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RAYMOND C. MOORE, State Geologist and Director
KENNETH K. LANDES, State Geologist and Assistant Director

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Relation of Thickness of Mississippian Limestones in Central and Eastern Kansas to Oil and Gas Deposits

By WALLACE LEE

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ABSTRACT

The thickness of the Mississippian limestones in central and eastern Kansas bears a close relation to the geologic structure features of the state, and thus to the occurrence of the oil and gas deposits. The limestones of this age are widely distributed in the central and eastern portions of the state, though they are absent over large areas in the central Kansas uplift and the northern part of the Nemaha ridge, as well as in many smaller areas in other parts of the state. They attain a thickness of 1,138 feet in Clark county, but in most of eastern Kansas they have a general thickness of only 300 to 450 feet.

The Mississippian limestones include representatives of the Kinderhook, Osage, Meramec, and Chester series. They were deposited on a nearly flat surface on the Chattanooga shale. After their deposition they were gently folded and elevated and the subsequent erosion reduced the surface in pre-Pennsylvanian time to a nearly flat horizontal peneplain. Rocks lowered below the plain of base leveling were preserved; those that had been raised above it were worn away. There is, therefore, a close relation between the thickness of the Mississippian limestones and the folding that occurred during the time interval between the final deposition of the Chattanooga shale and the close of base leveling. In western Kansas the Chattanooga shale was not deposited and the Mississippian limestones rest on an eroded pre-Chattanooga surface, so that the thickness there is not so significant of structure as in eastern Kansas.

During the pre-Pennsylvanian folding of the Mississippian rocks, pronounced anticlines, such as the Nemaha ridge fold, the Voshell anticline and many others of less prominence were initiated. They are expressed on the accompanying thickness map (Plate I) by thinning of the Mississippian limestones. The base leveling appears to have been complete. Over 1,100 feet of rocks were removed from the crest of such steep anticlines as the Burns dome and the Eldorado anticline. Erosion revealed the basement granite on parts

clines. The areas in which igneous intrusions occurred in Pennsylvanian or later time are shown to have been already slightly domed by pre-Pennsylvanian folding. An ill-defined area in Republic and adjoining counties appears to have no Mississippian rocks. The absence of Mississippian rocks in this area may indicate only a local pre-Mississippian topographic high. It may, on the other hand, indicate a folding that trends northwest, parallel to the central Kansas uplift.

As the structural features are closely related to the thinning of the Mississippian rocks, there is a close relation between thinning and the occurrence of oil and gas on the anticlines in the central and eastern parts of the state. Nearly all fields that produce from anticlines are underlain by thin sections of Mississippian rocks. It is concluded, therefore, that the presence of a thin section of the Mississippian in areas thus far unproductive may in some cases indicate the proximity of incompletely explored structural highs and warrant further investigation of the local conditions. Some prominent anticlines, however, are not productive of oil or gas. A list of unproductive areas where the Mississippian rocks are thin is presented.

The producing zones in Mississippian rocks appear to be independent of the stratigraphic formations. Production is dependent on the porosity of the limestone. The base leveling of the folded rocks brought the various formations of the Mississippian to the surface at different places and subjected them to weathering and leaching. In some places where the ground-water level had been lowered, porous zones are present to a depth of over 100 feet below the surface of the Mississippian. A list of fields that have produced from Mississippian rocks is given and the available production figures are presented.

records. The cuttings of about 400 widely distributed wells were examined by the writer. The top and bottom of the Mississippian are not accurately noted in the logs of wells drilled by rotary tools; for the determination of the thickness in such wells the writer is indebted to the geologists of oil companies in whose laboratories the samples were examined microscopically.

The accuracy of the map depends on the number of logs available for the drawing of the thickness lines; and in areas where few wells have been drilled some generalization has been necessary. In order to show the degree of control, the locations of the wells have been shown, but to avoid crowding of well symbols, about 1,200 wells that lie within oil pools have been omitted. Inasmuch as the logs are of unequal accuracy, the wells whose cuttings are known to have

TABLE No. 1.—Showing sequence of Mississippian limestones and lower Pennsylvanian units penetrated in wells in central and eastern Kansas.

	Lansing group	Missouri series	Pennsylvanian	Carboniferous
	Kansas City group			
	Bronson group			
Bourbon fm.				
~~		~~~~~~~~		
Fort Scott ls.	Marmaton group	Des Moines series		
Cherokee sh.				
~~		~~~~~~~~	~~~~	
*Limestone		Chester series	Mississippian	
~~		~~~~~~~~		
*Limestone		Meramec series		
~~		~~~~~~~~		
*Warsaw ls. *Keokuk ls. *Burlington ls. *Reeds Spring ls. } =Fern Glen ls. *St. Joe ls. }		Osage series		
*Northview sh. } =Chouteau ls. *Compton ls. } Chattanooga shale		Kinderhook series		
~~		~~~~~~~~	~~~~	~~~~
Pre-Chattanooga rocks (Devonian and older)				

Asterisks designate the units whose aggregate thickness is shown on the accompanying map.
Wavy lines indicate unconformities.

