The Geologic History of Kansas

By Daniel F. Merriam

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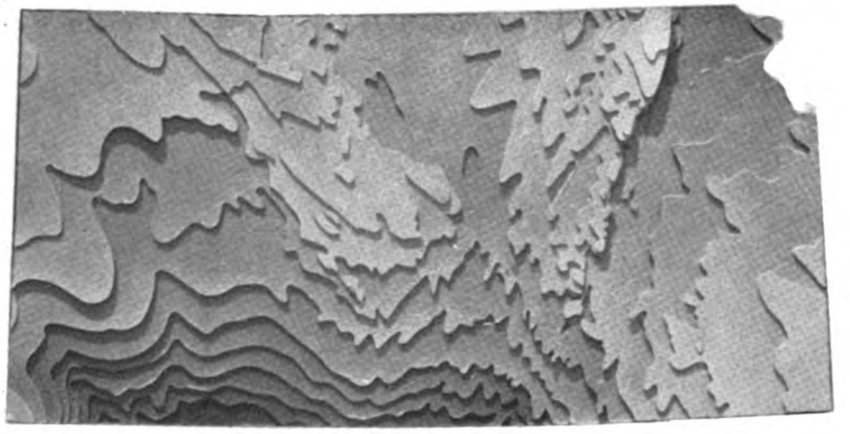

Model of present configuration of the foundation rocks of Kansas.

. . . the foundations of the world were discovered.
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DANIEL F. MERRIAM

The Geologic History of Kansas

ABSTRACT

Kansas, part of the stable interior, has a cover of sedimentary rocks, nowhere more than about 9,500 feet thick, which is thin when compared to the section in basinal areas on the craton. When viewed in proper perspective, the relatively simple succession of thin sedimentary strata, perhaps representing only 15 to 50 percent of post-Precambrian time, appears as a veneer covering the Precambrian basement complex.

Beds of Quaternary age, consisting of unconsolidated sand, gravel, silt, and clay, are confined mostly to present drainage systems and are relatively thin; Pleistocene glacial deposits cover much of northeastern Kansas. Nonmarine Tertiary (Pliocene) rocks, mainly unconsolidated gravel, sand, and silt, blanket the western one-third of Kansas, masking the underlying stratigraphy and structure. Rocks of Mesozoic age, predominantly thick accumulations of marine shale, limestone, and chalk, and nonmarine deposits of sandstone and shale, cover the western one-half of Kansas and increase in thickness westward. Basal units of the Mesozoic sequence overstep Paleozoic beds with a pronounced unconformity.

Rocks of Pennsylvanian and Permian age, characterized by cycles of marine and nonmarine strata, occur statewide. Thin but persistent units can be traced over large areas of the Midcontinent region. Lateral facies changes occur between the shallow shelflike areas and the deeper basins. Channel sandstones mark many of the disconformities, which are numerous owing to the cyclical deposition. There are rocks representing all pre-Pennsylvanian systems, consisting mainly of marine sediments—limestone and dolomite and some shale and sandstone. The thickest sections of pre-Pennsylvanian rocks are found near the centers of basins, where they have been protected from extensive erosion. Unconformities separate all rock systems.

Five peridotitic intrusive igneous plugs crop out in Riley County, and one peridotitic and one granitic outcrop are known in Woodson County. One of the plugs has been dated as early Tertiary.

The Precambrian basement complex consists mainly of granite, quartzite, and schist. Distribution of sediments, mafic igneous rocks, extrusives, granodiorite, syenite, and granite, however, is at best only vaguely known. A weathered or detrital material known as "granite wash" covers large areas beneath Paleozoic sediments at this major unconformity.

Two major structural units and parts of seven others are present in Kansas. Four of these are uparched areas that separate larger downwarped basins and serve to delimit them. These major pre-Desmoinesian post-Mississippian structures, almost unchanged since their formation, outline the petroliferous provinces of Kansas.

Only the southwestern part of the Forest City Basin extends into Kansas. It is bounded on the west by the Nemaha Anticline and on the southwest by the low, indistinct, northwest-trending Bourbon Arch. The basinal axis trends slightly east of north and lies close to and parallel to the Nemaha; hence, the basin has an asymmetrical profile and a steep west flank. The present basin, formerly part of the older North Kansas Basin, became a separate feature after Mississippian time. South of the Bourbon Arch in southeastern Kansas is the Cherokee Basin, which developed on the older Chautauqua Arch. The basinal axis lies near and parallel to the Nemaha Anticline, making the basin asymmetrical.

The long, narrow Nemaha Anticline trends northeastward across Kansas, separating the Forest City and Cherokee Basins on the east from the Salina and Sedgwick Basins on the west. The Precambrian core of the Nemaha, within about 600 feet of the surface near the Nebraska border and 4,000 feet at the Oklahoma border, is characterized by a series of local knobs along its crest. Pre-Pennsylvanian strata have been upturned, truncated, and overstepped on both sides at the north end, but farther south the Paleozoic beds are folded over the crest. The anticline is faulted along the east side in several areas, and earthquakes indicate that movement is continuing.

The northern part of the Salina Basin extends into Nebraska from Kansas; the axis of this second largest basin in Kansas trends northwestward. The Sedgwick Basin, a shelflike extension of the Anadarko Basin of Oklahoma, is roughly symmetrical and plunges southward. Strata are characterized by facies change and thicken southward.

The Central Kansas Uplift (and associated minor structures) is the structural backbone of Kansas and separates the Salina Basin on the east from the Hugoton Embayment on the west. On its higher parts, Precambrian rocks are overlain by rocks as young as Pennsylvanian, and on the flanks pre-Pennsylvanian units are upturned, truncated, and overstepped. To the northwest and on the same trend as the Central Kansas Uplift is the Cambridge Arch (and subsidiary features). This arch, the Central Kansas Uplift, and the Chadron Arch of Nebraska, form an arcuate chain of features convex to the southwest. The Pratt Anticline, a large, broad, southward-plunging nose of the Central Kansas Uplift, dies out southward in Oklahoma. On parts of its crest Mississippian rocks are absent and Pennsylvanian beds overlie Viola Limestone and older formations.

The Hugoton Embayment, a northern shelflike extension of the larger Anadarko Basin of Oklahoma, extends over parts of four states, including one-third of Kansas. The embayment plunges southward and sediments thicken both toward the axis and southward into the Anadarko Basin.

Present structure of Kansas is shown and contrasted by maps on top of the Ogallala (Pliocene), Dakota (Cretaceous), Stone Corral (Permian), Lansing (Pennsylvanian), Mississippian, "Hunton" (Silurian-Devonian), Arbuckle (Cambrian-Ordovician), and Precambrian rocks. Many shallow beds in the Paleozoic succession accurately reflect deeper structure, but because of effects of solution and other modifying conditions, others do not.

Patterns of deformation in Kansas have changed through geologic history; although some areas have always been structurally positive and others always negative, some have been reversed. Incompleteness of the rock record impedes interpretation of events, but stratigraphic studies show that at least since Precambrian time, Kansas has been in a tectonic setting similar to that of the present. By study of a series of isopachous maps it is possible to systematize the pulsating up-and-down movements of the crust and to recognize past patterns of deformation.

Small folds and faults exhibit cross trends at approximately N 12° E, N 40° E, and N 42° W. Structural closure ranges from near nothing to several hundred feet and may change in magnitude and position with depth. Some deep structures are represented at the sur-

face by mere nosing; conversely, many surface structures die out at depth. Structural shapes range from domes to sharp, elongated anticlines.

Small structures, commonly known as plains-type folds, are characterized by uplift with no adjoining depression, thinning of beds over the crest (or increased magnitude with depth), asymmetry, and association with normal faulting. Many explanations have been offered for the origin of these structures, according to the presumed major factor in forming them: (1) tangential compression, (2) torsional stress, (3) differential settling of sediments, and (4) local vertical uplift. Probably all four are important, and each may partly explain a given structure. The present structural pattern in Kansas is believed to be the result of vertical relief of stresses transmitted through the rigid crystalline basement. It is reasonable to assume that anticlinal structures developed as local areas remained high during regional subsidence. Zones or lines of weakness, along which adjustment has developed plains-type folds, are thought to be inherited from Precambrian orogenic movements.

Résumé

Le Kansas, partie de l'intérieur stable, a une couverture de roches sédimentaires, nulle part plus qu'à peu près 2900 mètres d'épaisseur, ce qui est mince en comparaison de la section dans les aires de bassin sur le kraton. Vu dans sa propre perspective, la succession relativement simple de minces couches sédimentaires, qui représent peut-être seulement 15 à 50 pour cent de l'âge post-précambrien, paraît comme couverture sur le gneiss fondamental précambrien.

Les couches de l'âge quaternaire, comprenant sable, gravier, vase, et argile, non consolidés, sont limités le plus souvent aux systèmes actuels de drainage, et sont relativement minces; des dépôts glaciaires du Pléistocène couvrent beaucoup de Kansas nord-est. Des roches tertiaires (pliocènes) non marines, principalement le gravier, le sable, et la vase non consolidés couvrent le tiers de Kansas ouest, cachant la stratigraphie et la structure sous-jacentes. Des roches de l'âge mésozoique, accumulations prédominantement épaisses de schiste marin, de calcaire, et de craie, et de dépôts non marins de grès et de schiste couvrent la moitié de Kansas ouest et deviennent plus épaisses vers l'Ouest. Des unités basiques de la série mésozoique recouvrent les couches paléozoiques d'une discordance prononcée.

Les roches des âges pennsylvanien et permien, caractérisées par de cycles de couches marines et non marines, se trouvent d'un bout de l'état à l'autre. On peut suivre les unités, minces mais constantes dans de grandes aires de la région moyenne du continent. Des changements latéraux de faciès se trouvent entre de basses aires qui se ressemblent à plate-forme et des bassins plus profonds. Les grès de chenal marquent beaucoup des dissemblances, qui sont numéreuses à cause du dépot cyclique. Il y a des roches qui représent tous les systèmes anté-pennsylvaniens, qui comprennent principalement les sédiments marins, le calcaire et la dolomie et du schiste et du grès. Les régions les plus épaisses des roches anté-pennsylvaniens se trouvent près des centres des bassins, où elles ont été protégées d'érosion étendue. Des nonconformités séparent tous les systèmes des roches.

Cinq culots ignés intrusifs de péridotite affleurent en Riley County et on reconnaît un affleurement depéridotite et un affleurement de granit en Woodson County. Un des culots on a daté du Tertiaire commençant.

Le gneiss fondamental Précambrien comprend principalement granit, quartzite, et schiste. La distribution des sédiments, roches ignées mafic, roches d'épanchement, granodiorite, syénite, et granit, cependant, n'est connue que vaguement. Un matériau altéré ou détritique couvre de grandes aires audessous des sédiments paléozoiques à cette non conformité majeure.

Deux unités de structure majeure et des parties de sept autres se trouvent en Kansas. Quatre en sont des aires élevées qui séparent des bassins déprimés d'une dimension plus grande et servent à les délimiter. Ces structures majeures anté-desmoinesiens, post-mississippiens, presque dans le même état dès leur formation, découpent les provinces pétrolifères de Kansas.

Seulement la partie sud-ouest du Forest City Basin s'étend en Kansas. A l'Ouest, la Nemaha Anticline le limite et au Sud-Ouest, le Bourbon Arch, qui, se dirigeant vers le Nord-Ouest, est basse et indistincte. L'axe du bassin se dirige légèrement à l'Est du Nord et repose près de, et parallèle à celui de Nemaha; d'ici le bassin a un profil asymétrique et un flanc raide à l'Ouest. Le bassin actuel, autrefois partie du bassin plus vieux de Kansas nord, est devenu un trait séparé après l'âge mississippien. Au Sud du Bourbon Arch se trouve le Cherokee Basin, en Kansas sud-est, qui s'est développé sur le Chautauqua Basin qui est plus vieille. L'axe du bassin repose près de, et parallèle à le Nemaha Anticline, ce qui rend le bassin asymétrique.

Le Nemaha Anticline, long et étroit, se dirige au Nord-Est à travers le Kansas, et sépare les Forest City et Cherokee Basins à l'Est des Salina et Sedgwick Basins à l'Ouest. Le noyau précambrien de Nemaha dans l'espace de 200 mètres, approximativement, de la surface près de la frontière de Nebraska et 1300 mètres à la frontière d'Oklahoma, est caractérisé par une série de boutons locaux le long de sa crête. Des couches anté-pennsylvaniens ont été tournées, tronquées, et transgressés aux deux côtés à l'extrémité du Nord, mais plus au Sud les couches paléozoiques se plient par-dessus de la crête. L'anticlinal devient une faille le long du côté est dans plusieures aires, et des tremblements de terre indiquent que le mouvement se continue.

La partie du Nord du Salina Basin s'étend en Nebraska, de Kansas. L'axe de ce bassin, le deuxième en grandeur en Kansas, se dirige vers le Nord-Ouest. Le Sedgwick Basin, une extension qui se ressemblent à plate-forme du Anadarko Basin d'Oklahoma, est à peu près symétrique et se plonge vers le Sud. Les couches sont caractérisées par un changement des faciès et deviennent plus épaisses vers le Sud.

Le Central Kansas Uplift (et d'associées structures mineures) est l'épine du dos structurale de Kansas et sépare le Salina Basin à l'Est du Hugoton Embayment à l'Ouest. Sur ses parties plus hautes les roches précambrien sont couvertes des roches aussi jeunes que Pennsylvanien, et sur les flancs les unités anté-pennsylvaniens sont retournées, tronquées, et transgressés. Au Nord-Ouest et en la même direction que le Central Kansas Uplift se trouve le Cambridge Arch (et des traits subsidaires). Cette voûet, le Central Kansas Uplift, et le Chadron Arch de Nebraska, forment une chaîne arquée de traits convexes au Sud-Ouest. Le Pratt Anticline, un grand, large saillant anticlinal qui se plonge vers le Sud, disparait vers le Sud en Oklahoma. Sur des parties de sa crête les roches mississippiens se manquent et les couches pennsylvaniens recouvrent le Viola Limestone et des formations plus veilles.

Le Hugoton Embayment, une extension qui se ressemblent à plate-forme du Nord du plus grand Anadarko Basin d'Oklahoma s'étend dans des parties de quatre états, et comprend un tiers de Kansas. L'Embayment se plonge vers le Sud et les sédiments s'épaississent et vers l'axe et vers le Sud dans le Anadarko Basin.

La structure actuelle de Kansas se montre et se met en contraste par des plans au sommet des roches Ogallala (pliocènes), Dakota (crétacées), Stone Corral (permiens), Lansing (pennsylvaniens), mississippiens, "Hunton" (si-

luriens-dévoniens), Arbuckle (cambriens-ordoviciens), et précambriens. Plusieurs couches basses dans la succession paléozoïque ressemblent exactement à une structure plus profonde, d'autres conditions modifiantes, d'autres ne lui ressemblent pas.

Les modèles de déformation en Kansas changeaient pendant l'histoire géologique; quoique quelques aires aient été toujours positives structuralement et d'autres négatives, quelques-unes ont été renversées. L'inachèvement de l'histoire des roches entrave l'interprétation des événements, mais des études stratigraphiques montrent que depuis l'âge précambrien, au moins, le Kansas a été dans un état tectonique semblable à celui du présent. Par une étude d'une série de cartes isopaques il est possible de systématiser les pulsatoires mouvements ascendants et descendants de la croûte et de reconnaître les antérieurs modèles de déformation.

De petits plis et failles montrent des directions transversales à N 12° E, N 40° E, et N 42° W approximativement. La fermeture structurale varie de presque rien à plusieurs cents pieds et puissent changer en grandeur et en position selon la profondeur. Seulement saillants anticlinals représentent quelques structures profondes à la surface; réciproquement, beaucoup de structures à la surface meurent dans la profondeur. Les formes structurales varient de dômes à anticlinaux aiguisés et allongés.

De petites structures, connues communément comme des plis de "plains-type" sont caractérisés par un soulèvement sans aucune dépression adjacente, amincissement de couches par-dessus de la crête (ou grandeur augmentée par la profondeur), asymétrie, et association avec des failles normal. On a offert beaucoup d'explications pour éclaircir l'origine de ces structures, selon le facteur majeur qu'on présume qui les forme: (1) compression tangentielle, (2) effort de torsion, (3) dépôts differentiels des sédiments, et (4) vertical soulèvement local. Probablement toutes les quatres explications sont importantes, et chacune puisse expliquer en partie une structure donnée. On croit que le modèle de la structure actuelle en Kansas est le résultat de l'allégement verticale des efforts transmis à travers le rigide gneiss crystallin. Il est raisonnable de supposer que les structures anticlinales ont développé quand les aires locales restaient hautes pendant l'affaisement régional. Les zones ou les lignes de faiblesse, le long desquelles l'adoptation a développé les plis de "plains-type," on croit être héritées des mouvements orogéniques du Précambrien.

Resumen

Kansas, parte de el estable interior, tiene una cubierta de rocas sedimentarias que en ninguna parte presenta un espesor de más de 2900 m aproximadamente, lo cual no es mucho cuando se compara con la sección en las cuencas de el cratón. Cuando la sucesión relativamente simple de los estratos sedimentarios que representan quizás de el 15 a el 50 por ciento de el tiempo después de el Precambrian es observada con la debida perspectiva, aparece como una delgada capa que cubre el complejo basal de el Precambrian.

Estratos de edad Quaternary, los cuales consisten de arena no consolidada, grava, limo y arcilla, están confinados mayormente a presentes sistemas de drenaje y no son espesos; depósitos glaciales de el Pleistocene cubren mucho de el noreste de Kansas. Rocas no-marinas de el Tertiary (Pliocene), principalmente grava no consolidada, arena y limo, cubren el tercio oeste de Kansas, cubriendo la estratigrafía y las estructuras de el subsuelo. Rocas de edad Mesozoic, en las que predominan espesas acumulaciones de lutitas marinas, caliza y tiza, y depósitos no-marinos de arenisca y lutita, cubren la mitad occidental de Kansas y aumentan en espesor hacia el oeste. Unidades basales de la secuencia de el Mesozoic transgresan estratos de el Paleozoic con una discordancia pronunciada.

Rocas de edad del Pennsylvanian y de el Permian, caracterizadas por ciclos de estratos marinos y no-marinos, se encuentran en todo el estado. Unidades delgadas pero persistentes pueden ser trazadas en extensas áreas de la región mid-continental. Cambios faciales laterales tienen lugar entre las áreas llanas casi platafórmicas y las más profundas cuencas. Areniscas de alveos marcan muchas de las numerosas discordancias debido a deposiciones cíclicas. Hay rocas representativas de todos los sistemas de el pre-Pennsylvanian y consisten en su mayoría de sedimentos marinos—calizas, dolomitas y algunas lutitas y areniscas. Las secciones más espesas de rocas de el pre-Pennsylvanian se encuentran cerca de el centro de las cuencas, donde han sido protegidas de erosión extensiva. Todos los sistemas están separados por unconformidades.

Cinco tapones ígneos intrusivos y peridotíticos afloran en Riley County y otros dos, uno peridotítico y el otro granítico, afloran en Woodson County. Uno de los tapones es de el principio de el Tertiary.

El complejo basal de el Precambrian consiste principalmente de granito, cuarcita y esquisto. La distribución de sedimentos, rocas ígneas máficas, rocas ígneas extrusivas, granodiorita, sienita y granito se conoce muy vagamente. Un material desegregado y detrítico conocido como "lavadura de granito," debajo de sedimentos de el Paleozoic, cubre extensas áreas en esta importante unconformidad.

Dos unidades estructurales de importancia y partes de siete otras están presentes en Kansas. Cuatro de éstas son áreas combadas que separan amplias cuencas sinclinales y a la vez las delimitan. Estas estructuras de edad pre-Desmoinesian, después de el Mississippian, que casi no han sufrido cambios desde su formación, delinean las provincias petrolíferas de Kansas.

Solamente la parte suroeste de la Forest City Basin se extiende dentro de Kansas. Está limitada en el oeste por el Nemaha Anticline y en el suroeste por el bajo e indistinto Bourbon Arch que tiende al noroeste. El eje de la cuenca tiende un poco al este de norte y está situado cerca y paralelo a el Nemaha Anticline, por lo cual la cuenca tiene un perfil asimétrico con un empinado flanco occidental. La cuenca actual, que formó parte de la más antigua North Kansas Basin, se transformó en un rasgo separado después de el Mississippian. En el suroeste de Kansas, al sur de el Bourbon Arch, está la Cherokee Basin que se formó sobre el más antiguo Chautauqua Arch. El eje de la cuenca está situado cerca y paralelo a el Nemaha Anticline, haciendo la cuenca asimétrica.

El estrecho y largo Nemaha Anticline tiende hacia el noreste a través de Kansas, separando la Forest City Basin y la Cherokee Basin que se encuentran en el este, de la Salina Basin y de la Sedgwick Basin que están en el oeste. El núcleo Precambrian de el Nemaha Anticline, que está aproximadamente a 200 m de la superficie en el límite con Nebraska y a 1,300 m de la superficie en el límite con Oklahoma, está caracterizado por una serie de prominencias locales a lo largo de su cresta. Estratos de el pre-Pennsylvanian han sido inclinados, truncados y transgresados en ambos lados en el extremo norte, pero hacia el sur los estratos de el Paleozoic están plegados sobre la cresta. El anticlinal está fallado a lo largo de el lado este en varios lugares y terremotos indican que el movimiento aún continúa.

La parte norte de la Salina Basin se extiende adentro de Nebraska; el eje de esta cuenca, segunda en amplitud en Kansas, tiene una dirección noroeste. La Sedgwick Basin, una extensión casi platafórmica de la Anadarko Basin de Oklahoma, es casi simétrica y tiene un buzamiento hacia el sur. Los estratos están caracterizados por cambios faciales y aumentan en espesor hacia el sur.

El Central Kansas Uplift (y las estructuras secundarias asociadas con él) es el espinazo estructural de Kansas y separa la Salina Basin en el este de el Hugoton Embayment en el oeste. En sus partes más altas, rocas de el Precambrian están cubiertas por rocas tan recientes como de el Pennsylvanian; en sus flancos, unidades de el pre-Pennsylvanian están inclinadas, truncadas y transgresadas. Hacia el noroeste y con una dirección similar a la de el Central Kansas Uplift, está el Cambridge Arch (y rasgos subsidiarios). Este arco, junto con el Central Kansas Uplift y el Chadron Arch de Nebraska, forma una cadena arqueada de rasgos que es convexa hacia el suroeste. El Pratt Anticline, una ancha nariz estructural de el Central Kansas Uplift con un buzamiento hacia el sur, desaparece en Oklahoma. En partes de su cresta, rocas de el Mississippian están ausentes y mantos de el Pennsylvanian cubren la Viola Limestone y otras formaciones de más edad.

El Hugoton Embayment, una extensión plataförmica al norte de la Anadarko Basin de Oklahoma, se extiende sobre partes de cuatro estados incluyendo un tercio de Kansas. La ensenada tiene un buzamiento hacia el sur y los sedimentos aumentan de espesor hacia el eje y hacia la Anadarko Basin.

La presente estructura de Kansas está expuesta y contrastada en mapas representando los horizontes de la Ogallala (Pliocene), la Dakota (Cretaceous), la Stone Corral (Permian), la Lansing (Pennsylvanian), la Mississippian, la "Hunton" (Silurian-Devonian), la Arbuckle (Cambrian-Ordovician), y las rocas del Precambrian. Muchos estratos poco profundos en la sucesión de el Paleozoic reflejan exactamente estructuras de más profundidad; debido a los efectos de solución y otras condiciones modificadoras otros estratos no las reflejan.

Las normas de deformación en Kansas han cambiado al través de la historia geológica; aunque algunas áreas han sido siempre estructuralmente positivas y otras estructuralmente negativas, otras han sido de ambas maneras. La condición incompleta de el registro litológico impide la interpretación de los eventos, pero estudios estratigráficos revelan que al menos desde los tiempos de el Precambrian, Kansas ha estado en un ambiente tectónico similar a el del presente. Por el estudio de una serie de mapas isopacos es posible sistematizar los movimientos pulsantes de arriba-abajo de la corteza y reconocer las normas de deformación en tiempos pasados.

Pequeños pliegues y fallas exhiben direcciones cruzadas a aproximadamente N 12° E, N 40° E, y N 42° O. Cierres estructurales recorren de casi nada a cientos de metros y pueden cambiar en magnitud y en posición con la profundidad. Algunas estructuras profundas están representadas en la superficie por narices, y a la inversa, muchas estructuras en la superficie desaparecen con la profundidad. Las formas estructurales varían entre domos y anticlinales elongados bien definidos.

Pequeñas estructuras conocidas como "pliegues típicos de las planicies" son caracterizadas por levantamiento sin depresiones adjuntas, adelgazamiento de los estratos sobre la cresta (o magnitud incrementada con la profundidad), y asimetría y asociación con fallas normales. Muchas explicaciones han sido ofrecidas sobre el origen de estas estructuras de acuerdo a el factor principal que se presume en su formación: (1) compresión tangencial, (2) esfuerzo torsional, (3) asentamiento diferencial de los sedimentos, (4) levantamiento vertical local. Probablemente todos cuatro son importantes y cada uno pueda explicar en parte cierta estructura. La presente norma estructural en Kansas se cree que sea el resultado de el aligeramiento vertical de esfuerzos trasmitidos a través de el rígido basamiento cristalino. Es rasonable asumir que las estructuras anticlinales, desarrolladas como áreas locales, permanecieron elevadas durante la subsidencia regional. Zonas o líneas de debilidad, a lo largo de las cuales ajustamiento ha desarrollado pliegues típicos de las planicies, se cree han sido heredadas de los movimientos orogénicos de el Precambrian.

Riassunto

Kansas, situato nell' "interno stabile," ha una copertura sedimentaria di non più di circa 2900 metri, sezione sottile in confronto ai bacini del cratone. Quando le proporzioni sono mantenute, questa copertura, costituita da una relativamente semplice successione di sottili strati sedimentari, probabilmente reppresentanti non più del 15 o 20 percento del tempo post-precambriano, appare come una verniciatura che copre il complesso basamento precambriano.

Strati di età quaternaria, costituiti da sabbia non consolidata, sono situati per lo più solamente nel presente sistema idrografico, e sono generalmente sottili; depositi glaciali pleistocenici coprono la maggior parte del Kansas nord-occidentale. Roccie terziarie (plioceniche) non marine, generalmente conglomerati non consolidati, sabbia ed argille coprono il terzo occidentale del Kansas, mascherando la stratigrafia e la struttura delle roccie più antiche. Roccie di età mesozoica, per lo più potenti accumulazioni di argillo-scisti marini, calcari, gessi, arenarie ed argillo-scisti non marini, coprono la metà occidentale del Kansas ed aumentano di potenza verso l'ovest. Unità di base del Mesozoico coprono roccie paleozoiche con una spiccata discordanza angolare. Roccie di età permiana e pennsilvaniana (Carbonifero superiore), caratterizzate da ripetizioni cicliche di strati marini e non marini, sono presenti dovunque.

Unità sottili, ma molto persistenti, sono tracciabili in estese aree della regione centro-continentale. Eteropie di facies sono presenti fra i più profondi bacini e le meno profonde aree di piattaforma. Molti piani di trasgressione, numerosi a causa della deposizione ciclica, sono intersecati da molti canali, ora riempiti da arenarie. Roccie reppresentanti tutti i sistemi pre-pennsilvaniani sono presenti, costituite generalmente da calcari dolomitici marini, dolomie ed, in grado minore, argillo-scisti ed arenarie.

Le sezioni di roccie pre-pennsilvaniane più potenti sono situate in prossimità del centro dei bacini, dove sono rimaste protette da erosione eccessiva. Tutti i sistemi stratigrafici sono separati da discordanze.

Cinque intrusioni peridotitiche affiorano nelle contea di Riley ed una intrusione peridotitica ed un altra granitica sono state riportate nella contea di Woodson. Una delle intrusioni è datata Terziario inferiore.

Il complesso basamento precambiano consiste per lo più di granito, quarzite e scisti. La presenza di sedimenti, roccie femiche, roccie effusive, granodioriti, sieniti e graniti è nota solamenti in maniera vaga. Un materiale detritico o ossidato, conosciuto come "granite wash" (sabbione granitico), copre estese aree sotto i sedimenti paleozoici, seguendo questa maggiore discordanza.

Due maggiori unità strutturali e parte di sette altre sono presenti nel Kansas. Quattro di queste sono brachi-anticlinali che separano vasti bacini e ne fungono da limite. Queste maggiori strutture sono post-mississippiane (post-Carbonifero inferiore) e pre-desmoinesione (pre-Carbonifero superore medio), e sono rimaste senza alterazioni dalla loro formazione. Esse formano i limiti delle provincie petrolifere del Kansas.

Solamente la parte sud-occidentale del bacino di Forest City si estende nel Kansas. Esso è limitato nella parte occidentale dall'anticlinale di Nemaha e nella parte sud-occidentale dal basso, indistinto, arco di Bourbon, che si estende in direzione nord-ovest.

L'asse di questo bacino ha direzione leggermente nord-est ed è situata vicino e parallelamente all'anticlinale di Nemaha, per cui il bacino ha un profilo non simmetrico e un ripido fianco occidentale.

Il presente bacino, una volta parte del più antico bacino del Kansas settentrionale, divenne un'unità separata dopo il Mississippiano (Carbonifero inferiore). A sud dell'arco di Bourbon è situato il bacino di Cherokee, nel Kansas sud-orientale. Questo bacino si sviluppò sopra il più antico arco di Chautauqua. L'asse del bacino è situata vicino e parallelmente all' anticlinale di Nemaha, causando così l'asimmetria del bacino. L'anticlinale di Nemaha, lunga e stretta, si dirige verso il nord-est attraverso il Kansas, separando il bacino di Forest City ed il bacino di Cherokee nell'est dai bacini di Salina e di Sedgwick nell'ovest.

Il nucleo dell'anticlinale, costituito da roccie precambriane, si trova ad una profondità di 200 m vicino al confine con il Nebraska e di 1300 m nei pressi del confine con l'Oklahoma, ed è una piega-faglia lungo il lato orientale in molti posti, e terremoti indicano che il movimento continua tuttora.

La parte settentrionale del bacino di Salina si estende dal Kansas nel Nebraska. L'asse di questo bacino, il secondo nel Kansas, si dirige verso nord-ovest.

Il bacino di Sedgwick, una piattaforma più che un bacino, estensione del bacino di Anadarko nell'Oklahoma, è quasi simmetrico e s'immerge verso il meridione. Gli strati sono caratterizzati da eteropie di facies e da un aumento di potenza verso il sud.

La brachianticlinale del Kansas Centrale (Central Kansas Uplift) (ed altre strutture minori associate) è la spina dorsale della struttura del Kansas e divide il bacino di Salina nell'est dalla baia di Hugoton nell'ovest. Nelle parti più elevate della brachianticlinale, roccie precambriane sono immediatamente sotto roccie molto più giovani, perfino pennsilvaniane, e sui fianchi roccie prepennsilvaniane sono raddrizzate, troncate e trasgresse dagli strati più giovani. Verso il nord-ovest lungo la stessa direzione di questa brachianticlinale è situato l'arco di Cambridge (e unità sussidiarie).

Questo arco, la brachianticlinale del Kansas Centrale e l'arco di Chadron nel Nebraska formano un'arcuata catena di unità strutturali convessa verso il sud-ovest.

L'anticlinale di Pratt, una larga, estesa estensione della brachianticlinale del Kansas Centrale, s'immerge verso il sud e sparisce nell'Oklahoma.

Su certi tratti della cresta di questa anticlinale, roccie Mississippiane sono assenti e roccie pennsilvaniane sono trasgressive sopra il calcare Viola (Ordoviciano) e formazioni più antiche.

La baia di Hugoton, un'estensione a piattaforma del più grande bacino di Anadarko nell'Oklahoma, si estende su parte di quattro stati, includendo un terzo del Kansas. Questa baia s'immerge verso il sud e i sedimenti aumentano di potenza sia verso l'asse del bacino sia verso il bacino di Anadarko. La presente struttura del Kansas è rappresentata e messa in contrasto da mappe della superfice superiore dell' Ogallala (Pliocene), del Dakota (Cretaceo), del Stone Corral (Permiano), del Lansing (Pennsilvaniano), del Mississippiano, del "Hunton" (Siluriano-Devoniano), dell' Arbuckle (Cambriano-Ordoviciano) e del Precambriano.

Molti strati di origine poco profonda riflettono accuratamente strutture più profonde, ma altri, per l'effetto di soluzioni ed altre condizioni modificatrici, non riflettono niente.

Lo stile delle deformzioni nel Kansas è cambiato nel tempo geologico. Quantunque alcune aree sono restate strutturalmente sempre positive o sempre negative, altre aree hanno cambiato.

L'assenza di molti strati impedisce la completa interpretazione degli eventi, ma studi stratigrafici mostrano che, almeno a cominciare dal Precambriano, il Kansas è rimasto in un disegno geologico simile a quello presente tuttora. È possibile di arrivare ad un sistema di pulsazioni verticali e di riconoscere passati stili di deformazione, analizzando une serie di carte isopache.

Piccole pieghe e faglie hanno direzioni intersecanti approssimativamente a N 12° E, N 40° E, N 42° W. La differenza di livello strutturale varia da praticamente zero a un paio di centinaia di metri. Alcune strutture profonde sono rappresentate in superfice solamente da una lieve variazione dell'isoipsa strutturale; e d'altra parte, molte strutture di superficie spariscono in profondità.

La forma delle strutture varia da duomi ad acute, allungate anticlinali.

Piccole strutture, generalmente chiamate "pieghe di tipo piano" (plains-type folds), sono caratterizzate da un'elevazione senza concomitante depressione, dall'assottigliarsi degli strati sulla cresta e dalla loro asimmetria ed associazione con faglie normali.

Molte spiegazioni sono state proposte, basate su presupposti fattori di formazione: (1) compressione tangenziole, (2) sforzo di torsione, (3) sedimentazione differenziale, (4) spinta verticale locale. Probabilmente tutte e quattro sono importanti, ed ognuna può spiegare una certa struttura. Il presente disegno strutturale nel Kansas possibilmente è il risultato del sollievo verticale di sforzi trasmessi attraverso il rigido basemento cristallino.

È ragionevole di assumere che le strutture anticlinali si svilupparono come aree locali che rimasero elevate durante lo sprofondamento regionale. Zone o linee di debolezza, lungo le quali un aggiustamento ha causato le pieghe di tipo piano, possibilmente sono un'eredità dei movimenti orogenici del Precambriano.

Auszug

Kansas, Teil des stabilen Binnenlandes, hat eine Decke von Sedimentär-Gestein, die nirgendwo dicker als ungefähr 2900 Meter ist, verglichen mit Schichtenfolgen in Beckengebieten auf dem Kraton also dünn. Aus der richtigen Perspektive gesehen, erscheint die relativ einfache Folge von dünnen Sedimentschichten, die vielleicht lediglich 15 bis 50 Prozent der post-Präkambrischen Zeit ausmachen, als eine Deckschicht, die das präkambrische Fundament bedecken.

Betten quartären Alters, die aus nichtverfestigtem Sand, Kies, Schlammgestein und Ton bestehen, beschränken sich zumeist auf gegenwärtige Entwässerungssysteme und sind relativ dünn; Pleistozäne Eisablagerungen bedecken einen Grossteil von Nordost-Kansas. Nicht-marine tertiäre (Pliocene) Gesteine, hauptsächlich nichtverfestigter Kies, Sand und Schlammgestein, bedecken das westliche Drittel von Kansas und maskieren die darunter liegende Stratigraphie und Struktur. Gesteine Mesozoischen Alters, ueberwiegend dicke Anhäufungen von marinem Schieferton, Kalk und Kreide sowie nichtmarine Ablagerungen von Sandstein und Schiefer, bedecken die westliche Hälfte von Kansas und nehmen nach Westen an Dicke zu. Basale Einheiten der Mesozoikum-Folge übergreifen Paläozoikum-Betten in hervorstechender diskordanter Lagerung.

Gesteine Pennsylvanischen und Permischen Alters, deren Charakteristikum marine und nichtmarine Schichten-Zyklen sind, treten im ganzen Staat auf. Dünne Einheiten konnen jedoch ständig über weite Gebiete des mittleren Kontinents verfolgt werden. Seitliche Faciesveränderungen treten zwischen den flachen schelfartigen Gebieten und den tieferen Becken auf. Kanal-Sandsteine markieren viele der zahlreichen Schichtungs-Diskordanzen, die der zyklischen Ablagerung zuzuschreiben sind. Es gibt Gesteine aus allen prä-Pennsylvanischen Systemen, die hauptsächlich aus marinen Sedimenten—Kalk und Dolomiten sowie etwas Schieferton und Sandstein—bestehen. Die dicksten Schichtenfolge prä-Pennsylvanischer Gesteine trifft man in der Nahe der Zentren von

Becken an, wo sie vor ausgedehnter Auswaschung geschützt gewesen sind. Diskordanzen trennen alle Gestein-Systeme.

Fünf peridotitische intrusive Erstarrungsgestein-Pfropfen treten im Riley County zutage, ein peridotitischer und ein granitischer Aufschluss ist im Woodson County bekannt. Der Peridotit ist auf das frühe Tertiär datiert worden.

Der Komplex des Präkambrischen Fundaments besteht überwiegend aus Granit, Quarzit und Schiefer. Verteilung von Sedimenten, mafischen Gesteinen, Extrusiva, Granodiorit, Syenit und Granit, ist jedoch im besten Falle nur vage bekannt. Ein Verwitterungs- oder Schuttmaterial, als "granite wash" bekannt, bedeckt weite Gebiete unter Paläozoischen Sedimenten auf dieser bedeutenden Diskordanz.

Zwei grössere strukturelle Einheiten und Teile von sieben anderen sind in Kansas gegenwärtig. Vier davon sind aufwärts gebogene Gebiete, die grössere abwärts verkrümmte Becken abtrennen und als deren Begrenzung dienen. Diese grösseren prä-Desmoinesian post-Mississippischen Strukturen, die sich seit ihrer Formation fast nicht veränderten, umreissen die ölliefernden Provinzen von Kansas.

Lediglich der südwestliche Teil des Forest City Beckens reicht nach Kansas hinein. Es ist im Westen durch die Nemaha Anticlinale und im Südwesten durch den niedrigen, undeutlichen, nach Nordwest ausgerichteten Bourbon Arch begrenzt. Die Beckenachse tendiert ein wenig aus der Nordrichtung nach Osten und liegt nahe und parallel zum Nemaha; somit hat das Becken ein asymmetrisches Profil und eine steile Westflanke. Das gegenwärtige Becken, früher Teil des älteren North Kansas Beckens, unterging nach der Mississippi-Zeit einer Trennung. Südlich vom Bourbon Gewölbe, in Südost-Kansas, liegt das Cherokee Becken, das sich auf dem älteren Chautauqua Gewölbe entwickelte. Die Beckenachse liegt nahe und parallel zur Nemaha Antiklinale, wodurch das Becken asymmetrisch wird.

Die lange, schmale Nemaha Antiklinale ist nach Nordosten quer durch Kansas ausgerichtet und trennt das Forest City und das Cherokee Becken im Osten vom Salina und vom Sedgwick Becken im Westen. Der Präkambrische Kern des Nemaha, in der Nähe der Nebraska-Grenze ungefähr 200 Meter und in der Nähe der Oklahoma-Grenze ungefähr 1300 Meter tief, hat eine charakteristische Reihe von örtlichen Auswüchsen entlang seines Höhenrückens. Prä-Pennsylvanische Schichten an beiden Seiten des nördlichen Endes sind aufgerichtet, abgestumpft und übergegriffen worden; weiter südlich sind die Paleozoicum-Betten über den Höhenrücken gefaltet. An seiner östlichen Seite ist die Antiklinale in verschiedenen Gebieten verworfen, und Erdbeben zeigen an, dass die Bewegungen anhalten.

Der nördliche Teil des Salina Beckens reicht von Kansas aus nach Nebraska hinein. Die Achse dieses zweitgrössten Beckens in Kansas tendiert nach Nordwest. Das Sedgwick Becken, eine riffartige Ausdehnung des Anadarko Becken in Oklahoma, ist im grossen Ganzen symmetrisch und fällt nach Süden ab. Die Schichten sind durch Faciesveränderungen gekennzeichnet und verdicken sich nach Süden.

Das Central Kansas Uplift (sowie zugehörige kleinere Strukturen) ist das strukturelle Rückgrat von Kansas und trennt das Salina Becken im Osten vom Hugoton Embayment im Westen. An seinen höher gelegenen Stellen sind Präkambrische Gesteine von so jungen Gesteinen wie Pennsylvanischen überlagert, und an den Flanken sind prä-Pennsylvanische Einheiten aufgerichtet, abgestumpft und übergegriffen worden. Im Nordwesten und in gleicher Weise ausgerichtet wie das Central Kansas Uplift ist das Cambridge Gewölbe (und untergeordnete Erscheinungen). Dieses Gewölbe, das Central Kansas Uplift und das Chadron Gewölbe von Nebraska bilden eine bogenförmige Kette, die nach Südwesten konvex ist. Die Pratt Anticlinale, eine grosse, breite, nach Süden abfallende Nase des Central Kansas Uplift, verschwindet im Süden in Oklahoma. Teilweise fehlen auf seinem Höhenrücken Mississippische Gesteine, und Pennsylvanische Betten überlagern Viola Kalk und ältere Formationen.

Das Hugoton Embayment, eine nördliche, schelfartige Ausdehnung des grösseren Anadarko Beckens von Oklahoma, erstreckt sich durch Teile von vier Staaten, einschliesslich eines Drittels von Kansas. Die strukturelle Bucht fällt nach Süden ab, und die Sedimente verdicken sich sowohl in Richtung auf die Achse als auch südwärts ins Anadarko Becken.

Es wird die derzeitige Struktur von Kansas gezeigt und an Hand von Karten auf folgenden Gesteinen kontrastiert: Ogallala (Pliozän), Dakota (Kreide), Stone Corral (Perm), Lansing (Pennsylvanian), Mississippian, "Hunton" (Silur-Devon), Arbuckle (Kambrium-Ordovizium) und Präkambrium. Viele flache Betten in der Paläozoikum-Folge spiegeln exakt tiefere Strukturen wieder, aber andere tun dies nicht infolge von Lösungseffekten und anderen modifizierenden Bedingungen.

Während der geologischen Geschichte hat sich das Deformationsbild in Kansas ständig geändert; wiewohl einige Gebiete immer strukturell positiv und andere immer strukturell negativ gewesen sind, haben einige eine Umkehrung erfahren. Die Unvollständigkeit der Gesteinsaufzeichnungen erschwert die Interpretation der Ereignisse, aber stratigraphische Studien zeigen, dass sich Kansas mindestens seit der Präkambrischen Zeit in einer tektonischen Erstarrung befindet, die der gegenwärtigen ähnlich ist. Durch das Studium einer Serie von Dicke-Karten ist es möglich, die pulsierenden Auf und Ab-Bewegungen der Erdkruste zu systematisieren und frühere Deformationsbilder zu erkennen.

Kleine Faltungen und Verwerfungen zeigen kreuzweise Ausrichtung nach ungefähr N 12° O, N 40° O und N 42° W. Strukturelle Abgeschlossenheit geht von nahe null bis zu mehreren dreissig Meter und kann sich in Grösse und Position mit der Tiefe ändern. Einige Tiefenstrukturen sind an der Oberfläche bloss durch flache "nasenartige" Faltung vertreten; umgekehrt verlaufen sich viele Oberflächenstrukturen in der Tiefe. Strukturelle Formen reichen von Wölbungen bis zu scharfen, verlängerten Antiklinalen.

Kleinere Strukturen, die gemeinhin als "plains-type folds" (ebenenartige Faltungen) bekannt sind, sind gekennzeichnet durch Aufwölbung ohne angrenzende Depression, Verdünnung von Betten über den Höhenrücken (oder zunehmende Stärke mit zunehmender Tiefe), Asymmetrie und Assoziation mit normaler Verwerfung. Viele Erklärungen sind für die Herkunft dieser Strukturen vorgeschlagen worden, entsprechend der Ursache, die als Hauptfaktor für ihre Formation angenommen worden ist: (1) tangentiale Compression, (2) Torsionsdruck, (3) differentielles Absetzen von Sedimenten und (4) örtliche vertikale Aufwerfung. Wahrscheinlich sind alle vier bedeutend, und jeder Faktor kann teilweise eine gegebene Struktur erklären. Es wird angenommen, dass das gegenwärtige strukturelle Bild in Kansas das Ergebnis einer vertikalen Spannungs-Minderung ist, die durch die feste kristalline Basis übertragen wurde. Es erscheint richtig anzunehmen, dass antiklinale Strukturen auftraten, wenn örtliche Gebiete während regionaler Senkung hoch blieben. Schwäche-Zonen oder -Strecken, entlang derer die Angleichung "plains-type folds" (ebenenartige Faltungen) schuf, werden auf Präkambrische orogene Bewegungen zurückgeführt.

INTRODUCTION

Kansas, located in the heart of the United States on a buried southern extension of the Canadian Shield, which is part of the continental nucleus, is ideally situated for a study of the stable interior of North America (Fig. 1). Sedimentary rocks of the region are those typical of a shallow-shelf environment, structure is gentle—in fact, so gentle that it is sometimes difficult to find—and the land is stable. Nothing in the geologic makeup is dramatic or spectacular; simplicity is the usual, rather than the unusual. The neatly arranged geology of Kansas has been described as monotonous, and perhaps rightly so, by those interested in the bizarre. Geology of the Interior Lowlands has been termed the "science of gently-dipping strata" by King (1959).

Kansas is in a critical position to supply information concerning correlations of the stratigraphy between surface outcrop areas in western Missouri; Nebraska and the Dakotas; the Rocky Mountain area including Wyoming, Colorado, and New Mexico; and Oklahoma. It is part of a vast area in Mid-America, known as the Great Plains, stretching from the Canadian border on the north to the Rio Grande on the south, and from the Rocky Mountains on the west to the Central Lowlands on the east. It is for the most part blanketed by unconsolidated deposits of Tertiary and Quaternary age that mask the stratigraphy and structure of older beds. The shape and mode of formation of the various geologic units, especially older ones in the area, are of utmost importance in determining geologic history of the Great Plains, as well as in locating buried deposits of mineral wealth.

Within the last decade accelerated test drilling for oil and gas and for ground water in the central part of the Great Plains, in Kansas in particular, has added much new information on the geology of rocks concealed beneath the mantle of younger, unconsolidated deposits. Sufficient control now is available to permit tracing of stratigraphic units and to allow reasonably accurate portrayal of regional structure. This information, in the form of electric and radioactivity logs and well samples, was utilized in preparing this report.

The objectives of this study were multiple. First, and perhaps most important, was the desirability of better understanding the geologic history of Kansas. With an appreciation of the geologic history of Kansas, special problems could then be investigated. Second, it was obvious that stratigraphic units on the surface in eastern and central Kansas should be traced into the subsurface in order to determine which units are present westward. Because only Tertiary, Mesozoic, and upper Paleozoic rocks crop out in Kansas, emphasis was placed on their stratigraphic relations, both at the surface and in the subsurface, and on their regional correlations into adjacent areas. As a result, lower Paleozoic units were, unfortunately, neglected; however, through the work of others considerable data are available regarding them. Special units were selected for study to serve as examples of types of sediments occurring in a stable-shelf environment. Third, it was hoped that some contribution toward the understanding of plains-type folding could be made, based on information accumulated in the last two decades. Plains-type folds are structurally unique in an otherwise almost featureless expanse. The key to the problem, the Precambrian basement complex, is elusive, and much work needs to be done on the predictability of various aspects of these most interesting structures (Merriam, 1961).

The scope of this endeavor is broad. Although much remains to be done, it is hoped that some aims of the project have been met and that with information assembled here other problems can be investigated advantageously. Work on the project began in the fall of 1953 and with only minor interruptions has continued until the present. Because of the nature of the project it was decided that information would be released as it became available. Accordingly, the first publication appeared in 1954 and others followed. A considerable amount of early work, therefore, had to be brought up to date for inclusion here. Most of the published material is included here for completeness and clarity, and credits are made where appropriate. The amount of material available for study—approximately 130,000 drillers logs, 35,000 electric and radioactivity logs, and 10,000 sample logs—required help to collect, compute, and plot in order to bring the project to the present stage of completion. The help, much of it voluntary, is most appreciated and is recognized in the acknowledgments. Although it is not always possible to acknowledge all work, it is hoped that no major omissions have been made; the bibliography is extensive but by no means complete.

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FIGURE 1.—Index map of North America showing Kansas in relation to Canadian Shield and Central Stable Region (adapted from Eardley, 1951). Kansas occupies a key position intermediate to cratonic shield area, north and east, and mobile belts, south and west.

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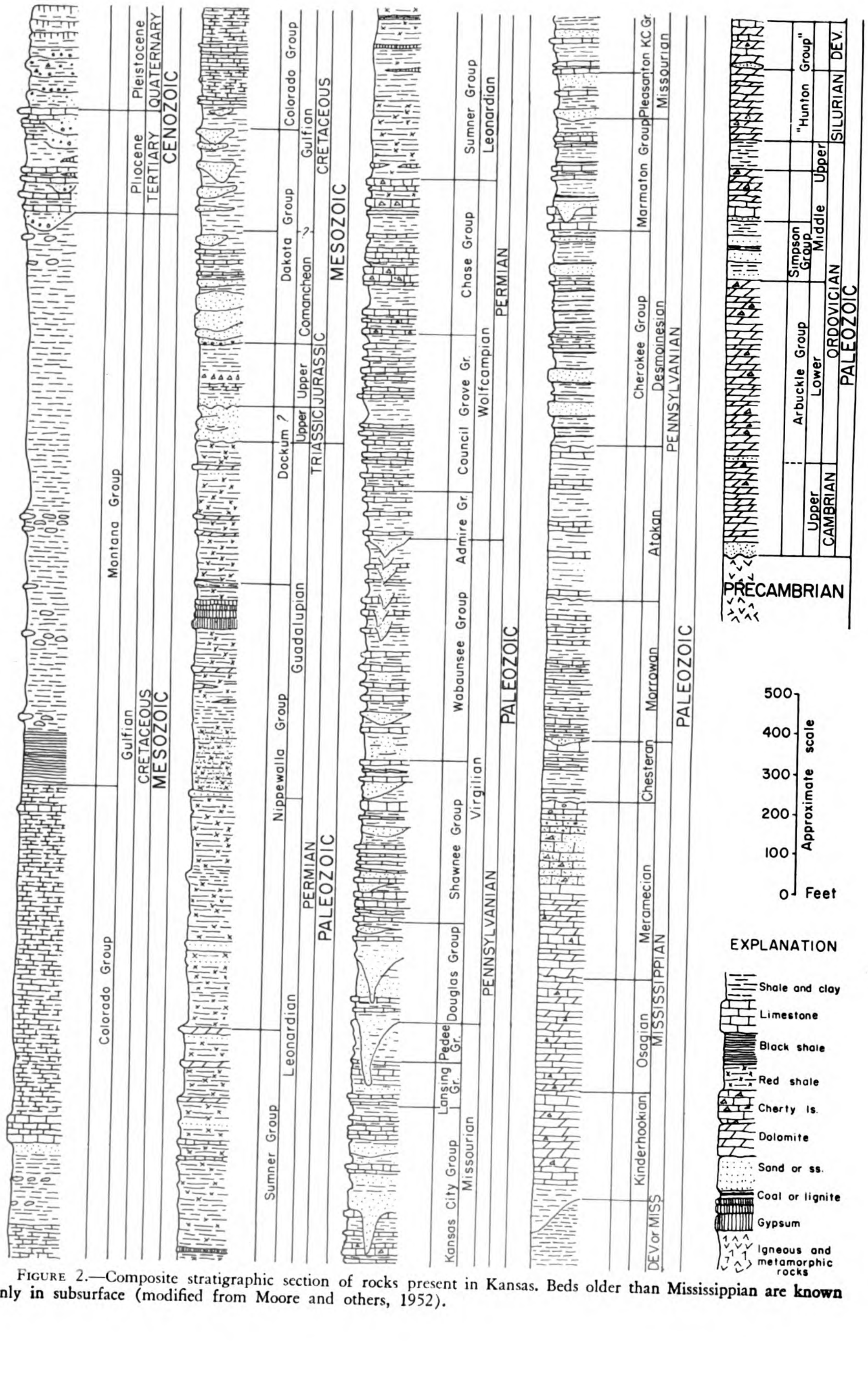


FIGURE 2.—Composite stratigraphic section of rocks present in Kansas. Beds older than Mississippian are known only in subsurface (modified from Moore and others, 1952).

STRATIGRAPHY

Discussions of Kansas stratigraphy* in this report are based mainly on subsurface information supplemented by surface data. Descriptions are necessarily brief and generalized. It is absolutely essential, however, in understanding the tectonics of the region, to have knowledge of the types of lithostratigraphic units involved. Detailed lithologic descriptions of stratigraphic units are necessary in correlation for determining time relations of events of regional nature, but gross lithologic descriptions are adequate for understanding and interpreting structure and structural development.

Rocks in Kansas range in age from Precambrian to Quaternary. Although at no one place in Kansas is there a complete, representative geologic section, all post-Precambrian systems are represented (Fig. 2, 3, 4, 5).

The section of sedimentary beds in Kansas is relatively thin as compared with geosynclinal troughs and the deeper basinal areas such as the Denver or Anadarko Basins. The maximum thickness of sedimentary rocks in the deepest part of the Kansas portion of the Hugoton Embayment is only about 9,500 feet. When viewed in proper perspective, the sedimentary strata appear almost as a veneer covering the Precambrian basement complex, which is, of course, nothing more than an extension of the Canadian Shield area. Also as compared with geosynclinal areas, the stratigraphy is simple, and this succession of many thin beds of sediments has been compared to that of a layer cake. The dip of beds, except in small "pseudostructures," such as those due to slumping into solution cavities, is known not to exceed 10 degrees (Jewett and Merriam, 1959). The reader must constantly keep in mind the unavoidable distortion, caused by vertical exaggeration, that is necessary in order to present the data graphically (see especially Dallmus, 1958).

Stratigraphic emphasis has been placed on outcropping rocks of Kansas and their correlation in the subsurface. Because of this, Cenozoic, Mesozoic, and upper Paleozoic rocks are treated in more detail than lower Paleozoic units. Also, because of the importance of the Precambrian in forming a base for all subsequent developments, it is given a more detailed treatment. With few exceptions, all major surface units have been examined in the field in order to recognize the more important characteristics of each unit.

In this report correlation of subsurface rock units is accomplished mainly by a combination of (1) lateral tracing of certain persistent key beds, (2) notice of the similar lithology of units, and (3) observation of like sequences of stratigraphic formations. In Kansas, little or no use is made of fossils or faunal assemblages in subsurface correlation, except where they may be obtained from cores, although distinctive fossils may be used in picking tops from rotary and cable-tool well samples. In this respect microfossils have considerable value for correlation and for mapping.

Most useful in correlation are electric and radioactivity logs, which portray, respectively, the electrical and radioactive properties of the rock. These properties may be characteristic of individual beds over large areas; for example, the Stone Corral Formation of the Sumner Group (Permian), which in the subsurface is composed chiefly of anhydrite, has a characteristic electric-log peak by which it may be traced from the outcrop in south-central Kansas into eastern Colorado. The double-pronged "kick" at top of the Greenhorn Limestone (Upper Cretaceous) may be traced over several states and as far as eastern Wyoming. These persistent beds are used as datum horizons for structural mapping and in the construction of isopachous maps.

Where characteristic beds can be followed, facies changes and changes in thickness between them may be interpreted with some degree of accuracy. Thin beds of limestone, anhydrite, bentonite, and volcanic ash, which are persistent over wide areas, may serve as excellent time-marker horizons. A bed of volcanic ash may be deposited in as little time as a few hours and would serve as an absolute time plane. Thin chert layers in the Morrison Formation (Jurassic), possibly altered volcanic ash beds, may represent fallout that was incorporated into the sediments. These thin beds, which may be traced over large parts of Colorado, Utah, Wyoming, Kansas, and New Mexico, serve as excellent reference horizons in this part of the geologic section. Bentonite beds are particularly valuable for correlation in Cretaceous formations; one, of pronounced persistency in the Graneros Shale (Upper Cretaceous), is known as the "bentonite marker bed" because it can be recognized on electric logs in Kansas, Nebraska,

* For the most part, the nomenclature used in this report follows that compiled in chart form by Jewett (1959). Where nomenclature on this chart differs from that recognized previously by the Kansas Survey, the usage presented by Moore and others (1951a) is followed unless subsequent changes were made following proper stratigraphic nomenclature procedure. In a few instances other nomenclature is used, especially where it is deemed more suitable than present usage. Almost all these exceptions involve usage differing from classification developed solely from surface data of limited scope. These differences in nomenclature are discussed and explained wherever they are introduced.

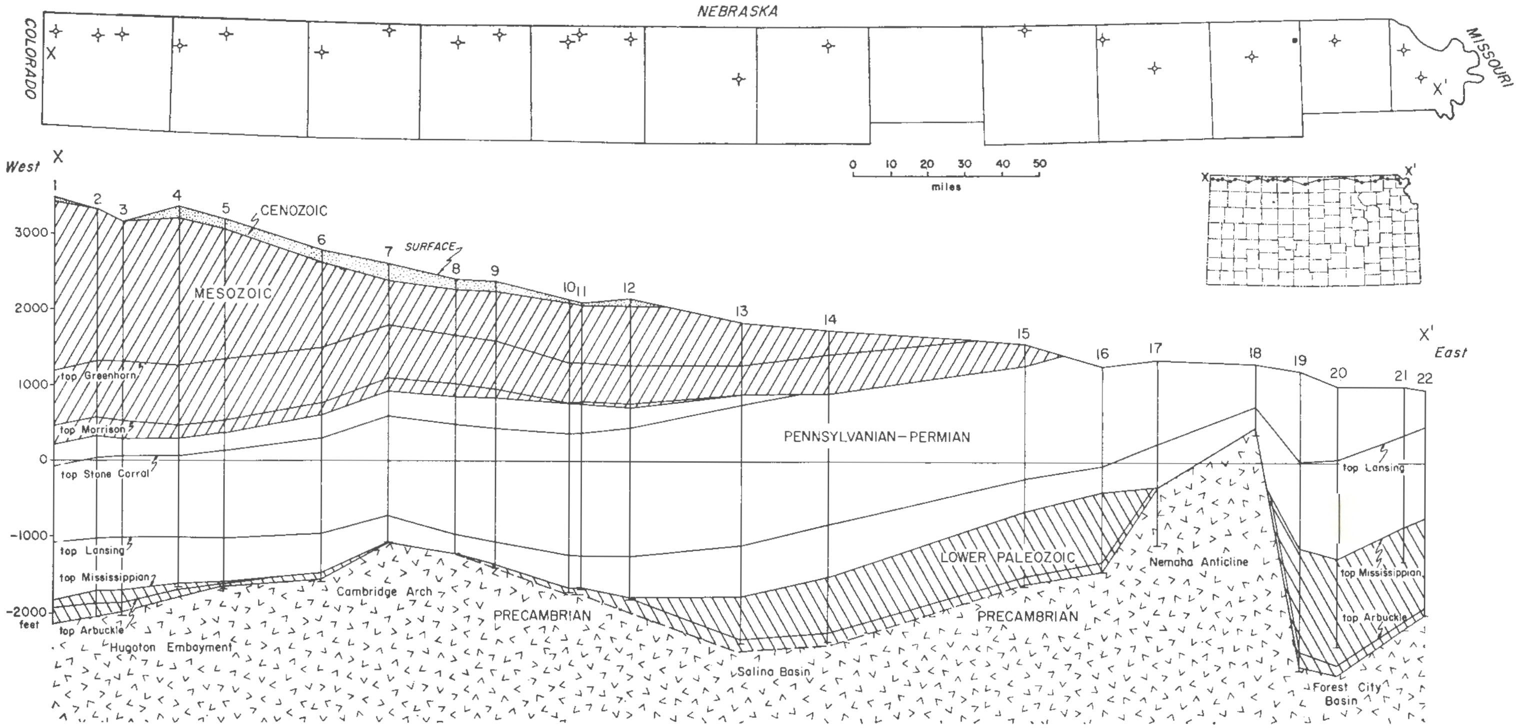


FIGURE 3.—West-east cross section from Cheyenne County to Doniphan County showing stratigraphic relation of major units (from Merriam and Hambleton, 1956). Numbers refer to wells listed in Appendix F.

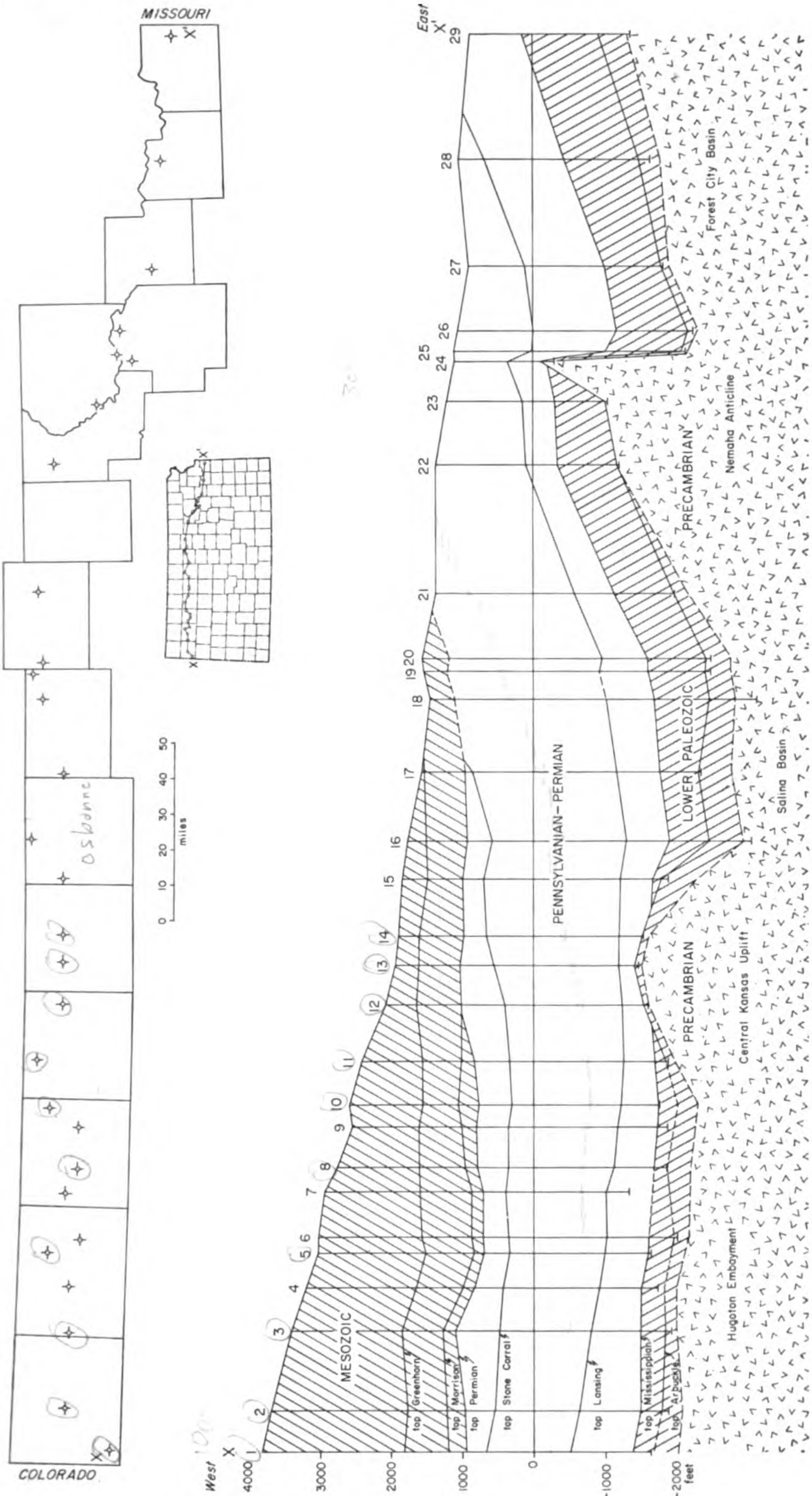


FIGURE 4.—West-east cross section from Sherman County to Johnson County showing stratigraphic relation of major units in Kansas (from Merriam and Hambleton, 1959).

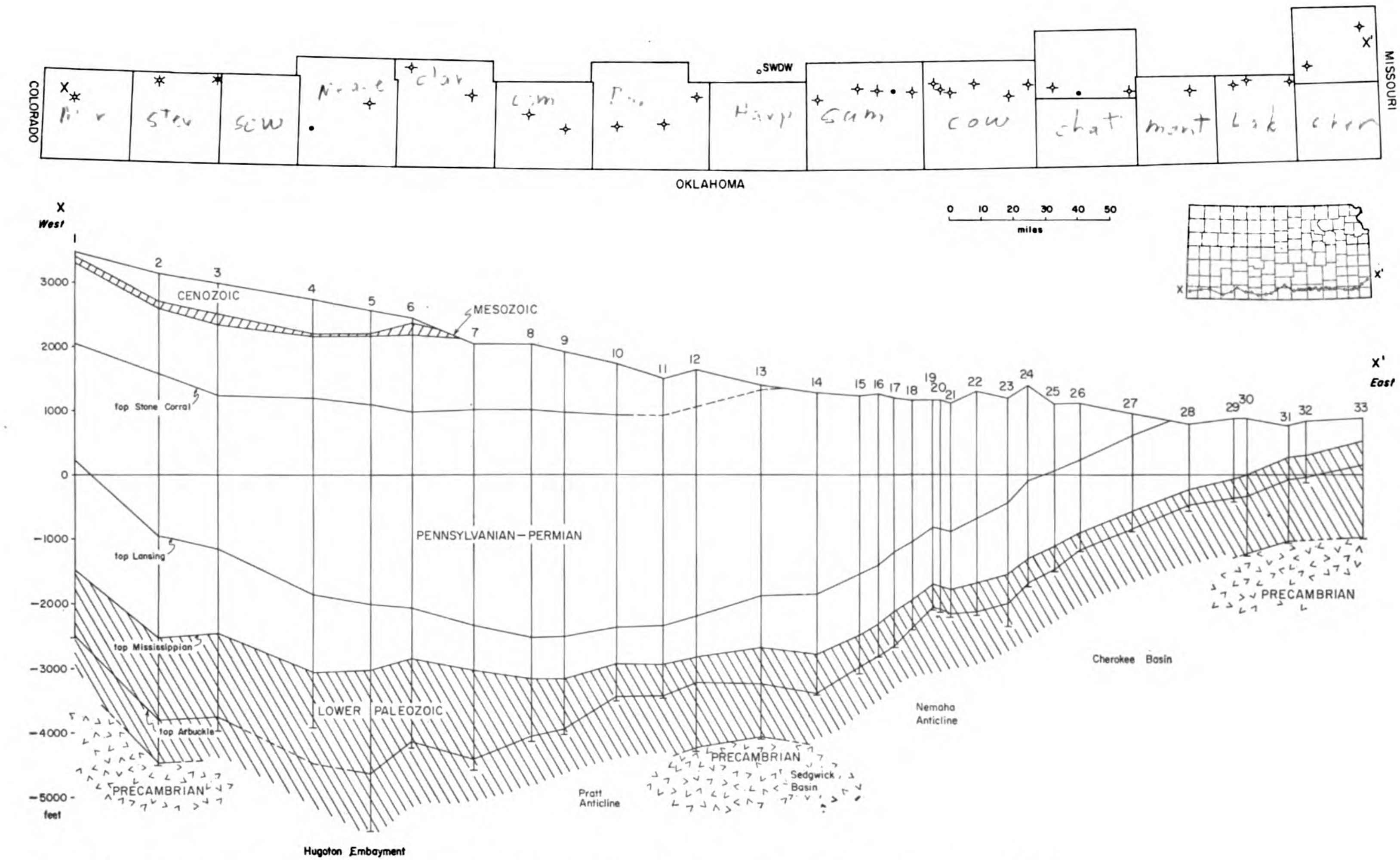


FIGURE 5.—West-east cross section from Morton County to Crawford County showing stratigraphic relation of major units in Kansas.

Colorado, and possibly Wyoming. Thus, where there are rapid facies changes and marker beds persist through the changes, it is possible to correlate rocks of equivalent age but unlike lithology.

Many other sources of data, in addition to electric and radioactivity logs, have been utilized in this study. Of considerable importance are sample logs prepared from cuttings of rotary and cable-tool wells. In addition to samples examined by me, sample logs prepared by other geologists are available in the Kansas Survey. Many excellent sample logs prepared by Wallace Lee and his associates were of particular value in the study of Mississippian and older units. Logs of the Kansas Sample Log Service were indispensable. Logs prepared by drillers and subsurface stratigraphic markers ("formation tops") reported by oil scouts were used where necessary.

Information available for the western part of the state is very satisfactory, but that for the eastern part is not. Although exploration and exploitation have been conducted in eastern Kansas for almost a century, and thousands of tests have been drilled, surprisingly little information is available. Moreover, what is available is generally incomplete, inaccurate, or unreliable. The only information available for most wells is a drillers log. Most of these logs, especially for the older wells, are too brief to be useful. Commonly, formations are described only as lime, shale, and sand; however, such lithologies as soapstone, mud, marble, slate, marl, gumbo, fire clay, and shells are occasionally encountered. More vivid formational descriptions include: broken lime, gray shale, red rock, muddy shale, sloppy sand, big shale, lime shells, and dead sand. Examples of the ultimate in detailed rock descriptions on drillers logs are "black sticky shale," "firm white lime," "light oil sand," and "flinty sharp limestone." Obviously, on the basis of information such as this, only key units can be recognized. Others can be recognized from their stratigraphic position in the sequence, although not always with certainty.

It is sometimes impossible to determine the exact location of a well. The sites of many wells are recorded only as to section in a township, and in many old producing areas it is impossible to tell whether one well or several are involved. Determining the surface elevations of well sites presents another problem. Most logs in eastern Kansas do not record elevation, because it is rarely surveyed. As a result, the geologist must compute a well elevation, which may be approximately correct, and, hoping that the well is located in the right place, he uses a drillers log for guessing the depth of key formations penetrated. From such data, duly calculated and plotted, he contours a phantom horizon. The difficulties referred to may be slightly exaggerated, but they should be kept in mind when evaluating subsurface maps and sections illustrating geologic conditions in eastern Kansas.

In addition to numerous detailed reports on the stratigraphy, several comprehensive reports have been used, particularly as background for studies of rock nomenclature and classification, as well as for general descriptions; especially helpful were papers by Moore, Frye, and Jewett (1944), Moore and others (1951a, 1952), and Jewett (1959). The Geologic Map of Kansas (Moore and Landes, 1937) was used, with only slight revision, for plotting areal distributions of outcropping formations and groups.

Stratigraphic descriptions are as detailed as necessary for adequate understanding of the rock sequence; consequently, some units as small as members must be discussed, whereas in parts of the column only groups are described. Several units in the column have been singled out for more detailed study than others, and they should serve to indicate the complexity of similar units.

Discussion of the stratigraphy is organized from the top down, that is, from the youngest rocks to the oldest. This is the arrangement with which the subsurface geologist works; units are described in sequence as encountered by the drill.

Cenozoic Rocks

Cenozoic deposits cover extensive areas in Kansas. Locally they attain considerable thickness, and this mantle of mainly unconsolidated material serves to mask the underlying stratigraphy and structure. The Cenozoic deposits are of great economic value, especially because the ground water they contain supplies the state with a large percentage of its water.

Quaternary (Neogene) Deposits

Quaternary deposits are relatively thin and consist of sand, gravel, silt, and clay. They are youngest Neogene in age.

Pleistocene and Recent

The Pleistocene geology of Kansas was not studied in detail because: (1) an excellent compilation was published recently by Frye and Leonard (1952), which is the most comprehensive study on this part of the geologic column;

(2) the Pleistocene is thin, in most places less than 30 feet, except in the southwestern and northeastern corners of the state, where thicknesses may be several hundred feet; and (3) no bed has sufficient continuity to be used as a datum, either for structural or isopachous mapping. The Pearlette Ash is the only bed that is widely distributed and lithologically distinctive (Pl. 1A, 1C). It is a wind-blown and partly water-laid volcanic ash, which was deposited on an irregular surface and thus incorporated into the sediment at topographically different levels, rendering it almost useless as a structural datum.

Pleistocene and Recent deposits in the northwestern part of the state generally consist of loess 2 to 30 feet thick, but loess is considerably thicker in the northeast (Pl. 1D). In southwestern Kansas, along Arkansas River in the vicinity of Great Bend and along Cimarron River in Morton, Stanton, and Seward Counties, eolian sand dune areas are extensive.

Along the present river systems are alluvial deposits, mainly of Wisconsinan and Recent age, underlying floodplains and terrace surfaces. Alluvial fill ranges in thickness to as much as 80 feet at Lawrence and 100 feet at Kansas City in the Kansas River valley (Merriam, 1954). The alluvial deposits of the Pleistocene consist mainly of unconsolidated silt, sand, and gravel, associated with minor but important beds of volcanic ash. Locally the beds are cemented loosely with calcium carbonate and may resemble the "mortar beds" of the older Ogallala Formation.

Thick deposits of glacial origin, restricted to northeastern Kansas, are composed of glacial till, of Kansan and Nebraskan age, and alluvial and outwash material (Pl. 1B). The Pleistocene deposits may attain thicknesses of several hundred feet, overlying bedrock of Pennsylvanian and Permian age.

Frye and Leonard (1952, pl. 1) have shown the generalized distribution of the Pleistocene sediments in Kansas and have discussed in some detail the stratigraphic relations of these deposits.

Tertiary (Neogene) Deposits

Tertiary deposits in Kansas are all of Neogene age and are represented solely by the Ogallala Formation. They are similar to Quaternary deposits, and in several areas, notably southwestern Kansas, it is extremely difficult to differentiate them.

Pliocene

OGALLALA FORMATION

The Ogallala Formation was named by Darton in 1899 from outcrops in Keith County, Nebraska. These beds had previously been referred to as part of the Loup Fork Formation, now an obsolete term. Darton considered the Ogallala to be equivalent, at least in part, to the "mortar beds," "tertiary grit," and "magnesia beds" of Kansas. In 1905, and again in 1920, he used the name for deposits of approximately the same age extending over most of the Great Plains. Before the name Ogallala (sometimes misspelled "Ogalalla") was proposed, the terms "Tertiary grit" and "Plains marl" had been used by some of the early workers in Kansas, such as Mudge (1874), Hay (1885, 1890, 1895), and Haworth (1897a, 1897b).

Since the work of Darton, there have been several notable publications on the Ogallala, including those by Elias (1931, 1932, 1942), Smith (1940), and Frye, Leonard, and Swineford (1956). The latter two contain extensive bibliographies. In addition to these papers, the Kansas Survey has issued many ground-water reports on central and western Kansas counties, many of which include data on the Ogallala Formation.

DISTRIBUTION.—Distribution of the Ogallala Formation in the Great Plains is shown in Figure 6; a similar map was published by Hesse in 1938. The outcrop belt parallels the Rocky Mountains for more than 800 miles, from South Dakota on the north to central Texas on the south, and is almost 400 miles wide in places. The Ogallala is present in parts of South Dakota, Nebraska, Kansas, Oklahoma, Texas, New Mexico, Colorado, and Wyoming. The easternmost known outliers of the formation are in McPherson County, Kansas, and Seward County, Nebraska.

In Kansas the Ogallala covers much of the western one-third of the state. Along the eastern margin of the outcrop, streams have eroded the relatively loose-cemented deposits, exposing Cretaceous strata in the valleys. As an example, erosion by Smoky Hill River has almost severed the continuous outcrop near the Colorado-Kansas border. Excluding the numerous small outliers of "Algal limestone," several outlying Ogallala areas are of notable size, for example, in McPherson, Smith, Osborne, Pratt, Kiowa, and Barber Counties, Kansas, and in eastern Colorado (Fig. 6). These, of course, indicate that the formation was once more widespread in Kansas than at present (Merriam, 1955d).

Outliers of "Algal limestone" found in Lincoln County (Berry, 1952, p. 31) may be described as typical. Exposures of the "Algal" unit, overlying weathered Greenhorn Limestone or Carlile Shale, were found at 12 localities in the county, ranging in thickness from a few

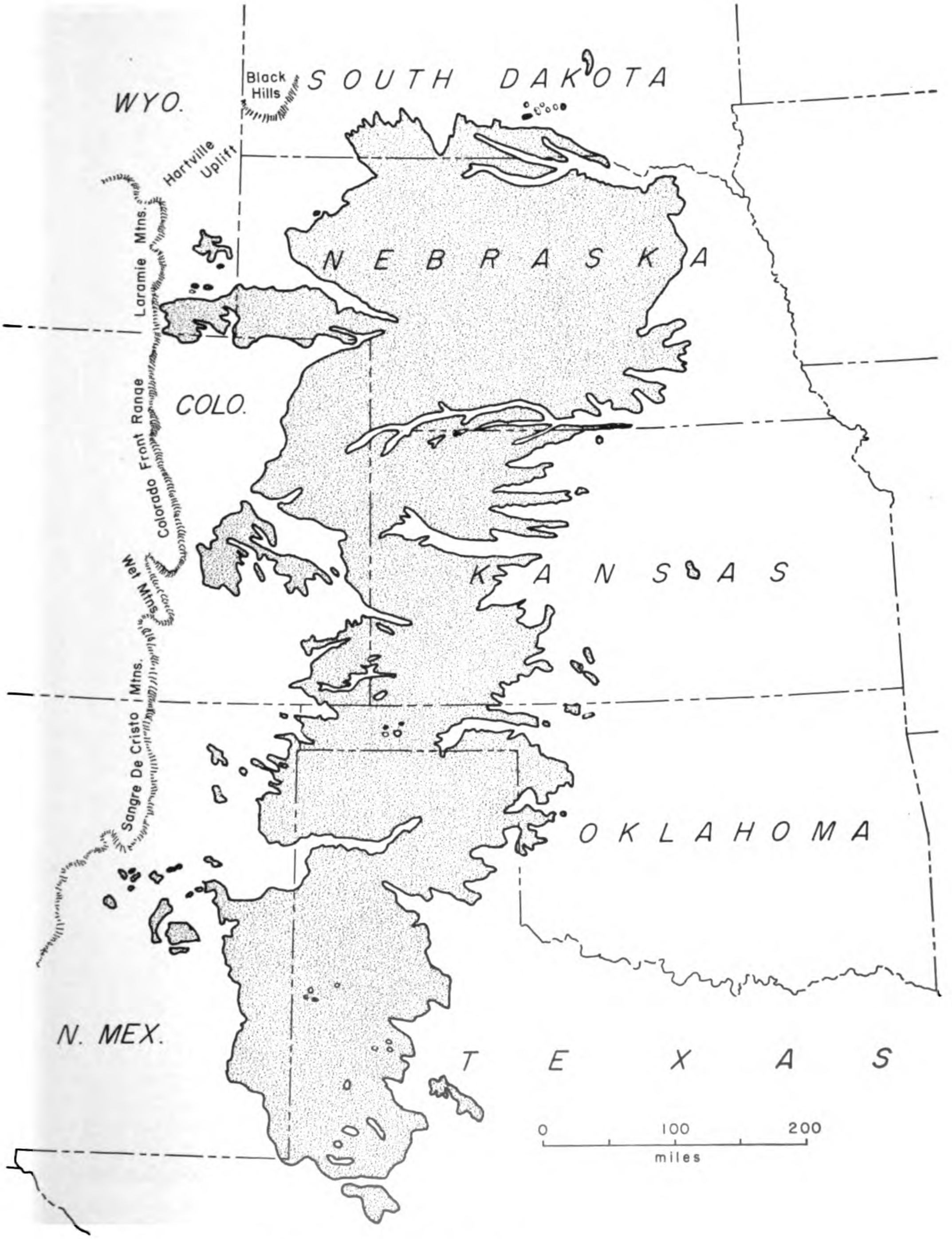


FIGURE 6.—Distribution of Ogallala Formation in Great Plains.

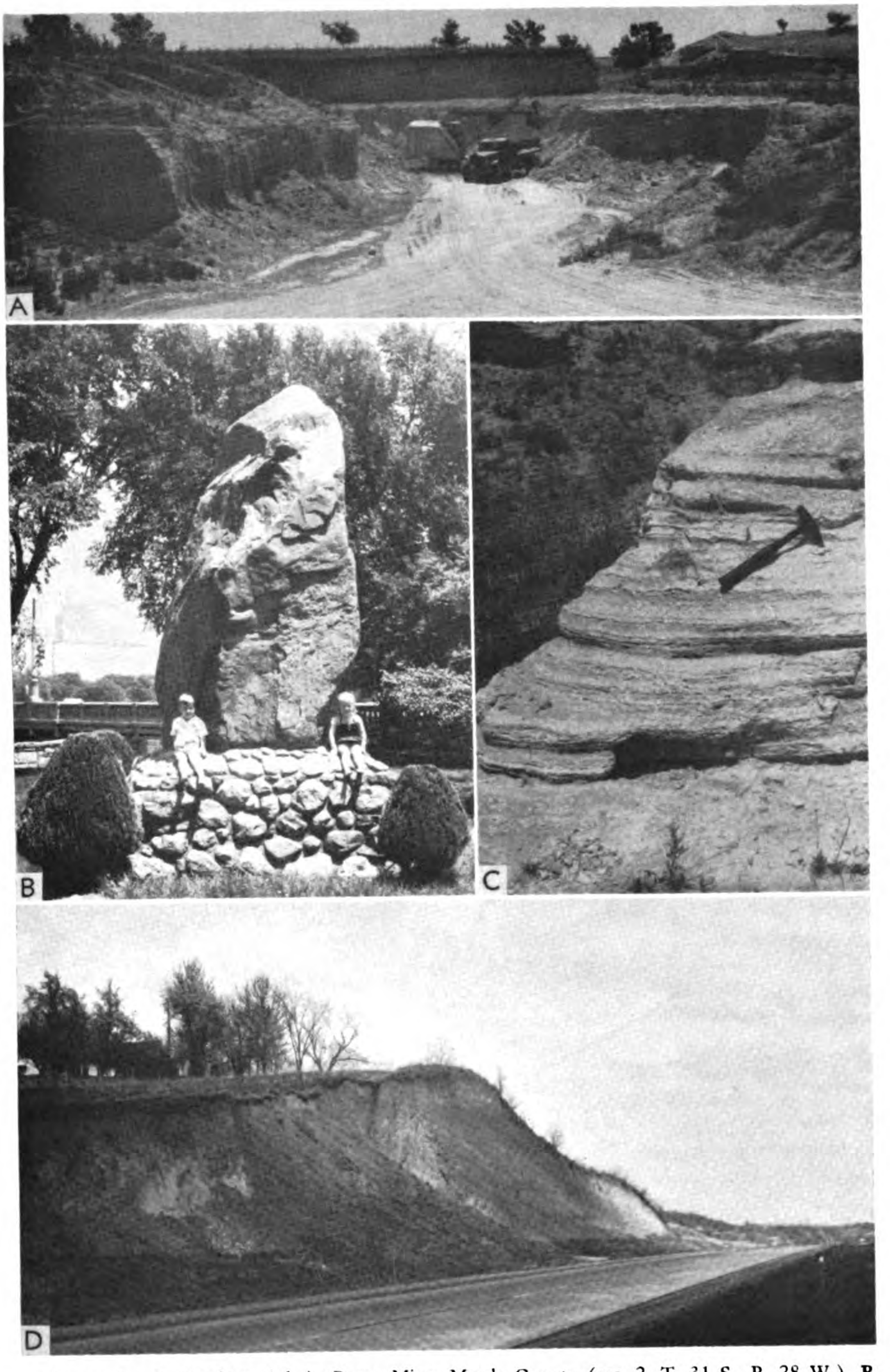


PLATE 1.—**A**, Pearlette Ash in Purex Mine, Meade County (sec. 2, T. 31 S., R. 28 W.). **B**, Glacial erratic of Sioux Quartzite in city park at 6th and Massachusetts Streets, Lawrence. **C**, Bedded Pearlette Ash in Purex Mine, Meade County. **D**, Loess deposit just west of Kansas City on Kansas Turnpike.

