarks as the Chautauqua arch and continued northwest as the Central Kansas uplift.

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). These local anticlines were folded after regional movement of the Chautauqua arch had ceased. They 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 initiated during the development of the Chautauqua arch.

The Central Kansas uplift itself began its upward movement shortly after St. Peter time, reached its period of maximum deformation before Hertha time, and continued to develop with declining intensity through late Pennsylvanian and early Permian time. Most of the productive anticlines on the uplift also trend northwest. The date of the initial movements of the anticlines cannot now be determined because the area was stripped of pre-Pennsylvanian and post-Lower Ordovician rocks by successive periods of exposure and erosion. It is probable, however, that such folds were being developed at the end of Mississippian time contemporaneously with the Salina basin.

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

The few wells in northern Lincoln County suggest anticlinal conditions there. The interpretation of the thickness of the Mississippian rocks for that area seems to indicate a northwesterly trending anticline but the thickness lines of the pre-Hertha Pennsylvanian rocks in the same area suggest a northerly trending anticline.

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. The occurrence of small amounts of low gravity oil in one well on the part of the anticline in Clay County (sec. 21, T. 9 S., R. 21 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 it was recontoured, eliminating post-Permian regional tilting. The structure as thus restored revealed a considerable shift in the position of the low crests on the axis of the present anticline. The crest upon which the small Clay County well was drilled was thus shifted about three-quarters of a mile toward the northwest and the crest of the steeper subsurface structure thus does not occur beneath the crest in the surface rocks. The recontouring of this area therefore suggests that some of the wells drilled on the Abilene anticline have not been well located to test the deeper rocks.

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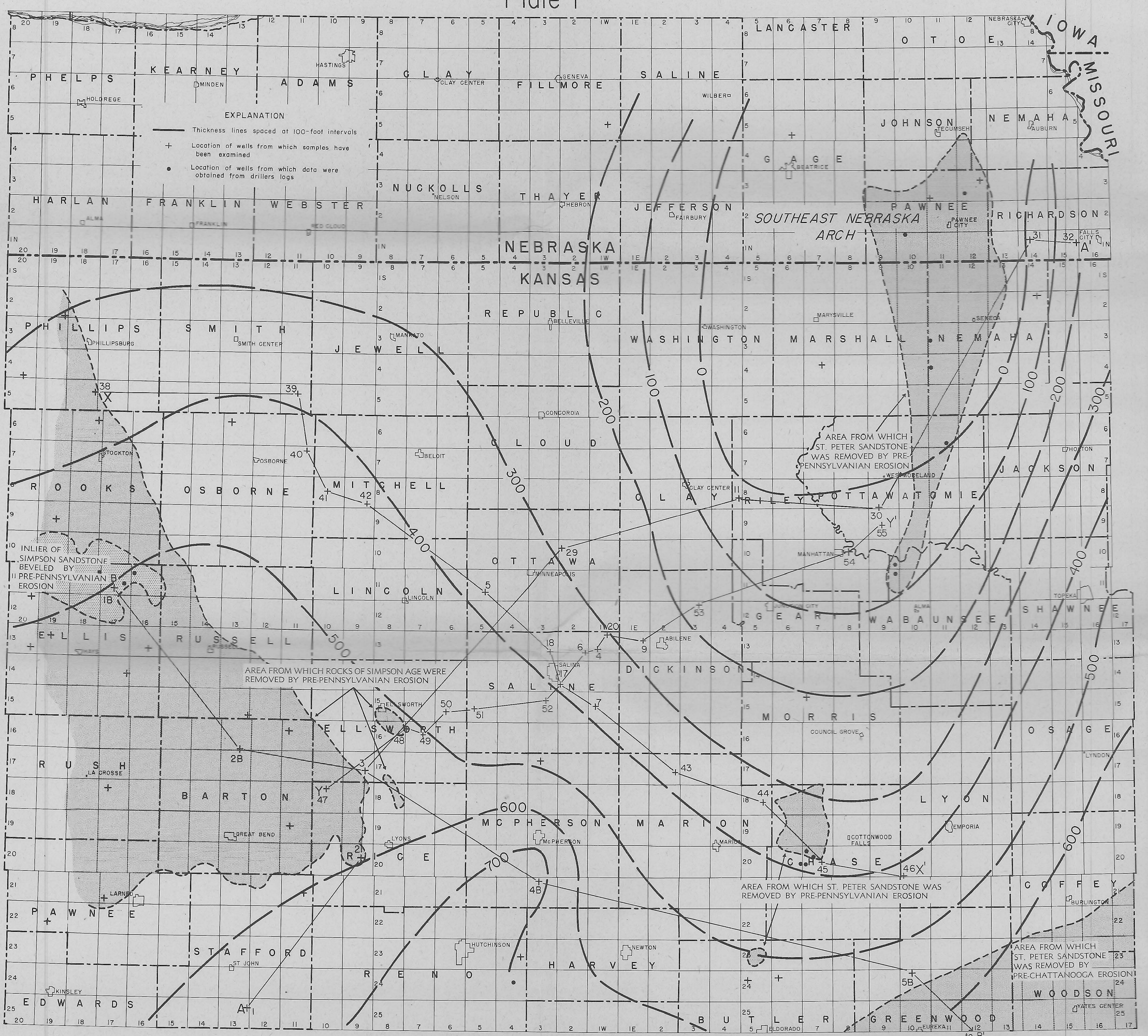
INDEX

THE STRATIGRAPHY AND STRUCTURAL DEVELOPMENT OF THE SALINA BASIN IN KANSAS

by Wallace Lee, Constance Leatherock and Theodore Botinelly

Prepared cooperatively by the State Geological Survey of Kansas and the United States Geological Survey, 1948

Plate 1



Map of the Salina basin area showing (a) the thickness of the pre-St. Peter sedimentary rocks and (b) a stratigraphic cross section on line A-A'. Cross section B-B' is shown in Figure 8. Cross sections X-X' and Y-Y' of Plates 13 and 14 show the present attitude of the rocks of this sequence. The thickness lines show the Southeast Nebraska arch and its southern extension as a plunging anticline and synclinal basin in McPherson County. The pre-Roubidoux arch in Barton County shown in cross section B-B' of Figure 8 is not revealed because the upper limit of this sequence was removed from that area by later erosion. The wells of cross section A-A' are correlated on the base of the St. Peter sandstone. Those of cross section B-B' are correlated on the top of the Roubidoux formations. The cross sections reveal a pronounced unconformity at the base of the Roubidoux dolomite and the beveling of pre-Roubidoux formations. The St. Peter sandstone also bevels older rocks. The data for all wells on cross section A-A' except wells 30 and 31 are from Keroher and Kirby (1948).

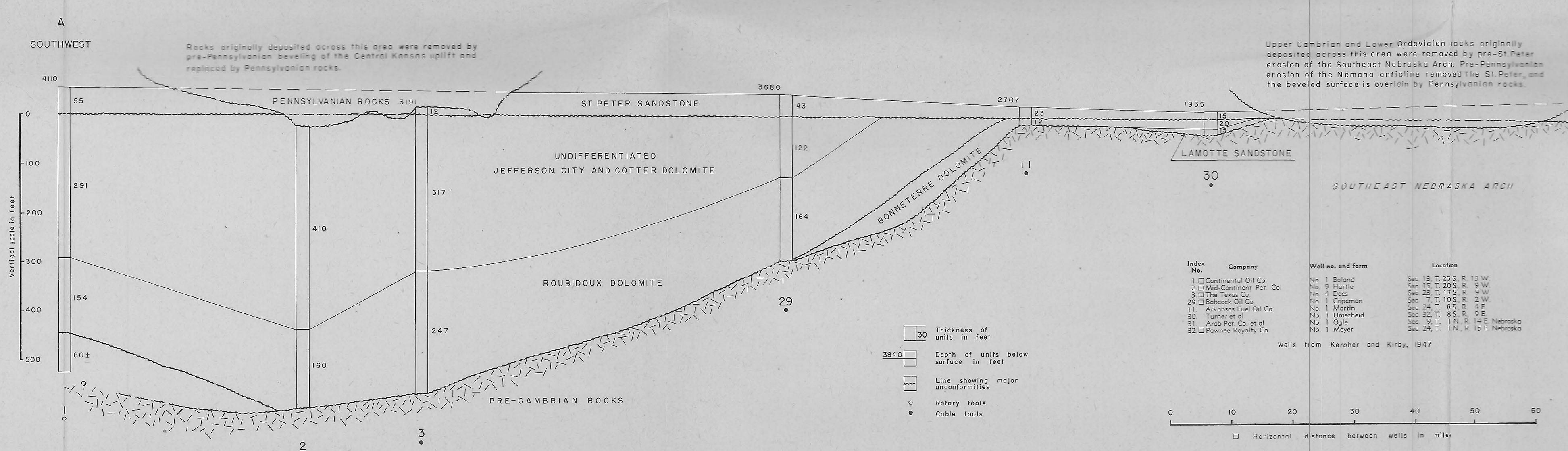
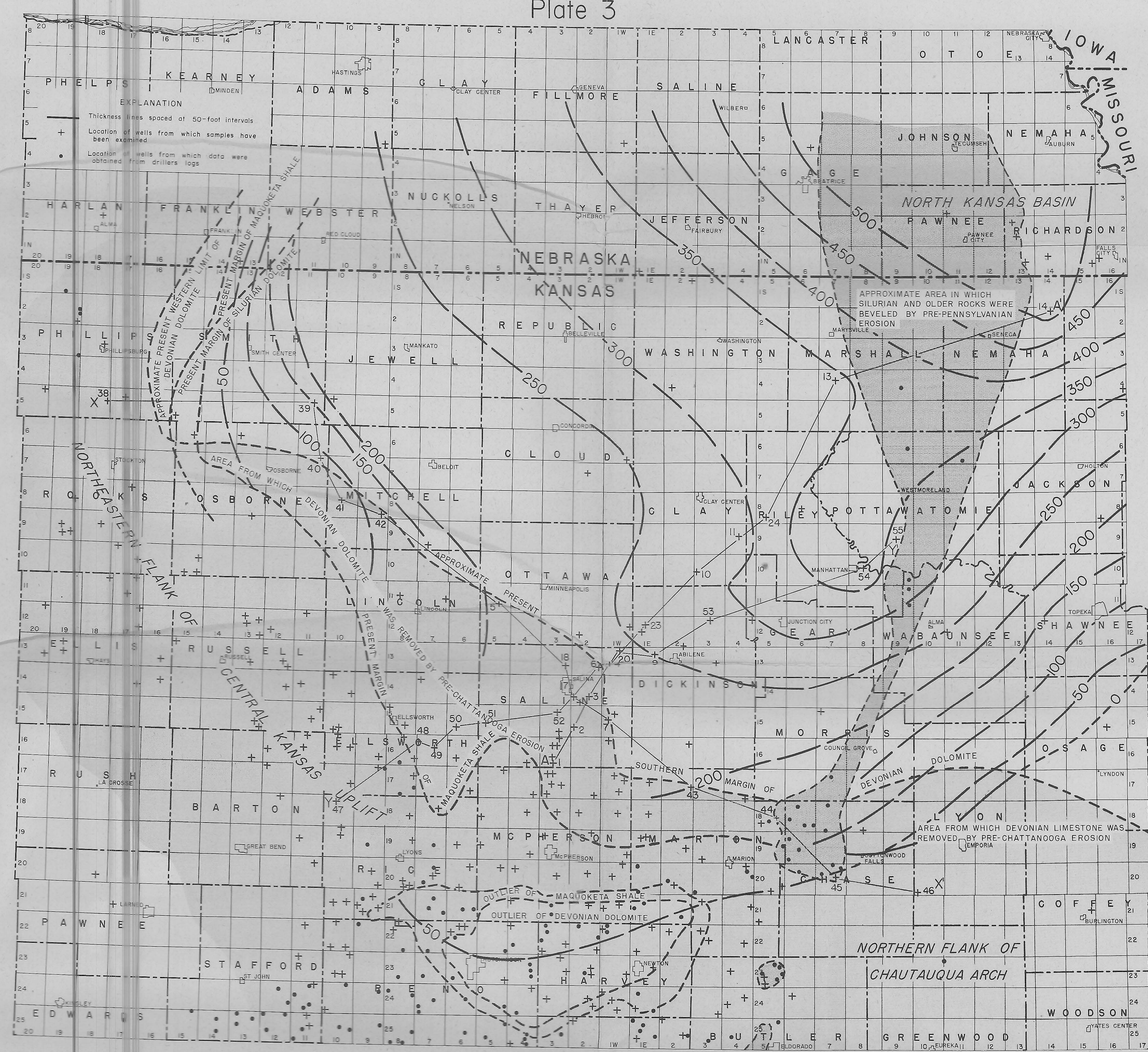