(Classification of Mississippian and Pennsylvanian rocks after R. C. Moore in Guide Book, Ninth Annual Field Conference, Kansas Geological Society, p. 245, 1935, and Stratigraphic classification of Pennsylvanian rocks in Kansas, Kansas Geological Survey, Bull. 22, 1935.)

places. On some sharp domes and anticlines, particularly in the southern part of the state, the limestones are less than 200 feet thick. A single isolated well near the Kansas line in T. 1 N., R. 14 E., in Nebraska (Plate I), penetrated only 35 feet of Mississippian limestone. This well was drilled on a local anticline in the surface rocks, and the thickness, therefore, probably represents only the local thinning of the Mississippian rocks that is usual on anticlines. The thickness of the Mississippian, as mapped along the Nebraska border east of the Nemaha ridge, is consistent with the data available; but, as wells are infrequent in this area, the thickness map is not as accurate as in areas of better control.

Between the Nemaha ridge and the central Kansas uplift the Mississippian limestones form a roughly lenticular body. They thin eastward on the flank of the Nemaha ridge. Toward the west they wedge out on the flank of the central Kansas uplift. Within this area there are local variations in thickness. The greatest thickness found in the area of the map is in Harper county, where the thickness of the limestones is more than 500 feet, but southwest of the central Kansas uplift, in Clark county, outside the area mapped, a thickness of 1,138 feet is known. Even greater thicknesses are reported from wells farther south and southwest, in Woods and Harper counties, Oklahoma. The Mississippian limestone is absent in part of sec. 33, T. 20 S., R. 3 W., where a fault brings 270 feet of Mississippian limestone against an area from which it has been removed. It is absent on the crest of the Cunningham dome, T. 27 S., Rs. 10 and 11 W., and on a considerable but as yet ill-defined structural high centering in Ts. 30 and 31 S., R. 14 W. The Mississippian is absent also on the central Kansas uplift, except on its flanks, on the northern part of the Nemaha ridge, and on a number of secondary anticlines along the crest of the southern part of the Nemaha ridge in Kansas. It appears to be absent also in parts of Republic and possibly in adjoining counties.

There is no reason to doubt the former presence of a normal section of the Mississippian on those parts of the Nemaha ridge where these rocks are now absent. In fact, it is probable that Mississippian limestones were originally deposited over all of Kansas. At least a part of the younger Mississippian may have extended across the central Kansas uplift, though no Mississippian limestones are now present on the central part.

few in number, the preparation of a thickness map of western Kansas has not been attempted. In parts of Cowley, Chautauqua, and southeastern Sumner counties, the Chattanooga shale was completely or partially removed in middle Mississippian time by erosion, and the base of the Mississippian limestones is an irregular surface in such areas. In consequence, the relation between thickness and structure is not as close as in other parts of the region mapped, although the major folds are rather generally indicated. In parts of northern Kansas immediately northeast of the central Kansas uplift, a hiatus exists between the Chattanooga shale and the next younger rocks. The surface of the Chattanooga, prior to the deposition of the next overlying beds, however, had very low relief, as indicated by the widespread overlap of a bed of brown dolomite, only 10 to 20 feet thick, upon the weathered surface of the Chattanooga.

The deformation expressed by the thickness map (Plate I) is a composite of a number of structural movements. Evidence of slight movement along the Nemaha ridge in early Mississippian time was noted by the writer during work on the stratigraphy of the Mississippian, the results of which have not yet been published. Slight southerly tilting seems to have occurred preceding the deposition of the Burlington and Keokuk limestones. Southwesterly tilting before the deposition of the Meramec beds is also suggested by the stratigraphic relations. Though none of these movements, so far as known, were of local importance in the area covered by the thickness map, all are included in the deformation shown by the thickening and thinning of the Mississippian.

The principal movement followed the deposition of the Mississippian rocks. The movement is definitely post-Meramec, for cores from the upper part of the Mississippian collected by the writer from several wells in southwestern Kansas were found by the late Geo. H. Girty, of the Federal Geological Survey, to contain fossils of Meramec age. No cores could be obtained from the upper 350 feet of the 1,138-foot section of Mississippian rocks in the Watchorn-Morrison No. 2 well (sec. 20, T. 32 S., R. 21 W.) in Clark county, immediately below which Doctor Girty reported fossils of probable Spergen (Salem) age. Roth,[3] who examined cores and cuttings from this well, reports that fossils of Chester age were found in its upper

3. Roth, Robert, oral communication quoted by Hugh W. McClellan, Subsurface distribution of the pre-Mississippian rocks of Kansas and Oklahoma. Amer. Assoc. Petroleum Geologists, Bull., Vol. 14, No. 12, pp. 1,548, 1930; confirmed by letter of June 8, 1932, to the writer.

It has been assumed by some geologists that even greater thicknesses of rocks have been eroded from the northern part of the Nemaha ridge, because broad areas of the pre-Cambrian there underlie the Pennsylvanian. However, on the crest of the Nemaha ridge in Nebraska east of Lincoln and also in a well east of the Nemaha ridge in Nebraska just north of the Kansas line, the St. Peter sandstone is in contact with pre-Cambrian rocks. Rocks older than the St. Peter, therefore, were thin or absent toward the north on both sides of the line of maximum displacement of the Nemaha ridge and because the rocks above the granite were thinner in northern Kansas and Nebraska than farther south, the pre-Cambrian rocks were broadly exposed in pre-Pennsylvanian time by much less erosion in the northern part than in the southern part of the state. On the southern part of the Nemaha ridge, except on sharp secondary anticlines, such as Burns and Eldorado and other anticlines, no erosion of pre-Mississippian rocks took place, for the Mississippian blanket was not entirely removed during the peneplanation.