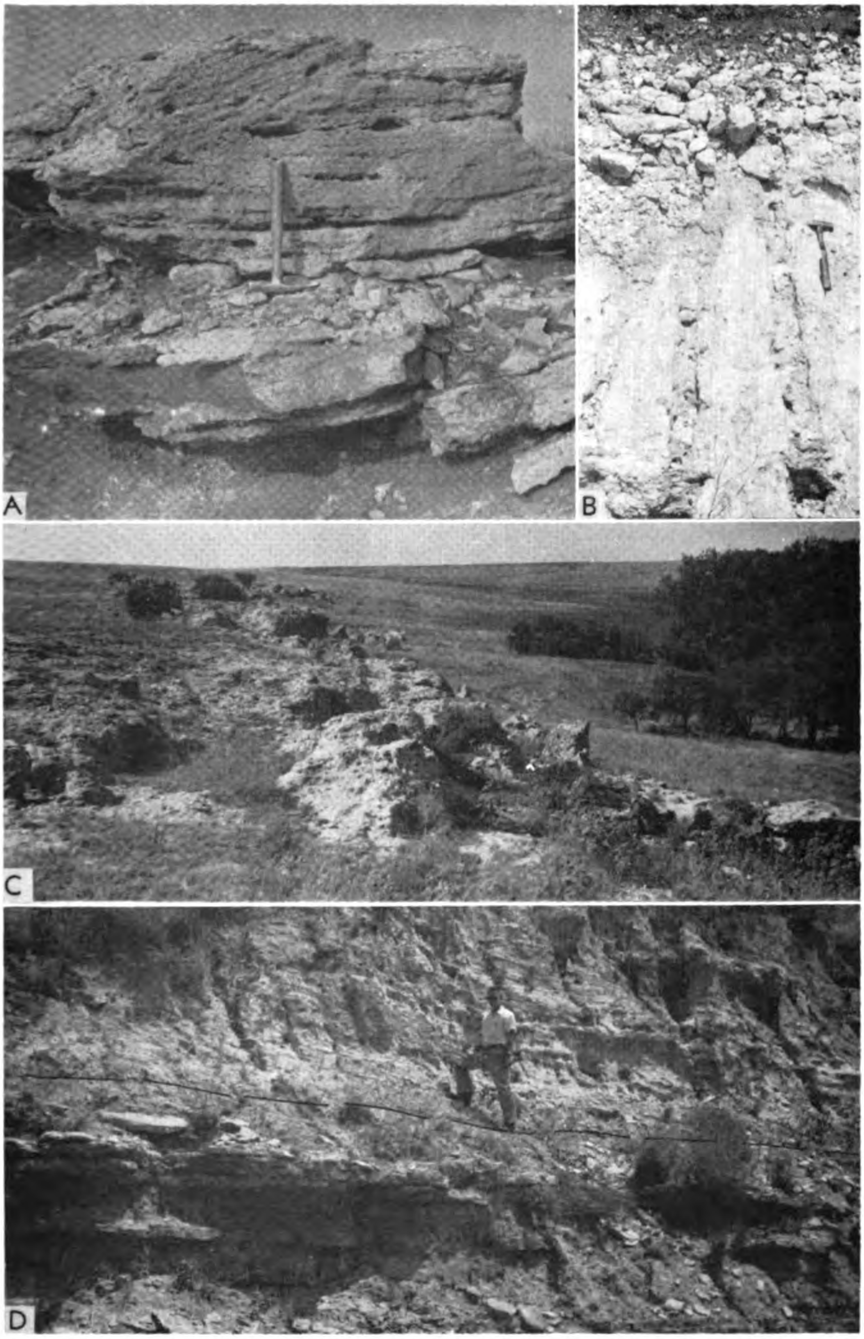


PLATE 2.—**A**, Siliceous Ogallala Formation about 3½ miles south of Glade, Phillips County. **B**, Nodular pisolitic limestone overlying Ogallala sand and silt above Kiowa Shale in Rice County (N2 sec. 27, T. 19 S., R. 10 W.); photo by Ada Swineford. **C**, "Mortar beds" in Ogallala Formation on Five Mile Creek, Ford County. **D**, Ogallala overlying Kiowa Shale (man standing on contact) near Clark County State Lake, Clark County (sec. 36, T. 30 S., R. 23 W.).

inches to about 2 feet. The bed consists of "pink-white or gray-green limestone containing concentrically banded structures" (Berry, 1952, p. 30). Many of these thin and small outliers of the "Algal limestone" occur east of the main outcrop of the Ogallala Formation.

CHARACTER.—The Ogallala Formation in Kansas is divided into three members (in descending order): Kimball, Ash Hollow, and Valentine. In Nebraska the term Ogallala is used as a group and is divided into four formations (in descending order): Kimball, Sidney, Ash Hollow, and Valentine. Boundaries between members are indistinct; subdivisions of the formation are recognized mainly on the basis of fossil seeds.

The Valentine, named by Barbour and Cook (1917; see Lugn, 1939, p. 1260) from exposures near Valentine, Nebraska, constitutes the lowest member of the formation. In Kansas it consists mostly of unconsolidated sands and gravels, but in many places it is cemented by silica (Pl. 2A), forming green opaline sandstone (Frye and Swineford, 1946). Also present in this member are some beds of soft, fresh-water limestone, bentonite (especially at the base), and volcanic ash. The overall color is greenish gray and gray. The Valentine is locally as much as 100 feet thick in Kansas.

The type section of the Ash Hollow Member is along Ash Hollow Canyon in the North Platte River valley, Keith County, Nebraska. This member was first named by Engelmann in 1876 (see Lugn, 1939). It consists of sand, gravel, and silt, and in many places is loosely cemented by calcium carbonate to form "mortar beds" (Pl. 2C). Fresh-water limestone and relatively large amounts of volcanic ash are found also. The ash occurs in at least ten separate beds, six of which have been given formal names (Swineford, Frye, and Leonard, 1955). The predominating colors are pink and gray. Thickness of the Ash Hollow in Kansas is as much as 130 feet.

The Sidney, which has not been given member status in Kansas, is found as lenticular gravels in some localities at the base of the Kimball Member. The type section is just north of Sidney, Nebraska (Lugn, 1939).

The uppermost member, the Kimball, receives its name from Kimball County, Nebraska (Lugn, 1939). In Kansas it consists of calcareous sand, gravel, and silt, as well as minor amounts of opaline chert and caliche. The color is mostly very light gray. Locally developed at the top of the member is the "Algal limestone" (Pl. 2B), a dense, sandy limestone showing concentric layering; it is sometimes called the "capping limestone" or "cap rock."

The "Algal limestone" was so named by Elias (1931) because of the presence of structures that he thought closely resembled the fossil alga *Chlorellopsis bradleyi*. The exact origin of the limestone, however, has been a subject of controversy ever since Elias first suggested that it was formed in an extensive lake that he postulated to have covered a large part of the High Plains area of Kansas (Merriam and Frye, 1954, p. 55). Alternate hypotheses as to its origin have included development as soil caliche on the alluvial plain, and in a series of disconnected water-table lakes judged to have existed in abandoned channel segments and "back-swamp" areas on the initial eastward-sloping constructional surface (Frye, 1945a). Swineford, Leonard, and Frye (1958) maintained that the bed developed mainly as a result of inorganic soil-forming processes, and they cited evidence that the rock is not algal in origin. Thus the question of origin of this limestone bed is not settled. Regardless of its origin, the stratigraphic position of the bed is unquestioned. A list of "Algal limestone" localities in Kansas is given in Appendix A.

THICKNESS.—Between Smoky Hill and Republican Rivers in northwestern Kansas the Ogallala has a maximum thickness of 300 feet, known from subsurface test-hole information. Figure 7 shows the thickness of the Ogallala Formation in northwestern Kansas, north of Hamilton, Kearny, and Finney Counties. Because both the upper and lower contacts are erosional, the thickness of the formation is very irregular. In southwestern Kansas the thickness may be as much as 600 feet, but the upper and lower limits of the formation in this part of the state have not been determined; therefore, no isopachous map was attempted.

Cardwell (1953) has reported that the thickness of the Ogallala in parts of Cheyenne, Kit Carson, and Lincoln Counties, Colorado, ranges from a featheredge to several hundred feet. The "Algal limestone" in this area ranges from 2 to 3.5 feet in thickness and is remarkably uniform. His map shows configuration of the erosion surface developed on the Pierre Shale in the area. According to McLaughlin (1954), the thickness of the Ogallala Formation in Baca County, Colorado, ranges from a featheredge to about 260 feet. According to Lugn (1939, p. 1264), thickness of the Ogallala in Nebraska ranges from 0 to 500 feet.

STRATIGRAPHIC RELATIONS.—The Ogallala was deposited on a surface of moderate relief by eastward-flowing streams. Deposits gradually filled

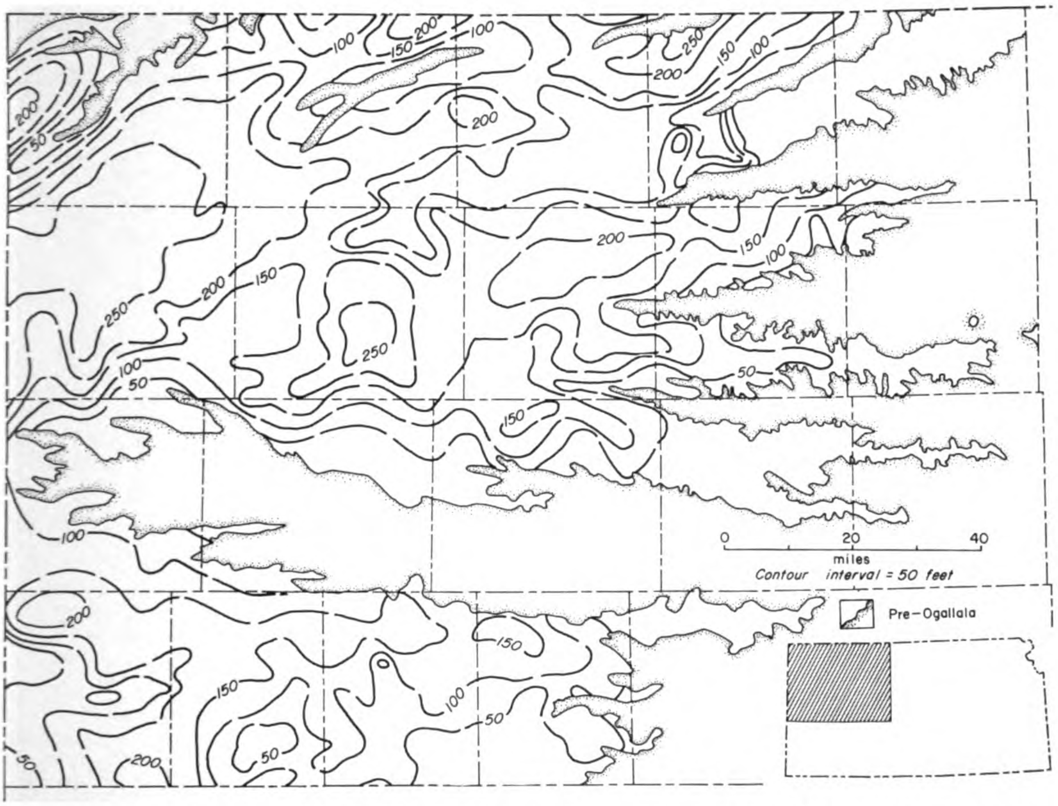


FIGURE 7.—Isopachous map of Ogallala Formation in northwestern Kansas. Outcrop has been intricately dissected by westward-heading streams and almost severed in Kansas by Smoky Hill River in Wallace, Logan, and Gove Counties.

the pre-Ogallala valleys, and, near the close of deposition, sediments merged across former bedrock divides and coalesced to form a plain of alluviation (Merriam and Frye, 1954, p. 55). It was on this surface that the "Algal limestone" was deposited.

Figure 8 shows a stratigraphic cross section of the Ogallala Formation from Scott County to Cheyenne County, Kansas; the datum is top of the "Algal limestone." Where the "Algal" has been removed by post-Ogallala erosion, the original thickness was estimated. Because this cross section is approximately at right angles to the direction of stream flow that deposited the formation, it shows nicely the stratigraphic relations of the Ogallala to the older bedrock. It can be seen that the Ogallala deposits first filled the pre-Ogallala valleys and then coalesced over the bedrock divides. Correlation of any beds in the sequence, except the "Algal limestone," is extremely difficult beyond short distances. Part of the difficulty in correlation is probably caused by variations in the deposits produced by lateral shifting of streams in the valleys.

After uplift of the territory west of Kansas near the end of the Pliocene, streams began to incise the soft Ogallala sediments. In places in southwestern Kansas the Ogallala was eroded to a depth of nearly 500 feet. These valleys later were filled with Pleistocene deposits, mainly reworked Ogallala sediments, which subsequently were partly eroded.

The restored thickness of the Ogallala Formation is indicated in Figure 9. This is a convergence map constructed by superimposing structure on top of the "Algal limestone" on pre-Cenozoic bedrock topography. This should show the original thickness of the formation, if deposition had proceeded to the extent that the "Algal limestone" covered the entire area. It is

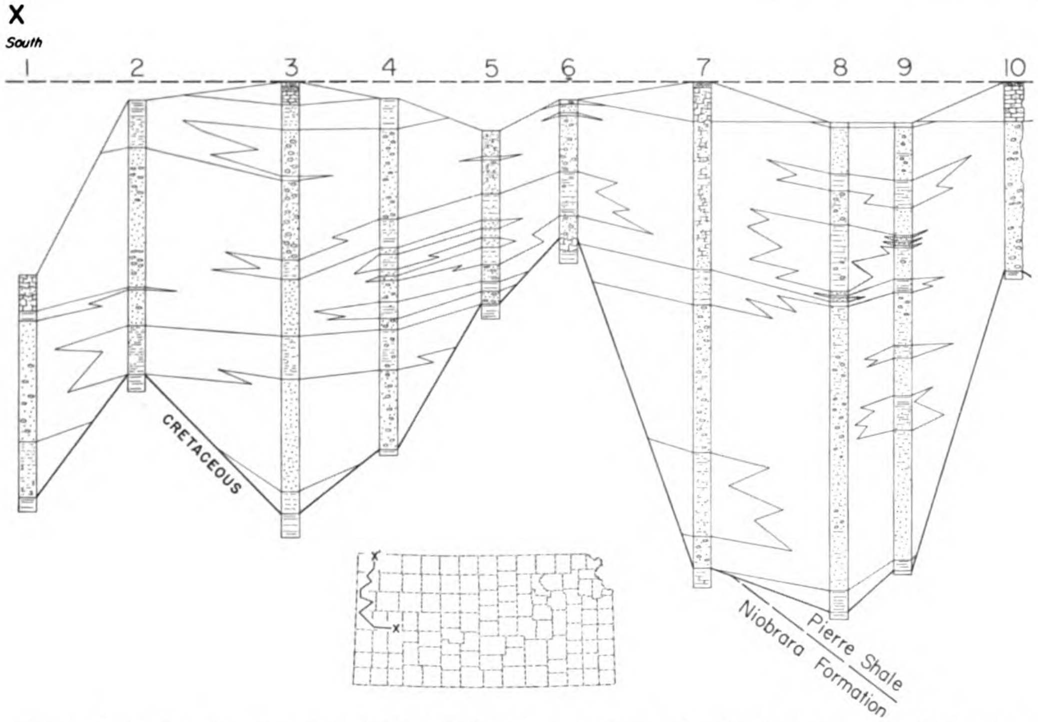
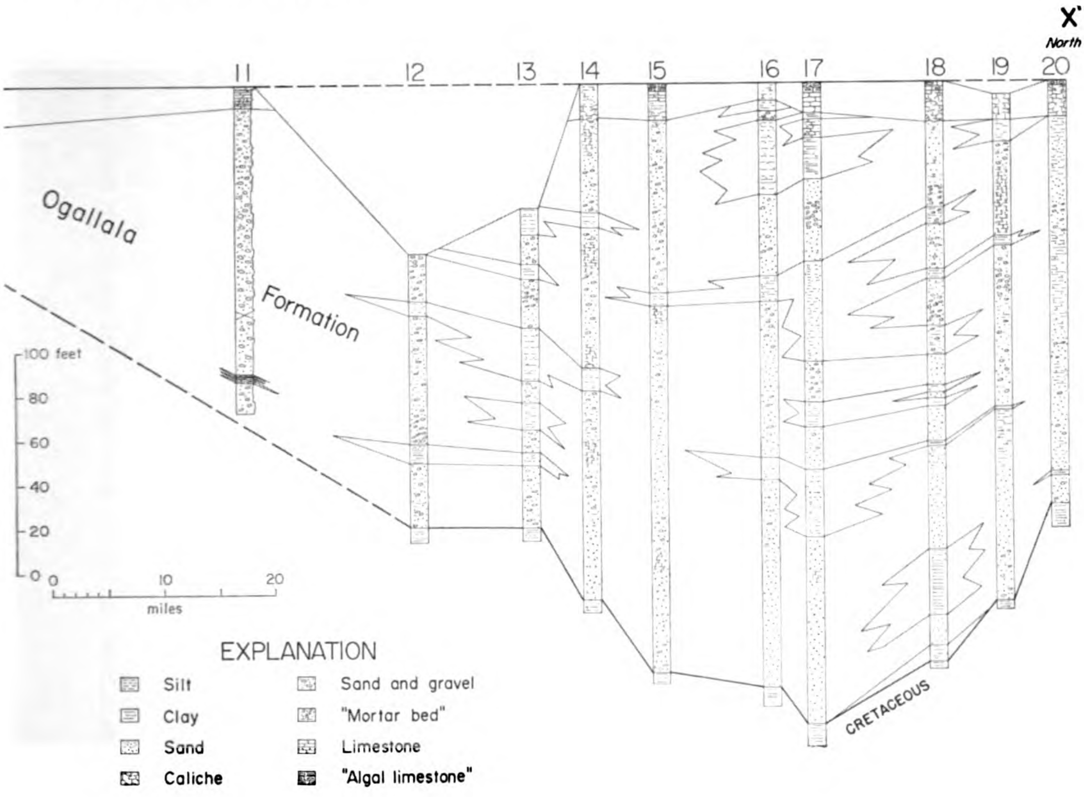


FIGURE 8.—South-north cross section from Scott County to Cheyenne County showing general lithology and stratigraphic relation of beds of Ogallala Formation in western Kansas. Note topographic relief on pre-Ogallala surface and lenticularity of individual beds. Datum: top "Algal limestone."

probable, however, that the "Algal" never constituted a continuous bed. Originally the maximum thickness of the formation may have been more than 800 feet in southern Seward and Stevens Counties. It is possible that some of the sediments are Miocene in age, but the absence of observed fossils in samples makes this impossible to determine. Several prominent bedrock "highs" (including one extending east-west just north of the present Smoky Hill River, another in Wichita County, and a third in Greeley County) also are shown in Figure 9.

In southwestern Kansas determination of the relationship between Pleistocene and Pliocene sediments is a difficult problem, especially in the subsurface. It is almost impossible to recognize the boundary between them in well samples, and difficult even on the outcrop, where exposures are poor. This difficulty can be attributed to the lack of discovered fossils in samples and to the fact that the lithology of much of the Pleistocene is nearly identical to that of the older Ogallala Formation, from which much of it was derived. In 11 southwestern Kansas counties—Stanton (Latta, 1941), Morton (McLaughlin, 1942), Hamilton and Kearny (McLaughlin, 1943), Finney and Gray (Latta, 1944), Grant, Haskell, and Stevens (McLaughlin, 1946), Kiowa (Latta, 1948), and Seward (Byrne and McLaughlin, 1948)—the Pleistocene and Pliocene were undifferentiated or separated questionably on the basis of sample logs of ground-water test wells. Schoff (1939, 1943) also had difficulty in separating with certainty the Pleistocene and Pliocene deposits in well samples in Texas and Cimarron Counties, Oklahoma.

Elias (1948), on the other hand, has cited several criteria for differentiating the Ogallala from post-Ogallala (Pleistocene) deposits. Among these are observations that: (1) the Ogallala contains some cementing calcium carbonate, whereas Pleistocene deposits are mostly noncalcareous; (2) silicified seeds are present in the Ogallala but unknown in the Pleistocene except by redeposition; (3) post-Ogallala sediments are distinguished by a content of unctuous clays; and (4) Pleistocene deposits are characterized by the occurrence in many places of shells of snails and clams, which are rare or lacking in the Ogallala. At the same time, Elias has noted that in the



northeastern Great Plains the division between Pliocene and Pleistocene is difficult to recognize. The description by Frye, Leonard, and Swineford (1956) of a molluscan faunal succession in the Ogallala seems to indicate that Elias' fourth criterion is no longer valid. The first criterion may not be everywhere usable, because the Pleistocene deposits may be locally loosely cemented with calcium carbonate (see Frye, 1948). Where the "Algal limestone," the recognized top of the Pliocene deposits in Kansas, is present, the difficulty is resolved.

ENVIRONMENT OF DEPOSITION.—Smith (1940) thoroughly discussed the origin of the Ogallala Formation, and the following are some important conclusions resulting from his study: (1) the Ogallala was deposited as a warped and dissected piedmont alluvial plain; (2) sedimentary materials were derived mainly from the Rocky Mountain region; (3) deposition of the Ogallala was mainly of channel and floodplain type, whereas eolian deposition was of minor importance; and (4) cause of deposition was a combination of climatic change and tectonic factors.

Figure 10 is a clastic-ratio map of the Ogallala Formation. At first glance, distribution of clastic and nonclastic materials appears to be very irregular; a vaguely discernible pattern, however, reveals several interesting features. North of the present Smoky Hill River valley the trend of coarser clastic materials is in a northeast direction. No pattern indicates any single former stream valley, possibly excepting one in Cheyenne County. In this part of Kansas elongation of the coarser clastic areas indicates that drainage was northeastward in Ogallala time. South of Smoky Hill River valley in Greeley, Wichita, and Scott Counties, the pattern of clastic distribution indicates a western source of the material. South of a line drawn along the north side of Hamilton, Kearny, and Finney Counties, the coarse clastic material is concentrated in a belt trending southeastward, reaching to Meade County in an area now known as the Meade Artesian Basin. This distribution seems to indicate that Ogallala streams in southwestern Kansas flowed southeastward and that the source of material carried by them was to the west and northwest in Colorado.

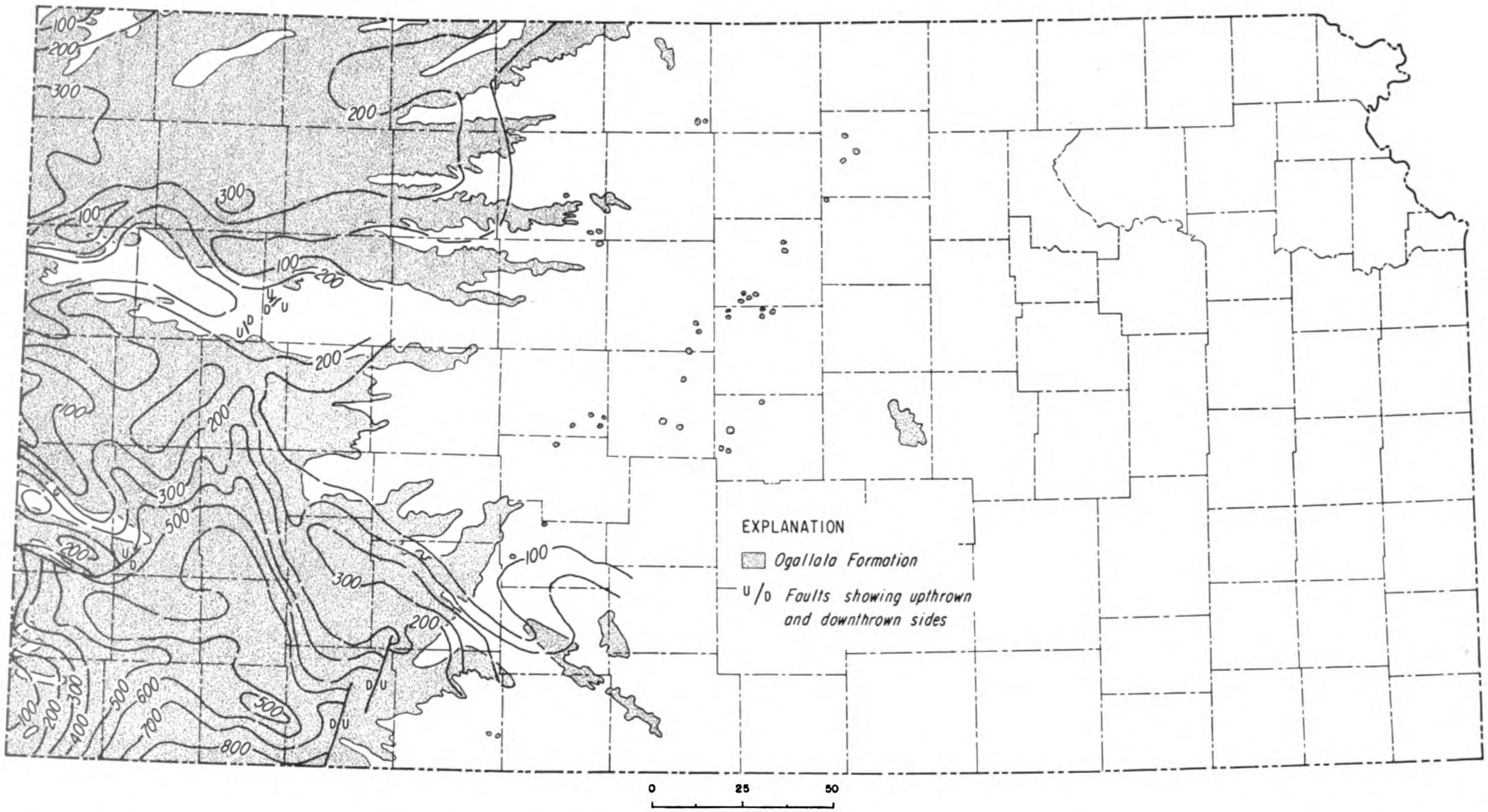


FIGURE 9.—Convergence map showing restored thickness of Ogallala Formation from top of "Algal limestone" to top of Mesozoic bedrock. Crooked Creek, Fowler, Syracuse, Elkader, and Monument Rocks Faults are shown. Contour interval 100 feet.

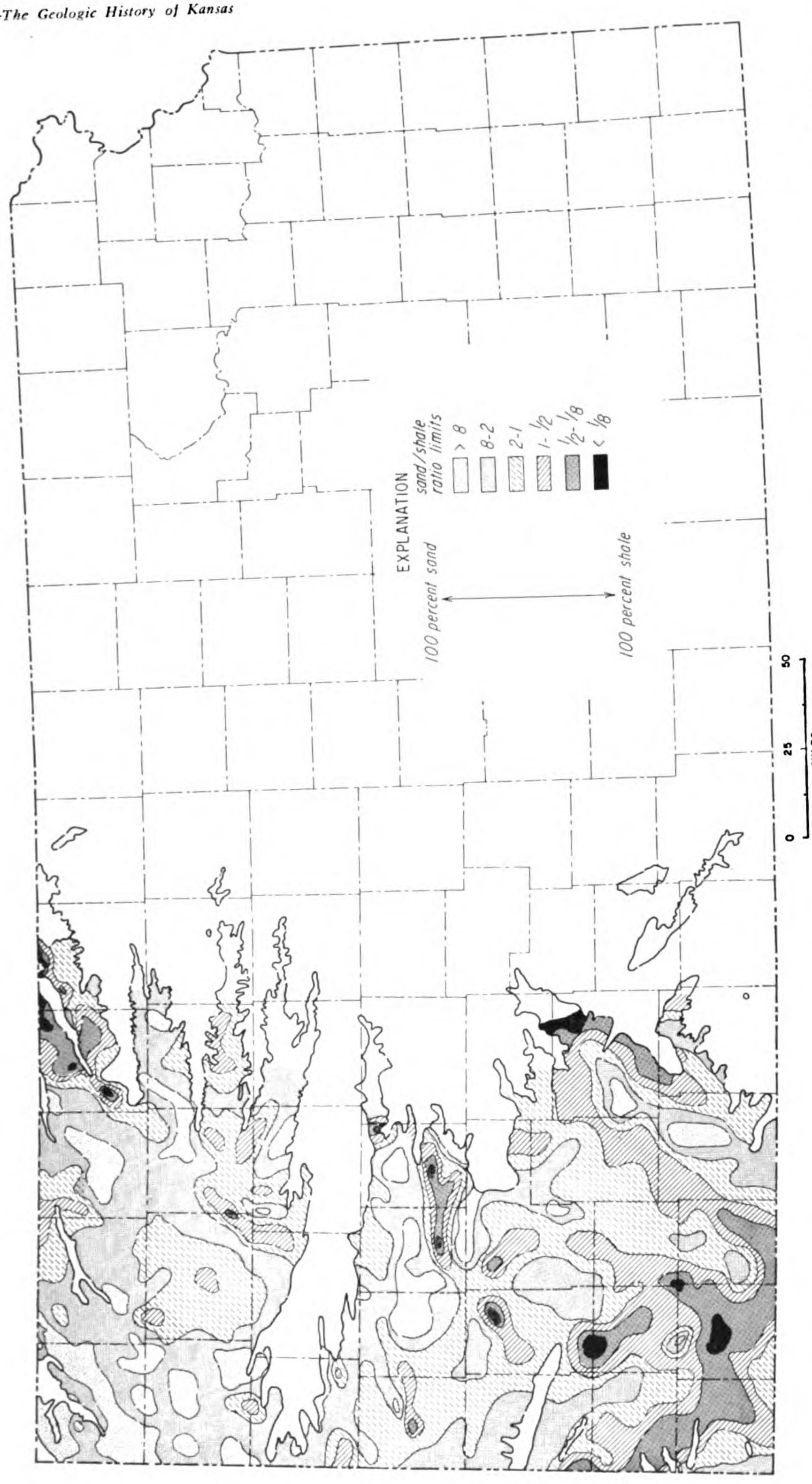


FIGURE 10.—Map of Kansas showing clastic ratio limits of sediments in Ogallala Formation (Pliocene). Note elongated areas of coarser clastics, which indicate general areas of channel deposition.

The described pattern is very similar to that of present-day streams of the region and to the distribution of the Ogallala Formation as shown by Smith (1940, p. 81). This pattern of semi-radial drainage diverges from an area in east-central Colorado that is a pronounced physiographic "high" not far east of the Front Range.

The clastic-ratio pattern, in general, shows the distribution of major drainage systems during deposition of the Ogallala Formation, and it indicates that the main streams were remarkably similar in geographic location to older channels cut on the pre-Cenozoic bedrock surface (Fig. 11). Because the pre-Cenozoic topographic bedrock map and the clastic-ratio map of the Ogallala, as well as present drainage, indicate a stable drainage pattern, it is believed that the physiographic "high" east of the Front Range in Colorado existed at least as early as the end of Miocene time. This conclusion agrees with that reached by Smith (1940). Nevertheless, it is probable that the area west of Kansas was upwarped and its eastward slope accentuated by post-Ogallala uplift. If the conclusions just stated regarding Pliocene drainage patterns are correct, any Ogallala sediments derived directly from the Rocky Mountains could have been deposited only in the southwestern part of Kansas, because Arkansas River is the only Kansas drainage system heading in the mountains proper. Streams flowing through northwestern Kansas originate east of the mentioned physiographic "high," indicating that materials of the Ogallala Formation in this area must have been derived from areas east of the Rocky Mountains.

AGE AND CORRELATION.—The age of the Ogallala is Pliocene, as shown by the vertebrate and molluscan fauna and the flora. Wood and others (1941) have interpreted the Ogallala as late Sarmatian, Pontian, Plaisancian, and earliest Astian, in terms of European Cenozoic stages.

In eastern Colorado the equivalent of the Ogallala is the Nussbaum Formation, which Gilbert (1897) named from Nussbaum Spring, near the south end of Baculite Mesa. The Nussbaum consists chiefly of loosely cemented sand and some silt, but it contains pebble lenses at various levels. It is about 100 feet thick. The Laverne Formation in southwestern Kansas is equivalent to the Valentine Member of the Ogallala Formation (Moore and others, 1951a, p. 20).

Sub-Cenozoic Surface

Before deposition of the Ogallala Formation, Kansas was extensively eroded and rock many hundreds of feet thick was stripped away. Cretaceous sediments were beveled (Pl. 2D), and in central and eastern Kansas completely removed, so as to expose Permian and older rocks. This erosion probably was intermittent, as indicated by local deposition and preservation of lower Tertiary sediments in eastern Colorado near the Rockies. In Kansas, considerable local relief was developed on this erosional surface, which was by no means a peneplain. The configuration of the surface in part of western Kansas is represented in Figure 11.

Subsurface control for this map is almost entirely derived from test holes drilled by the cooperative Ground-Water Division of the State and Federal Geological Surveys. Distribution of these data, although not uniform throughout the region, is believed to be sufficient to permit drawing of 100-foot contours.

Contours drawn on the unconformity at the base of Cenozoic deposits show a composite erosional surface of several ages (Merriam and Frye, 1954). North of Arkansas River, except in Scott and Finney Counties, this is the surface on which the Ogallala Formation was deposited; therefore, it is the surface of subaerial erosion that existed at or near the close of Miocene time. Four major pre-Ogallala valleys are outlined by the contours. The northernmost one extends eastward from southern Cheyenne County through a broad and somewhat indistinct trough to western Phillips County. Farther south, a valley trends eastward from central Wallace County in the approximate position of the present Smoky Hill Valley. A third valley extends east-southeastward from southeastern Wallace County, and a fourth trends southeastward from the southeastern corner of Greeley County. These valleys are separated by bedrock divides.

South of Arkansas River, the only surface that may be safely identified as a predominantly pre-Pleistocene development is in Morton and Stanton Counties and southern Hamilton County, but even here the suggested valleys coincide with the upper reaches of valleys farther east which are known to have been occupied by Pleistocene streams (Merriam and Frye, 1954, p. 57). Therefore, in this region either Pliocene and Pleistocene valleys fortuitously coincide, or Pleistocene erosion removed the Ogallala Formation and incised bedrock as far west as the Colorado-Kansas line.

From Grant and Stevens Counties eastward to Kiowa County the bedrock topography (Fig. 11) is a complex pre-Ogallala surface, which was incised to various depths by at least two episodes of erosion during Pleistocene time. A major southward-trending early Pleistocene valley (Frye and Leonard, 1952) is incised below the

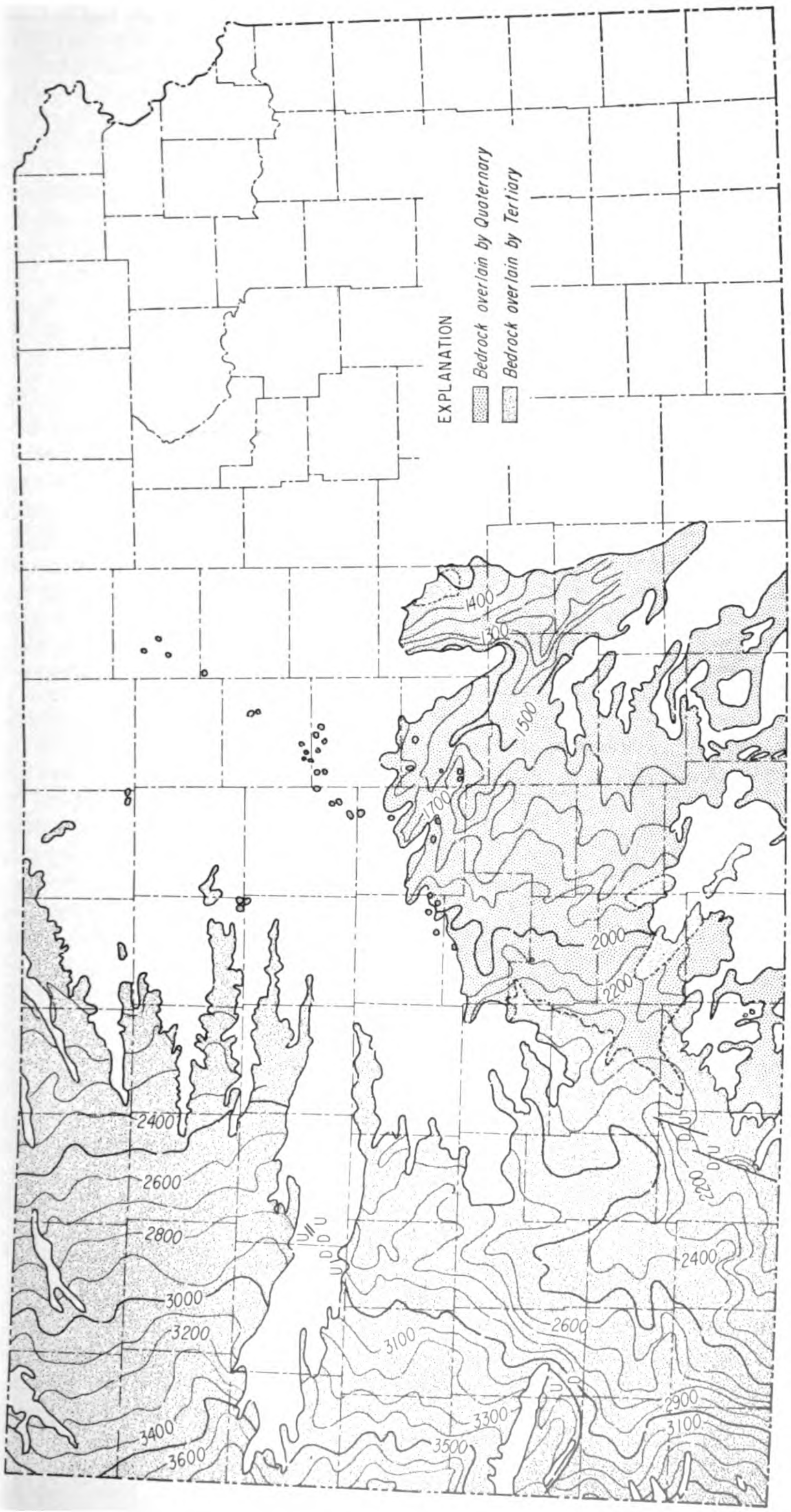


FIGURE 11.—Map showing topography of surface below Cenozoic deposits of western Kansas (adapted from Merriam and Frye, 1954). Contour interval 100 feet.

pre-Ogallala surface southward from central Scott County, and in central Haskell County it is joined by a major tributary from the west. In Meade County the trend of this major valley system is obscured by the Crooked Creek and Fowler Faults. Another major Pleistocene valley extends from eastern Gray County southeastward into northern Comanche County.

A prominent bedrock divide that trends southeastward from northern Ford County across Kiowa County into northwestern Barber County separates the early Pleistocene drainage systems of southwestern Kansas from those of the south-central area, or Great Bend region, Eastward from Kiowa County the bedrock topography was developed, essentially in its entirety, by Pleistocene erosion. In this area the bedrock valley systems have been described by Fent (1950b), and the drainage patterns he indicated generally agree with the features shown in Figure 11. An integrated system of bedrock valleys trends east-southeastward under the region from central Kiowa County to central Reno County, limited on the northeast by a distinct divide, which is roughly parallel to and south of the present position of Arkansas River in Reno County. Northeast of this divide, the prominent Kansan-age McPherson valley and its tributary from the northwest are shown distinctly by the contours (Merriam and Frye, 1954, p. 58).

Mesozoic Rocks

Recently, considerable interest in the rocks of Mesozoic age in western and northwestern Kansas has been aroused by the possibility of finding commercial quantities of oil and gas in them (Merriam, 1958d). Several publications of the State Geological Survey of Kansas have called attention to possible economically exploitable minerals, both fuel and nonfuel, in rocks of Cretaceous age. At present this mineral wealth, except for clay, is not being developed extensively. In addition to the clay, cropping out in Dakota areas (Plummer and Romary, 1947; Plummer and others, 1954), materials that merit attention include lignitic coal in the Dakota (Schoewe, 1952); oil shale of poor quality in the Dakota and Pierre Formations (Runnels and others, 1952); glass sand in the Cheyenne Formation (Nixon and others, 1950; Rose, 1950); bentonite (Kinney, 1942); vanadium in clays (A. C. Reed, 1950); cemented sandstone for concrete aggregate, riprap, building stone, etc., in the Kiowa and Dakota Formations (Swineford, 1947); and chalk in the Fort Hays Member of the Niobrara Formation (Runnels and Dubins, 1949).

Rocks of Mesozoic age in Kansas are recognized as belonging to the Triassic, Jurassic, and Cretaceous Systems. Their relation to each other and to adjoining units is shown in Figures 12, 13, and 14. Triassic rocks are confined to the extreme southwest, in Morton, Stanton, and Hamilton Counties. Redbeds 40 feet thick, exposed in a small outcrop in Morton County, have been correlated (Moore and others, 1951a) with the Dockum? Group of Triassic age, which crops out in parts of Texas and Oklahoma. Jurassic rocks assigned to the Morrison Formation are distributed in the northwestern one-fifth of Kansas west of a line drawn from Smith County to Morton County, and are restricted to the subsurface. Cretaceous strata cover roughly the western one-half of Kansas and include both Comanchean (Lower Cretaceous), chiefly exposed in Clark, Comanche, and Barber Counties, and Gulfian (Upper Cretaceous).

Mesozoic rocks unconformably overlie older Paleozoic rocks and, for the most part, mask the structure of older beds. At different places Triassic, Jurassic, or Cretaceous formations overlie Permian strata. Locally, a conglomerate is developed at the base of the Cretaceous rocks. Over much of the area, rocks of Mesozoic age are in turn unconformably overlain by the Ogallala Formation of Pliocene (Tertiary) age or by Pleistocene deposits. Best exposures of Mesozoic rocks are along the valleys of major streams in western Kansas.

Mesozoic rocks in Kansas are mostly marine deposits consisting of shale, sandstone, limestone, and chalk; but they include also considerable amounts of nonmarine sandstone and clay, and minor amounts of lignitic coal, bentonite, chert, and anhydrite. Several thin beds are important stratigraphic markers. Both megafossils and microfossils are abundant in the marine beds.

Many studies of Mesozoic rocks in Kansas have been published, but they deal mainly with surface exposures and stratigraphic relations of beds seen at the outcrops. Some of the more important early works include reports by Prosser (1897), Logan (1897), Williston (1897), and Adams (1898), which are mainly stratigraphical; papers by Williston (1898) and Logan (1898) are mainly paleontological. In 1920 Darton published a report on the geology of the Syracuse and Lakin Quadrangles, and in 1924 Twenhofel described the geology and invertebrate paleontology of Comanchean and "Dakota" Formations in Kansas. Then, in succeeding years, papers dealing with the geology of different western Kansas counties were published by

Rubey and Bass (1925), Bass (1926), Wing (1930), Landes (1930), Elias (1931), Moss (1932), Elias (1937b), and Landes and Keroher (1938, 1939). In the early 1940s the State Geological Survey of Kansas began issuing a series of reports on the geology and ground-water resources of Kansas counties. These reports, which deal with about 40 central and western counties, have added much to the knowledge of surface geology in this region.

Although a great amount of detailed work on stratigraphy of Mesozoic beds has been published, only a few of the studies are mentioned here. Elias (1931) differentiated members within the Pierre Shale by detailed stratigraphic work; Loetterle (1937) published a mainly micropaleontological paper, and Miller (1958) a stratigraphic study of the Niobrara Formation. Hattin (1962) was able to zone the Carlile Shale; Bergman (1950) traced the Greenhorn Limestone across Kansas. Preliminary work on the Dakota in Nebraska and adjoining states was published by Tester (1929). Plummer and Romary (1942) described the stratigraphy of pre-Greenhorn beds in Kansas and followed this with a detailed study (1947) of the Dakota Formation; Merriam and others (1959) described a Dakota core from Cheyenne County. Loeblich and Tappan (1950) made a micropaleontological study of the Kiowa Shale; Latta (1946) published on the Kiowa Shale and Cheyenne Sandstone of south-central Kansas; Swineford and Williams (1945) described the Cheyenne Sandstone in central Kansas. Merriam (1955a) wrote a report on the Morrison Formation (Jurassic). McLaughlin (1942) described the Dockum? Group (Triassic) in Morton County, and Merriam (1963) described briefly the Triassic rocks in Kansas. Lee (1953) showed correlation of Mesozoic beds along the line of cross section from Meade County to Smith County.

The geologic structure of western Kansas and its development during Mesozoic time are discussed in papers by Darton (1905, 1918), Bass (1926), Lee and Merriam (1954a), Merriam and Atkinson (1955), and Merriam (1955b).

General information on Mesozoic rocks in Kansas can be obtained from Moore and Landes (1937), Moore, Frye, and Jewett (1944), Jewett (1951), Moore and others (1951a), and Merriam (1957b).

*Cretaceous Deposits**

The Cretaceous System is divided into the Comanchean (Lower) and Gulfian (Upper) Series. In each series are recognized groups, formations, and members. The dividing line between the two series is placed at base of the Omadi Formation and top of the Kiowa Shale (Cobban and Reeside, 1952). Distribution of Cretaceous rocks in Kansas is shown in Figure 15.

Total thickness of Cretaceous rocks in Cheyenne County, in the northwest corner of the state, is 3,000 feet. The sequence thins eastward, southeastward, and southward to a featheredge, mainly as a result of truncation by post-Cretaceous erosion of the upper part, but also to some extent by overstep of the lower units onto pre-Cretaceous rocks. The overall shape is wedgelike (Fig. 16).

Because of absence of traceable beds and paucity of fossils in some Cretaceous units, correlation from the surface into the subsurface is extremely difficult, especially for beds between the Kiowa Shale and Graneros Shale, but tentative correlations have been made. It has been necessary to adopt an unofficial terminology for some units in the subsurface until positive correlations can be made. Figure 17 shows present Kansas Survey classification of Mesozoic rocks and their correlation, or tentative correlation, with subsurface units and terminology. The most obvious departure from Kansas Survey usage is in use of the term "Dakota," which is used as a formational term at the surface but is tentatively used as a group name for Cheyenne Sandstone, Kiowa Shale, and Omadi Formation in the subsurface. Another minor difference is that the Codell Sandstone is treated as a member in the Carlile Shale (see Hattin, 1962) rather than as a zone in the Carlile, as in past usage.

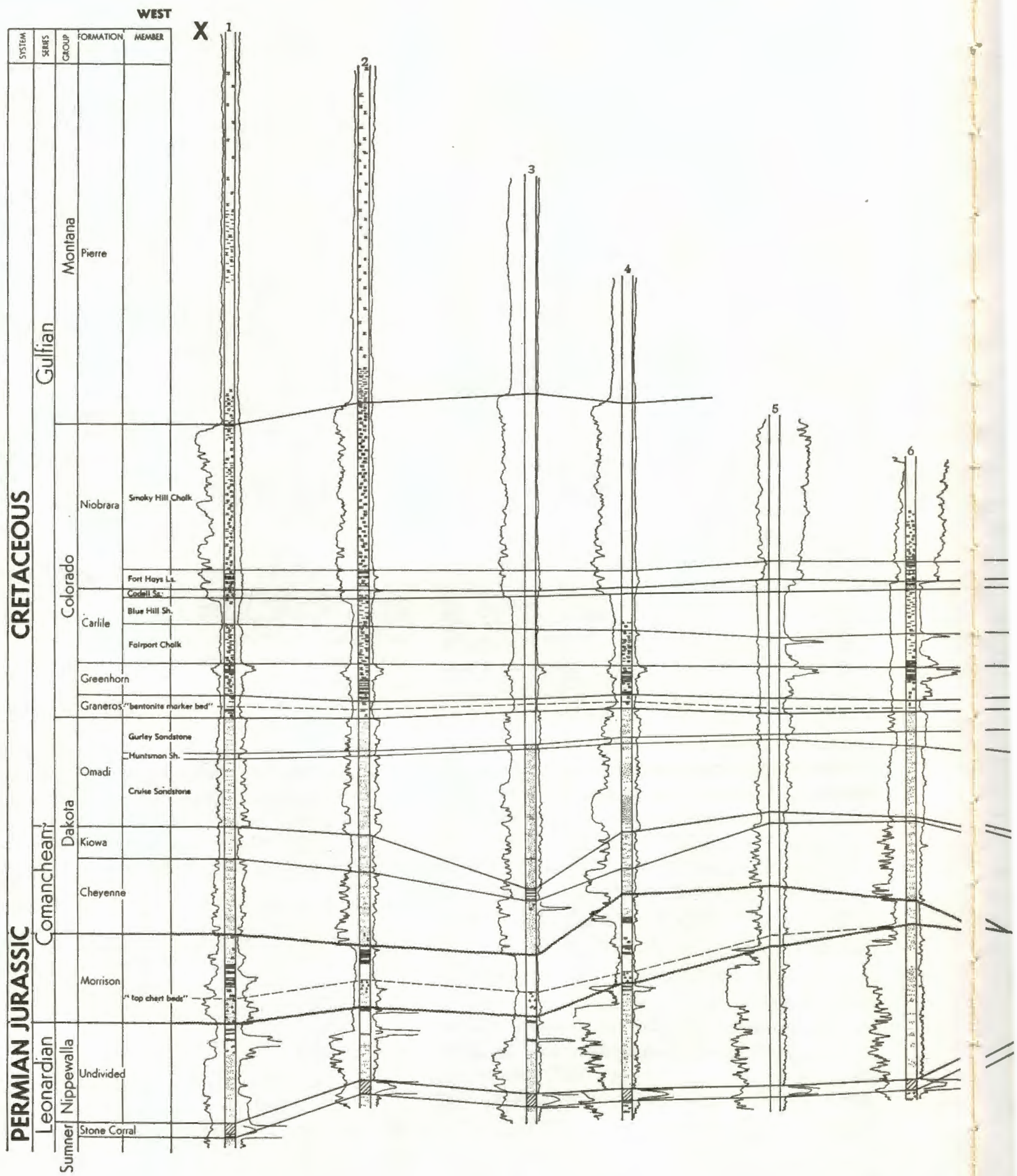
Montana Group

Only one formation of the Montana Group, the Pierre Shale, is present in Kansas. It is the oldest part of the group, which is more extensively developed farther to the north and west.

PIERRE SHALE

The Pierre Shale is the uppermost Cretaceous formation found in Kansas. The term Pierre was first used by Meek and Hayden in 1862 for rock exposures at old Fort Pierre, in Stanley or Hughes County, South Dakota. In Kansas the unit was first recognized by S. W. Williston

* The classification used here follows essentially that of Merriam (1957b).


WEST
X
1
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SYSTEM
SERIES
GROUP
FORMATION
MEMBER
CRETACEOUS
PERMIAN JURASSIC
Gulfian
Comanchean
Leonardian
Montana
Colorado
Dakota
Nippewalla
Sumner
Pierre
Niobrara
Smoky Hill Chalk
Fort Hays Ls.
Codell Ss.
Carlile
Blue Hill Sh.
Fairport Chalk
Greenhorn
Graneros
"bentonite marker bed"
Omadi
Gurley Sandstone
Huntsman Sh.
Cruise Sandstone
Kiowa
Cheyenne
Morrison
"top chert beds"
Undivided
Stone Corral

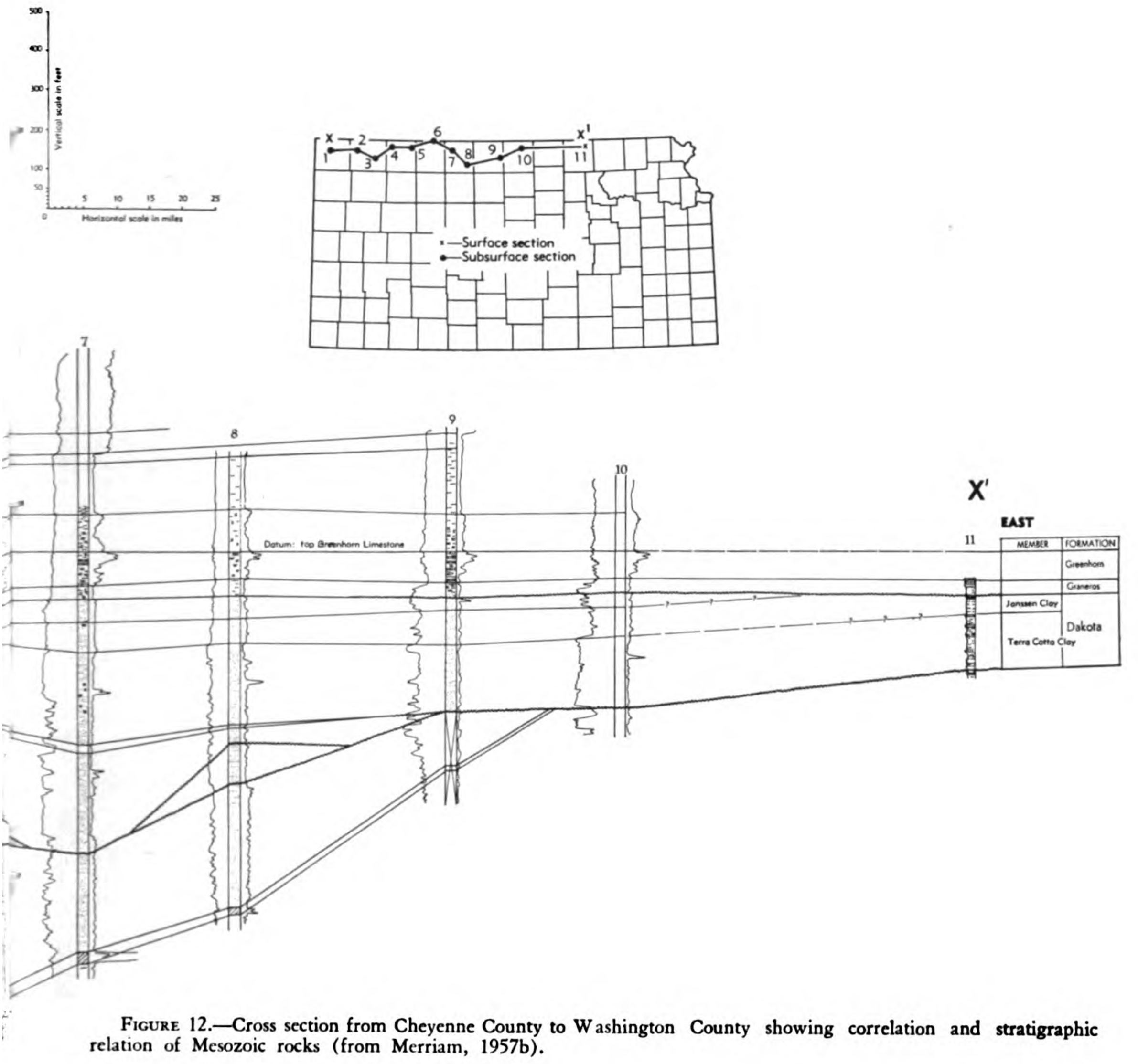


Figure 12.—Cross section from Cheyenne County to Washington County showing correlation and stratigraphic relation of Mesozoic rocks (from Merriam, 1957b).

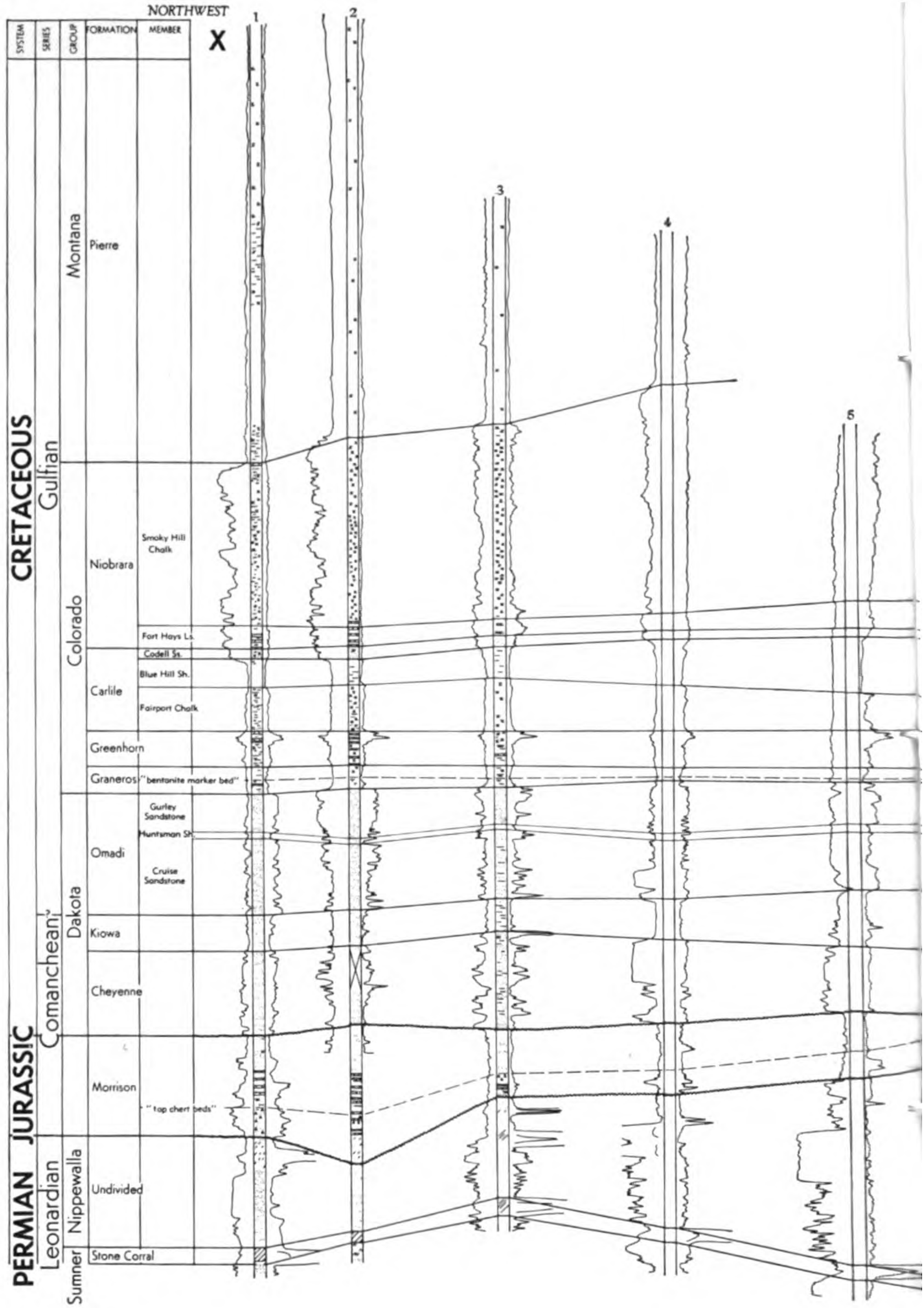
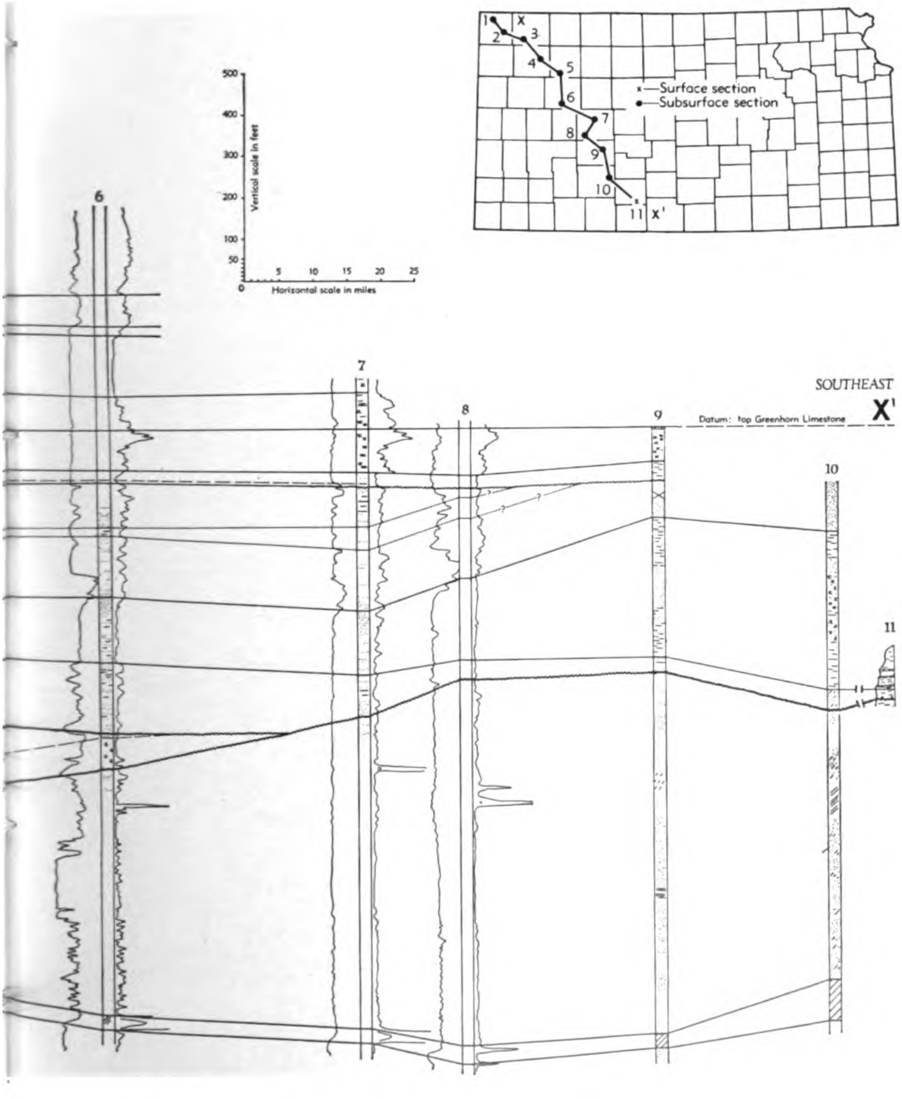


FIGURE 13.—Cross section from Cheyenne County to Kiowa County showing correlation and stratigraphic relatic



of Mesozoic rocks (from Merriam, 1957b).

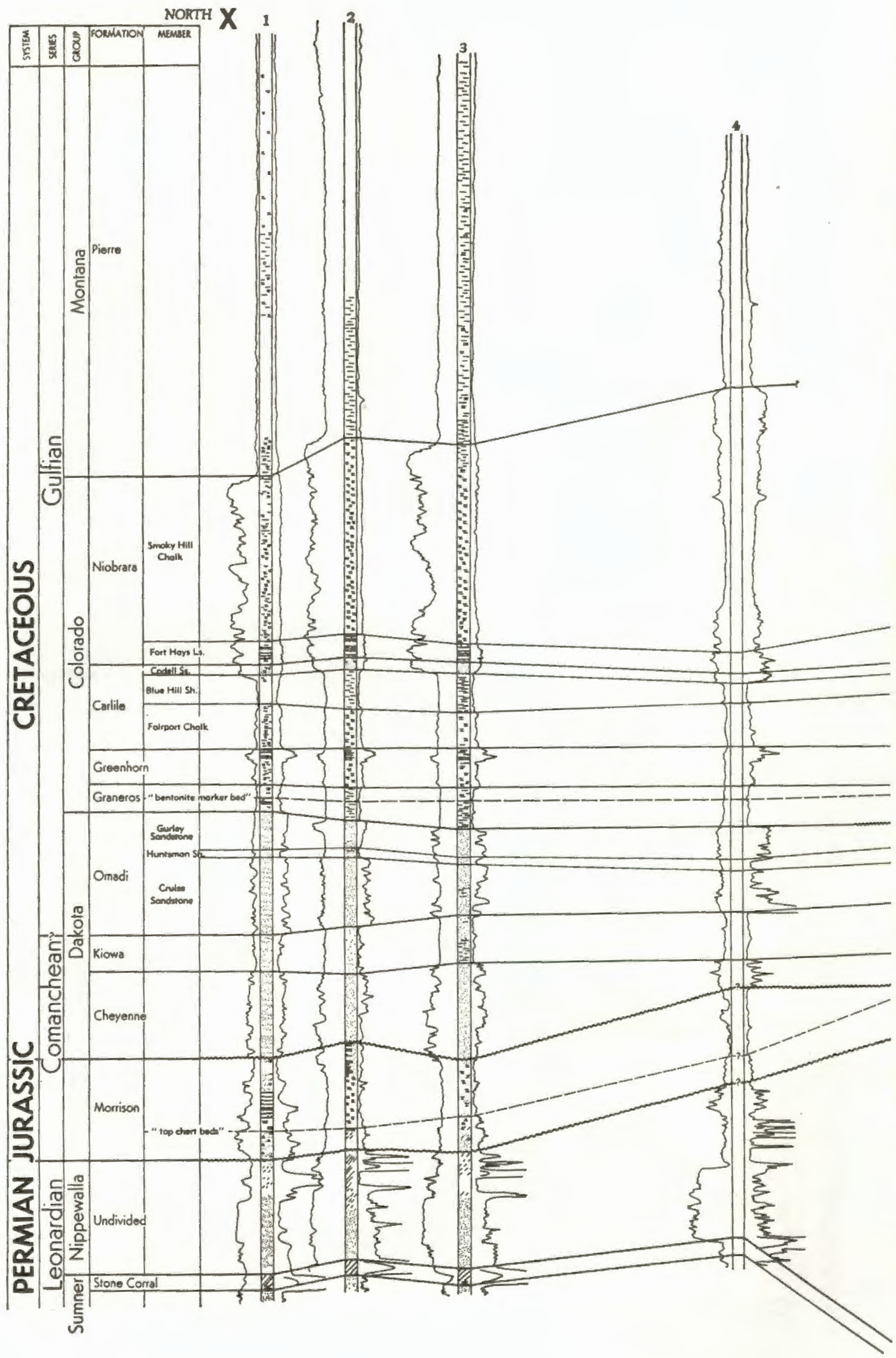
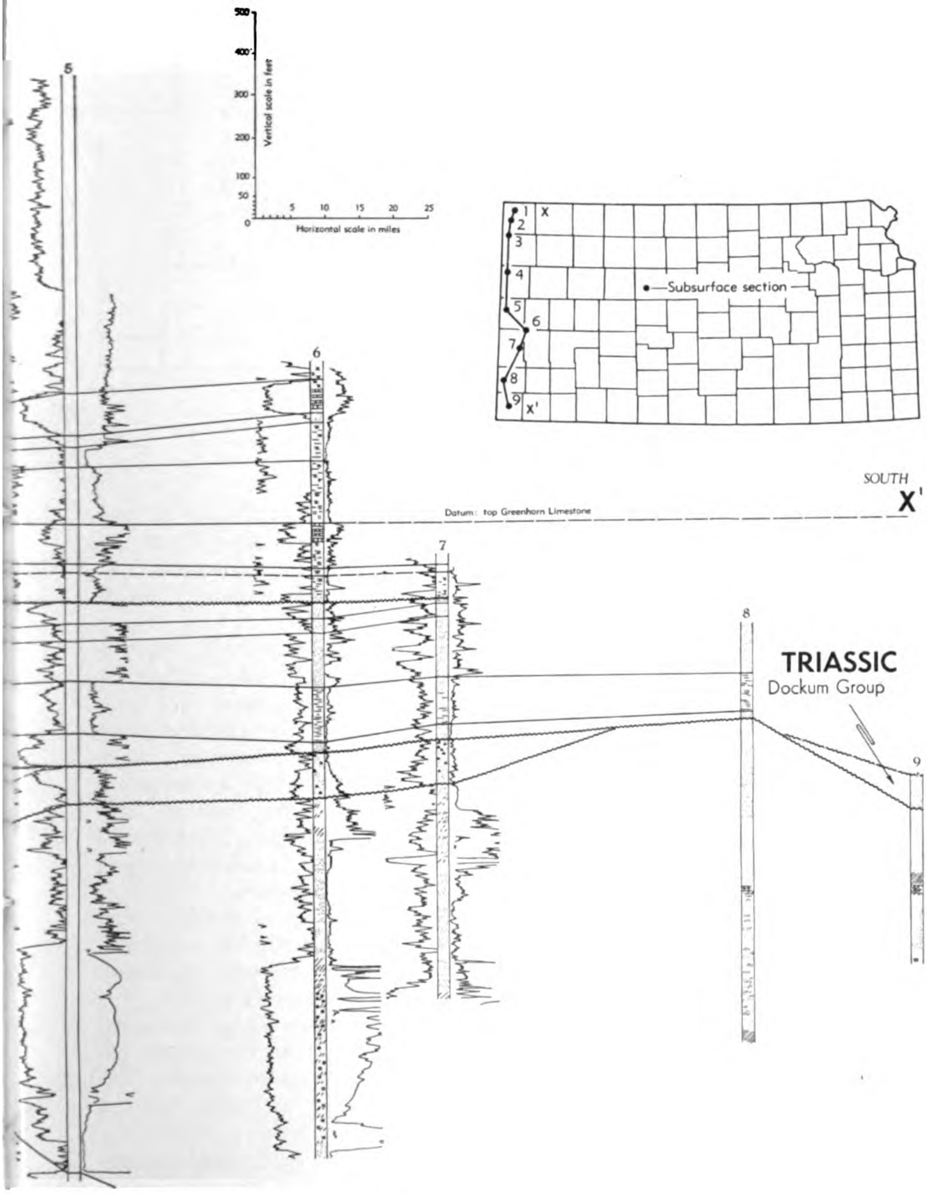


FIGURE 14.—Cross section from Cheyenne County to Morton County showing correlation and stratigraphic relation



of Mesozoic rocks (from Merriam, 1957b).

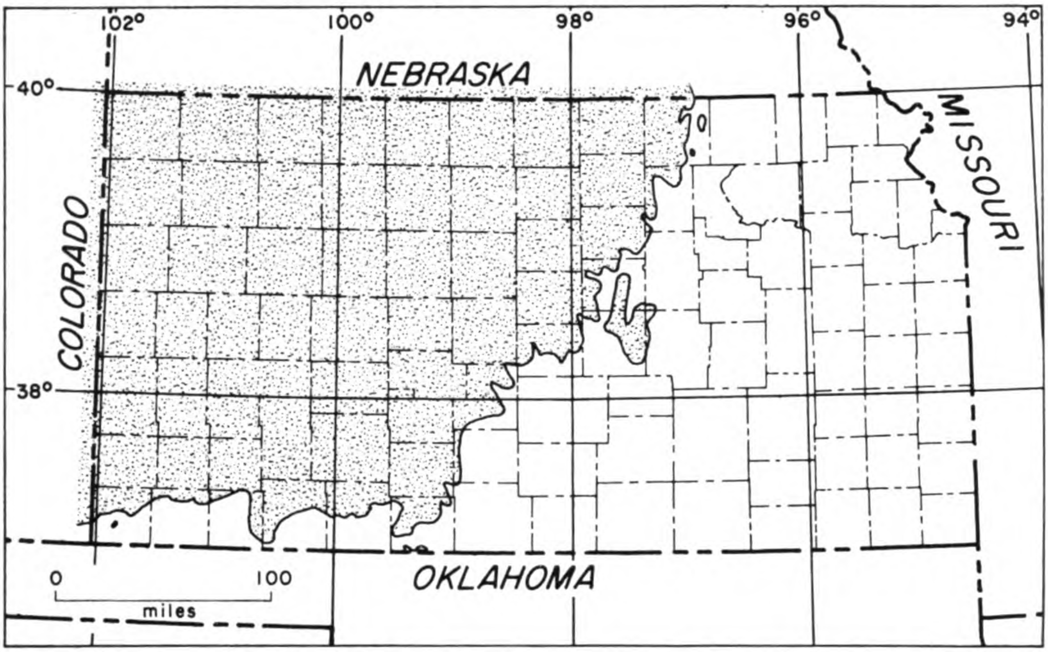


FIGURE 15.—Map of Kansas showing surface and subsurface distribution of Cretaceous rocks.

(1897) in 1891, whose correlation of these beds in Kansas was based mainly on comparison of vertebrate fossils. It was not until the publication by Elias (1931) appeared, however, that any notable contribution was made in the description and classification of the Pierre Shale in Kansas. In this report Elias first named and described members of the formation as now recognized.

DISTRIBUTION.—In Kansas the formation occurs only in the northwestern corner of the state. The best outcrops are those along Smoky Hill and Republican Rivers and in Rawlins County along Beaver Creek. Most of the area of the Pierre is covered by the younger Ogallala Formation. Several outliers both on the surface and in the subsurface are present east of the eastern margin of the formation. These are located in Phillips, Norton (Frye and Leonard, 1949), Graham, Gove, and Logan Counties. Remnants in Gove and Logan Counties are preserved in down-faulted blocks (Moore and Landes, 1937). The outliers in Graham and Norton Counties are apparently preserved in down-faulted areas also. The Pierre Shale, no doubt, once covered a more extensive area than at present.

CHARACTER.—Elias (1931) divided the Pierre Shale into six members (in descending order): Beecher Island Shale, an unnamed member, Salt Grass Shale, Lake Creek Shale, Weskan Shale, and Sharon Springs Shale. In Wallace County only the lower four members and lowermost part of the unnamed member are present. The uppermost member, the Beecher Island Shale, is exposed farther west in Colorado.

The Pierre is predominantly shale, which is light to dark gray, soft, slightly calcareous, micaceous, fissile, and fossiliferous (Pl. 3A). The Sharon Springs Member, identified in many logs, is dark-gray to black, micaceous, clayey shale. The formation as a whole contains numerous concretionary zones, but they are difficult to recognize in the subsurface. Thin streaks of bentonite are common. *Inoceramus* and *Baculites* fragments are numerous.

THICKNESS.—The thickness of the Pierre in Kansas ranges from a featheredge at the southeast limit to 1,600 feet in the extreme northwestern corner of Cheyenne County (Fig. 18).

STRATIGRAPHIC RELATIONS.—Where it is overlain by the Ogallala Formation, the upper contact of the Pierre Shale is unconformable, but farther west, in Colorado, the Pierre was not truncated, and Fox Hills Sandstone overlies the shale with conformable and gradational contact. The lower contact, with the Niobrara Formation, where observable, seems to be conformable and in places gradational, indicating continuity of the marine sedimentation from Niobrara to

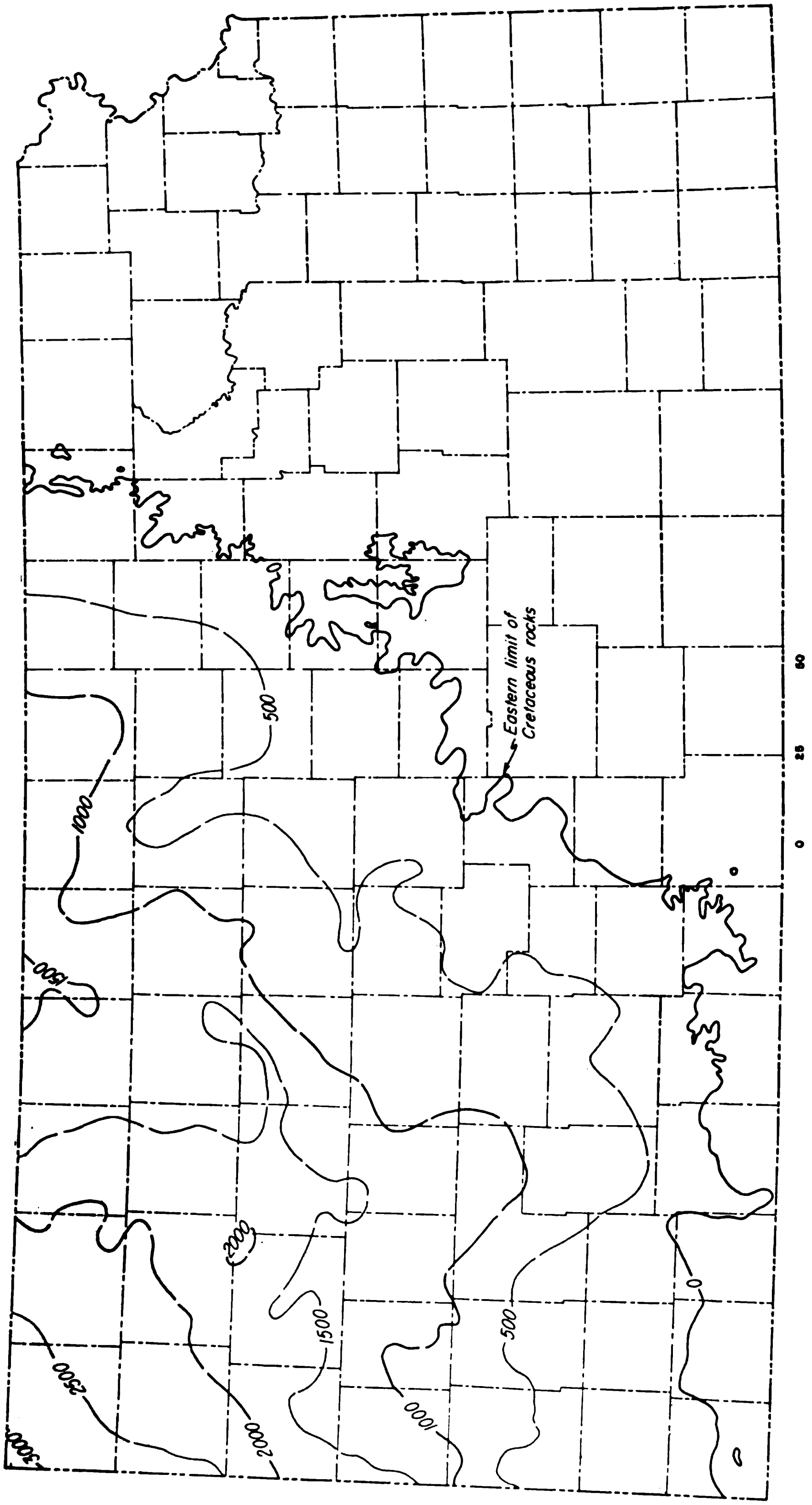


FIGURE 16.—Map of Kansas showing thickness of Cretaceous deposits, a wedge-shaped mass of material between Permian, Triassic, or Jurassic units beneath and Tertiary beds above. Contour interval 500 feet.

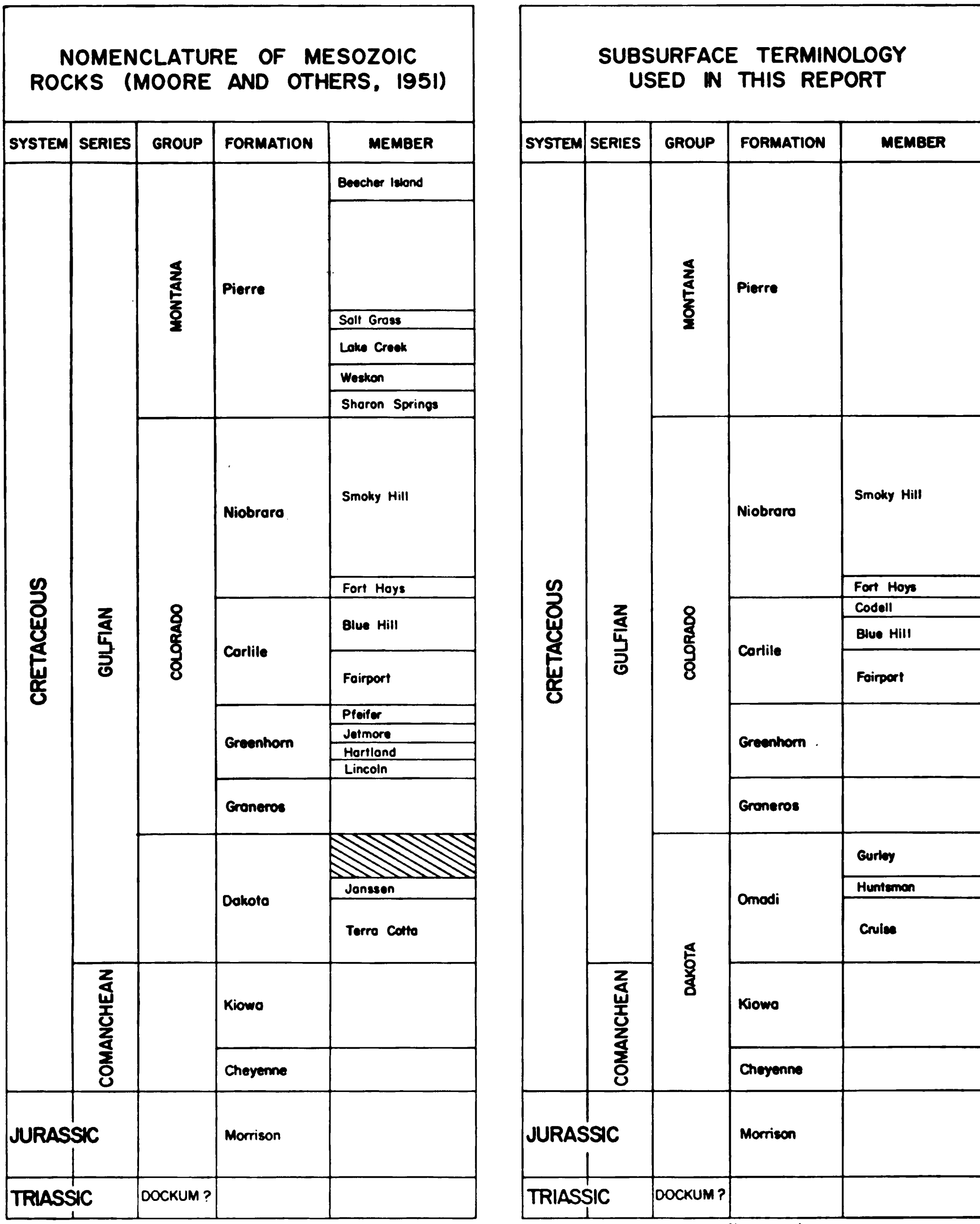


FIGURE 17.—Chart showing nomenclature of Mesozoic rocks as proposed by Moore and others (1951a) and equivalent terminology used in subsurface (adapted from Merriam, 1957b).