Plate 3



Map of Salina basin area showing (a) the combined thicknesses of the Maquoketa shale (Sylvan of Oklahoma) and the Silurian dolomite where they lie beneath Devonian dolomite and (b) a stratigraphic cross section on the line A-A'. Cross sections X-X' and Y-Y' of Plates 13 and 14 show the present attitude of Maquoketa and Silurian rocks. The Maquoketa and Silurian sequence thickens toward the North Kansas basin and thins southeastward toward the Chautauqua arch and southwestward toward the Central Kansas uplift. Due to the fact that the unconformity between the Maquoketa and Silurian occurs within the sequence, the thickness lines conform more closely to the general pattern of deformation than does the thickness of the Kimmswick-Maquoketa sequence (Pl. 2), whose upper limit is the irregular eroded surface at the top of the Maquoketa. The stratigraphic cross section along line A-A' is based on logs made from samples and insoluble residues. The wells are correlated on the top of the second lithologic zone of the Silurian dolomite. The cross section shows (1) the general northeastward thickening of the lithologic zones of the Silurian; (2) beveling of the Silurian rocks by the Devonian dolomite; and (3) the pre-Chattanooga erosion of the sequence in the southwestern part of the area. Major unconformities occur at the base of the Devonian dolomite and at the base of the Chattanooga shale. An erosion surface of low relief occurs at the base of the Maquoketa shale and one of slightly greater relief at the base of the Silurian rocks.

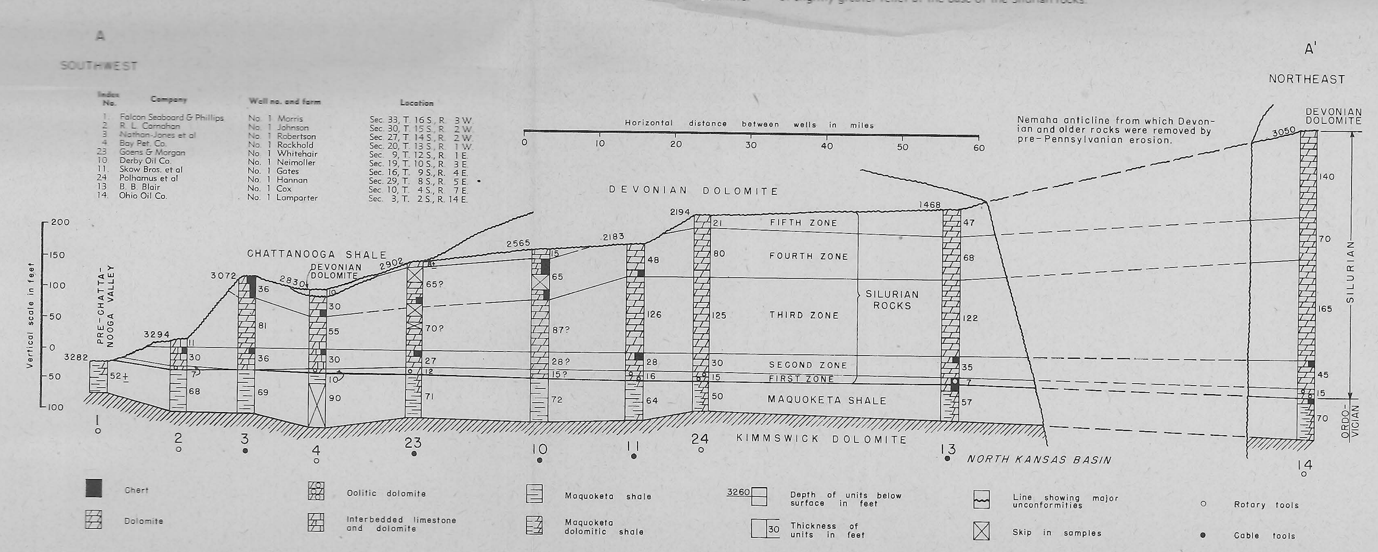
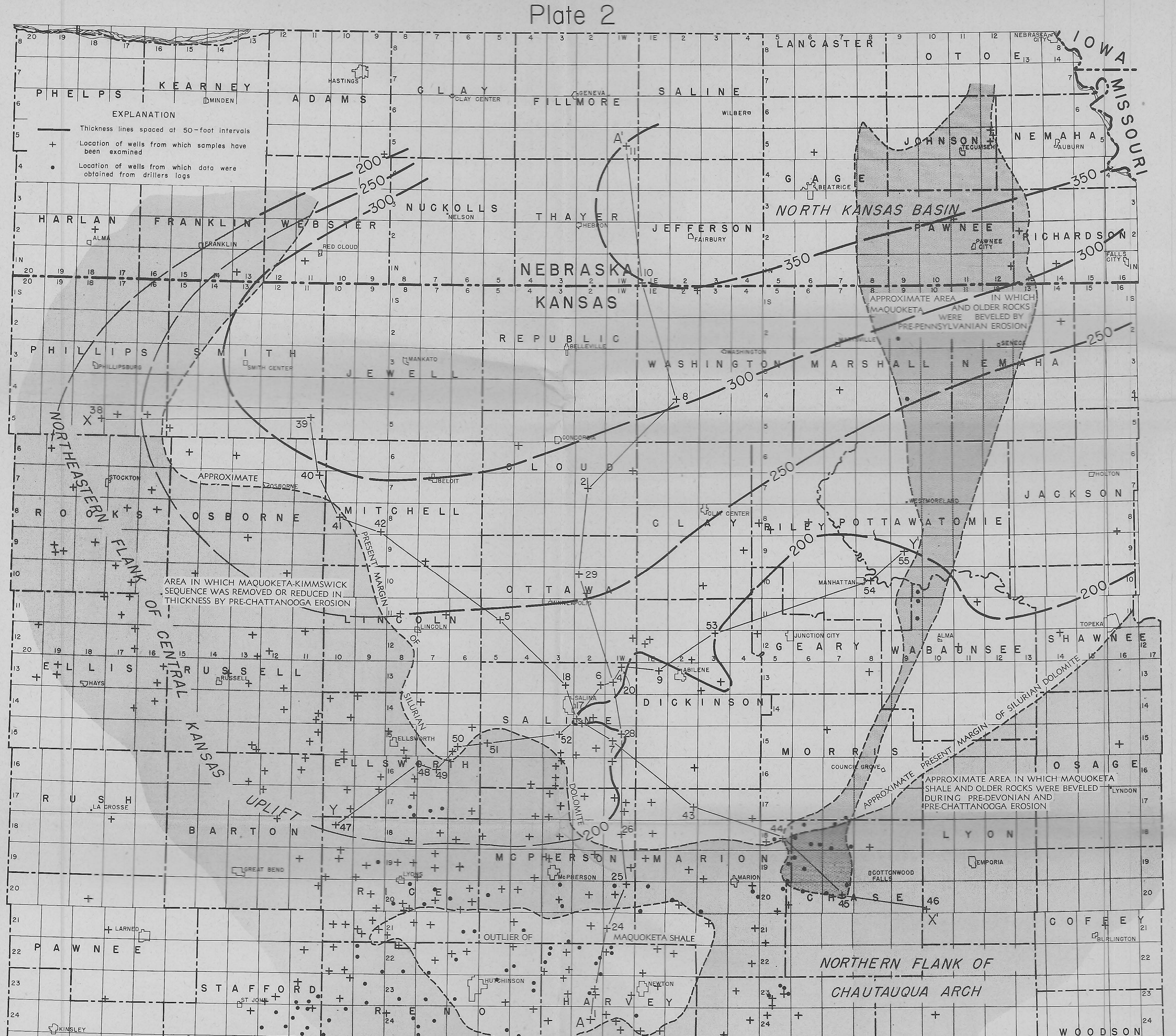


Plate 2



Map of the Salina basin area showing (a) the the combined thicknesses of the Kimmswick dolomite (=part of the Viola of Oklahoma) and the Maquoketa shale (= Sylvan of Oklahoma) where they lie beneath Silurian dolomite and (b) a stratigraphic cross section along line A-A'. Cross sections X-X' and Y-Y' of Plates 13 and 14 show the present attitude of the Kimmswick and Maquoketa rocks. The map shows the thickening of the Kimmswick-Maquoketa sequence northeastward into the North Kansas basin and the thinning southeastward toward the Chautauqua arch and southwestward toward the Central Kansas uplift. The unusual elongation of the thickness lines toward the west is interpreted as the result, in part, of pre-Silurian erosion of the Maquoketa shale. The stratigraphic cross section along line A-A' is based on sample logs. The logs are correlated on the base of the Maquoketa shale which is believed to have approximated a level surface although it retained some topographic relief. The cross section shows (1) the northerly thickening of each of the three lithologic zones of the Kimmswick and the overlap of the second zone upon the Platteville on the flank of the Chautauqua arch (well 1); (2) the local overlap of the Kimmswick onto the St. Peter sandstone in McPherson County (well 25); (3) beveling of the Kimmswick by the Maquoketa shale; (4) overlap toward the south of the Devonian dolomite from the Silurian onto the Maquoketa; and (5) the valley cut by pre-Chattanooga erosion in the southern part of the area. Erosion surfaces of low relief occur at the base of the Kimmswick and base of the Maquoketa. The surface between the Maquoketa and Silurian has slightly greater relief.