At the close of peneplanation, the Nemaha ridge was simply a pronounced truncated fold that differed from other parallel folds formed at the same time only by its greater length and more pronounced folding. It did not constitute a ridge in the topographic sense, for its surface, like the surface of the less prominent folds, was reduced to base level.

Moore[5] as early as 1917, reported that the evidence showed "a rather pronounced though local deformation in central Kansas (Nemaha mountains) in late Mississippian or early Pennsylvanian time, followed by rapid erosion which removed all the sediments covering at least the top of the granite."

McClellan[6] concluded that the northeast-trending Nemaha ridge fold had not come into existence at the time of the post-Devonian pre-Chattanooga erosion. McClellan's areal geologic map of the pre-Mississippian rocks shows their distribution after folding and peneplanation of the Mississippian rocks. Where the Mississippian rocks were denuded, the underlying formations were also eroded in varying degree. Unless it is borne in mind that the map represents the pre-Mississippian rocks, as they were after post-Mississippian peneplanation, the map may result in a misapprehension as to the age of the Nemaha ridge fold.

Lugn[7] has discussed speculatively the amount of pre-Mississip-

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5. Moore, Raymond C., Oil and gas resources of Kansas. Kansas Geol. Survey, Bull. 3, p. 169, 1917.

6. McClellan, Hugh W., op. cit., p. 1553, 1930.

7. Lugn, A. L., Pre-Pennsylvanian of Nebraska. Am. Assoc., Petroleum Geologists, Bull. 18, pp. 1610-1611, 1934.

areas of thin limestone, none of which indicates a relief of more than 50 feet. The Halstead pool, Tps. 22 and 23 S., R. 2 W., lies on a fold that shows a deformation of over 100 feet at the time of peneplanation. The Graber pool in T. 21 S., R. 1 W., shows prepeneplain folding of about 50 feet. Many other northeasterly trending anticlines are shown by the thinning of the limestones on Plate I. Most of these anticlines show a deformation of less than 50 feet at the end of the peneplanation. Many of them appear to be isolated folds, but alignment with other similar folds is apparent in some places. It is possible that future drilling will develop a relationship to trends not apparent from the data at hand.

The Cherokee basin of southeastern Kansas and the Forest City basin in the northeastern part of the state are both prominent structural synclines. Both were well developed in early Pennsylvanian time. As neither has any expression on the Mississippian map, it appears that the structural movements that caused them were not inaugurated until after peneplanation.

Northwesterly Trending Folds.—Folds trending toward the northwest are, in general, less conspicuous than those trending toward the northeast. However, the Salina basin, a broad regional syncline extending along the northeastern side of the central Kansas uplift, is well expressed by the thickening of the Mississippian rocks. This basin is broad, though not sharply defined in Lincoln county. From Saline county, where the Mississippian rocks are thickest, it extends with diminishing intensity southeastward toward central Greenwood county. At the point where this fold crosses the Nemaha ridge, in T. 21 S., Rs. 6 and 7 E., only a few wells have been drilled, but pronounced thickening of the Mississippian limestones occurs in T. 20 S., R. 5 E. The disposition of the thicker parts of the Mississippian rocks in Greenwood county, though somewhat irregular, may be an extension of the same fold.

Barwick,[8] who named the Salina basin, described it as "the pre-Pennsylvanian syncline bounded on the east by the Nemaha ridge, on the southwest by the Barton arch,[9] 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 unknown." The Salina basin, as defined by Barwick, is

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8. Barwick, J. S., The Salina basin of north-central Kansas. Am. Assoc. Petroleum Geologists, Bull., Vol. 12, No. 2, p. 179, 1928.

9. The central Kansas uplift of later writers.

trend of the Voshell anticline. A similar but smaller syncline in T. 24 S., R. 1 E., cuts off the northern end of the Valley Center anticline.

Low anticlines and parallel synclines trending northwest are shown in northern Chautauqua county and southern Elk county. These folds do not have very pronounced expression on the thickness map, for their structural relief at the close of peneplanation reached a maximum of not much over 50 feet.

Northwesterly trending folds are represented in Wilson county by local anticlines, such as the fold in T. 28 S., R. 13 E., and the Fredonia anticline in sec. 10, T. 29 S., R. 15 E. These minor anticlines are elongated toward the northwest and show a thinning of the Mississippian of about 100 feet.

Northwest-trending folds of low relief occur in Cherokee and Crawford counties. So few wells have been drilled through the Mississippian in this area, however, that the drawing of the thickness lines is largely speculative and was guided by the knowledge of similar folds in the Pennsylvanian rocks shown on the geologic structure map of Crawford county prepared by Pierce, Courtier and others.[11] The thickness lines as shown in this district, therefore, express only the probability that the Pennsylvanian folding here was on the axis of earlier folds, there being no data to the contrary.

The general east-west pattern of the thickness lines showing anticlinal thinning in Douglas county also is based on relatively few wells. A slight thinning of the Mississippian in northern Allen county suggests that a low doming of the peneplain in that area may have anticipated the broad northwest trending fold which was formed in early Pennsylvanian time.

A prominent anticlinal dome is shown in northwestern Barber county, Tps. 30 and 31 S., Rs. 14 and 15 W., from which the Mississippian has been removed. Not enough wells have been drilled in this area to define its area or trend. Another ill-defined anticline in Franklin county, centering in T. 17 S., R. 19 E., is outlined on the basis of a few wells. The direction of its trend is uncertain.

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11. Pierce, W. G., and Courtier, W. H., Geology and coal and resources of southeastern Kansas coal field. Kansas Geol. Survey, Bull. 24, Plate 5, 1937.