Pierre time. In the type area, where the Pierre lies conformably on the Niobrara, the contact is sharp, although some chalk is interbedded between shale beds at the contact through a thickness of a few inches to a few feet (Searight, 1937, p. 3).

Colorado Group

The Colorado Group in Kansas consists of four formations (in descending order): Niobrara Formation, Carlile Shale, Greenhorn Limestone, and Graneros Shale. Outcrops of the group in Kansas are only a portion of the total outcrop area, which extends through parts of Montana, Wyoming, South Dakota, Nebraska, Colorado, and New Mexico. The group is world famous for its chalk beds.

NIOBRARA FORMATION

The Niobrara Formation was named by Meek and Hayden in 1862 from exposures along Missouri River near the mouth of Niobrara River in Knox County, Nebraska. In Kansas, rocks belonging to the Niobrara have long attracted attention because they form some of the more spectacular landscape features of western Kansas, such as Castle Rock (Pl. 4A), Cobra Rock (Pl. 4B), Monument Rocks (Pl. 4C), and the Sphynx (Pl. 4D), in Gove County. These are erosional remnants that tower as much as 70 feet above the surrounding, monotonously flat plain. The early interest in these features, and the consequent availability of photographs taken over a period of 50 years, made it possible for Smith (1944) to investigate modifications of these landmarks.

DISTRIBUTION.—The belt of outcrop of the chalk beds in Kansas extends from Jewell, Smith, and Phillips Counties to Kearny and Hamilton Counties; the formation is restricted to approximately the northwestern one-fifth of the state. The eastern edge of the outcrop has been indented by incision of streams, so that it forms a very irregular pattern. Much of the formation is concealed by Pierre and Ogallala deposits, but along many of the present stream valleys exposures are numerous, those of the Fort Hays Limestone Member being very good. The character of the Smoky Hill Chalk is such that outcrops are poor and small. Two outliers of the Niobrara, one in Mitchell County and the other in Osborne County, provide conclusive evidence that the Niobrara once was more extensively developed in Kansas.

CHARACTER.—The Niobrara Formation is divided into two members: Smoky Hill Chalk, above, and Fort Hays Limestone, below. The term Smoky Hill Chalk was first used by Cragin (1896b; see Wilmarth, 1938, p. 2015), and is taken from Smoky Hill River in Kansas. The Smoky Hill is a gray to white, yellow, or orange chalky shale, which contains limonitic concretions, locally massive chalk beds, and many bentonites (Pl. 3B, 3C). The small oyster *Ostrea* and fragments of the large clam *Inoceramus* are abundant. The member may be as much as 700 feet thick in Wallace and Logan Counties. The Fort Hays Limestone consists mainly of chalk and chalky limestone that is light gray to gray and massive and ranges in thickness from about 40 to 85 feet (Pl. 5A). Thin beds of light- to dark-gray chalky shale separate the massive chalky limestone layers. Individual chalk beds may be as much as 7 feet thick; shale partings range in thickness to as much as 9 inches (Runnels and Dubins, 1949, p. 8). The Fort Hays Limestone, like the Smoky Hill Chalk, is very fossiliferous, being especially rich in foraminifers. The term Fort Hays is derived from old Fort Hays, a well-known landmark in western Kansas, and was first used by Williston in 1893.

In well samples the two members are especially characteristic and easy to identify. The whitish, very calcareous, soft fossiliferous shale (Smoky Hill) and the white, massive, porous chalky limestone (Fort Hays) are good marker units. The formation also is easily identified on electric logs.

THICKNESS.—Thickness of the Niobrara Formation in Kansas ranges from 0 to 750 feet (Fig. 19).

STRATIGRAPHIC RELATIONS.—The contact of the Smoky Hill Chalk and Fort Hays Limestone is gradational; where the lower part of the Smoky Hill contains numerous chalk beds it is almost impossible to pick a contact.

From evidence available at present, the Fort Hays seems to be slightly older than the Timpas Limestone of eastern Colorado. Preliminary correlations of electric logs indicate that the Timpas may be equivalent to a portion of the lower part of the Smoky Hill Chalk, at least in part of Nebraska (Fig. 20). This conclusion is agreed to by E. C. Reed (personal communication, December 9, 1955), but not by V. B. Cole (personal communication, June 2, 1962).

CARLILE SHALE

In 1896, Gilbert named the Carlile Shale from exposures in the Arkansas Valley region of eastern Colorado. Hawn (in Meek and Hayden, 1857) and Leconte (1868) gave the first descriptions of the Kansas Carlile (Hattin, 1962); later, more detailed descriptions were published by Hayden (1872), who worked along the Union Pacific Railroad in western Kansas.

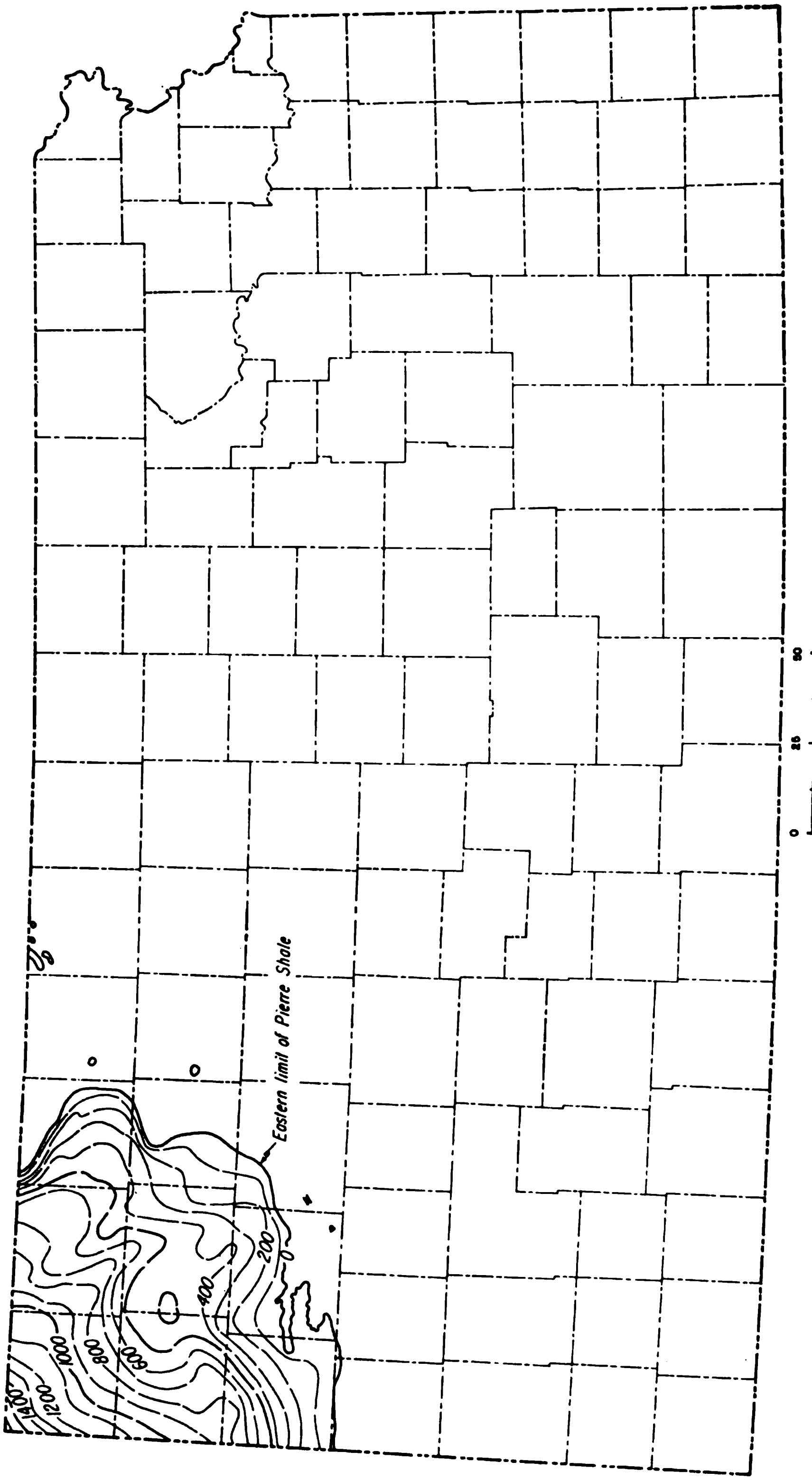


FIGURE 18.—Map showing thickness of Pierre Shale in northwestern Kansas. Several small outliers of Pierre Shale, probably occurring in grabens, are east of east limit of formation. Contour interval 100 feet.

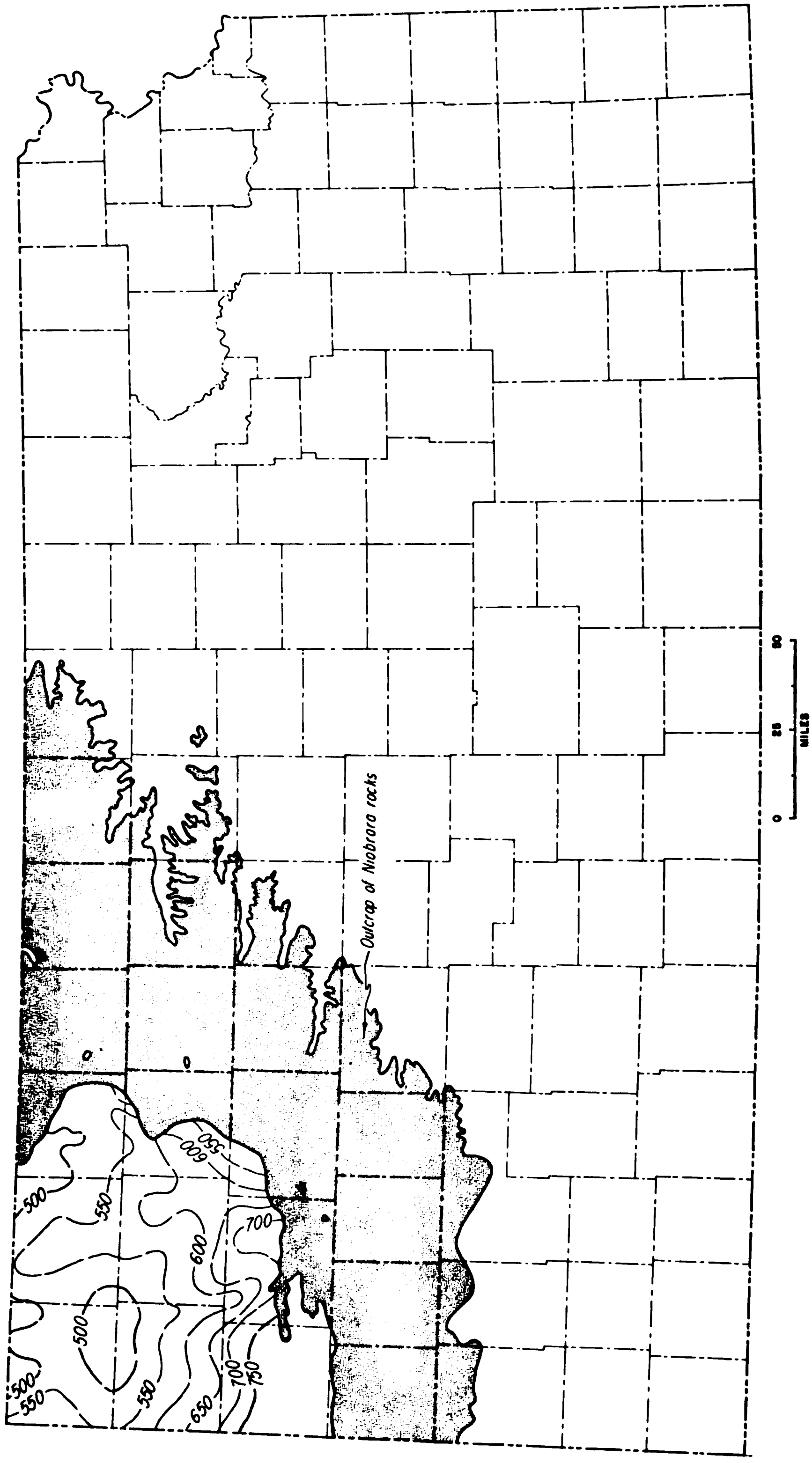


Figure 19.—Isopachous map of Niobrara Formation in Kansas. Contour interval 50 feet.

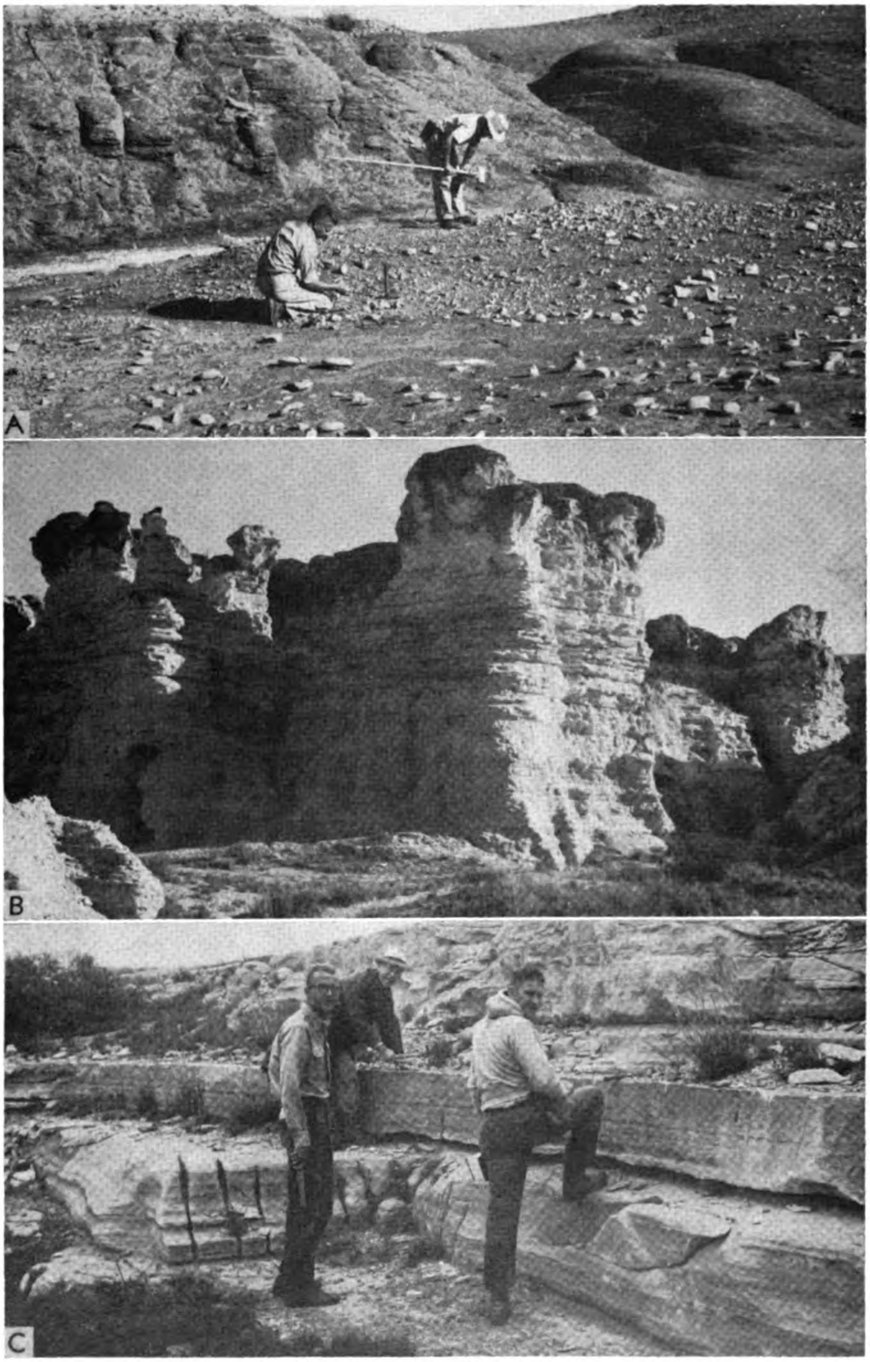


Plate 3.—**A**, Dark-gray, fissile, concretionary Pierre Shale exposed at McAllaster Buttes, Logan County (sec. 13, T. 12 S., R. 37 W.). **B**, Niobrara Formation exposed in the vicinity of Cobra Rock, Gove County. **C**, Upper part of the Niobrara Formation (Smoky Hill) in abandoned quarry, Graham County (sec. 7, T. 8 S., R. 24 W.).

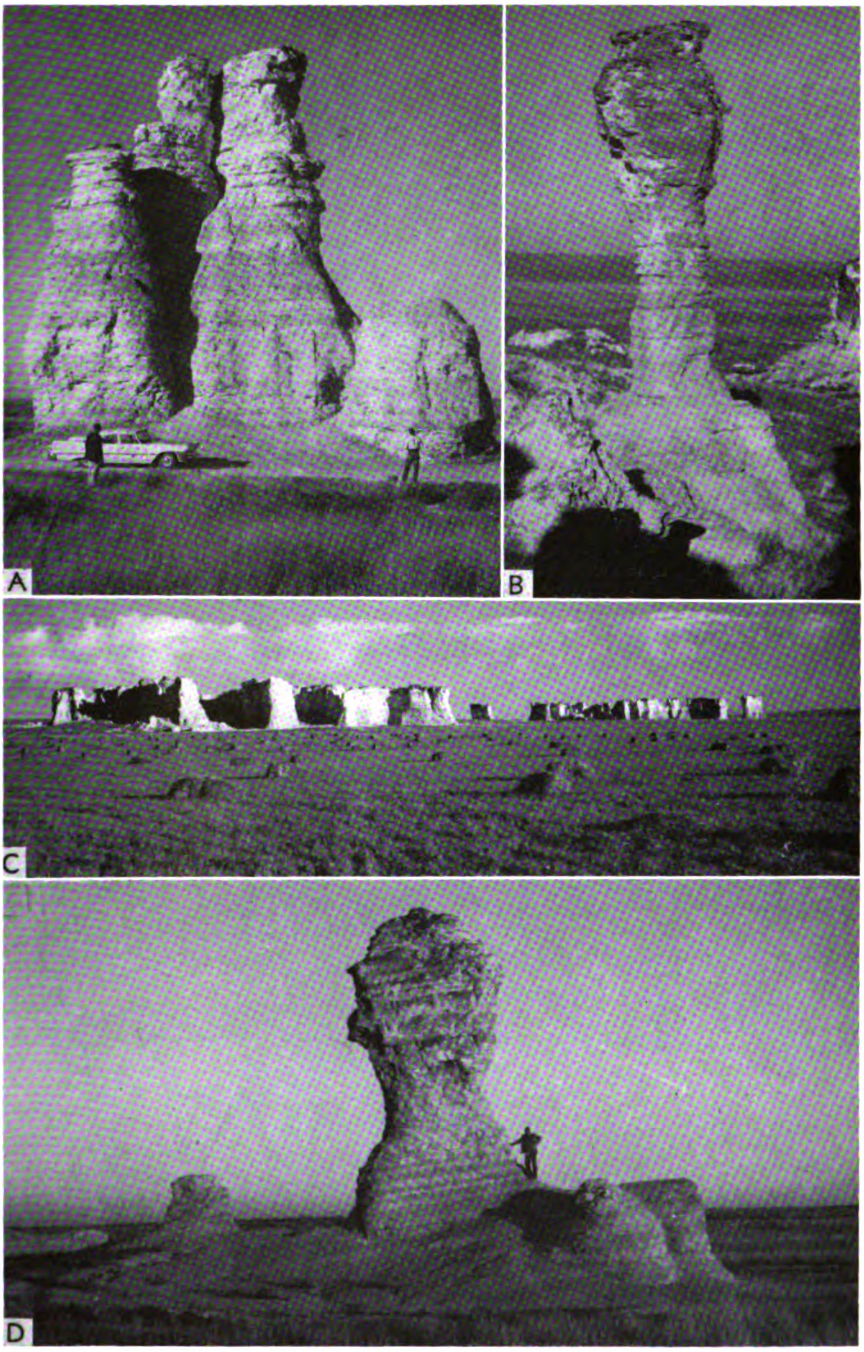


PLATE 4.—Sculptured forms of Niobrara chalk, Gove County. **A**, Castle Rock (SW sec. 1, T. 14 S., R. 26 W.). **B**, Cobra Rock (sec. 12, T. 14 S., R. 26 W.). **C**, Monument Rocks (sec. 33 and 34, T. 14 S., R. 31 W.). **D**, The Sphynx (NE sec. 33, T. 14 S., R. 31 W.).

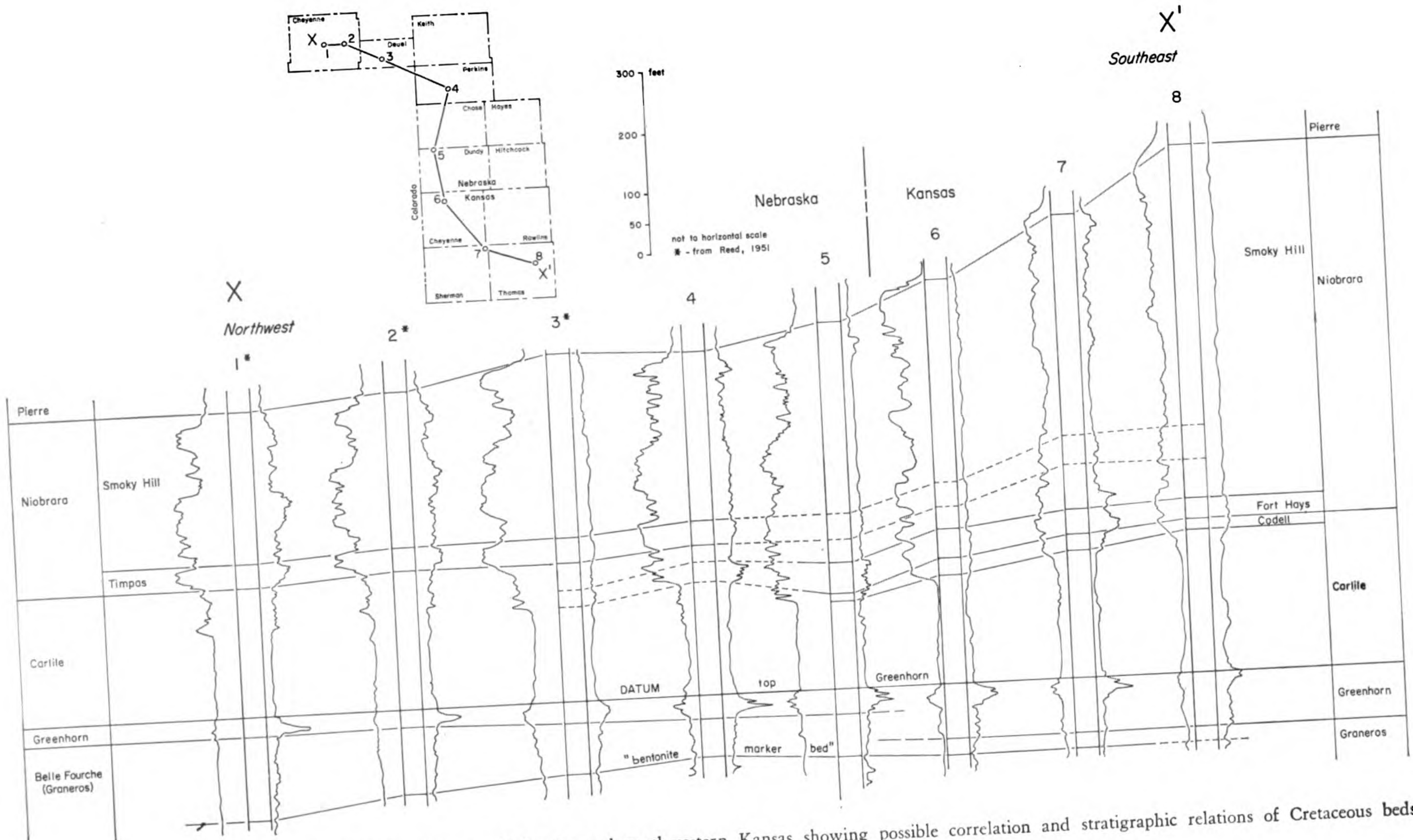


Figure 20.—Electric-log cross section in southwestern Nebraska and northwestern Kansas showing possible correlation and stratigraphic relations of Cretaceous beds between Graneros Shale and Pierre Shale.

DISTRIBUTION.—The formation is found throughout large areas of the Western Interior, including about the western one-third of Kansas. The Carlile extends eastward to a line from Republic County on the north to Hamilton County on the south. The best exposed sections are along major drainage systems, which cut diagonally across the belt of outcrop, and in the Blue Hills of Mitchell County and adjacent territory. Exposures of the upper part of the formation are generally good on washed slopes beneath the prominent Fort Hays escarpment, but the lower part usually forms low, rolling, wheat-covered surfaces.

CHARACTER.—The Carlile is part of the unit originally defined as the Fort Benton Group and later recognized as the upper unit of the Benton Shale or Benton Formation, a term still used in parts of Colorado and Wyoming. The earliest proposal to divide the Benton in Kansas was made by Cragin (1896b). The Carlile is now divided into three members (in descending order): Codell Sandstone, Blue Hill Shale, and Fairport Chalk. The Codell Sandstone, uppermost member of the Carlile, was named by Bass in 1926. It is brown to gray, fine to medium grained, subangular, and silty (Pl. 5B). Locally, it is a siltstone. Also, in places the Codell is represented only by a silty or gritty zone (Pl. 5C). The Blue Hill, named by Logan in 1897, is gray to blue-gray, fossiliferous, clayey, noncalcareous shale. It contains several zones of calcareous concretions as much as 8 feet in diameter (Pl. 6A); these concretionary zones are not recognizable in the subsurface. Shale members of the Carlile are easily differentiated, both on electric logs and in well samples, because the Fairport is very calcareous and the Blue Hill only slightly calcareous, if at all. The Fairport, named by Rubey and Bass in 1925, is predominantly a very fossiliferous chalky shale containing stringers of limestone (Pl. 6B). Thin seams of bentonite occur near the base of the member.

Hattin (1962) was able to trace numerous key beds in the Carlile for considerable distances. He has suggested a reclassification of the Carlile Shale which would elevate Carlile to subgroup status, Fairport and Blue Hill to formations; and he has proposed the name Saline Valley for the lower member of the Blue Hill and retention of Codell for the upper member. This change, however, has not been adopted by the Kansas Survey.

THICKNESS.—Overall thickness of the Carlile is almost uniformly about 250 to 300 feet. The Fairport ranges in thickness from about 80 to 150 feet, and the Blue Hill from about 50 to 160 feet. The Codell ranges from about 2 to 80 feet and normally is about 25 feet thick (McKellar, 1962).

Figure 21 shows the thickness of units from top of the Dakota to base of the Fort Hays, and includes the Carlile, Greenhorn, and Graneros Formations. These three units range in thickness from a featheredge on the outcrop to about 450 feet in western Gove County.

STRATIGRAPHIC RELATIONS.—Members of the Carlile Formation are conformable with each other, and the upper and lower boundaries of the formation are conformable with overlying and underlying units. Hattin (1962) was able to demonstrate a hiatus between the Carlile and Niobrara, but found no break between the Carlile and Greenhorn.

GREENHORN LIMESTONE

The Greenhorn Limestone is also part of the old Fort Benton Group, a name applied by Meek and Hayden in 1862. Later, Gilbert (1896) divided the Benton into several formations, of which the Greenhorn was one. The unit is named for Greenhorn Station and Greenhorn Creek, 14 miles south of Pueblo, Colorado. Important works dealing with this unit in Kansas include those by Rubey and Bass (1925), Bass (1926), and Bergman (1950).

DISTRIBUTION.—The Greenhorn crops out in a narrow band from Washington County on the northeast to Hamilton County on the southwest. Inasmuch as the upper part of the formation is moderately resistant to erosion, it forms a gentle east-facing scarp. The middle and lower parts are less well exposed, except in stream banks and road cuts.

CHARACTER.—Along the outcrop, the Greenhorn Limestone is divided into four members (in descending order): Pfeifer Shale, Jetmore Chalk, Hartland Shale, and Lincoln Limestone, but they have not been recognized generally in the subsurface. The upper two members are commonly grouped together under the name Bridge Creek Limestone.

The formation consists mostly of limestone and chalky shale (Pl. 6C). The limestone is gray to light brown, chalky or crystalline, and fossiliferous. The shale is gray to brownish, calcareous, and fossiliferous. In the uppermost part of the formation there is a persistent bed known as the Fencepost Limestone (Pl. 6D). This bed causes an easily identifiable double-pronged "kick" on electric logs, which can be traced from well to well as far as to Wyoming. Because of the easy recognition of this bed, it is often used as a stratigraphic and structural datum.

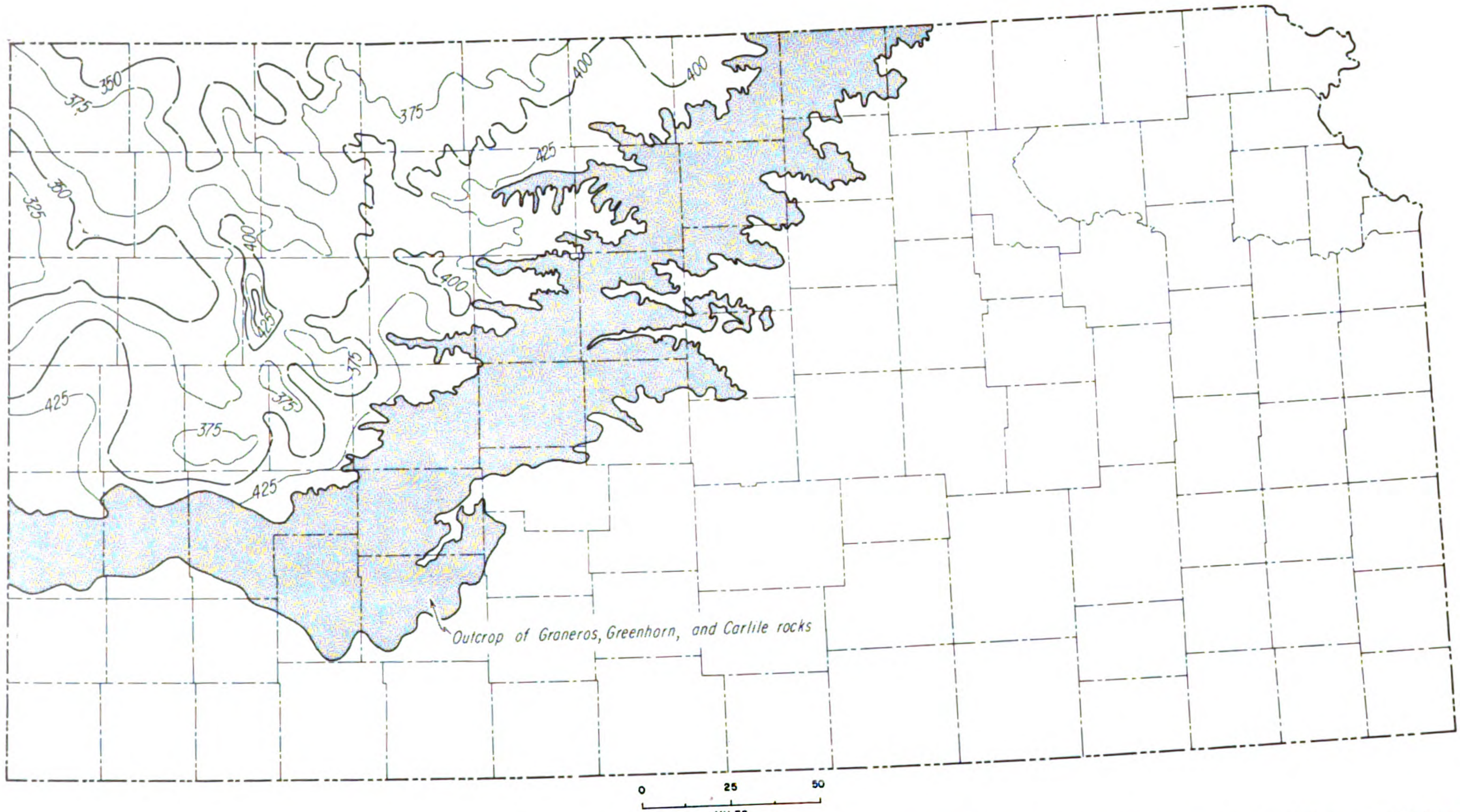


FIGURE 21.—Isopachous map from base of Fort Hays Limestone to top of Dakota; interval includes Carlile, Greenhorn, and Graneros Formations. Maximum thickness is in western Gove County. Contour interval 25 feet.

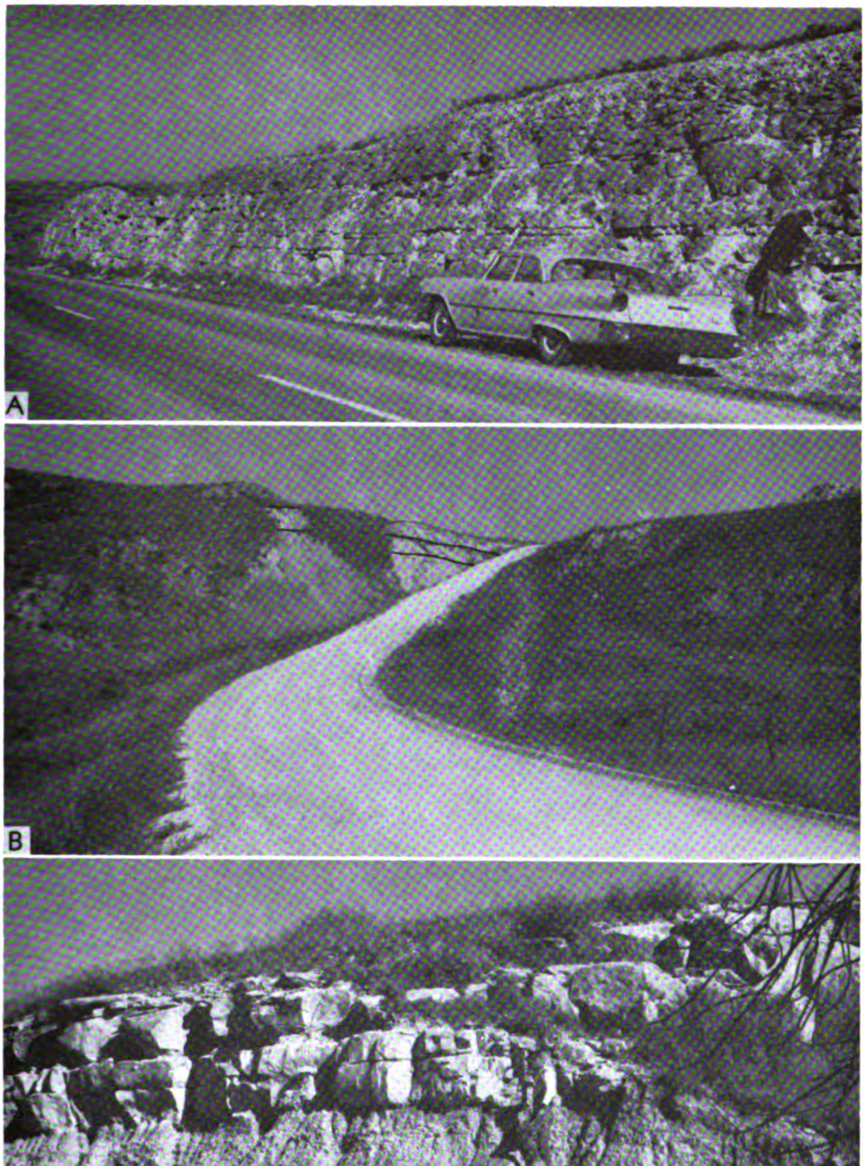


Plate 5.—**A,** Fort Hays Limestone Member of Niobrara Formation exposed on U.S. Highway 283 south of Wakeeney, Trego County. **B,** Below Fort Hays scarp is Codell Sandstone of Carlile Shale near type locality, Ellis County (NE sec. 3, T. 11 S., R. 17 W.). **C,** Contact of Carlile Shale (below) and Fort Hays Limestone (above) south of Cedar Bluff Dam, Trego County (NW sec. 27, T. 15 S., R. 22 W.). Note apparent absence of Codell Sandstone.

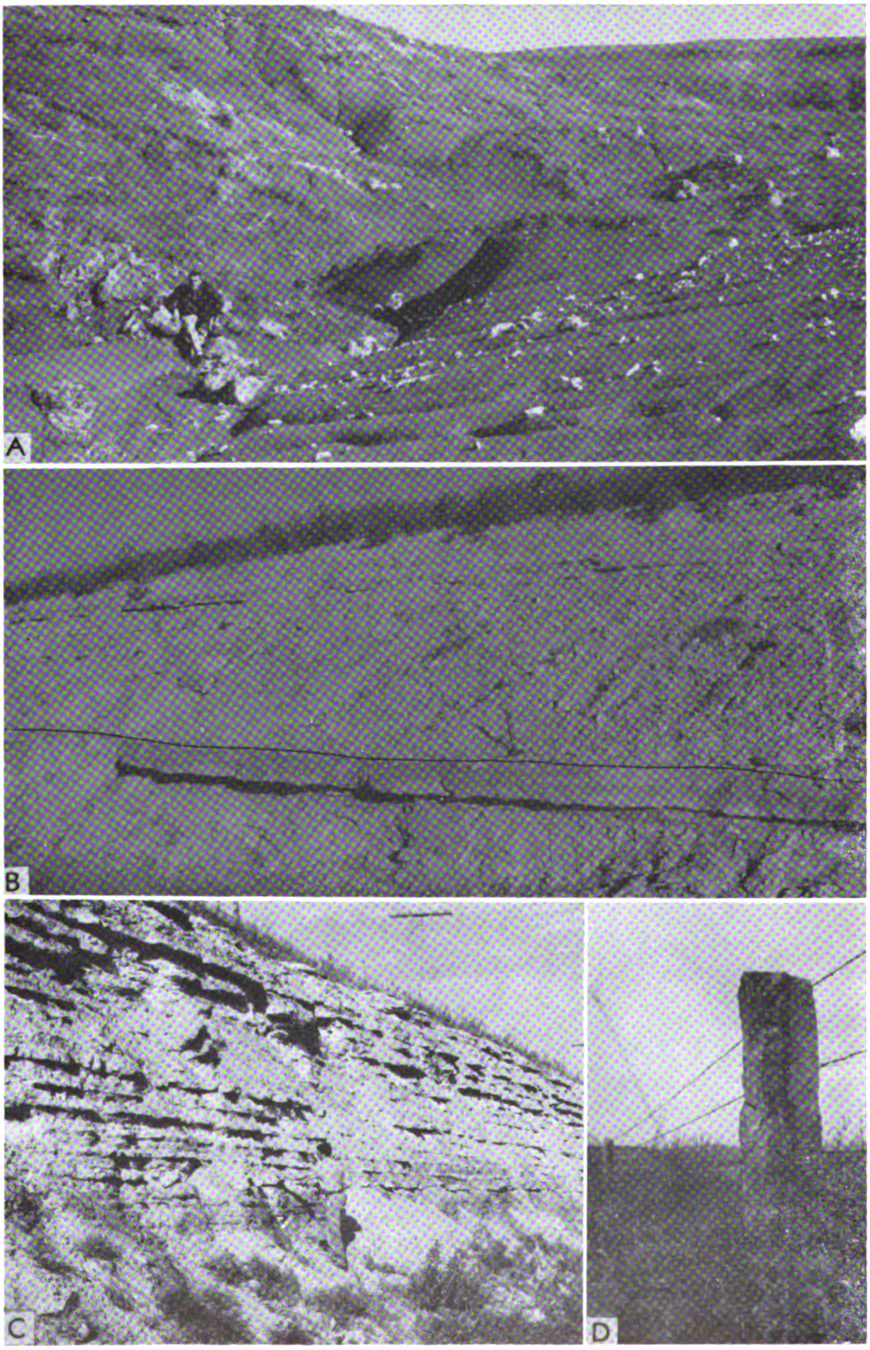


Plate 6.—**A**, Upper part of Carlile Shale (Blue Hill Shale) with many concretions, Ellis County (NE sec. 9, T. 11 S., R. 18 W.). **B**, Contact of Greenhorn Limestone (below) and Fairport Chalk (above), Russell County (SE sec. 2, T. 15 S., R. 14 W.). Hammer on Fencepost Limestone bed. **C**, Greenhorn Limestone along U.S. Highway 36 in east-central Republic County. **D**, Fencepost Limestone fencepost 3½ miles south of Simpson, Mitchell County.

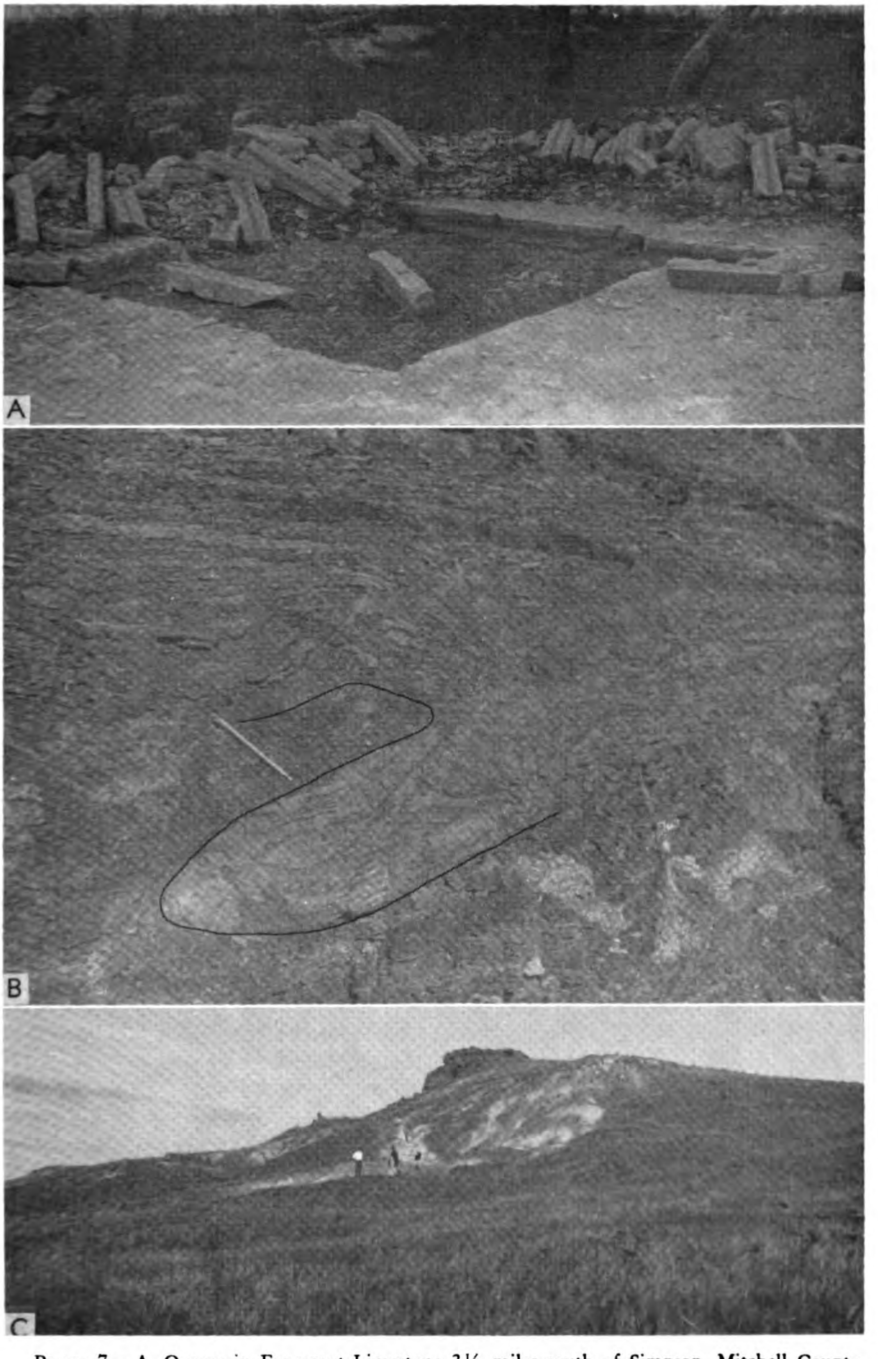


PLATE 7.—**A**, Quarry in Fencepost Limestone 3½ miles south of Simpson, Mitchell County. **B**, Slump structure in Graneros Shale exposed on Canyon Road just northwest of Russell, Russell County. **C**, Dakota (Terra Cotta Member) rocks exposed at Buzzard's Roost, Ellsworth County (NE sec. 15, T. 15 S., R. 6 W.).

Bergman (1950) was able to recognize in this unit several marker beds that could be traced in the field. Three important ones are the Fencepost Limestone at top of the Greenhorn (Pl. 7A), a "granular calcite bed" or "sugar sand" about 6 feet below the Fencepost, and a unit locally called the "shell-rock limestone," which marks the top of the Jetmore Chalk Member; also, some of the numerous bentonites are traceable over large areas. Bergman (1950, p. 15) described the Fencepost as ". . . 0.5 to 1.0 foot thick. It is a massive, chalky limestone, generally tan gray with a characteristic rust-colored streak in the middle part. . . . The bed contains shells of the pelecypod *Inoceramus* and cephalopods occasionally are found in it. It forms a minor bench, which is sufficiently well developed on many hillsides that the contact between the Greenhorn Limestone and the overlying Carlile can be located readily. . . ."

THICKNESS.—Thickness of the Greenhorn in Kansas ranges from about 90 to 100 feet. The following are average thicknesses for the individual members: Pfeifer, 20 feet; Jetmore, 22 feet; Hartland, 30 feet; and Lincoln, 28 feet (Moore and others, 1951a). Thickness of the formation is included in the thickness map of the Benton Shale (Fig. 21).

STRATIGRAPHIC RELATIONS.—All members are conformable with each other, as is the formation with overlying and underlying units. Individual beds show remarkable lateral persistence, and they can be traced for considerable distances.

GRANEROS SHALE

The Graneros Shale, the lowermost unit of the old Fort Benton Group, was named by Gilbert (1896). The Graneros is now recognized as the lowest formational unit of the Colorado Group, which includes not only the Benton but also the Niobrara. Because the Graneros is poorly exposed and thin for the most part, it has received little attention. At present, however, stratigraphic studies are being conducted by D. E. Hattin and his associates.

DISTRIBUTION.—The extent of the Graneros is only slightly greater than that of the Greenhorn; it covers about two-fifths of Kansas. The formation is also exposed in adjacent states.

CHARACTER.—The Graneros is a medium-gray to black, noncalcareous or slightly calcareous, silty marine shale (Pl. 7B). Locally, it is abundantly fossiliferous, containing both vertebrates and invertebrates. Oysters and shark teeth are common fossils. Many thin streaks of bentonite are found in the shale, and one in particular, the "bentonite marker bed," is traceable over large areas and serves to subdivide the formation. In Kansas this marker bed, a bluish-gray bentonite 1 to 2 feet thick, causes an easily identifiable "kick" on electric logs. Some lenses of sandstone occur in the Graneros Shale.

The "bentonite marker bed" (or "BMB") is a light-gray, thinly laminated claystone that breaks with conchoidal to blocky fracture. It swells in water, a characteristic trait of some bentonite. The following is part of a description prepared by P. C. Franks (Merriam and others, 1959, p. 42):

> In thin section, it can be seen that the bentonite is composed of montmorillonite showing orientation along wavy laminae that are subparallel to bedding. Locally, the montmorillonite is segregated into coarse wormlike books that amount to about 5 percent of the rock and measure 0.1 to 0.3 millimeter in length. The rock is vertically jointed and shows distinct bedding. . . .
>
> In addition to montmorillonite, the thin section contains about 5 percent small angular fragments of quartz and plagioclase. . . . A small percentage of pyrite is present. . . .
>
> In the fraction finer than 2 microns, the sample is composed completely of sodium montmorillonite . . . [Fig. 22].

THICKNESS.—Thickness of the formation ranges from about 40 to 100 feet. In general it thickens southward, but in northwestern Kansas the Graneros has an almost uniform thickness of about 40 feet. The combined thickness of Graneros, Greenhorn, and Carlile strata is shown in Figure 21.

STRATIGRAPHIC RELATIONS.—The Graneros conformably underlies the Greenhorn Limestone (Plummer and Romary, 1942). Over much of the area where the Graneros rests on the Dakota it is conformable; however, locally there is evidence of a disconformity.

Dakota Group

Dakota was a name proposed by Meek and Hayden in 1862 for rocks exposed along Missouri River in Dakota County, Nebraska. The use of the name in recent years has resulted in almost complete confusion. Dakota has been employed variously as a formational or group name, expanded or restricted to include more or fewer units than originally defined, miscorrelated, and geographically extended to rock units where correlation has not been possible.

Similarly, in Kansas the term Dakota has been used in various ways by different authors. For example, in the late 1800s the Dakota Sandstone was classed as a formation with rank equivalent to the Cheyenne Sandstone and Kiowa Shale. In the 1920s Dakota was defined to include all strata between the Graneros Shale and Permian rocks. Thus the term included not only the Dakota Sandstone of previous usage but also the Cheyenne and Kiowa Formations.

The term Dakota Group was recognized in this sense by Moore (1935a) and was so used on the Geologic Map of Kansas prepared by Moore and Landes in 1937. According to Waite (1942), at a conference of Kansas Survey geologists in January 1941, it was decided that the term Dakota Group should include all strata from the base of the Cheyenne Sandstone to the base of the Graneros Shale. At about this time, Latta (1941) introduced the term Cockrum Sandstone in southwestern Kansas for beds formerly called Dakota. According to the classification proposed by Latta, the Dakota Group included the Cheyenne Sandstone, Kiowa Shale, and Cockrum Sandstone, and this was later accepted by McLaughlin (1942). In February 1942, however, another conference of Kansas Survey geologists led to restriction of Dakota to beds between the Kiowa Shale and Graneros Shale. In Kansas Survey usage since then, Dakota has held the rank of formation on an equal status with Cheyenne Sandstone and Kiowa Shale.

At this latter conference several reasons were given for restricting the term Dakota to formational rank. According to Waite (1942, p. 137):

> . . . The group as previously defined, transgressed the Upper Cretaceous-Lower Cretaceous boundary line; a multiplicity of names has existed for the various units involved, many of them having been applied to such nonpersistent units as channel sandstone that cannot be correlated with certaintv beyond the confines of their type localities; many of the stratigraphic units were never adequately described. Moreover, the Dakota group, as used previously in Kansas, could not be correlated with the Dakota sandstone at the type locality; it was not acceptable to the Committee on Geologic Names of the U.S. Geological Survey; it did not constitute a satisfactory genetic grouping of strata; and the term Dakota group was confused with other usages of Dakota and almost universally implied a sandstone.

Although good reasons can be offered for restricting application of the name Dakota to

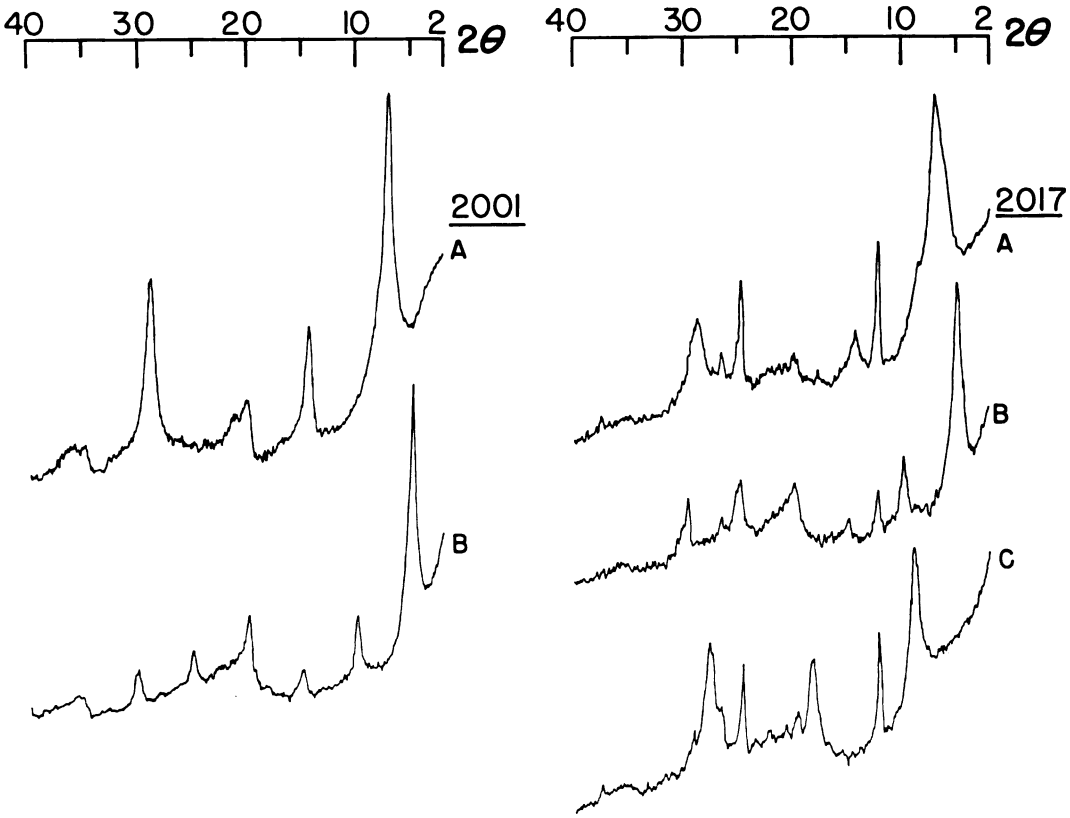


FIGURE 22.—Diffractometer patterns for fractions finer than 2 microns from Atkinson No. 1 Beaumeister well, Cheyenne County. "Bentonite marker bed," 2,001 feet: **A**, air dried; **B**, glycerated. Graneros Shale, 2,017 feet: **A**, air dried; **B**, glycerated; **C**, heated to 575°C (adapted from P. C. Franks, *in* Merriam and others, 1959).

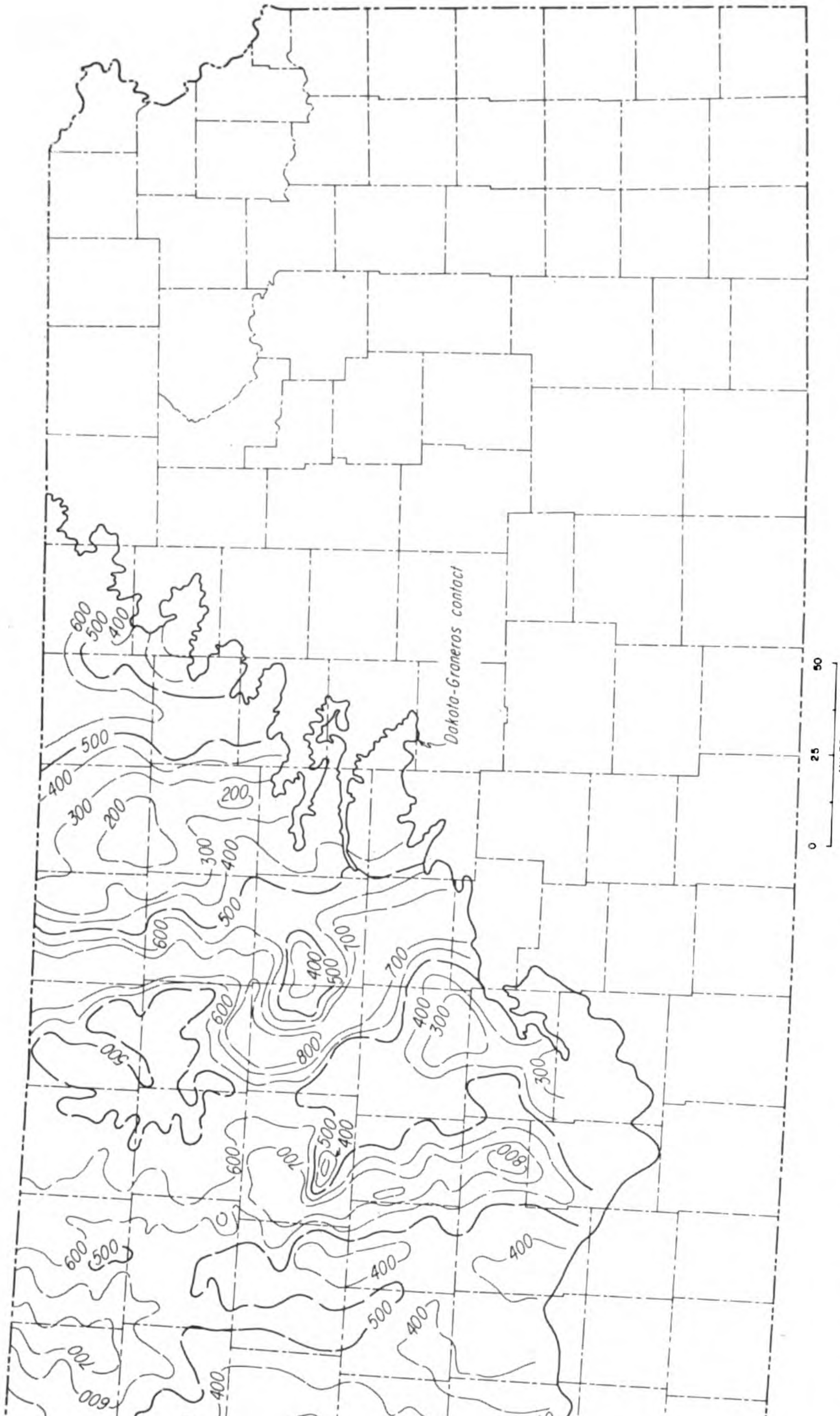


FIGURE 23.—Isopachous map of beds between top of Dakota and base of Cretaceous. Inasmuch as the upper surface was essentially flat and horizontal and the lower surface is erosional, contours show position and shape of pre-Cretaceous topographic features. Contour interval 100 feet.

strata between the Kiowa and Graneros, in my judgment it is preferable to employ the term in a group sense. The Kansas Survey, however, presently uses the word Dakota as a formational designation (see Appendix B).

Thickness of the Dakota Group (from the top of the Omadi to the base of the Cretaceous) is shown in Figure 23. Inasmuch as the upper surface is essentially depositional and the lower surface is erosional, the contour lines show pre-Cretaceous topography. Three north-trending areas of thick deposits are shown separated by areas of thinner deposits; the topographic features of this sub-Cretaceous surface are discussed in the section Major Unconformities.

OMADI FORMATION

For want of a better term, Omadi is used here in place of Dakota for subsurface rocks occurring between the Kiowa Shale, below, and the Graneros Shale, above—hence corresponding to Kansas Survey usage of "Dakota Formation" as applied to outcropping rocks. The formational name Omadi was proposed by Condra and Reed in 1943 as an appropriate substitute for Dakota Sandstone and was intended to include strata of Nebraska occurring between the Fuson Shale and Graneros Shale. The type section is in Omadi Township, Dakota County, Nebraska, along the Missouri River bluffs. The term has not been generally accepted, although C. W. Sternberg and A. J. Crowley recently applied it to beds in the Denver Basin between Graneros and Skull Creek Shales (Boreing, 1953). In Kansas, Omadi, if accepted, would include beds between top of the Kiowa (Skull Creek) Shale and base of the Graneros Shale.

Norman Plummer has contributed the following description of the formation as exposed at outcrops (Pl. 7C; Merriam, 1957b, p. 11):

> The Dakota [Omadi] formation as defined by Plummer and Romary (1942), and adopted for usage by the Geological Survey of Kansas at that time, included the rocks above the Kiowa shale and below the Graneros shale. The formation was divided into the Terra Cotta member below and the Janssen member above. The Janssen member is more regularly bedded than the Terra Cotta and contains fairly persistent beds of silt, lignite, and clay. The clays and sandstones of the Terra Cotta member for the most part occur in lenses and elongated irregular masses, although the clays and silts in the lower part of the Terra Cotta member occur in fairly regular and persistent beds, especially in Ellsworth, Lincoln, and Ottawa Counties. This fact was not discussed by Plummer and Romary (1942), but was mentioned later by Plummer and others (1954). These beds in the lower part of the Terra Cotta are similar in appearance to those in the Janssen member and probably could be classed as a separate member in the area designated.
>
> The upper two-thirds to three-fourths of the Terra Cotta member is an extremely complex unit as observed on the outcrop in Kansas. The most conspicuous rock is the massive gray and red mottled clay, which in some places comprise over a hundred feet of the member. Relatively pure clays, lacking the red mottling from ferric oxide, also occur in long narrow masses, which are paralleled by similar masses of sandstone. Most of the sandstones appear to be channel, beach, or bar deposits, which if viewed in three dimensions would consist of a complex network of elongated bodies. In one horizontal plane the directional trend is northeast-southwest and in an adjacent plane the directional trend is northwest-southeast. The evidence obtained from test holes along the outcrops of the Dakota [Omadi] formation in Kansas is extremely confusing. One test hole may penetrate more than 100 feet of sandstone, but another drilled at the same elevation and a few hundred yards from the first may penetrate only clay. Viewed on a larger horizontal scale, the surface exposures of the Dakota [Omadi] are not susceptible of easy interpretation. The general appearance of supposedly equivalent beds varies greatly from west to east. The clay mineral content of the clay beds also varies. In general the proportion of kaolinite to illite is greater in eastern Ellsworth County, for example, than it is in southwestern Dickinson County. Similar variations have also been found from southwest to northeast. Clays in the Janssen member in Ellsworth and Washington Counties are commonly more refractory than equivalent beds in Ford, Hodgeman, Barton, Lincoln, and Ottawa Counties. Also the ferric iron content is higher in these same clays in Washington County than it is in their equivalents in Ellsworth County.
>
> The upper and lower limits of the Dakota [Omadi] formation were primarily defined by Plummer and Romary on the basis of lithology. The shale of the Dakota, including those occurring in the sandstones, are predominantly composed of the clay mineral kaolinite and fire to light colors unless contaminated by ferric oxide. The Graneros and Kiowa shale, on the contrary, are predominantly composed of illite and montmorillonite. Experts on the genesis of clays are agreed that kaolinite is most likely to occur in a nonmarine environment where oxidizing, nonalkaline conditions prevail and where leaching is possible. Illite is more likely to be formed (or preserved) under marine conditions. Therefore, the lithological basis of classification is in reality based on the environments of sedimentation, and the clay minerals of the respective members are diagnostic of marine and nonmarine sediments. Plummer and Romary were of the opinion that the Kiowa and Graneros shale formations are marine in origin and that the Dakota [Omadi] formation is predominantly nonmarine.

The Omadi Formation in the subsurface of Kansas can be divided into three members, which are correlated with divisions recognized in the Nebraska portion of the Denver Basin. In descending order, these are: Gurley Sandstone, Huntsman Shale, and Cruise Sandstone.

Although the terms Omadi, Cruise, Huntsman, and Gurley have not been widely used by petroleum geologists, this terminology, based on geographic place names, has a sounder basis for permanency than designations by letters of the alphabet, which are used by many geologists.

Gurley Sandstone.—The Gurley Sandstone is the upper member of the Omadi Formation and uppermost unit of the Dakota Group as used here. Distribution of the Gurley in Kansas is slightly smaller in area than that of the Cruise and Huntsman Members. Generally speaking, the member becomes more shaly both to the east and south.

In extreme northwestern Kansas, the Gurley comprises two sandstones separated by a thin shale unit, but in other places the member consists of a series of alternating thin sandstones and shales. The sandstone is composed of light-gray, fine- to medium-grained, subrounded quartz fragments and minor amounts of mica, glauconite, and pyrite. The sand locally is carbonaceous; it may contain streaks of dark-gray to black shale, and in some places the sand is coarse grained and even conglomeratic.

Thickness of the Gurley Sandstone ranges from a featheredge to about 120 feet. In general the member thins eastward and southward, but throughout a large area in Kansas it is surprisingly uniform in thickness. Near the eastern limit of the Omadi in Kansas the Graneros Shale seemingly oversteps the truncated Gurley; consequently, in all probability the member does not crop out in Kansas. A few marine fossils have been reported from the Gurley, hence it is at least partly marine.

The Gurley corresponds to the "D" and "G" sands as recognized in the Denver Basin. Both the Gurley and Huntsman are Gulfian in age (Cobban and Reeside, 1952).

Huntsman Shale.—The Huntsman Shale, the middle member of the Omadi Formation, overlies the Cruise Sandstone and in turn is overlain by the Gurley Sandstone. Areal distribution of the Huntsman in Kansas is probably about equal to or slightly less than that of the Cruise Sandstone.

The Huntsman is predominantly greenish-gray to gray, noncalcareous, micaceous, clayey or silty shale containing some interbedded light-gray micaceous siltstone. Siderite pellets are common and in many places abundant, especially in the clay. Thickness of the member ranges from 20 feet to about 90 feet. No marine fossils have been reported from the Huntsman.

The Huntsman is tentatively correlated with the Janssen Clay Member of the Dakota Formation, as described by Plummer and Romary (1942).*

Cruise Sandstone.—The Cruise Sandstone is the lowest member of the Omadi Formation. It overlies the Kiowa Formation (Lower Cretaceous) or Permian beds where the Comanchean is absent. The Cruise probably has the largest areal distribution of any Cretaceous deposit in Kansas.

The Cruise is mainly a light-gray, gray, or light-brown sandstone consisting of fine- to medium-grained, subrounded, friable quartz fragments and minor amounts of mica, glauconite, and carbonaceous material. Eastward, the member becomes more and more shaly and clayey; the sandstones become finer grained and grade into siltstones (Pl. 8A). The amount of sand also decreases eastward to such an extent that on the outcrop about three-fourths of the member is clay or shale (Pl. 8B). The shale is medium gray, noncalcareous, soft, and in part clayey. Siderite pellets are present locally. Large concretions composed mostly of quartz grains cemented by calcite are common locally, for example, at Rock City in Ottawa County (Mack, 1962) and at Pulpit Rock in Ellsworth County (Pl. 8C, 8D). Sandstones on the outcrop show evidence of having been deposited as channel fills (Pl. 9A, 9B, 9C). Thickness of the member ranges from 100 to 200 feet.

Fossils indicate that the member is at least in part marine. The Cruise Sandstone seems to correlate in stratigraphic position with the Terra Cotta Member of the Dakota Formation (described by Plummer and Romary, 1942) at outcrops in north-central Kansas.* Some or all of these beds may be equivalent to the Cockrum Sandstone of southwestern Kansas. Some geologists use the term "J" sandstone for beds that are here called Cruise. In this report the Cruise is tentatively placed entirely in the Gulfian Series, although the exact position of the boundary between the Lower and Upper Cretaceous is not known. Cobban and Reeside (1952) assigned the Omadi (Dakota Formation) to the Upper Cretaceous.

KIOWA SHALE

The Kiowa Shale, the uppermost formation of the Comanchean Series, was named by Cragin in 1894 from rock exposures in Kiowa County, south-central Kansas. Cragin later redefined the Kiowa to exclude the "Champion shell bed" and still later changed its boundary to include the shell bed as the lowermost part of the formation. This usage of the term has been followed subsequently.

DISTRIBUTION.—The best exposed outcrops of the Kiowa are in south-central Kansas in the

* Additional studies by Norman Plummer (personal communication) on clay materials of the Huntsman Shale indicate that they are identical to clays composing the Janssen Member and that both are seemingly nonmarine.

* Norman Plummer (personal communication) believes from preliminary studies of the clay materials in the Cruise Sandstone that possibly they are not equivalent to the Terra Cotta Member. His work indicates that the clays of the Cruise are marine, whereas clays of the Terra Cotta are nonmarine.

vicinity of Cheyenne Sandstone outcrops. The formation is distributed over a slightly larger area than that of the Cheyenne Sandstone.

CHARACTER.—The formation is predominantly a medium- to dark-gray, micaceous, silty, carbonaceous, soft to hard marine shale, but it includes minor amounts of limestone, sandstone, and bentonite (Pl. 10A). The limestone, which occurs as thin "stringers" in the shale, is composed principally of shell fragments. At outcrops, beds of light-gray limestone, containing gypsum or pyrite, are commonly less than 18 inches thick (Latta, 1948, p. 87). The "Champion shell bed" (Latta, 1946) occurs at the base of the formation, but seemingly this bed can not be recognized from well samples. Lenticular light-gray sandstone is composed of fine- to medium-grained quartz fragments. Latta (1948) described several of the sandstone lenses that occur at different stratigraphic horizons in the formation. Bentonite, which occurs as thin seams in the shale, is white or bluish gray.

THICKNESS.—Maximum thickness of the Kiowa is about 380 feet; its average thickness is probably about 100 feet. Some of the apparent variation in thickness of the formation results from uncertainty in determining the upper boundary of the unit.

STRATIGRAPHIC RELATIONS.—In some areas, sandstone in the lower part of the Omadi Formation seems to interfinger with shale in the upper part of the Kiowa Shale; consequently, the limit between the two units is arbitrary. Locally, however, an unconformity separates the two formations (Latta, 1948, p. 86). In areas where the Cheyenne is missing, the Kiowa lies directly on Permian rocks.

CHEYENNE SANDSTONE

The Cheyenne Sandstone, lowest unit of the Cretaceous System in Kansas, was named by Cragin in 1889 from exposures of sandstone at Cheyenne Rock in south-central Kansas. The formation includes beds between the Kiowa Shale, above, and strata then called Triassic but now known to be Permian. Later, Cragin divided the formation into several members, but the proposed names were later discarded by the Federal Geological Survey as applicable only to facies of the Cheyenne.

DISTRIBUTION.—Areal distribution of Comanchean rocks is more restricted than that of Gulfian rocks. The Comanchean is best exposed in the Belvidere region and adjoining areas in Barber, Kiowa, Comanche, and Clark Counties, in south-central Kansas.

CHARACTER.—The Cheyenne is mainly a light-colored, fine- to medium-grained, friable, cross-bedded sandstone containing lenses of sandy shale and conglomerate and minor amounts of clay, selenite, ferruginous nodules, and pyrite. Sandstone is the dominant rock type (Pl. 10B, 10C). Subsurface samples of the formation consist almost entirely of white, fine to medium, subrounded, frosted, loose or slightly cemented quartz grains. In most samples the cement is pyrite or calcium carbonate. At the Champion Draw section (sec. 9, T. 30 S., R. 16 W.) in Kiowa County, pebbles and cobbles of quartzite, quartz, and chert are present at the base of the Cheyenne Sandstone. According to Latta (1946, p. 237), the thickness of this conglomerate ranges to 45 feet.

THICKNESS.—Total thickness of Cheyenne Sandstone along the outcrop ranges from 33 to 94 feet. In the subsurface the formation reaches a maximum thickness of about 300 feet; it is in excess of 200 feet in north-central Ellis County (Frye and Brazil, 1943). Abrupt changes in thickness in short distances result from the fact that the formation was deposited on an unevenly eroded pre-Cretaceous surface of considerable local relief (Pl. 11A). In general the formation thins to the east and south.

STRATIGRAPHIC RELATIONS.—The contact with the overlying Kiowa Shale is conformable, but the lower contact is erosional.

Sedimentary History

First Cretaceous deposition on the irregularly eroded Permian-Triassic-Jurassic surface was a conglomerate of pebbles and cobbles, just above the unconformity, which is variously assigned to the Cheyenne, Kiowa, or Omadi, whichever is the lowest Cretaceous unit present. Pebbles consist of igneous and metamorphic rocks and chert; quartzite and chert predominate (Pl. 11B, 11C). On the basis of fossils in the chert, the conglomerate is presumed to have had an eastern source (Moore and others, 1951a, p. 28).

The Cheyenne Sandstone was deposited on the eroded pre-Cretaceous surface. It is natural to assume that the first deposition took place in topographically low areas and that, as sedimentation continued, valleys were filled and sedimentation eventually extended over the divides. One of these large filled valleys is shown in Figure 12. As the Cretaceous sea advanced from the south, the strand line probably oscillated. Gradually a completely marine environment came to characterize Kansas in Kiowa time. To the east, land was still high enough to prevent accumulation of early Cretaceous deposits. As the sea swept farther north and east, sediments came to have an overlapping relation on the

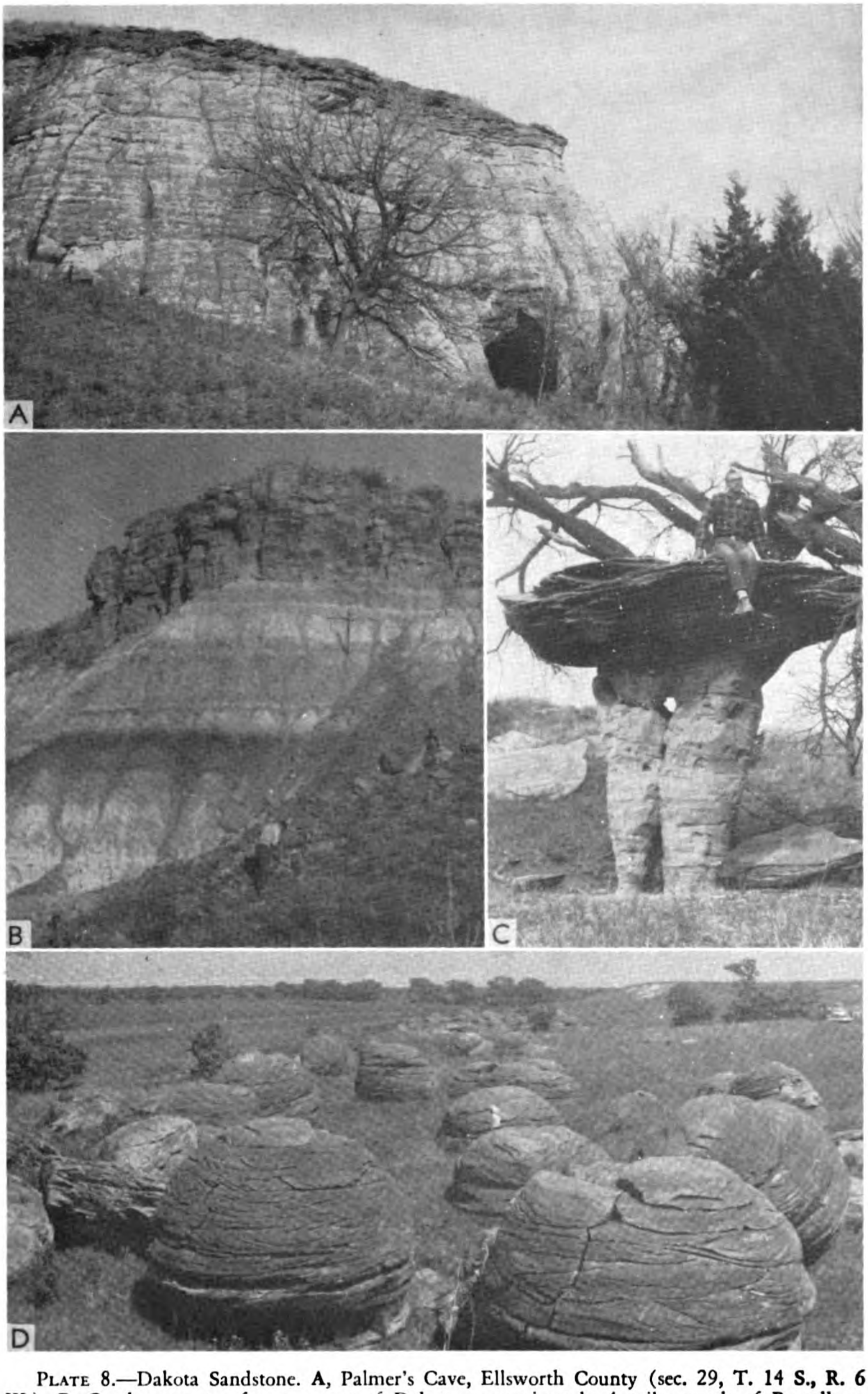


PLATE 8.—Dakota Sandstone. **A**, Palmer's Cave, Ellsworth County (sec. 29, **T. 14 S., R. 6 W.**). **B**, Good exposure of upper part of Dakota, approximately 4 miles north of **Russell** on U.S. Highway 281, Russell County. **C**, Pulpit Rock just south of Carneiro, **Ellsworth County** (sec. 19, T. 15 S., R. 6 W.). **D**, Rock City concretions southwest of **Minneapolis, Ottawa County** (sec. 14, T. 11 S., R. 4 W.).

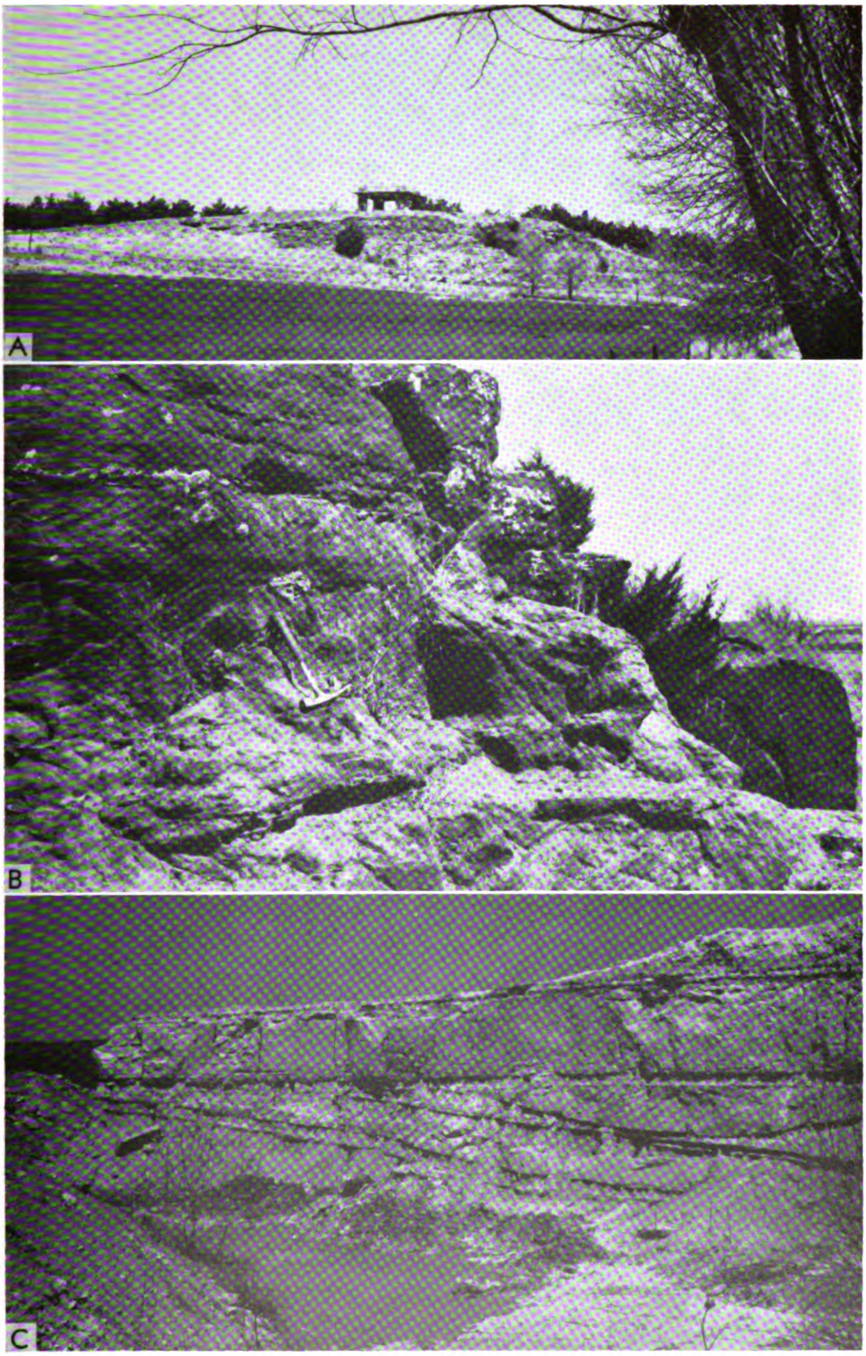


Plate 9.—Dakota Sandstone. **A** and **B**, Pawnee Rock, Barton County (NE sec. 33, T. 20 S., R. 15 W.). **C**, Exposure in abandoned clay pit on southwest side of Cheyenne Bottoms, Barton County (sec. 9, T. 19 S., R. 13 W.).

Plate 10.—A, Exposures of Kiowa Shale underlain by Cheyenne Sandstone in Champion Draw near Belvidere, Kiowa County. **B,** Cheyenne Sandstone erosional remnant near Belvidere, Kiowa County. **C,** Cheyenne Sandstone outcrop near Belvidere, Kiowa County.