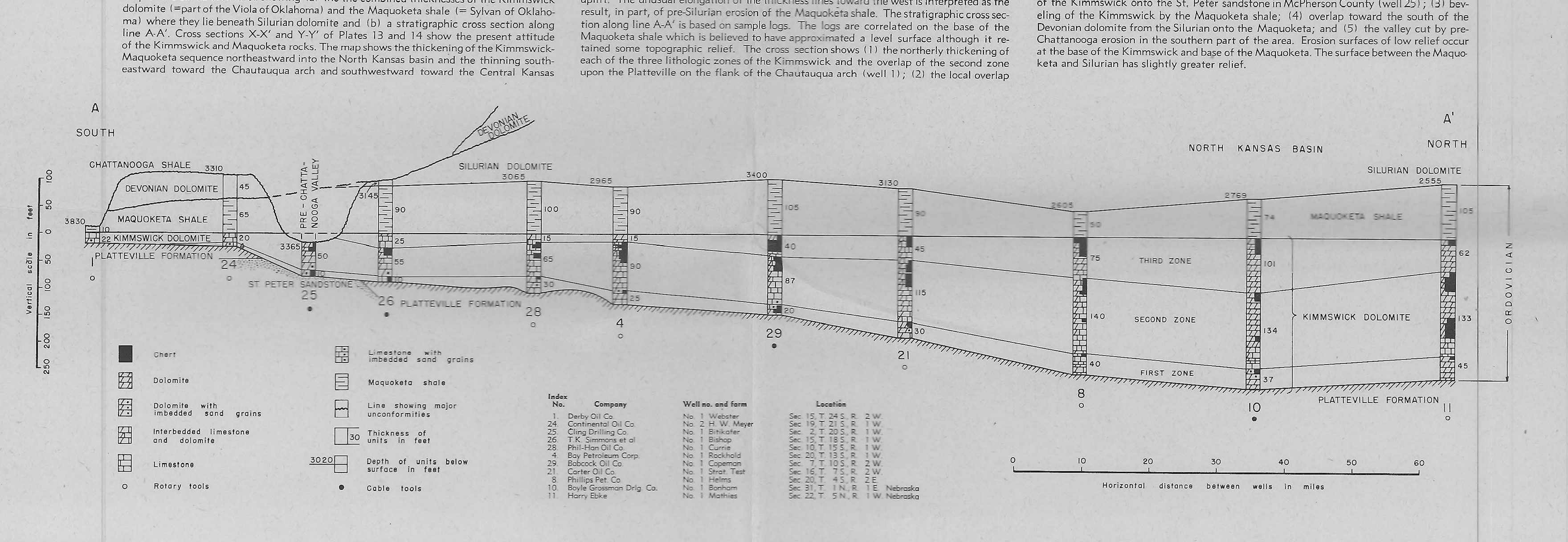
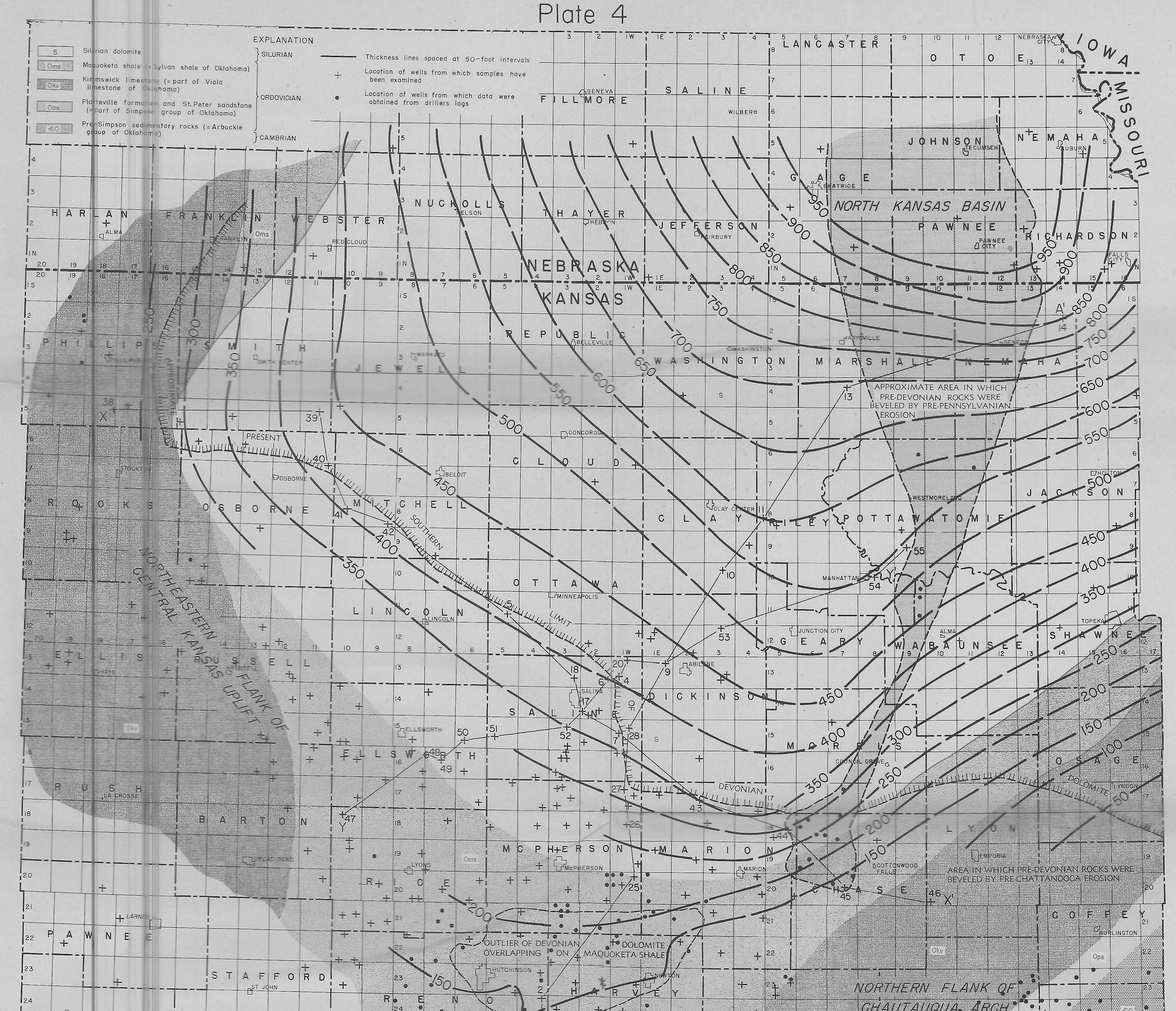


Plate 4



Map of the Salina basin area showing (a) the combined thickness of rocks from the base of the St. Peter sandstone to the base of the Devonian dolomite and the pre-Devonian areal geology; and (b) a stratigraphic cross section along line A-A'. Cross sections X-X' and Y-Y' of Plates 13 and 14 show the present attitude of this sequence of rocks. The thickness lines show thickening of the sequence into the North Kansas basin and thinning toward the Central Kansas uplift and the Chautauqua arch. The areal map shows the distribution of the formations as they appeared on the pre-Devonian beveled surface. Where pre-Chattanooga erosion removed parts of the sequence in Marion, McPherson, and adjoining areas (see Pl. 5) the pre-Devonian outcrops have been restored. The stratigraphic cross section along line A-A' is based on sample logs and drillers logs. The logs are correlated on the top of the St. Peter sandstone. The cross section shows (1) the thickening of the sequence and its several formations into the North Kansas basin; (2) the beveling of the earlier rocks by the Devonian dolomite; and (3) the effect of pre-Chattanooga erosion in cutting through the Devonian dolomite into older rocks. Major unconformities occur at the base of the St. Peter, at the base of the Devonian dolomite, and at the base of the Chattanooga shale.

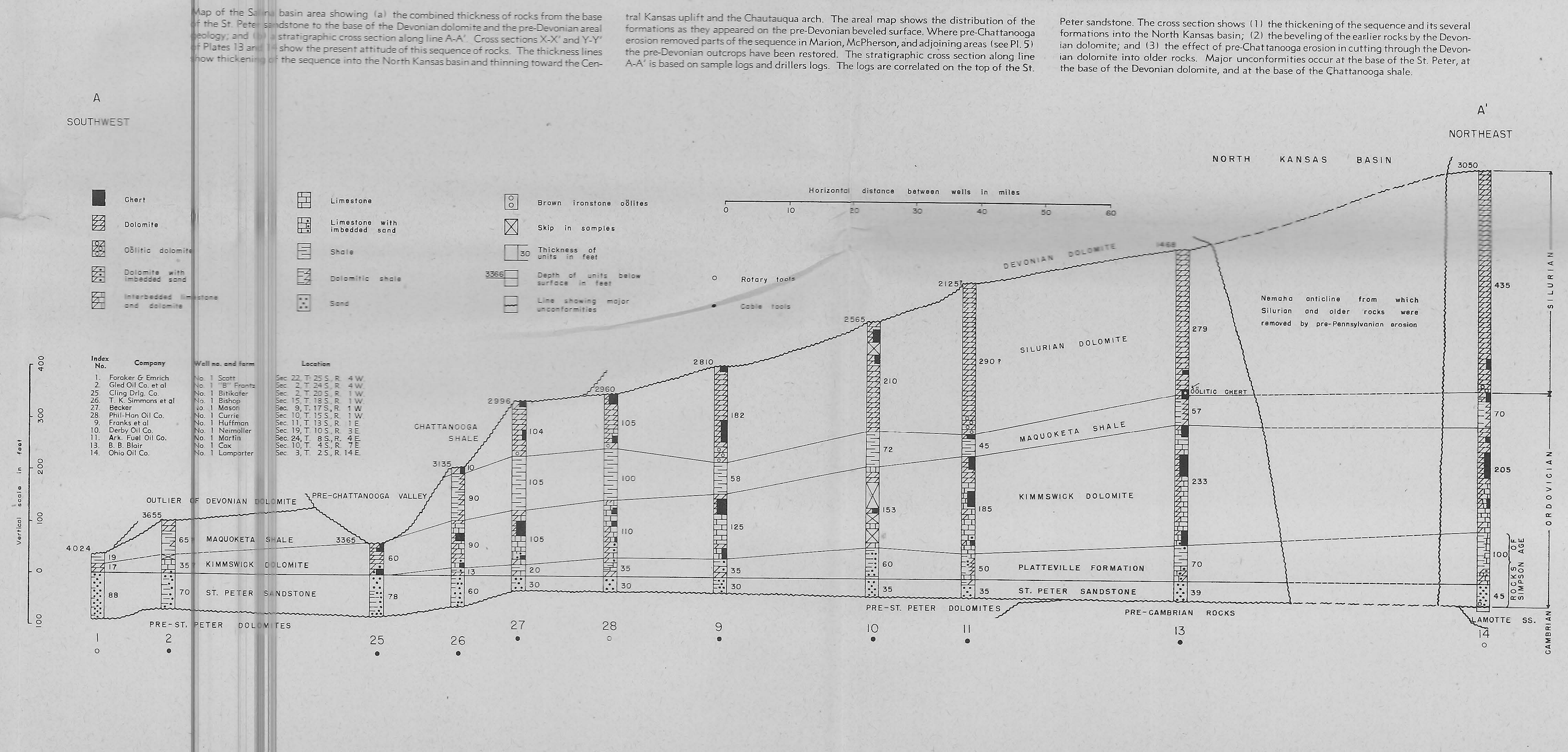


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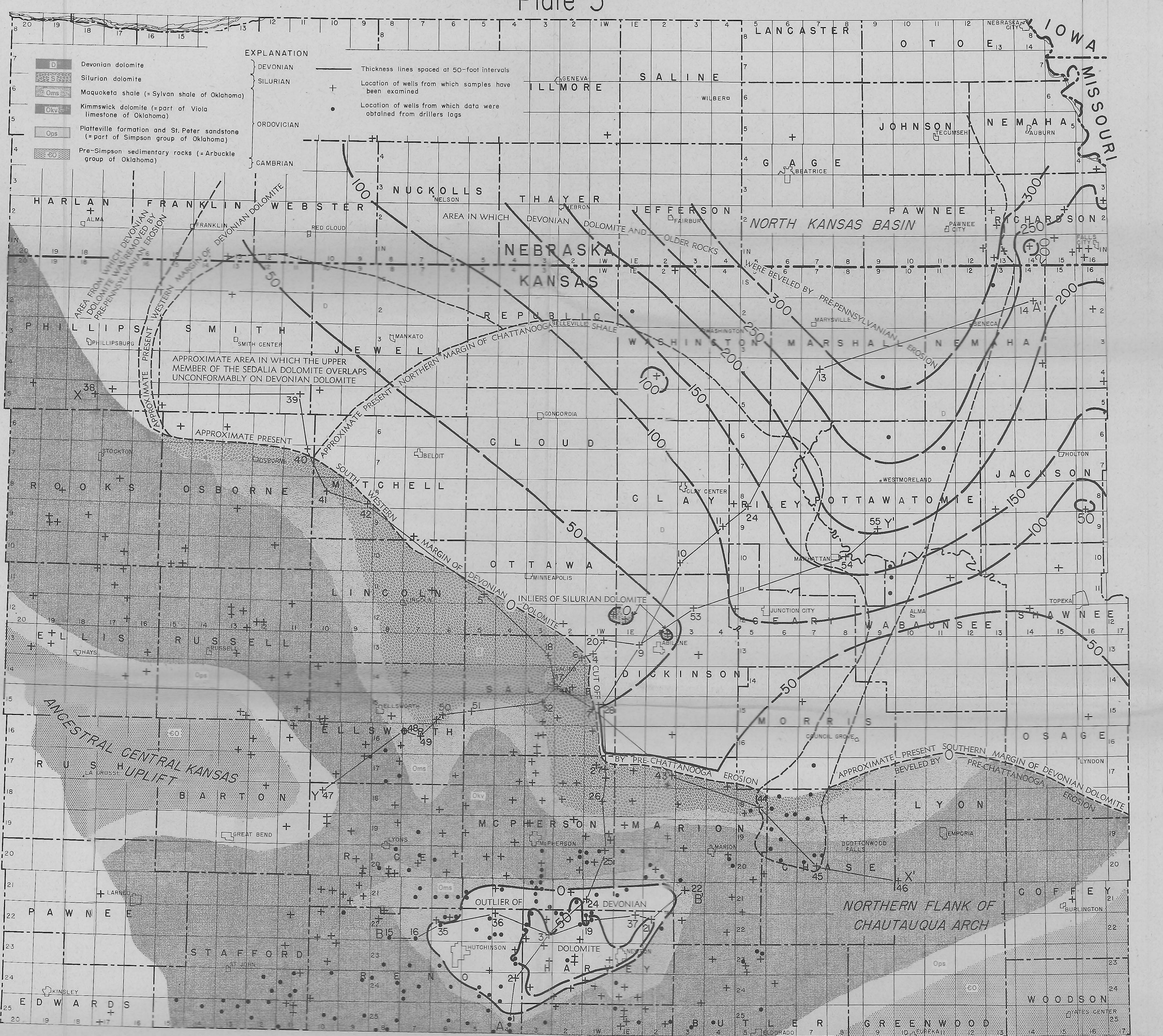
Plate 5