Thinning of Mississippian Limestones in Areas of Igneous Intrusions

The Rose dome is a small anticline in sec. 13, T. 26 S., R. 15 E., in southern Woodson county. It is one of the few places in Kansas where igneous rocks are known to be intruded into the sedimentary rocks. Weathered granitic rocks are found on the surface in a small area and two wells drilled on the southwestern flank of the dome penetrated basic igneous rocks considered by Knight and Landes[12] as probably a sill. One of these wells was studied by Twenhofel and Bremer,[13] who reported 102 feet of peridotite. Loose fragments of much-altered igneous rock have been described by Weidman[14] from the small Silver City dome in sec. 32, T. 26 S., R. 15 E.

Several wells in adjoining townships found hydrothermally metamorphosed rocks at various depths on small, steep domes. On the Silver City dome, hydrothermally metamorphosed rocks are reported at the surface. Knight and Landes concluded that intrusions were responsible for these small domes, although no igneous rock was penetrated by the drill except on the Rose dome. The date of these intrusions is known only to be later than the Pennsylvanian rocks that are affected.

The greater part of the townships in which the intrusions of the Rose and Silver City domes occur, and in which most of the metamorphic rocks are found, shows broad pre-Pennsylvanian thinning of the Mississippian limestones, amounting to 60 feet at one point. This thinning seems to indicate that the general area in which the intrusions and metamorphism occurred had already been slightly arched long before the igneous activity.

Similar post-Pennsylvanian metamorphism was noted by Knight and Landes in samples from a well in sec. 8, T. 24 S., R. 17 E., on the crest of the Neosho Falls anticline, which produces oil. They inferred that deep-seated intrusions of igneous rock had caused the fold. It is interesting to note that in this well also there is a thinning of the Mississippian of about 50 feet on the crest of the anticline, indicating that in this locality also part of the folding movements antedated the intrusion.

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12. Knight, G. L., and Landes, K. K., Kansas laccoliths. Jour. Geology, Vol. 40, pp. 8-12, 1932.

13. Twenhofel, W. H., and Bremer, Bernard, An extension of the Rose dome intrusives, Kansas. Am. Assoc. Petroleum Geologists, Bull., vol. 12, No. 7, p. 758, 1928.

14. Weidman, Samuel, Igneous intrusions in Silver City area, Kansas. Am. Assoc. Petroleum Geologists, Bull., vol. 17, No. 10, p. 1, 268, 1933.

in the deeper parts of the basins of eastern Kansas. The folding that formed the deeper parts of the basins in Oklahoma was going on contemporaneously with the deposition of the rocks in that region and probably continued in some degree during the expansion of the sea into Kansas.

Pierce and Courtier[17] state that the Cherokee shale is "only 375 feet thick in northeastern Crawford county (Kansas). It increases in thickness to the southwest, and in southern Labette county (Kansas) reaches a thickness of 560 feet. This increase in thickness is gradual and occurs principally in the lower half of the formation. The thickness of the upper half of the Cherokee shale remains remarkably uniform except for two small local areas in the northeastern part of the district." The significance of this observation lies in the fact that this cross section lies transverse to the steep east side of the Cherokee basin (see Pl. II), where gradual subsidence, if it had been going on during the interval of deposition, would have been expressed by convergence between datums.

Bass[18] states that "the more uniform and more widespread persistence of the strata in the upper part of the formation (Cherokee) than in the lower part, suggests that the marine waters were not only more widespread in late Cherokee time, but that the Cherokee basin had been leveled with sediments permitting the accumulation of sheetlike deposits of uniform thickness and character."

The absence of dependable datum beds in the lower part of the Cherokee rocks of Kansas makes it impossible to determine whether the same degree of parallelism prevailed in the lower part of the overlapping rocks as in the upper part. Although the strata in the upper part are essentially parallel, it seems probable that local deformation of the rocks in such localities, as mentioned by Pierce and Courtier, was taking place. It is probable also that, although the area on the northeast side of the Cherokee basin of southeastern Kansas at the close of Cherokee time was not being deformed except locally, other parts of the region may have been subjected to gradual and irregularly repeated deformation.

If the Cherokee basin had been formed by erosion of the underlying Mississippian limestone, a thinning of the limestone conforming to the basin should be evident on Plate I. If the basin had been originally folded before peneplanation the thickness lines of the Mississippian rocks should outline the basin. Since Plate I shows

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17. Pierce, W. G., and Courtier, W. H., Geology and coal resources of the southeastern Kansas coal field. Kansas Geol. Survey, Bull. 24, 1938, p. 37.

18. Bass, N. W., Origin of the Shoestring sands of Greenwood and Butler counties, Kansas. Kansas Geol. Survey, Bull. 23, pp. 26-27, 1936.

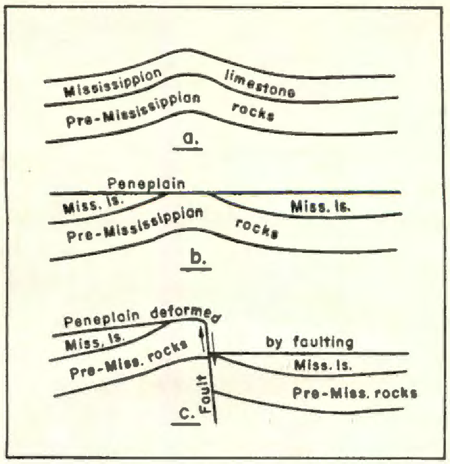

FIGURE 2.—Diagrammatic cross sections, illustrating peneplanation and postpeneplain faulting of anticline in Mississippian rocks.