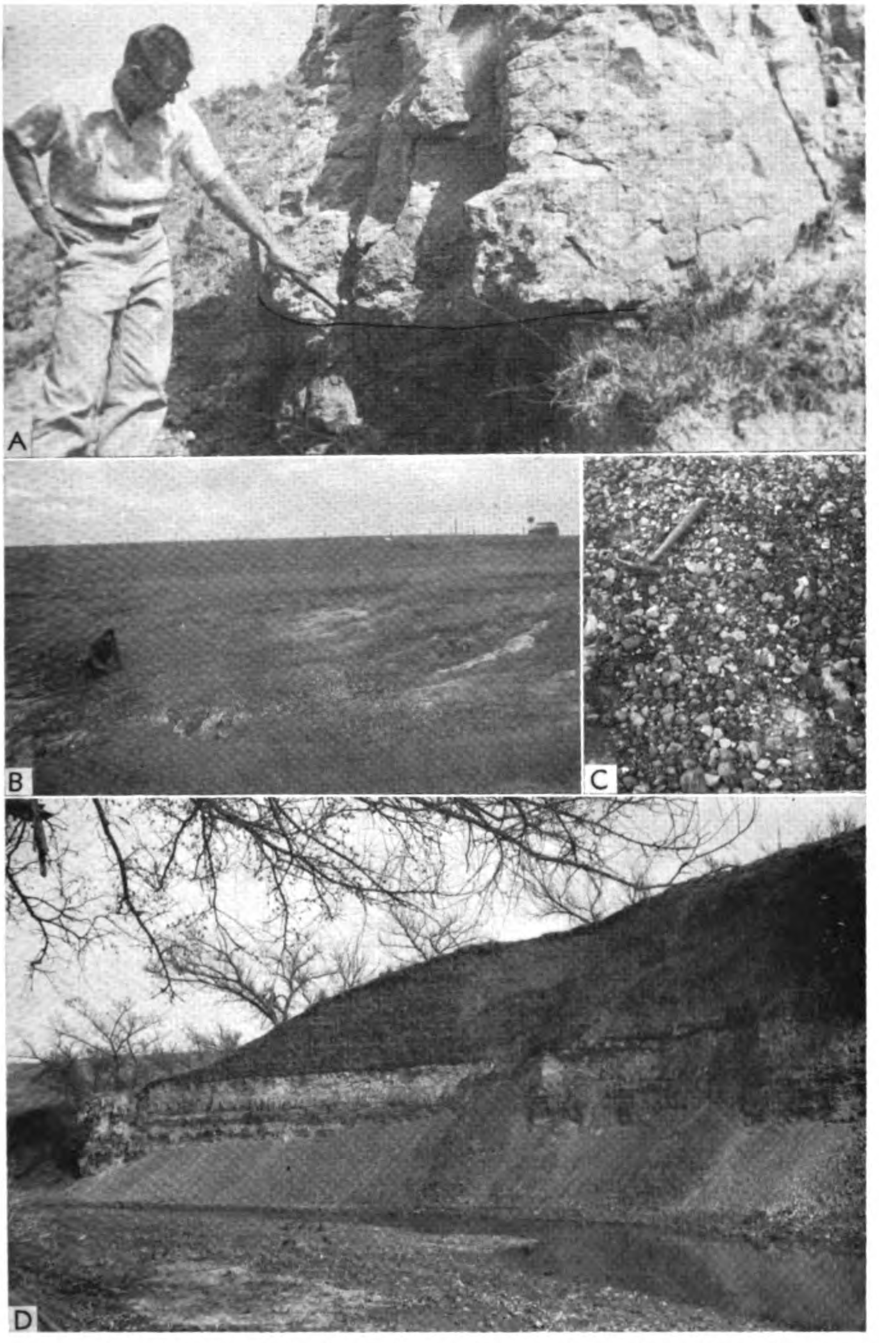
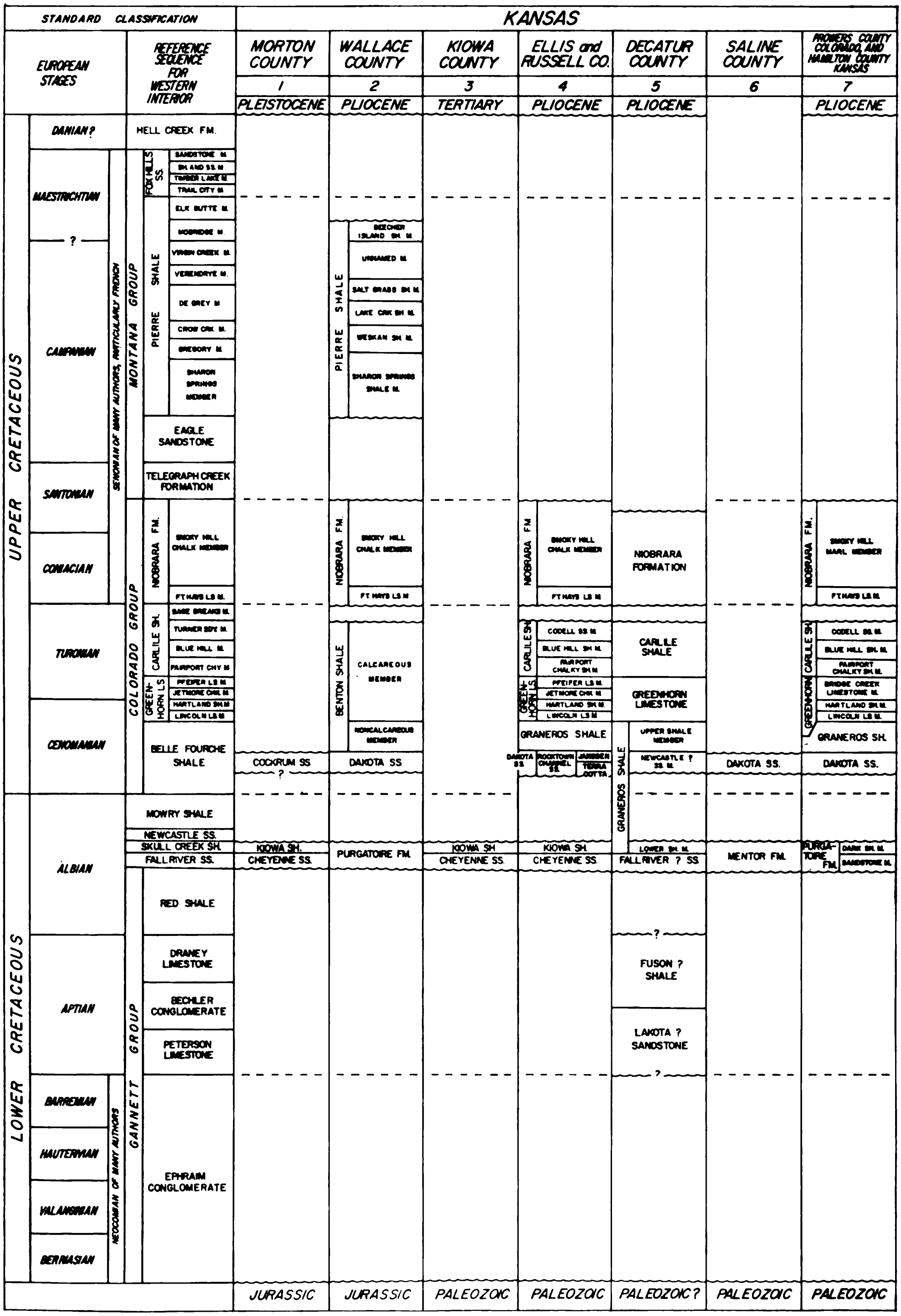


PLATE 11.—**A,** Cheyenne Sandstone (Lower Cretaceous) overlying "Taloga Formation" (Permian), Clark County (E2 sec. 25, T. 32 S., R. 25 W.). **B,** Basal Cretaceous conglomerate, Rice County (SW sec. 32, T. 19 S., R. 6 W.). **C,** Pebbles and cobbles of basal Cretaceous conglomerate consisting of igneous and metamorphic rocks and chert, Rice County (SW sec. 32, T. 19 S., R. 6 W.). **D,** Kiowa Shale (Lower Cretaceous) overlying Ninnescah Shale (Permian), Ellsworth County (sec. 2, T. 17 S., R. 6 W.).


STANDARD CLASSIFICATION
KANSAS
EUROPEAN STAGES
REFERENCE SEQUENCE FOR WESTERN INTERIOR
MORTON COUNTY 1
WALLACE COUNTY 2
KIOWA COUNTY 3
ELLIS and RUSSELL CO. 4
DECATUR COUNTY 5
SALINE COUNTY 6
PROWERS COUNTY COLORADO, AND HAMILTON COUNTY KANSAS 7
PLEISTOCENE
PLIOCENE
TERTIARY
PLIOCENE
PLIOCENE
PLIOCENE
UPPER CRETACEOUS
LOWER CRETACEOUS
DANIAN?
MAESTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
SENONIAN OF MANY AUTHORS, PARTICULARLY FRENCH
NEOCOMIAN OF MANY AUTHORS
HELL CREEK FM.
MONTANA GROUP
FOX HILLS SS
PIERRE SHALE
ELK BUTTE M.
MOBRIDGE M.
VIRGIN CREEK M.
VERENDRYE M.
DE GREY M.
CROW CRK. M.
GREGORY M.
SHARON SPRINGS MEMBER
EAGLE SANDSTONE
TELEGRAPH CREEK FORMATION
COLORADO GROUP
NIOBRARA FM.
SMOKY HILL CHALK MEMBER
FT HAYS LS M.
CARLILE SH.
SAGE BREAKS M.
TURNER SDY M.
BLUE HILL M.
FAIRPORT CHY M
GREEN-HORN LS
PFEIFER LS M.
JETMORE CHK M.
HARTLAND SH M.
LINCOLN LS M.
BELLE FOURCHE SHALE
MOWRY SHALE
NEWCASTLE SS.
SKULL CREEK SH.
FALL RIVER SS.
GANNETT GROUP
RED SHALE
DRANEY LIMESTONE
BECHLER CONGLOMERATE
PETERSON LIMESTONE
EPHRAIM CONGLOMERATE
COCKRUM SS
KIOWA SH.
CHEYENNE SS.
PIERRE SHALE
BEECHER ISLAND SH. M.
UNNAMED M.
SALT GRASS SH M.
LAKE CRK SH M.
WESKAN SH M.
SHARON SPRINGS SHALE M.
NIOBRARA FM.
SMOKY HILL CHALK MEMBER
FT HAYS LS M
BENTON SHALE
CALCAREOUS MEMBER
NONCALCAREOUS MEMBER
DAKOTA SS
PURGATOIRE FM.
KIOWA SH
CHEYENNE SS.
NIOBRARA FM.
SMOKY HILL CHALK MEMBER
FT HAYS LS M
CARLILE SH
CODELL SS M.
BLUE HILL SH M.
FAIRPORT CHALKY SH M.
GREEN-HORN LS
PFEIFER LS M.
JETMORE CHK M.
HARTLAND SH M.
LINCOLN LS M
GRANEROS SHALE
DAKOTA SS
ROCKTOWN CHANNEL SS
JANSSEN
TERRA COTTA
KIOWA SH.
CHEYENNE SS
NIOBRARA FORMATION
CARLILE SHALE
GREENHORN LIMESTONE
GRANEROS SHALE
UPPER SHALE MEMBER
NEWCASTLE ? SS. M.
LOWER SH. M.
FALL RIVER ? SS
FUSON ? SHALE
LAKOTA ? SANDSTONE
DAKOTA SS.
MENTOR FM.
NIOBRARA FM.
SMOKY HILL MARL MEMBER
FT HAYS LS M.
CARLILE SH.
CODELL SS M.
BLUE HILL SH. M.
FAIRPORT CHALKY SH M.
GREENHORN
BRIDGE CREEK LIMESTONE M.
HARTLAND SH M.
LINCOLN LS M.
GRANEROS SH.
DAKOTA SS.
PURGA-TOIRE FM.
DARK SH M.
SANDSTONE M.
JURASSIC
JURASSIC
PALEOZOIC
PALEOZOIC
PALEOZOIC?
PALEOZOIC
PALEOZOIC

pre-Cretaceous surface, each younger deposit extending farther to the north and east (Pl. 11D).

By the beginning of Omadi deposition, the sea floor had become relatively smooth, even though minor irregularities of the pre-Cretaceous surface persisted (Plummer and Romary, 1942, p. 325). Locally, as the shoreline separating marine and nonmarine conditions shifted, the upper part of the Kiowa Shale and the lower part of the Omadi Formation interfingered. In some areas conditions must have fluctuated from marine to near-marine to nonmarine many times during deposition of the Omadi. The end of Omadi time was marked by a readvance of the Cretaceous sea over the Kansas region. It is especially evident along marginal areas that marine planation truncated part of the Omadi sediments.

The Graneros Shale was deposited when marine conditions returned. Volcanic eruptions added layers of ash, now altered to bentonite. As the basin subsided, Greenhorn limestone and limy shale were laid down. Volcanoes were still active and contributed ash to the sediments. Conditions again changed before deposition of the Fairport Chalk. Hattin (1952, p. 20) believed that this shale was deposited during a period of areally restricted sedimentation and that the silt present in this member was transported by wind. The Blue Hill Shale was deposited in shallower water and probably far from high land, as shown by the absence of coarse clastic particles of the kind so common in the Fairport Member. Volcanoes were still active during deposition of the Carlile Shale and supplied quantities of material to the sediments. Rapid deposition of the Codell Sandstone indicates a temporary regression of the sea (Hattin, 1952).

The Fort Hays Limestone indicates a clear-water marine environment. A moderate change of conditions, seemingly marked by increased turbidity of the shallow sea, resulted in deposition of the Smoky Hill Chalk. Volcanic activity must have been at a maximum at this time in order to produce the many bentonite beds in the Niobrara. Following Niobrara time evidence of many ash falls was recorded in the Pierre. Some time after Pierre Shale deposition in Kansas, the area was tilted toward the Denver Basin, and Cretaceous beds east of Colorado were elevated, eroded, and beveled. It is impossible to ascertain the eastern limit of Cretaceous deposition because all evidence of eastern marginal areas of the Cretaceous seaway has been removed by erosion. In post-Pierre time the amount of Cretaceous and older rock material removed by erosion from Kansas must have been great. Considerable time elapsed from the end of Pierre sedimentation until deposition of the Ogallala Formation.

Age and Correlation

The relative age of Cretaceous beds is shown in Figure 24, which is adapted from Cobban and Reeside (1952). Some of the nomenclature used in various parts of Kansas prior to publication of the chart is also shown. Cretaceous stratigraphic names used in Kansas and their present status are given in Appendix B.

Sub-Cretaceous Surface

After deposition of the Morrison Formation (Late Jurassic), considerable time elapsed before the first Cretaceous sediments were deposited in Kansas. During this interval, unknown quantities of pre-Cretaceous rock were weathered, eroded, and transported from Kansas and redeposited elsewhere. The configuration of the erosional surface beneath the Cretaceous, perhaps partly much older than Jurassic in origin, is shown in Figure 25.

Because it is almost impossible to identify the erosional surface from data given by electric and radioactivity logs, information for the map was obtained chiefly from sample logs of the Kansas Survey and the Kansas Sample Log Service. Some data were gathered from logs of ground-water test holes drilled by the Ground-Water Division of the State and Federal Geological Surveys, especially along the eastern margin of the Cretaceous outcrop where the Cretaceous is thin.

Configuration of the contours reveals a northward-sloping surface having sizeable relief. Although the map shows the surface as it is now (datum, sea level), it is believed that deformation during and after Cretaceous time changed it only slightly. The surface is cut into beds of Permian, Triassic, and Jurassic age.

Three major north-trending valleys and numerous minor tributaries are cut on the surface. One of these valleys extends from eastern Rawlins County through eastern Thomas County, western Gove County, and Lane County to east-

FIGURE 24.—Chart showing terminology used for Cretaceous units in Kansas (adapted from Cobban and Reeside, 1952). 1, McLaughlin (1942); 2, Elias (1931); 3, Twenhofel (1924); 4, Bass (1926), Plummer and Romary (1942), Rubey and Bass (1925); 5, Condra, Schramm, and Lugn (1931); 6, Twenhofel (1924); 7, Bass, (1926), Dane, Pierce, and Reeside (1937), Patton (1924). Correction: the Fairport Member of the Carlile Shale is now referred to as Fairport Chalk.

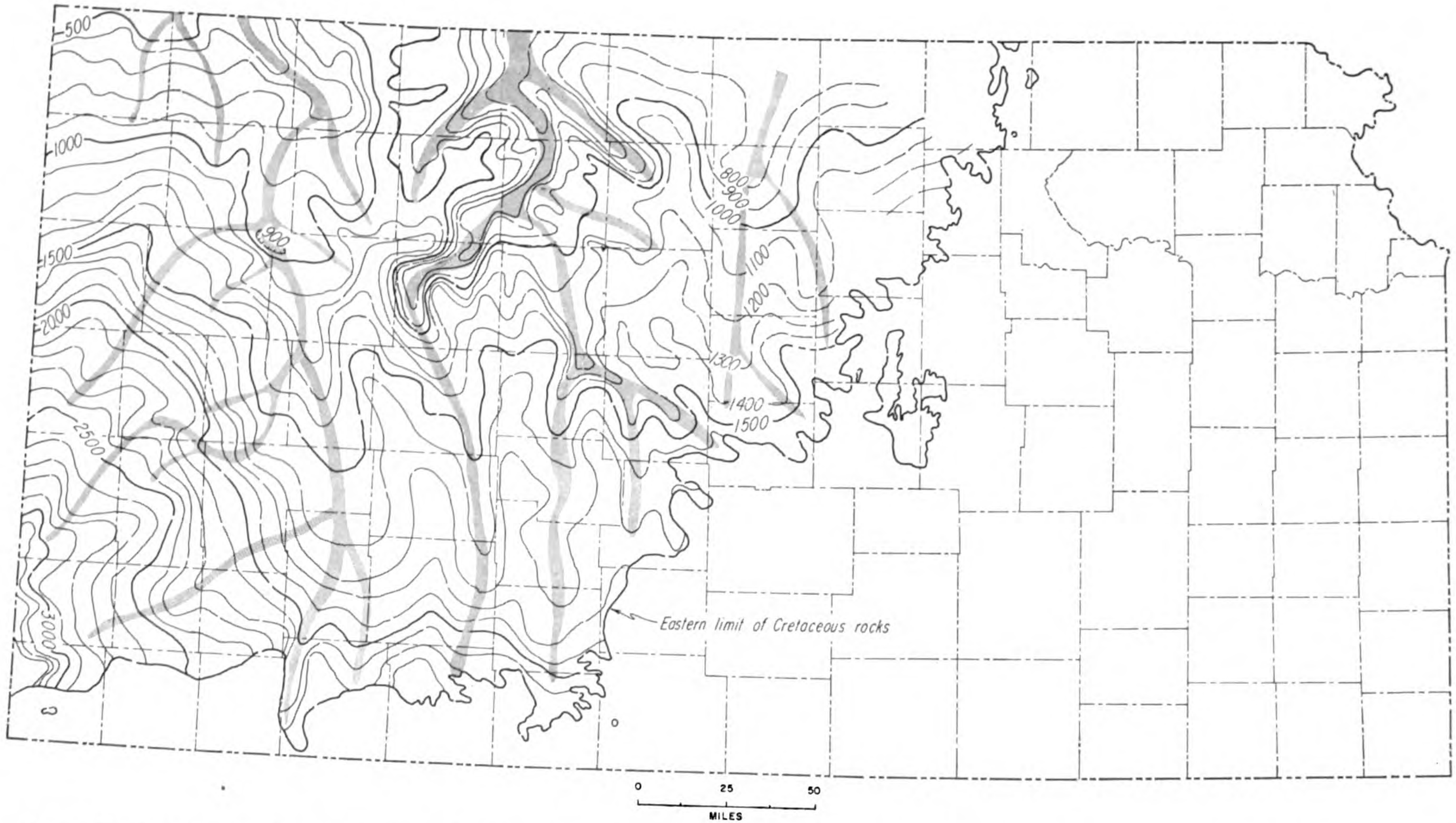


FIGURE 25.—Map of Kansas showing present configuration of surface at base of Cretaceous beds, i.e., topographic features that were developed on pre-Cretaceous surface. Three major northward-trending valleys and their tributaries are shaded. Contour interval 100 feet. Additional detailed work was done on this surface by Schuman (1963); Jesse McNellis (personal communication, August 13, 1963) believes the valley as shown in Rush County is due to a miscorrelation of placing the Cretaceous-Permian contact too low.

ern Finney County. Another extends from western Phillips County through western Rooks County and Trego and Ellis Counties to Rush County. The easternmost valley is located in Jewell and Mitchell Counties and western Lincoln and Ellsworth Counties. From the angle at which the tributaries meet the main trunks, it appears that the streams were incised on a north-sloping surface.

Divides separating the valleys show that at least 400 feet of topographic relief was developed on the erosional surface. Until they were filled, these large valleys must have exerted considerable influence on deposition of lower Cretaceous sediments.

Jurassic Deposits

It has long been recognized that Jurassic rocks in the subsurface underlie about the western one-fifth of Kansas (Fig. 26); yet, little work was done to describe these sediments until the early 1950s, partly because of lack of available well data and partly because the Jurassic beds as yet have no economic significance. All Jurassic deposits in Kansas, ranging in thickness from a featheredge to 350 feet, are assigned to the Morrison Formation.

Previous brief descriptions of the Jurassic in Kansas have been published by Elias (1937b), Landes and Keroher (1939), Norton (1939), Ver Wiebe (1939), Latta (1941), McLaughlin (1942, 1943, 1946), Landes and Keroher (1942), Moore and others (1951a), Prescott (1951), and Lee and Merriam (1954a). Moore and others (1951a) and McCoy (1953) presented generalized maps to show the areal extent of the Jurassic in Kansas. Lee and Merriam (1954a) presented a more detailed map of the distribution of these sediments, along with a brief description of their lithology. Merriam (1955a) published a detailed description of Jurassic rocks in Kansas. In 1956 McKee and others, in an excellent, comprehensive publication on the system, described Jurassic deposits of the United States.

Jurassic rocks occur only in the subsurface in the western part of the state, west of a line extending from Phillips County to Morton County. The outcropping Jurassic rocks nearest to Kansas occur in Cimarron County, Oklahoma (Stovall, 1943), Union County, New Mexico (Harley, 1940), and at Two Buttes, Prowers and Baca Counties, Colorado (Sanders, 1934). Portions of these Jurassic rocks have been correlated with the type Morrison Formation, located near the town of Morrison, Colorado (Waldschmidt and LeRoy, 1944). The Morrison of the subsurface of western Nebraska has been described by Condra and Reed (1943). The strata lying between the Permian and Triassic? and the Cretaceous in Kansas are tentatively correlated with the Morrison Formation because of their similarity to Jurassic beds assigned to the Morrison in neighboring states.

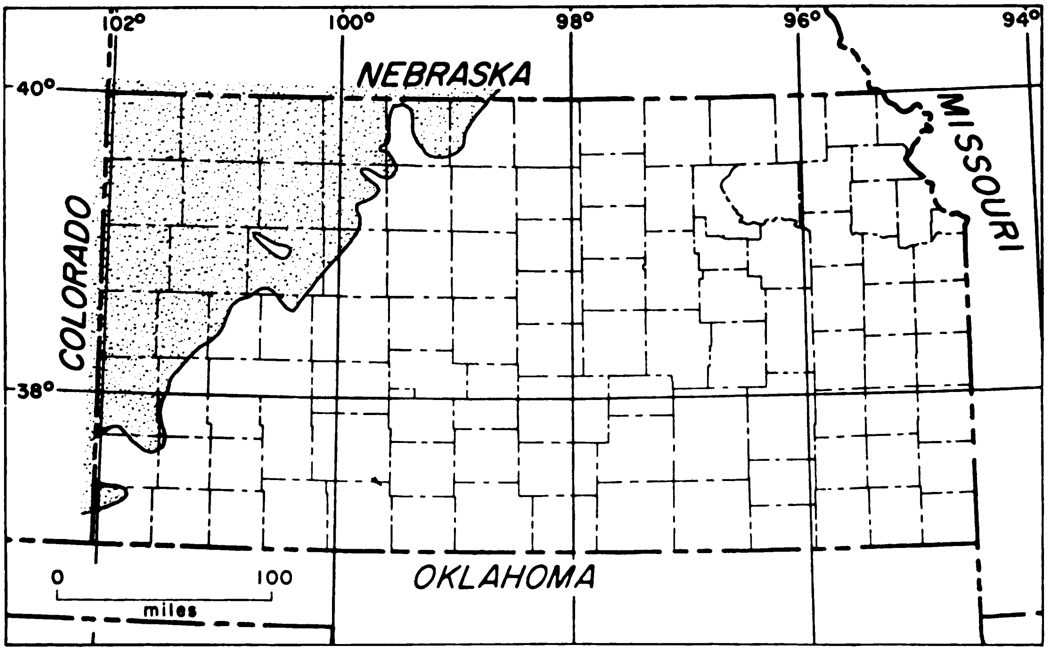


FIGURE 26.—Map of Kansas showing subsurface distribution of Jurassic rocks.

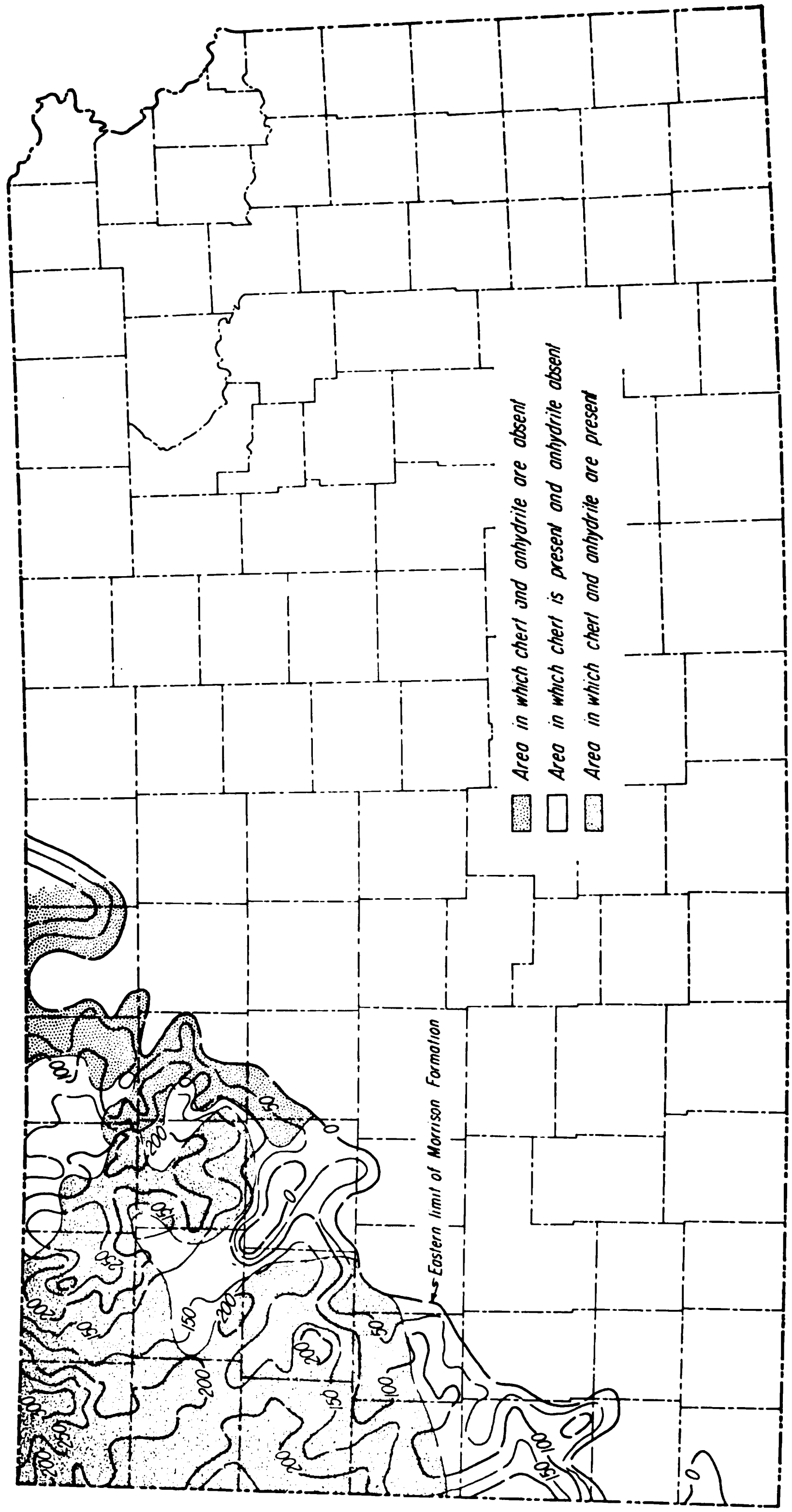


FIGURE 27.—Isopachous map of Morrison Formation (Jurassic) in western Kansas (adapted from Merriam, 1955a). Contour interval 50 feet.

Upper Jurassic

MORRISON FORMATION

The Morrison Formation, which was named by G. H. Eldridge in 1896 (*in* Emmons, Cross, and Eldridge, 1896), consists of shale, sandstone, and limestone, and small amounts of chert and anhydrite. Shale is the predominate lithologic type (Merriam, 1955a).

Two distinct lithologic units of the Morrison Formation are recognizable in Kansas. Both units consist of sandy shale, but the upper one contains limestone "stringers" and the lower is cherty and contains anhydrite. All the shale seems to be similar lithologically; the units are recognized by the associated limestone, chert, and anhydrite.

A tripartite division of the formation might be possible if better well samples were available. In surface sections the chert forms a single thin bed or several thin layers within a thickness of 10 to 20 feet of shale (S. S. Oriel, personal communication). Thus, it might be possible to distinguish an upper unit of sandy shale and limestone, a middle unit of shale interbedded with chert, and a lower unit of shale containing anhydrite. Although this tripartite division is only vaguely recognizable in the well logs, the units are fairly consistent in relation to one another over the entire area. Because the top of the chert is probably the most consistent and best defined datum, it has been used for structural mapping. Ogden (1954) described this same chert, which also occurs in Colorado, Utah, Wyoming, and New Mexico, and suggested that it may be an altered volcanic ash. If true, it represents a very valuable time-surface marker. An alternate suggestion has been made by Frederickson, DeLay, and Saylor (1956); they conclude that the chert was formed as concretionary deposits of chalcedony concentrated by ground water. The chert is absent in Phillips County, eastern Norton, Graham, and Gove Counties, and Trego County. The anhydrite does not extend east as far as the chert and is absent in Norton County, northeastern Decatur County, most of Graham, Gove, and Thomas Counties, southern Wichita and Greeley Counties, and Kearny and Hamilton Counties (Fig. 27). In parts of Gove and Thomas Counties where anhydrite is absent, the Morrison thins in an area over the approximate location of the Oakley Anticline.

The upper unit is the more extensive of the two and is present over the entire area of occurrence. The absence of limestone in some wells is probably due to local conditions during deposition. Where only sandy shale is present (no chert or anhydrite), it is assumed that the sediments represent the upper unit. Because it is possible to recognize the units and their areal extent, one is able to show that younger divisions of the Morrison Formation overstep older ones on the Permian-Triassic surface.

The Morrison units are also recognized and correlated by LeRoy (1946), Ogden (1954), and S. S. Oriel (personal communication) over an area of several states.

CHARACTER.—The lithologic descriptions herein presented apply to the formation as a whole and not to any particular unit. The lithology is about the same for a given rock type, regardless of its stratigraphic position in the section. Characteristically the shale is predominantly greenish gray but locally is tinted buff, brown, red, or purple; many beds are silty or sandy, calcareous, and soft. Disseminated at random throughout the shale are very fine to fine, subrounded to rounded sand grains and clear or white quartz fragments. In general the amount of calcium carbonate in the shale increases westward and northwestward. Small flakes of mica and grains of pyrite are also present, as well as very small round pellets resembling the siderite pellets found in the Dakota rocks.

Except in part of Phillips County, where it constitutes a considerable part of the section, sandstone is sparse in the formation. It is composed of white, fine-grained, subrounded, frosted, loosely cemented quartz fragments chiefly in the basal part of the formation. Other thin beds of sandstone of similar lithology are scattered throughout the formation, but they are more abundant in the eastern part of the area. White to gray-green siltstone is a minor constituent.

The limestone "stringers" are white to light gray, gradational from chalky to shaly or crystalline, variously soft to hard, and in places contain small cubes of pyrite. The limestone seemingly occurs as thin beds in the shale and may be found stratigraphically anywhere in the formation, but it commonly lies above the chert. Insoluble residues of the limestone consist of very finely disseminated matted siliceous material.

The chert is white to pink, although some has a bluish tinge; it is generally translucent and is conchoidally fractured. Some of the chert is chalcedonic. The anhydrite is white to pinkish and crystalline or sugary.

DISTRIBUTION AND THICKNESS.—Distribution of the Morrison Formation is shown by an isopachous map (Fig. 27). The thickness of the formation ranges from a featheredge along the southeastern side of the area to 300 feet in

Cheyenne County. Thus, the Morrison increases in thickness to the northwest, forming a wedge-shaped mass between the Permian-Triassic? and the Cretaceous sediments. Several northwest-elongated areas of thinning of the Morrison are shown, especially in eastern Phillips County, northeastern Graham County, northwestern Gove County, central Wichita County, and southeastern Greeley County. In northwestern Gove County the Morrison has been completely removed, and Cretaceous beds lie directly on Permian. Areas of thicker deposits flank both sides of areas in which the Morrison is thin or absent. Although the zero line of the formation is irregular, its overall trend is persistently toward the northeast.

There are two areas of semi-isolated Morrison, one in northwestern Morton County and the other in southeastern Phillips County. In Morton County a ground-water test penetrated 28 feet of blue-green clay and marl and 12 feet of blue-green, light-gray, and brown sandstone, which McLaughlin (1942, p. 72) regarded as Morrison. These rocks lie between the Cheyenne Sandstone of Cretaceous age and Triassic? redbeds. The rocks thus described closely resemble the Morrison, and they are classed as such. Morrison was reported from four wells in southeastern Phillips County, but samples were available from only one well. Examination revealed Morrison-like beds, but not typical Morrison, such as occurs farther west in Kansas. On the other hand, the samples do not resemble Dakota, Kiowa, or Cheyenne, and are certainly not redbeds. Although most of the samples consist of sandstone, some light-green sandy micaceous noncalcareous shale is present, and it is judged that these beds all belong to the Morrison. Some support for this conclusion is found in the evidence that the Jurassic extends farther east in Nebraska than in Kansas (E. C. Reed, 1950). The deposits in Nebraska are also sandier in the east than in the west.

STRATIGRAPHIC RELATIONS.—The Morrison Formation in Kansas unconformably overlies Permian or Triassic? beds and is unconformably overlain by Cretaceous formations—Dakota, Kiowa, or Cheyenne. The Morrison overlies the Permian, except in part of Morton County in the extreme southwestern part of the state, where it overlies beds of Triassic? age.

A study of the distribution of the divisions of the Morrison Formation reveals an interesting relationship. The eastern limit of these units is shown on Figure 27. Each successively younger rock type extends farther to the east, forming an overstep relationship on the Permian-Triassic surface. The anhydrite is missing in parts of Gove and Thomas Counties that correspond in position to the Oakley Anticline (Lee and Merriam, 1954a, pl. 3A). The eastern limit of the anhydrite also borders the western edge of the Cambridge Arch, and it is concluded that these structurally positive areas were high during deposition of the lower Morrison. Because the chert extends across both of these areas, it is assumed that the low areas were filled by deposition of anhydrite and shale, allowing the chert to overlap eastward. The upper unit extends still farther eastward.

The top of the persistent chert is assumed to represent a stratigraphic datum that was originally approximately flat and horizontal; Figure 28 shows the approximate relief on the lower and upper surfaces of the Morrison Formation. Although the period of erosion extended from the Permian to Late Jurassic, and although the pre-Morrison beds were extensively beveled, the

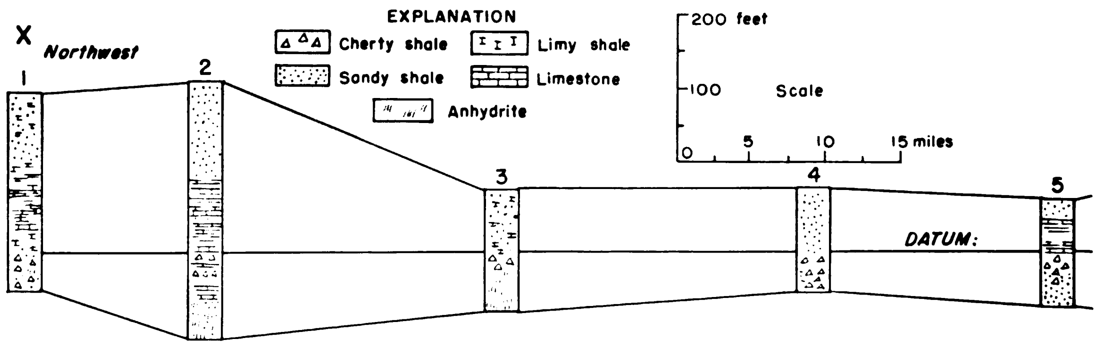


FIGURE 28.—Cross section of Morrison Formation (Jurassic) showing

topographic relief of the erosional surface was about 110 feet.

ENVIRONMENT OF DEPOSITION.—The Morrison Formation in Kansas probably is nonmarine, although this can not be proved by available information. At the nearest outcrops, the sediments of the Morrison are fluvial in origin (Stovall, 1943, p. 67), and the deposits in Kansas resemble them in lithologic nature and in geologic setting; hence, it is believed that they also are nonmarine.

In Figure 29, which is a clastic-percentage map of the Morrison Formation, the 100-percent line indicates all-clastic material, the 90-percent line indicates 90 percent clastics and 10 percent nonclastics, etc. The percentage of nonclastic material in the total section ranges from 0 to 36 percent. The clastic sediments are mainly sandstone and shale, whereas the nonclastics are limestone and anhydrite.

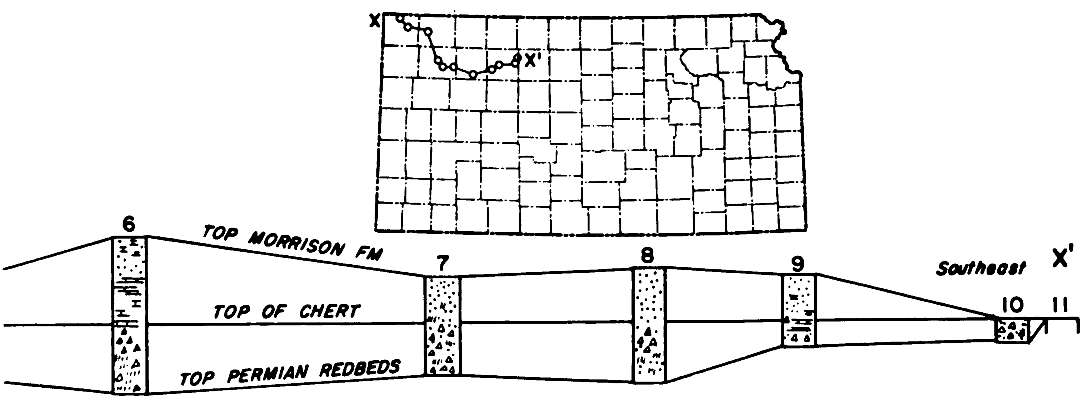
A belt of clastic sediments 6 to 40 miles wide is located along the southeastern side of the area from Phillips County to Morton County. The formation is similarly clastic in an area in Thomas County and southeastern Rawlins County. Except in part of eastern Phillips County, where the section is composed mostly of sandstone, the clastic materials consist mostly of sandy shale. Because coarser clastics, normally expected along a depositional pinchout, are absent, it is believed that the present margin of the upper unit of the Morrison Formation represents an erosional boundary. In general, the map shows that the nonclastic material in the formation increases from southeast to west and northwest, except in two northwest-trending areas: (1) southwestern Sherman County and Wallace and Wichita Counties, and (2) northeastern Sheridan County and eastern Decatur County. Between these areas of nonclastic material there are places in Gove and Thomas Counties and southeastern Rawlins County where the clastic content of the Morrison exceeds 90 percent. This area corresponds roughly to the position of the Oakley Anticline. As already pointed out, this structural feature, which was topographically high, controlled deposition of the sediments that compose the lower unit.

Distribution and position of the clastic materials of the Morrison indicate that the source of sediments was to the southeast. Hence, the direction of stream flow must have been northwesterly. Because the streams flowed on a surface of low relief, they must have been sluggish and capable of carrying only fine-grained sediments. Small lakes and back-water areas also must have developed on low, flat, marginal areas. Anhydrite accumulated under desiccating conditions, which alternated with humid conditions that favored fluvial deposition.

Deposition of the lower unit ended with an ash fall. The clastic sediments in Gove and Thomas Counties seemingly are delta deposits. Behind this delta, if it existed, would be quiet water favorable for deposition of fresh-water limestone. Limestone would also be deposited farther northwest in areas where clastic sediments were not deposited.

AGE AND CORRELATION.—It is probably only by chance that no fossils have been found in the well samples of the Morrison Formation; many fossils have been found at surface exposures. Stovall (1943, p. 68) has described dinosaur remains, some chara, ostracodes, gastropods, and pelecypods from Cimarron County, Oklahoma.

The chert bed is the best marker in the section and can be traced throughout most of the area where Jurassic rocks are present. This chert



topographic relief on lower and upper surfaces (from Merriam, 1955a).

bed is undoubtedly the one described by Ogden (1954). The unit can be traced into Wyoming, where it occurs in the marine upper Sundance (S. S. Oriel, personal communication). The lower unit of the Morrison Formation in Kansas, then, is believed to be equivalent to the upper Sundance of Wyoming and possibly to the Ralston Formation of Colorado (LeRoy, 1946). McKee and others (1956) have shown this unit to be equivalent to the Wanakah For-

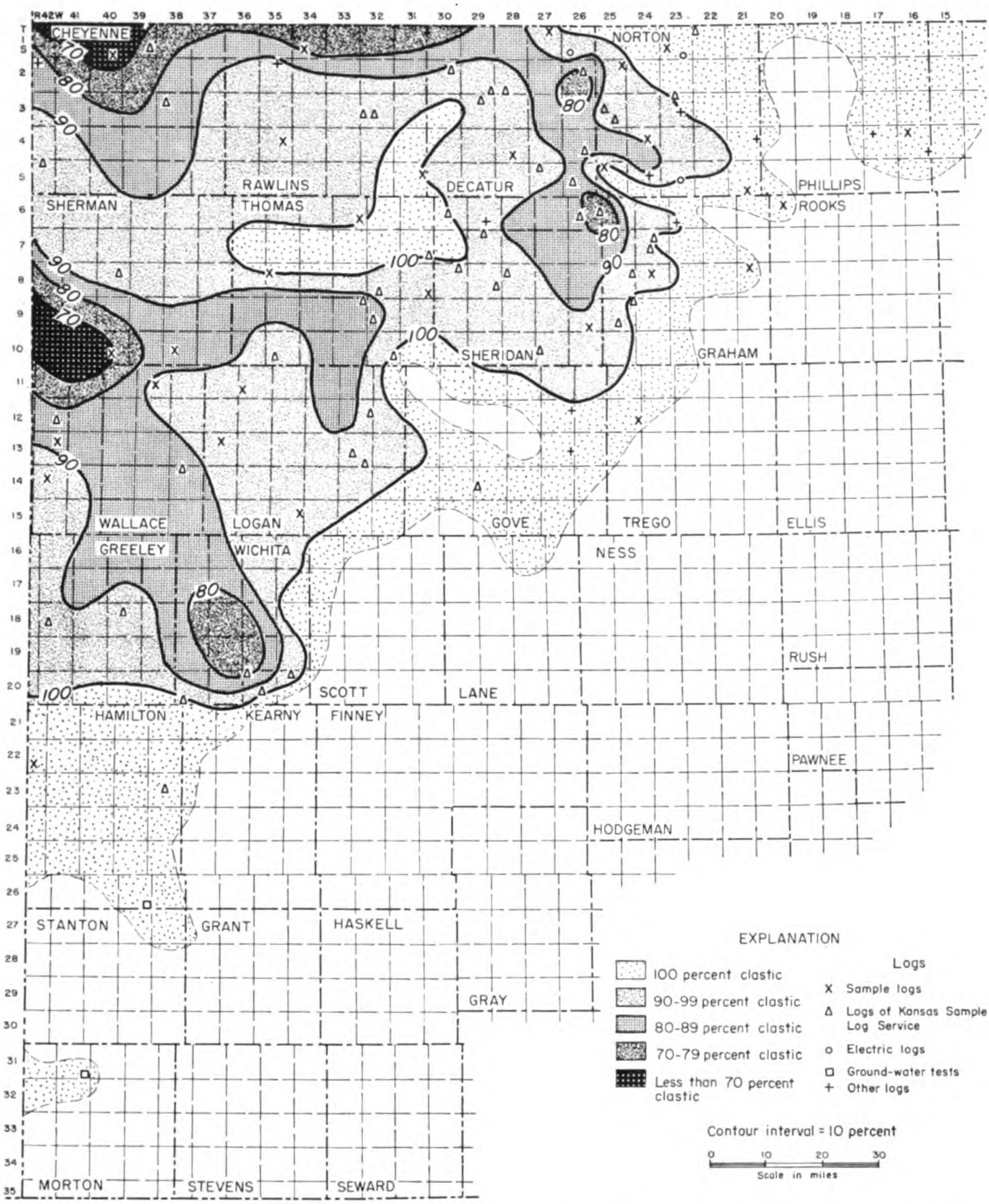


FIGURE 29.—Clastic-percentage map of Morrison Formation (Jurassic) in western Kansas. Distribution of clastics suggests that beds were deposited by northwestward-flowing streams and that source of sediments was southeast (from Merriam, 1955a).

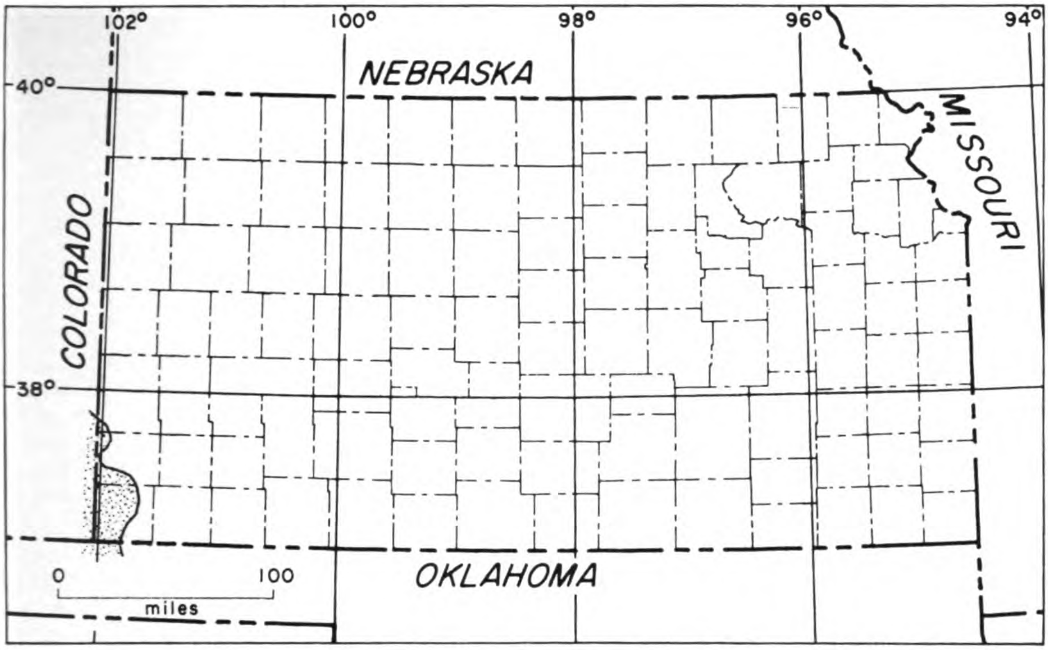


FIGURE 30.—Map of Kansas showing surface and subsurface distribution of Triassic rocks.

mation of Colorado and New Mexico, Summerville Formation of Arizona, and Swift Formation of North Dakota and Montana. The upper unit of the Morrison Formation in Kansas is equivalent to the type Morrison, as described by Waldschmidt and LeRoy (1944). The age of the Morrison in Kansas is Late Jurassic (Imlay, 1952).

Triassic Deposits

In Kansas Triassic deposits are known to occur only in the extreme southwestern part. Little interest has been shown in them, mainly because at present they have no economic value except for local ground-water supplies. They are assigned to the Dockum? Group.

Dockum? Group

The Dockum Group was named by W. F. Cummins in 1890 (p. 189) from exposures near Dockum, Dickens County, Texas. In Texas the group is divided into the Trujillo Formation (above) and Tecovas Shale (below). The Dockum unconformably overlies Permian rocks and is unconformably overlain by the Blanco Formation of Pliocene age (Wilmarth, 1938, p. 616).

Rocks in Kansas between the top of the "Taloga Formation" (Permian) and base of the Morrison Formation (Jurassic) have been assigned by Moore and others (1951a, p. 29) to the Dockum? Group, but no attempt has been made to subdivide them. These rocks, which consist of redbeds regarded as continental in origin, have been traced from Oklahoma and Texas into Kansas.

DISTRIBUTION.—Distribution of the Dockum? Group in Kansas is shown in Figure 30. It is present only in the extreme southwest, mainly in Morton and Stanton Counties but also in part of Hamilton County. It is found both on the surface and in the subsurface.

CHARACTER AND THICKNESS.—The Triassic redbeds crop out at two localities in Morton County (sec. 5 and 7, T. 34 S., R. 42 W.; sec. 12, T. 34 S., R. 43 W.) along the north bank of Cimarron River (McLaughlin, 1942). At Point of Rocks, a section of almost 40 feet of Triassic is exposed, composed almost entirely of sandstone (Pl. 12A). The base is not exposed and the section is capped by Ogallala "mortar beds." The sandstone is red, brown, yellow, maroon, tan, and green, fine to medium grained, and soft. Some of it is limonitic and some is cross bedded (Pl. 12B). One bed is conglomeratic. About one-eighth mile upstream is another section similar to the Point of Rocks outcrop but containing several shale "breaks" as much as 3 feet thick. The shale is dark red, silty, and platy (Merriam, 1963).

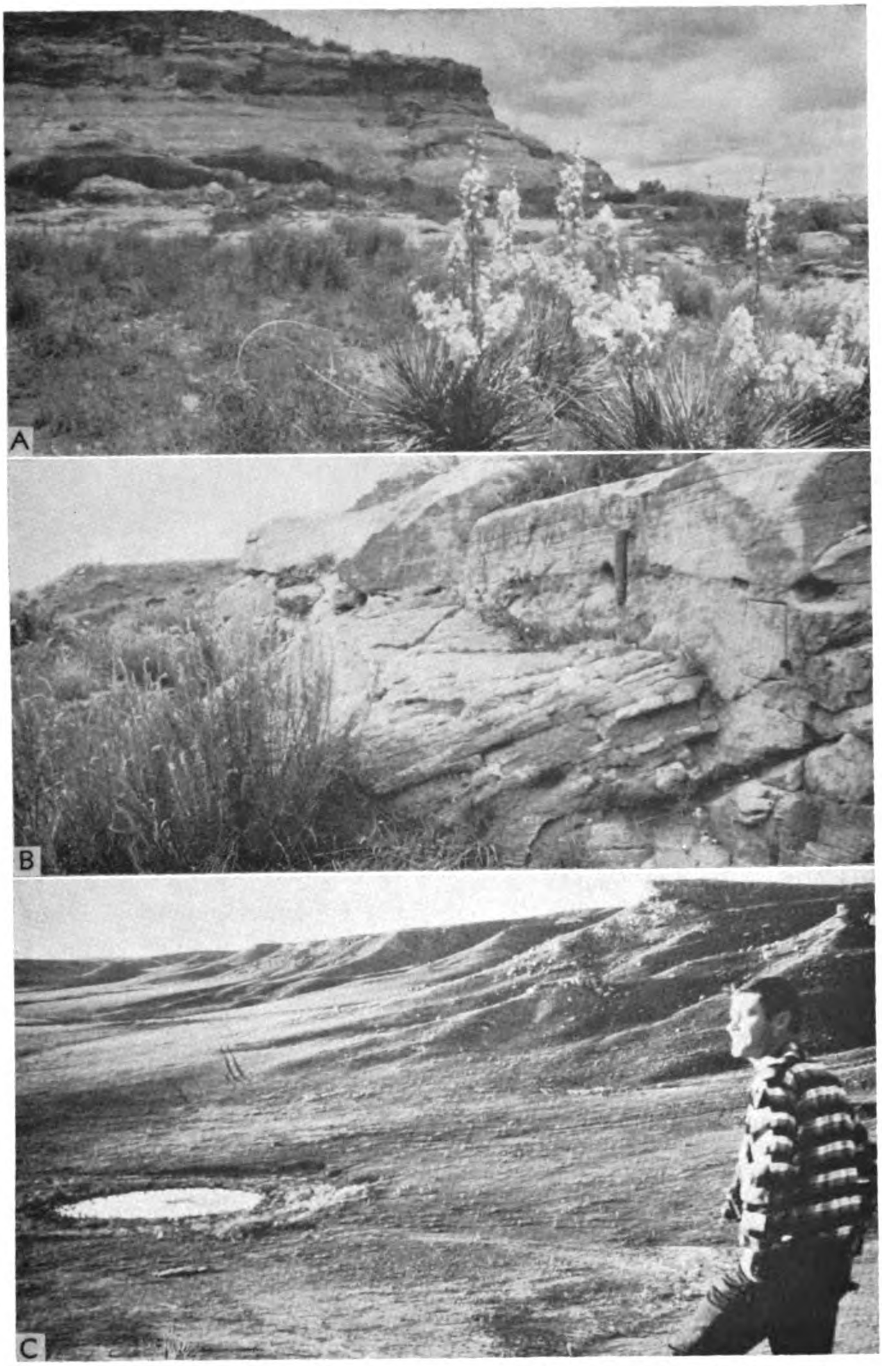


PLATE 12.—**A,** Redbeds of the Dockum? Group, Triassic, at Point of Rocks, Morton County (sec. 12, T. 34 S., R. 43 W.). **B,** Cross-bedded sandstone of Dockum? Group at Point of Rocks. **C,** "Taloga Formation" (Permian) capped by Ogallala "mortar beds" in Big Basin, Clark County (sec. 25, T. 32 S., R. 25 W.).

Numerous ground-water test wells have penetrated rocks that have been tentatively assigned to the Triassic. McLaughlin (1942, p. 71) has identified 320 feet of redbeds in Hamilton County as Triassic. He stated that the contact between Triassic and Permian redbeds is indefinite because rocks of the two systems are very similar.

Although the Permian-Triassic boundary is difficult to determine, especially in the subsurface, Oriel and Mudge (see McKee and others, 1959, p. 3) have listed five important general differences, as follows: (1) bedded evaporites are absent in the Dockum Group; (2) mudstones in the Dockum are brightly variegated, whereas those in the "Taloga Formation" are dark red to dark red brown; (3) grain size in the Dockum is fine to coarse, but rarely exceeds fine in the "Taloga"; (4) mica flakes in the Triassic are larger than those in the "Taloga"; and (5) in Colorado, locally, fragments of chert are abundant in the lowermost Dockum but are rare in the upper part of the Permian.

STRATIGRAPHIC RELATIONS.—The Dockum? Group unconformably overlies the "Taloga Formation." The interval of time represented by this hiatus is believed to be considerable. The surface on which the Triassic was deposited was probably beveled and had low topographic relief. No conglomerate has been reported at the Permian-Triassic boundary. Erosion of the Permian-Triassic surface had developed a certain degree of relief by the time of deposition of the Morrison Formation. It is not known whether the present limits of the Dockum? are depositional or erosional, but part of the deposit probably was eroded prior to deposition of the Morrison Formation.

ENVIRONMENT OF DEPOSITION.—In a remarkably fine summary of the Triassic of the United States, McKee and others (1959) have shown that the Dockum? beds of southwestern Kansas, as well as equivalent deposits in southeastern Colorado and northwestern Oklahoma, were deposited in the northern end of a large basin which centered in western Texas and eastern New Mexico.

AGE AND CORRELATION.—Moore, Frye, and Jewett in 1944 (p. 154) and Moore and others (1951a, p. 29) tentatively placed the outcropping redbeds in the Dockum? Group, which is assigned to the Upper Triassic. Oriel and Craig (1960) put the Dockum Group of southeastern and south-central Colorado in the Upper Triassic, as did McKee and others (1959). Oriel and Craig have shown the Kansas Dockum? to be equivalent, or partly so, to the Jelm Formation of north-central Colorado and the Chinle Formation of western Colorado.

PALEOZOIC ROCKS

Rocks of Paleozoic age in Kansas have attracted more than passing interest since their first description in the 1850s. This interest has been based not only on their richness in mineral wealth but also on their academic value for basic stratigraphic studies. The Midcontinent Permian-Pennsylvanian beds, for example, are world famous as field laboratories in the development of the science of stratigraphic geology. Many fundamental ideas have been formulated or rejected on the basis of information gained from studies of this sequence.

In Kansas, Paleozoic rocks yield large quantities of ground water, especially in the eastern part of the state. Both in eastern and western Kansas they have yielded tremendous quantities of petroleum; in fact, all commercial oil and gas in Kansas comes from these rocks (Hilpman, 1958; Goebel, 1958; Merriam and Goebel, 1959a, 1959b, 1960) except a small amount from Precambrian rocks (and that undoubtedly originated in Paleozoic rocks). The value of these resources is immeasurable (Jewett and Schoewe, 1942; Kansas Geological Survey, 1951; Schoewe, 1960). Lead and zinc deposits in extreme southeastern Kansas, although now almost exhausted, have made important contributions to the national economy. In addition to water, petroleum, lead, and zinc, the following materials in Paleozoic rocks have been or could be exploited: (1) coal (Pierce and Courtier, 1937; Whitla, 1940; Bowsher and Jewett, 1943; Schoewe, 1944, 1946, 1951, 1955, 1959; Abernathy, 1946; Abernathy, Jewett, and Schoewe, 1947; Hambleton, 1953), (2) salt (Bowdish, 1951; Runnels, Reed, and Schleicher, 1952; Kulstad, 1959), (3) gypsum (Kulstad, Fairchild, and McGregor, 1956), (4) limestone (Runnels, 1951; Runnels and Schleicher, 1956; Ives and Runnels, 1960), (5) building stone (Risser, 1960), (6) germanium (Schleicher and Hambleton, 1954; Schleicher, 1959), (7) phosphate (Runnels, 1949), (8) uranium (Runnels, Schleicher, and Van Nortwick, 1953), (9) cement (Runnels, 1959), (10) lightweight aggregate (Plummer and Hladik, 1951), (11) riprap, etc. (Kulstad and Nixon, 1951), and (12) asphalt (Jewett, 1940).

Rocks of Paleozoic age, in downward succession as shown by well penetrations, belong to the Permian, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian Systems (Fig. 2). Although all Paleozoic systems are represented in Kansas, many of the

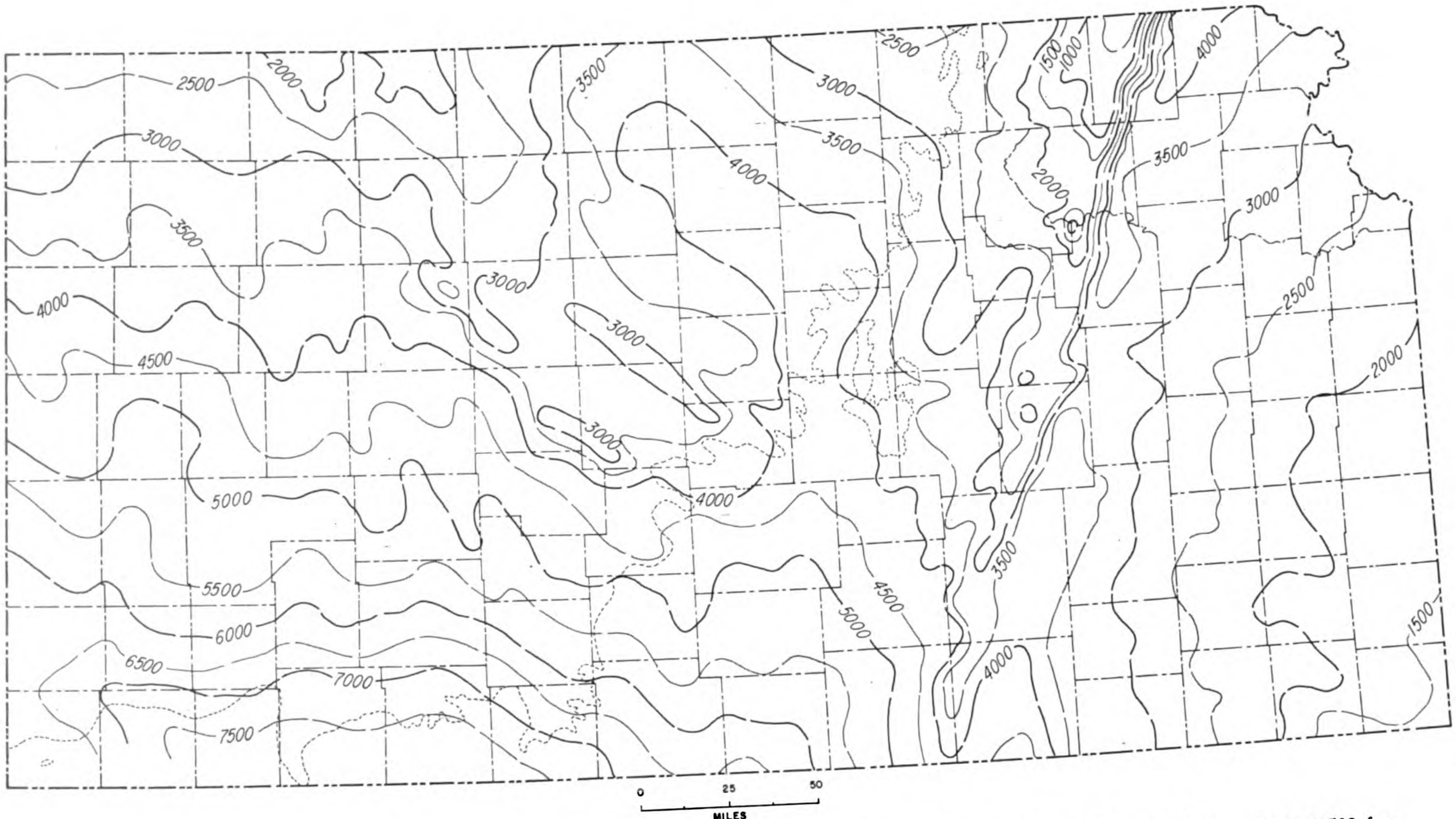


FIGURE 31.—Map showing thickness of Paleozoic rocks in Kansas. Area northwest of dashed line is buried beneath Mesozoic deposits. Contour interval 500 feet.

series are absent or only very incompletely developed. As will be explained later in detail, much of geologic time is not represented by rock deposits in Kansas. Permian rocks are limited to the western four-fifths of the state; the Pennsylvanian has virtually statewide distribution. Both Permian and Pennsylvanian units consist mainly of thin-bedded, alternating marine and nonmarine deposits. Covering much of the state, except on uplifted areas, is the mainly carbonate sequence of beds of Mississippian age. This division of the Paleozoic is relatively thick, especially in basinal areas. Silurian-Devonian rocks are restricted to north-central and northeastern Kansas and have a thickness much less than that of the older Cambrian-Ordovician rocks. The Silurian-Devonian Systems have the smallest areal distribution of major units. Cambrian-Ordovician rocks overlie Precambrian everywhere except on higher parts of uplifts where they have been removed by erosion and younger deposits rest directly on the basement complex. These strata attain considerable thickness in southwestern Kansas (Fig. 31).

Paleozoic rocks nonconformably overlie the Precambrian everywhere in Kansas. They are unconformably overlain by Mesozoic or Cenozoic deposits or are exposed at the surface. Beds older than Mississippian are not exposed in Kansas; Pennsylvanian and Permian beds are well exposed in the eastern third of the state except in the northeast corner, where they are covered by glacial deposits.

Pre-Pennsylvanian rocks in the state are mainly shelf-type marine sediments consisting of limestone and dolomite and some shale and sandstone. Salt, gypsum, coal, underclay, and black shale are locally important and abundant in the Pennsylvanian and Permian. Unconformities are common and widespread in the Paleozoic section. Major unconformities occur between: (1) Mesozoic and Paleozoic, (2) Pennsylvanian and Mississippian, (3) Mississippian? and Devonian, and (4) Paleozoic and Precambrian. Many disconformities in the Permian-Pennsylvanian part of the section are marked by channel sandstones. Disconformities are numerous, owing to the conditions controlling deposition of the sediments. The end of the Paleozoic is marked by a complete change in depositional and structural conditions.

A complete list of publications dealing with the Paleozoic in Kansas would contain almost everything written about the geology of the state, and is far beyond the scope of this report. Moore (1935b), in a comprehensive paper, listed work up to that time concerning Pennsylvanian rocks of Kansas, and the list is indeed extensive. In 1949 he gave further information on the Pennsylvanian rocks in Kansas. Recent information on the Permian may be obtained from Swineford (1955) and Dunbar and others (1960). Because the Pennsylvanian and Permian crop out in eastern Kansas, more information is generally available concerning them than the other Paleozoic units. General references for the Paleozoic rocks of Kansas may be obtained from Moore and others (1951a).

Some of the more important recent papers pertaining to stratigraphy of the Pennsylvanian and Permian include: Bass (1936), Branson (1962), Hattin (1957), Howe (1956), Jewett and Newell (1935), Jewett (1945), Lane (1958), Laporte (1962), Lins (1950), Moore (1940, 1948, 1957b), Moore and Merriam (1959), Moore and Mudge (1956), Moore and Thompson (1949), Moore and others (1944), Mudge (1957a, 1957b), Newell (1935), Norton (1939), O'Connor and Jewett (1952), Rascoe (1962), Thompson (1944), Wagner (1954), Wagner and Harris (1953), and Winchell (1957). Early works include those by Adams, Girty, and White (1903), Cragin (1896a, 1897), Haworth (1894, 1895), Haworth and Bennett (1908), Meek and Hayden (1859), Mudge (1866), Prosser (1895, 1902, 1905), and Swallow (1866, 1867). In recent years the State Geological Survey of Kansas has issued several county reports that concern Permian-Pennsylvanian rocks (Jewett, 1941a; Moore and others, 1951b; O'Connor, 1960; O'Connor and others, 1953, 1955; Verville and others, 1958; K. L. Walters, 1953, 1954).

Publications dealing with Paleozoic rocks include: Barwick (1928), Byrne and others (1958), Clair (1948), Collins (1947), Dott (1941), Edson (1945, 1947), Elias (1937a, 1937b), Keroher and Kirby (1948), Kellett (1932), Koester (1935), Leatherock (1945), Lee (1939, 1940, 1943, 1949, 1953, 1956), Lee and Merriam (1954b), Lee, Leatherock, and Botinelly (1948), Lee and others (1946), McClellan (1930), McCracken (1955), Maher (1946, 1947), Maher and Collins (1949), Merriam and Atkinson (1956), Mudge and Burton (1959), Mudge, Matthews, and Wells (1958), Mudge, Walters, and Skoog (1959), and Ockerman (1935).

Present structure on different Paleozoic rock units of Kansas is shown on maps by Merriam (1958b, 1960b), Merriam and Kelly (1960), Merriam and Smith (1961), and Merriam, Winchell, and Atkinson (1958).

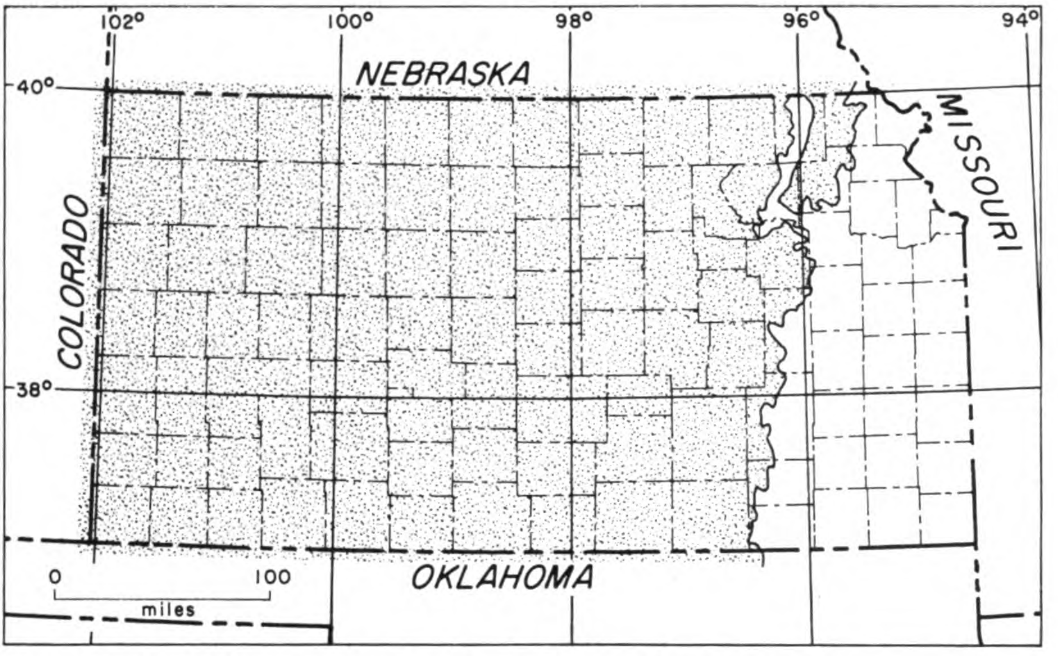


FIGURE 32.—Map of Kansas showing surface and subsurface distribution of Permian rocks.

Permian Deposits

The Permian is subdivided into two series by the Federal Geological Survey, into three by Moore (1958) and Jewett (1959), and into four by Moore and others (1951a) and by Dunbar and others (1960).* It is deemed advisable to follow Moore and others (1951a) until the nomenclature is stabilized.† Actually it makes little difference whether a time-stratigraphic unit is treated as a series or a stage or is given another rank in the hierarchy, as long as the reasons are understood for placement at a particular level.

Three of the four series are recognized in Kansas (in descending order): rocks of Ochoan are not represented, Guadalupian, Leonardian, and Wolfcampian. Post-Wolfcampian beds are mainly redbeds and evaporite deposits. Wolfcampian strata are very similar to and gradational with the underlying Pennsylvanian beds; indeed, the contact chosen as the boundary has been changed repeatedly. Permian rocks are present in the western four-fifths of the state (Fig. 32) and crop out in a wide band extending across Kansas from the northeastern to the south-central part. Wolfcampian beds, many of them cherty, are exposed in and give name to the well-known Flint Hills.

The Wolfcampian in Kansas, consisting (in descending order) of the Chase, Council Grove, and Admire Groups, is mainly an alternation of thin shale and limestone units (Fig. 33, 34). These are traceable for long distances in Kansas and neighboring states, and they exhibit cyclic characteristics similar to those of beds in the upper part of the Pennsylvanian System (Jewett, 1933). Conformably overlying lower Permian rocks is a sequence of shale, siltstone, and sandstone, most of which is predominantly red, interbedded locally with relatively thick deposits of salt, gypsum, anhydrite, and dolomite (Fig. 35). In these beds are recognized 9 formations bundled into 2 groups and 3 formations not assigned to a group, which are classified in the Leonardian and Guadalupian Series.

Redbeds in Kansas received much attention from early workers and were at various times

* The Geologic Names Committee of the U.S. Geological Survey reported (June 30, 1960) "The Chief Geologist has approved the recommendation of the Geologic Names Committee that a twofold subdivision of the Permian system and period be adopted for use by the U.S. Geological Survey. The divisions (Lower and Upper series and Early and Late epochs) are to coincide as nearly as possible with those recognized in the type Permian and are to be drawn according to existing concepts of biotal correlation with the type sequence. The reference sequence for the United States shall be the Permian outcrops of northwestern Trans-Pecos Texas (Delaware Mountains, Guadalupe Mountains, and Sierra Diablo Mountains), where the approximate faunal boundary is taken as that between the Cherry Canyon and Bell Canyon formations."

† The Kansas Survey recently returned to essentially the classification used three decades ago by proposing Gearyan for pre-Wellington beds and Cimarronian for all younger Permian rocks in Kansas (O'Connor, 1963).

included in the Permian, Triassic, Jurassic, and Cretaceous Systems before the classic publication by Cragin in 1896. He regarded the redbeds as Permian in age, and his classification of these sediments still serves as a basis for stratigraphic work. Many papers on the redbeds appeared in the late 1800s and early 1900s, of which those by Cragin (1896a, 1897), Grimsley and Bailey (1899), Hay (1889, 1891), Prosser (1897, 1902), and St. John (1887) should be mentioned. Other papers on the redbeds in Oklahoma and Texas were written about this same time and a little later.

Upper Permian Units

The uppermost beds of the Permian System are not presently grouped into larger rock units, although several names have been used for part or all of this sequence, including Whitehorse Group, Quartermaster Group, and upper Cimarron. The three formations not assigned to a group are (in descending order): "Taloga Formation," Day Creek Dolomite, and Whitehorse Formation—in other words, all Permian rocks in Kansas above the Dog Creek Formation.

DISTRIBUTION.—The units are confined to the southwestern part of the state. Each of the formations crops out in south-central Kansas in Clark and Meade Counties and southwestern Kiowa County.

CHARACTER.—The "Taloga"* is mainly a red-brown, anhydritic, silty shale that forms rolling hills (Pl. 12C). The Day Creek is a fine-grained, dense, locally oolitic dolomite on the outcrop, but in the subsurface it may be dolomitic anhydrite or anhydritic dolomite. The change is similar to the surface-to-subsurface change described for the Stone Corral Formation. The underlying Whitehorse is reddish-brown, anhydritic, silty mudstone and shale, siltstone, and sandstone. In the subsurface the group may be distinguished from the overlying, more brightly colored Triassic by its brownish color; and it differs materially from the greenish-gray, anhydritic or limy shale of the Jurassic and the brown sandstones or black shales of the Cretaceous.

THICKNESS.—In Kansas the thickness of these upper Permian units ranges from a featheredge to a maximum of slightly more than 700 feet in the southwestern corner. The "Taloga" ranges in thickness to about 300 feet, the Day Creek to 65 feet, and the Whitehorse to 400 feet. Inasmuch as the upper boundary of the Permian is defined by an erosion surface, thickness of the strata varies with configuration of the surface, but in general it decreases to the north and east. On the outcrop, thicknesses of the "Taloga," Day Creek, and Whitehorse are about 45, 2, and 270 feet, respectively.

STRATIGRAPHIC RELATIONS.—The formations are conformable with each other, and the Whitehorse is conformable with underlying beds of the Nippewalla Group. The upper contact, as previously mentioned (Fig. 36), is an erosional one. The upper part of the succession is locally leached of its red color, especially where the beds are sandy.

Nippewalla Group

The Nippewalla Group is a thick sequence of redbeds between the overlying Whitehorse Formation and the underlying Sumner Group. The Nippewalla is composed of six formations (in descending order): Dog Creek Shale, Blaine Formation, Flowerpot Shale, Cedar Hills Sandstone, Salt Plain Formation, and Harper Sandstone.

DISTRIBUTION.—The Nippewalla Group extends over approximately the western one-half of Kansas. Beds of the group are exposed in south-central Kansas, where they strike approximately north and dip gently westward. This strike changes to about northwest near the middle of the state, where the beds are concealed under a cover of younger, mainly Cretaceous, beds.

CHARACTER.—A variety of rock types makes up this group, including silty shale, siltstone, very fine grained sandstone, dolomite, gypsum, and salt, truly a sequence of redbeds. Two of the formations are sufficiently distinct to be recognized with certainty in the subsurface, the Blaine Formation and Cedar Hills Sandstone. With sufficient study it might be possible to differentiate the other formations according to their lithologic characteristics.

The Blaine, probably anhydritic gypsum, or locally entirely anhydrite, gives a very characteristic "kick" on electric logs and may be recognized easily in samples. With caution, it possibly could be used as a shallow structural marker bed (Donald J. Malone, personal communication). The Cedar Hills is sufficiently porous to be used as a shallow disposal zone for oil-field brine.

Several salt beds in this part of the stratigraphic section are restricted to the subsurface of parts of western Kansas (Fig. 37). Although their distribution and thickness are not precisely

* According to Robert O. Fay (personal communication), beds in Kansas termed "Taloga" have been miscorrelated with the type Taloga of Oklahoma, which is actually older. This being the case, another stratigraphic term for the Kansas "Taloga" is necessary, and Big Basin has been suggested (O'Connor, 1963).

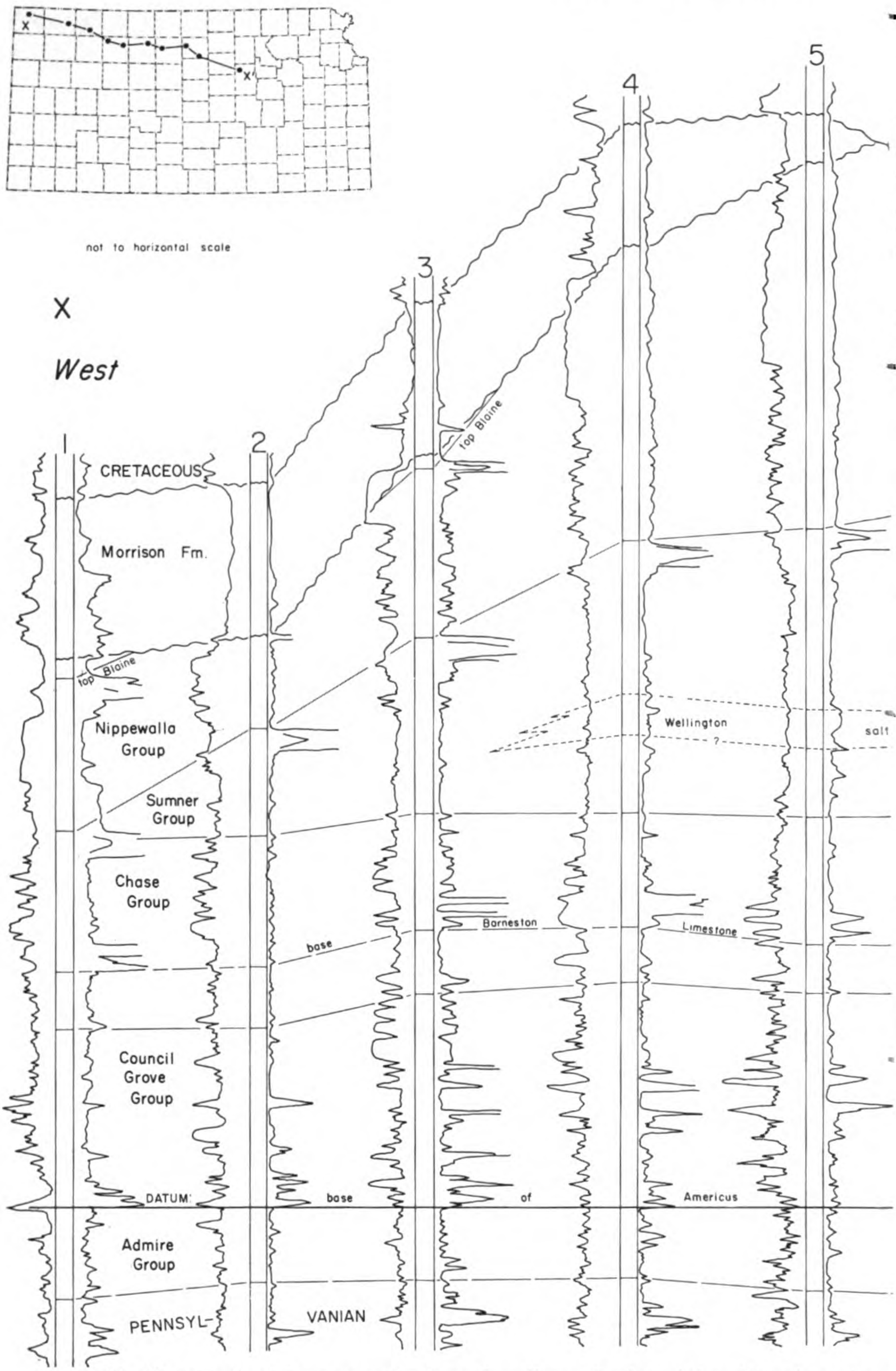
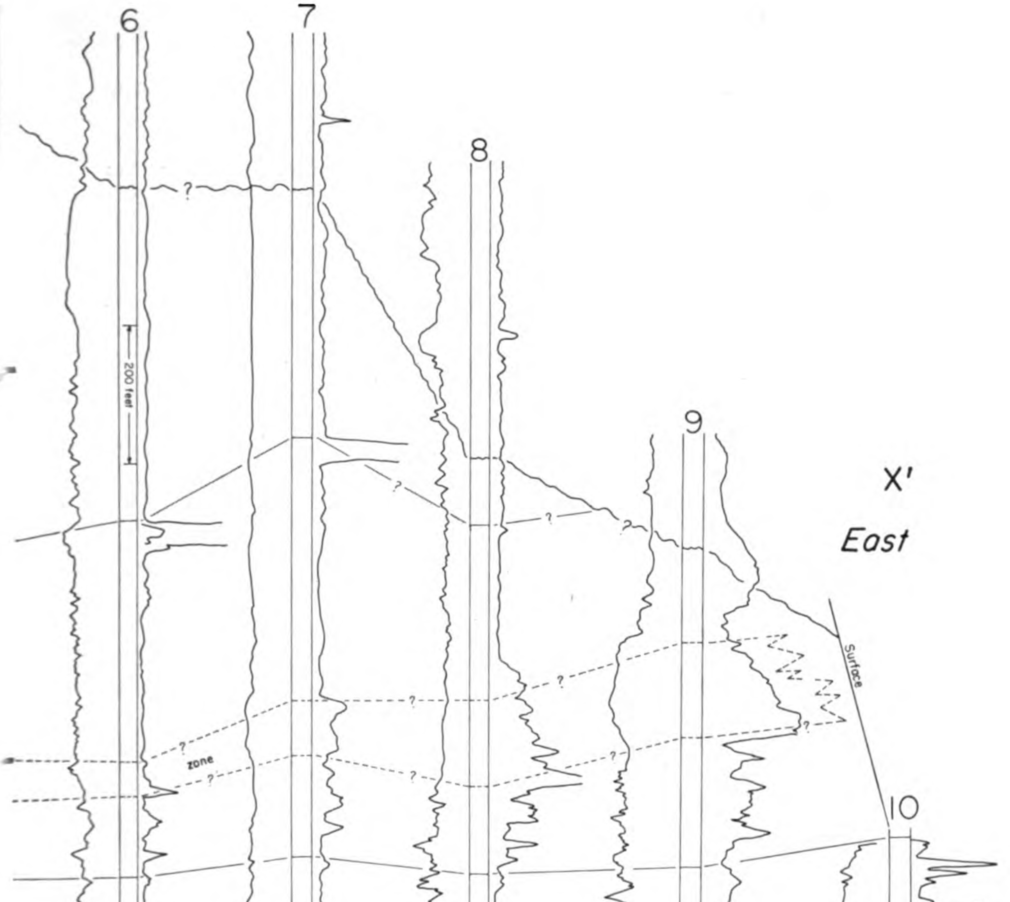


FIGURE 33.—West-east electric-log cross section in northern Kansas showing relation of Permian units to



each other and to adjacent beds.

known at present, they are important for many reasons, especially for their possible use for underground storage of liquefied petroleum gases and other fluids (Jewett and Goebel, 1960) and for their effect on velocity computations in seismic exploration (Glover, 1959). Distribution of Nippewalla salt deposits is shown in Figure 37.

THICKNESS.—The exact thickness of the group is not known with certainty, but in places it is at least 1,000 feet and may be much more. Generally speaking, the units are thinnest along the outcrop and thickest near the deeper part of the Hugoton Embayment. Moore and others (1951a) gave the following approximate thicknesses on the outcrop: Harper, 220 feet; Salt Plain, 265 feet; Cedar Hills, 180 feet; Flowerpot, 190 feet; Blaine, 50 feet; and Dog Creek, 53 feet.

STRATIGRAPHIC RELATIONS.—The exact stratigraphic relations of the units to each other and to adjacent units are not definitely known, but it is believed that they are conformable. An interesting feature shown on Figure 38 is the facies change of the Nippewalla salt zone, which lies just below the Blaine-Dog Creek? beds. A "solid" salt bed in the west becomes anhydritic eastward, then all anhydrite, and finally passes laterally into clastic sediments. This same sequence from "solid" salt to clastics can also be seen grading downward. It is important to note that the presence of the salt does not increase stratigraphic thickness.

Sumner Group

The Sumner Group, between the overlying Nippewalla Group and the underlying Chase Group, comprises three formations (in descending order): Stone Corral Formation, Ninnescah Shale, and Wellington Formation. The Sumner, like previously mentioned groups, consists mainly of redbeds and evaporites. The Stone Corral Formation (Pl. 13A, 13B) and the Hutchinson Salt Member of the Wellington Formation (Pl. 13C) are two stratigraphically important units. The Stone Corral is noteworthy enough to warrant special mention and will be discussed in more detail than other units.