Map of the Salina basin area showing (a) the thickness of the Devonian dolomite where it lies beneath Chattanooga shale and the pre-Chattanooga areal geology and (b) a stratigraphic cross section on the line A-A′. Cross section B-B′ is shown in Figure 9. Cross sections X-X′ and Y-Y′ of Plates 13 and 14 show the present attitude of the Devonian rocks. The map shows the thickness of the Devonian dolomite in areas where the normally overlying Chattanooga shale has survived subsequent erosion. The contact of the Devonian with the Chattanooga shale formerly extended north into Nebraska but pre-Pennsylvanian erosion stripped the Chattanooga shale from broad areas and thinned or removed the Devonian dolomite thus exposed. Pre-Sedalia erosion removed the Chattanooga shale from parts of Jewell and Smith Counties but the underlying Devonian rocks were not deeply eroded at this time. The rocks exposed in the southeastern corner of the map lay on the flank of the Chautauqua arch and were beveled during the pre-Chattanooga exposure. In the southwestern part of the area a broad pre-Chattanooga valley cut through the Devonian dolomite and exposed the underlying Silurian, Maquoketa, and Kimmswick rocks. It is probable that before the valley was eroded rocks from the St. Peter to Devonian inclusive were beveled on the flank of the Central Kansas uplift in the same way as on the flank of the Chautauqua arch. The rocks outlining the pre-Chattanooga valley toward the west were removed by pre-Pennsylvanian erosion but the broadening of the Kimmswick area toward the northwest suggests that the valley continued in that direction. The valley is revealed also by the thickness of the Chattanooga shale in Plate 6. Pre-Devonian hills of Silurian dolomite were re-exposed in Dickinson County by pre-Chattanooga beveling. Similar hills are probably represented in Washington County by local thinning of the Devonian dolomite. The thickness map reveals continued subsidence of the North Kansas basin and a northerly trending anticline on the eastern margin of the map. This fold is more clearly indicated on the map of the Forest City basin (Lee, Grohskopf, Hershey, and Reed, 1946, sheet 3). The stratigraphic cross section on the line A-A′ is based mainly on sample logs. The logs are correlated on the base of the upper member of the Sedalia because this surface presents a more nearly flat and level surface than the top of the Devonian. The cross section shows (1) the thickening of the Devonian dolomite into the North Kansas basin; (2) the southward overlap of the Devonian from Silurian dolomite onto Maquoketa shale; (3) the beveling the surface of the Devonian except where it is interrupted by the pre-Chattanooga valley; and (4) the pre-Chattanooga valley and the outlier of Devonian dolomite toward the southwest. Major unconformities occur at the base of the Devonian and at the base of the Chattanooga.

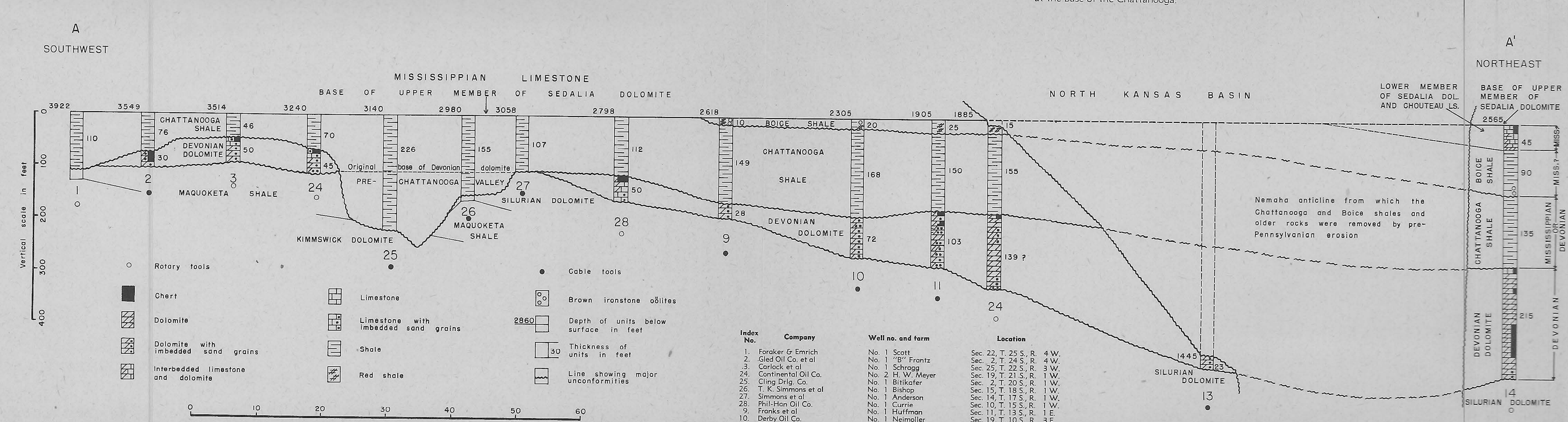
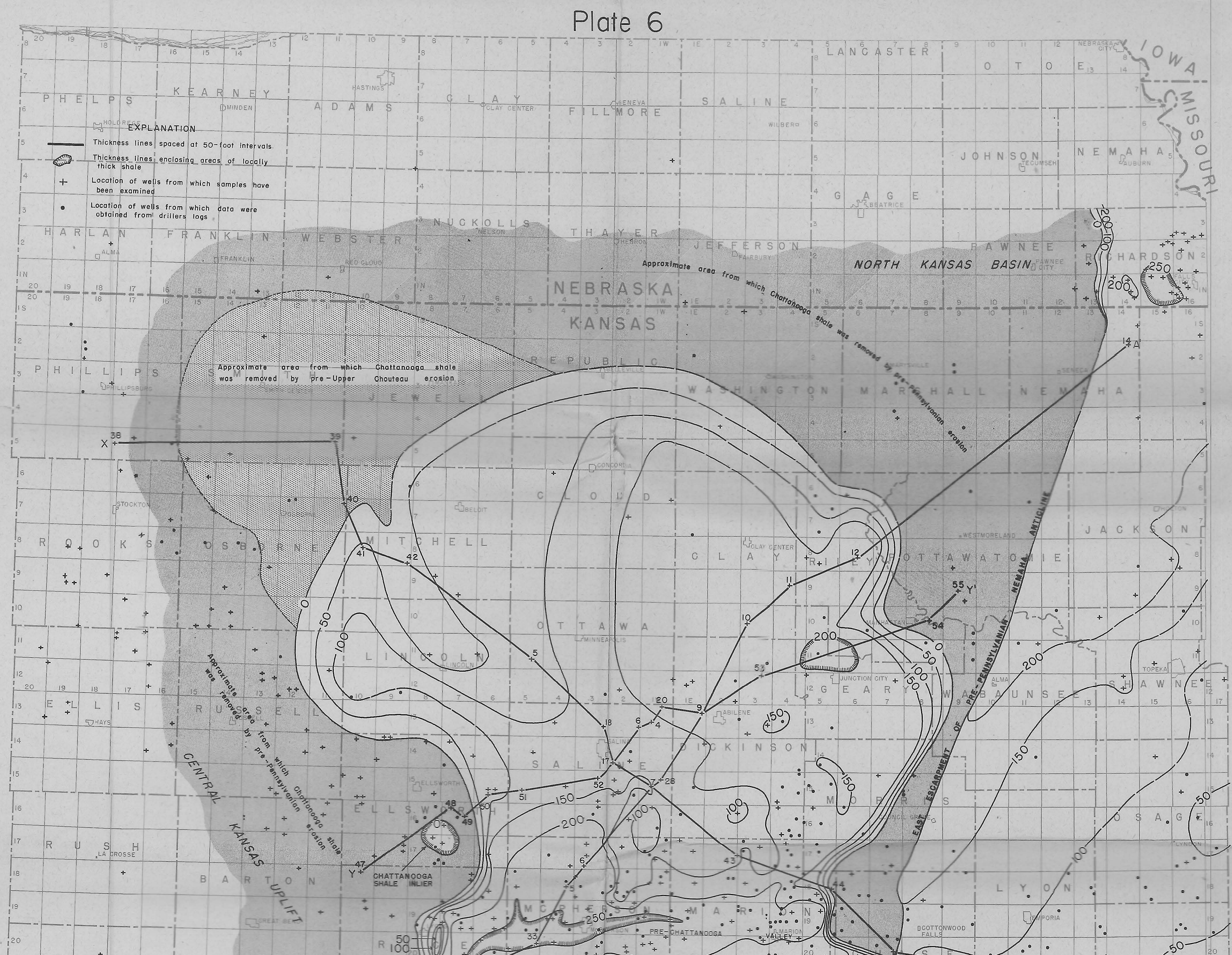


Plate 6



Map of the Salina basin area showing (a) the present thickness and distribution of the combined Chattanooga and Boice shales and (b) a stratigraphic cross section on line A-A′. Cross sections X-X′ and Y-Y′ of Plates 13 and 14 show the present attitude of these formations. The formerly more widespread Chattanooga shale was reduced in areal distribution toward the northwest by erosion that preceded the deposition of the upper member of the Sedalia in Smith County and adjacent areas. The Chattanooga shale was later restricted by the erosion and beveling that preceded Pennsylvanian deposition. The variations of the thickness of the Chattanooga shale in the Salina basin area indicate a pre-Chattanooga topography of considerable relief. The greater thickness in Marion and McPherson Counties reveals a well-defined broad open valley joined in Rice County by a tributary from the south. Drainage probably escaped northwest from McPherson County. The stratigraphic cross section which is based on sample logs is correlated on the base of the upper member of the Sedalia dolomite. It shows the thickening of the shale in the pre-Chattanooga erosion basin in McPherson County and, in other areas, a gradual but irregular thickening of the shale toward the northeast. The cross section also shows the relation of the Chouteau limestone and Sedalia dolomite to the Boice and Chattanooga shales on the east side of the axis of the already developing Nemaha anticline, and the overlap of the upper member of the upper Sedalia upon Boice and Chattanooga shales toward the west. Major unconformities occur at the base of the Devonian, the base of the Chattanooga shale, and probably at the base of the Boice shale.