Section *a*, simple anticline; section *b*, peneplanation of anticline, showing beveling of Mississippian rocks on both sides of the crest; section *c*, faulting of beveled anticline with displacement of peneplaned surface. These cross sections illustrate the origin of the faulted anticlines on the Nemaha ridge fold.

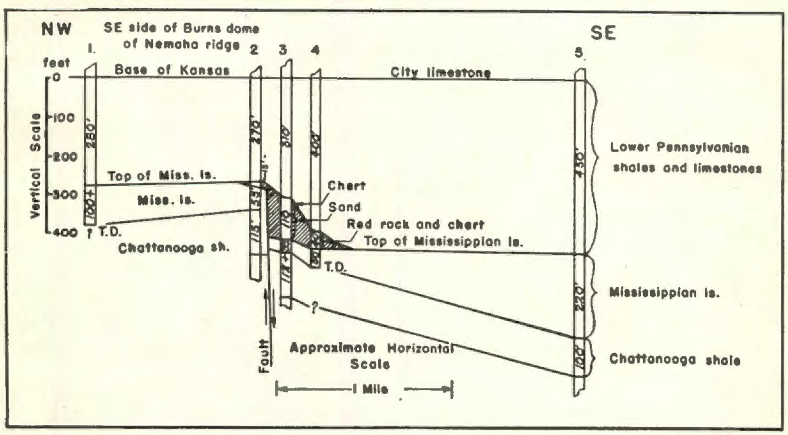

FIGURE 3.—Sketch showing in cross section a fault southeast of the Burns dome and east of the Nemaha ridge in section 6, T. 24 S., R. 6 E. The deposit, cross-lined in the section, is believed to have accumulated after the deformation of the pre-Pennsylvanian peneplain but before the deposition of the lower Pennsylvanian shales and limestones. Wells:

1. Gordon et al.—Ramsey No. 1, SE, NW, sec. 36, T. 23 S., R. 5 E.
2. Ramsey; Wiebe No. 1, SW, SW, NW, sec. 6, T. 24 S., R. 6 E.
3. Mayflower—Piatt No. 4, SE, SW, NW., sec. 6, T. 24 S., R. 6 E.
4. Preston and Marconette—Piatt No. 2, SW, NE, sec. 6, T. 24 S., R. 6 E.
5. Smith and Ash—Cameron No. 1, NE, NE, sec. 8, T. 24 S., R. 6 E.

22. Clark, Stuart K., and Daniels, James I., Relation between structure and production in Mervine, Ponca, Blackwell and South Blackwell oil fields, Kay county, Oklahoma. Am. Assoc. Petroleum Geologists, Structure of Typical American Oil Fields, vol. I, p. 170, fig. 9, 1929.

23. Clark, Stuart, Thomas oil field, Kay county, Oklahoma. Am. Assoc. Petroleum Geologists, Bull., vol. 10, No. 7, p. 647, fig. 2, 1926.

24. McGee, D. A., and Clawson, W. W., Jr., Geology and development of Oklahoma City field, Oklahoma county, Oklahoma. Am. Assoc. Petroleum Geologists, Bull., vol. 16, p. 984, fig. 11, 1932.

The surface of the beveled Mississippian rocks west of the crest of the Nemaha ridge fold, when referred to the Fort Scott limestone, shows a low westward slope, which appears to be the expression of rejuvenation of folding during the period of faulting.

The relation of the beveled Mississippian rocks on the downthrow side of the faults and the overlap of the Cherokee rocks upon the crest of the Nemaha ridge indicate that the variations in thickness of the Cherokee along the ridge are not the result of erosion, but are due to folding and faulting that took place between peneplanation and the end of Cherokee time. Folding on the crest of the Nemaha ridge and displacement along its east side continued by small increments throughout Pennsylvanian and Permian time.

REËLEVATION OF THE FREDONIA ANTICLINE DURING CHEROKEE TIME.—The area of thin Cherokee rocks in Wilson county includes the Fredonia anticline in T. 29 S., R. 15 E. Stryker[27] has published two detailed cross sections of Wilson county. Both include the Fredonia anticline, which lies on the elevated area. His sections show that the intervals between Pennsylvanian datum beds are thinner on the anticline than in near-by synclinal areas, and that they express progressive growth of the anticline during post-Fort Scott deposition. The Cherokee shale below the Fort Scott is about 200 feet thicker in the syncline north of the Fredonia anticline than on its crest.

Not many wells had been drilled through the Mississippian at the time the cross sections were drawn, so that the full relation of the Pennsylvanian folds to the thickness of the Mississippian is not disclosed. The northeast-southwest cross section, however, shows that the thickness of the Mississippian on the crest of the Fredonia anticline is about 90 feet less than in a well in a synclinal area about 5 miles to the north.

The thickness of the Cherokee rocks on the flanks of the anticline is more than double that of the Mississippian in the same position. If the relief necessary for the deposition of this thickness of the Cherokee had been produced by erosion, as shown in section C of Figure 4, the Mississippian could not have remained thicker on the flank than on the crest. The existing relations, as shown in section D of Figure 4, could only have been caused by the rejuvenation of the eroded prepeneplain fold during or before the deposition of the Cherokee rocks of the area, and are not the result of pre-Cherokee erosion.