DISTRIBUTION.—Rocks of the Sumner Group cover about two-thirds of Kansas. Both the redbeds and the underlying nonred strata (Wellington) dip gently westward into the subsurface from the outcrop, which extends from Sumner County on the south to Washington and Marshall Counties on the north. On the whole, the group is poorly exposed.

CHARACTER.—The group consists mainly of silty shale; limestone, dolomite, anhydrite, gypsum, and salt, although minor in amount, are important economically and as stratigraphic markers. The lower part of the Wellington Formation is gray shale, and no thick redbed

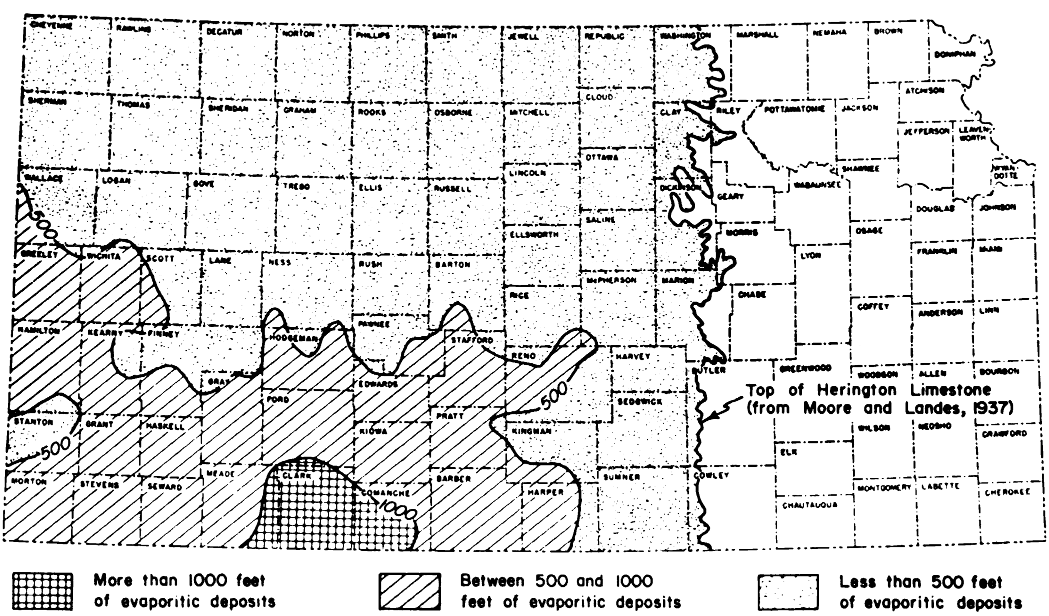


FIGURE 35.—Map of Kansas showing total thickness of evaporitic deposits in Permian redbed sequence. Maximum thickness is about 1,400 feet in Clark County. Contour interval 500 feet.

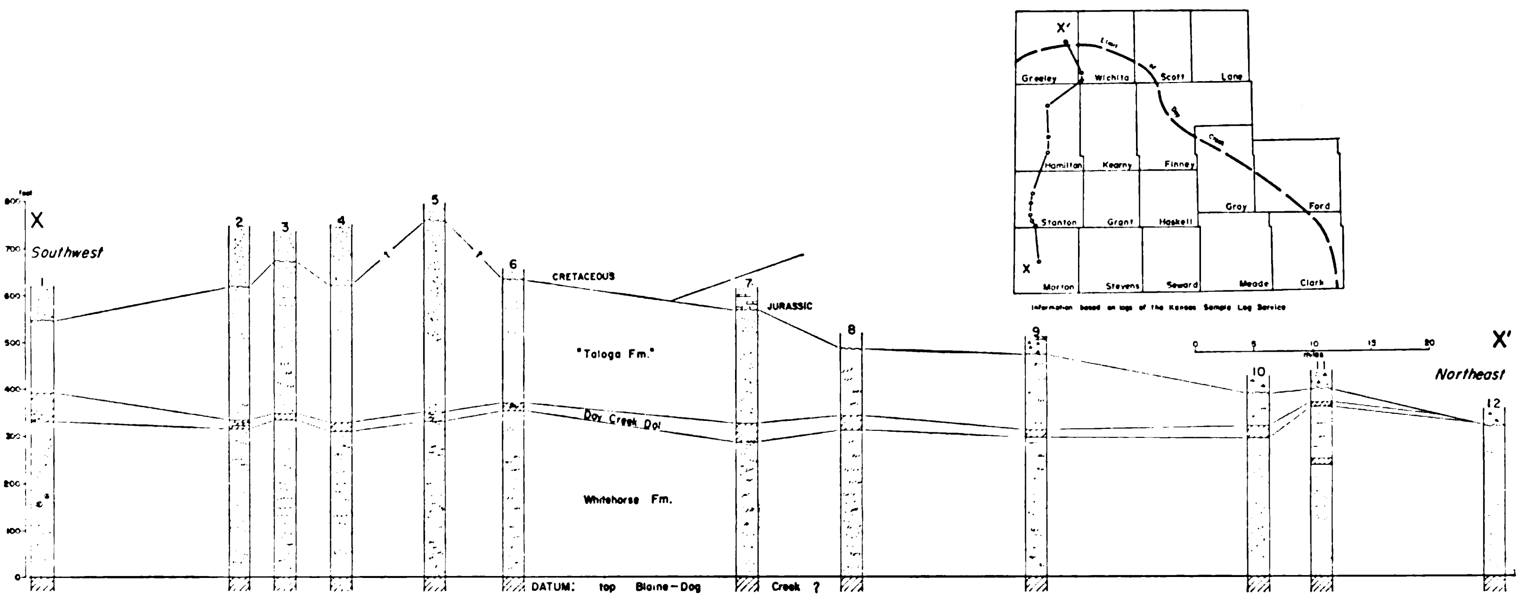


FIGURE 36.—Southwest-northeast cross section showing stratigraphic relations of beds in upper Permian in southwestern Kansas. Note uniform thickness of Whitehorse Formation, lateral persistence of Day Creek Dolomite, which in subsurface is mostly anhydrite, and northward thinning of "Taloga Formation" by post-Permian erosion.

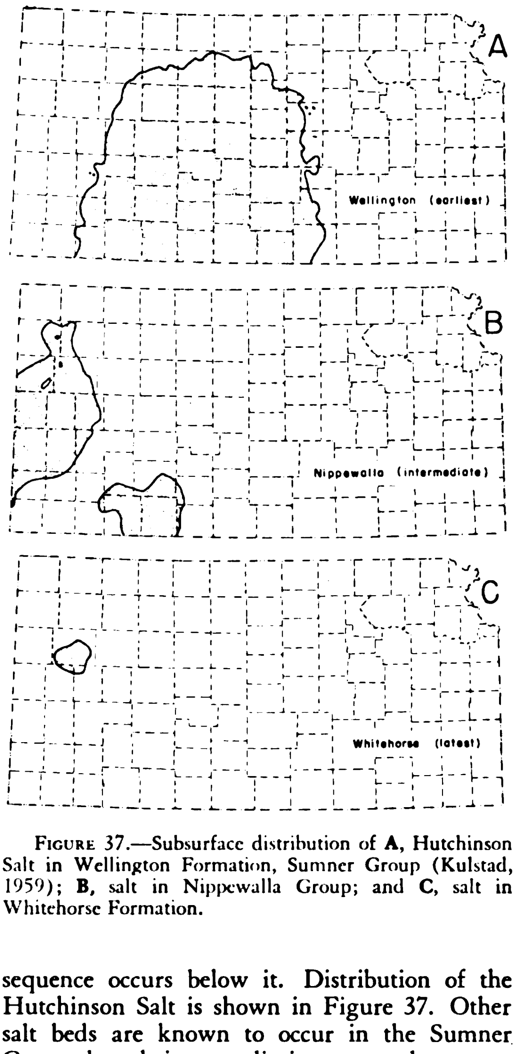


FIGURE 37.—Subsurface distribution of **A**, Hutchinson Salt in Wellington Formation, Sumner Group (Kulstad, 1959); **B**, salt in Nippewalla Group; and **C**, salt in Whitehorse Formation.

sequence occurs below it. Distribution of the Hutchinson Salt is shown in Figure 37. Other salt beds are known to occur in the Sumner Group, but their exact limits are not known at present. The Hutchinson Member is the most widespread and thickest of the salt deposits found in Kansas and is mined in several areas where near the surface. The salt does not crop out, owing to its solubility, and along the area where it has been dissolved, the overlying beds are badly slumped. Recognition of the occurrence of this solution and the subsequent collapse of overlying units is extremely important in mapping and interpreting structure.

THICKNESS.—Moore and others (1951a) state the thicknesses of the Wellington along the outcrop to be about 700 feet, Ninnescah Shale about 300 feet, and Stone Corral about 6 feet. Kulstad (1959) has shown the Hutchinson Salt Member of the Wellington to be as much as 700 feet thick in the subsurface of Clark County; thus, the total thickness of the Wellington must be appreciably more than 700 feet in southwestern Kansas.

STRATIGRAPHIC RELATIONS.—An important unconformity is now recognized at the base of the Stone Corral (Fig. 33 and 34), although the other units are believed to be conformable with each other and with overlying and underlying units.

STONE CORRAL FORMATION

In the Permian redbed section, which is about 1,900 feet thick, few beds can be traced very far laterally; the Stone Corral is one formation that is persistent over a large area. Because it is easily identifiable in well samples and on electric and radioactivity logs, and because it lies at shallow to moderate depth under much of Kansas, it serves as an important marker for structural and stratigraphic work. This unit often is used as a datum for core-hole drilling and also serves as a good reference layer for reflection seismograph work (Glover, 1953; Pakiser, Mabey, and Warrick, 1954).

Cragin (1896a, p. 17, 18) seemingly was the first to notice the dolomite (Stone Corral) that crops out in south-central Kansas, and he included this bed in his "Wellington shales":

> The massive ledge of hard, cellular, gray dolomite on the Little Arkansas river at the eastern border of Rice county, west of south from Windom, is provisionally referred to the Wellington formation.

Norton (1939) named and described in detail the Stone Corral dolomite-anhydrite. He first proposed the name in 1935, and it was used more or less informally by Koester (1935), Norton (1937), and Green (1937). Norton (1939, p. 1777) stated:

> Credit for first recognizing the correlation of the subsurface "Cimarron Anhydrite" with the outcropping Stone Corral at its type locality and in the adjacent Welch pool, goes to William L. Ainsworth, of Wichita, Kansas, who established this correlation after core-drilling to the dolomite marker in Rice County, and so informed the writer in 1929.
>
> The name "Stone Corral" was first applied to this dolomite by the writer in a preliminary abstract of this paper published in the program of the March 21, 1935, annual meeting of the American Association of Petroleum Geologists at Wichita, Kansas, where it was read by title, the paper itself being presented before the Kansas Geological Society at Wichita, Kansas, April 17, 1935, and this name has since been used by Koester and Green, using the writer's section. . . .

The name comes from an old stone corral that was built for protection from the Indians along the Santa Fe Trail near a ford on Little Arkansas River north of Wichita. Because of the diverse lithologies found within the formation, Lee (1953, p. 6) proposed that the descriptive

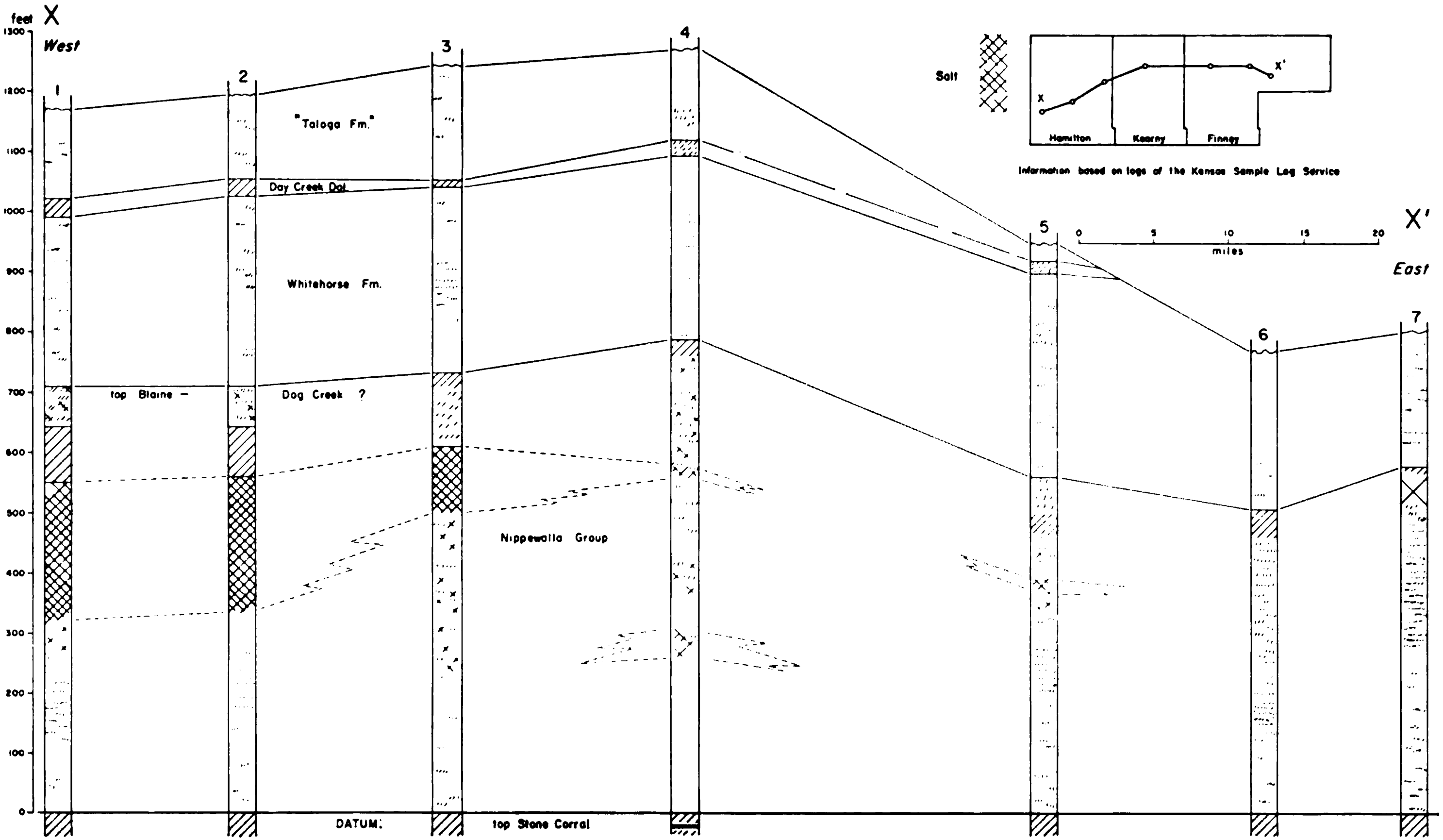


Figure 38.—Cross section in southwestern Kansas showing stratigraphic position of salt in Nippewalla Group in Permian redbed sequence. Where not possible in subsurface to differentiate Dog Creek, which is stratigraphic top of Nippewalla, top of Blaine is shown. Note lateral equivalent of "solid" salt.

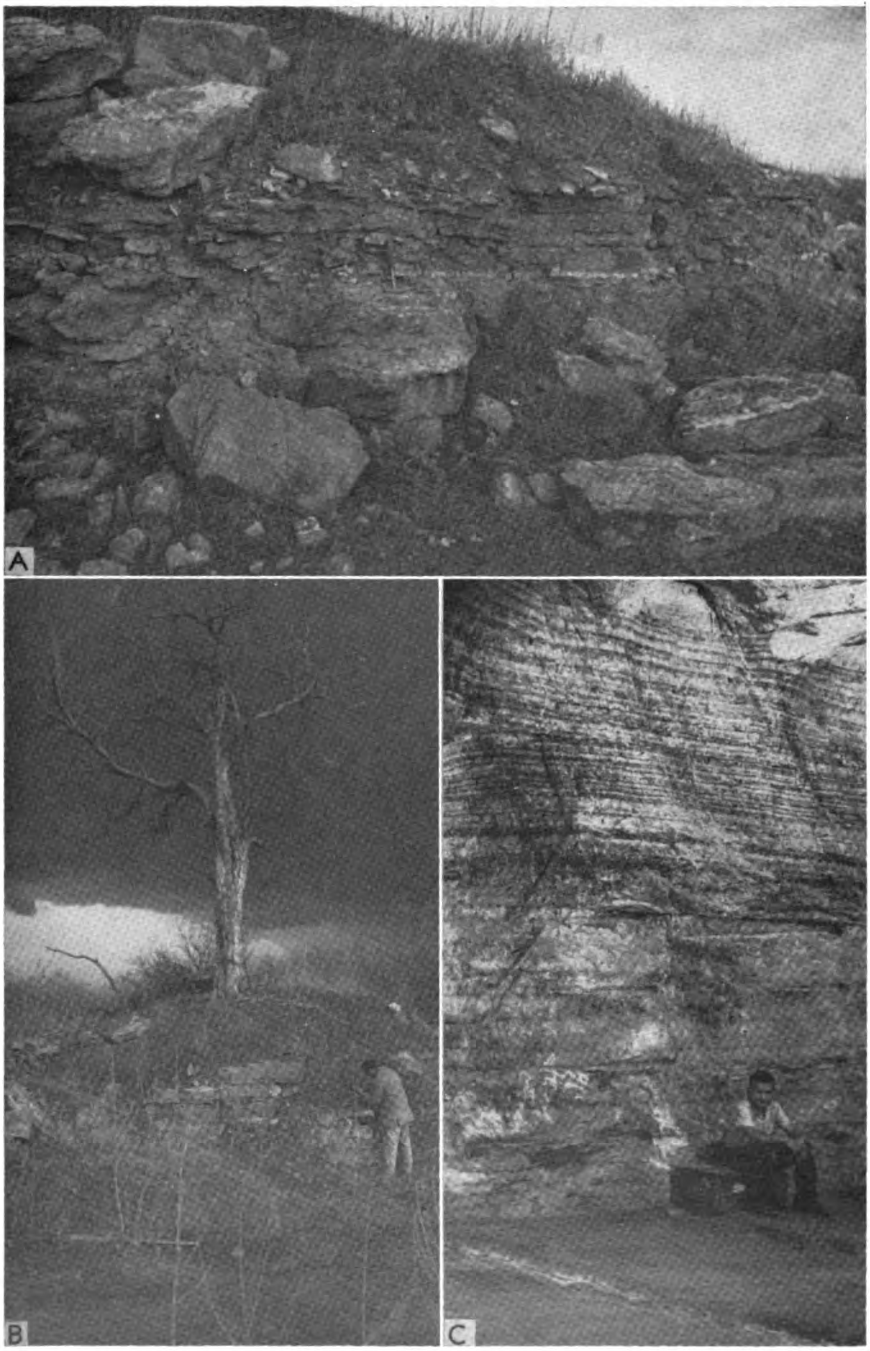


PLATE 13.—**A,** Type section of Stone Corral Formation (Permian), Rice County (**sec. 11,** T. 20 S., R. 6 W.). **B,** Quarry exposure of about 6 feet of dolomite constituting the Stone Corral Formation on outcrop, Rice County (sec. 11, T. 20 S., R. 6 W.). **C,** Hutchinson Salt Member of Wellington Formation in Carey Salt Mine, Hutchinson, Reno County.

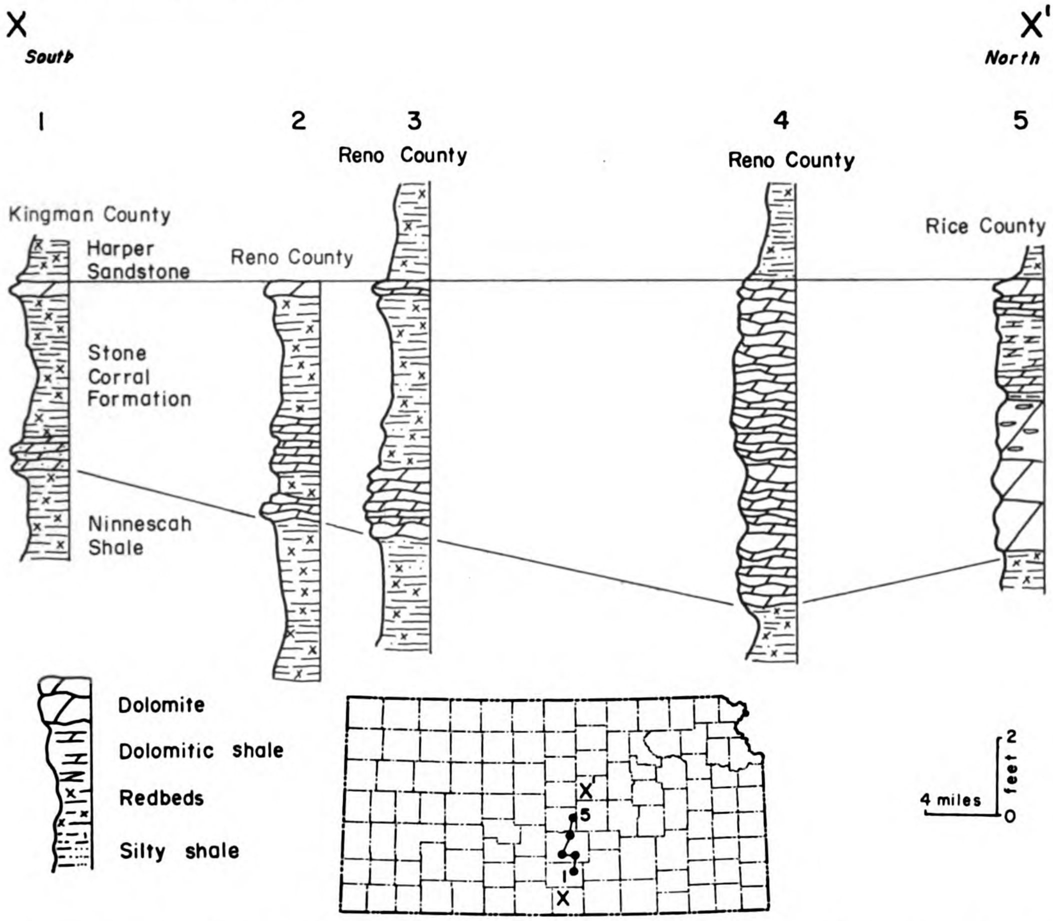


FIGURE 39.—Correlation of surface outcrops of Stone Corral Formation in south-central Kansas; datum is top of Stone Corral. Note that formation becomes more shaly southward, and massive dolomite beds present at type locality (sec. 11, T. 20 S., R. 6 W.) are not recognizable (from Merriam, 1957a).

term "dolomite" be dropped and "formation" substituted. This suggestion was followed by Lee and Merriam (1954a) when they referred to the Stone Corral Formation.

SURFACE.—The Stone Corral Formation consists of dolomite, anhydrite, shale, and minor amounts of salt and gypsum. At the type locality, in sec. 11, T. 20 S., R. 6 W., in Rice County, the formation is almost entirely dolomite and dolomitic shale (Fig. 39; Pl. 13A). In this area the formation is 6 feet thick and forms a low escarpment. The surface of the upper dolomite bed is ripple marked. Swineford (1955, p. 47) described the exposure as follows:

> . . . The dolomite is dense to cellular, and grayish buff in color. It contains many vugs partly or completely filled with coarsely crystalline calcite or gypsum. The basal one-third is in part oolitic, with individual oolites up to one-half mm in diameter. Large oolites (1 mm diameter) also occur 2 feet below the top. The top 2 inches, also locally oolitic, is in part pink. The material of the oolites is more soluble, under ordinary conditions of weathering, than that of the matrix.

Tracing this bed to the south along the outcrop reveals that the thickness of dolomite decreases and the amount of shale increases to such an extent that in Kingman County the formation is hardly recognizable (Fig. 39). Farther south, in Harper County, Swineford (1955, p. 49) reported that the formation is represented only by scattered dolomite rhombs in silty shale.

Norton (1937, 1939) recognized the existence of a disconformity between the Stone Corral and underlying shale, based chiefly on the presence or absence of a wedge of maroon shale that occurs between the Runnymede Sandstone

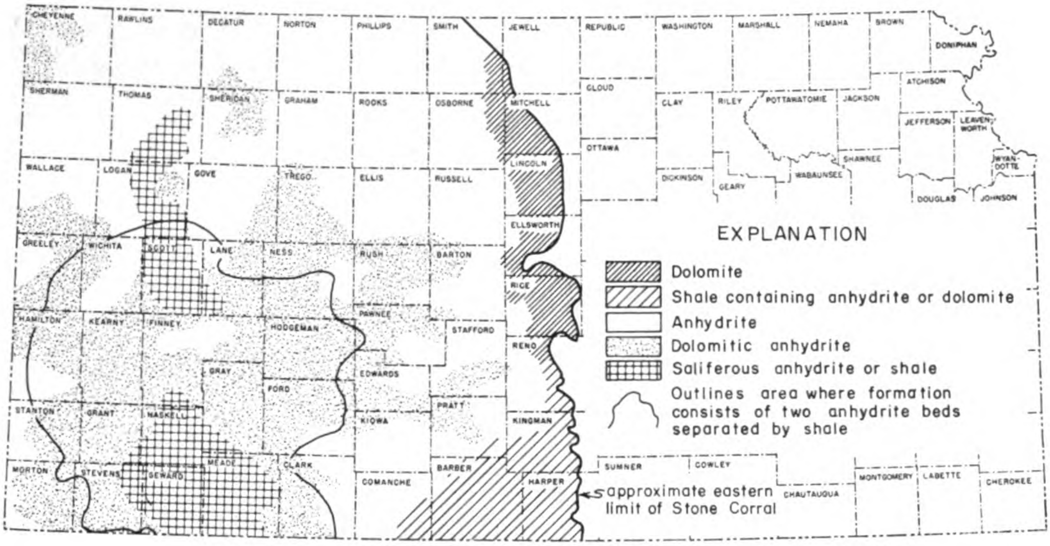


FIGURE 40.—Generalized surface and subsurface distribution of lithologic types in Stone Corral Formation. North of Rice County, eastern limit of formation is covered by later deposits, whereas formation crops out discontinuously south of east-central Rice County (from Merriam, 1957a).

Member of the Ninnescah Shale and the Stone Corral. He also believed that the presence or absence of gypsum beds at the top of the formation indicates a disconformity at the top of the Stone Corral. Maher (1946) also found some evidence of a minor unconformity above the Stone Corral in the subsurface.

According to Norton (1939, p. 1779), no fossils have been found in the Stone Corral, but fragmental carbonized wood occurs in a core from Stafford County. The fossil *Cyzicus ("Estheria")* occurs in some beds near the middle of the underlying Ninnescah Shale. Also, some fossils have been reported from the Whitehorse

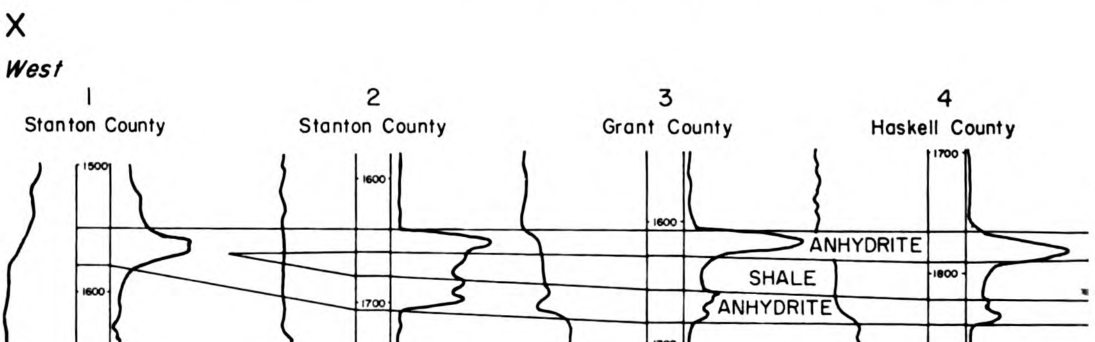


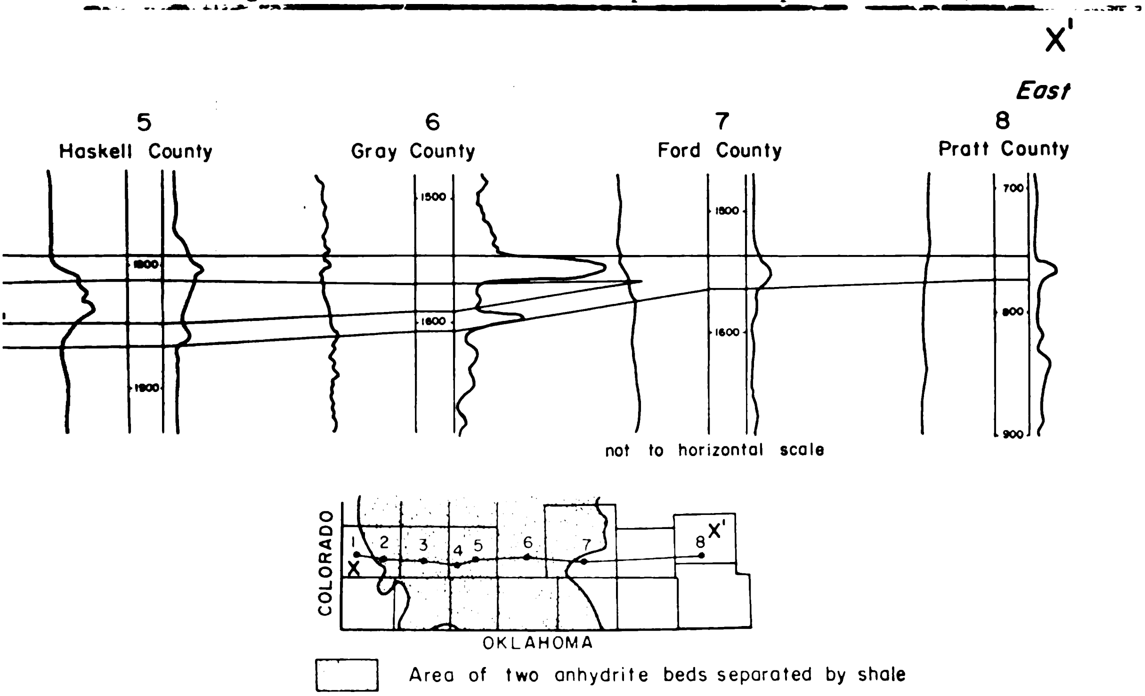
FIGURE 41.—West-east electric-log cross section of area in southwestern Kansas where Stone Corral ("Cimarron anhydrite" of subsurface terminology) consists of two anhydrite beds separated by red silty shale. Datum is top of uppermost anhydrite bed. To west and east the formation has characteristic "kick" on logs and consists of one bed of anyhdrite (from Merriam, 1957a).

in Oklahoma (Gould, 1901). Newell (1940) reported that the Whitehorse fauna includes *Dielasma, Composita, Schizodus, Pleurophorus, Edmondia, Allorisma, Parallelodon, Conocardium, Pernopecten,* and *Pseudamusium?,* indicating a normal marine environment. In addition to these brachiopods and pelecypods there are bryozoans and gastropods. These invertebrates, plus a few known vertebrates, definitely indicate Permian age of beds at least this high in the column. This, of course, would include the Stone Corral Formation, because it lies stratigraphically below the Whitehorse.

SUBSURFACE.—A short distance downdip from the outcrop of the Stone Corral, the formation consists almost entirely of anhydrite. To the south, in an area comprising parts of Reno, Kingman, Harper, Barber, and Comanche Counties, the Stone Corral is represented by anhydritic or dolomitic shale (Fig. 40). Farther west and throughout a considerable part of western Kansas, the unit consists of pure to dolomitic anhydrite, or it includes a dolomite bed in the lower part or at the base of the formation. In southwestern Kansas in an area covering parts or all of 21 counties, the formation is split into two anhydrite beds separated by red shale (Fig. 41). The lower anhydrite is dolomitic in most places and is less extensive than the upper bed. The shale in parts of Meade, Seward, Stevens, Haskell, Finney, Lane, Scott, and Logan Counties is saliferous. In Logan and Thomas Counties the anhydrite is locally saliferous. In the subsurface the formation is underlain and overlain by beds of red silty shale and shaly sandstone. A gypsiferous red shale is present above the Stone Corral in some areas, whereas in others a salt-bearing shale is present below the formation.

Because the Stone Corral is composed mostly of anhydrite in the subsurface, and also was named Cimarron, it is commonly called the "Cimarron anhydrite." Most of this anhydrite is pinkish white or white mottled gray, massive, and crystalline. It may be finely crystalline and have a sugary texture. Rarely present is a thin limestone. Most of the shale is silty and red, although gray shale is not uncommon.

Several explanations can be offered for the lithologic change of the Stone Corral between the surface and subsurface (Merriam, 1957a). Anhydrite may have been leached by surface waters, leaving the less soluble dolomite at outcrops; whether anhydrite was formerly interbedded with the dolomite or was above it is not known, however. Possibly the dolomite is the same bed that in the subsurface forms the base of the formation and lies below the anhydrite, and the upper part of the formation does not crop out. Another possibility is that the facies may change between the outcrop and the subsurface. Furthermore, it is possible that the anhydrite was never deposited as far east as the present outcrop of the dolomite, and thus never



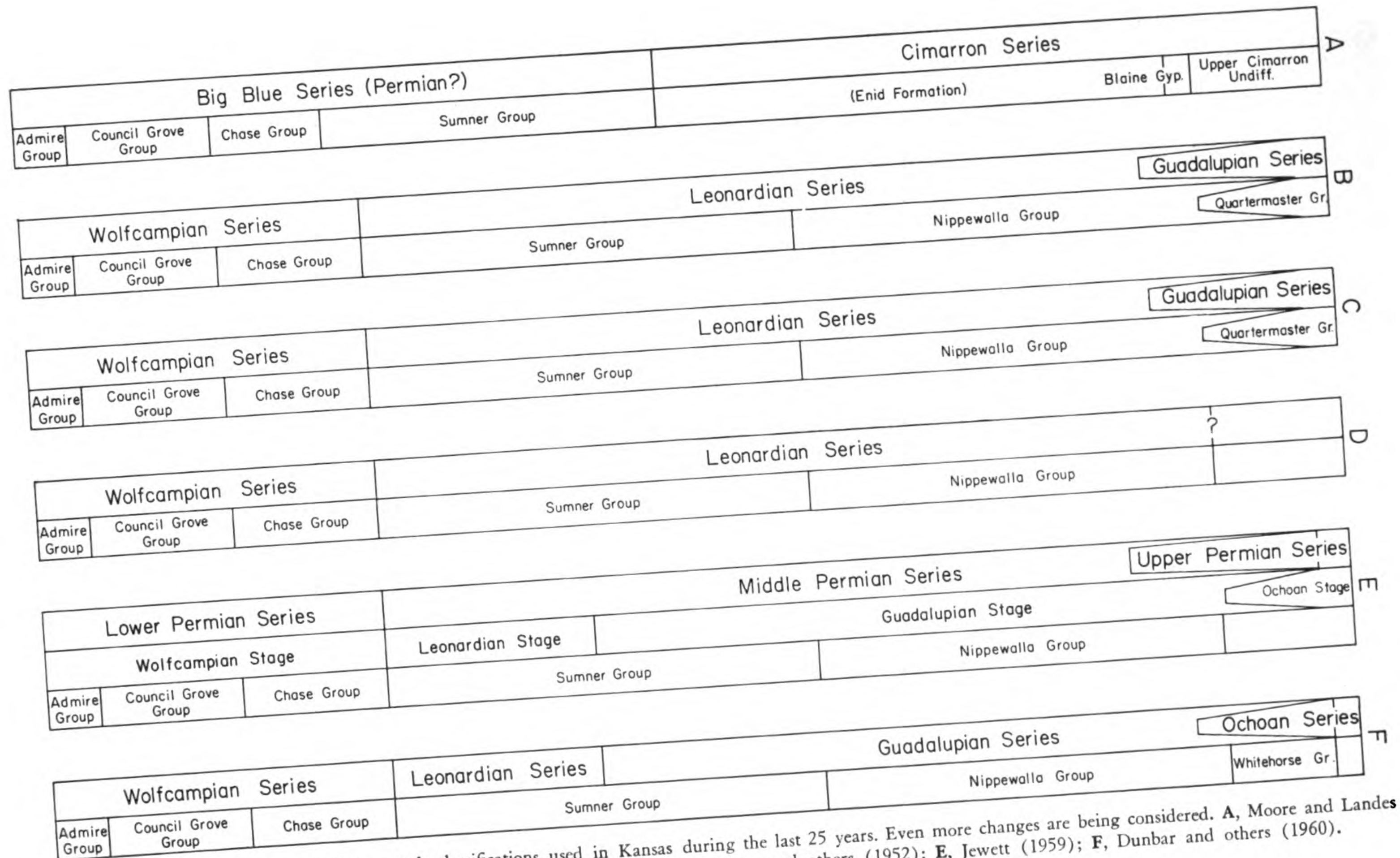


FIGURE 42.—Chart showing Permian rock classifications used in Kansas during the last 25 years. Even more changes are being considered. **A**, Moore and Landes (1937); **B**, **Moore, Frye, and Jewett (1944)**; **C**, **Moore and others (1951a)**; **D**, Moore and others (1952); **E**, Jewett (1959); **F**, Dunbar and others (1960).

was present in Rice, Reno, Kingman, and Harper Counties. Considering all known evidence, a logical explanation is that the upper part of the formation, which consists of anhydrite, has been leached on the surface and thus does not crop out. The outcropping dolomite, then, probably represents the dolomite bed at the base of the formation in the subsurface.

The thickness of the Stone Corral in the subsurface is generally between 25 and 45 feet. In southwestern Kansas, however, in Gray, Finney, Kearny, and Grant Counties, the maximum thickness of the formation, 90 to 100 feet, was deposited near the center of the area in which the formation consists of two anhydrite beds separated by shale. It seems that this area was near the center of the depositional basin.

By means of samples and electric and radioactivity logs, it is possible to trace the Stone Corral into the adjacent states of Nebraska, Colorado, New Mexico, and possibly Oklahoma. Maher (1948) remarked that because of its irregularity and because of the presence of other unnamed anhydrite beds, the Stone Corral is not so easily identified in eastern Colorado as in western Kansas. He was able, however, to trace the unit to the Front Range in Colorado, where he correlated it with the "contact limestone" at the top of the Fountain Formation (Maher, 1953a, p. 921).

Environment of Deposition of Redbeds

Swineford (1955, p. 164) has summarized nicely the interpretation of the origin of these deposits, and part of her summary is presented here.

> . . . The general picture of the area in post-Wolfcampian Permian time is one of a broad, shallow, fairly stable basin, bounded on the west by the Front Range and Wet Mountains, which supplied most of the feldspathic debris . . . .
>
> On the north and east the Permian basin was probably bounded by low-lying land areas which supplied little or no debris. To the south of the Anadarko basin was a restricted connection with the open sea, and several local uplifts which formed islands of mountain ranges, such as the Arbuckles, the Wichitas, and possibly intermediate mountains. Other possible land areas are the Ozark uplift and the Ouachita system.
>
> It is thought that the source of the large rounded quartz and chert grains was in the Cambro-Ordovician orthoquartzitic sediments that underlay the entire area and were exposed to erosion locally in the isolated uplifted areas. Such a wide-spread source would account for the ubiquitous distribution of these grains.
>
> Almost no clastics coarser than silts reached the Kansas outcrop area before Cedar Hills time, when numerous wide-spread very fine sandstones were deposited. Cedar Hills deposition was followed by another period of extremely fine clastic supply, and the Flowerpot shale was deposited in quiet water rich in calcium and sulfate ions. This episode culminated in deposition of wide-spread evaporite deposits (Blaine gypsum-anhydrite). An influx of fine feldspathic sand, perhaps both from the west and south, produced the Whitehorse formation. The supply of medium-grained clastic material gradually diminished during Whitehorse time, and montmorillonitic (bentonitic?) clays were deposited, as was also a thin persistent dolomite (Day Creek). The poorly sorted sands and silts of the Taloga formation suggest the incidence of slight instability and perhaps the deposition of poorly reworked flood-plain materials before the Permian seas withdrew entirely from the area.

Age and Correlation of Permian Redbeds

The precise age and correlation of the Permian redbed sequence in Kansas are far from settled. Within the last two decades the classification of these beds has been changed by the Kansas Survey four times, although only one major publication dealing with them was published in this period (Swineford, 1955). Swineford (1955, p. 21) concluded that "The problem of correlation of nonfossiliferous red clastics in Kansas with a type marine section in west Texas seems almost insurmountable. . . ."

Dunbar and others (1960, p. 1789) have reported the following: "The Nippewalla and Whitehorse groups of Kansas and Nebraska, and their equivalents in Oklahoma, are virtually unfossiliferous. Correlations are therefore based on physical stratigraphy. They are related to the section in central Texas by surface tracing and to the exposures in Colorado and Wyoming by subsurface correlation under the Great Plains. It is impossible to reconcile some of the conflicting opinions. . . ."

Figure 42 shows the differences in interpretation of the Permian redbeds in Kansas as compared with the previously recognized subdivisions that appeared on the Geologic Map of Kansas (Moore and Landes, 1937). The rock unit boundaries have remained stable since 1944, although several names have been used (or none at all) for the sequence above the Nippewalla Group. Not so for the Leonardian, Guadalupian, and "Ochoan" boundaries, which have moved up and down. It seems desirable to reach some agreement concerning these beds so that their nomenclature in the Kansas region can be stabilized.

Lower Permian Units

Lower Permian rocks, as classified in Kansas, belong to three groups of the Wolfcampian Series (in descending order): Chase, Council Grove, and Admire. Because they are similar in character, it is convenient to treat them together. The overall thickness of the three groups is about 800 feet.

Seven alternating (cyclic), predominantly shale-and-limestone formations compose the Chase Group, which conformably overlies the Council Grove Group. Many of the units are distinctive enough to be recognizable in the subsurface. The shales are mostly red and green or varicolored, and most of the limestones are cherty. In the lower part of the group, three members—Florence Limestone Member of the Barneston Limestone (Pl. 14A) and Threemile Limestone and Schroyer Limestone Members of the Wreford Limestone (Pl. 14B, 14C)—contain a great abundance of chert (flint). It is mainly from these scarp-forming, prominent beds that the Flint Hills derive their name. Some of the limestones in the upper part of the Chase are somewhat dolomitic and many are characterized by the occurrence of concretions and geodes. The base of the Barneston Limestone is one of the obvious, persistent stratigraphic boundaries that can be traced on electric logs as well as lithologic logs.

The Council Grove Group underlies the Chase Group and conformably overlies the Admire Group. It comprises 14 formations, all of which can be recognized with some certainty in the subsurface. Like the Wabaunsee (Upper Pennsylvanian) and Admire Groups, the Council Grove is mostly shale, but it contains a greater percentage of limestone than the other mentioned groups. Considering the Council Grove as a whole, it contains more varicolored and red shales than do the underlying units, and the limestones contain more chert. The presence of chert in some of these beds was an important factor aiding Moore and Merriam (1959, p. 28) to recognize the megacyclic nature of this part of the sequence. Several limestone units are distinctive lithologically—for example, the Cottonwood Member of the Beattie Limestone (Pl. 14D), Neva Member of the Grenola Limestone, and Americus Member of the Foraker Limestone. Both the Cottonwood and Americus are fusulinid-bearing limestones; so abundant are the fusulinids, as a matter of fact, that they are an important lithologic constituent and the units may be identified in sequence on this aspect alone. In addition to having lithologic attributes that may be identified in samples, the Cottonwood, Neva, and Americus Limestones, in contrast to adjoining beds, form conspicuous "kicks" on electric logs. Some evaporite deposits also are found in the Council Grove Group, although they are relatively minor in amount. Most of the Council Grove units are traceable westward into Colorado.

The Admire Group consists chiefly of shale but includes some thin limestones, of which the Five Point Limestone may be recognized in most logs with reasonable certainty. The sequence is similar to that of the underlying Wabaunsee Group (Pennsylvanian) and is difficult to differentiate in the subsurface.

Correlation of stratigraphic units from the surface to the Stanolind No. 1 Equitable Life well in Dickinson County is shown on Figure 43 (Merriam, 1959b). The surface sequence was compiled from sections measured by various geologists, principally along Kansas River valley in Douglas, Shawnee, and Wabaunsee Counties. Generally speaking, thicknesses of the different units are greater at the surface than in the well. Only formations are indicated in the section, although many members can be identified. Certain units recognized at outcrops are not identified in Dickinson County or farther west, and certain beds distinguished in the Stanolind well are not identified in the composite surface section.

A west-east cross section indicating the group boundaries of upper Pennsylvanian and lower Permian rocks is shown in Figure 44. From this cross section it is evident that the Wabaunsee-Admire contact is indefinite. Most other contacts are readily distinguishable, especially in all of northeastern Kansas. Difficulties are encountered, however, in tracing the groups westward to the Colorado line and southward into Oklahoma. Of special interest is the random distribution of sandstone bodies in various stratigraphic positions in different wells, indicating minor local unconformities.

FLORENA SHALE MEMBER

The Florena Shale occurs near the center of the Council Grove Group as the middle member of the Beattie Limestone. It is underlain by the Cottonwood Limestone Member and overlain by the Morrill Limestone Member. By virtue of its stratigraphic position, lithology, and distinctive paleontological characteristics, the exposed Florena is easily traced from Nemaha and Marshall Counties in the north to Cowley County in the south.

Detailed surface, stratigraphic, and paleontologic studies of the Florena Shale have been conducted by Imbrie (1955) and Walker (1951). Several county studies by the Kansas Survey, including those for Cowley (Bass, 1929), Riley and Geary (Jewett, 1941b), Jackson (K. L. Walters, 1953), Marshall (Walters, 1954), Chase (Moore and others, 1951a), and Lyon (O'Connor and others, 1953), have mentioned the Florena Shale at least briefly.

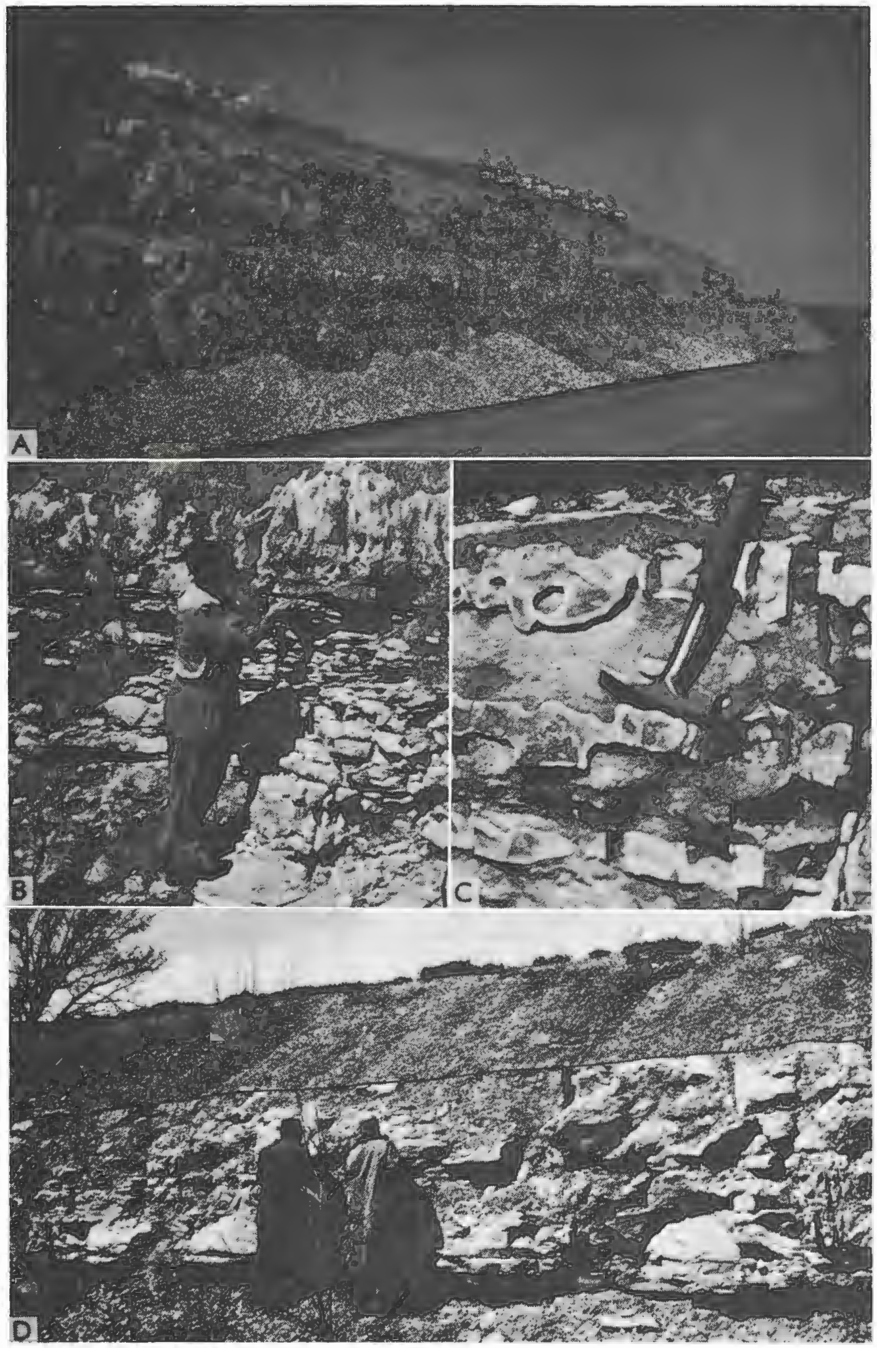
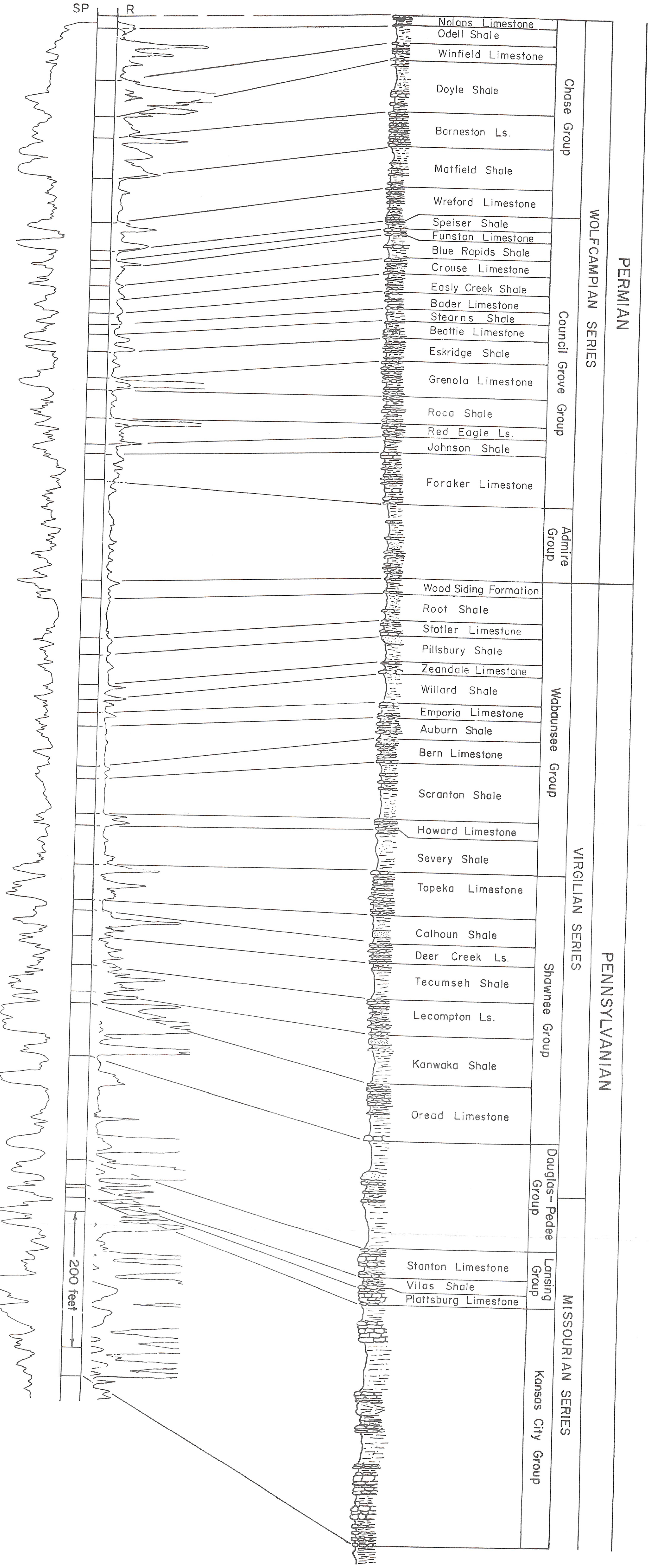


PLATE 14.—**A,** Deep road cut in Florence flint on U.S. Highway 40 about 7 miles east of Junction City, Geary County. **B,** Clam borings in Wreford Limestone on Kansas Highway 38, Cowley County (sec. 29 and 30, T. 32 S., R. 7 E.). **C,** Chert in Wreford Limestone about 2 miles north of intersection U.S. Highway 40 and Kansas Highway 13, Riley County. **D,** Florena Shale (above) and Cottonwood Limestone (below) about 1½ miles southwest of Manhattan, Riley County (NW SE sec. 23, T. 10 S., R. 7 E.).



IGURE 43.—Correlation of units between composite surface section and Stanolind No. 1 Equitable Life well in Dickinson County (from lerriam, 1959b).

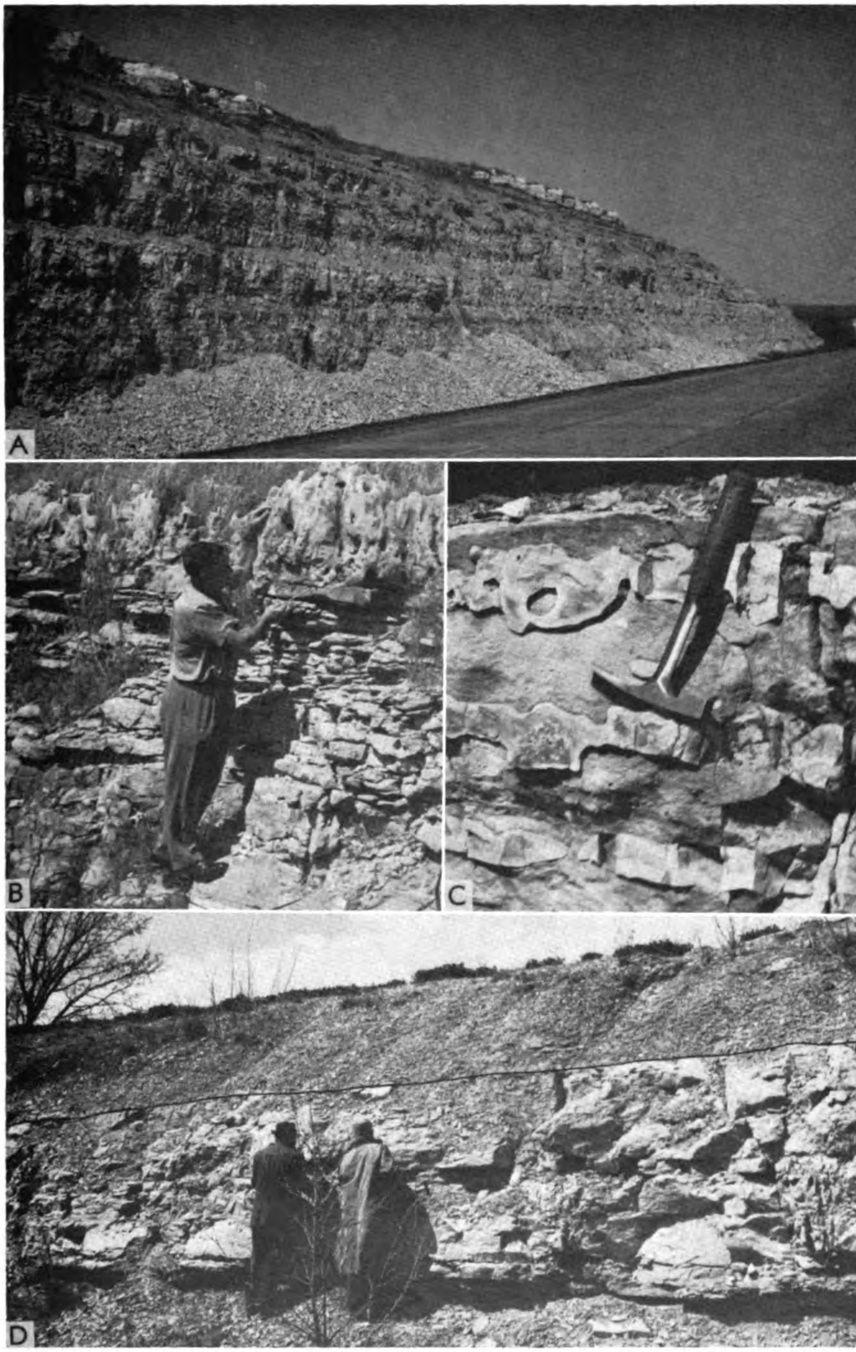


PLATE 14.—**A,** Deep road cut in Florence flint on U.S. Highway 40 about 7 miles east of **Junction** City, Geary County. **B,** Clam borings in Wreford Limestone on Kansas Highway 38, **Cowley County** (sec. 29 and 30, T. 32 S., R. 7 E.). **C,** Chert in Wreford Limestone about 2 miles **north of** intersection U.S. Highway 40 and Kansas Highway 13, Riley County. **D,** Florena Shale **(above) and** Cottonwood Limestone (below) about 1½ miles southwest of Manhattan, Riley **County** (NW SE sec. 23, T. 10 S., R. 7 E.).

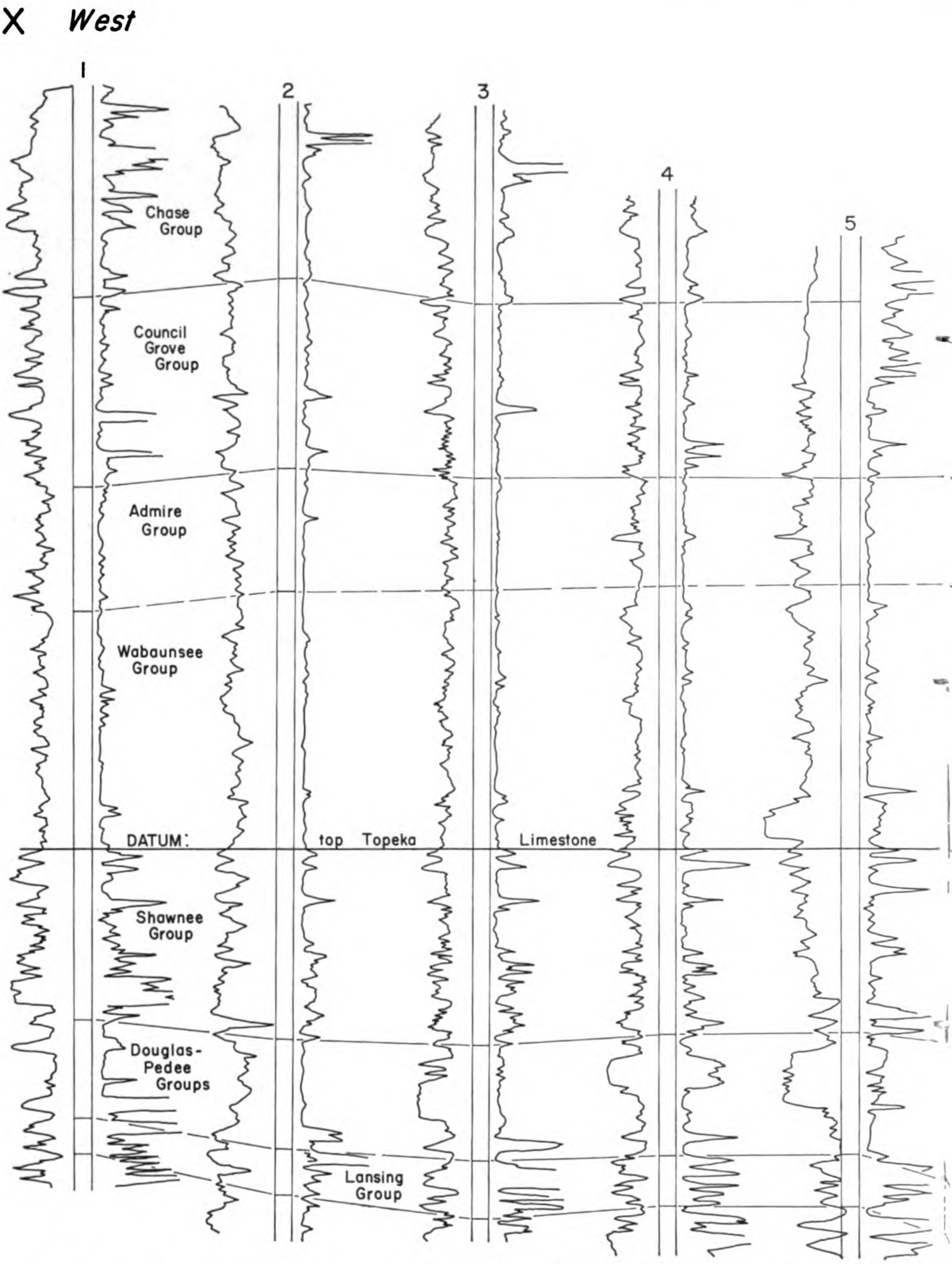
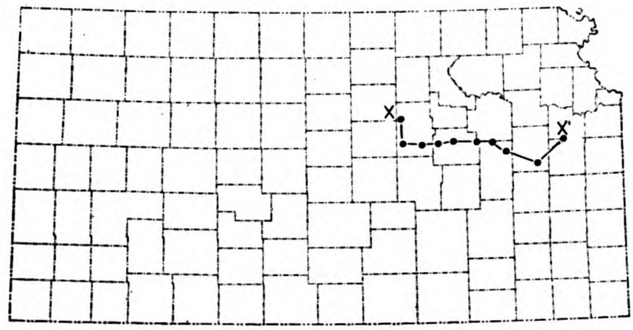
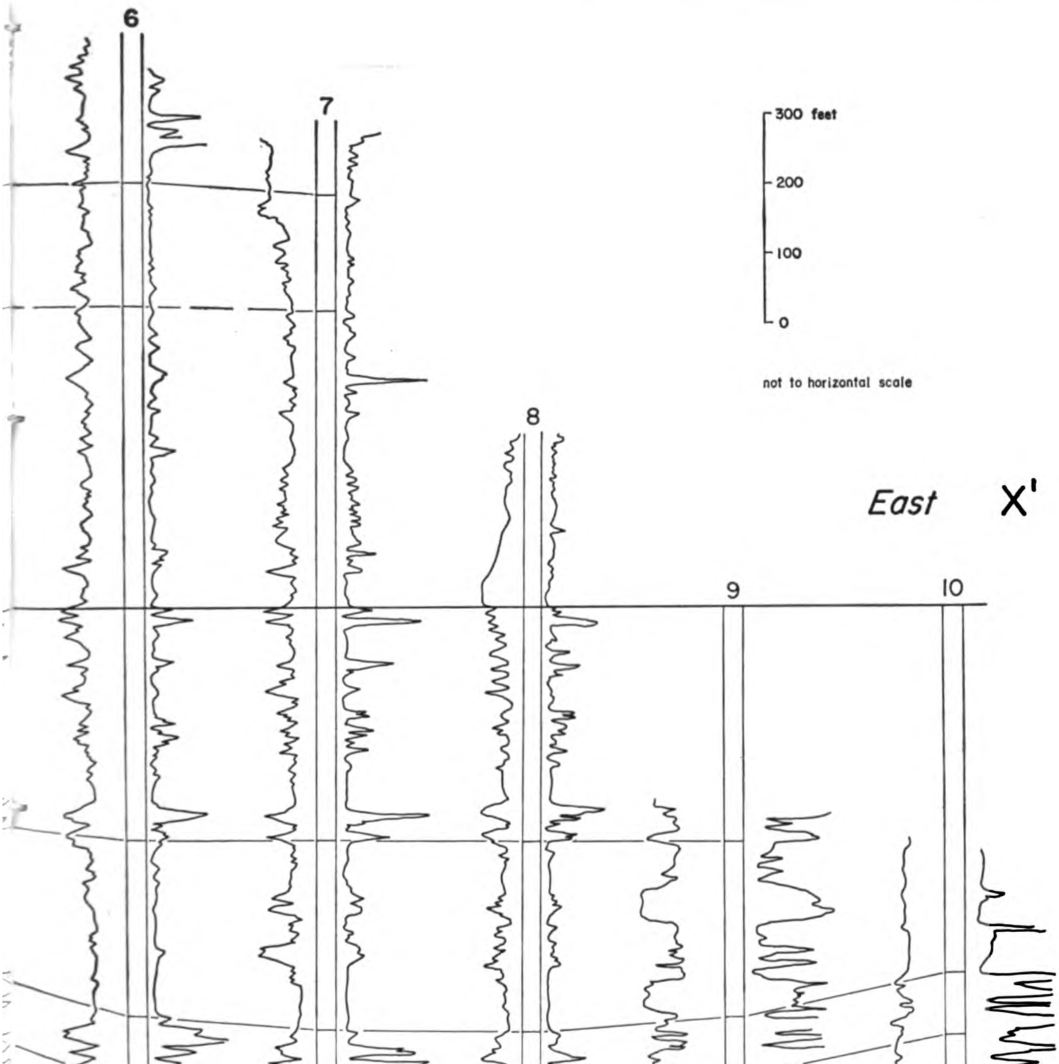


FIGURE 44.—West-east electric-log cross section from Dickinson County to Douglas County showing relation of lower Permian and upper Pennsylvanian units. Recognition of Pennsylvanian-Permian contact is difficult, owing to transitional nature of sequence (from Merriam, 1959b).


X
X'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7
8
9
10
300 feet
200
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0
not to horizontal scale
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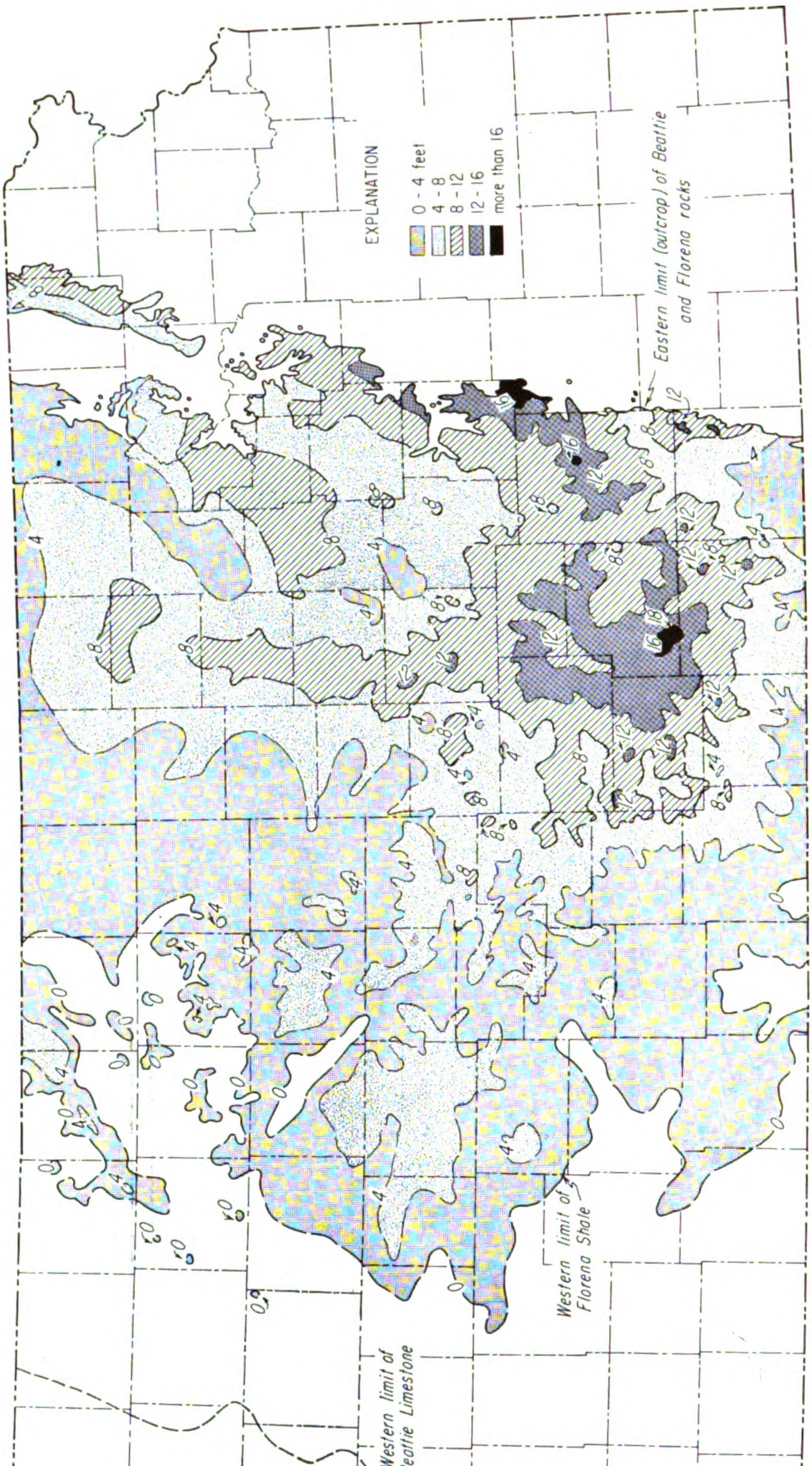


Figure 45.—Isopachous map of Florena Shale in Kansas, based on about 2,500 control points (Fig. 46). Contour interval 4 feet. Maximum thickness, about 18 feet, in southwestern Sedgwick County.

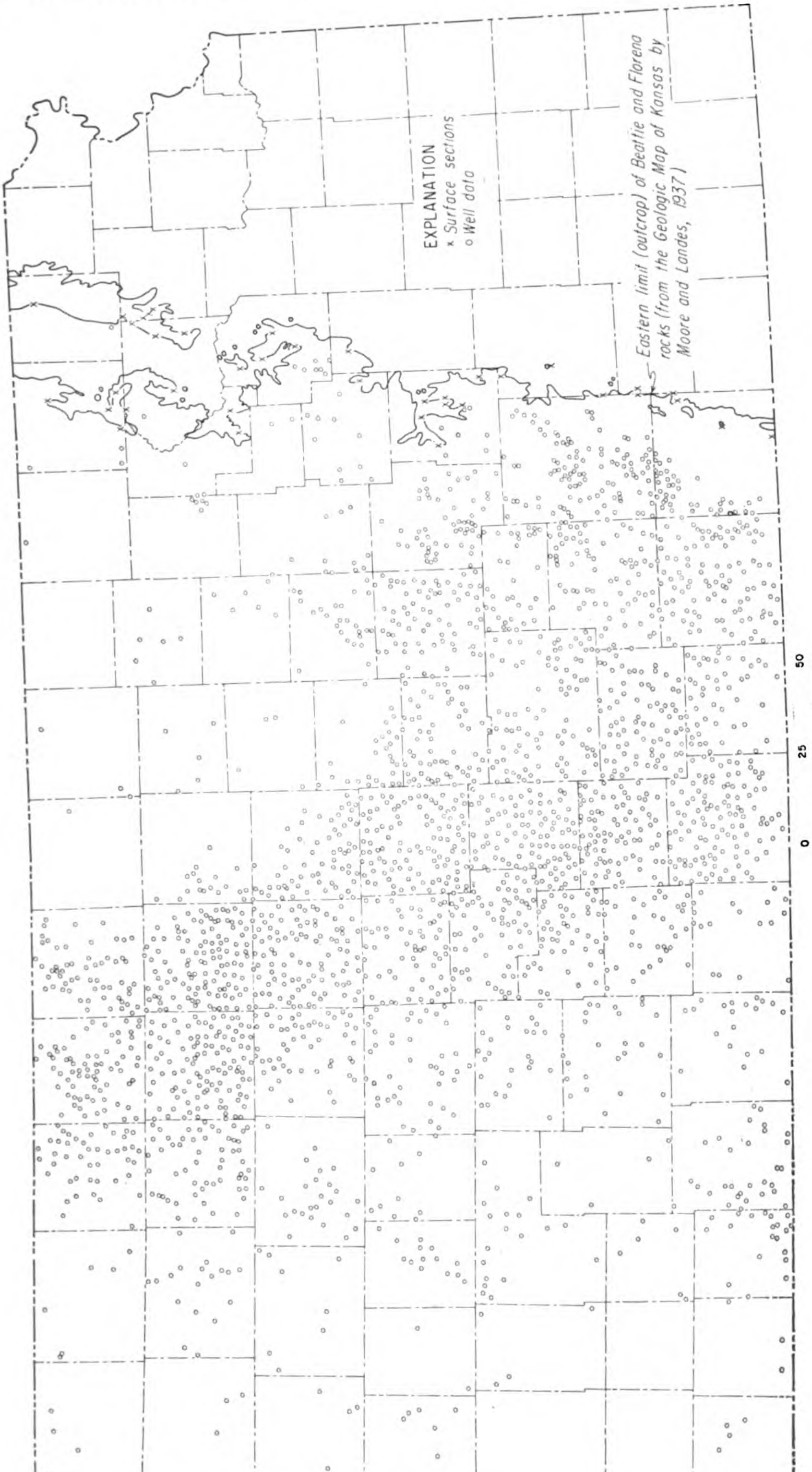
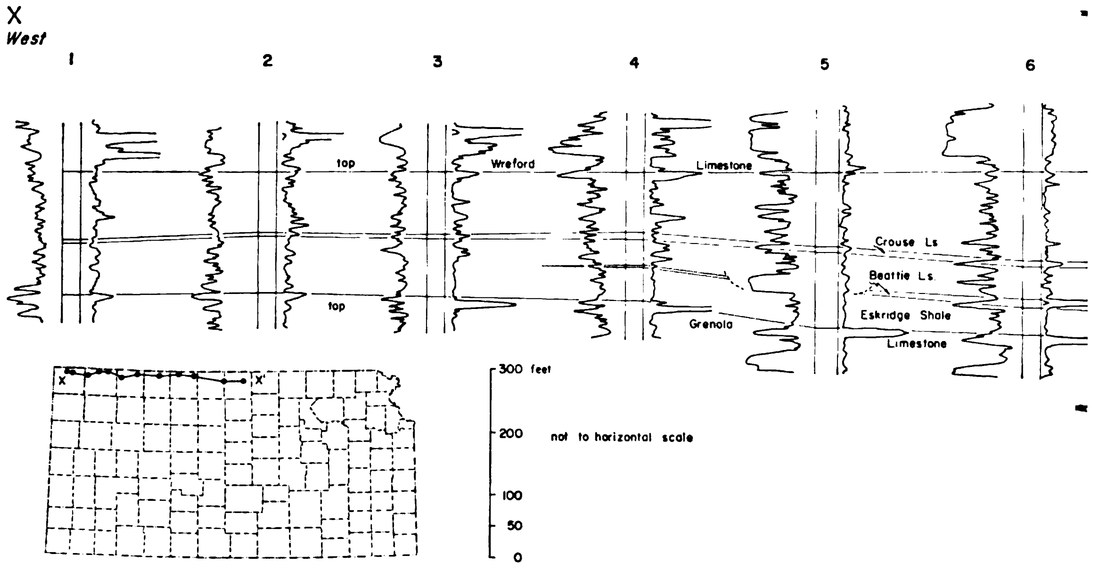


FIGURE 46.—**Map showing location of surface and subsurface control points used in constructing Florena isopachous map (Fig. 45).**



Measured surface sections were compiled into composite sections, and individual rock units were traced into the subsurface by means of sequence and lithology and were correlated with the electric log of the Stanolind No. 1 Equitable Life well in Dickinson County (Fig. 43). After the electrical and radioactive characteristics of the Florena Shale and adjacent rock units had been identified, it was possible to trace these units by electric and other types of logs. Inasmuch as it was not possible to identify the Florena in cuttings from rotary samples, they were not studied.

Cross sections, based chiefly on electric and radioactivity logs and intersecting each other, were constructed so as to check stratigraphic correlations. The cross sections were so arranged that they also intersect previously published sections—including those by Collins (1947), Kansas Geological Society (1950, 1951, 1956), Lee (1953), Liberal Geological Society (1956), Lukert (1949), and Maher (1946, 1947)—as a means of checking the identification and correlation of the Florena Shale in the subsurface.

An isopachous map of the Florena Shale is presented in Figure 45 (Imbrie, Laporte, and Merriam, 1959). Configuration of the contours is based on about 2,500 surface and subsurface control points (Fig. 46). The eastern limit of control is marked by the outcrop pattern of the Cottonwood Limestone, which underlies the Florena Shale. The isopachous map was prepared at a scale of 1:1,000,000 and contoured at 2-foot intervals, although only 4-foot contours are reproduced in the figure.

Along the outcrop area, Imbrie (personal communication, July 10, 1958) found the formation to range in thickness from a featheredge to 15 feet. The maximum thickness along the outcrop was found in Chase County, from which area the Florena thins both northward and southward. In Osage County, northern Oklahoma, the Florena thins to a bedding plane between the Morrill and Cottonwood Limestones. To the north, in Nemaha County, Nebraska, the unit thins to 1.3 feet thick. In the subsurface the formation was found to range in thickness from a featheredge to 18 feet, the maximum thickness occurring in southwestern Sedgwick County. In the subsurface of south-central Kansas, the Florena seemingly is absent in south-central Cowley County. The western edge of the Florena Shale in western Kansas extends in an irregular line from Norton County on the north to Clark County on the south. Several small outliers in northeastern Decatur County, western Sheridan County, and northeastern Logan County lie west of the pinchout.

In extreme northwestern Kansas, diagonally across western Rawlins County, eastern Sherman County, and Wallace and Greeley Counties, the Beattie Limestone pinches out. In the area between the Beattie Limestone pinchout and the zero line of the Florena (Fig. 45), the Morrill Limestone is in contact with Cottonwood Limestone, as shown by the stratigraphic cross section (Fig. 47). A paleogeographic sketch map prepared by Moore (1953) also shows the geographic extent of the Beattie Limestone; however, information obtained subsequent to the

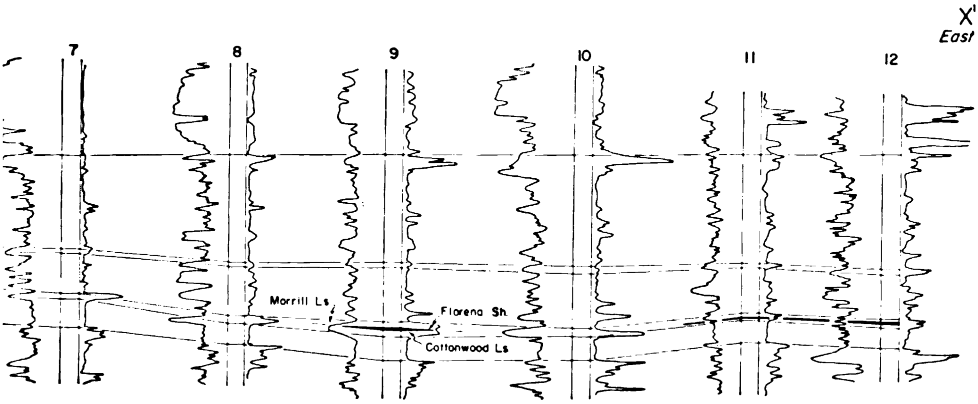


FIGURE 47.—West-east electric-log cross section showing relation of Florena Shale to adjacent units, and westward pinchout of Beattie Limestone.

preparation of Moore's map reveals that the Beattie Limestone pinches out in extreme northwestern Kansas.

Within the area where Florena beds are present in the subsurface of Kansas, the configuration of contours seems to reveal irregular thickness. On closer examination, however, the changes in thickness can be interpreted to reflect present and past structure.

Pennsylvanian-Permian Boundary

Because of the similarity of rock units of the Wabaunsee Group (Upper Pennsylvanian) and Admire Group (Lower Permian) in the subsurface, it is difficult to determine the boundary between the two systems. A disconformity separates the Pennsylvanian from the Permian at least locally and may be demonstrated at the surface where exposures can be examined in more detail than is possible in work with rotary well samples; however, little evidence from subsurface data supports or denies the existence of a regionally significant break at or near the Wabaunsee-Admire boundary. In places a sandstone may be present at about the stratigraphic position of the Brownville Limestone (uppermost division of the Wabaunsee Group), possibly indicating channel cutting and therefore at least a local hiatus (Pl. 15A, 15B). The regularity in thickness of the two groups (Wabaunsee and Admire) suggests that the contact generally is conformable. About the contact, Mudge has stated (1957b, p. 116):

> . . . In most places remote from the outcrop, the writer could not be certain which thin beds of limestone, if any, were correlative with the uppermost limestone members of Pennsylvanian age and with the lowermost limestone members of Permian age . . . . In the lowermost Permian beds, the base of the Foraker limestone, and in places the Five Point limestone member of the Janesville shale, can be identified . . . . In the uppermost Pennsylvanian rocks, the Tarkio and Howard limestones locally are identifiable above the Topeka limestone. . . . The present writer, for example, tentatively assigns the boundary between the systems at 100 to 150 feet beneath the base of the Foraker limestone, in logs near the outcrop area . . . .

My study supports Mudge's conclusion that placement of the boundary in the subsurface is arbitrary. Lee (1956, p. 107) also had trouble placing the boundary, for he said:

> The relation of the Wabaunsee group at the top of the Pennsylvanian System to the overlying Admire group at the base of the Permian System is obscure in the subsurface. The lower beds of the Admire, like the upper beds of the Wabaunsee, consist of sandy shale, sandstone, and thin interstratified limestone beds, none of which can be satisfactorily identified in the subsurface in either sample or electric logs . . . .