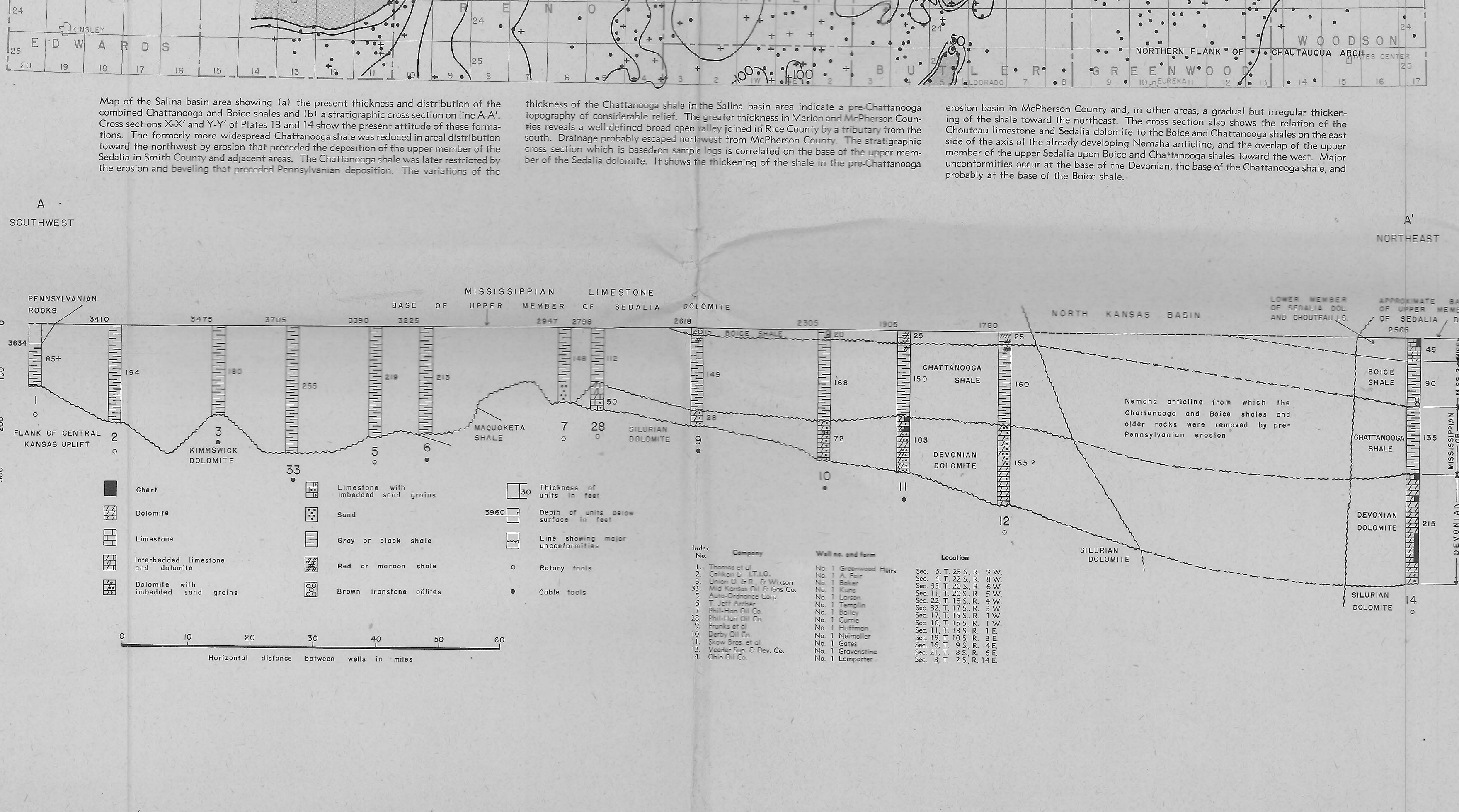
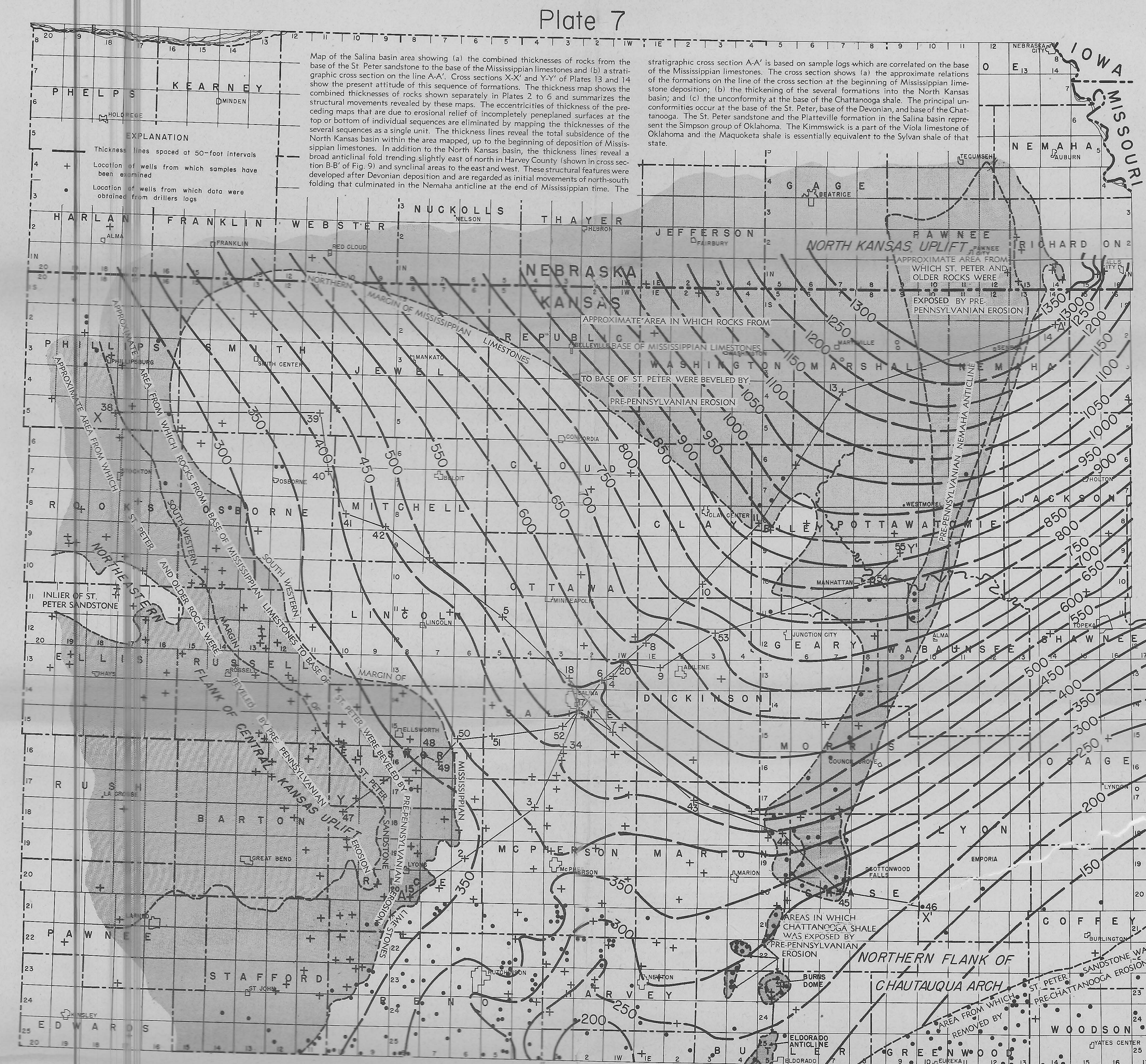


Plate 7



Map of the Salina basin area showing (a) the combined thicknesses of rocks from the base of the St Peter sandstone to the base of the Mississippian limestones and (b) a stratigraphic cross section on the line A-A′. Cross sections X-X′ and Y-Y′ of Plates 13 and 14 show the present attitude of this sequence of formations. The thickness map shows the combined thicknesses of rocks shown separately in Plates 2 to 6 and summarizes the structural movements revealed by these maps. The eccentricities of thickness of the preceding maps that are due to erosional relief of incompletely peneplaned surfaces at the top or bottom of individual sequences are eliminated by mapping the thicknesses of the several sequences as a single unit. The thickness lines reveal the total subsidence of the North Kansas basin within the area mapped, up to the beginning of deposition of Mississippian limestones. In addition to the North Kansas basin, the thickness lines reveal a broad anticlinal fold trending slightly east of north in Harvey County (shown in cross section B-B′ of Fig. 9) and synclinal areas to the east and west. These structural features were developed after Devonian deposition and are regarded as initial movements of north-south folding that culminated in the Nemaha anticline at the end of Mississippian time. The stratigraphic cross section A-A′ is based on sample logs which are correlated on the base of the Mississippian limestones. The cross section shows (a) the approximate relations of the formations on the line of the cross section at the beginning of Mississippian limestone deposition; (b) the thickening of the several formations into the North Kansas basin; and (c) the unconformity at the base of the Chattanooga shale. The principal unconformities occur at the base of the St. Peter, base of the Devonian, and base of the Chattanooga. The St. Peter sandstone and the Platteville formation in the Salina basin represent the Simpson group of Oklahoma. The Kimmswick is a part of the Viola limestone of Oklahoma and the Maquoketa shale is essentially equivalent to the Sylvan shale of that state.