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27. Stryker, W. L., Subsurface geology of Wilson county, Kansas. Am. Assoc. Petroleum Geologists, Bull., vol. 9, No. 8, p. 1207, 1925.

Anticlinal elevations on the Mississippian surface are shown on the cross section (Plate III) to underlie anticlines affecting the rocks between the top of the Lansing and the base of the Fort Scott limestone. They also overlie thin sections of the Mississippian that represent prepeneplain anticlines. Synclinal depressions on the Mississippian surface similarly underlie thick intervals between the same datum beds and they overlie thick sections of Mississippian rocks. Elevations and depressions of the surface of the Mississippian on the line of the Kellett cross section are thus closely related to both prepeneplain and early Pennsylvanian folds. This close relation of the Mississippian surface to the structural features appears to indicate that they were caused by the rejuvenation of pre-Cherokee folds during Cherokee time and that the folds continued to grow during later Pennsylvanian deposition. They do not, therefore, appear to be the result of incomplete reduction of the surface to a peneplain.

Other Rejuvenated Folds.—In Bass'[30] report on Cowley county, after pointing out the close relation between the folds and the thickness of the Mississippian, he notes that an unpublished map prepared by him showing the thickness of the Cherokee rocks in Cowley county "indicates that the Mississippian surface sloped gently southeastward and was characterized by very low hills over anticlines and domes with intervening shallow valleys. The surface was nearly a peneplain. The topographic relief in the area of the Slick-Carson dome (sec. 19, T. 32 S., R. 3 E.) was only 10 feet to 15 feet; in the area of the Winfield anticline (Tps. 32 and 33 S., Rs. 4 and 5 E.), even less, and in the area of the Dexter-Otto anticline (Tps. 33 and 34 S., Rs. 6 and 7 E.) there was a maximum relief of 35 feet." These observations by Bass in the closely studied area of Cowley county illustrate again the close relation of the pre-Cherokee topography to structure.

The low mounds of the pre-Cherokee surface in Cowley county all overlie earlier folds that are shown by the thinning of the Mississippian. The post-Cherokee deformation, which continued through the Pennsylvanian and Permian, deformed the peneplain and increased considerably the structural relief of the pre-Pennsylvanian rocks.

The pre-peneplain folding of the Dexter-Otto anticline (T. 34 S., Rs. 6 and 7 E), as indicated by the thickness of the Mississippian, is so low as to be scarcely distinguishable, being no more than 10 to

30. Bass, N. W., Geology of Cowley county, Kansas. Kansas Geol. Survey, Bull. 12, p. 124, 1929.

The Slick-Carson dome shows a thinning of the Mississippian of about 50 feet. The relief of the Mississippian surface, referred to the Fort Scott, is given by Bass as 10 to 15 feet, and the deformation of the Mississippian surface reached about 100 feet during or after the Pennsylvanian and Permian. The folds were, therefore, growing during the entire postpeneplain period.

Such modest secondary mounds on the pre-Pennsylvanian surface, as have been mentioned in connection with the Slick-Carson dome and similar folds, might reasonably be interpreted as residual hills on the base-leveled surface, caused by greater resistance to erosion of upturned beds at the center of anticlines. The surface of the Mississippian, referred to the Fort Scott limestone, however, shows a greater relief in some places than the folding of the Mississippian. The surface was thus more deformed in these places during the time interval between peneplanation and the end of the Cherokee than before peneplanation. As shown in Figure 4, this relation is inconsistent with the origin of the mounds by means of erosion. The elevations of the Mississippian surfaces, even though of low relief, may therefore have been due to the general deformation of the region that occurred during the long period of time between peneplanation and the end of Cherokee time.

Summary of Cherokee Folding. — The deformation during Cherokee time involved the gradual reëlevation of parts of eastern Kansas and the lowering of adjacent areas. At this time there was a slow rejuvenation of old folds and the initiation of some new folds. The Kansas part of the Cherokee basin is a northward continuation of the syncline produced by the folding of the deep contemporaneously filled Cherokee basin of Oklahoma. The forest City basin appears to be a part of the same syncline, since it lies on the northern extension of the same axis of folding. As the basin extends toward the east around the northwestern flank of the Ozark uplift, other synclinal elements may have contributed to its development. The Forest City basin is cut off from the Cherokee basin by a broad northwesterly trending arch from Bourbon and Allen counties to southern Lyon county.

The folding of these basins was accompanied by rejuvenation of the Nemaha ridge fold and by the downward displacement of the region on its east side. The displacement, which extends from southeastern Nebraska to central Oklahoma took the form of faulting in some areas and monoclinal folding in others. The surface on the western side of the Nemaha ridge was tilted gently toward in T. 20, Rs. 5, 6 and 7 E. Less well-defined examples of interrupted northeasterly trending folds may be noted at several other points. The writer interprets these interruptions of northeasterly trending anticlines as due to local resistance offered by the presence of earlier synclinal cross folds, though this cannot be fully demonstrated, since the pre-Mississippian history of these northwesterly trending folds is not now known. The northwesterly trending minor folds shown in Elk and Chautauqua counties on Plate I may be the revival of earlier folds on the northwesterly trending Chautauqua arch, the detailed structure of which in pre-Mississippian time is not known.