Branson (1960a; 1960b) has recently recommended that the Pennsylvanian-Permian boundary be moved upward to the base of the Wellington Formation. The strata now classified as Wolfcampian (Lower Permian) would then be placed in a so-called Lyonian Series (named from Lyon County, Kansas) of Late Pennsylvanian age, and the term Wolfcampian would be abandoned. There is some merit in this proposal, but at present little is to be gained by moving a boundary that reached reasonable stability only in the last two decades after being moved up and down numerous times. In the

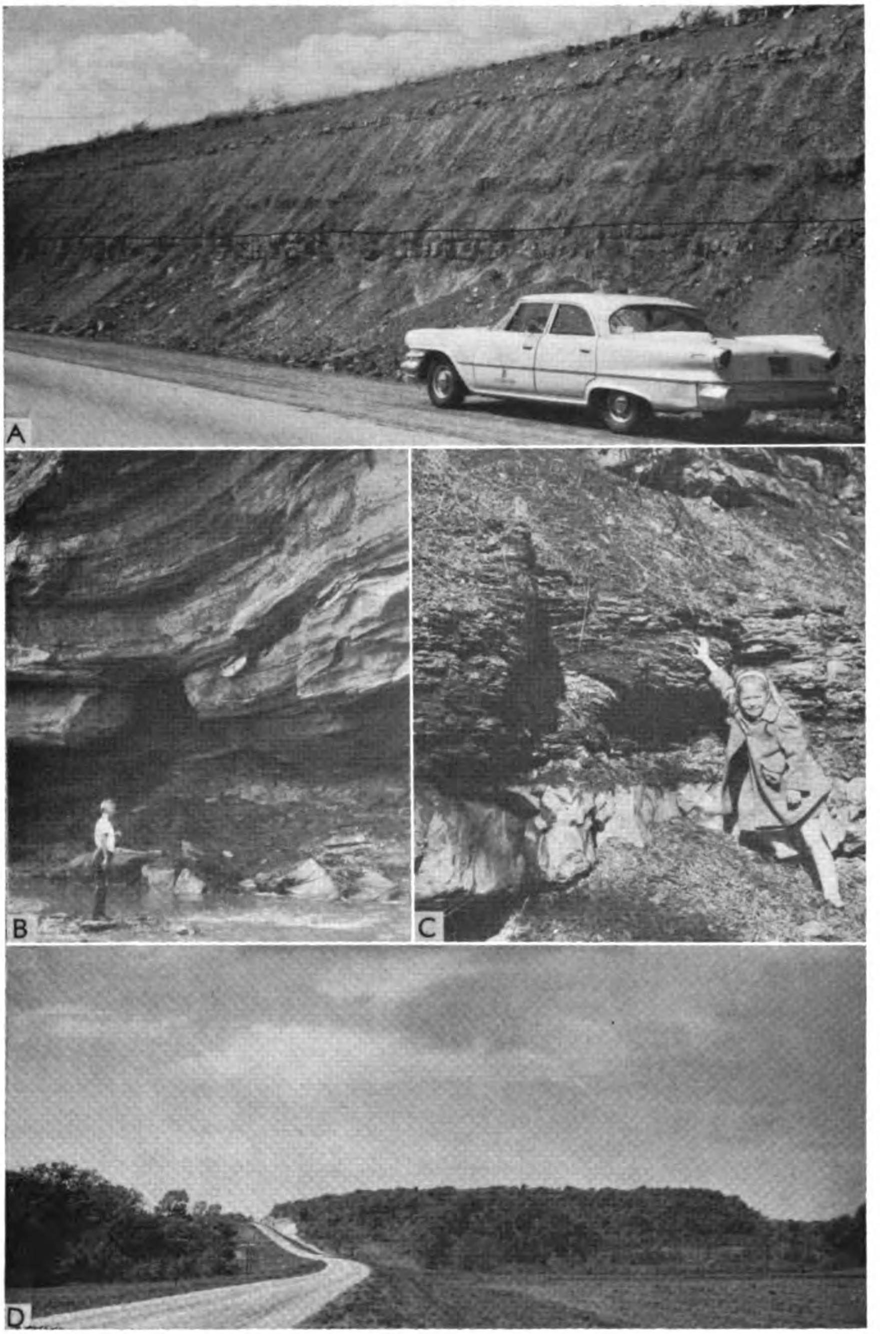


Plate 15.—A, Contact of Permian (Towle Shale) and Pennsylvanian (Brownville Limestone) on U.S. Highway 40 just west of Maple Hill road, Wabaunsee County (sec. 26, T. 11 S., R. 12 E.). **B,** Indian Cave Sandstone (basal Permian) exposed at Echo Cliffs near Dover, Wabaunsee County (NW SW sec. 5, T. 13 S., R. 13 E.). **C,** Heebner Shale overlying Leavenworth Limestone (Oread Formation) in road cut on West 7th Street, Lawrence, Douglas County. **D,** Topographic escarpment held up by Captain Creek Limestone, just west of Altoona on Kansas Highway 47, Wilson County.

subsurface it is locally as hard to recognize the base of the Wellington as the Brownville; the easiest boundary to recognize in the subsurface is judged to be the base of the Americus Limestone (Foraker Limestone), but little purpose is served by changing the boundary a few feet in transitional beds.

Pennsylvanian Deposits

Pennsylvanian deposits in Kansas are divided into five series (in descending order): Virgilian, Missourian, Desmoinesian, Atokan, and Morrowan.* Because much has been written on the stratigraphy of the outcropping Pennsylvanian rocks of Kansas, little needs to be said here other than to reemphasize the cyclic nature of these beds. For the most part, the cycles consist of marine limestone and shale, alternating with nonmarine clastic deposits. At the upper contact, as already stated, Pennsylvanian rocks in Kansas are gradational with Permian rocks, and the lower contact with Mississippian rocks is unconformable. Deposits of Pennsylvanian age cover all of Kansas except the extreme southeastern corner in Cherokee County (Fig. 48).

In eastern Kansas Pennsylvanian beds dip gently westward, forming cuestas with very gentle dip slopes to the west and relatively steep east faces (Pl. 15D); the area is known as the Osage Plains. Pennsylvanian rocks form a wide outcrop band which crosses the state diagonally from Doniphan and Nemaha Counties on the north to Cherokee and Chautauqua Counties on the south. East-flowing streams have scalloped the many prominent east-facing escarpments to form an irregular pattern.

The nature of Pennsylvanian deposits in Kansas has been treated in detail by Moore (1949a). His condensed description of these beds is especially apropos and is reproduced here (1949a, p. 9):

> The Kansas Pennsylvanian rocks may be compared to a small stack of many-colored sheets of paper ranging in weights from thinnest onion-skin to cardboard. Each sheet of some specified color represents a certain kind of rock, such as black platy shale, light-gray calcareous shale, coal, a particular sort of limestone, and so on. The extreme relative thinness of the sheets as compared to their lateral dimensions suggests the small vertical measurements (ranging from less than 1 foot to not more than 25 feet generally) of Pennsylvanian rock units which can be traced 100 to 400 miles along the outcrop and similar distances at right angles to the outcrop underground. Of course, there are irregularities. Some layers vanish here and there, and they may show local pinching or swelling in the area where they persist. These are features which we should expect to find. The outstanding character of the Pennsylvanian rocks north of Oklahoma, nevertheless, is stratigraphic regularity and this makes possible application of the same classification and nomenclature of divisions (with very minor variations) throughout the States of Kansas, Missouri, Iowa, and Nebraska.

Actually, this succession of beds could be and has been described as monotonous. Several important features of stable-shelf-deposited sedimentary units have been pointed out, including: (1) lateral persistence of ultrathin beds, (2) tremendous ratio of width to thickness (in some layers millions of times), (3) extreme sharpness of boundaries (Pl. 15C), and (4) cyclic nature of the deposits. Any explanation of their origin must satisfy these parameters.

Although much has been written on the origin and development of cyclothems, they are little understood. Several explanations of their formation have been suggested; generally these include eustatic changes of sea level, tectonic movements, complex environmental changes, or a combination of factors.

Cyclothems may be symmetrical or asymmetrical, depending on the arrangement of the marine and nonmarine components. A nonmarine to marine to nonmarine arrangement is symmetrical and gives rise to units of a cyclic nature, whereas nonmarine to marine followed by nonmarine to marine is asymmetrical or hemicyclic. Inasmuch as the transgressive phase of the cyclothem is usually better represented (or better preserved) than the regressive part, most cyclothems exhibit asymmetrical aspects. Members of an ideal cyclothem are presented in Table 1 (Moore, 1935b). Seldom are all members of a cyclothem represented at a single locality; either they were not developed or they were developed and subsequently destroyed. Because cyclothems are bundles of genetically related rocks, they do not necessarily represent the best

TABLE 1.—Members of an ideal cyclothem, designated upward (from Moore, 1935b).

.9	Shale (and coal).
.8	Shale, typically with molluscan fauna.
.7	Limestone, algal, molluscan, or with mixed molluscan and molluscoid fauna.
.6	Shale, molluscoids dominant.
.5	Limestone, contains fusulinids, associated commonly with molluscoids.
.4	Shale, molluscoids dominant.
.3	Limestone, molluscan, or with mixed molluscan and molluscoid fauna.
.2	Shale, typically with molluscan fauna.
.1c	Coal.
.1b	Underclay.
.1a	Shale, may contain land-plant fossils.
.0	Sandstone.

* Recent Kansas Survey usage of these terms has been as stages, although they have been widely regarded as series.

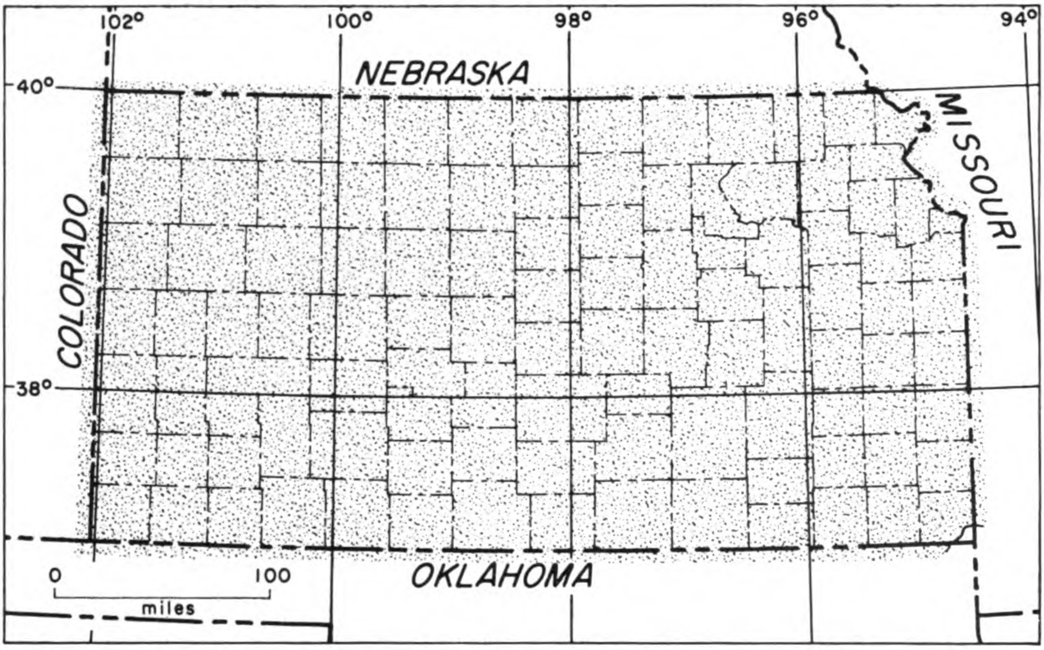


FIGURE 48.—Map of Kansas showing surface and subsurface distribution of Pennsylvanian deposits.

grouping of units for mapping; in Kansas they are not mapped.

The different fundamental lithologic compositions of major stratigraphic units allow different types of cyclothems, of which only two are presented here graphically (Fig. 49). Each Permian Wolfcampian cyclothem represents a single advance and retreat of the sea, i.e., nonmarine to marine to nonmarine conditions. Location of the cyclothemic boundaries follows the usage of Elias (1937a) and differs somewhat from that shown by Jewett (1933). Note in particular that the Cottonwood cyclothem (Fig. 49A) consists of parts of three formations. Following previous practice, the cyclothem is named for the limestone unit representing the culminating phase of transgression.

The Wabaunsee Group (Virgilian) cyclothems are well exemplified by the Dover Limestone and adjacent formations (Fig. 49C). Both transgressive and regressive units are present in the cyclothem, which includes nonmarine to marine to nonmarine deposits, making it symmetrical.

A complex bundle of related units forms what R. C. Moore has referred to as a megacyclothem. An example of a Permian megacyclothem is shown in Figure 49B. The boundaries of this megacyclothem were adjusted from those proposed by Moore and Merriam (1959) in order to coincide with individual cyclothemic boundaries as recognized previously by M. K. Elias. The name of the megacyclothem is taken from a prominent limestone formation in the unit. The type megacyclothem is perhaps represented by the Oread Limestone and adjacent units (Fig. 49D).

A megacyclothem has been considered to be a grouping of partial cyclothems or to be one complex unit. Weller (1958, 1960) has proposed that a group of closely associated successive megacyclothems, supposedly as represented by those of the Shawnee Group (Virgilian), be termed a hypercyclothem.

Major stratigraphic units, genetically related and systemic in size although not necessarily corresponding to systemic boundaries, have been recognized for many years.* Historically these were the first units to receive attention from early workers, at a time when little if any data were available. As more and more detailed work was done the big units were forgotten; however, in recent years more attention has been given to these units.

* Even larger, grand cycles were recognized by Elias (1945).

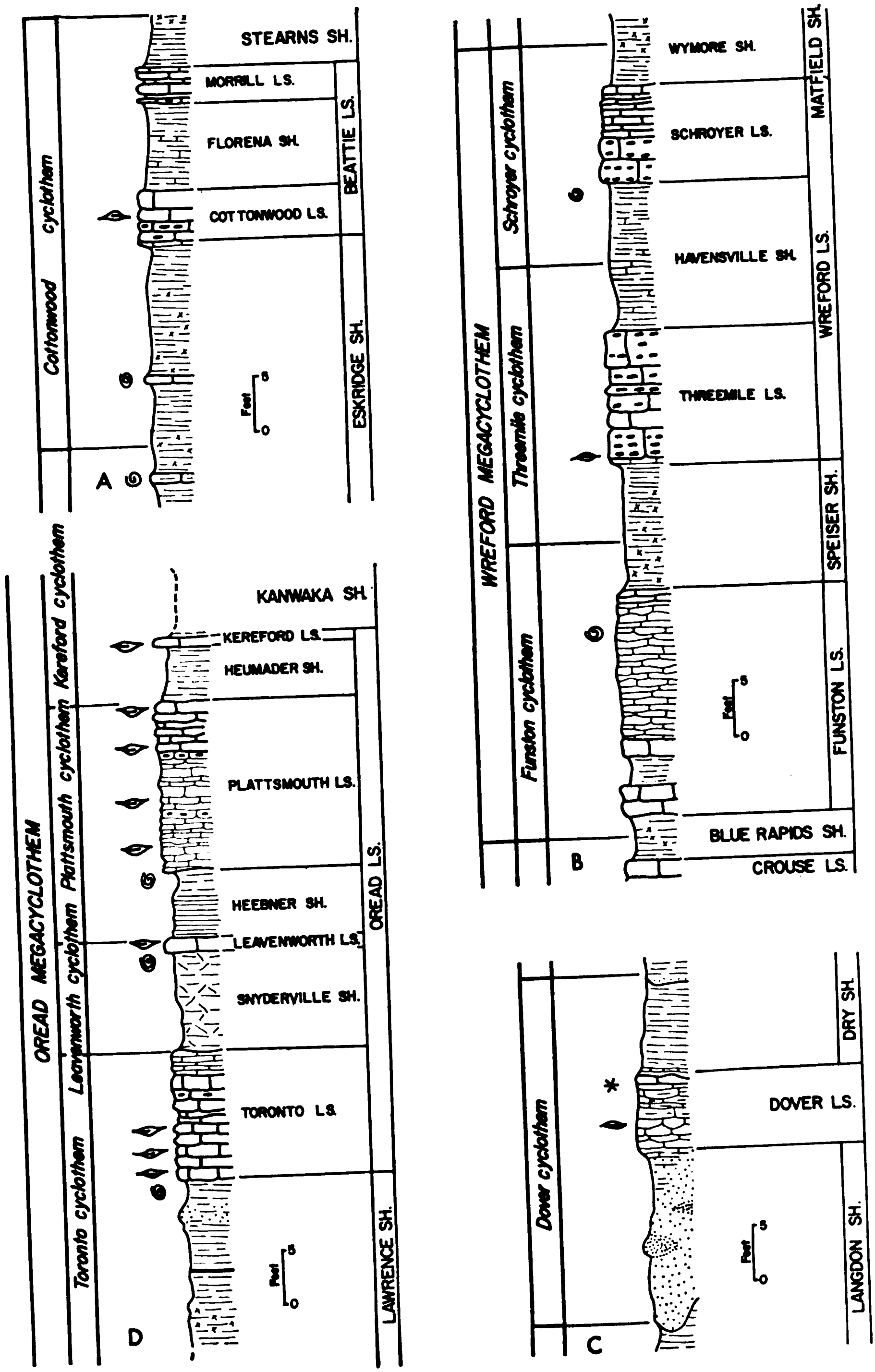


FIGURE 49.—Examples of types of cyclothems and megacyclothems represented in Pennsylvanian and Permian deposits of Kansas: A, Cottonwood cyclothem (Wolfcampian); B, Wreford megacyclothem (Wolfcampian); C, Dover cyclothem (Virgilian); and D, Oread megacyclothem (Virgilian). Correction: read Pillsbury for Langdon; Dover Limestone and Dry Shale are members of Stotler Limestone (Moore and Mudge, 1956).

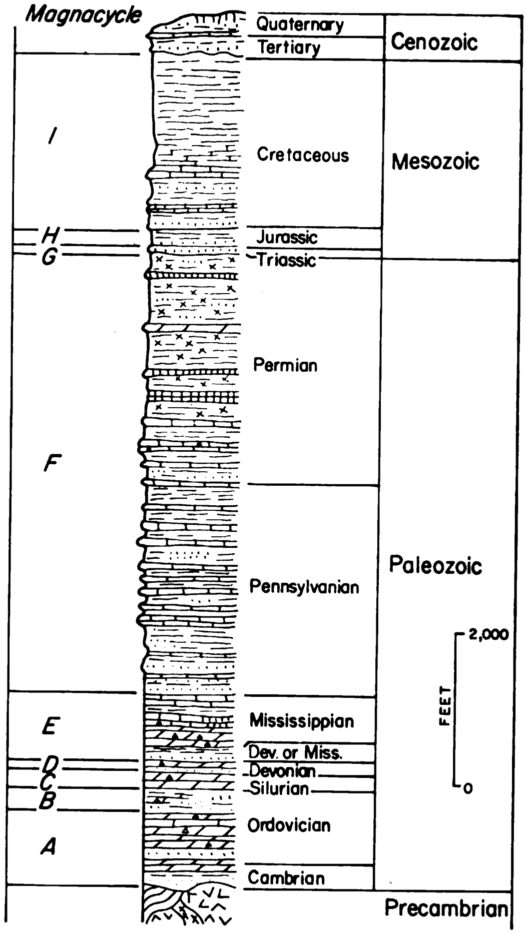


FIGURE 50.—A generalized columnar section of Kansas rocks showing relation of major units to magnacycles. At least nine magnacycles are recognizable in Paleozoic and Mesozoic rocks.

These major stratigraphic units, many of which are present in Kansas, have been termed megagroups in Illinois and formally named by Swann and Willman (1961). Sloss, Krumbein, and Dapples (1949) termed large assemblages sequences and considered them rock units that could be named. These large rock groupings termed megagroups or sequences represent major events in the course of earth history, and because they follow a repetitious pattern can be considered cyclic in nature. The term *magnacycle*, suggested by R. C. Moore, is here proposed for these large, complex, cyclic rock units.

Magnacyclothems in Kansas are shown in relation to major stratigraphic units in Figure 50. Since it is not proposed here to introduce names for these features, letter symbols are used.

Although most magnacycles are either incompletely developed or repeated in portions, the Pennsylvanian-Permian one is the best and most complete example in Kansas. An ideal magnacyclothem, which is asymmetrical, begins with coarse clastics grading into finer ones interspersed with some carbonate units. The number of carbonate units increases and they may become cherty. Dolomite, gypsum, anhydrite, and other evaporitic deposits, along with redbeds, become abundant in the section; salt is present. The redbed and evaporitic sequence completes the magnacycle and another starts anew with the clastics. Many cyclothems and megacyclothems are discernible in the magnacyclothem, but the character of the cycles changes as the magnacyclothem develops in response to outside influence. Although this sequence is, of course, highly generalized and many exceptions can be found, the concept is usable and valuable in understanding stable, shelflike, rhythmic deposits such as are found in Kansas.

Because numerous units are recognized in the Pennsylvanian System of Kansas, only groups and a few key units will be mentioned here. For a detailed description of the units the reader is referred to Moore (1949a).

Pennsylvanian studies in Kansas began as early as 1859, when Meek and Hayden, two of the early Federal Survey geologists, studied the Kansas River section (Moore, 1949a). Other early studies include those of Mudge (1866), Swallow and Hawn (1865), and Swallow (1866). Studies in adjacent states were made by Broadhead (1866) in Missouri, White (1870) in Iowa, and Meek (1872) in eastern Nebraska. Later, work was carried on by Haworth (1894, 1895), Haworth and Kirk (1894), Adams, Girty, and White (1903), Beede and Rogers (1908), and many others. Beginning in the late 1920s, numerous important papers on the Kansas Pennsylvanian were published by M. K. Elias, J. M. Jewett, N. D. Newell, and W. H. Schoewe, and especially by R. C. Moore. In addition to Kansas studies, considerable work was undertaken in neighboring states (Moore, 1949a).

Wabaunsee Group

The Wabaunsee Group (Virgilian Series) conformably overlies the Shawnee Group and is made up principally of shale, but it contains thin interbedded limestone and local sandstone lenses. None of the shales in the subsurface have any particularly outstanding characteristics that make them readily identifiable (Merriam, 1959b). Likewise, the limestones, most of which represent a culminating phase of the cyclothem to which they belong, are indistinguishable in well samples (Fig. 49A). Most Wabaunsee limestones are light gray to brownish, slightly crystalline, and fusulinid bearing. Identification of units is based mainly on their thickness and sequence, although under some conditions the Dover (Pl. 16A), Zeandale (Pl. 16B, 16C), and Howard (Pl. 16D) Limestones can be recognized by their lithology. Channel-sandstone bodies can and do occur at almost any stratigraphic position in the group (Mudge, 1956), confusing the normal sequence and correlations. The top of the Wabaunsee Group is marked by the Brownville Limestone (Pl. 15A), which is the topmost unit of the Pennsylvanian as now recognized; regrettably, this unit is not easily recognized in the subsurface.

Thickness of the Wabaunsee Group (Fig. 51) ranges from about 320 to 520 feet. The northern part of the Nemaha Anticline appears

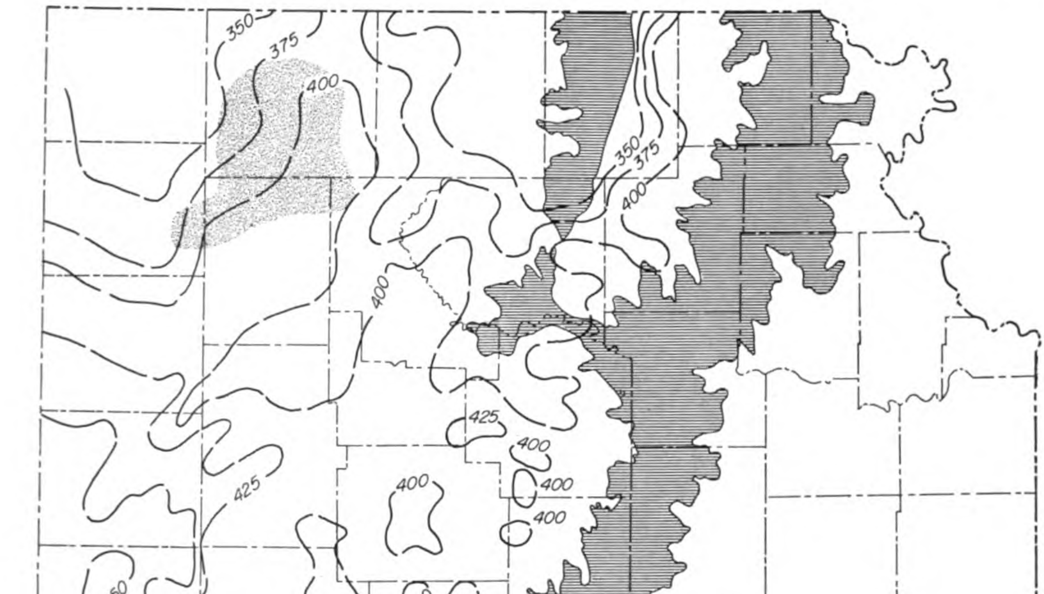


FIGURE 51.—Isopachous and percentage-carbonate map of the Wabaunsee Group in eastern Kansas. Horizontal ruling indicates area of outcrop. Control density shown on Figure 58. Contour interval 25 feet.

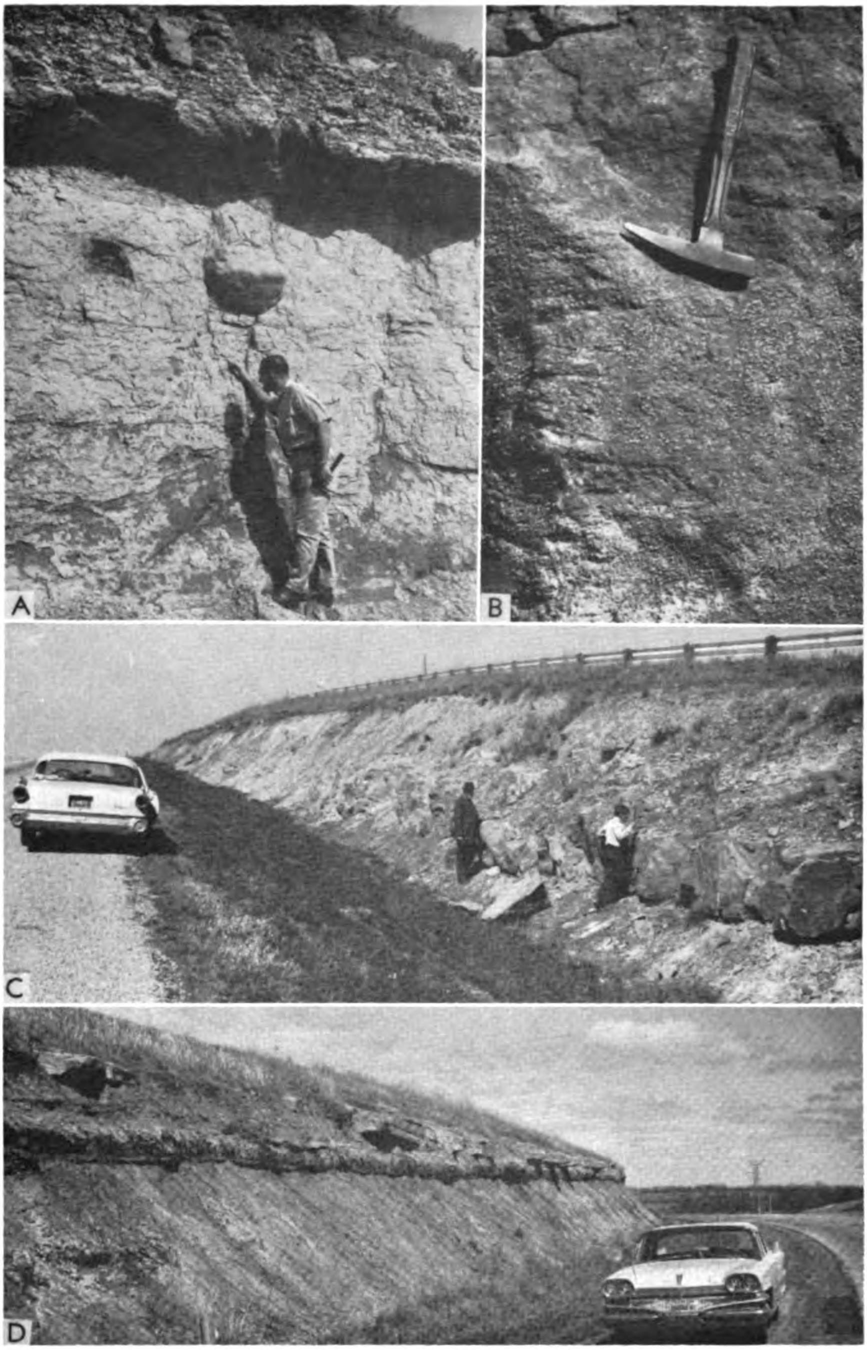


PLATE 16.—**A,** Pillsbury Shale overlain by Dover Limestone in road cut on Kansas Turnpike, Lyon County (SE SE NW sec. 18, T. 16 S., R. 13 E). **B,** Closeup of Tarkio Limestone showing many fusulinids. **C,** Tarkio Limestone overlain by Wamego Shale approximately 8 miles west of Topeka, Shawnee County (sec. 29, T. 11 S., R. 14 E.). **D,** Howard Limestone (note Nodaway coal in Aarde Shale Member beneath Church Limestone Member) on Kansas Turnpike just east of South Topeka Interchange, Shawnee County.

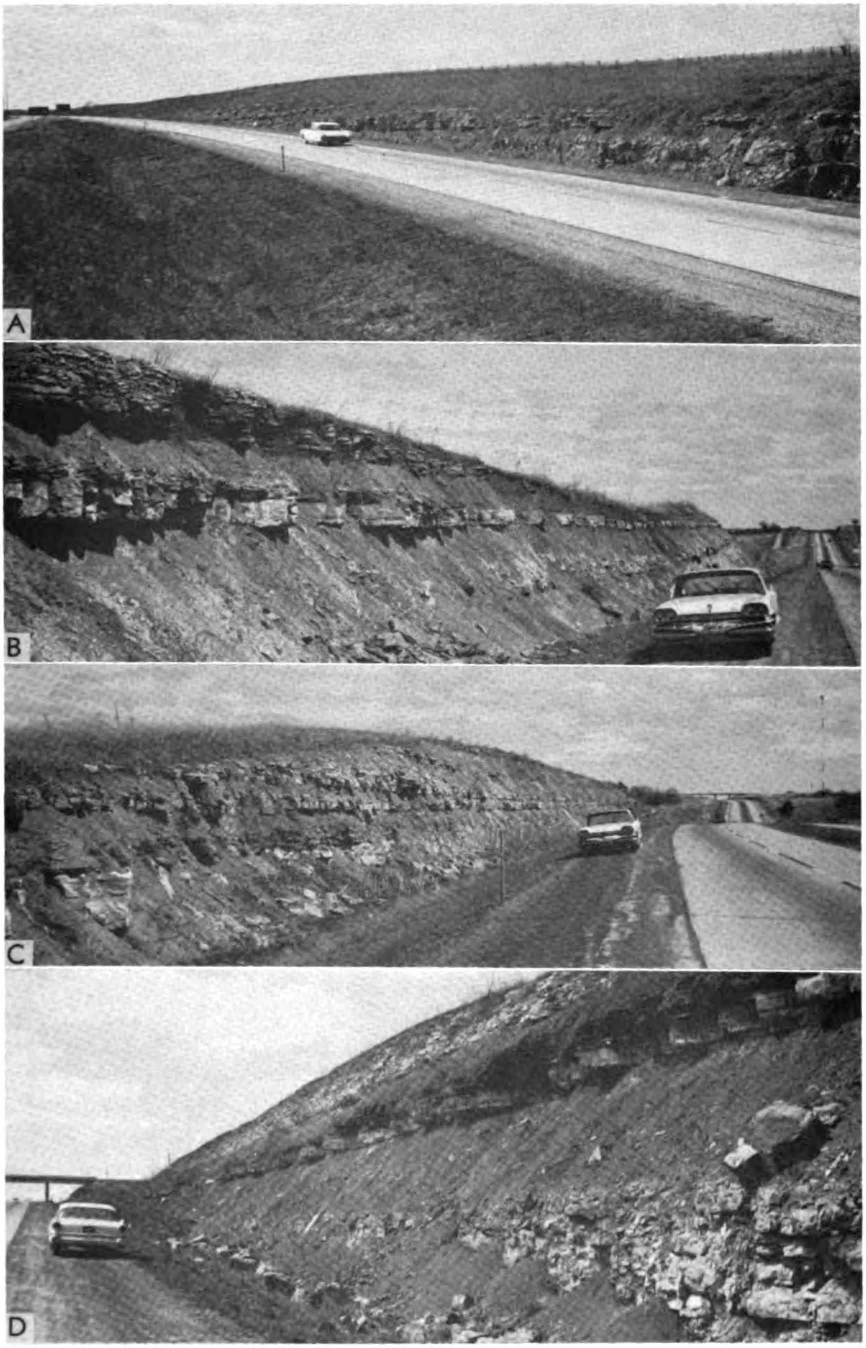
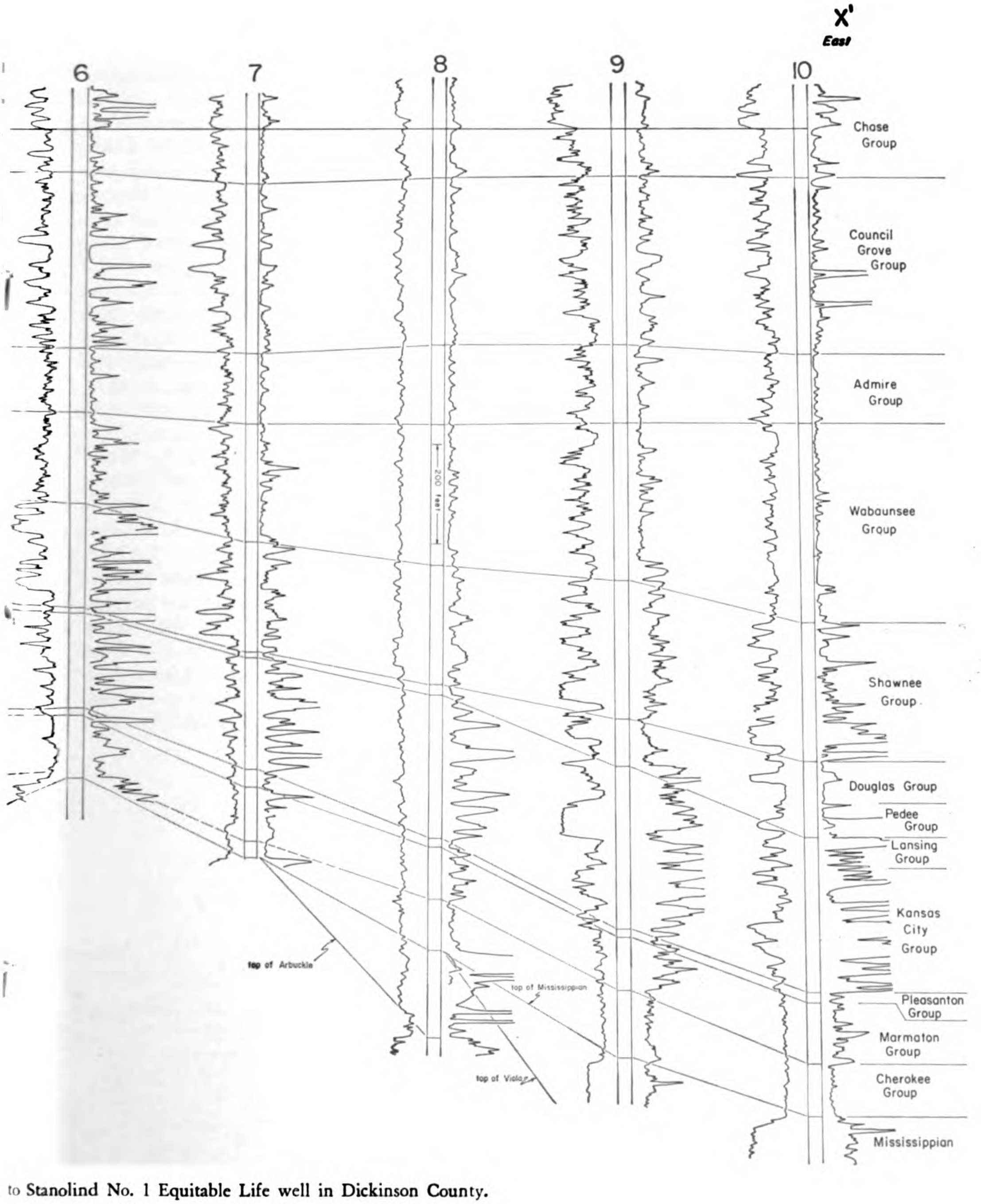


PLATE 17.—**A**, Topeka Limestone exposed on Kansas Turnpike at Topeka Service Area, Shawnee County. **B**, Deer Creek Limestone, underlain by Tecumseh Shale, on Kansas Turnpike about 8 miles west of West Lawrence Interchange, Douglas County (sec. 22, T. 12 S., R. 18 E.). **C**, Lecompton Limestone in road cut on Kansas Turnpike 6 miles west of West Lawrence Interchange, Douglas County (sec. 24, T. 12 S., R. 18 E.). **D**, Oread Limestone (lowest formation of Shawnee Group) about 3 miles west of West Lawrence Interchange, Douglas County (NW sec. 21, T. 12 S., R. 19 E.). Members recognized include (ascending): Toronto Limestone, Snyderville Shale, Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone.

Figure 52.—West-east electric-log cross section of Pennsylvanian and lower Permian rocks from Sherman County



to **Stanolind No. 1 Equitable Life well in Dickinson County.**

as an area of thinning, but farther south this relation of thickness to structure is poorly shown. On the other hand, the Abilene Anticline is reflected prominently by thinning of the group over its crest. Wabaunsee deposits thicken in the Salina Basin and east of the Nemaha Anticline. The carbonate ratios of the Wabaunsee Group are low, ranging from about 5 to 29 percent. The area of the Salina Basin has the highest ratio.

In northwestern Kansas, Hockens (1959) found that the group consists mainly of shale containing thin but persistent limestone beds. Sandstone lenses are present throughout the sequence, but they can be traced only short distances. The shale units thin and many pinch out on the Central Kansas Uplift (Fig. 52). Hockens determined that all units below the Auburn Shale in the Wabaunsee Group seemingly are absent in northwestern Kansas. The group comprises white to gray, thin-bedded, dense, locally fusulinid-bearing limestone interbedded with gray to red, calcareous, sandy shale (Hockens, 1959, p. 15).

Shawnee Group

The Shawnee Group (Virgilian Series) contains seven formations: four bundles of limestone separated by three shales. A limestone bundle plus parts of the overlying and underlying shale formations constitutes a megacyclothem, as defined by Moore (1935b). Within each megacyclothem are several members with characteristic lithologies, for example, radioactive black shale, which are identified easily both in well samples and on electric and radioactivity logs.

Of the black shale members, the Heebner is the most important, because it can be recognized with the least difficulty over the largest area (Pl. 15C). Indeed, it is used as a datum for much stratigraphic and structural work in the subsurface of central and western Kansas (Fig. 53; Merriam and Jewett, 1956). Other shale units are more difficult to recognize in the subsurface because they lack identifying characteristics and because they tend to be mixed with other samples by caving in rotary holes. As on the surface, however, other lithologies of the megacyclothem can be recognized—for instance, red shale and coal, which underlie some of the limestone bundles; dense, fusulinid-bearing limestone subjacent to the black shale; and very fossiliferous, locally cherty limestone overlying the black shale. Of the last-mentioned limestone type, the Ervine Creek Member of the Deer Creek Limestone (Pl. 17B) and the Plattsmouth Member of the Oread Limestone (Pl. 17D) are easier to recognize on well logs than the Beil Member of the Lecompton Limestone (Pl. 17C). The Topeka Limestone (Pl. 17A), uppermost formation of the Shawnee Group, also is readily identified because of the preponderance of shale in the overlying Wabaunsee Group, which is in sharp contrast to the limestone-dominated Shawnee Group. The top of the Topeka in the subsurface, however, probably is not precisely equivalent to the stratigraphic

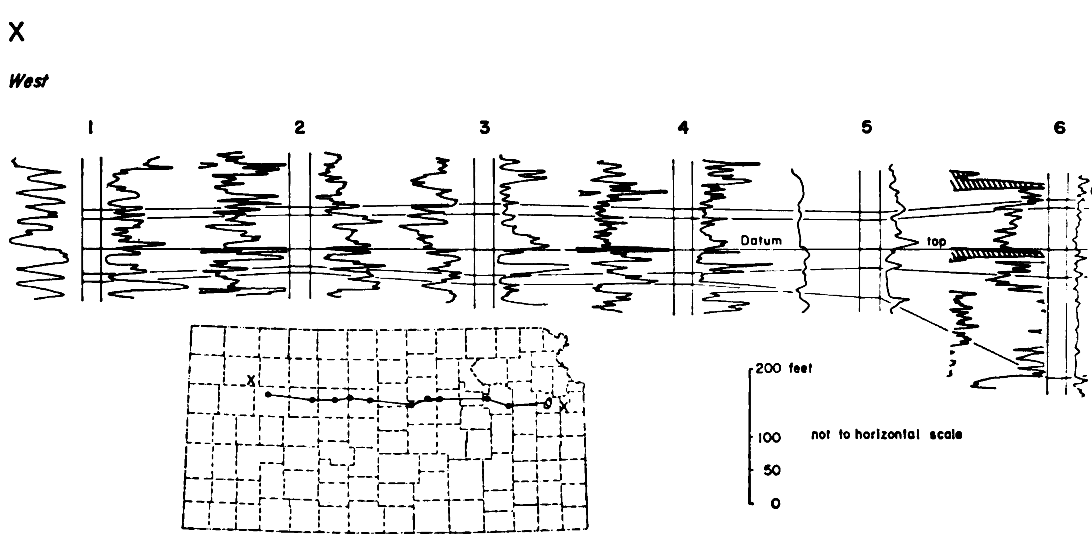


FIGURE 53.—West-east electric-log cross section showing stratigraphic relation of Oread Limestone (Shawnee

top of the formation as defined on the surface, because the upper part of the unit seems to be absent in the subsurface.

The Lecompton Limestone is a good example of overall increase in thickness because shale units thicken southward (Fig. 54). The formation increases from 40 feet in northwestern Douglas County to about 95 feet in northwestern Woodson County, a distance of approximately 40 miles, whereas the ratio of limestone to total section decreases from 1:2 to 1:6. The ratio decreases more in Oklahoma, where only some of the limestone members may be recognized, and the amount of clastic material increases. Special notice should be made of the increase in prominence southward of the Avoca Limestone and decrease in prominence of the Spring Branch Member. This also occurs in other units, notably in the Beattie Limestone, where in the northern part of the state the Cottonwood Limestone Member is the bench former and southward the Morrill Limestone Member is the scarp former. Such a reversal in prominence has resulted in many a miscorrelation by those placing too much emphasis on topographic expression.

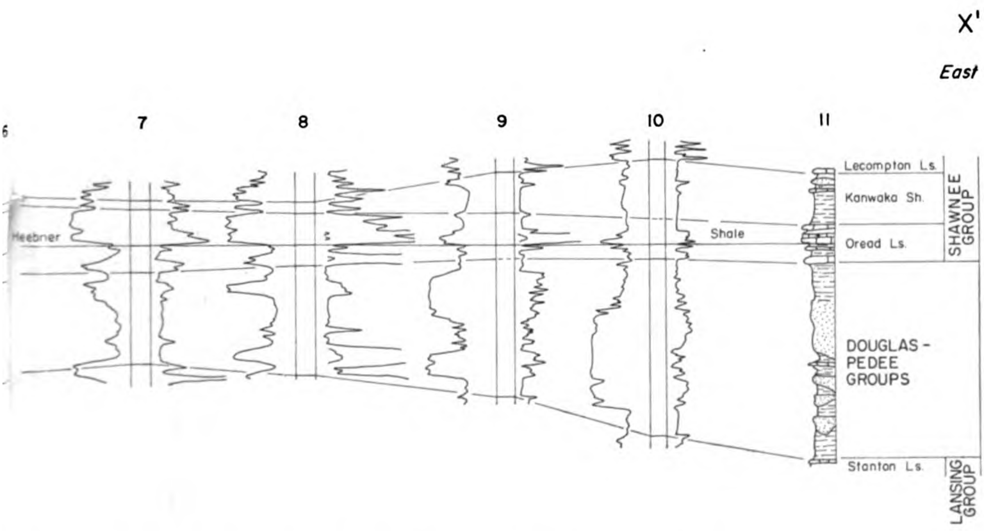
The thickness pattern of the Shawnee Group (Fig. 55) is similar in many ways to that of the Douglas-Pedee. Thickness of the Shawnee ranges from about 200 to 510 feet. Thin areas overlie the crests of the Nemaha and Abilene Anticlines. East from the Nemaha, the deposits thicken into a trough which extends irregularly northeastward from Chase County through Lyon, Wabaunsee, Shawnee, Jackson, and Brown Counties to Doniphan County. The axis of this trough is west of the one discernible on the Douglas-Pedee map. East of the basinal trough, which probably represents the axis of the Forest City Basin in Shawnee time, the group thins toward the outcrop area. A low carbonate ratio in two areas just east of the Nemaha Anticline suggests some relationship to that feature. The highest carbonate ratio is in the Salina Basin and in two small areas on and adjacent to the Nemaha in Pottawatomie and Atchison Counties.

The Shawnee Group in northwestern Kansas is easily recognized but thins westward from Dickinson County (Hockens, 1959). Some of the shales between the limestone bundles thin so much that they are thinner than the shale units within the limestone formations. This makes identification based on sequence and thickness all but impossible.

Douglas-Pedee Groups*

The Douglas (Virgilian) and Pedee (Missourian) Groups are composed almost entirely of shale but contain a few thin limestone beds, local sandstone channel fillings (Pl. 18A, 18B, 18C), and coal beds. Lacking any distinguishing gross lithologic characteristics, the groups can be differentiated only with great difficulty, and it is not possible to recognize any of their subdivisions in the subsurface (Fig. 56). Thus, they will be considered together because the

* Recent work by S. M. Ball (personal communication, December 10, 1962) indicates the desirability of dropping the term Pedee and including the units in the Douglas Group.



Group) and Douglas-Pedee Groups. Note persistent and easily recognized black Heebner Shale Member.

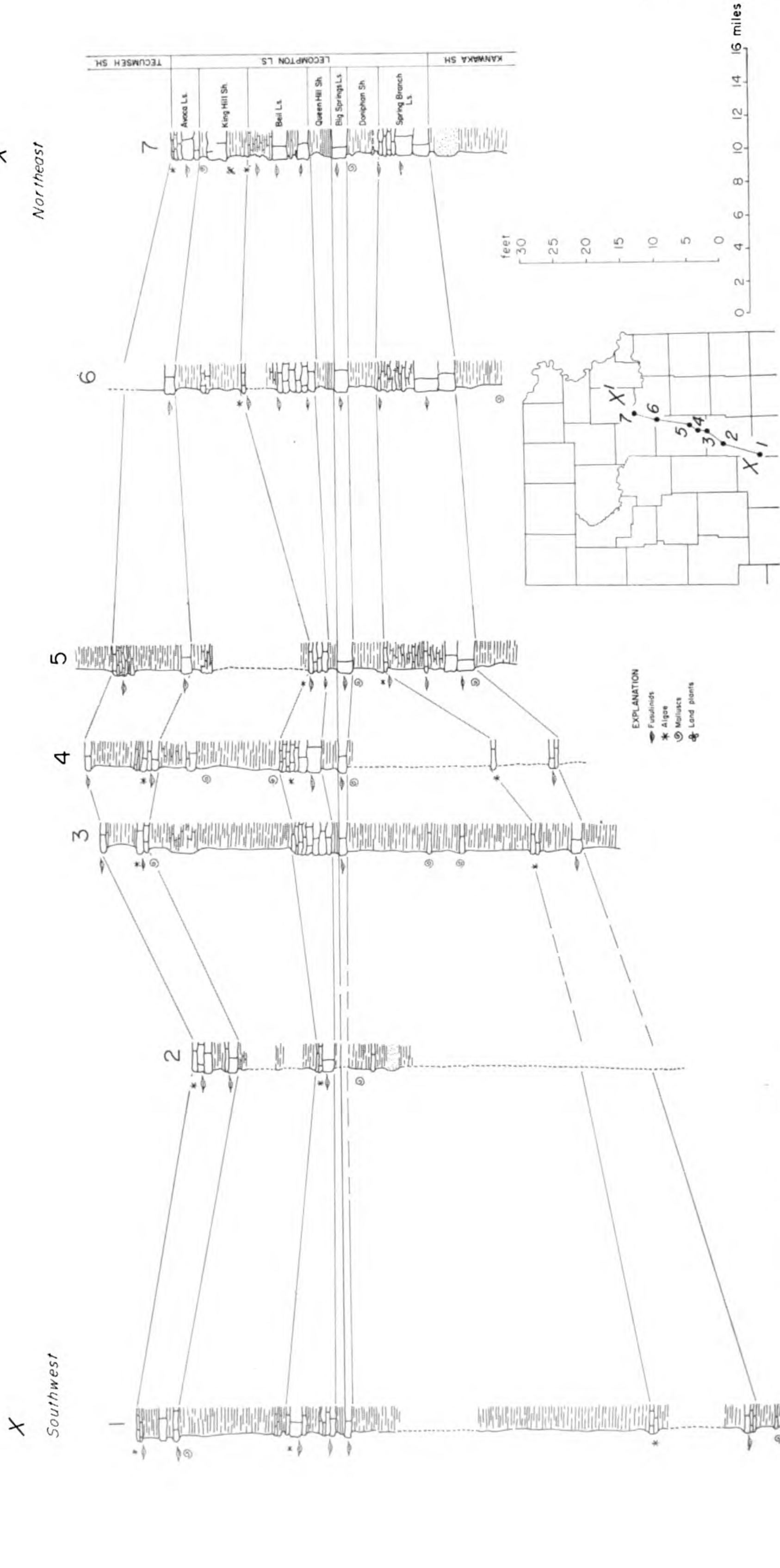


FIGURE 54.—Southwest-northeast cross section of outcropping units of Lecompton Limestone (Shawnee Group) in east-central Kansas. Note general southward thickening of clastic section.

unconformity between the Missourian and Virgilian Series at the base of the Douglas Group is obscure. As a matter of fact, it is difficult to ascertain the contact at many places on the surface where the beds are well exposed.

The Douglas-Pedee thickness map (Fig. 57) shows little agreement between structural provinces and thickness, especially along the Nemaha Anticline. Thickness of the combined groups ranges from about 20 to 350 feet. The thinnest Douglas-Pedee is in northeastern Marshall County and northwestern Nemaha County along the northern part of the Nemaha and Abilene Anticlines. The Nemaha is not reflected farther south, indicating possible quiescence of this structure at the time of Douglas-Pedee deposition; however, the Abilene structure is fairly obvious. One area of great thickness occurs in the Forest City Basin, extending in an irregular belt northeastward through Lyon, Osage, and

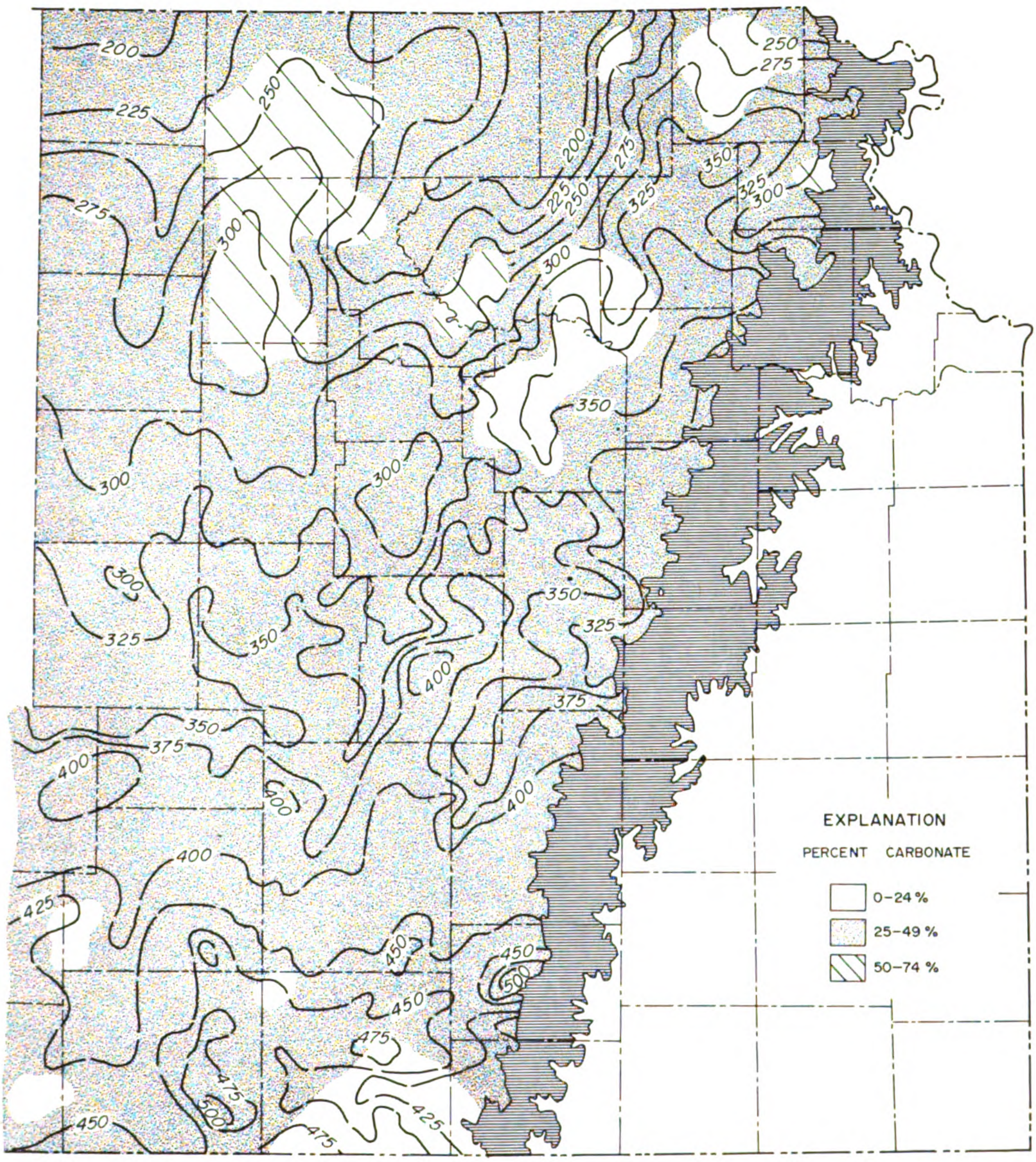


FIGURE 55.—Isopachous and percentage-carbonate map of the Shawnee Group in eastern Kansas. Horizontal ruling indicates area of outcrop. Control density shown on Figure 58. Contour interval 25 feet.

Douglas Counties. This thick section was probably the basinal trough in Douglas-Pedee time. The highest carbonate ratios occur in the area of the Salina Basin. In many areas no carbonate rocks are present in the Douglas-Pedee sequence; the range of carbonate percent is from 0 to about 50.

Sanders (1959) mapped the respective net thicknesses of sandstone above and below the Haskell Limestone in northeastern Kansas. Above the Haskell is the Ireland Sandstone and below it is the Tonganoxie; contour lines on both maps (Sanders, 1959, pl. 1 and 2) reveal a sinuous pattern, which suggests drainage channels. Thicknesses range from 0 to 100 feet for sandstones above the Haskell and from 0 to 160 below it.

The Douglas-Pedee in northwestern Kansas consists of gray-green calcareous shale and ranges in thickness from a featheredge to 13 feet (Hockens, 1959). Locally, the groups are absent on uplifts. The Toronto Limestone of the Oread Formation also pinches out in the northern part of Cheyenne, Rawlins, and Decatur Counties, so that it is impossible to distinguish shale of the Douglas from the Snyderville Shale, the next

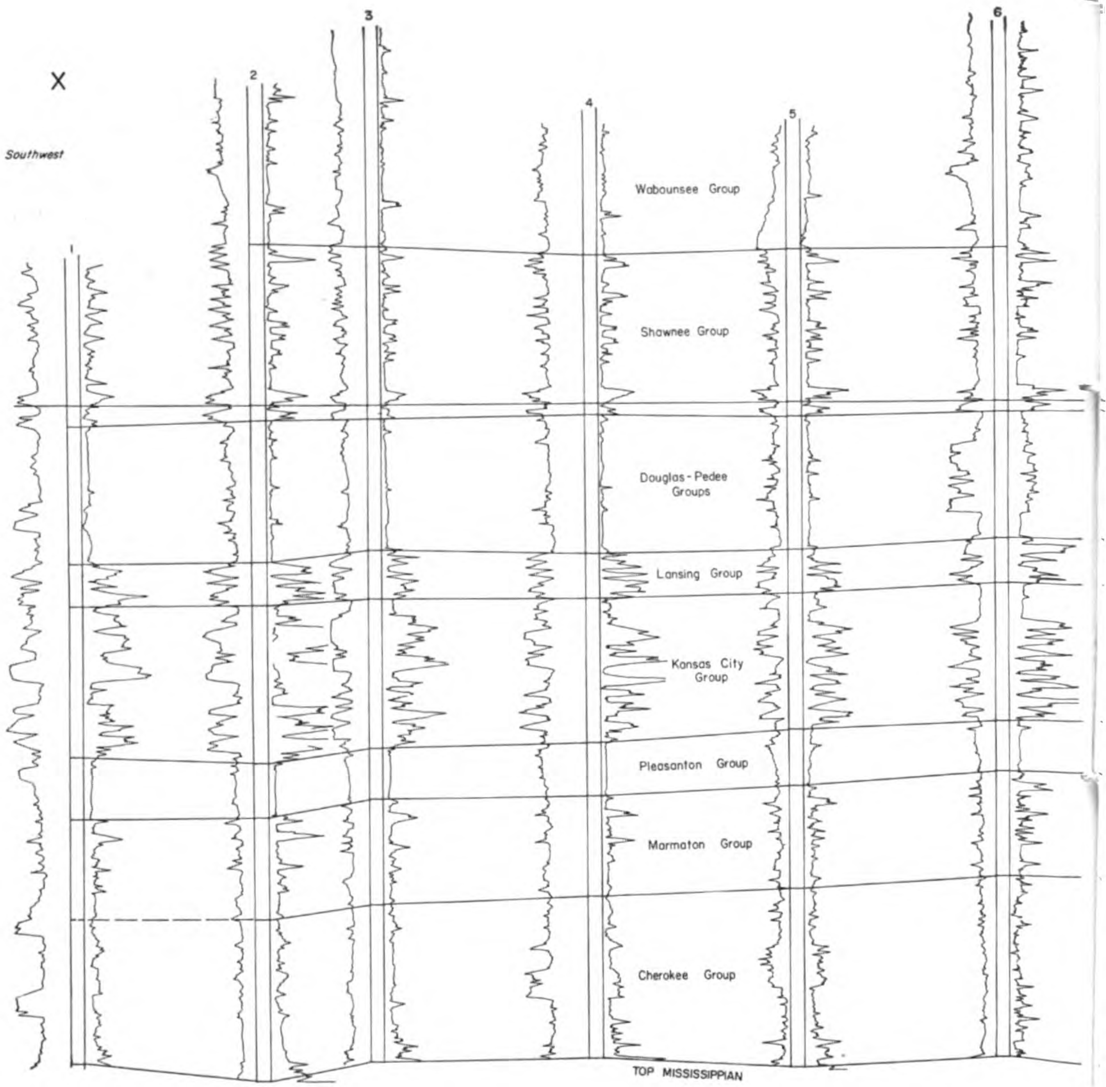
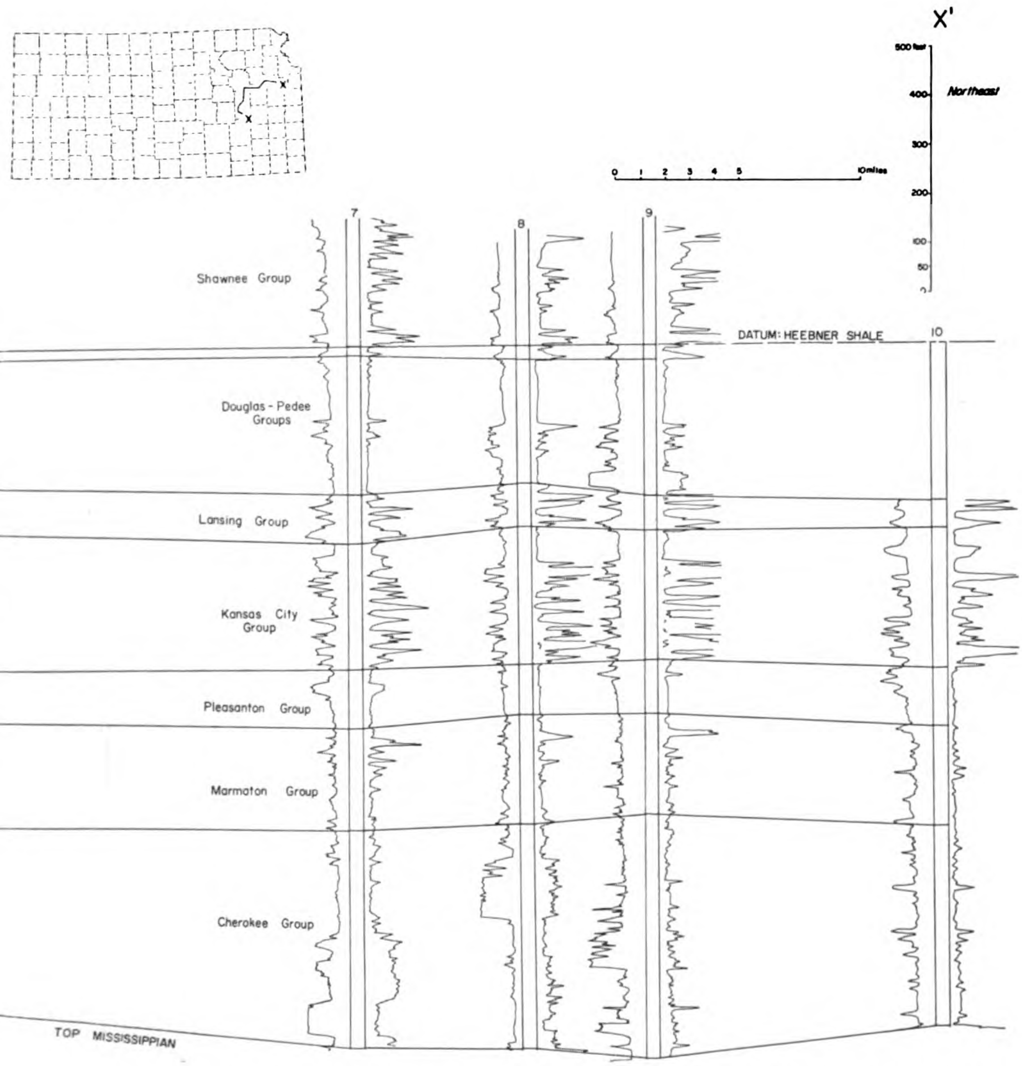


FIGURE 56.—Subsurface cross section of Pennsylvanian rocks along Kansas Turnpike in east-central Kansas (from

member above the Toronto in the Oread Limestone. Preliminary investigations indicate that in northwestern Kansas the areal extent of the Pedee is very small (Hockens, 1959).

Lansing Group

The Lansing Group (Missourian Series) consists mainly of alternating beds of limestone and shale, which have been grouped together in three formations. Units of this group can be recognized, although in places with difficulty, westward into Colorado (Parkhurst, 1959a). Lithologically, the most distinctive division in the subsurface of this group is the Eudora Shale. In many places the Eudora is a dark-gray to black, radioactive shale, easily recognized on gamma-ray logs, as well as in well samples. The Lansing is conformable with the underlying Kansas City Group, but the upper contact is unconformable; locally the upper part of the Lansing has been removed by erosion. Although the South Bend Limestone is defined as the topmost unit of the Lansing Group, the member is not everywhere present because it has been removed by erosion or was never deposited. Where the South Bend is absent, the underlying



Merriam and Jewett, 1956). Note varied nature of Douglas-Pedee Groups and seeming lack of persistent beds.

Rock Lake Shale and overlying Weston Shale can not be differentiated; thus the Stoner Limestone is used to mark the top of the Lansing.

Thickness of the Lansing Group in the subsurface of eastern Kansas ranges from about 20 to 250 feet (Fig. 58). The thin areas generally overlie the crests of the Nemaha and Abilene Anticlines, whereas thicker deposits occupy the Forest City and Salina Basins. Because most of the irregularities of the pre-Pennsylvanian surface were concealed by burial under Desmoinesian and lower Missourian deposits, this thickening and thinning can be explained by structural movements. The carbonate ratio of the Lansing Group ranges from about 20 to 90 percent but has no readily apparent correlation with thickness. The highest percentages of carbonate are found in the Salina Basin and in irregular patches along the crest of the Nemaha Anticline and in the Forest City Basin. Carbonate ratios

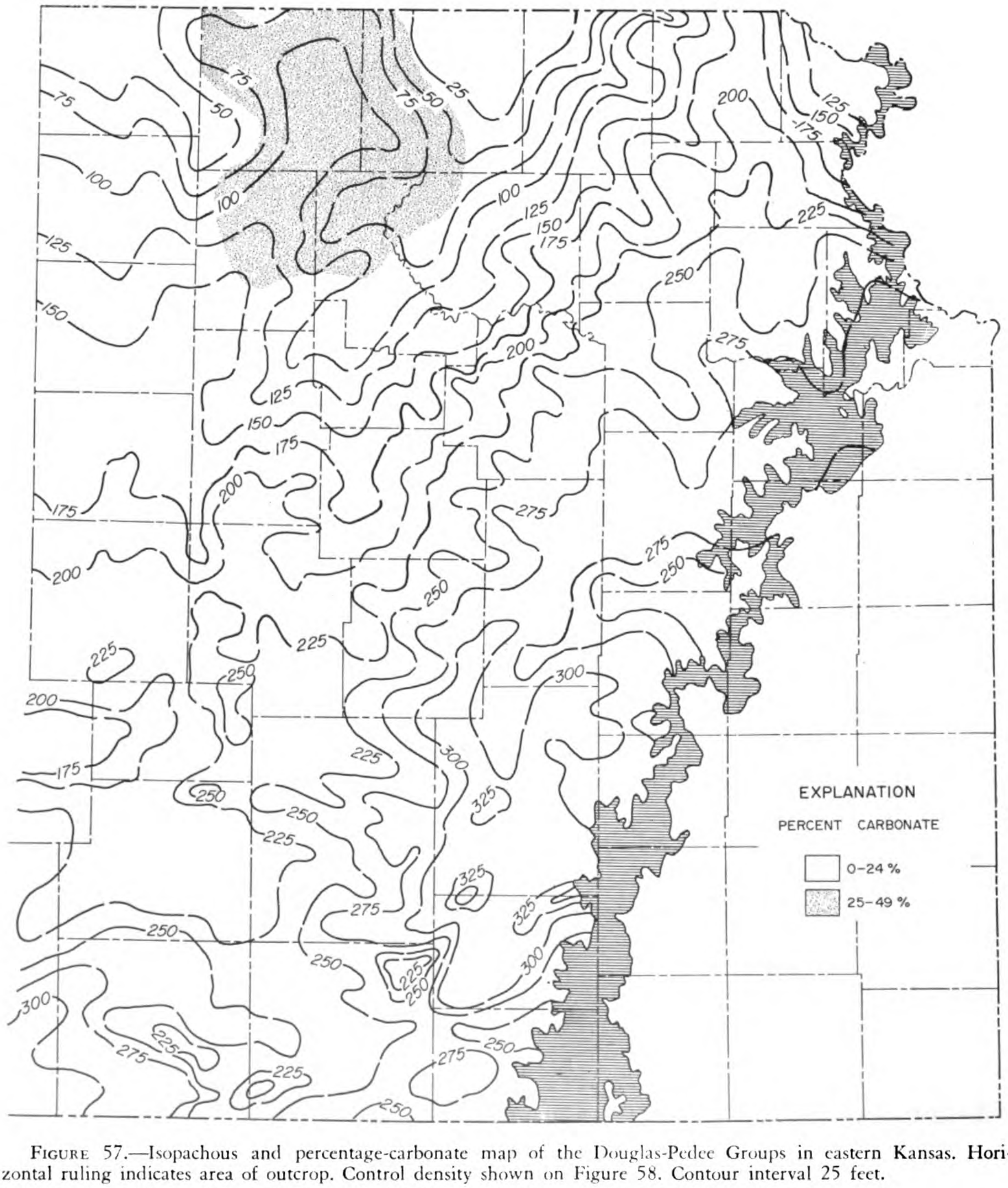


FIGURE 57.—Isopachous and percentage-carbonate map of the Douglas-Pedee Groups in eastern Kansas. Horizontal ruling indicates area of outcrop. Control density shown on Figure 58. Contour interval 25 feet.

are low just east of the Nemaha in the vicinity of the Brownville Syncline and in southern Chautauqua County near the Oklahoma line. The irregular high carbonate ratios may indicate marine limestone buildups similar to those at the surface in Wilson and Montgomery Counties.

The area of limestone buildups in southeastern Kansas in the Lansing Group has attracted considerable attention, and rightly so, because farther west in the subsurface, limestone buildups may control oil accumulation. Many have pointed out various aspects of this increased thickening, including Newell (1933), Wagner and Harris (1953), Wilson (1957), Davis (1959), Harbaugh (1959, 1960), and Kansas Geological Society (1962). A generalized cross section along the outcrop in eastern Kansas is shown in Figure 59. It may be seen from this cross section that all limestone members of the

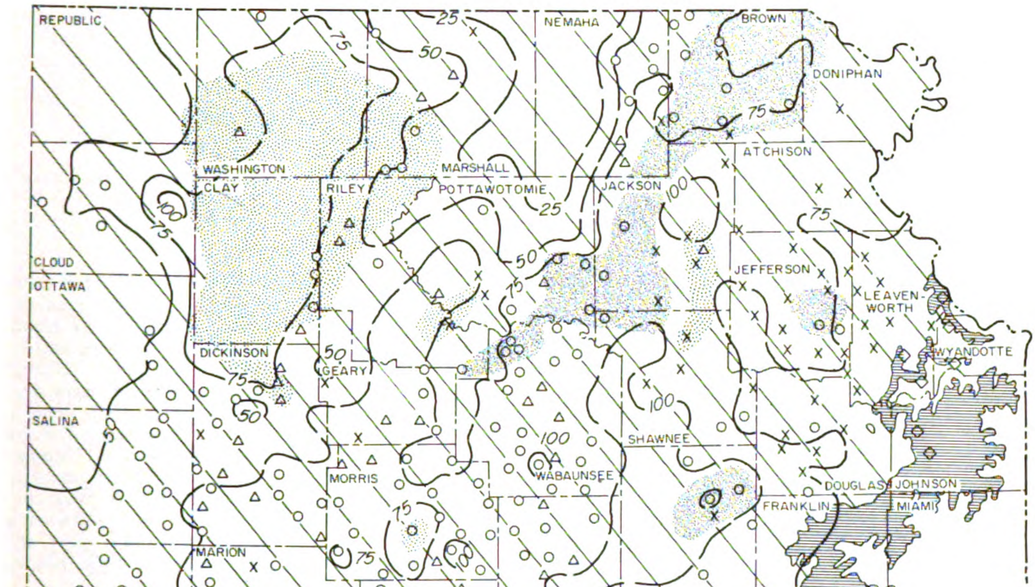


Figure 58.—Isopachous and percentage-carbonate map of the Lansing Group in eastern Kansas. Horizontal ruling indicates area of outcrop. Contour interval 25 feet.

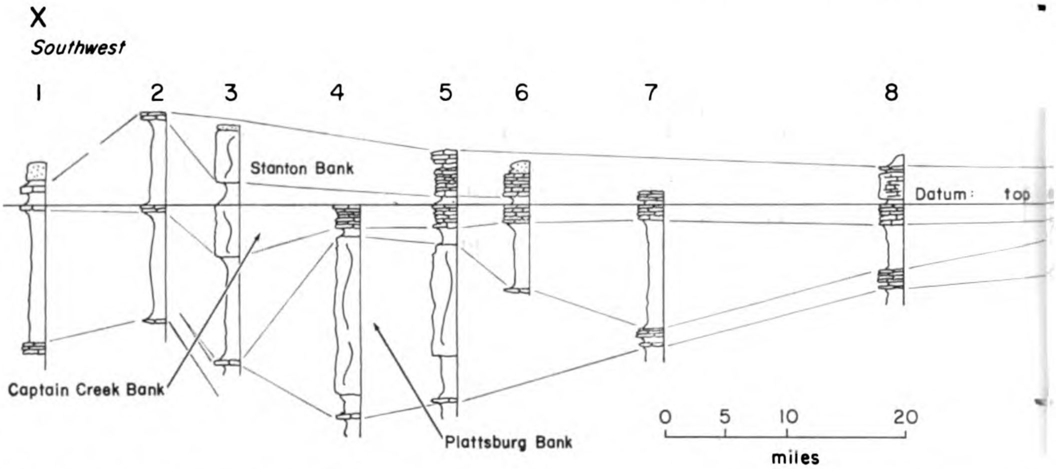


FIGURE 59.—Southwest-northeast cross section of outcropping units of Lansing Group in eastern Kansas (com... ward thickening of carbonate units.

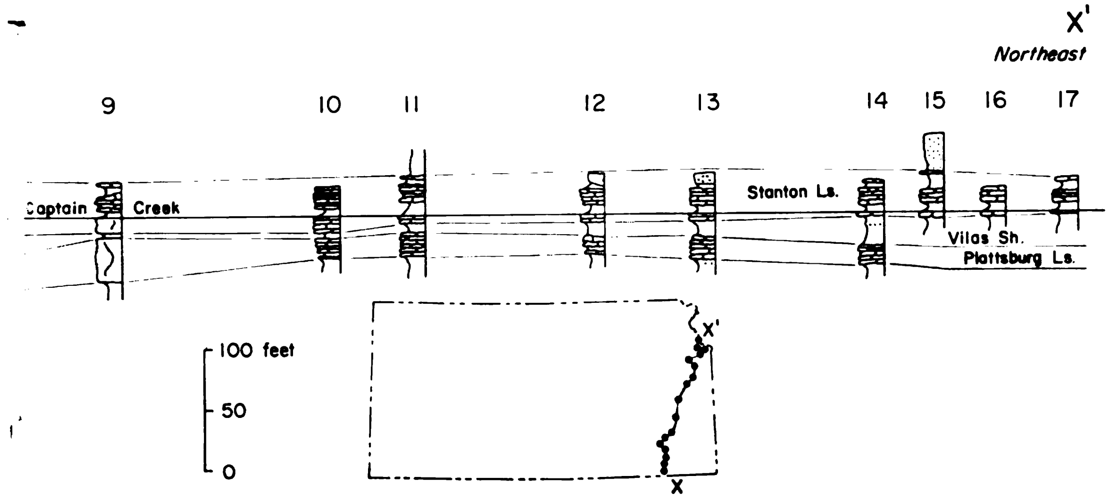
group, except the Merriam, increase in thickness southward.

Areal distribution of the thick marine bank in the Plattsburg Limestone in the Neodesha-Fredonia area is shown in Figure 60. Harbaugh (1959, p. 291) came to the following conclusions regarding this anomaly:

> The Plattsburg Limestone is anomalously thick in the Neodesha-Fredonia area, increasing from an average of about 20 feet to a maximum thickness of 115 feet. Thickening is due to increase in the Hickory Creek Shale (middle member) from 1 to 45 feet, and the Spring Hill Limestone (upper member) from 3 to 88 feet in thickness. . . .
>
> The principal cause of thickening of the Plattsburg Limestone is interpreted to be deposition of an extensive, lens-shaped marine bank that rose above the general level of the surrounding sea floor. The bank was at least 14 miles long in a northwest-southeast direction, and about 10 miles wide. Two smaller, detached thickened portions of the Plattsburg Limestone in the area probably represent small banks. A second cause of thickness variations in the Plattsburg Limestone is local structural warping during deposition, which permitted greater thicknesses to accumulate over downwarps and lesser thicknesses over upwarps. Thickness of the Vilas Shale also has been affected by this cause.
>
> Thickness of the Vilas Shale has been observed to be inversely related to thickness of the Plattsburg Limestone at most localities. Part of the Vilas Shale is interpreted to be an off-bank time equivalent of part of the thickened Spring Hill Member.
>
> Deposition of the bank is interpreted to have been strongly influenced by lime-secreting organisms, including crinoids, bryozoans, brachiopods, mollusks, and algae. The organisms may have influenced deposition of silt and clay (Hickory Creek Member) by exerting a sediment-binding effect, and probably helped stabilize slopes at least as great as 7° on the edges of the bank. In addition, they contributed large quantities of calcareous material to the upper part (Spring Hill Member) of the bank.
>
> Where thick, the Spring Hill Member of the Plattsburg is divided into three tabular lithologic subdivisions in regular vertical sequence. The lower subdivision contains abundant irregular fragments and pellets, much of it seemingly of algal origin. The middle subdivision contains abundant visibly crystalline calcite intimately associated with encrusting calcareous algae. The upper subdivision contains abundant calcarenite composed of grains of various degrees of rounding and sorting. During deposition of the crystalline subdivision, lime-secreting algae may have imparted rigidity to deposits forming on the bank, thus creating a reef if the bank extended into shallow water. During deposition of other parts of the Plattsburg bank, the deposits probably were not wave resistant.
>
> Porosity in the Spring Hill Member is related to limestone lithology. The crystalline limestone subdivision, where pores and vugs are conspicuous in visibly crystalline calcite, is most porous. The thickened Spring Hill Limestone of the Neodesha-Fredonia area may provide an example of a porous limestone lens that might serve as an oil reservoir; some oil pools in Pennsylvanian limestones of central and western Kansas may occur in porous lenses of similar origin.

The Plattsburg Limestone is about 20 feet thick in the northeastern and east-central part of the state (Pl. 19A) and thickens in southeastern Kansas to a maximum of about 115 feet (Pl. 19B, 19C). Small marine banks in the Plattsburg, such as the one near Garnett in Anderson County (Pl. 20A), also are known along the outcrop belt.

Limestone units in the Stanton Formation also thicken southward. Marine banks are known in the Captain Creek, Stoner, and South Bend Limestones. Thickness of the Captain Creek increases southward from about 10 feet (Pl. 20A) to about 45 feet (Pl. 20B). Upper Lansing limestone in southern Montgomery County near Tyro (Pl. 20C) is composed of a



piled from surface sections measured by Kansas Survey staff, especially R. C. Moore and N. D. Newell). Note south-

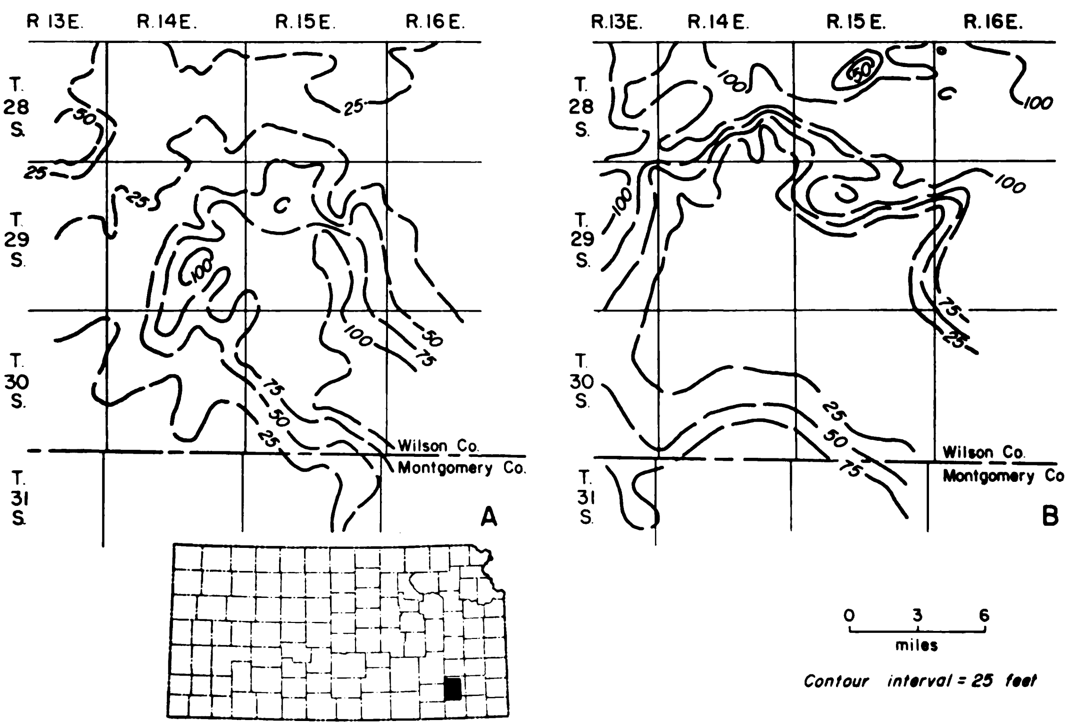


Figure 60.—Isopachous maps of rock units in Neodesha-Fredonia area: **A,** Plattsburg Limestone; **B,** Vilas Shale (adapted from Harbaugh, 1959).

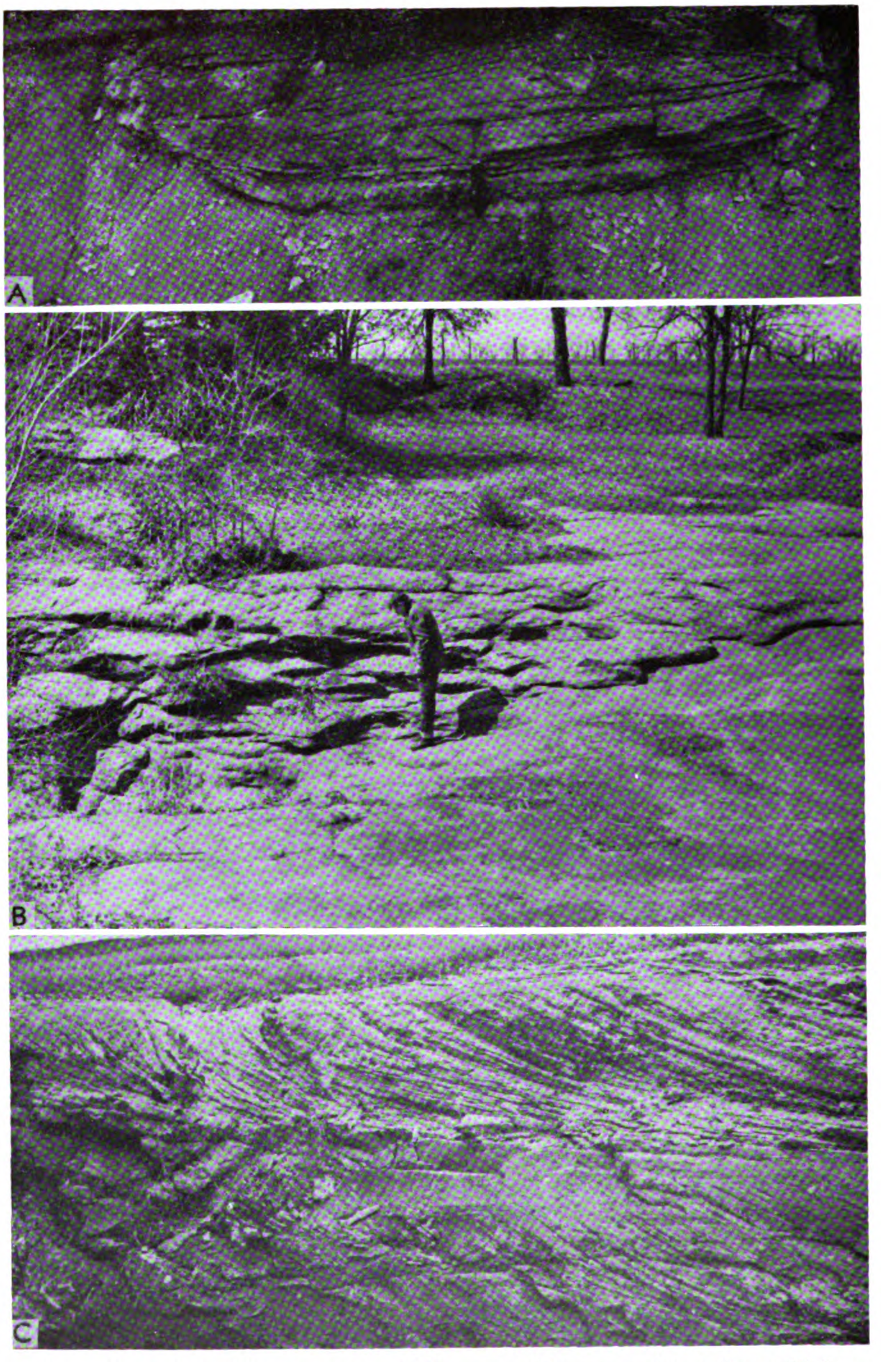


PLATE 18.—**A**, Ireland Sandstone channel filling exposed in cross section on Kansas Highway 96 approximately 3 miles west of junction with Kansas Highway 39, Wilson County (SE sec. 8, T. 28 S., R. 14 E.). **B**, Ireland Sandstone at Hole-in-the-rock near Baldwin Junction just west of intersection of U.S. Highways 59 and 56, Douglas County (NW sec. 2, T. 15 S., R. 19 E.); photo by W. R. Atkinson. **C**, Cross-bedded Tonganoxie Sandstone exposed on Kansas Turnpike at Mile 16.