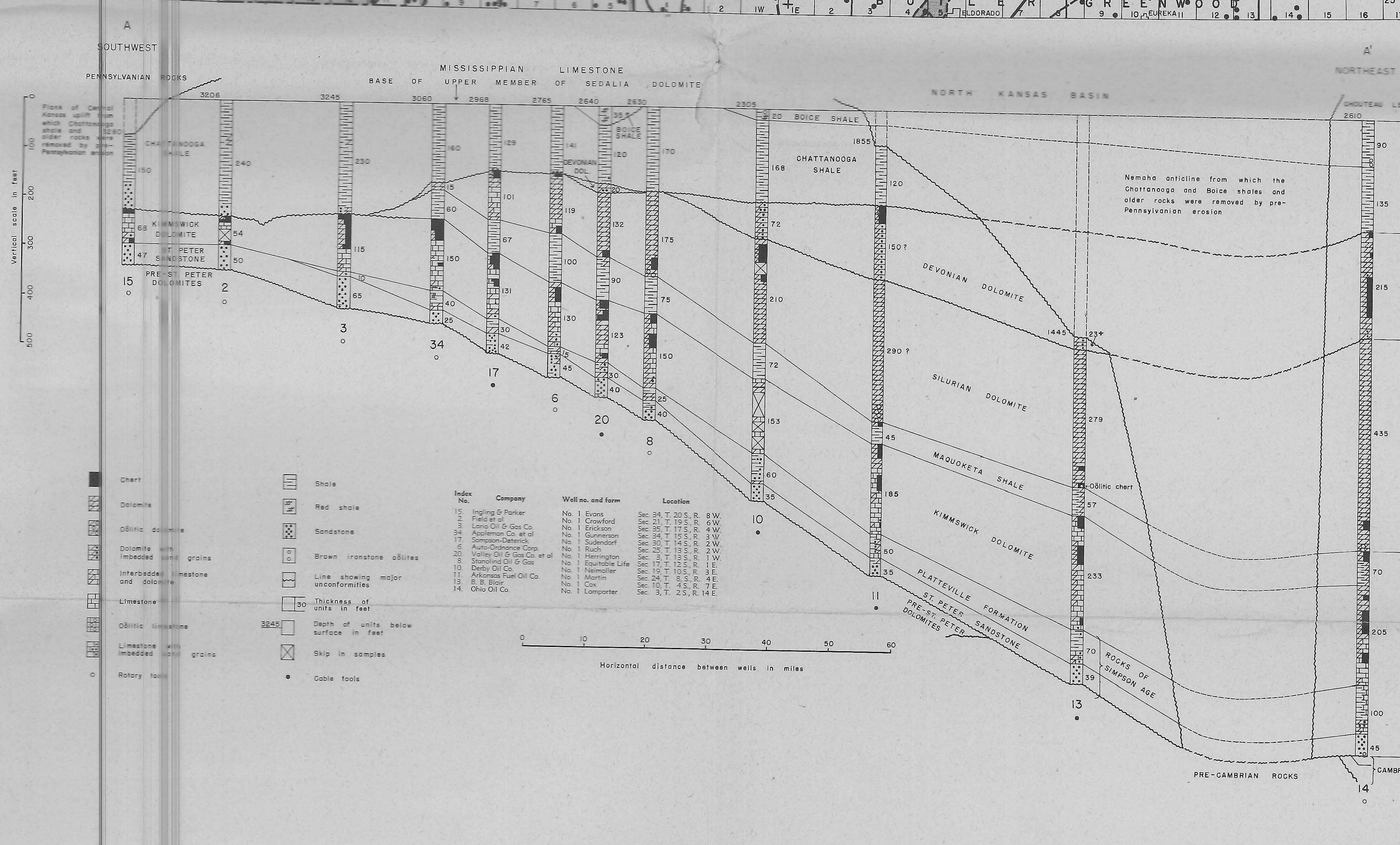
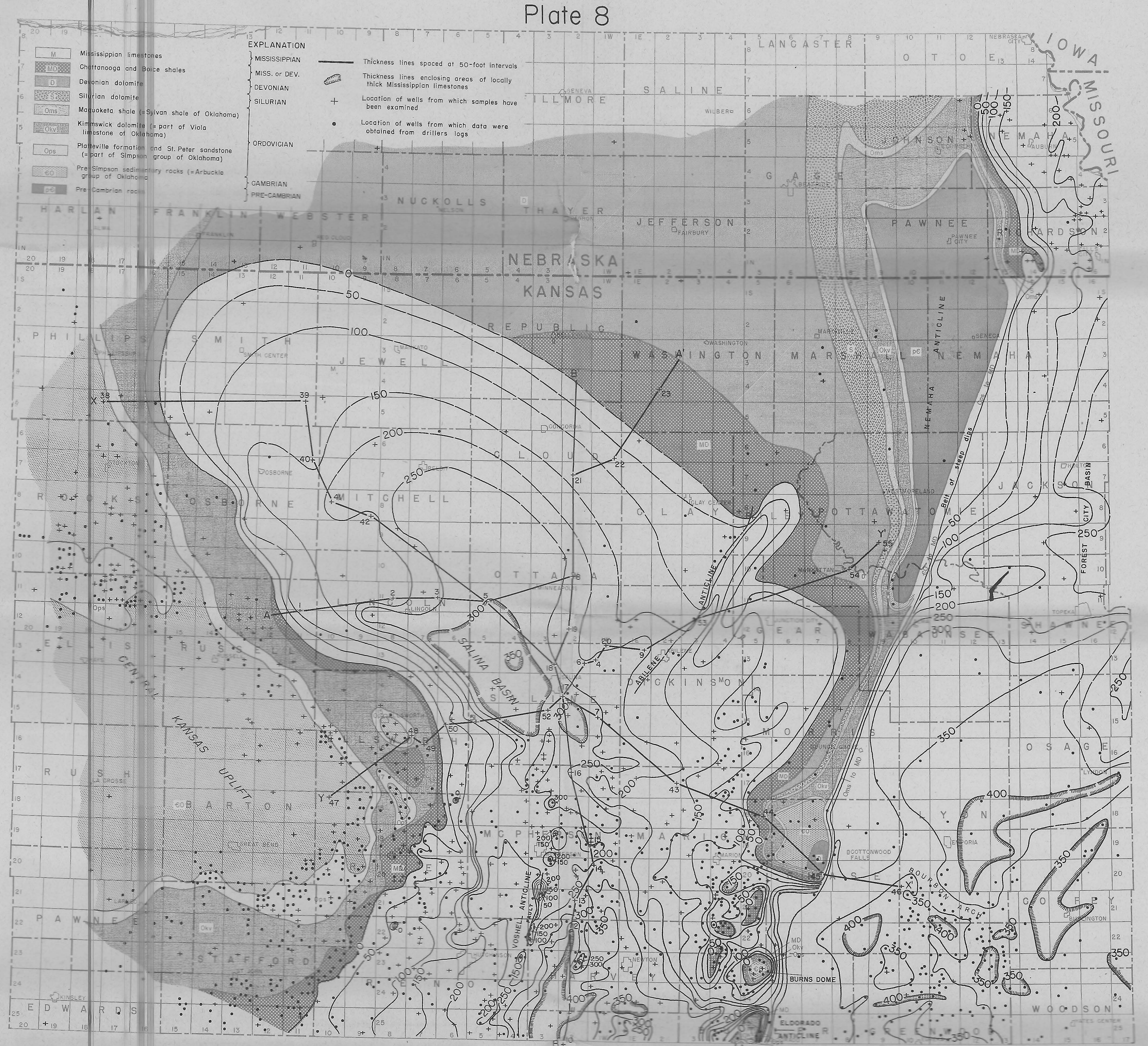


Plate 8



Map of the Salina basin area showing (a) the thickness of the Mississippian limestones and the Pennsylvanian basal conglomerate, (b) the pre-Pennsylvanian areal geology, and (c) a stratigraphic cross section on the line A-A′ showing the attitude of the Mississippian formations at the end of post-Mississippian beveling. Cross section B-B′ is shown in Figure 6. Cross section X-X′ and Y-Y′ of Plates 13 and 14 show the present attitude of the Mississippian limestone. The thickness map shows (a) the northeasterly trending Nemaha anticline, from whose northeastern end the Mississippian limestones were eroded; (b) the contemporaneously developed northwesterly trending Salina basin syncline which is recognized by the thickening of the Mississippian limestones beneath the beveled surface; and (c) the Central Kansas uplift which continued active. Secondary anticlines paralleling the Nemaha anticline were also developed. The areal geologic map shows the pre-Mississippian formations cropping out in bands on the peneplaned surface on the flanks of the Central Kansas uplift and the Nemaha anticline. The stratigraphic cross section on line A-A′ is based on sample logs which are correlated on the base of Pennsylvanian rocks. Cross section A-A′ shows the attitude and relations of the Mississippian formations at the end of peneplanation in a line extending from southwest to northeast across the center of the Salina basin. The stratigraphic cross section on line B-B′ is shown in Figure 6. Important unconformities occur at the base of the Chattanooga shale, at the base of Osagian rocks, and at the top of the Mississippian limestones. Less prominent unconformities occur at the base of the Kinderhookian rocks, at the base of the Gilmore City, at the base of the Keokuk, and at the base of the "Warsaw."