Both northwesterly and northeasterly trending folds were active during Cherokee time. They were chiefly revivals of folds known to have deformed the Mississippian rocks prior to peneplanation. The northerly trending Cherokee and Forest City basins, however, are not represented on the Mississippian thickness map. The broad northwesterly trending structural swell, which separates these basins on the Cherokee thickness map (Plate II), trends more or less parallel to the Chautauqua arch. Like the Cherokee and Forest City basins, it had no obvious pre-Cherokee history east of the Nemaha ridge, unless the broad low dome in Allen county on Plate I represents prepeneplain deformation on this trend. Folding of the Chautauqua arch, if it were revived during Cherokee time, is not shown by the 50-foot thickness lines of Plate II. The Fredonia and associated anticlines, which overlie northwesterly trending local folds in the Mississippian, were strongly rejuvenated during Cherokee time and more slowly during later Pennsylvanian time. Slow growth of most of the northeasterly trending folds continued through the Pennsylvanian and Permian. The activity of northwesterly trending folds is exemplified by the Ellsworth-Kanapolis anticline in Ellsworth county, on which Pennsylvanian, Permian and Cretaceous beds are folded.

It appears, therefore, that only northwesterly trending folds were active in pre-Mississippian time. The folds with this trend and the more important northeasterly trending folds were active in pre-Pennsylvanian time when the Mississippian rocks were deformed, and again through the Pennsylvanian and the Permian and even during the Cretaceous. Either the stresses that produced these two sets of folds were alternately active or the folds represent different expressions of the same stresses more or less simultaneously relieved.

Most of the folds trending in a northeasterly direction, as dis-

En Echelon Folds

On Plate I the anticlines on the Halstead-Graber structural trend (T. 23 S., R. 2 W., to T. 21 S., R. 1 W.) show offset relations. Parts of the Nemaha ridge in Sumner, Cowley and Butler counties show secondary folds trending north or northwest at a slight angle with the axis of the Nemaha ridge. It is believed by many geologists[34] that en echelon faults and folds in the relatively incompetent Pennsylvanian and Permian rocks are the expression of deep-seated horizontal displacements in the pre-Cambrian rocks. The deep-seated vertical and horizontal movements in these rocks would, it is believed, be expressed by similar displacements in the overlying relatively competent Paleozoic rocks, chiefly limestones of pre-Pennsylvanian age.

Relation of Anticlinal Thinning to Occurrence of Oil and Gas

Productive oil and gas pools in Mississippian rocks and in anticlinal folds in other rocks are shown in Plate I. Productive pools in lenticular sand bodies,[35] including shoestring sands, have been omitted. A great many of the pools shown, although their oil and gas are produced from rocks older or younger than the Mississippian, lie in areas of anticlinal thinning of the Mississippian limestones. The clearness with which the outlines of the pools are indicated by the thickness lines depends on the number of available well logs. The Ritz-Canton pool in T. 19 S., Rs. 1 and 2 W., and the Lerado pool in T. 26 S., R. 9 W., are not very sharply indicated by the 50-foot thickness lines, but an intermediate 25-foot thickness line, omitted from the map, shows a close relation between productive oil and gas areas and thinning. Some anticlinal pools east of the Nemaha ridge are in areas where drilling has not yet shown the thickness of the Mississippian and its relation to the structure.

In many places the oil and gas pools do not coincide exactly with the structurally high areas indicated by thinning of the Mississippian rocks. This is shown in the Graber pool in T. 21, S., R. 1 W., in the McPherson pool in T. 18 S., R. 2 W., in the Halstead pool in T. 23 S., R. 2 W., in the Haven pool in T. 24 S., R. 4 W., in the Florence pool in T. 21 S., R. 5 E., and elsewhere. In some

34. Fath, A. E., The origin of the faults, anticlines and buried "granite ridge" of the northern part of the Mid-continent oil and gas field. U. S. Geol. Survey, Prof. Paper, 128, 1920; and Geology of the Eldorado oil and gas field, Butler county, Kansas, Kansas Geol. Survey, Bull. 7, p. 150, 1921.

35. The writer is indebted to W. L. Stryker, of Fredonia, for the identification of productive anticlinal structures in Wilson and adjoining counties, where a large part of the production has come from lenticular sandstones.

T. 29 S., R. 2 E. (A well drilled in section 18 shows a thickness of Mississippian limestone of only 285 feet, whereas in the nearest well a mile distant to the southwest, in sec. 24, T. 29 S., R. 1 E., the thickness is 343 feet.)

T. 27 S., R. 5 W. (A locally thin area in the southeast quarter is shown by a well in section 25 where only 252 feet of Mississippian limestone are present.)

T. 31 S., R. 3 E. (A well in the SE¼, NE¼, sec. 31, shows the limestone to have an exceptional local thinness of 190 feet.)

T. 29 S., Rs. 2 and 3 W. (At the southwestern end of the Valley Center anticline a detached area of slightly thinner limestone is present.)

Tps. 24 and 25 S., R. 7 E. (An area of slightly thinner limestone is vaguely indicated.)

Some areas of thinning, which have been contoured as noses in areas of few wells, suggest the possibility of structurally high areas in their general vicinity. These include the following localities:

T. 13 S., R. 3 E., and T. 12 S., R. 4 E. (The nose southeast of Abilene projecting southwest from Riley county appears to have been inadequately explored from a structural standpoint, though other conditions may not be promising for oil.)

T. 33 S., Rs. 1, 2, 3 and 4 W. (An area showing on the map as a divide between thick areas north and south, might hold some promise, though it lies in an area where the relation between thickness and structure is not so close as elsewhere on account of the unconformable relations between the Chattanooga shale and the overlying Mississippian limestones.)