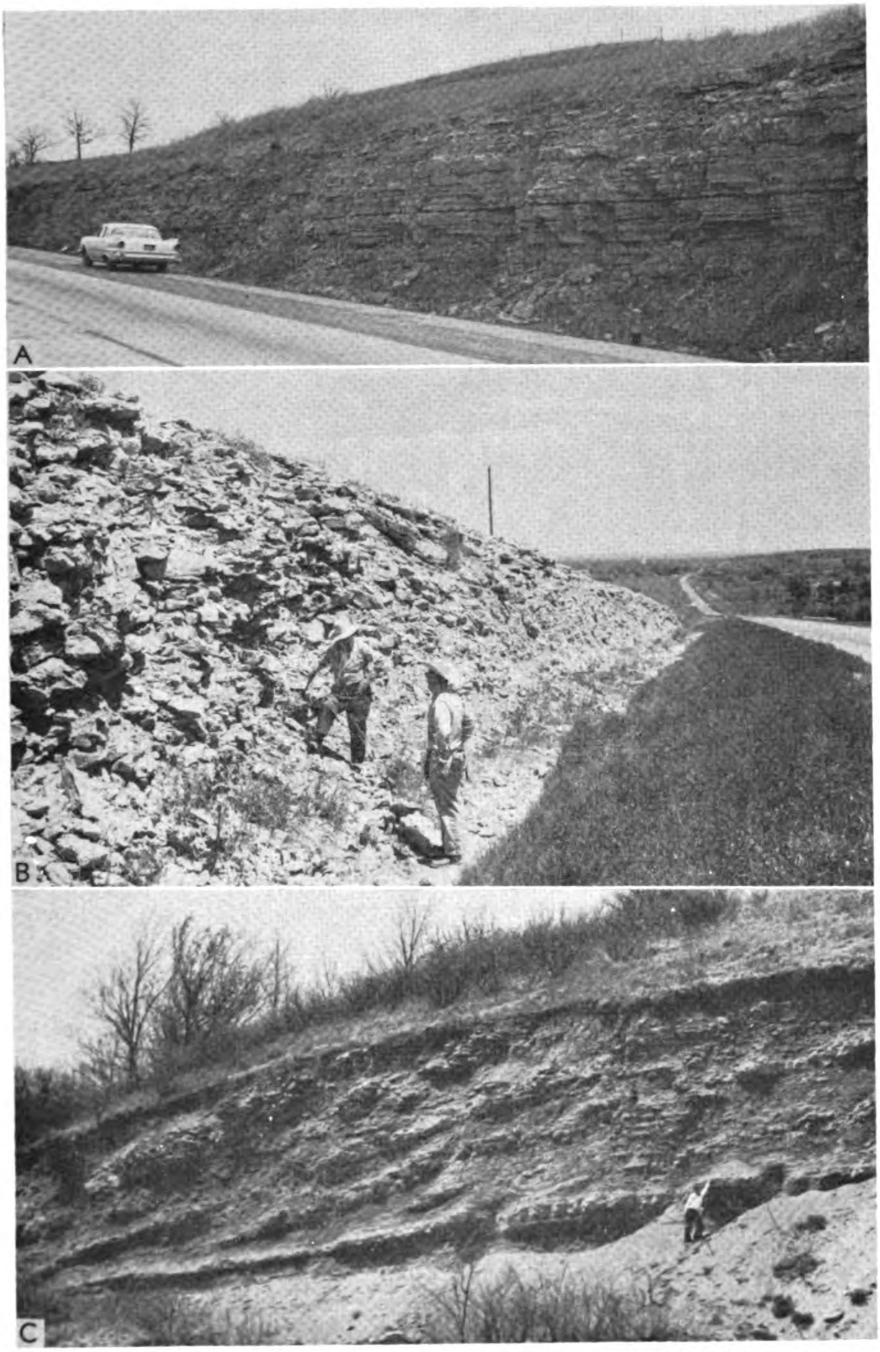


PLATE 19.—**A**, Plattsburg Limestone on Kansas Turnpike at Mile 14, Wyandotte County. **B**, Plattsburg Limestone forming marine bank, exposed in road cut on Kansas Highway 96 west of intersection with U.S. Highway 75 and just southwest of Neodesha, Wilson County. **C**, Large-scale cross beds in Hickory Creek Shale, underlain by Merriam Limestone and Lane-Bonner Springs Shale, exposed in abandoned shale pit at Brickton, Montgomery County (SW sec. 7, T. 31 S., R. 16 E.).

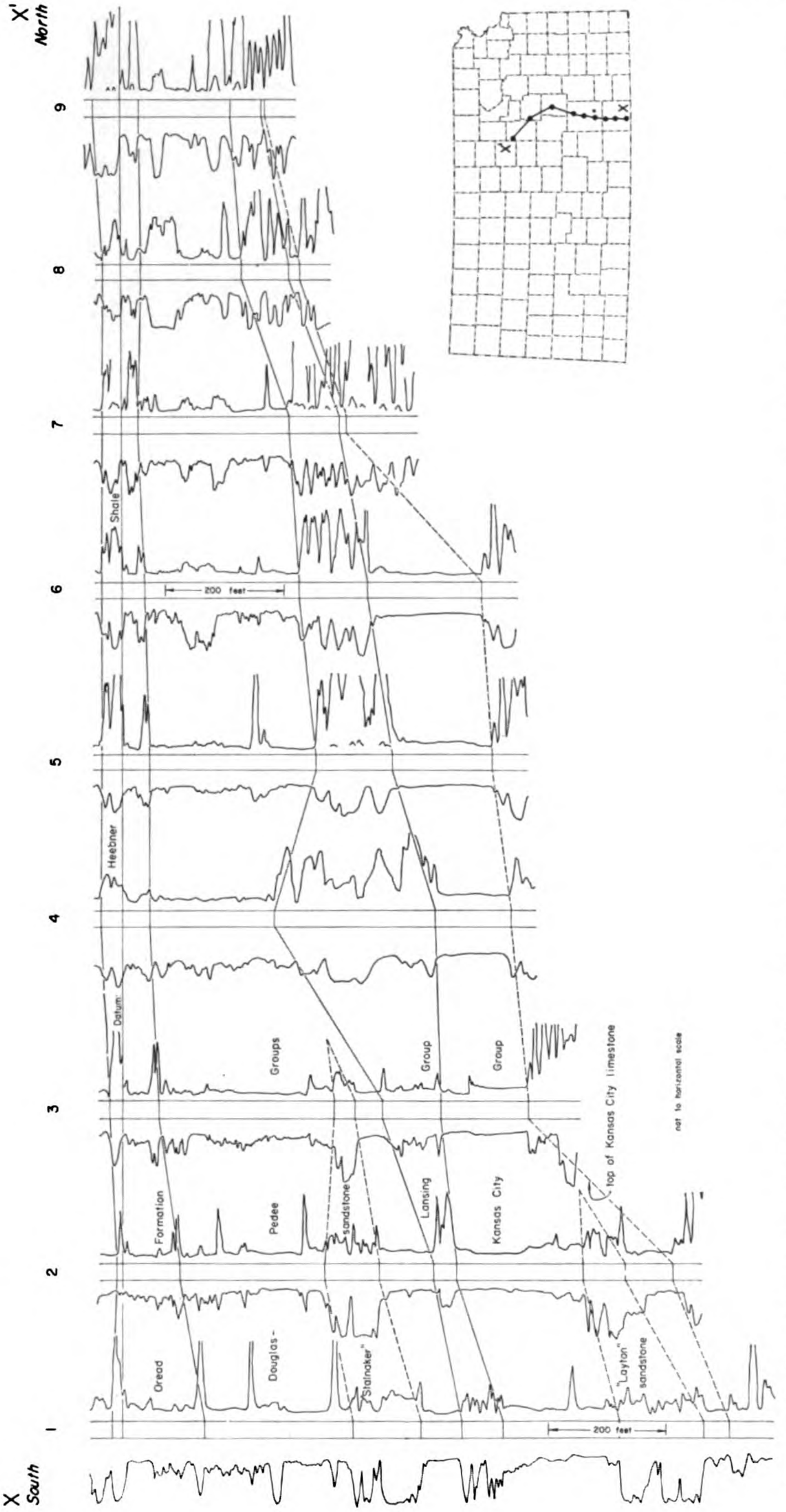


Figure 61.—Electric-log cross section showing relation of Lansing rocks to adjacent units. Stratigraphic position of "Stalnaker" and "Layton" sandstones also is shown. Of special interest is abnormally thick carbonate section, which may represent a marine bank, in well 4 in south-central Butler County.

cross-bedded oolite believed to have been deposited in shallow lagoons or over shallow shoals (Harbaugh, 1960).

A cross section (Fig. 61) prepared to show stratigraphic relations of Lansing beds also shows an anomalous thick Lansing section in south-central Butler County. In addition, the relation of the "Stalnaker" and "Layton" sandstones to the limestones of the Lansing and Kansas City Groups is depicted.

Many of the anomalously thickened limestones are known in Kansas; some seemingly are "buildups" or are in addition to the regular lithology, whereas others consist of a thickening of individual units within the "normal" sequence, and some "stray" limestones occur within predominantly shaly formations (Merriam, 1962a). These abnormalities are not by any means limited to the Pennsylvanian but are known also in Lower Permian rocks. Some units known to include thick or "extra" limestone are: Havensville Shale, Threemile Limestone, Cottonwood Limestone, Neva Limestone, Bennett Shale, and Hughes Creek Shale, all of Permian age; Soldier Creek Shale, Avoca Limestone, Toronto Limestone, Stoner Limestone, Captain Creek Limestone, Spring Hill Limestone, Iola Limestone, Drum Limestone, Winterset Limestone, Bethany Falls Limestone, and Pawnee Limestone, all of late Pennsylvanian age. Some of these and other units are known to "pinch and swell" in the subsurface farther west and this may be important in the entrapment of petroleum.

Winchell (1957) and Schulte (1959) showed their interpretation of relations of the subsurface units called "Stalnaker" and "Layton" to surface formations. The "Stalnaker" is equivalent to the Tonganoxie Sandstone and the "Layton" to the Cottage Grove and Noxie Sandstones. Winchell found that "the lithologic difference between the 'Stalnaker' and the Lansing is not the result of contemporaneous deposition of different facies but is the result of erosion of the Lansing and deposition of the Tonganoxie ('Stalnaker') sandstone in the erosional depressions and basins left after post-Missourian erosion." Schulte concluded that "the sheetlike distribution and uniform sorting of the sandstones are evidence of marine origin. . . . The Noxie Sandstone was deposited on an eroded surface as there is evidence for a disconformity both at the surface and in the subsurface."* The distribution of these sandstones in south-central Kansas is shown in Figure 62.

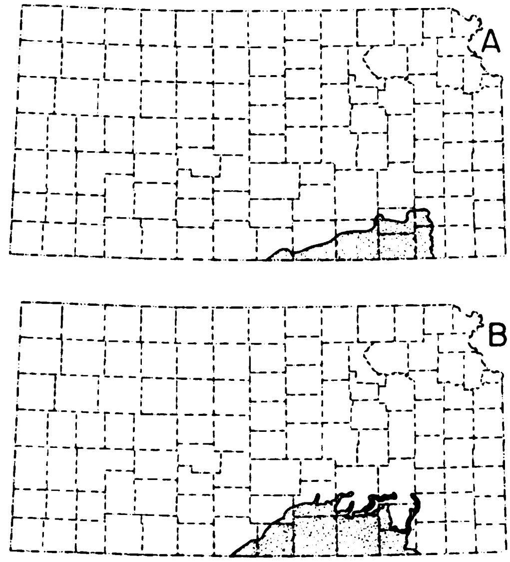


FIGURE 62.—Distribution of sandstone units in subsurface of south-central Kansas. **A**, "Cottage Grove" and "Noxie" sandstones (Schulte, 1959); **B**, "Stalnaker" sandstone (Winchell, 1957).

Kansas City Group

The Kansas City Group (Missourian Series) conformably underlies the Lansing and conformably overlies the Pleasanton Group. The group contains 12 formations and 27 named members of alternating marine and nonmarine units and has a thickness of about 350 feet on the outcrop. Many of the limestones are cross bedded, oolitic, and algal and locally thicken to form marine banks similar to those in the Lansing Group. Parkhurst (1959b) correlated surface units with the subsurface (Fig. 63) in conjunction with a study of Pennsylvanian units in northwestern Kansas.

The Bonner Springs Shale, Wyandotte Limestone, and Lane Shale are conveniently referred to the upper of three subgroups. Where the Wyandotte pinches out, the Bonner Springs comes in contact with the Lane and the undifferentiated unit is termed the Lane-Bonner Springs Shale. Parkhurst found the pinchout of the Wyandotte Limestone to occur between Range 17 and 21 East in the southern part of the Forest City Basin in northeastern Kansas. In Franklin County, the Wyandotte pinches out

* Certain lines of evidence, however, point to a facies change from units of limestone in the north to units composed mainly of sandstone in the south. If one subscribes to these data, then the "Stalnaker" and Tonganoxie are not equivalent, but the "Stalnaker" is a southern facies of Lansing beds farther north. This relationship could also be true of the sandstone units in the Kansas City Group. The relationships are still open to interpretation and further work needs to be done on the problem.

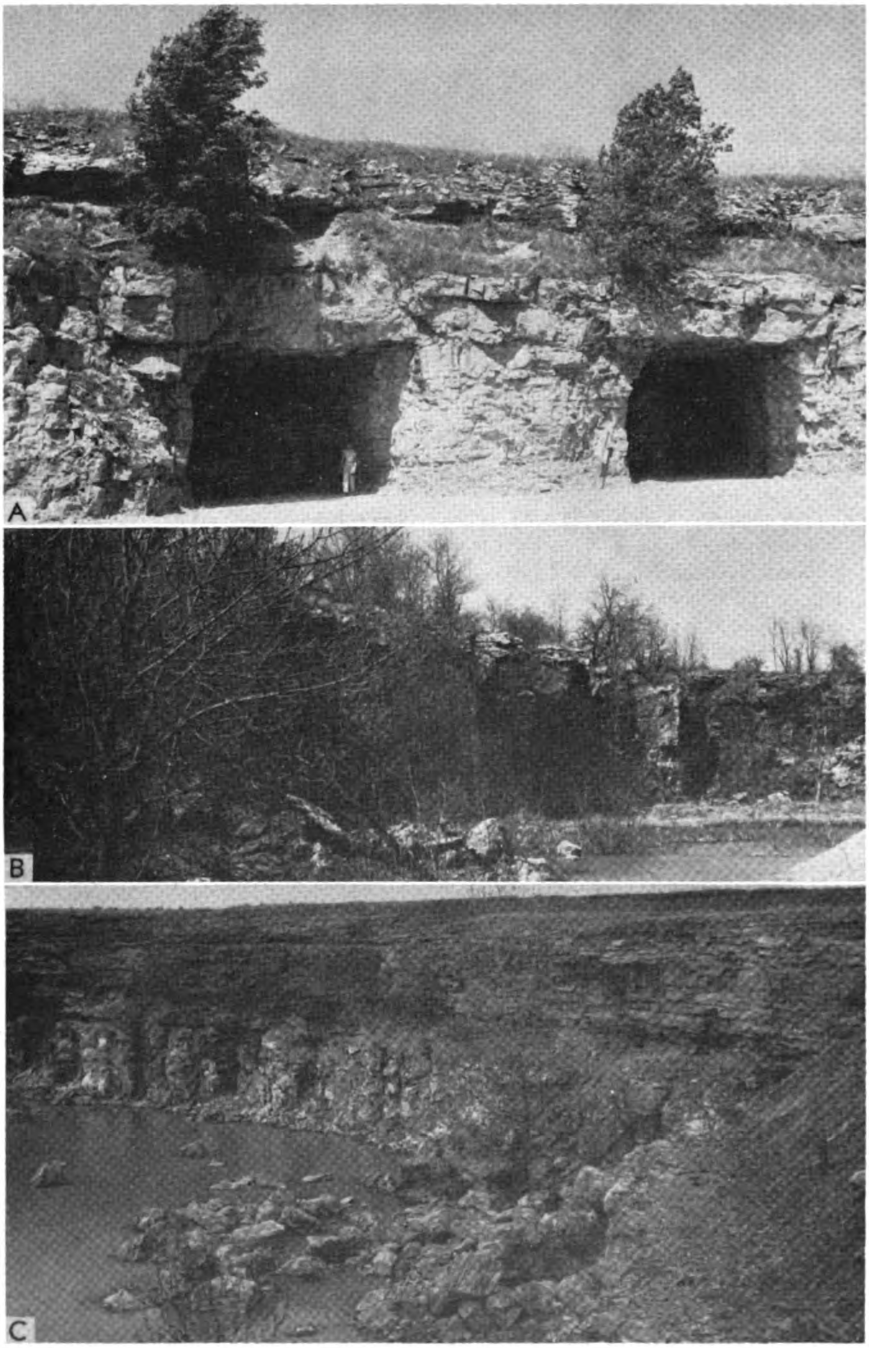


PLATE 20.—**A**, Spring Hill Limestone, Vilas Shale, and Captain Creek Limestone (ascending) in abandoned quarry about 2½ miles north of Garnett, Anderson County (sec. 12, T. 20 S., R. 19 E.). **B**, Captain Creek Limestone exposed in quarry on Table Mound, just west of Lehunt, Montgomery County (SE SE sec. 9, T. 32 S., R. 15 E.). **C**, Upper Lansing rocks exposed in abandoned quarry near Tyro, Montgomery County (sec. 30, T. 34 S., R. 15 E.).

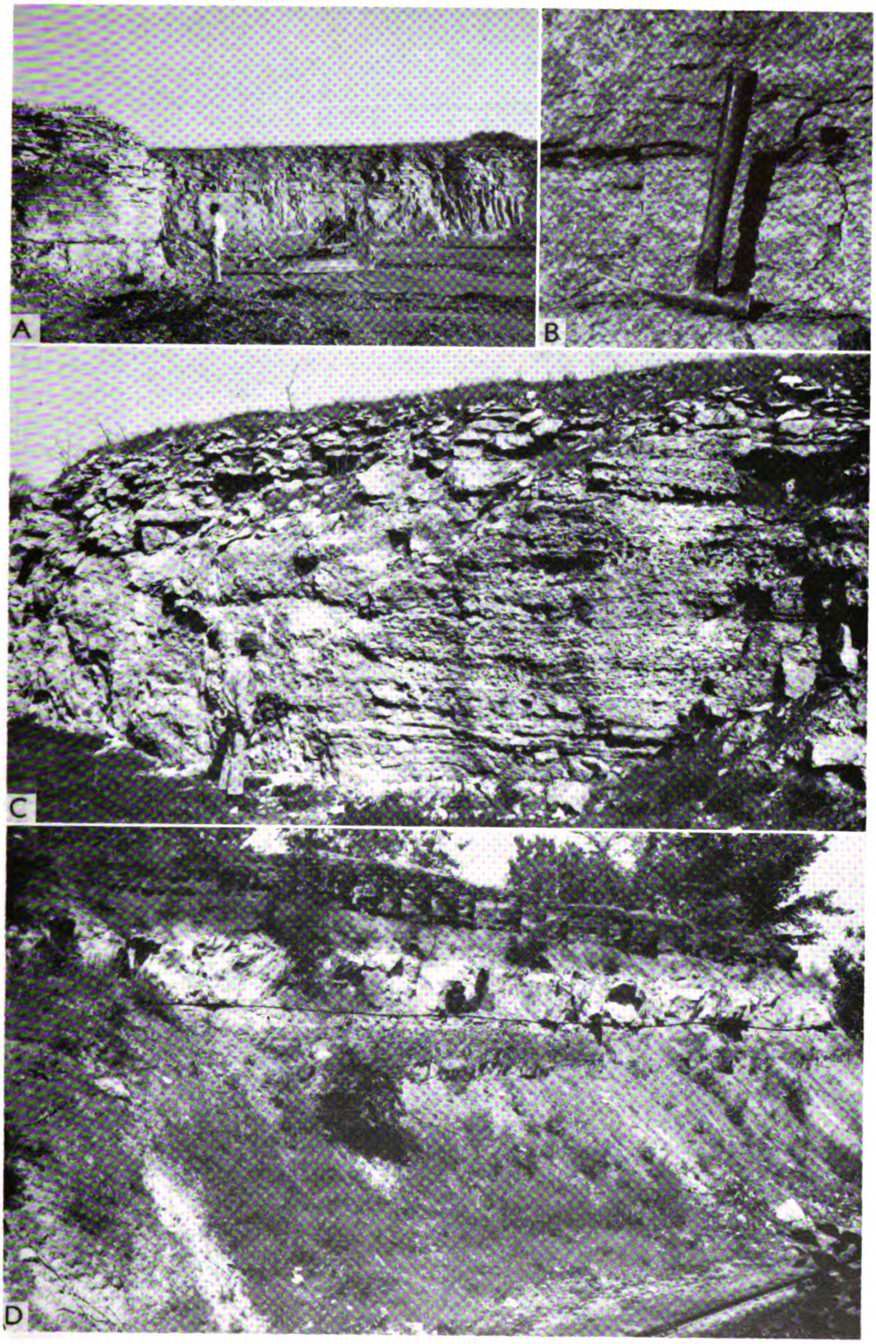


PLATE 21.—**A**, Iola Limestone in abandoned quarry near Carlyle, Allen County (NE SE sec. 5, T. 24 S., R. 19 E.). **B**, Closeup of algal Iola Limestone in Carlyle quarry. **C**, Winterset Limestone on east side of Canville Creek on Kansas Highway 39, Neosho County (NE sec. 23, T. 27 S., R. 20 E.). **D**, Lower part of Fort Scott Limestone and upper part of Cherokee Group in railroad cut in Fort Scott, Bourbon County.

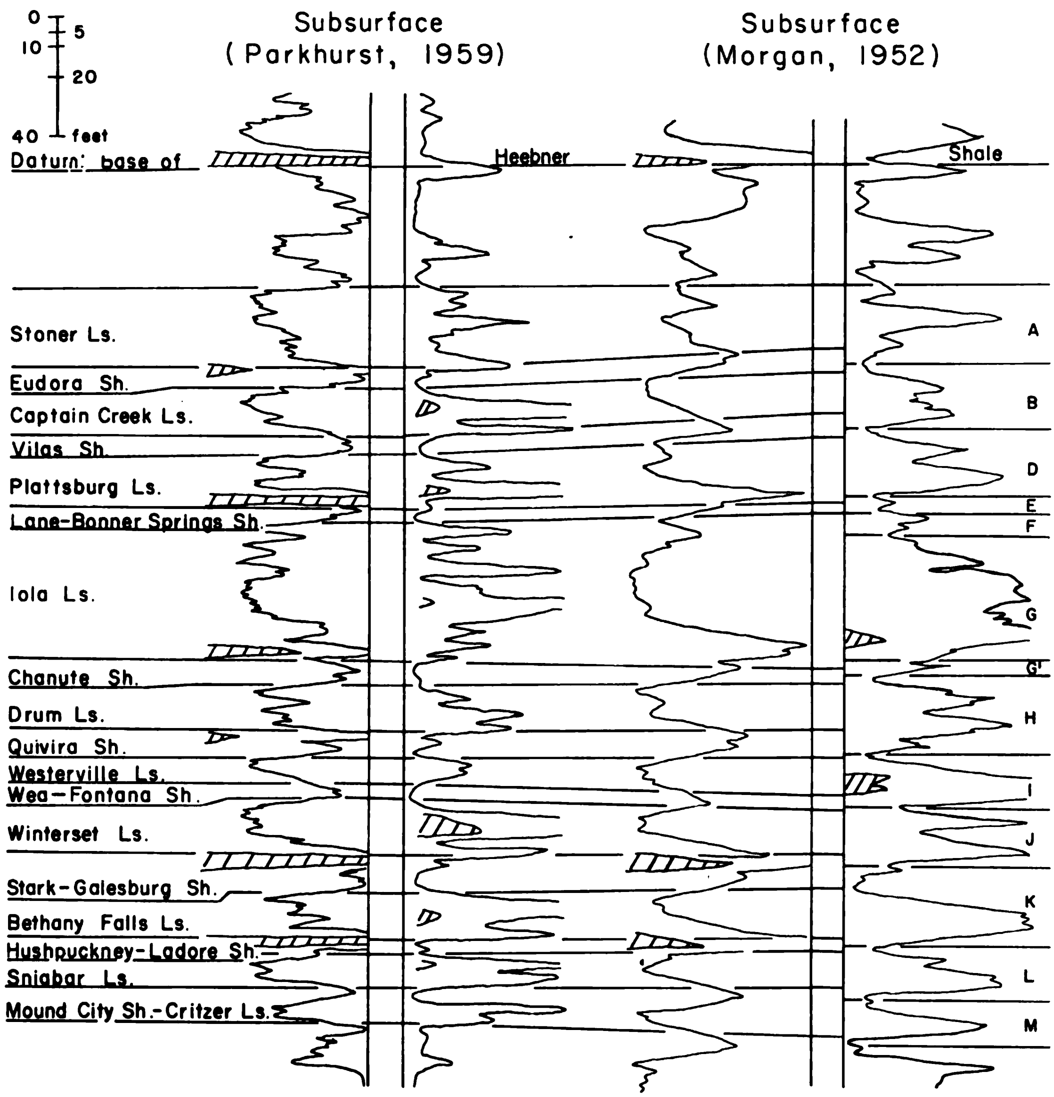


FIGURE 63.—Relation between Morgan's (1952) alphabetical designations and equivalent surface terminology, as determined by Parkhurst (1959a).

in the subsurface along a north-south line about in the middle of the county. The maximum thickness of the unit is approximately 45 feet (S. M. Ball, personal communication, June 14, 1962). Parkhurst found that the Lane-Bonner Springs thins markedly westward but that west of the Nemaha Anticline it is nearly uniform in thickness.

Below the Lane Shale are (in descending order): Iola Limestone, Chanute Shale, Drum Limestone, and Cherryvale Shale, which have been placed together in a subgroup. The Iola Limestone is composed of three members; the middle unit, Muncie Creek Shale, west of the Nemaha Anticline exhibits strong radioactivity indicative of black shale. The upper limestone unit is persistent, but its upper boundary is difficult to determine. According to Parkhurst (1959b, p. 98):

> The Raytown Limestone is a persistent unit in the subsurface; however, there is difficulty in establishing its upper boundary . . . westward . . . . This limestone increases in thickness westward and contains much interbedded shale. Many eastern Kansas exposures of the Iola formation contain a "super" limestone that overlies the massive Raytown Limestone, but no correlation is implied herein. The limestone and shale above the

Raytown probably represent a build up of strata belonging to the Iola formation, but could represent a facies change of the Lane-Bonner Springs Shale or could represent beds of the Wyandotte formation.

The Iola Limestone also builds up on the surface, and where thick it is quarried extensively (Pl. 21A, 21B). The buildup is similar to those in the Lansing Group and represents a marine bank mainly algal in origin.

The lowest of the three subgroups of the Kansas City consists of the following formations (in descending order): Dennis Limestone, Galesburg Shale, Swope Limestone, Ladore Shale, and Hertha Limestone. The presence of several persistent radioactive black shales makes this sequence of rocks easy to identify in the subsurface. Of the upper unit, the Dennis Limestone, Parkhurst said (1959b, p. 98):

> The Dennis Limestone comprises three members, the Winterset Limestone at the top, Stark Shale, and Canville Limestone at the base. The Winterset Limestone is persistent along the line of cross section and is easily recognized by its stratigraphic position above the Stark Shale. From the outcrop to the east flank of the Central Kansas Uplift the Winterset maintains a fairly uniform thickness. In general, the unit thins over the Central Kansas Uplift, and there are pronounced local variations in thickness.
>
> The Stark Shale is recognized by its strong radioactivity and by its position in the stratigraphic sequence. It is a persistent unit along the line of cross section. The unit next below the Stark Shale, the Canville Limestone, is not present in the surface composite section and is not recognized on the cross section, therefore, the interval is referred to as the Galesburg-Stark Shale.

The Winterset Limestone has one of the more spectacular marine banks, consisting of algal limestone and cross-bedded oolitic limestone (Pl. 21C), which has its maximum development in Allen and Neosho Counties. The Hushpuckney in the Swope Limestone is a persistent and readily traceable unit because it is a radioactive black shale. Where the Middle Creek Limestone is absent, the underlying Ladore Shale can not be distinguished from the Hushpuckney and they are considered as one unit. Parkhurst (1959b, p. 100) observed the following in regard to the lowest unit of the Kansas City Group:

> The Hertha Limestone consists of three members. In descending order these are the Sniabar Limestone, Mound City Shale, and Critzer Limestone. In the composite measured section only the Sniabar Limestone is present. . . . In the Forest City Basin there is little difficulty in establishing the base of the Kansas City Group. There, a predominantly shale section underlies and contrasts sharply with the limestone of the Bronson Subgroup. The recognition of the base of the Kansas City Group in the Salina Basin, however, is more difficult. Here, the limestone unit identified as the Sniabar member of the Hertha formation is underlain by limestone and shale that probably represent the lower two members of the Hertha.

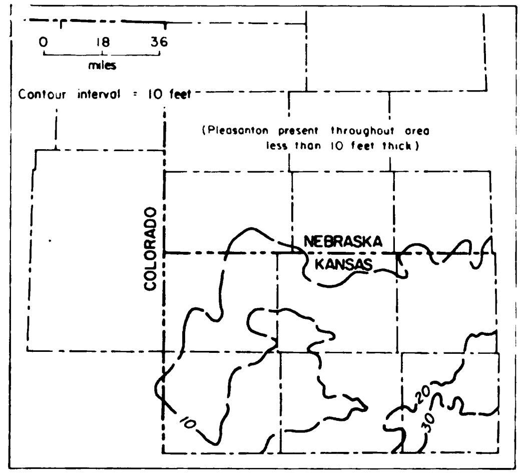


FIGURE 64.—Isopachous map of Pleasanton Group in northwestern Kansas and adjacent areas (from Walton, 1960).

Walton (1960) found that in northwestern Kansas several units of the Kansas City Group pinch out, including the Westerville Limestone and upper limestone units of the Raytown Limestone. He also concluded that the location of the source area was probably a dominant factor in distribution of the sediments of the Kansas City Group, more so than local structure. Overall, the carbonate percentage increases westward and southwestward into Colorado.

Pleasanton Group

Rocks beneath the Kansas City Group and overlying the Marmaton Group are placed in the Pleasanton Group (Missourian Series). The Pleasanton is mainly composed of clastic material, mostly shale but also sandstone, limestone, and coal. Along the outcrop, the group ranges in thickness from about 70 to 130 feet. In the subsurface, recognition of these beds is by position only; thus, their recognition is dependent on tracing the base of the Kansas City and top of the Marmaton.

In northwestern Kansas, Walton (1960) found that the thickness of the group ranges from about 4 to 38 feet (Fig. 64). The northwestward thinning is mainly the result of the pinchout of a gray, fine-grained, micaceous, shaly, calcareous sandstone.

Marmaton Group

The Marmaton Group (Desmoinesian Series) disconformably underlies the Pleasanton Group. It consists of four bundles of limestone units separated by four shale formations. The formations are (in descending order): Memorial

Shale (Holdenville Shale), Lenapah Limestone, Nowata Shale, Altamont Limestone, Bandera Shale, Pawnee Limestone, Labette Shale, and Fort Scott Limestone (Jewett, 1941a). On the outcrop the group is approximately 250 feet thick. Several of the limestone units support prominent scarps that can be traced for many miles.

Distribution of beds of this age, together with the underlying Atokan beds, is shown in Figure 65. Desmoinesian beds crop out in southeastern Kansas but Atokan beds are present only in the deeper parts of some basinal areas, although their exact distribution is not well known. Desmoinesian-Atokan beds are absent on the higher parts of the Nemaha Anticline and Central Kansas Uplift-Cambridge Arch (McMurray, 1962). Upper Pennsylvanian beds of Missourian and Virgilian age, however, are present on these structures, and locally beds as young as Missourian rest on rocks as old as Precambrian.

Because the Marmaton beds generally form a bundle of prominent "kicks" (limestone beds) as shown on electric logs, they may be traced over much of Kansas with relative ease (Fig. 66). Lemmons (1946) made a subsurface study of the Marmaton in southeastern Kansas. In southwestern Kansas, however, as with many other units, the Marmaton is much more difficult to differentiate with any degree of accuracy. The Fort Scott is widespread and easily recognized and thus is used as a datum for structural and stratigraphic work.

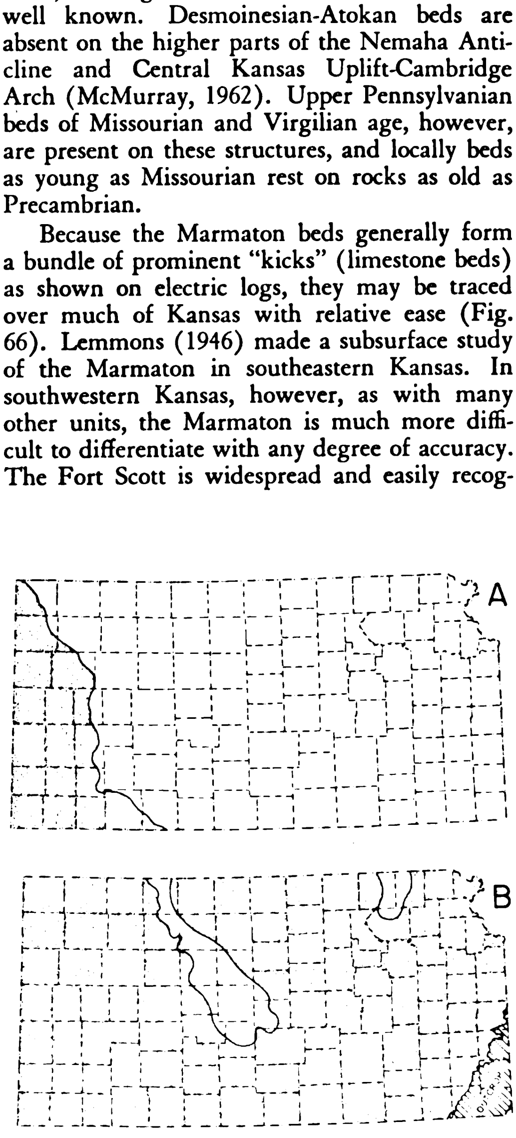


FIGURE 65.—Subsurface distribution of lower Pennsylvanian rocks in Kansas. A, Morrowan (McManus, 1959); B, Desmoinesian and Atokan (in part from Lee, 1956).

The Fort Scott Limestone includes three members: two limestone beds separated by a shale. The upper limestone is referred to as Higginsville Limestone, the separating shale as the Little Osage Shale, and the lower limestone as Blackjack Creek Limestone (Fig. 67; Pl. 21D). An isopachous map of the Fort Scott in a ten-county area in southeastern Kansas reveals that the formation ranges in thickness from 13 to 145 feet (Fig. 68). The configuration of the contours suggests that the thickening is somewhat erratic and possibly could be due to marine bank development. A study of the thickness of the Fort Scott along the outcrop reveals that the increase in thickness seemingly is due chiefly to the great abundance of *Chaetetes* (see Moore, 1949b).

Stratigraphic relations of the units of the Marmaton are shown in Figure 69.

Cherokee Group

The Cherokee Group is the lowest major division of the Desmoinesian Series. Everywhere in Kansas, except where Atokan rocks are present, the Cherokee consists of all Pennsylvanian beds between the base of Fort Scott and top of "Mississippi lime." Lithologically, the group is composed mostly of shale, some sandstone, and sandy shale and important coal beds. Limestone is rare. Howe (1956) recognized 17 formations in the Cherokee, aggregating 450 to 500 feet in total thickness at outcrops in southeastern Kansas. The lower six formations were grouped in the Krebs Subgroup; the overlying Cabaniss Subgroup contained the other 11 formations. Later, Jewett (1959) used the terms Krebs and Cabaniss to refer to formations of the Cherokee Group. The issue regarding the stratigraphic rank of Krebs and Cabaniss is not settled; however, this makes little difference here because it is not possible to recognize the units in the subsurface, regardless of whether they are termed formations or subgroups. It is common practice at present for subsurface geologists to "lump" all Cherokee beds together.

The geologic history of eastern Kansas during Cherokee time and the relation of Cherokee beds to those in Oklahoma were pointed out by Weirich (1953). The correlation between Cherokee beds in Kansas and Oklahoma was discussed by Branson (1957). Distribution of earliest Pennsylvanian sediments on the older Mississippian rocks was shown by Wanless (1957). The lower part of the Cherokee Group

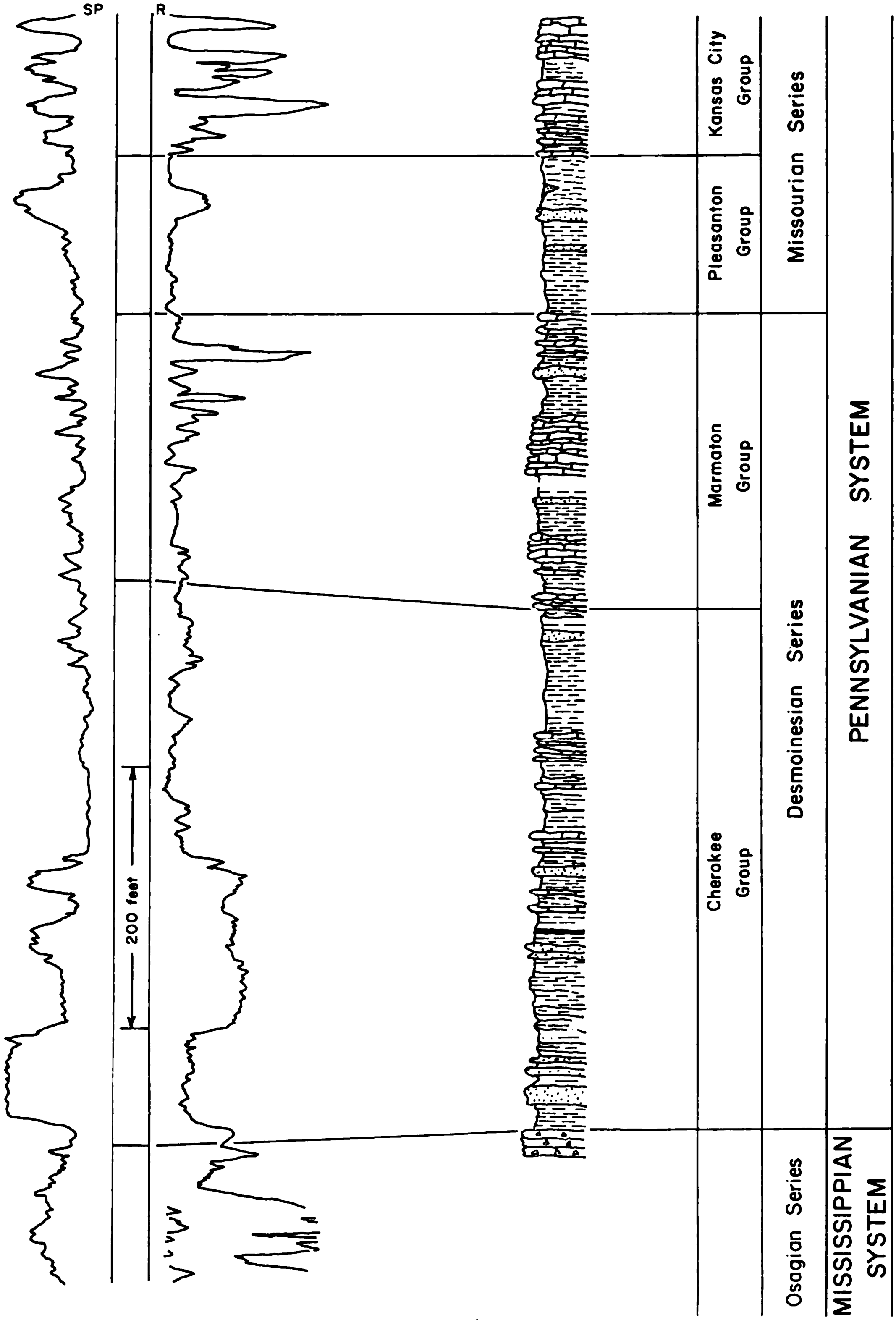


FIGURE 66.—Correlation of units between composite surface section in east-central and southeastern Kansas and Woods No. 1 Oberle well (in SW SW NW sec. 14, T. 14 S., R. 15 E.) in Osage County.

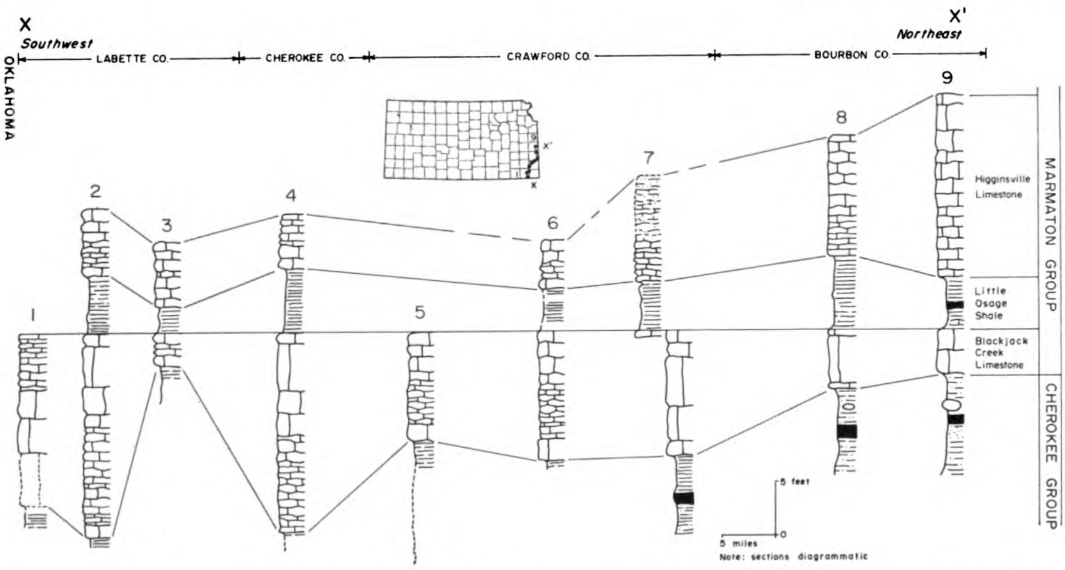


FIGURE 67.—Cross section of outcropping Fort Scott Limestone in southeastern Kansas showing relation of three members to each other and to underlying Cherokee beds.

in the Forest City Basin may be Atokan in age (Branson, 1962; Searight, 1959). The Pennsylvanian sea advanced from the south onto an eroded surface of Mississippian and pre-Mississippian rocks. Material derived from the erosion of these Paleozoic and Precambrian rocks, especially from the newly uplifted Nemaha granite ridge, which formed a low chain of hills, was dumped into the downwarped adjacent areas and was reworked by the advancing sea. The area was near sea level, as shown by coal and other swamp deposits, and the sequence of geologic events resulted in a series of cyclic deposits, in which were incorporated the famous shoe-string sands (Bass, 1936), long narrow channel fillings or bar deposits. Cherokee deposits essentially filled the basinal areas formed by the upwarping of anticlinal elements near the end of Mississippian time, as shown by their configuration and nature.

In western Kansas, Cherokee strata overlie rocks ranging in age from Precambrian to Atokan. The Marmaton Group, which consists mostly of limestone and shale, conformably overlies the Cherokee.

A southwest-northeast cross section from Kearny County to Ellis County (Fig. 70) shows the stratigraphic relations of Cherokee rocks to older and younger units. The Central Kansas Uplift is evident to the northeast, and Cherokee rocks are shown to abut against this positive uparched element. Toward the southwest, away from the uplift, the Cherokee thickens into the Hugoton Embayment. Near the uplift the Cherokee is composed mostly of clastic material, whereas farther southwestward in the embayment it consists mostly of limestone and black shale. Basal sands are present locally.

A northwest-southeast cross section from Ness County to Barber County (Fig. 71) roughly parallels the trend of the Central Kansas Uplift. Near the southeastern end of the section the Pratt Anticline is evident because the Cherokee does not extend across it. Other structural "highs" are revealed by thin Cherokee over their crests.

Pre-Desmoinesian Units

Correlation and proper age placement of the pre-Desmoinesian units in Kansas is at best poorly known; at least, very little has been published on these beds. For the most part they are confined to deeper parts of basinal areas, especially the Hugoton Embayment.

Distribution of Morrowan beds, as interpreted by McManus (1959), is shown in Figure 65. Distribution of these sediments and comments concerning them* have also been given by Moore (1949a), Moore and others (1951a), Maher and Collins (1952, 1953), and Beebe (1957).

* Rascoe (1962) recently published a comprehensive paper on Pennsylvanian and lower Permian rocks of southwestern Kansas and adjacent areas.

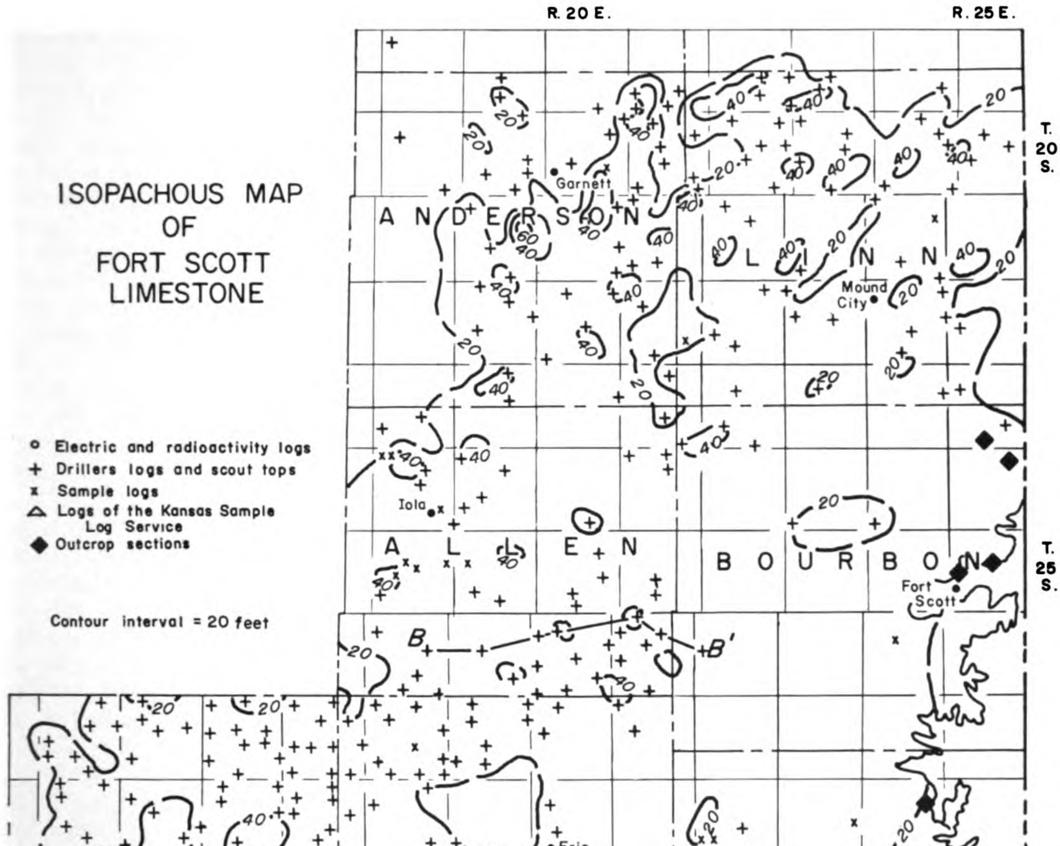


FIGURE 68.—Isopachous map of Fort Scott Limestone in southeastern Kansas. A-A′ and B-B′ are lines of sections in Figure 69 (from Ashley and Merriam, 1961).

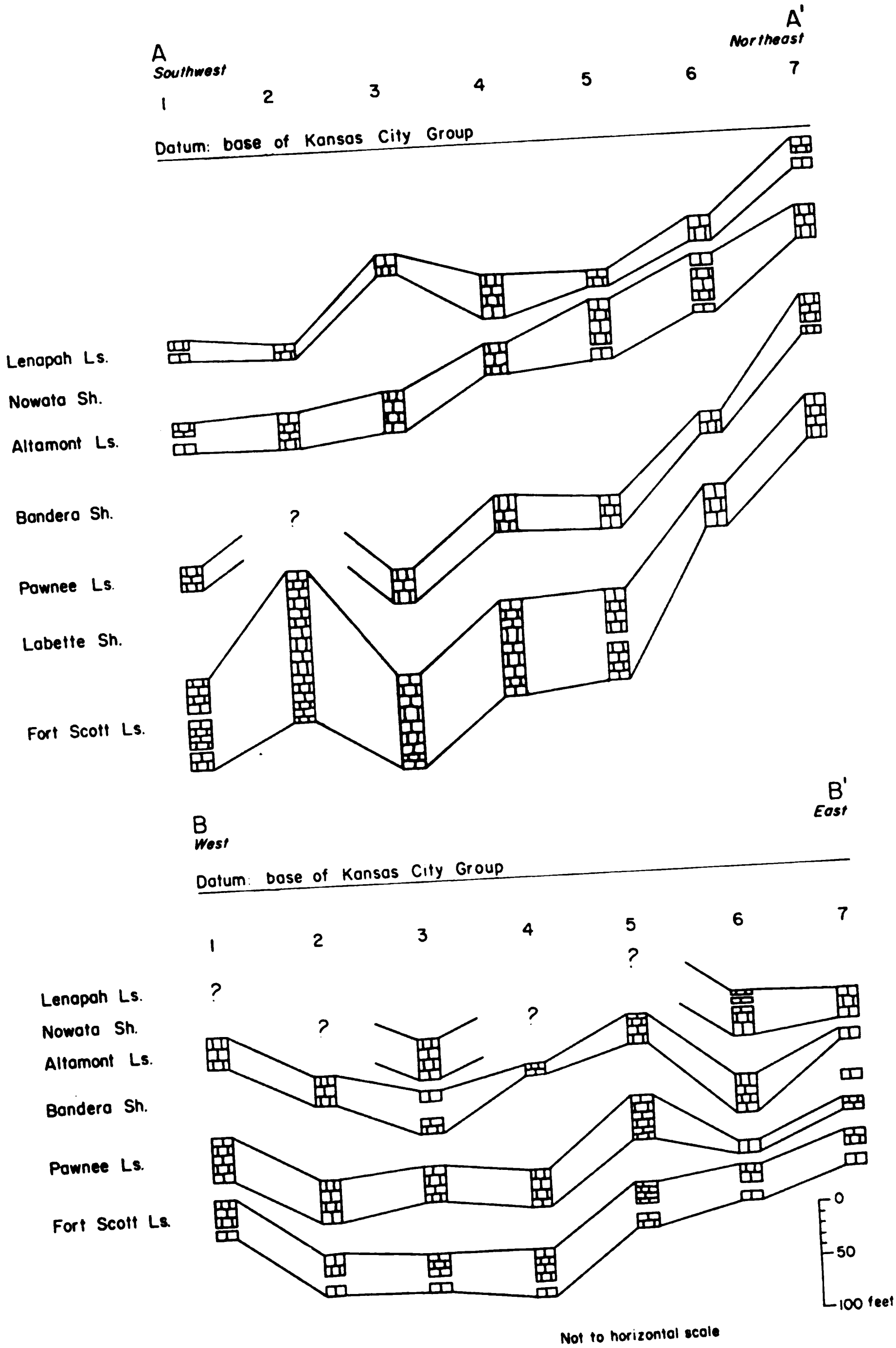


FIGURE 69.—Cross sections along lines shown in Figure 68, showing thickness and stratigraphic relation of units in Marmaton and Pleasanton Groups in southeastern Kansas (from Ashley and Merriam, 1961).

Moore and others (1951a) have the following to say about Atokan rocks in Kansas: "Rocks ranging in thickness from a featheredge to about 500 feet and encountered at a depth of about 4,500 feet in southwestern Kansas are assigned to the Atokan Series. These rocks comprise chiefly limestone and shaly limestone. The Atokan deposits are separated from overlying Desmoinesian rocks and from underlying Morrowan deposits by unconformities." They say the following in regard to the Morrowan: "In Kansas rocks of Morrowan age are known only in the southwestern part of the State, at a depth of about 5,500 feet. These rocks, in part classified as the Kearny formation, comprise shale, limestone, and sandstone. The maximum thickness in Kansas is about 350 feet."

Thompson named the Kearny Formation in 1944 ". . . for the 127 feet of rocks encountered between the base of the producing sand at a depth of 4,752 feet and the top of the highly oolitic limestone believed to be of Mississippian age at a depth of 4,879 feet in the Stanolind Oil and Gas Company No. 1 Patterson well. The name is derived from Kearny county in which the well is located." Rocks in this well were assigned a Morrowan age by Thompson mainly on the basis of their fusulinid faunas, which include several species of *Millerella*. McManus (1959) was able to recognize two members in the Kearny, a lower one, chiefly of sandstone and limestone, and an upper one of shale containing limestone and sandstone. He found that the underlying Chesteran rocks were difficult to differentiate from the Kearny. Atokan rocks of the region are principally interbedded dark-gray, black, and dark-brown cherty limestone and dark-gray to black shale. Some fine-grained sandstone is present (McManus, 1959, p. 111).

The contact of the Pennsylvanian and Mississippian is unconformable. Older Pennsylvanian rocks are confined to the basinal areas and progressively younger rocks overstep higher and higher on adjacent upwarped areas.

Basal Pennsylvanian Deposits

Erosion at and near the end of Mississippian and during early Pennsylvanian time reduced the Mississippian surface to a peneplain as crests of anticlines were truncated, leaving a greater thickness of Mississippian deposits preserved in synclines. The surface was deeply weathered, and solution features developed locally. Lee (1939, p. 10) reported of the Mississippian surface:

> Chert deposits occur on the eroded surface of the Mississippian limestones. The chert was accumulated during the weathering of the Mississippian and a portion of it was reworked during the invasion of the early Pennsylvanian sea. The weathered chert that has remained in place in the Mississippian limestones is, of course, Mississippian in age, and the chert that was reworked by the Cherokee sea is classed as detrital deposits of Pennsylvanian age. Unless well samples are studied with the aid of a microscope, however, no distinction can be made between chert weathered in place and the reworked chert of Pennsylvanian age, and even where samples are studied, chert weathered in place, residual chert and reworked chert are not everywhere distinguishable. For this reason, although it is recognized that part of the chert at the top of the Mississippian is really the basal deposit of the Pennsylvanian, it has been necessary to consider the top of the chert as the top of the Mississippian in compiling data . . . . Also, relatively few well samples of these rocks from the eastern part of the area are available for study.

These deposits are differently named, depending mostly on the area; however, generally speaking, they are called "Mississippi chat" in eastern Kansas, "Gorham" or "Burgess" sand or "Sooy" conglomerate in the central part, and Pennsylvanian basal conglomerate ("PBC") or Pennsylvanian basal sand in the far west.

In most places it is not possible by examination of well samples to differentiate the reworked material (Merriam, 1960d). The material may be of different ages, ranging from late Mississippian to Desmoinesian.

Mississippian or Devonian and Mississippian Deposits in Eastern Kansas

Mississippian rocks in eastern Kansas have long been recognized as economically important, not only for petroleum reserves but also on account of their metalliferous deposits. In the Tri-State District (Kansas, Missouri, and Oklahoma), large quantities of lead and zinc have been mined since the late 1800s. Thus, Mississippian rocks were of commercial importance in the eastern part of Kansas more than a half century before discovery of oil in them.

Information about Mississippian rocks in northeastern Kansas, except for local areas, is sparse. Usable information, accumulating slowly as a result of oil and gas exploration, generally has been disappointing. On the other hand, considerable data is available for southeastern Kansas, as petroleum was discovered in Mississippian rocks in Chautauqua and Montgomery Counties prior to 1917 (Moore and Haynes, 1917, p. 195). Subsequent drilling has yielded a mass of data, although much of it is of doubtful value. Mississippian rocks are present throughout eastern Kansas, except on higher parts of the Nemaha Anticline (Fig. 72).

Kansas Geol. Survey Bull. 162, 1963

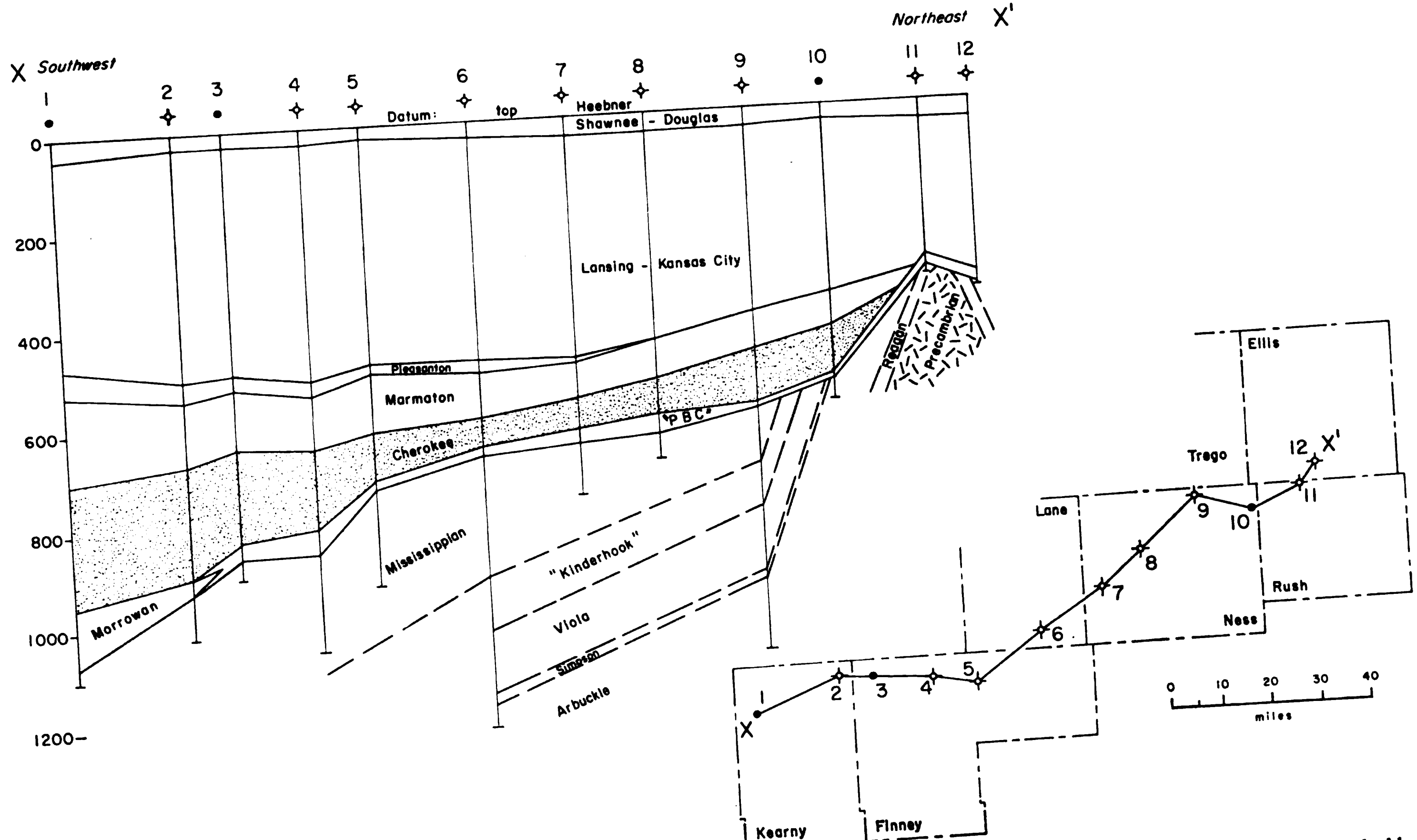


FIGURE 70.—Southwest-northeast cross section from Kearny County to Ellis County showing stratigraphic relation of Cherokee rocks to younger and older units southwest of Central Kansas Uplift (from Goebel and Merriam, 1957).

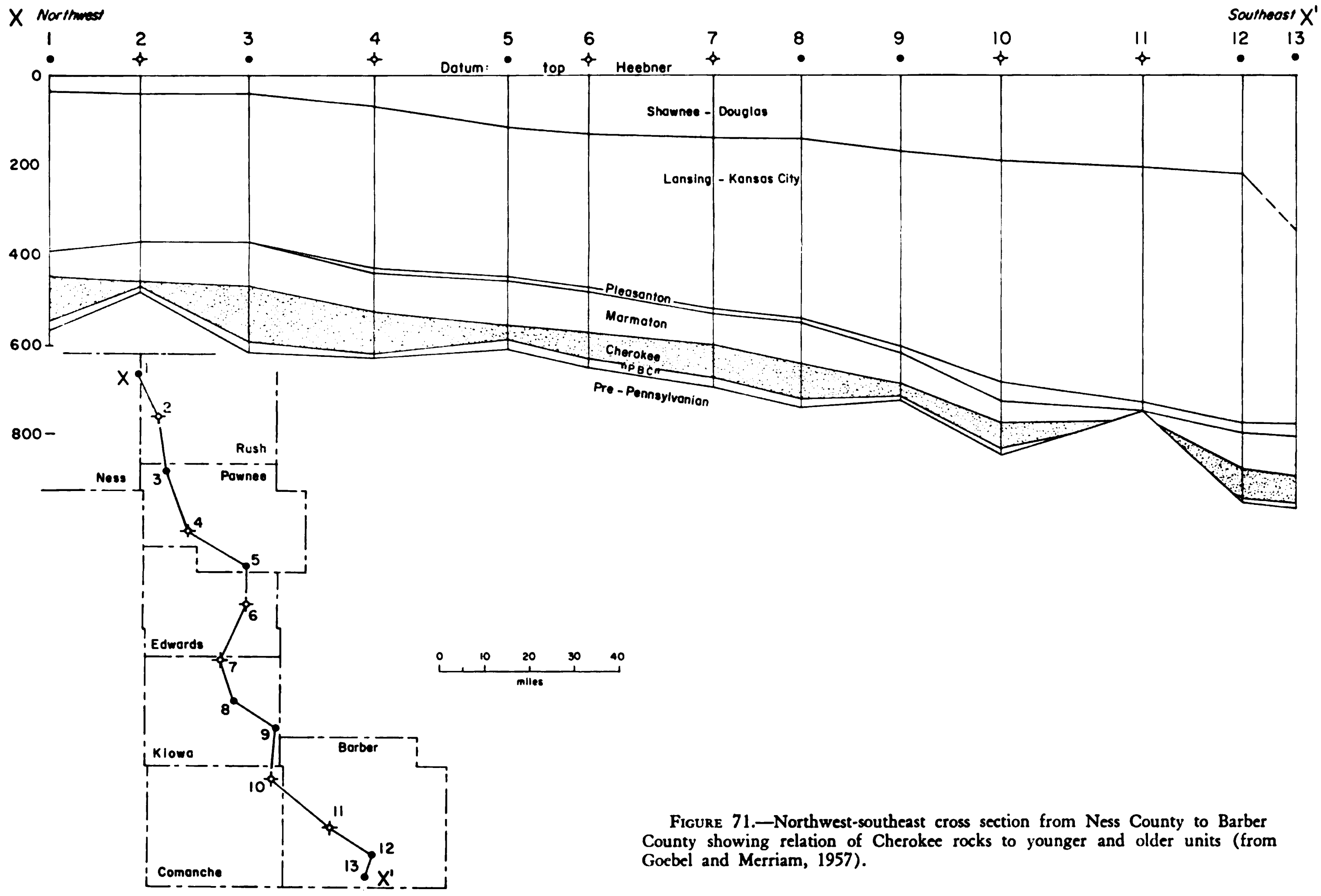


FIGURE 71.—Northwest-southeast cross section from Ness County to Barber County showing relation of Cherokee rocks to younger and older units (from Goebel and Merriam, 1957).

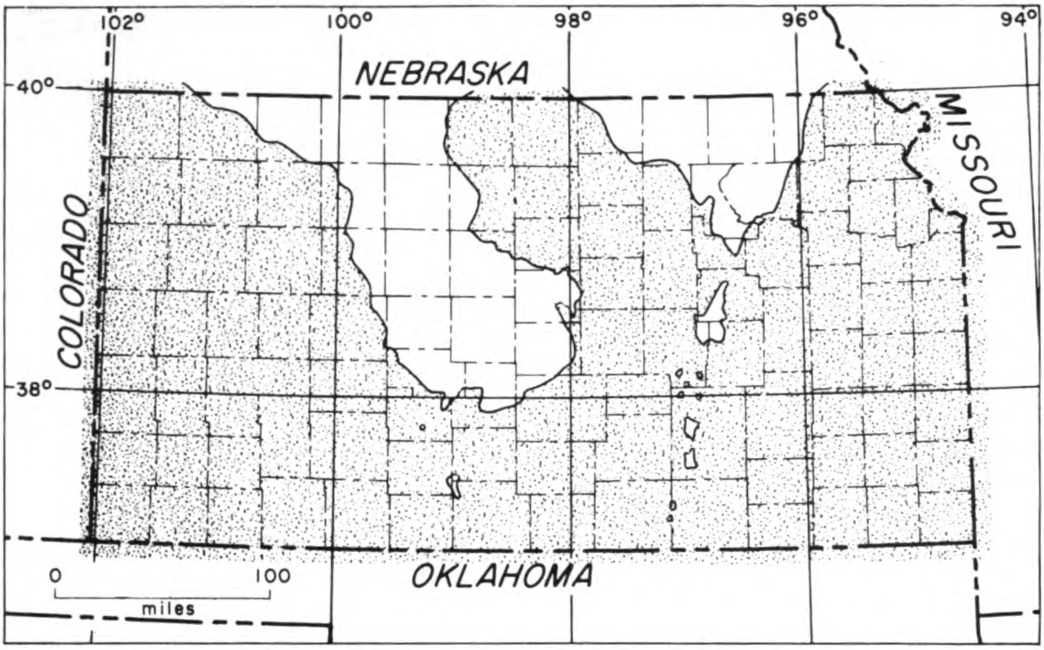


FIGURE 72.—Map of Kansas showing surface and subsurface distribution of Mississippian deposits.

CHARACTER.—The Chesteran Series unconformably overlies the Meramecian in the southeastern part of Kansas (Table 2). In Cherokee County about 20 feet of limestone of Batesville age rests unconformably on the Warsaw (Lee, 1940).

The Warsaw contains a distinctive microfossiliferous chert that makes it easily recognizable. At the base of the Meramecian is placed the controversial Cowley Formation, which consists chiefly of dark silty limestone and dolomite. This unit may comprise deposits filling a southern Kansas basin cut into rocks of Osagian age or may represent a southern facies of other formations. The Salem, St. Louis, and Ste. Genevieve Limestones have been collectively termed Watchorn Formation where it was not convenient to differentiate the subdivisions of the upper part of the Meramecian (Lee, 1940, p. 10).

Unconformably underlying the Meramecian are beds of the Osagian Series, comprising (in descending order): Keokuk Limestone, Burlington Limestone, Reeds Spring Formation, and St. Joe Limestone. They are difficult to differentiate from one another except by the characters of included cherts.

In descending order the formations in the Kinderhookian are Gilmore City Limestone, Sedalia Dolomite, Northview Shale, and Compton Limestone (Lee, 1940). The Gilmore City, consisting of white semigranular limestone that is oolitic in most places, is probably the most

TABLE 2.—Classification of Mississippian units in Kansas (adapted from Moore and others, 1952).

System	*Series*	*Formation*
Pennsylvanian		
Mississippian	Chesteran	
	Meramecian	Ste. Genevieve Limestone St. Louis Limestone Salem Limestone Warsaw Limestone Cowley Formation
	Osagian	Burlington-Keokuk Limestone Reeds Spring Formation St. Joe Limestone
	Kinderhookian	Gilmore City Limestone Sedalia Dolomite (Northview Shale) Chouteau Limestone (Compton Limestone) Boice Shale
Mississippian or Devonian		Chattanooga Shale
Silurian-Devonian		

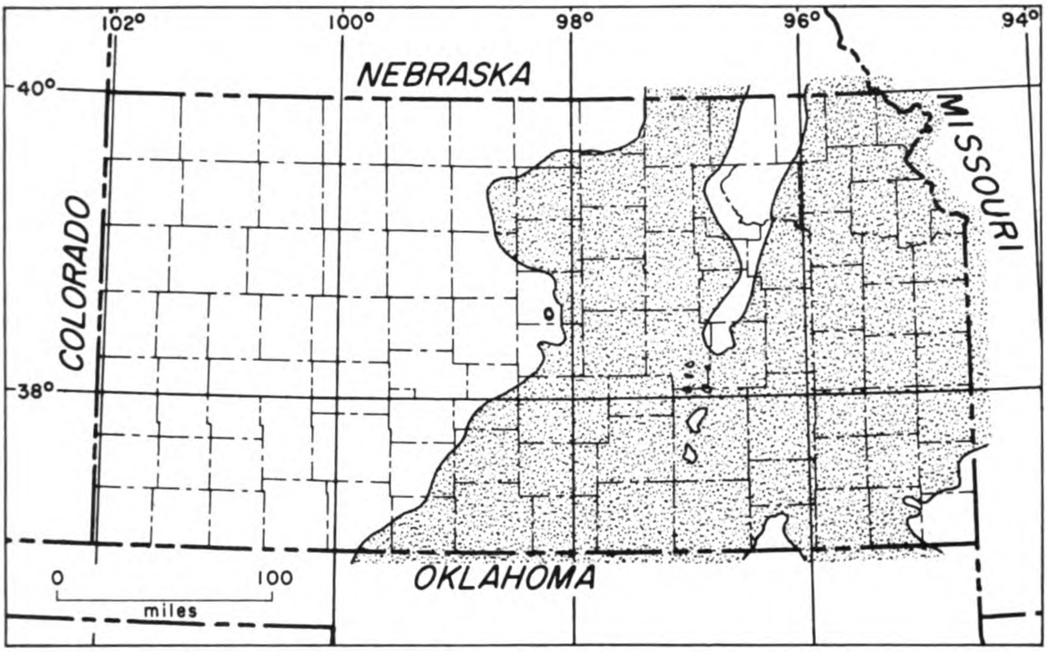


FIGURE 73.—Map of Kansas showing subsurface distribution of Chattanooga Shale.

distinctive unit of this Kinderhookian sequence. The Boice Shale, if present, is not recognized in southeastern Kansas (Reed, 1946).

Criteria for recognizing the different units of the Mississippian in the subsurface are mainly differences in insoluble residues. Early workers (Fowler, 1933; Hiestand, 1938) used only letter designations for subdividing the Mississippian, but subsequent studies, especially by Lee (1940), revealed that formational units could be recognized in the subsurface, and subsequently surface terminology from the adjoining states of Missouri and Oklahoma was applied in Kansas.

Underlying the Kinderhookian is the Chattanooga Shale, often called "Kinderhook shale," which may be either Devonian or Mississippian in age (Fig. 73). Because of the unconformity separating the Chattanooga from older rocks and the apparently conformable contact with overlying rocks, it is convenient to consider the Chattanooga (though classified currently as Devonian or Mississippian) with the Mississippian. The Chattanooga is a silty, pyritiferous, black or dark-gray shale. Spores are commonly disseminated throughout the formation. In eastern Kansas the basal "Misener sandstone" is represented only by disseminated, rounded sand grains (Moore and others, 1951a, p. 111).

THICKNESS.—The thickness pattern of the "Mississippi lime" (Fig. 74) is considerably different from that of the Chattanooga Shale. It has long been recognized that in southeastern Kansas the thickness of the Mississippian is directly related to structure (Bass, 1929; Lee, 1939). Hence, northeast-trending thick and thin belts correspond to northeast-trending basinal and anticlinal structures (Merriam and Goebel, 1959c). This pattern is almost at right angles to that revealed by the thickness map of the Chattanooga (Fig. 75).

Little is known about outcropping Mississippian rocks in Kansas; rocks seemingly of Osagian age, and possibly also of Meramecian age, crop out in Cherokee County, in extreme southeastern Kansas (Smith and Siebenthal, 1907). Northwestward from there to the area of the Nemaha Anticline, the Mississippian alternately thickens and thins across synclines and anticlines, ranging in thickness from about 200 to 450 feet. In southern Woodson County the unit is cut by a granitic intrusive at Rose Dome and by the Hills Pond Peridotite at Silver City (Wagner, 1954). The Mississippian rocks have been completely eroded from the higher parts of the Nemaha Anticline in Chase, Marion, and Butler Counties. West of the Nemaha structure the Mississippian thickens into the Salina and Sedgwick Basins.

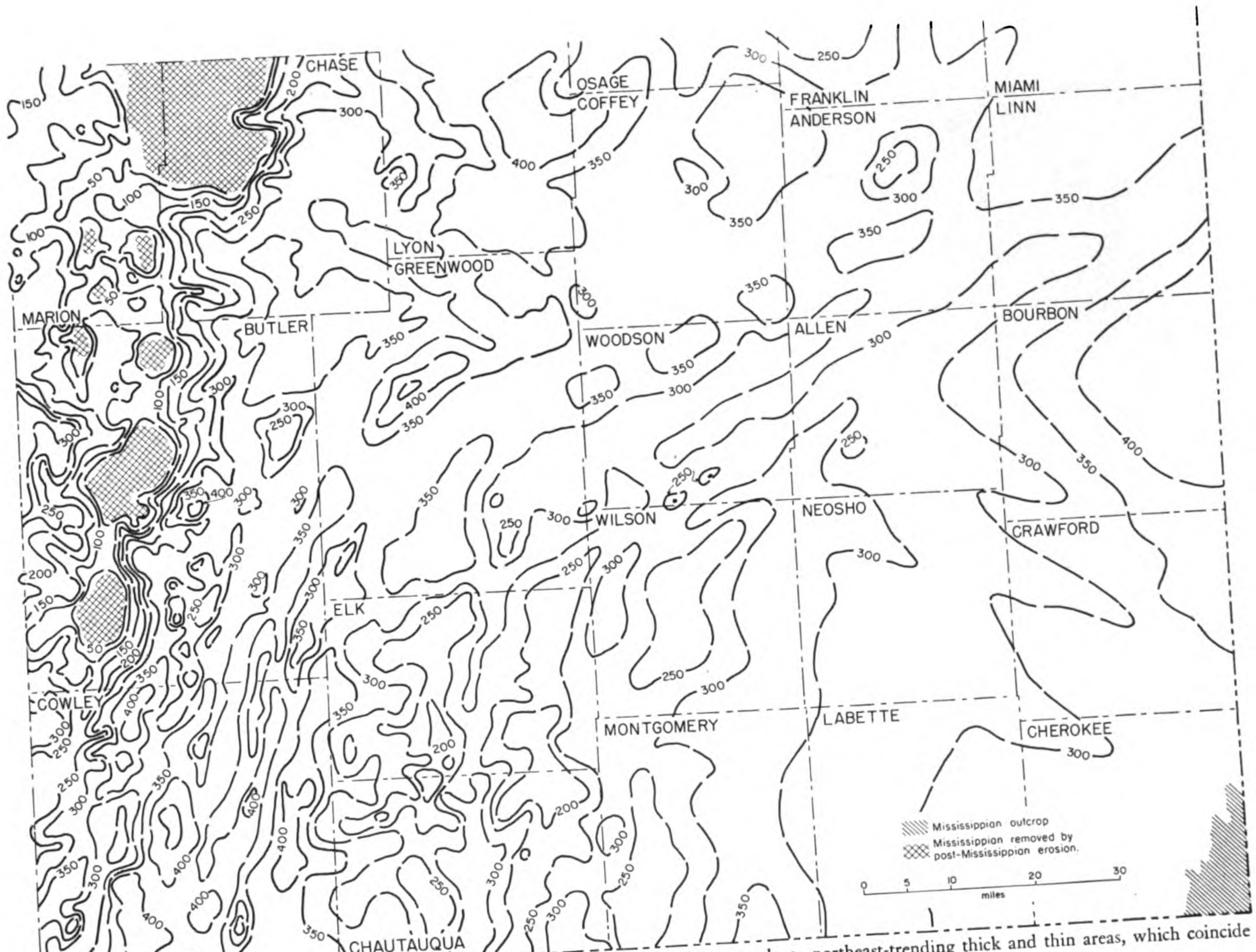


FIGURE 74.—Isopachous map of "Mississippi lime" in southeastern Kansas. Note north- to northeast-trending thick and thin areas, which coincide with known synclines and anticlines (from Goebel and Merriam, 1959). Contour interval 50 feet.

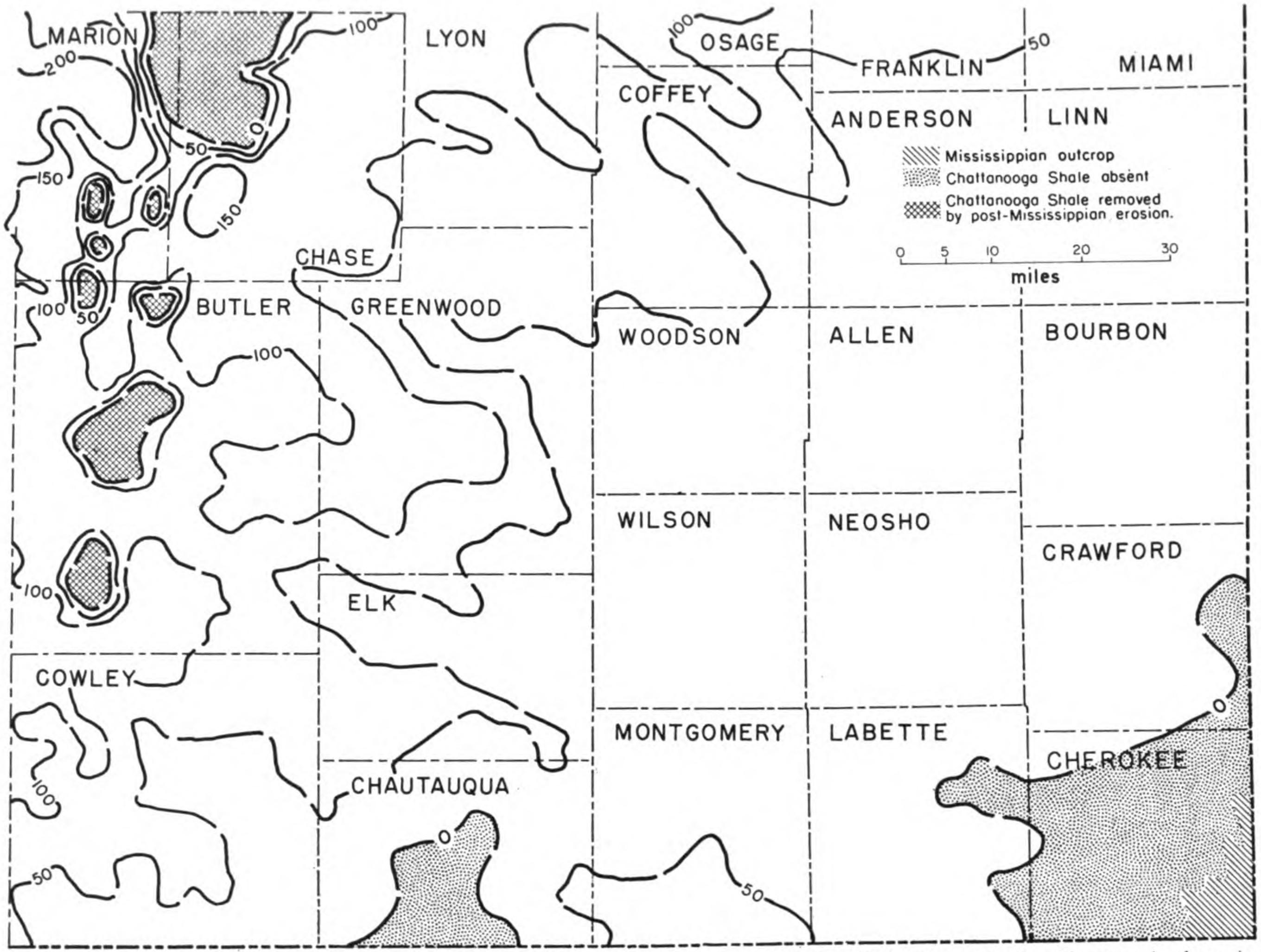


FIGURE 75.—Isopachous map of Chattanooga Shale, Boice Shale where present, and Northview Shale where Compton Limestone is absent in southeastern Kansas (from Goebel and Merriam, 1959). Contour interval 50 feet.

For the eastern part of the map control is sparse, but in the western part configuration of the contours is based on many well logs. In areas of scant control, the isopachous lines were sketched and thus actually are only form lines, but it is believed that the regional trends implied by the 50-foot contours are essentially correct.

Several minor anticlinal structures in southeastern Kansas are discernible on the map because the Mississippian thins over their crests. These include the Fredonia Dome, Longton Ridge, Dexter-Otto Anticline, and Winfield Anticline. After more wells are drilled in the area, some of these minor structures will be more precisely definable.

An isopachous map of the Chattanooga Shale and the Boice Shale, if present, and also possibly the Northview Shale where the Compton Limestone is absent, is presented in Figure 75. The thickness of this sequence, from the "Hunton" limestone or older formations to the base of the "Mississippi lime," ranges from a featheredge in extreme southeastern Kansas to approximately 200 feet in Marion County. The Chattanooga is absent in part of Chautauqua County; Lee (1940, p. 25) believed that it was removed by post-Osagian erosion. In Chase, Marion, and Butler Counties the Chattanooga has been removed by post-Mississippian erosion along the crest of the Nemaha Anticline. In two small areas in southern Woodson County, the intrusives at Rose and Silver City cut the unit.