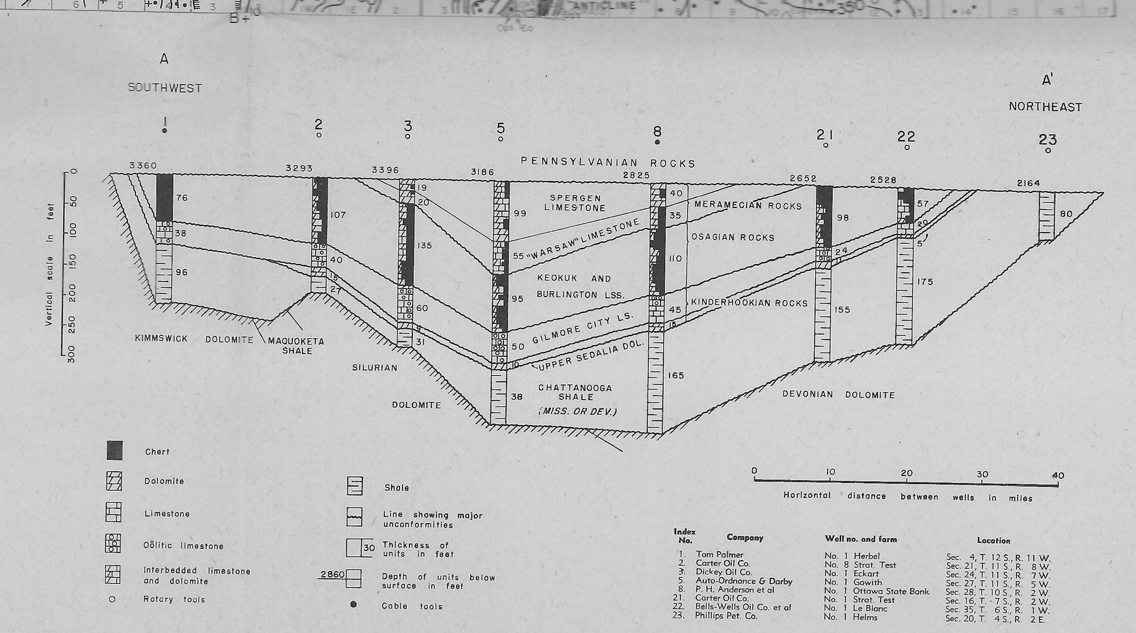


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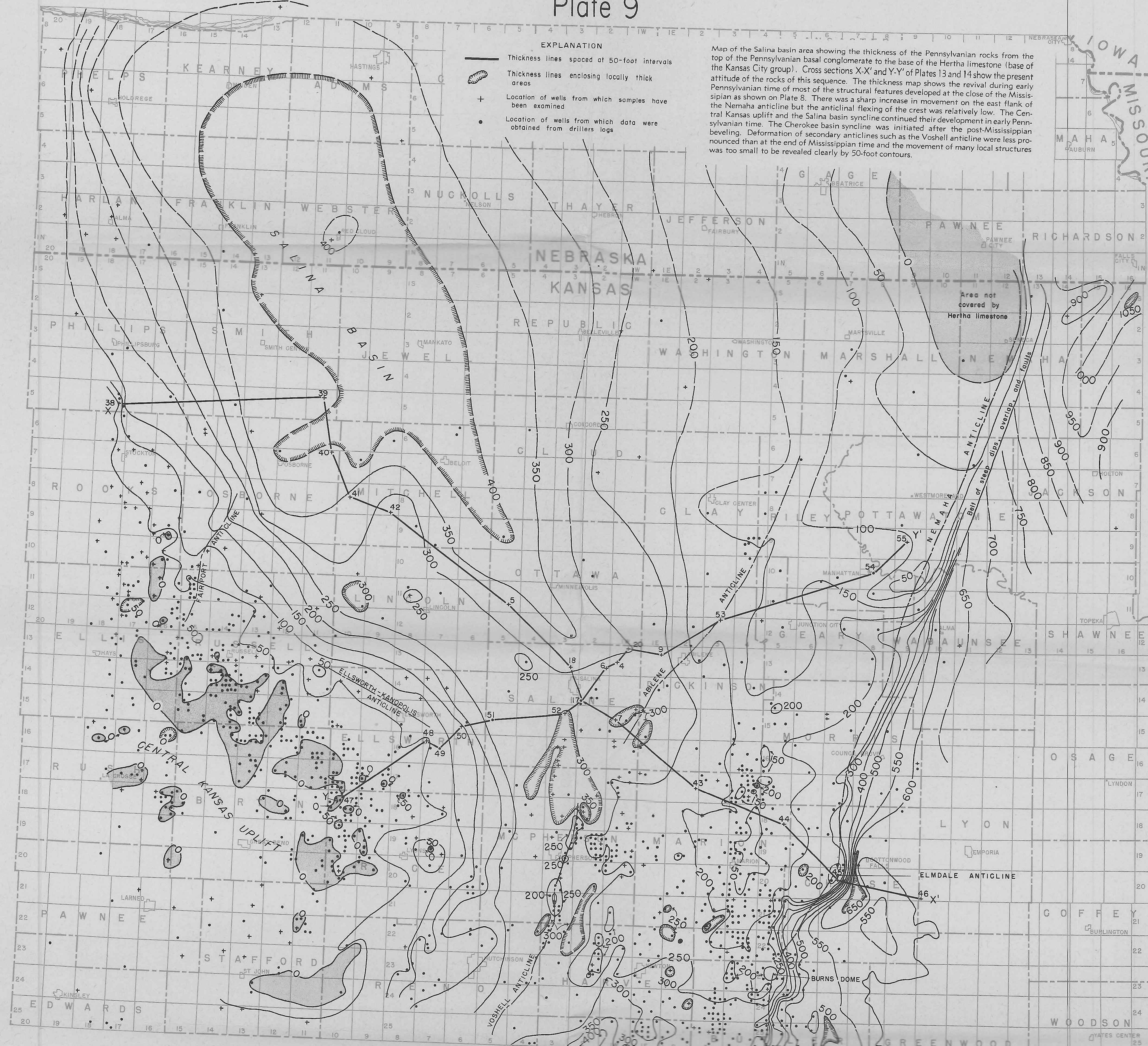
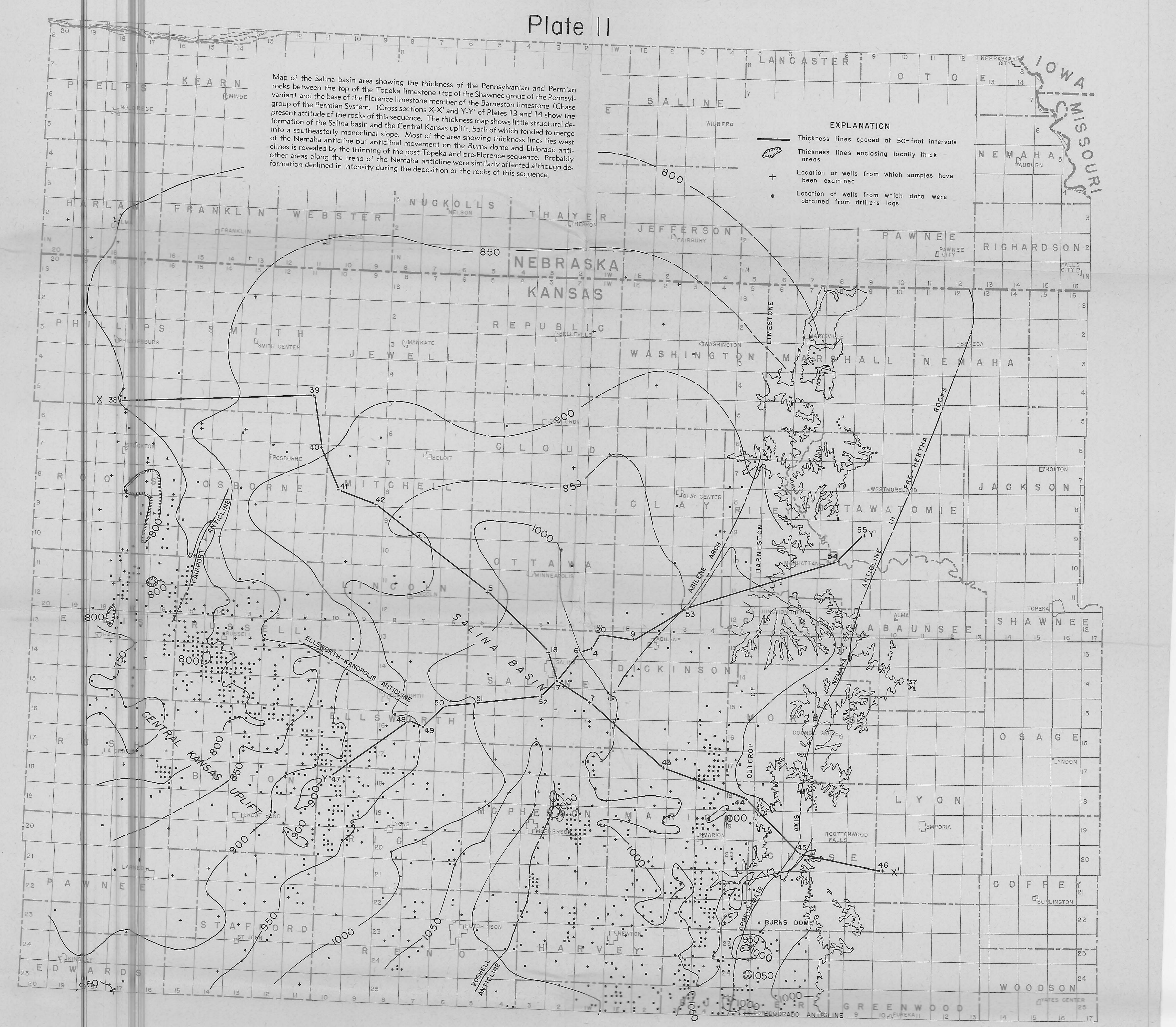
Plate 9



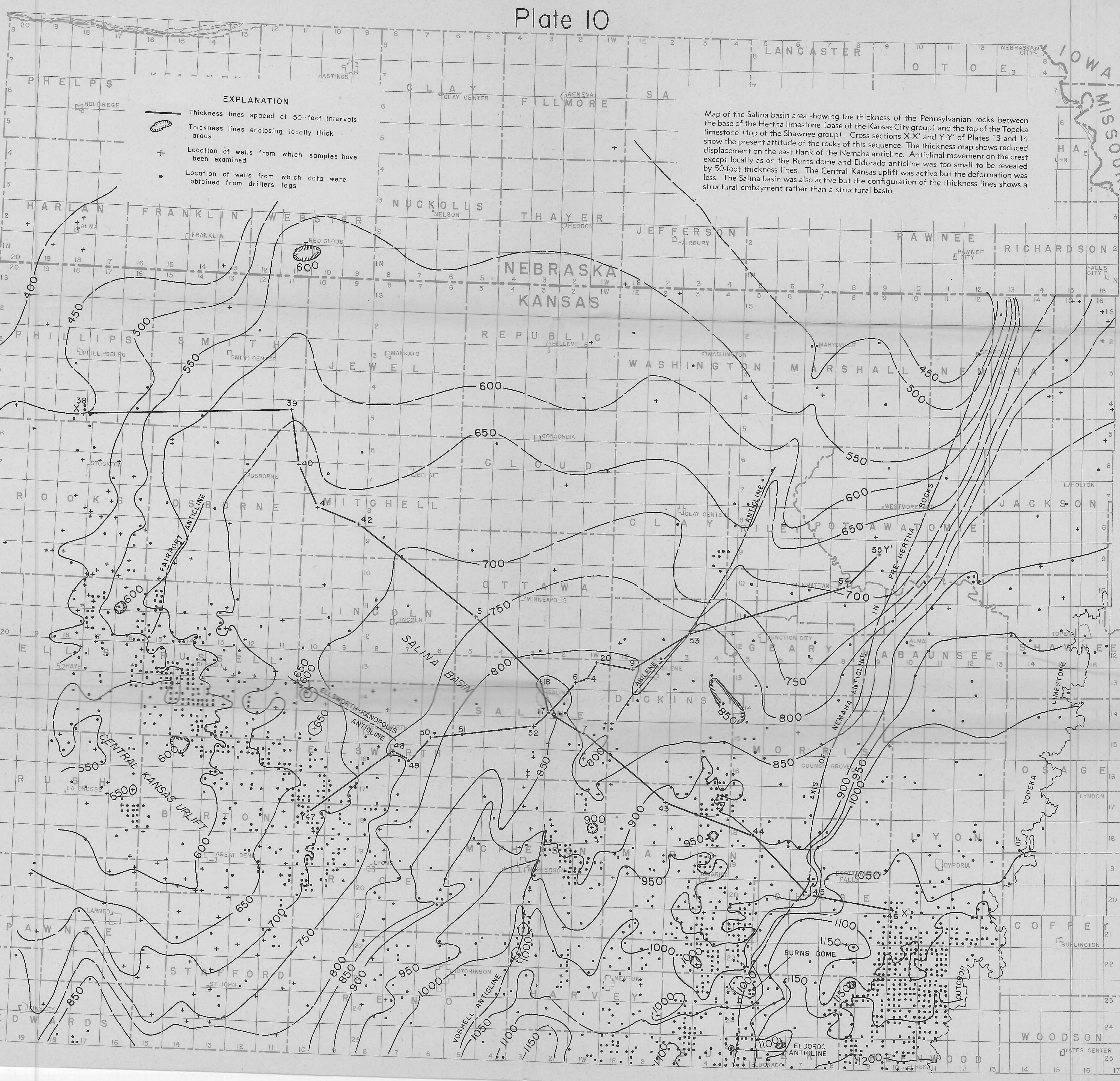
Map of the Salina basin area showing the thickness of the Pennsylvanian rocks from the top of the Pennsylvanian basal conglomerate to the base of the Hertha limestone (base of the Kansas City group). Cross sections X-X' and Y-Y' of Plates 13 and 14 show the present attitude of the rocks of this sequence. The thickness map shows the revival during early Pennsylvanian time of most of the structural features developed at the close of the Mississipian as shown on Plate 8. There was a sharp increase in movement on the east flank of the Nemaha anticline but the anticlinal flexing of the crest was relatively low. The Central Kansas uplift and the Salina basin syncline continued their development in early Pennsylvanian time. The Cherokee basin syncline was initiated after the post-Mississippian beveling. Deformation of secondary anticlines such as the Voshell anticline were less pronounced than at the end of Mississippian time and the movement of many local structures was too small to be revealed clearly by 50-foot contours.

Plate 11



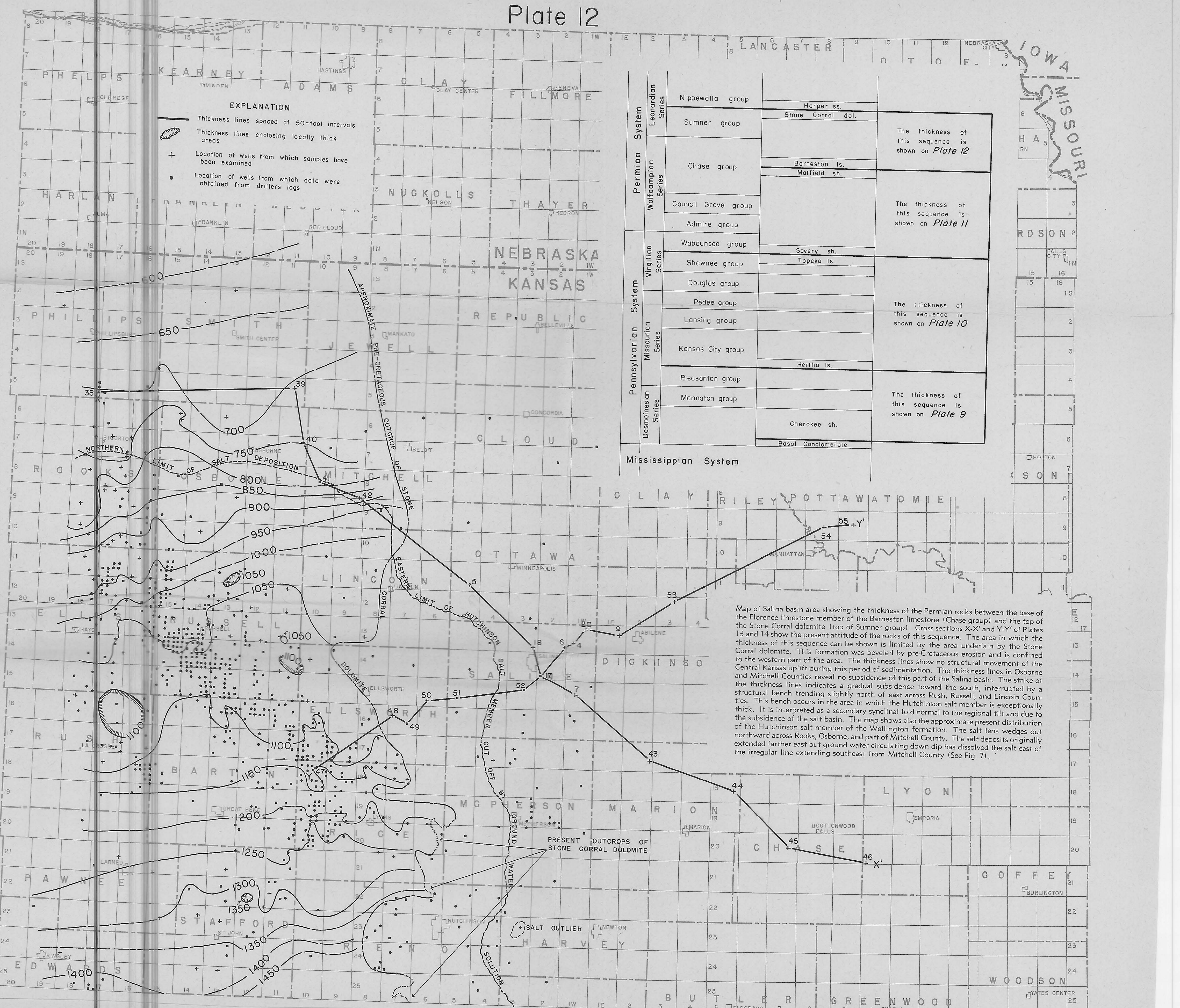
Map of the Salina basin area showing the thickness of the Pennsylvanian and Permian rocks between the top of the Topeka limestone (top of the Shawnee group of the Pennsylvanian) and the base of the Florence limestone member of the Barneston limestone (Chase group of the Permian System. (Cross sections X-X' and Y-Y' of Plates 13 and 14 show the present attitude of the rocks of this sequence. The thickness map shows little structural deformation of the Salina basin and the Central Kansas uplift, both of which tended to merge into a southeasterly monoclinal slope. Most of the area showing thickness lines lies west of the Nemaha anticline but anticlinal movement on the Burns dome and Eldorado anticlines is revealed by the thinning of the post-Topeka and pre-Florence sequence. Probably other areas along the trend of the Nemaha anticline were similarly affected although deformation declined in intensity during the deposition of the rocks of this sequence.