T. 25 S., R. 4 W. (A nose shown in the southwest corner suggests the possibility of anticlinal thinning in this or the adjoining southeast corner of T. 25 S., R. 5 W.)

A broad area of thinning occurs in southern Douglas and Franklin counties. The thinner parts of this area in Douglas county show a trend from east to west. In Franklin county not enough wells have been drilled to show the trend. Other less pronounced areas of thinning are suggested at many points by the configuration of the thickness lines.

In some of the areas mentioned other factors may perhaps already have condemned them as possible oil- or gas-producing areas. Detailed structural maps of the region are not available to the author, but enough oil- and gas-producing areas are eccentric to areas of thin Mississippian limestone to suggest that further examination and perhaps exploration of some of the areas of thin limestone is warranted, even though dry holes appear to have been drilled near the crests of some of the anticlines.

pools producing from Mississippian rocks west of the Nemaha ridge. Most of the pools are still producing. The data are adapted from a report by Ver Wiebe.[38]

TABLE No. 2.—Partial list of all fields producing from Mississippian limestone. Shows variability of per-acre production.

	Date of discovery.	Acres.	Total production to Jan. 1, 1938.	Production in barrels per acre.
Harvey County:				
Halstead pool, T. 23 S., R. 2 W	Apr., 1929	1,200	636,000	530
McPherson County:				
Johnson pool, Tps. 19 and 20 S., R. 3 W	Jan., 1932	1,200	2,100,000§	1,750
McPherson pool, T. 18 S., R. 2 W	July, 1928	2,000	600,000§†	300†
Voshell pool,* Tps. 20 and 21 S., R. 3 W	Aug., 1929	3,500	21,068,598*	6,020*†
Ritz-Canton pool,* Tps. 19 and 20 S., Rs. 1 and 2 W	Dec., 1928	13,000	28,850,360*†	2,219*†
Rice County:				
Welch pool,‡ Tps. 20 and 21, R. 6 W	Apr., 1924	1,500	3,800,774‡	2,534‡
Reno County:				
Burrton pool, Tps. 23 and 24 S., R. 4 W	Apr., 1931	5,000	21,410,489†	4,282†
Sedgwick County:				
Robbins pool, T. 28 S., R. 1 E	Apr., 1929	420	2,511,311	6,000
Sumner County:				
Wellington pool, Tps. 31 and 32 S., R. 1 W	Dec., 1929	1,200	2,504,685	2,087

* Includes production from Viola limestone and Wilcox sand.
† Large production of gas in addition to oil.
‡ Production in part from Pennsylvanian basal conglomerate.
§ Estimated.

The accompanying table (Table III), gives a list of oil and gas pools that derive their production in whole or in part from the Mississippian rocks, together with such production figures as are available for the various pools. Most of the data has been taken from a production report in the transactions of the American Institute of Mining and Metallurgical Engineers for 1937, compiled by Ver Wiebe and Dahlgren[39] and their predecessors who assembled the information in a series of annual reports.

38. Ver Wiebe, Walter A., Oil and gas resources of western Kansas. Kansas Geol. Survey, Mineral Resources Circular 10, 1938.

39. Ver Wiebe, W. A., and Dahlgren, E. C., Kansas oil and gas during 1937. Petroleum development and technology, Am. Inst. Min. and Met. Eng., Trans., vol. 127, pp. 370-397, 1938.

The Occurrence of Oil and Gas in the Limestone

The oil occurs in cavities in the limestone or in weathered chert. The openings in the limestone are probably in part capillary openings, but most of the voids are relatively large and are irregularly connected by devious solution channels. Many of these openings have become partly or wholly sealed since they were charged with oil. Oil in interconnecting large openings penetrated by the drill escapes readily toward drill holes. Solution openings which may have been partly or wholly sealed off by cementation are opened up by the use of acid, thus establishing more direct and open channels for the escape of the oil. It is because the oil is mostly found in coarse and openly connected cavities that oil wells in the Mississippian lime have generally a large initial yield, but a rapid decline.

Most of the pools in Mississippian rocks produce considerable amounts of salt water with the oil. Each of the large and small connected chambers of the reservoir has its own gravitational arrangement of gas, gas-saturated oil, and water under a uniform pressure. When the well is drilled these static conditions are destroyed by the escape of gas; oil and gas rush to the drilled hole; and the oil and water in the small interconnected chambers become mixed by the violent agitation of the escaping gas. More water is thus brought to the surface from oil reservoirs in limestone than from oil in sandstone reservoirs, where the water is more sharply segregated around the flanks of the structure in the more minute but more freely connected openings between sand grains.

OIL-PRODUCING BEDS IN THE MISSISSIPPIAN.—At the close of peneplanation in pre-Cherokee time a considerable diversity of Mississippian formations was exposed on the surface, owing to the beveling of the folded Mississippian formations. The ground-water level of this period, which must have been near the surface, cut across the contacts of the different formational units and produced more or less horizontal porous zones in all the exposed formations at and near the surface. In pre-Cherokee time, when parts of the region stood considerably above sea level, particularly west of the Nemaha ridge, horizontal solution zones were, it is believed, formed in the more soluble and less shaly portions of the limestones, irrespective of the stratigraphy. Oil and gas are found, in consequence, in nearly every one of the formational units of the upper part of the Mississippian, as the occurrence of oil and gas is dependent more on the occurrence of porous zones than on the character of any par-