Plate 10



Map of the Salina basin area showing the thickness of the Pennsylvanian rocks between the base of the Hertha limestone (base of the Kansas City group) and the top of the Topeka limestone (top of the Shawnee group). Cross sections X-X' and Y-Y' of Plates 13 and 14 show the present attitude of the rocks of this sequence. The thickness map shows reduced displacement on the east flank of the Nemaha anticline. Anticlinal movement on the crest except locally as on the Burns dome and Eldorado anticline was too small to be revealed by 50-foot thickness lines. The Central Kansas uplift was active but the deformation was less. The Salina basin was also active but the configuration of the thickness lines shows a structural embayment rather than a structural basin.

Plate 12



Map of Salina basin area showing the thickness of the Permian rocks between the base of the Florence limestone member of the Barneston limestone (Chase group) and the top of the Stone Corral dolomite (top of Sumner group). Cross sections X-X' and Y-Y' of Plates 13 and 14 show the present attitude of the rocks of this sequence. The area in which the thickness of this sequence can be shown is limited by the area underlain by the Stone Corral dolomite. This formation was beveled by pre-Cretaceous erosion and is confined to the western part of the area. The thickness lines show no structural movement of the Central Kansas uplift during this period of sedimentation. The thickness lines in Osborne and Mitchell Counties reveal no subsidence of this part of the Salina basin. The strike of the thickness lines indicates a gradual subsidence toward the south, interrupted by a structural bench trending slightly north of east across Rush, Russell, and Lincoln Counties. This bench occurs in the area in which the Hutchinson salt member is exceptionally thick. It is interpreted as a secondary synclinal fold normal to the regional tilt and due to the subsidence of the salt basin. The map shows also the approximate present distribution of the Hutchinson salt member of the Wellington formation. The salt lens wedges out northward across Rooks, Osborne, and part of Mitchell County. The salt deposits originally extended farther east but ground water circulating down dip has dissolved the salt east of the irregular line extending southeast from Mitchell County (See Fig. 7).

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Plate 13

Cross section X-X' showing the present regional attitude and relations of all the formations on a line from northwest to southeast across the Salina basin. The first deforming movements affecting each formation or sequence of formations have been shown in Plates 1 to 12. The attitude of each formation was modified by all the subsequent structural readjustments. After the deposition of the Pennsylvanian and Permian rocks and before Cretaceous time, the region was tilted southwestward toward a pre-Cretaceous syncline in western Kansas, the axis of which is shown in Figure 2. After Cretaceous deposition, the region was tilted toward the north and northeast and elevated above sea level. Terrestrial deposits of considerable thickness accumulated in some areas, particularly toward the west. The contrast between the horizontal scale and the necessarily exaggerated vertical scale gives a false impression of the rate of dip of the various formations. The inset shows the value in feet per mile of the dips shown on the cross section. The thickness of the older formations in wells that did not penetrate a complete section to the top of the Pre-Cambrian have been plotted from the thickness maps.

Index No.	Company	Well no. and farm	Location
38.	(J. J. Hall et al and	No. 1 J. R. Donaldson	Sec. 25, T. 5 S., R. 18 W.
	Phillips Pet. Corp.)	No. 1 McKinley	Sec. 13, T. 5 S., R. 18 W.
39.	Helmerich & Payne	No. 1 Meyer	Sec. 10, T. 5 S., R. 11 W.
40.	Helmerich & Payne	No. 1 Verhage	Sec. 2, T. 7 S., R. 11 W.
41.	Seidhoff et al	No. 1 Grief	Sec. 16, T. 8 S., R. 10 W.
42.	Northern Ordnance Inc.	No. 1 Mary Burr	Sec. 35, T. 8, S., R. 9 W.
5.	Auto-Ordnance & Darby	No. 1 Gawith	Sec. 27, T. 11 S., R. 5 W.
18.	Central Oil & Gas Co.	No. 1 Crawford	Sec. 26, T. 13 S., R. 3 W.
17.	Sampson-Deterick et al	No. 1 Sudendorf	Sec. 30, T. 14 S., R. 2 W.
7.	Phil-Han Oil Co.	No. 1 Bailey	Sec. 17, T. 15 S., R. 1 W.
43.	White Eagle Oil & Ref. Co.	No. 1 Ucker	Sec. 24, T. 17 S., R. 2 E.
44.	Tidewater Assoc. Oil Co.	No. 1 C. R. Junghams	Sec. 23, T. 18 S., R. 5 E.
45.	Aladdin Pet. Corp.	No. 1 Drummond	Sec. 15, T. 20 S., R. 7 E.
46.	Bird, Hanley & Sheedy	No. 1 M. F. Welch	Sec. 31, T. 20 S., R. 10 E.

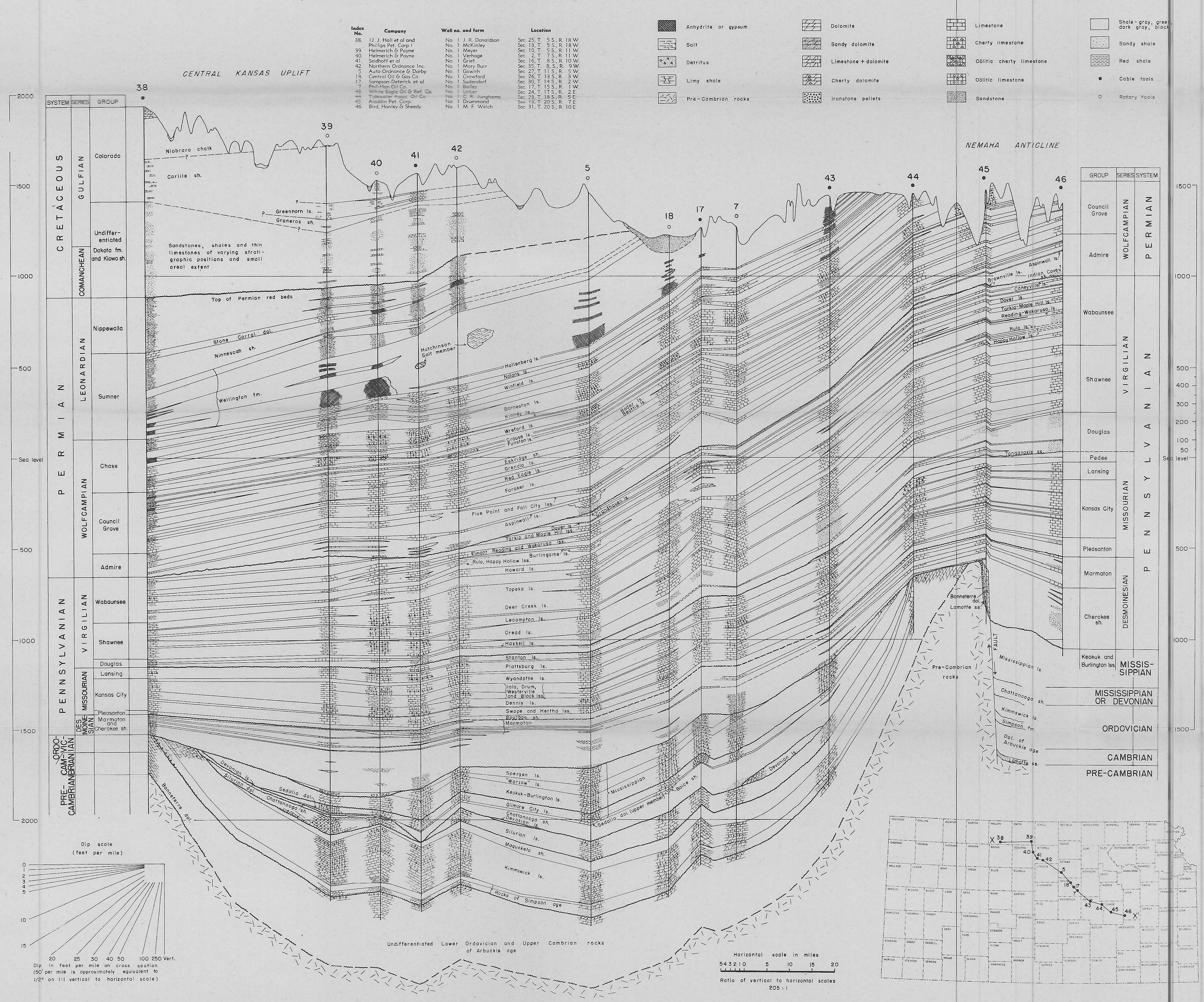

Plate 14

Cross section Y-Y' showing the present attitude and relations of the formations from southwestto northeast across the Salina basin. The inset shows the value in feet per mile of the dips in the cross section. The thickness of the older formations in wells that did not penetrate a complete section to the top of the Pre-Cambrian have been plotted from the thickness maps.

Index No.	Company	Well no. and farm	Location
47.	Allison-Fitzwilliams	No. 1 Blake	Sec. 9, T. 18 S., R. 10 W.
48.	Empire Oil & Ref. Co.	No. 1 Dolacheck	Sec. 7, T. 16 S., R. 7 W.
49.	Mid-Kansas Oil & Gas Co.	No. 1 T. G. Kanak	Sec. 15, T. 16 S., R. 7 W.
50.	N. Appleman Oil Co.	No. 1 McManus	Sec. 29, T. 15 S., R. 6 W.
51.	W. E. Templeman	No. 1 Laubengayer	Sec. 20, T. 15 S., R. 5 W.
52.	Northern Ordnance Inc.	No. 1 W. L. Warner	Sec. 10, T. 15 S., R. 3 W.
17.	Sampson-Deterich	No. 1 Sudendorf	Sec. 30, T. 14 S., R. 2 W.
6.	Auto-Ordnance Corp.	No. 1 Ruch	Sec. 25, T. 13 S., R. 2 W.
4.	Bay Petroleum Corp.	No. 1 Rockhold	Sec. 20, T. 13 S., R. 1 W.
20.	Valley Oil Co. et al	No. 1 Herrington	Sec. 3, T. 13 S., R. 1 W.
9.	Fred Franks	No. 1 Huffman	Sec. 11, T. 13 S., R. 1 E.
53.	Empire Oil & Ref. Co.	No. 1 Duffey	Sec. 3, T. 12 S., R. 3 E.
54.	Coronado Oil Co.	No. 1 Parks	Sec. 16, T. 10 S., R. 8 E.
55.	Lashelle et al	No. 1 Umscheid	Sec. 16, T. 9 S., R. 9 E.