In general, thickness of the Chattanooga is irregular, increasing to the northwest. Four vague northwest trends of thinning cross Coffey County and east-central Lyon County, central Greenwood County, central Elk County and southeastern Butler County, and central Cowley County, respectively. These areas of thinning may represent old structural trends, but the control for this map is not adequate to warrant such a conclusion. Discrepancies between this map and a similar one prepared by Lee (1940, pl. 3) are probably due to differences in well control available at time of construction of the maps.

STRATIGRAPHIC RELATIONS.—The locations of cross sections showing the relation of present structure to major post-Mississippian structural provinces in Kansas are shown in Figure 76.

A west-east cross section (cross sections adapted from Lee and Merriam, 1954b) from Marion County on the west to Miami County on the east, shows the relation of Mississippian rocks to major structure (Fig. 77). Mississippian rocks dip gently westward into the Brownville Syncline but are sharply upturned and truncated adjacent to the Nemaha Anticline, giving the Forest City Basin an asymmetrical profile. On the western side of the cross section, Mississippian rocks dip gently westward into the Sedgwick Basin. Permian and Pennsylvanian beds arch over the anticline, revealing its presence. The gross exaggeration of the cross section gives a false impression as to the intensity

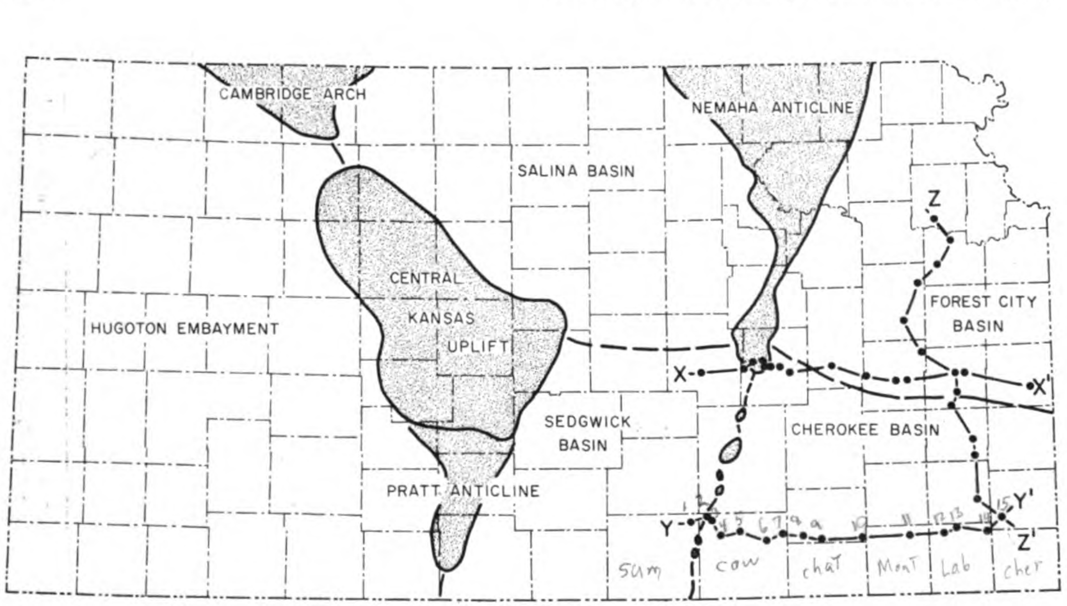


FIGURE 76.—Major pre-Desmoinesian post-Mississippian structural features of Kansas and location of cross sections shown in Figure 77.

of the structure; the maximum dip is only about 8 degrees on the eastern flank of the Nemaha.

Another west-east cross section, which extends from Sumner County on the west to Crawford County on the east across the Cherokee Basin and Nemaha Anticline, is also shown in Figure 77. Mississippian rocks dip gently westward to the eastern flank of the Nemaha Anticline, where the dips are reversed and the Mississippian is arched over the structure. The anticline is weakly reflected in Pennsylvanian and Permian beds.

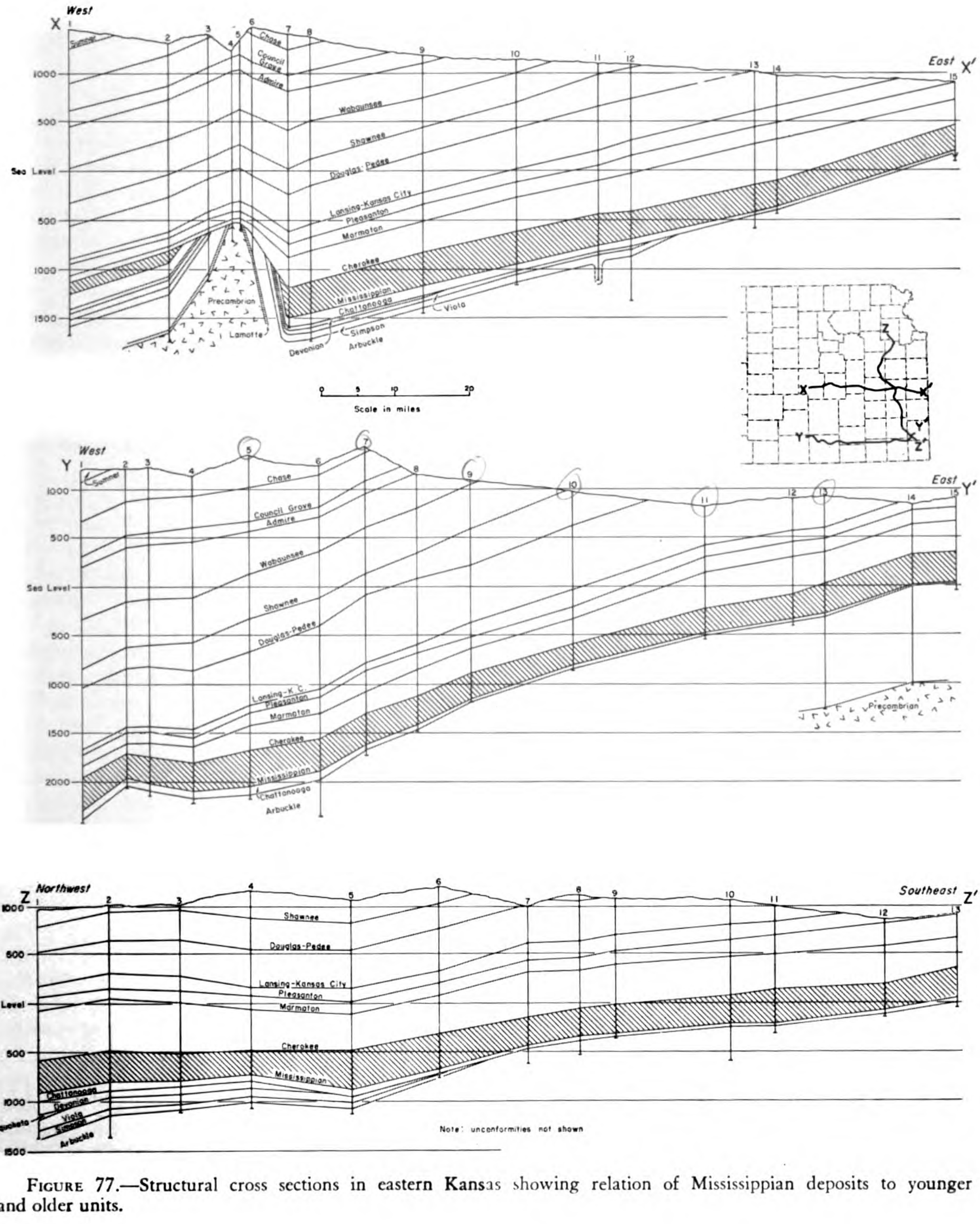


FIGURE 77.—Structural cross sections in eastern Kansas showing relation of Mississippian deposits to younger and older units.

A third cross section extends northwest-southeast across the Forest City Basin, Bourbon Arch, and Cherokee Basin (Fig. 77). Mississippian rocks dip gently toward the northwest into the deeper part of the Forest City Basin. Although the section crosses the Bourbon Arch almost at a right angle, the position of this arch is not revealed.

ENVIRONMENT OF DEPOSITION.—The environment of deposition of Mississippian rocks in Kansas was adequately summed up by Moore (1957a, p. 124) in a discussion of the carbonate deposits of the Ozark region:

> In Mississippian time, as in many other parts of the Paleozoic era, very large epicontinental seas spread over the North American and other continental platforms and because these seas were bordered only locally by land sufficiently elevated to furnish clastic detritus, the waters were predominantly clear and probably moderately warm. Benthonic invertebrates and other marine organisms that secreted hard parts of calcium carbonate were widespread and their populations were prodigious. Relatively uniform, widely distributed limestone formations were made.

Mississippian Deposits in Western Kansas

In 1948 Clair was able to divide the "Mississippi lime" of western Kansas on the basis of lithology and by means of insoluble residues. His work serves as a guide to recognizing the Mississippian subdivisions. Many of the units of eastern Kansas are recognizable in the west, including the Chesteran, Meramecian, Osagian, and Kinderhookian (Veroda, 1959). These rocks have been described in some detail by Maher and Collins (1949), and Maher (1953b). Distribution of Mississippian deposits in Kansas is shown in Figure 72. Rocks classified as the Meramecian, Osagian, and Kinderhookian Series are represented in the Cambridge Arch area (Merriam and Atkinson, 1955).

In western Kansas several Mississippian formations are recognized to be present. The most distinctive of these are the Warsaw (Meramecian), Fern Glen and Burlington-Keokuk (Osagian), and Gilmore City (Kinderhookian). These rocks unconformably overlie "Kinderhook shale" and consist of white, dense, cherty or oolitic limestone. Present at the top of the Mississippian sequence is a residual chert, locally as much as 50 feet thick, which may be very latest Mississippian or earliest Pennsylvanian in age. The chert is white, smooth, and opaque to subopaque. This chert overlies progressively older beds to the northeast, and on the southwestern flank of the Cambridge Arch it overlies beds as old as Arbuckle. This same sort of situation, on a smaller scale, occurs on the eastern side of the Central Kansas Uplift, where according to Lee (personal communication), the chert is present but less well developed.

The "Kinderhook" is a green to brown shale that is present locally and is placed, as a matter of convenience, in the Mississippian rather than the Devonian. It is possible that this shale is Chattanooga or Boice or equivalent to one or both. The Chattanooga Shale is known to be thin on the western side of the Central Kansas Uplift and to be present farther south (Lee, 1953).

Lower Paleozoic Deposits

The stratigraphy of the lower Paleozoic rocks was not studied in detail except to plot accurately the areal distribution of the different units. Much important work remains to be done with these rocks, although study of them in Kansas must be entirely in the subsurface. These units, which crop out in adjacent states, will have to be traced into the subsurface in Kansas before correlations can be made with certainty. This has been done for only a few of the beds.

The pre-Mississippian rocks consist mainly of limestone and dolomite but they include some shale and sandstone. Rocks of Cambrian-Ordovician and Silurian-Devonian age are recognized; the thickest sections of these rocks occur near the centers of the different basins, where they have been preserved from extensive erosion. These rocks are missing from the crests of uplifts; hence, unconformities are widespread in this part of the section.

Much of the published knowledge regarding the pre-Pennsylvanian rocks in Kansas, and the Mississippian in particular, is the work of Wallace Lee, whose publications have been cited along with many others pertaining to this part of the stratigraphic column. Additional works that should be mentioned include those by: Aurin, Clark, and Trager (1921), Udden (1926), Twenhofel (1927), Edson (1929, 1935), Ver Wiebe (1946, 1948), and Taylor (1946, 1947a, 1947b).

Silurian-Devonian Rocks

Rocks, predominantly limestone and dolomite, of Devonian and Silurian age lie unconformably below the Mississippian and unconformably on Ordovician rocks. In places they overstep different Ordovician formations, but in general their structural attitude and distribution (Fig. 78) accord more closely with Ordovician than with Mississippian rocks. These commonly undifferentiated rocks are known as "Hunton"; however, Lee (1943, 1956) has

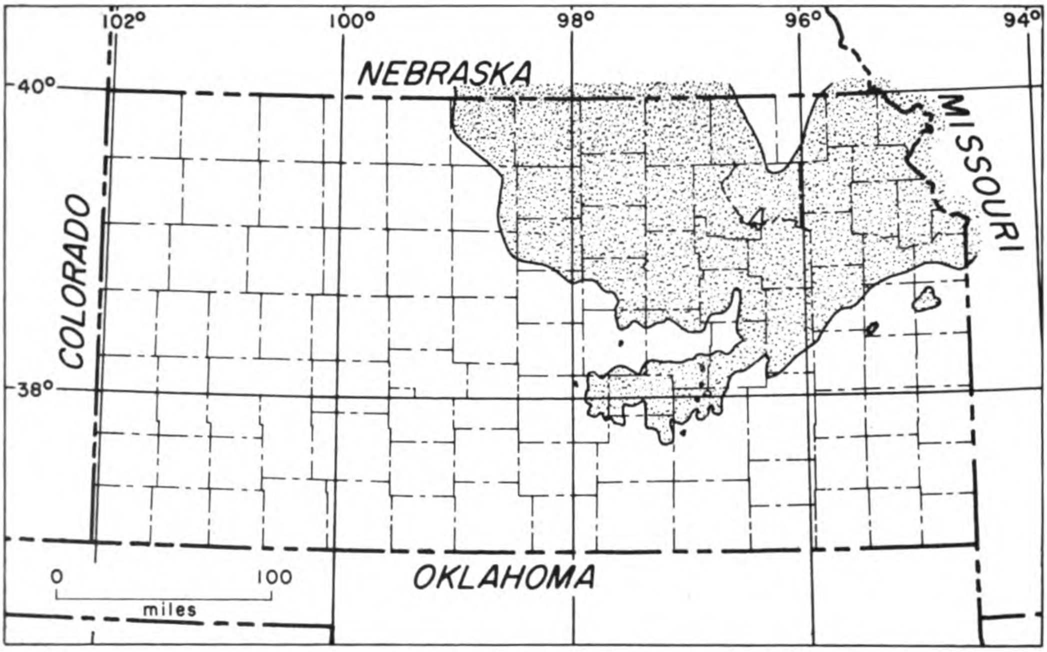


FIGURE 78.—Map of Kansas showing subsurface distribution of "Hunton" rocks (Silurian-Devonian).

shown that a disconformity separates Devonian and Silurian rocks. Like Mississippian rocks, the "Hunton" has been removed by erosion from the highest parts of the Nemaha Anticline, Central Kansas Uplift, and Chautauqua Arch; elsewhere in northeast and north-central Kansas (the North Kansas Basin), these rocks are present and attain a maximum total thickness of 650 feet (Jewett and Merriam, 1959). "Hunton" rocks are not known to be present elsewhere in the state, except in the northern part of the Sedgwick Basin in Harvey County and in parts of McPherson, Marion, Sedgwick, Butler, and Reno Counties. Small outliers of "Hunton" are known beyond the larger areas of occurrence (Lee, 1956).

In Kansas and Missouri the contact between the Devonian and the Silurian occurs at the base of a dolomite or limestone zone in which rounded sand grains are disseminated; the basal Devonian bed is locally a dolomitic sandstone. The Devonian in eastern Kansas commonly includes gray to brownish, dense to finely crystalline dolomite or sublithographic limestone. Except where it is very thin, it includes some opaque white chert. Silurian rocks consist of light-gray to buff, fine- to medium-crystalline dolomite, which is locally very vuggy and porous. Chert is also present in various amounts. The base of the Silurian is characterized by large dolomitized oolites (Lee and Merriam, 1954b). In some wells arenaceous Foraminifera are found in the lower part of the Silurian portion of "Hunton" (H. A. Ireland, personal communication).

Cambrian-Ordovician Rocks

Cambrian-Ordovician rocks consist chiefly of dolomite but include some limestone, sandstone, and shale. Subdivisions are (in descending order): Maquoketa (Sylvan) Shale, Viola (Kimmswick) Limestone, Simpson Group (including St. Peter Sandstone), Arbuckle Group, Eminence Dolomite, Bonneterre Dolomite, and Reagan (Lamotte) Sandstone. The last three formations are of Late Cambrian age. These units unconformably overlie the Precambrian basement. The combined thickness of these rocks is about 1,500 feet, but in many places thinning due to a retarded rate of sedimentation, nondeposition, or erosion leaves as little as a few feet of these rocks. They, like other Paleozoic units, are absent from higher parts of the Nemaha Anticline, Central Kansas Uplift, and Cambridge Arch.

MAQUOKETA SHALE

The Maquoketa Shale (Upper Ordovician) is gray-green to gray silty dolomitic shale and gray fine-granular silty dolomite. It is locally

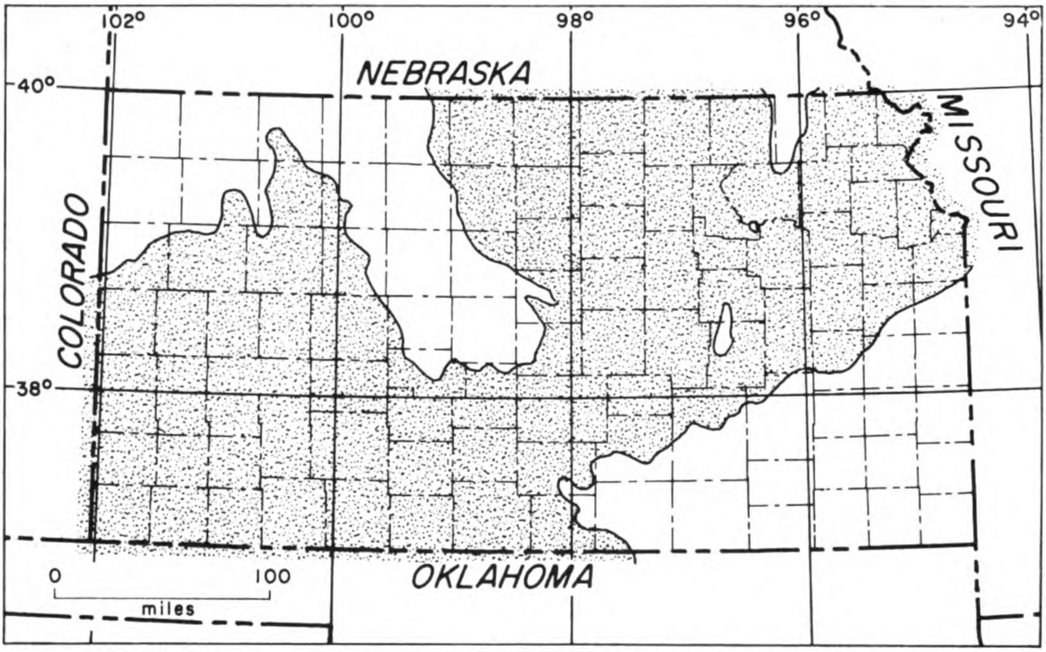


FIGURE 79.—Map of Kansas showing subsurface distribution of Viola Limestone (Middle Ordovician).

cherty. The Maquoketa attains a maximum thickness of about 155 feet. In the extreme southeastern part of the Hugoton Embayment, Maquoketa has been reported from several wells, but the exact extent, distribution, and correlation of the shale are not known with certainty.

VIOLA LIMESTONE

The Viola Limestone (Middle Ordovician) consists of gray, buff, and brown medium- to coarse-crystalline dolomite, which is vuggy and contains various amounts of gray and white opaque, generally spicular chert. In the northeastern part of Kansas (Lee, 1943) the formation attains a maximum thickness of about 310 feet. In the Hugoton Embayment the Viola oversteps the underlying Simpson Group and older rocks both eastward (Merriam and Atkinson, 1955) and westward (Maher and Collins, 1949). The formation is absent in the northwestern corner of Kansas and along the southwestern flank of the Cambridge Arch and Central Kansas Uplift (Fig. 79). In a small area in northwestern Pawnee County, the Reagan, Arbuckle, and Simpson are missing and the Viola is in direct contact with Precambrian rocks.

SIMPSON GROUP

In Kansas the Simpson Group is divided into two formations: the Platteville Formation (upper), and the St. Peter Sandstone (lower). Distribution of this group is shown in Figure 80. A map showing distribution of the group in parts of five states—Nebraska, Kansas, Missouri, Iowa, and Illinois—has been published by Lee and others (1946). A detailed description and correlation of the rocks of Simpson age in Kansas has been given by Leatherock (1945).

The Platteville Formation consists of green shale, limestone, dolomite, and sandstone. A bed in this formation that may be used for correlation is a persistent basal dolomite, which ranges in thickness from 5 to 35 feet (Leatherock, 1945). The formation as a whole is characterized by lateral changes. The maximum thickness of the formation is about 104 feet (Leatherock, 1945, p. 13). Twenhofel and others (1954) assign a Blackriveran age to the Platteville.

According to Leatherock (1945), the St. Peter Sandstone consists of three zones: upper and lower zones of sandstone and a middle zone of green clay shale. The St. Peter is composed of white, fine to medium, well-rounded frosted quartz sand. It is loosely cemented with calcareous cement, but in well samples it may occur as loose sand grains. The sand is locally stained reddish by minor amounts of iron oxide in the cement. The normal thickness of the St. Peter in eastern Kansas is 10 to 84 feet (Leatherock,

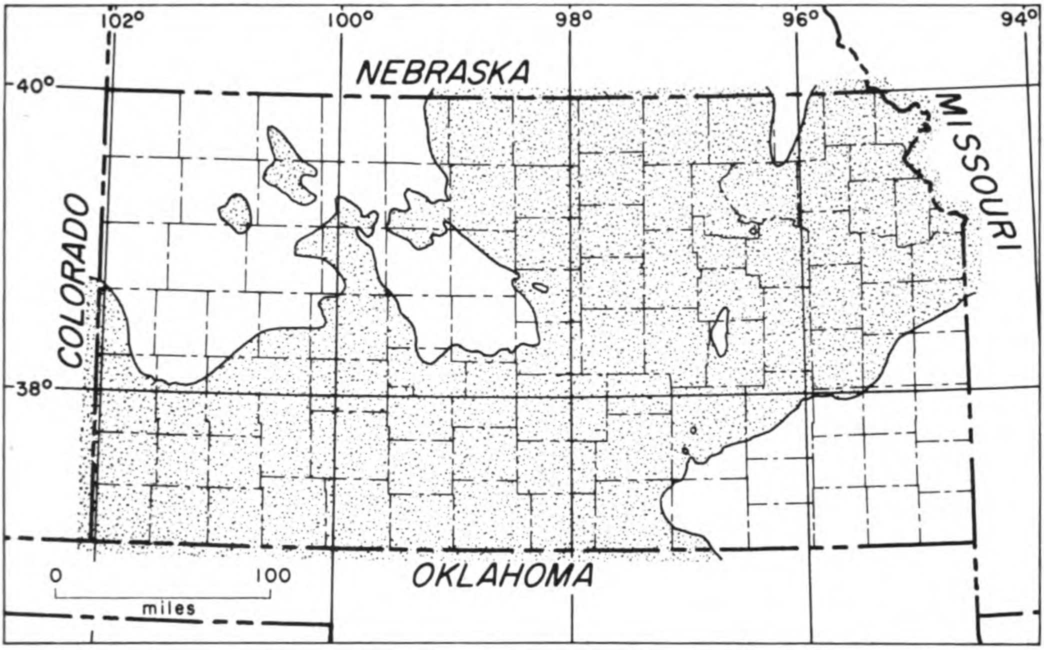


FIGURE 80.—Map of Kansas showing subsurface distribution of Simpson Group (Middle Ordovician).

1945, p. 11). According to Twenhofel and others (1954), the St. Peter is Chazyan in age.

The Simpson Group unconformably overlies the Arbuckle Group and in an area on the Southeast Nebraska Arch it overlies rocks as old as Precambrian. Any one of the three zones of the St. Peter may be in contact with the Arbuckle. The Platteville in turn unconformably overlies the St. Peter Sandstone, so that it too may be in contact with any one of the three zones. Likewise, the Kimmswick (Viola) Limestone unconformably overlies the Platteville Formation. These relations are shown on a series of stratigraphic cross sections published by Leatherock (1945, pl. 1).

SIMPSON-FILLED SINKHOLES IN EASTERN KANSAS

Sinkholes in eastern Kansas filled with Simpson rocks have been mentioned by Lee and others (1946), Lee, Leatherock, and Botinelly (1948), and Lee and Merriam (1954b). In west-central Missouri it is possible to observe on the surface a similar sinkhole filled with Simpson (St. Peter) rocks near Otterville, Cooper County (Kansas Geological Society, 1941), and there are many others.

Examination of logs of wells drilled in eastern Kansas revealed six wells that penetrated abnormally thick sections of Simpson (Merriam and Atkinson, 1956). The six wells are (Fig. 81): (A) Kasper No. 1 James in Johnson County (sec. 8, T. 13 S., R. 25 E.); (B) Clark No. 1 Vaughn in Miami County (sec. 28, T. 17 S., R. 22 E.); (C) Cram No. 1 Allen in Coffey County (sec. 13, T. 21 S., R. 15 E.); (D) Herbel and Tyrell No. 1 Henning in Coffey County (sec. 22, T. 21 S., R. 16 E.); (E) Evan et al No. 1 Cook in Linn County (sec. 4, T. 22 S., R. 24 E.); and (F) Sinclair-Prairie No. 9 McClaskey in Woodson County (sec. 29, T. 23 S., R. 14 E.). Samples were available from only four of them. A sample log, which had been prepared by Hundhausen and Grohskopf, was available for the Clark No. 1 Vaughn well. In the absence of samples or a sample log for the Herbel and Tyrell No. 1 Henning well, information had to be obtained from a drillers log.

Because of the scarcity of wells that have been drilled as deep as the Arbuckle in this region, as many as six sinkholes is somewhat surprising and would seem to indicate the presence of extensively developed solutional features in Arbuckle rocks in eastern Kansas. Because information is decidedly scanty, it is difficult to make exact interpretations, but available data perhaps warrant a few preliminary statements.

The term "abnormal thickness" is relative, depending on local conditions. For example, in the Evan et al No. 1 Cook well, 40 feet of Simpson is regarded as abnormal because no Simpson

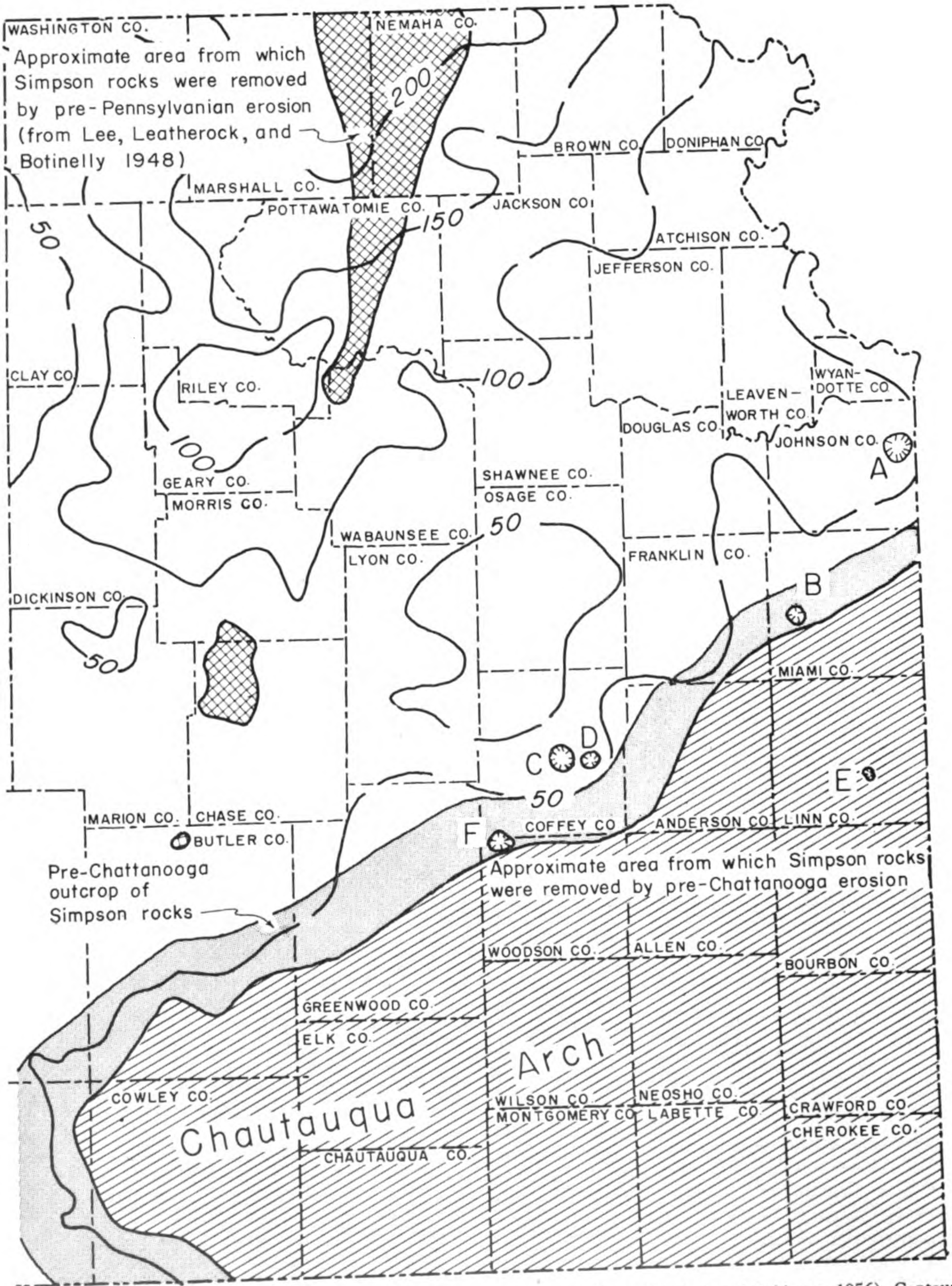


FIGURE 81.—Isopachous map of Simpson Group in eastern Kansas (from Merriam and Atkinson, 1956). Contour interval 50 feet. Letters refer to test wells identified in text.

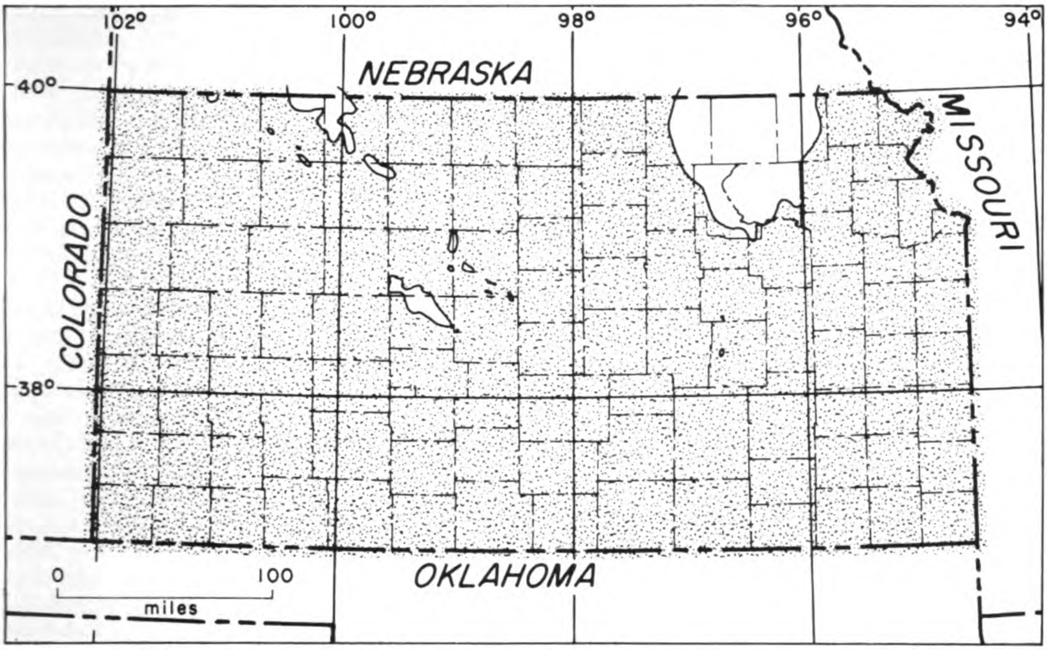


Figure 82.—Map of Kansas showing subsurface distribution of Arbuckle Group (Cambrian-Ordovician).

is present in any nearby wells in Linn County. The thickest known section of Simpson in eastern Kansas is 465 feet in the Kasper No. 1 James well. Normal sections of the Simpson range in thickness from about 35 to 170 feet (Leatherock, 1945).

An isopachous map of the Simpson Group in eastern Kansas, contoured at 50-foot intervals, shows roughly the outline of part of the North Kansas Basin and Chautauqua Arch (Fig. 81). The pre-Chattanooga outcrop pattern of the Simpson Group outlines the northwestern, western, and part of the southwestern flanks of the Chautauqua Arch. Thickness of Simpson rocks increases to the north into the North Kansas Basin. Because both the upper and lower boundaries of the group are erosional, the contours are irregular. If control were more detailed, the contours would be even more irregular.

The sinkholes seem to be definitely related to the pre-Chattanooga subcrop pattern of the Simpson Group along the northern flank of the Chautauqua Arch (Fig. 81); no abnormally thick Simpson was found at any appreciable distance downdip from the subcrop. Updip, the St. Peter in Miami County is probably an erosional remnant preserved in a sinkhole.

Considering all possibilities, sinkholes seem the most plausible explanation for these areas of thick St. Peter sediments. No deep channeling (on the order of 400 feet) of the pre-Simpson surface has been recognized either on the surface in Missouri or in the subsurface in Kansas. Distribution of the anomalies parallel to the pre-Chattanooga Simpson subcrop also suggests sinks rather than channeling. Channels would tend to develop perpendicular to the structure and to diverge from the crest of the Chautauqua Arch; the present known distribution does not simulate drainage patterns. Also, there is apparently a similarity between the Otterville surface feature in Missouri and the sinkholes in the subsurface of eastern Kansas.

One possible explanation for distribution of the sinkholes is that the Arbuckle was subjected to solution on the flanks of the rising Chautauqua Arch but not in the deeper part of the North Kansas Basin. Until more evidence is accumulated, however, this explanation is only tentative. Because the Platteville Formation is not involved in the sinkholes, they are at least pre-Platteville in age; probably they are pre-St. Peter (or pre-Simpson).

"ARBUCKLE GROUP"

The "Arbuckle Group" of Late Cambrian and Early Ordovician age consists of five recognizable divisions in the subsurface of eastern Kansas (Lee and Merriam, 1954b). The lower two, Bonneterre Dolomite and Eminence Dolomite, are Cambrian in age, whereas the upper three, Gasconade Dolomite, Roubidoux Dolomite, and undivided Cotter and Jefferson City Dolomites, are of Ordovician age. Correlation of the upper Arbuckle from Missouri into Kansas has been made by McCracken (1955).

Definitions of the Arbuckle differ considerably; the name is used herein to designate collectively all rock units between the overlying Simpson Group and underlying Reagan or Lamotte Sandstone. Other authors variously exclude the Bonneterre or both the Bonneterre and Eminence from the group; in the latter case the group is restricted to rocks of Ordovician age, and the Gunter Sandstone is the lowest unit in the group. Distribution of Arbuckle rocks is shown in Figure 82.

The Arbuckle Group as a whole consists mainly of dolomite and is white, buff, light gray, cream, and brown. The rocks are mainly crystalline or dense, and especially in the upper parts they contain large amounts of various types of chert. Some of the beds are sandy and some contain minor amounts of glauconite and pyrite. Where the Lamotte Sandstone is missing, Arbuckle rocks overlie the Precambrian surface. In general, the Arbuckle thickens to the east and southeast toward the Ozark region of Missouri and toward the south in Oklahoma.

The Arbuckle in the vicinity of the Cambridge Arch (Merriam and Atkinson, 1955) consists mostly of gray to buff, dense or porous and vuggy, medium- to coarse-crystalline limestone and dolomite. Some of the rocks contain light-gray subopaque chert or oolitic chert. Many of the beds are glauconitic. Where Reagan Sandstone is absent, Arbuckle lies directly on the Precambrian surface (Fig. 83).

It is probable that most of the rocks reported as Arbuckle in western Kansas are or are equivalent to the Bonneterre Dolomite, although the Bonneterre is not recognized by some as part of the Arbuckle Group. This is also the opinion expressed by Maher and Collins (1949). In a note on a log of the Kansas Sample Log Service, of a well drilled in Rawlins County (sec. 21, T. 3 S., R. 32 W.), R. A. Carmody stated that the Arbuckle was topped at 4,694 feet and Bonneterre or equivalent at 4,800 feet. The rocks above the Bonneterre he believed to be pre-Roubidoux and probably Late Cambrian in age. However, it is not clear to what formation these rocks should be assigned in the classification, although presumably they belong to the Eminence Dolomite, as the Eminence is recog-

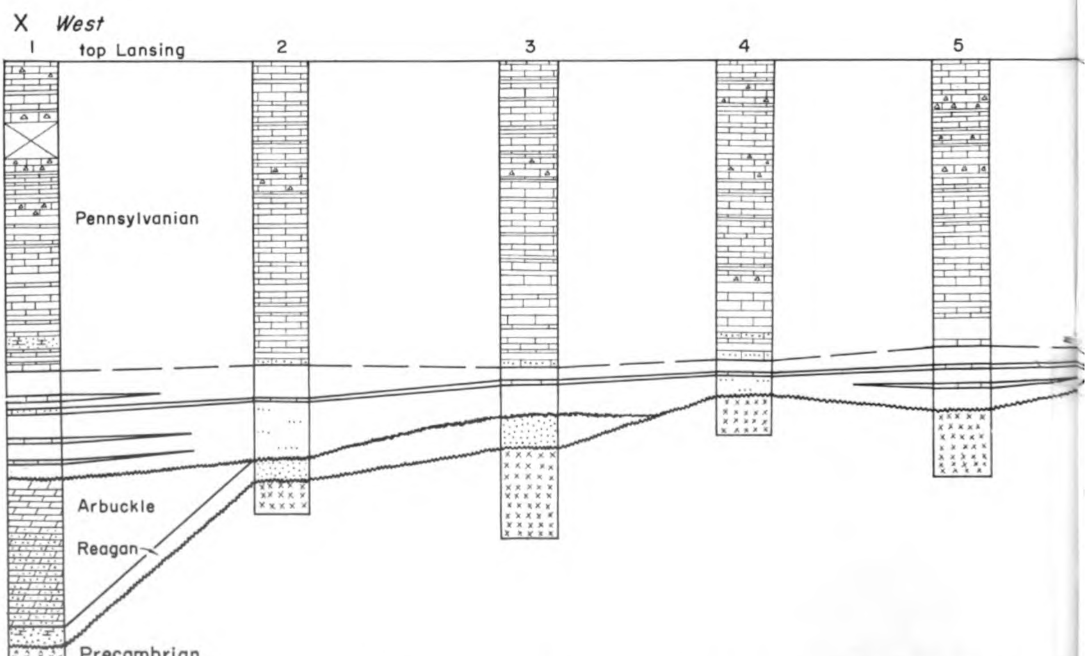


FIGURE 83.—West-east cross section, based on logs of Kansas Sample Log Service, across Cambridge Arc in direct contact with underlying Precambrian (from Merriam and Atkinson, 1955).

nized in western Kansas (Moore and others, 1951a).

Where the Arbuckle was exposed to erosion on and along the flanks of uparched areas such as the Cambridge Arch, the dolomite and limestone were deeply weathered. It is this weathered zone, where more porosity and permeability were developed, that forms petroleum reservoirs.

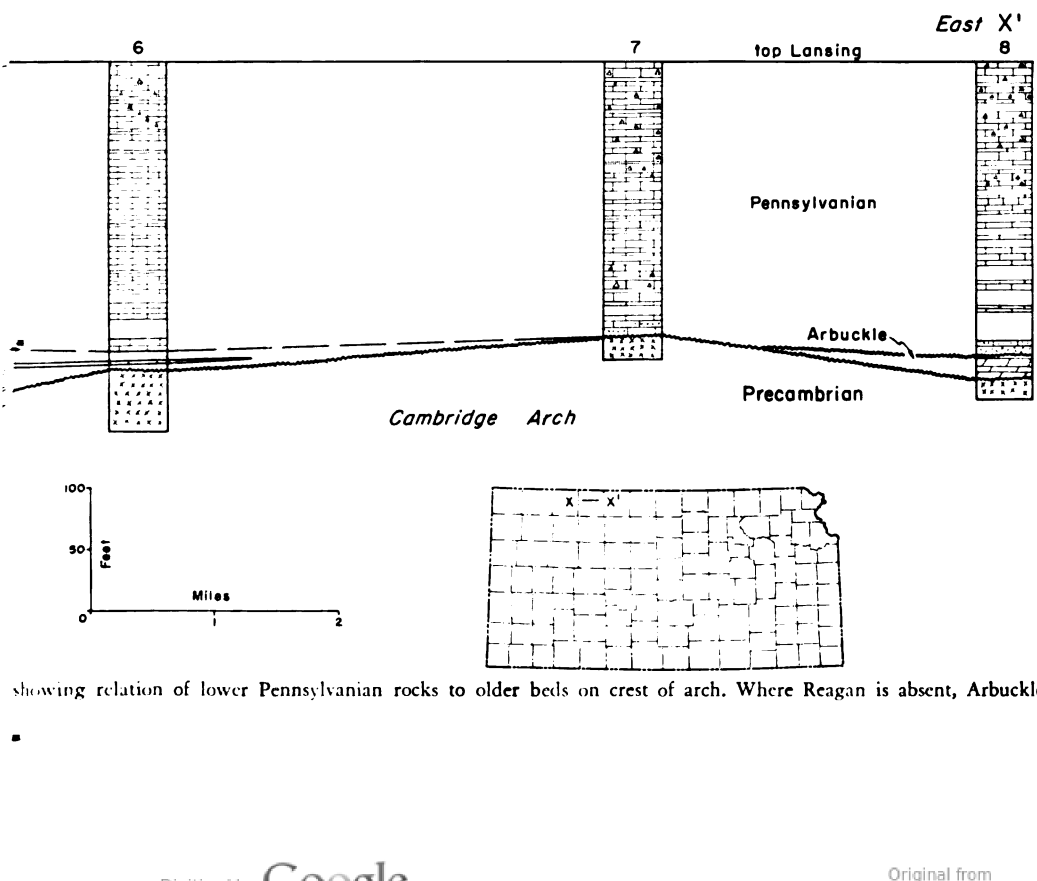
REAGAN OR LAMOTTE SANDSTONE

Arbitrarily, the term Lamotte is used in eastern Kansas and Reagan in western Kansas to indicate clastic beds, chiefly sandstone, that occur beneath the Arbuckle Group. The Lamotte is a basal Paleozoic sand (Late Cambrian), which was deposited on a surface of moderate relief; some local areas were too high to be submerged during Lamotte deposition but in some areas the unit is as much as 130 feet thick.

In western Kansas the Reagan is composed of fine to coarse, angular to rounded, poorly sorted quartz grains. It is assumed to have been deposited continuously over the Hugoton Embayment, because it has been found in all wells drilled deep enough to encounter it (Merriam, 1955b). In the vicinity of the Cambridge Arch the sandstone is composed of white to gray, medium to coarse, angular to subrounded, frosted quartz grains. In places the formation is dolomitic and in places it contains traces of glauconite. Locally the formation is missing where it has been removed by post-Reagan erosion or where it was not deposited.

Igneous and Metamorphic Rocks of Unknown Age

Igneous rocks are exposed in several small outcrops in Riley and Woodson Counties. In Riley County, in northeastern Kansas, five pluglike intrusions of basic igneous rock crop out in an area of lower Permian sedimentary rocks (Pl. 22A): the Bala intrusive (NW sec. 6, T. 9 S., R. 5 E.), Leonardville (SE NW sec. 22, T. 8 S., R. 5 E.), Randolph 1 (SE NW sec. 35, T. 6 S., R. 6 E.), Randolph 2 (NE sec. 35, T. 6 S., R. 6 E.), and Stockdale (NW SE sec. 23, T. 8 S., R. 6 E.). Cook (1955) related that ". . . all the serpentine masses are somewhat similar in that (1) they consist of a dark green, fine-grained ground mass of igneous rock containing many xenoliths composed of fragments of the neighboring sedimentary rocks; (2) they tend to form small mounds on the landscape, thus indicating their greater re-



showing relation of lower Pennsylvanian rocks to older beds on crest of arch. Where Reagan is absent, Arbuckle is sistance to weathering and erosion; and (3) they are magnetic." Moore and Haynes (1920) described the rock at Bala in detail as a green, serpentinized and carbonatized, porphyritic, peridotite breccia containing numerous shale xenoliths. Magnetic studies of Bala by Dreyer (1947a) indicate that the intrusive is a vertical, eastwardly plunging dike. Cook (1955), on the basis of magnetic studies, postulated that Randolph 1 ". . . is possibly a truncated cylindrical or prismatic body plunging to the south-southeast . . ."; Randolph 2 ". . . is possibly a south-southeasterly plunging, fingerlike pipe . . ."; Stockdale ". . . is possibly a parallelepiped-shaped body plunging south-southeast . . ."; and Leonardville ". . . is interpreted as a northwesterly trending, vertical or steeply dipping dike that is more than 1700 ft long and locally up to 500 ft wide. . . ." Cook concluded that location of the intrusions may have been controlled by joint sets associated with the Abilene Anticline. Previously Taylor (1950) had suggested that they may have been emplaced along gash fractures associated with a basement strike-slip fault.

In Woodson County, on the crest of Rose Dome (sec. 13, T. 26 S., R. 15 E.), coarse-grained granite crops out over about 40 acres (Pl. 22C; 22D). Rocks of Missourian age are slightly arched surrounding the granite outcrop (Fig. 84). The origin of the granite was a subject of speculation for some time before Knight and Landes (1932) suggested that the granite is intruded as a dike. This explanation has been accepted since that time mainly on the premise that contact metamorphic zones occur in the intruded Pennsylvanian shales; however, recently, some doubt has been expressed that

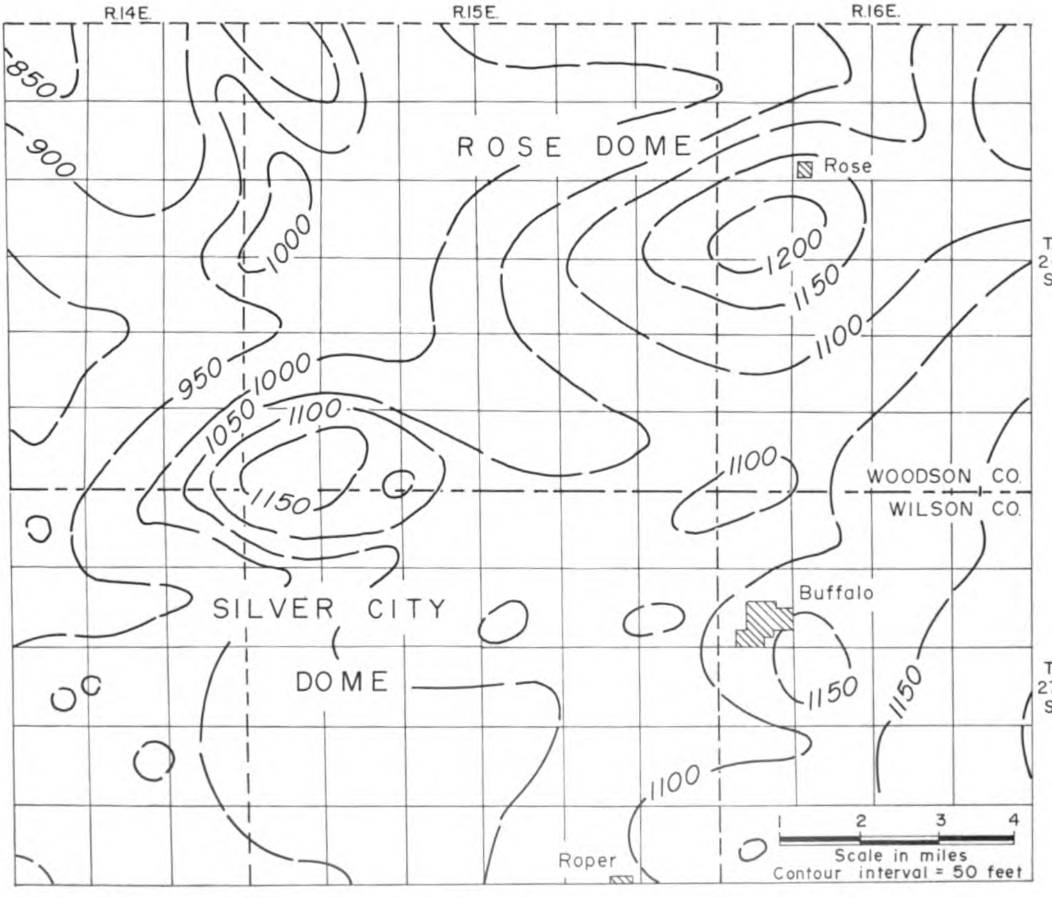


FIGURE 84.—Structure map on base of Plattsburg Limestone (Missourian) in southern Woodson and northern Wilson Counties showing configuration of Rose and Silver City Domes (from Hambleton and Merriam, 1955). Contour interval 50 feet.

PLATE 22.—**A**, Peridotitic intrusive rock exposed on Stockdale Dome, Riley County (NW SE sec. 23, T. 8 S., R. 6 E.). **B**, Metamorphic rocks on north flank of Silver City Dome, a peridotitic intrusion, Woodson County (sec. 29 and 32, T. 26 S., R. 15 E.). **C**, Western flank of Rose Dome, Woodson County (sec. 13, T. 26 S., R. 15 E.). **D**, Granite exposed on the apex of Rose Dome.

contact zones are present (P. C. Franks, personal communication).*

Also in Woodson County, at a locality known as Silver City, a few miles southwest of the granite exposure, peridotitic igneous rocks are exposed along with fine-grained quartzite altered from sandstone of the Douglas Group (Virgilian). The Hills Pond Peridotite is exposed in the NE sec. 32 and NW sec. 33, T. 26 S., R. 15 E. The largest exposure of peridotite and metamorphic rocks (Pl. 22B) is associated with a west-northwest-trending, high-angle north-dipping fault. Wagner (1954) said of the dome, "The doming is apparently due chiefly to the injection of layers of igneous material into the Pennsylvanian sequence, increasing the thickness of the stratigraphic interval between the top of the Mississippian rocks and the base of the Kansas City group by more than 200 feet near the apex. . . ." Wagner postulated that the magma was intruded along the fault, spreading laterally into the Pennsylvanian beds ". . . where it crystallized rather slowly into biotite, olivine, augite, hypersthene, apatite, and titanite, forming a medium-grained mica peridotite." The present configuration of the structure is shown in Figure 84.

The Neosho Falls Dome (Fig. 85) is an elongate feature to the north. Closure amounts to about 60 feet on top of the "Mississippi lime," which occurs at a depth of 1,150 to 1,200 feet. Much more data for preparing a structure map are available now than were available to Knight and Landes in 1932. They believed that the siliceous crystalline rocks encountered in the Southern Kansas Gas Company No. 8 Harris well (SW SW SW sec. 8, T. 24 S., R. 17 E.) in Woodson County are metamorphosed post-Cambrian sediments rather than a buried hill of metamorphosed Precambrian rock (Fig. 86); and they concluded that (1932, p. 11) ". . . the replacement of the sediments underlying the black shale by silica and magnetite was effected by solutions emanating from an underlying igneous mass, which, by the force of its intrusion produced the Neosho Falls dome." Other structures formed by intrusion of igneous material, such as the Silver City and Neosho Falls Domes, probably are present in southeastern Kansas.

The age of outcropping igneous rocks in Kansas is unknown. Because vulcanism in Arkansas and Texas is believed to be of Cretaceous age, it has been suggested that the igneous rocks in Riley County are Cretaceous. Thermoluminescence studies by Pearn (1959), however, indicate an early Tertiary age for the Silver City intrusive. A potassium-argon date of 65±5 million was made recently for the Silver City material, indicating a very early Tertiary date (W. C. Pearn, personal communication).

Because the Riley County basic rocks are fine grained and contain inclusions of the adjacent sediments that are not greatly altered, it seems probable that the material was emplaced in a plastic state under overlying rocks (Jewett

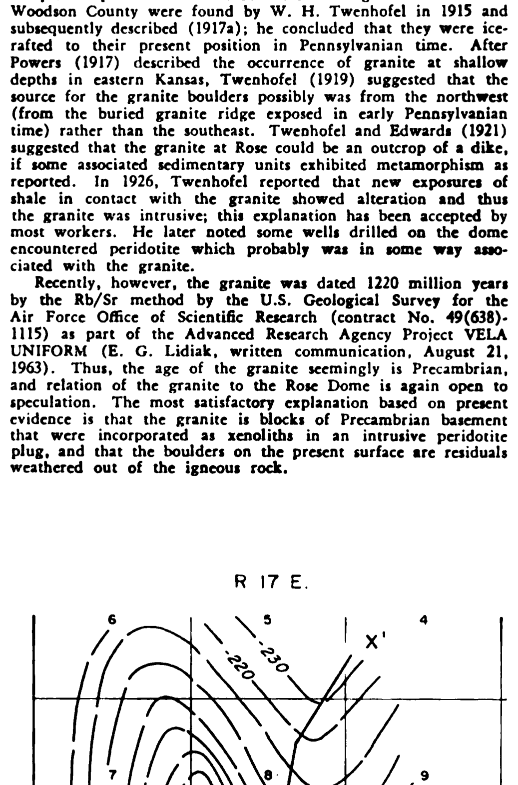


FIGURE 85.—Structure map contoured on top of "Mississippi lime" of Neosho Falls Dome in northeastern Woodson County. Contour interval 10 feet. X-X' is line of cross section in Figure 86.

* Recent developments have again opened the question of the relation of the Rose Dome to the exposed granite; therefore, a more complete explanation is in order here. The granite boulders in Woodson County were found by W. H. Twenhofel in 1915 and subsequently described (1917a); he concluded that they were ice-rafted to their present position in Pennsylvanian time. After Powers (1917) described the occurrence of granite at shallow depths in eastern Kansas, Twenhofel (1919) suggested that the source for the granite boulders possibly was from the northwest (from the buried granite ridge exposed in early Pennsylvanian time) rather than the southeast. Twenhofel and Edwards (1921) suggested that the granite at Rose could be an outcrop of a dike, if some associated sedimentary units exhibited metamorphism as reported. In 1926, Twenhofel reported that new exposures of shale in contact with the granite showed alteration and thus the granite was intrusive; this explanation has been accepted by most workers. He later noted some wells drilled on the dome encountered peridotite which probably was in some way associated with the granite.

Recently, however, the granite was dated 1220 million years by the Rb/Sr method by the U.S. Geological Survey for the Air Force Office of Scientific Research (contract No. 49(638)-1115) as part of the Advanced Research Agency Project VELA UNIFORM (E. G. Lidiak, written communication, August 21, 1963). Thus, the age of the granite seemingly is Precambrian, and relation of the granite to the Rose Dome is again open to speculation. The most satisfactory explanation based on present evidence is that the granite is blocks of Precambrian basement that were incorporated as xenoliths in an intrusive peridotite plug, and that the boulders on the present surface are residuals weathered out of the igneous rock.

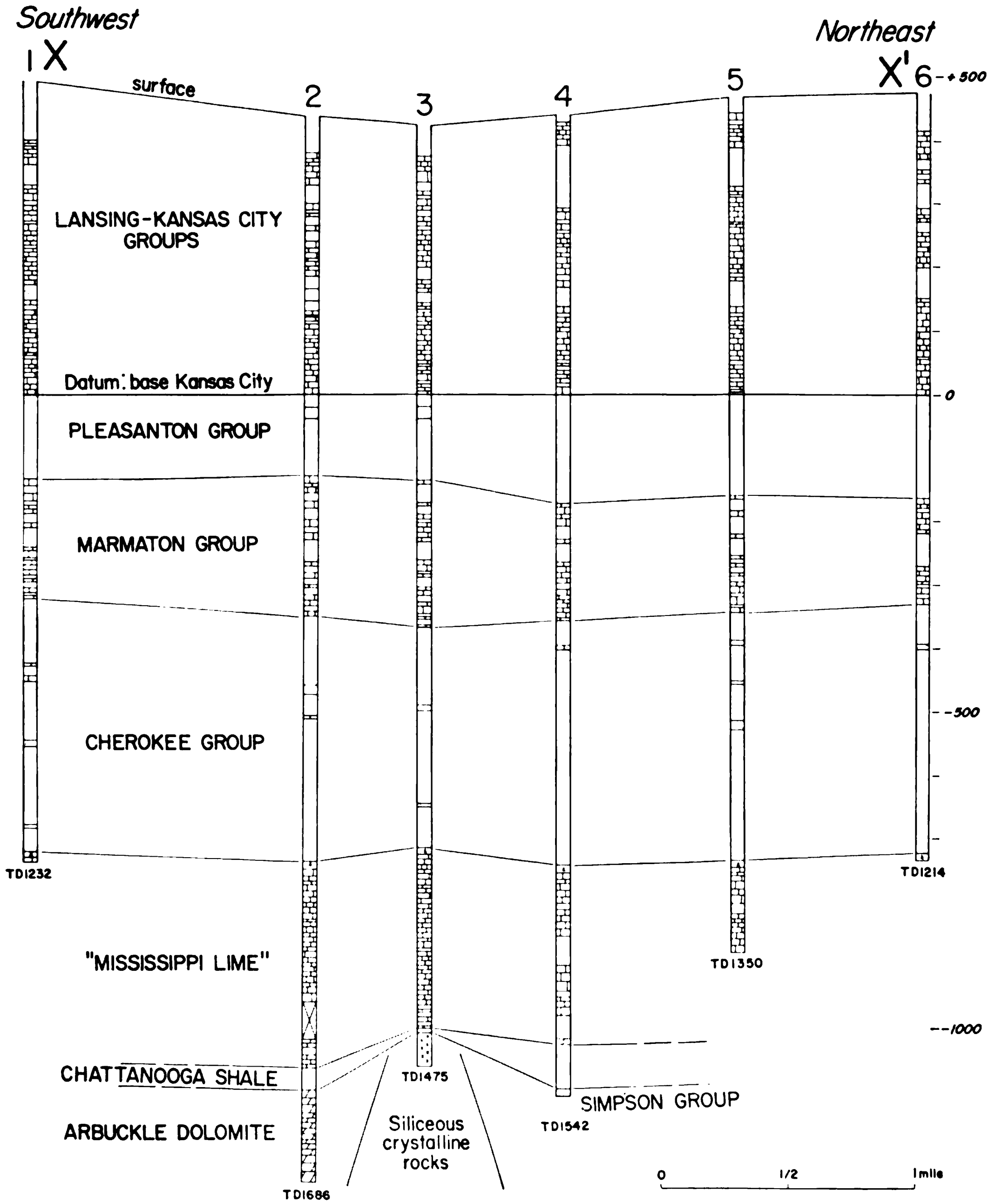


FIGURE 86.—Southwest-northeast cross section of Neosho Falls Dome, northeastern Woodson County. Location of cross section shown in Figure 85. Siliceous crystalline rocks are present in well 3. Information based on drillers logs.

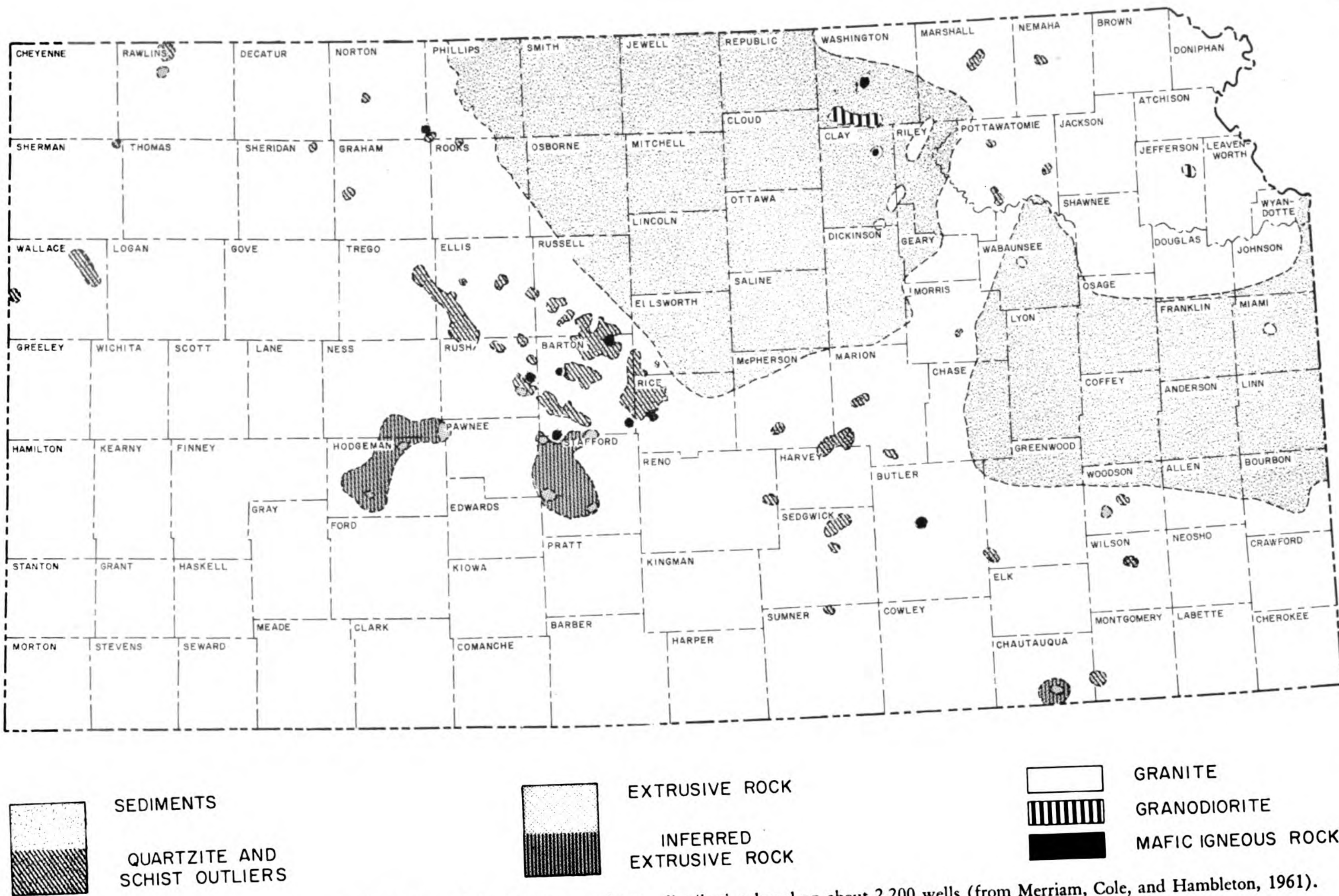


FIGURE 87.—Map of Kansas showing generalized Precambrian basement rock-type distribution based on about 2,200 wells (from Merriam, Cole, and Hambleton, 1961).

and Merriam, 1959). It is believed that the pre-Cretaceous and early Cretaceous land surface in eastern Kansas was at about the same position as the present surface in relation to lower Permian strata; hence, a few hundred feet of Cretaceous sediments may have been the only cover originally above the intrusions, and igneous material may even have reached the surface. It is also probable that the peridotite at Silver City was emplaced under the same conditions as the Riley County peridotite. Because the granite at Rose Dome is coarse grained, it probably cooled under a considerable thickness of rock.

Additional references on Kansas intrusives and associated metamorphic rocks include: Hay (1883), Jewett (1941b), Knight and Landes (1932), Mudge (1881), Schaffner (1938), Twenhofel (1917a; 1917b; 1926), Twenhofel and Bremer (1928), Twenhofel and Edwards (1921), and Weidman (1933).

Precambrian Rocks

Precambrian rocks are not exposed in Kansas but are extensively known from well data. Approximately 2,300 wells are known to have penetrated the Precambrian basement rock complex, which is shallowest at about 600 feet, over the Nemaha ridge in northeastern Kansas, and deepest at about 9,500 feet in the Hugoton Embayment.

Sources of Information

Information concerning the wells that have reached the Precambrian in Kansas has been compiled from both published and unpublished sources. Reliability of information for each well, although it has been checked as thoroughly as possible, is dependent on its source. Of the information reported in the published lists (Cole and others, 1961; Cole and Merriam, 1962; Cole, Merriam, and Hambleton, 1963), that which deals with the type of basement rock is least reliable, because identifications range from a cursory glance by a driller to a minute, detailed examination by a petrographer.

Only two published works (Walters, 1946; Farquhar, 1957) yield detailed information concerning distribution of Precambrian lithologies. Other sources of published data are listed in a complete bibliography by Cole and others (1961). Unpublished data have been assembled from sample logs, logs of the Kansas Sample Log Service, and drillers logs. This information was made available by several Kansas state agencies and private industry. In fact, without the cooperation of the petroleum industry in the state, assembly of the Precambrian data would have been an insurmountable task. Some data based on petrographic study of samples and thin sections by O. C. Farquhar and P. C. Franks were also available.

Because of the diversity of Precambrian rock types reported and because of the vagueness of much of the information available at this time, distribution of only a few major categories of rock types is shown on the accompanying map (Fig. 87). Exotic rock types, for the most part, are not shown separately, pending verification by further work. The tendency for drillers to report "granite," signifying futility of further exploratory drilling for oil or gas, gives rise to large areas of "granite" in Kansas that upon additional study no doubt will resolve into a more meaningful pattern.

Precambrian Rock Types

The Precambrian basement complex consists mainly of igneous and metamorphic rocks (Merriam, Cole, and Hambleton, 1961). The most often reported igneous rock is granite; the most often reported metamorphics are quartzite and schist. The overall distribution of rock types is at best only vaguely known, despite more than two thousand control points, because most of the wells are located along the crests of the Nemaha Anticline and Central Kansas Uplift. In vast areas in Kansas, no tests have been drilled to the basement, especially in basinal areas.

A weathered or detrital material known as "granite wash" covers large areas beneath Paleozoic sediments. In this report, the "granite wash" or pre-Reagan (Upper Cambrian) rocks are interpreted to be Precambrian in age. The arguments for assigning them to the Precambrian are beyond the scope of this report; suffice it to point out that no faunal evidence has been noted and that no Lower or Middle Cambrian sedimentary rocks are known in the Midcontinent area (Skillman, 1948).

Where several rock types have been reported in vertical succession, only the uppermost is shown. About 200 wells penetrate the basement to more than 100 feet; nine penetrate to more than 1,000 feet. The greatest penetration is reported to be 2,551 feet, in the Nemaha No. 1 Seneca well (sec. 19, T. 3. S., R. 11 E.) in Nemaha County.

The shallowest known Precambrian rocks encountered by test wells occur in northeastern Kansas, in Nemaha County, where the surface of the Precambrian rises to 588 feet above sea level; the deepest occurrence is in the southwest, in Barber County, at 4,595 feet below sea level. Additional exploration undoubtedly will reveal both shallower and deeper Precambrian in Kansas.

SEDIMENTS

A wide band of thick, alternating hard and soft layered sediments trends northwestward across northeastern Kansas and constitutes a regional province (Fig. 87). Rock types reported from this province include: schist, quartzite, arkosic quartzite, arkose, undifferentiated metamorphics, clastics, gneiss, and "granite wash" (in thicknesses far exceeding that of "granite wash") which must be layered sediments. The continuity of the band is broken along the crest of the Nemaha Anticline in Pottawatomie County, southeastern Riley and Geary Counties, northwestern Wabaunsee County, and Morris County, where seemingly the sequence was removed prior to cover by younger units. Along the Nemaha, as well as to the northeast and southwest of the province, are outliers of sediments.

Included within the province are rock types that may prove to be either windows or igneous intrusions in the sediments. Evidence is lacking to suggest which interpretation, or both, is correct. These areas include mafic rocks,* granodiorite, and granite. Sediments are absent along parts of the crest of the Abilene Anticline in northwestern Riley County and southeastern Clay County.

Thickness of these sediments and the lithology of the underlying rock are for the most part not known, but the sequence seemingly is underlain by granitic rock. The deepest penetration without encountering crystalline rock is almost 1,600 feet (Fig. 88). Comparable thicknesses are known in adjacent states, where the province is known to extend eastward into Missouri (Grenia, 1960) and northwestward into Nebraska.

From preliminary information it may be suggested that a recognizable sequence of bedded material, only slightly metamorphosed if at all, is present in the province. It may be further suggested that the beds dip gently, as in southwestern Missouri. In Vernon County, Missouri, just across the Kansas-Missouri line, gently dipping units could be recognized and traced between wells (Skillman, 1948).

* Lyons (1959) believed that the Greenleaf maximum gravity anomaly in northeastern Kansas represents ". . . an extension of the sedimentary prism of the Lake Superior Syncline to the southwest, and that the sedimentary rocks have been intruded extensively by basic rocks, as in the Lake Superior region."

METASEDIMENT OUTLIERS

Numerous outliers of metasediments composed mostly of quartzite and schist are located mainly along and adjacent to the Nemaha Anticline and Central Kansas Uplift. Some of the outliers along the Central Kansas Uplift are the famous buried Precambrian hills in northeastern Barton County which have been described in detail by Walters (1946). In his excellent paper on the origin and subsequent history of these hills, Walters wrote (1946, p. 660), "These flat-topped hills were quartzite monadnocks on a Cambrian peneplain eroded across pre-Cambrian quartzite, schist, granite, syenite, granite-gneiss, and pegmatite." Sufficient detail is available regarding this area to show the complexity of the basement.

Along the crest of the Central Kansas Uplift in Ellis, Russell, Rush, and Barton Counties, the Precambrian monadnocks are elongated northwestwardly. Two prominent trends may be noted, one in the position of the Rush Rib on the southwestern side of the uplift and the other along the Russell Rib. Of interest to the petroleum geologist is the fracture system in these metasediments, especially in the quartzites, that contain petroleum. In Kansas about 12 fields produce petroleum from rocks of Precambrian age.

MAFIC IGNEOUS ROCKS

Ten areas of mafic igneous rocks are known at present. In most places only one well penetrated this rock type although nearby wells encountered other Precambrian rock. Seemingly the areal extent of mafic rocks is very small. Most of the areas of mafic rock are located along the Cambridge Arch and the Central Kansas Uplift; two areas located just west of the Nemaha Anticline are exceptions. The association of this rock type and positive structural features strongly suggests a genetic relationship. These igneous bodies may have been emplaced along fracture systems developed in the rigid basement. Woollard (1959) found that the gravity anomalies are arranged parallel to structural features, suggesting structural control of intrusions along fracture lines.

The dark, mafic igneous rocks are described as peridotite, diabase, diorite, basalt, gabbro, mafic rock, and basic igneous rock. Much of the rock is weathered. The greatest penetration of this material is about 100 feet. In one well, mafic igneous rock was encountered below quartzite and granite.

EXTRUSIVE ROCKS

Rock types described as rhyolite, felsite, rhyolite porphyry, felsite porphyry, and quartz porphyry are interpreted as extrusive rocks. So far as is known only one well, or a group of wells in a small area, encounters these rock types, which normally are structurally high. Several of these areas have been grouped together tentatively to indicate areas of possible genetically related suites.

The "flow" areas are all located adjacent to major structural units; the largest areas seemingly occur on the southwest flank of the Central Kansas Uplift. Like the mafic igneous rocks, these small bodies of structurally high extrusive material may represent feeder remnants, and if so, a basement fracture pattern may be discernible when additional data are available.

GRANODIORITE

Two small areas of granodiorite have been reported in northeastern Kansas. Further study may show that large areas now reported to be granite are granodiorite.

GRANITE

By far the most common rock type reported in Kansas is granite or "granite wash." Granite is the most "popular" rock type because much granite has been found on uplifts where the Precambrian is shallow, and the term has become synonymous with Precambrian "bottom."

Many varieties of granite are present, and without doubt this province has a complex history. Descriptions of the granite are varied and include: red, coarsely crystalline, fractured granite; biotite granite, pink granite, pegmatitic granite, microgranite, syenitic granite, hornblende granite, gray granite, chloritized granite, and gneissic granite. It is impossible in this report to show geographic distribution of the many variants of granitic rock.

On the crests of upwarped areas, the granite is deeply weathered. Locally the rock may be weathered as deep as 150 feet, although 10 to 50 feet is more common. Part of this degeneration took place prior to cover by lower Paleozoic rocks, but most of it is the result of weathering and erosion of high positive structures formed or emphasized during the Wichita orogeny. In other areas, especially in the Hugoton Embayment, the Precambrian surface is clean, and lower Paleozoic rocks rest on unweathered granite.

No wells have penetrated through Precambrian granite. In southeastern Kansas several post-Precambrian intrusions are known and often are confused with the basement. Where "granite" is encountered at extremely shallow depths, it is possibly one of these small "plugs." Enough control is available now to show that in the extreme southeastern part of Kansas numerous Precambrian hills similar to those in northeastern Oklahoma rise above the

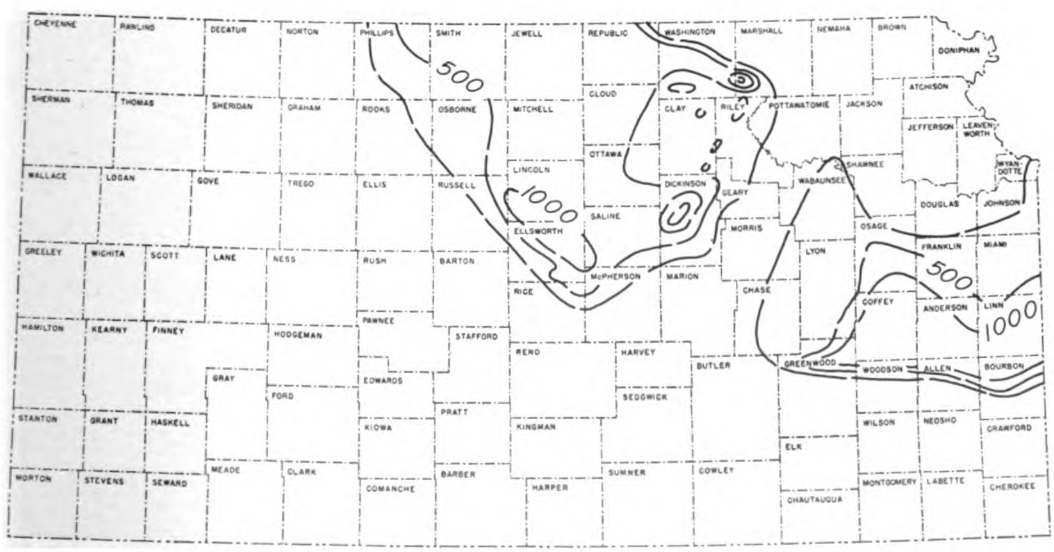


FIGURE 88.—Present known thickness of Precambrian sediments in northeastern and north-central Kansas. Thicknesses represent minimum values inasmuch as very few wells have penetrated to the "crystallines." Contour interval 500 feet.

general level of the basement floor as monadnocks (Ireland, 1955).

Farquhar recognized "earlier" and "later" granite. The "earlier" granite has a gneissic texture resulting from metamorphism; it is described as metamorphic, foliated, folded and interbanded with metasediments. The "later" granite is intrusive, and according to Farquhar is postmetamorphic, hypidiomorphic, and batholithic. The "later" granite is the most widespread rock type of the Precambrian (Farquhar, 1957, p. 82).

Several wells have reported syenite or syenitic granite, although these rock types have not been differentiated on the accompanying map. In most areas syenite was recorded from only one well even though surrounding tests also encountered Precambrian; therefore, it is assumed that its areal distribution is small. In the vicinity of the Central Kansas Uplift, the five wells encountering syenite are on two alignments both trending approximately N 55° W. This alignment suggests that the syenite is intrusive and perhaps was intruded along Precambrian zones of weakness. There is no evidence to suggest that the syenite is later than Precambrian.

Precambrian Age Dates

Potassium-argon ages of five samples from Barton, Rush, and Morris Counties were determined by J. L. Kulp of Lamont Geological Observatory of Columbia University (Table 3; Fig. 89). Dates obtained range from 1165 to 1460 million years, comparable to ages elsewhere in the central United States (J. L. Kulp, personal communication to W. W. Hambleton, 1961).

TABLE 3.—Potassium-argon dates of samples of Kansas Precambrian rocks.

Well	*Location*	*County*	*Rock type*	*Age, million years*
Atlantic No. 10 "A" Patzner	E2 W2 SE sec. 36, T. 17 S., R. 11 W.	Barton	Altered chiastolite? schist	1165
Skelly No. 1 Betz	NE SE SW sec. 5, T. 18 S., R. 16 W.	Rush	Gneissic granite	1260
Skelly No. 4 Dyer	NE SE NW sec. 21, T. 18 S., R. 16 W.	Rush	Quartz-sericite schist	1200
Skelly No. 7 Schultz	NW NW NE sec. 5, T. 19 S., R. 15 W.	Barton	Quartz-sericite schist	1460
Leslie No. 1 "A" McConnell	SE SE SE sec. 14, T. 16 S., R. 9 E.	Morris	Muscovite quartzite	1290

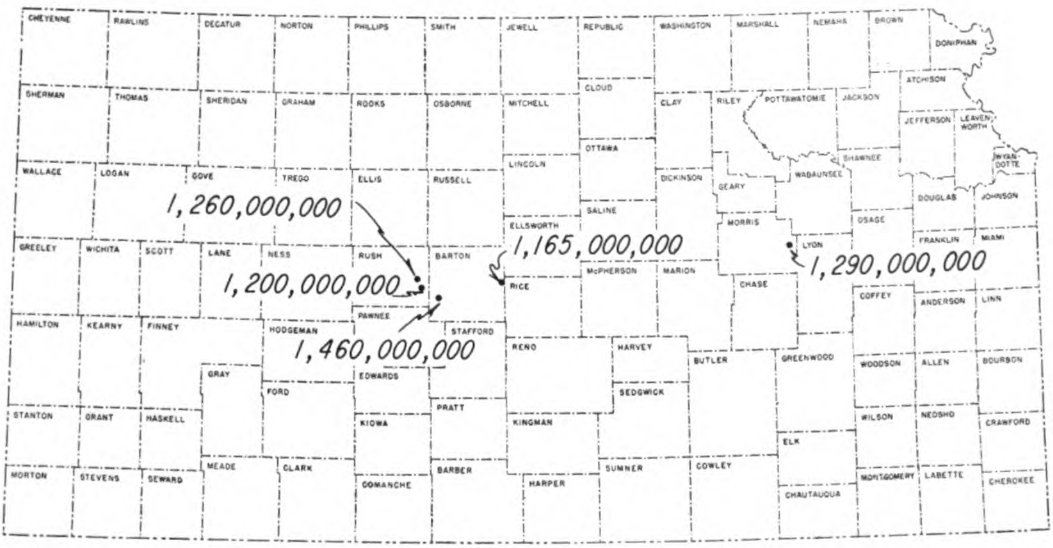


FIGURE 89.—Location of wells from which samples were obtained for dating and ages determined by potassium-argon method.

MAJOR UNCONFORMITIES

The numerous unconformities of various orders of magnitude in the Kansas rock section include several major ones. Recognition of these interruptions in the record is extremely important in helping to understand the geologic history of the area. Distribution of rock units and their thicknesses at the interface of an unconformity, including the present surface, is sometimes more important than the attitude of the rocks in understanding what has happened in the past.*

Seven important breaks occur in the Kansas record: (1) the present surface; (2) pre-Tertiary post-Cretaceous; (3) pre-Cretaceous post-Jurassic; (4) pre-Triassic post-Permian; (5) pre-Pennsylvanian post-Mississippian; (6) pre-Mississippian (considering Chattanooga as Mississippian) post-Devonian; and (7) pre-Paleozoic post-Precambrian.

Such designations as "pre-Tertiary post-Cretaceous," as applied to the surfaces discussed in this section, are obviously imprecise. Geologic time is conceived to be continuous, and a land surface produced or modified by erosion cannot originate instantaneously. It follows that placement of the surface in geologic time is only approximate, that is, partly pre-Tertiary, or late Cretaceous, and partly post-Cretaceous, or early Tertiary. The same observations apply to each of the other surfaces.

Present Land Surface

The present land surface in Kansas is an important key to understanding the geologic history of the area (Jewett and Merriam, 1959). This surface slopes gently eastward through the eastern part of the High Plains (Pl. 23A), Plains Border, Smoky Hills (Pl. 23B), and scarped Osage Plains (Pl. 24D) in the east. The altitude of the highest point, Mount Sunflower in Wallace County, is 4,039 feet above sea level, and the lowest point, in Montgomery County, where Verdigris River enters Oklahoma, is about 700 feet. Areal geology of the present land surface is shown in Figure 90. Eastward inclination of the land surface is discordant with the regional structure of all outcropping rocks older than Tertiary. It is believed that the present eastward slope of the land was established late in Tertiary time.

In Kansas, from the Flint Hills eastward, outcropping Pennsylvanian and Permian rocks dip gently to the west and northwest. Average inclination of beds is only 20 to 25 feet per mile. The Nemaha Anticline interrupts and locally reverses the dip of outcropping strata, and the westward regional dip is also modified in many

* An excellent book on paleogeologic maps has recently been published by Levorsen (1960). Krumbein (1942) has set forth 35 criteria for recognition of unconformities in the subsurface. Unconformities recognized generally agree with those of Billings (1946); a new term *paraconformity* is proposed by Dunbar and Rodgers (1957, p. 119) for beds that are parallel with an even contact not distinguishable from a simple bedding plane.

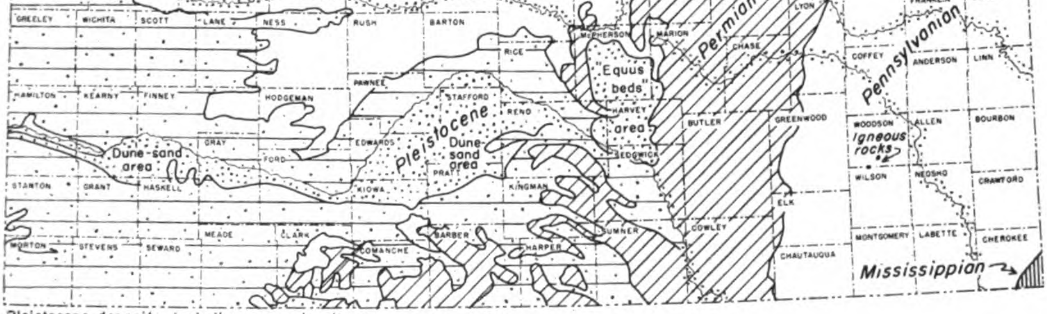


FIGURE 90.—Generalized geologic map of Kansas (adapted from Moore and Landes, 1937). Older bedrock formations are exposed progressively eastward. Seven small igneous bodies crop out in Riley and Woodson Counties.

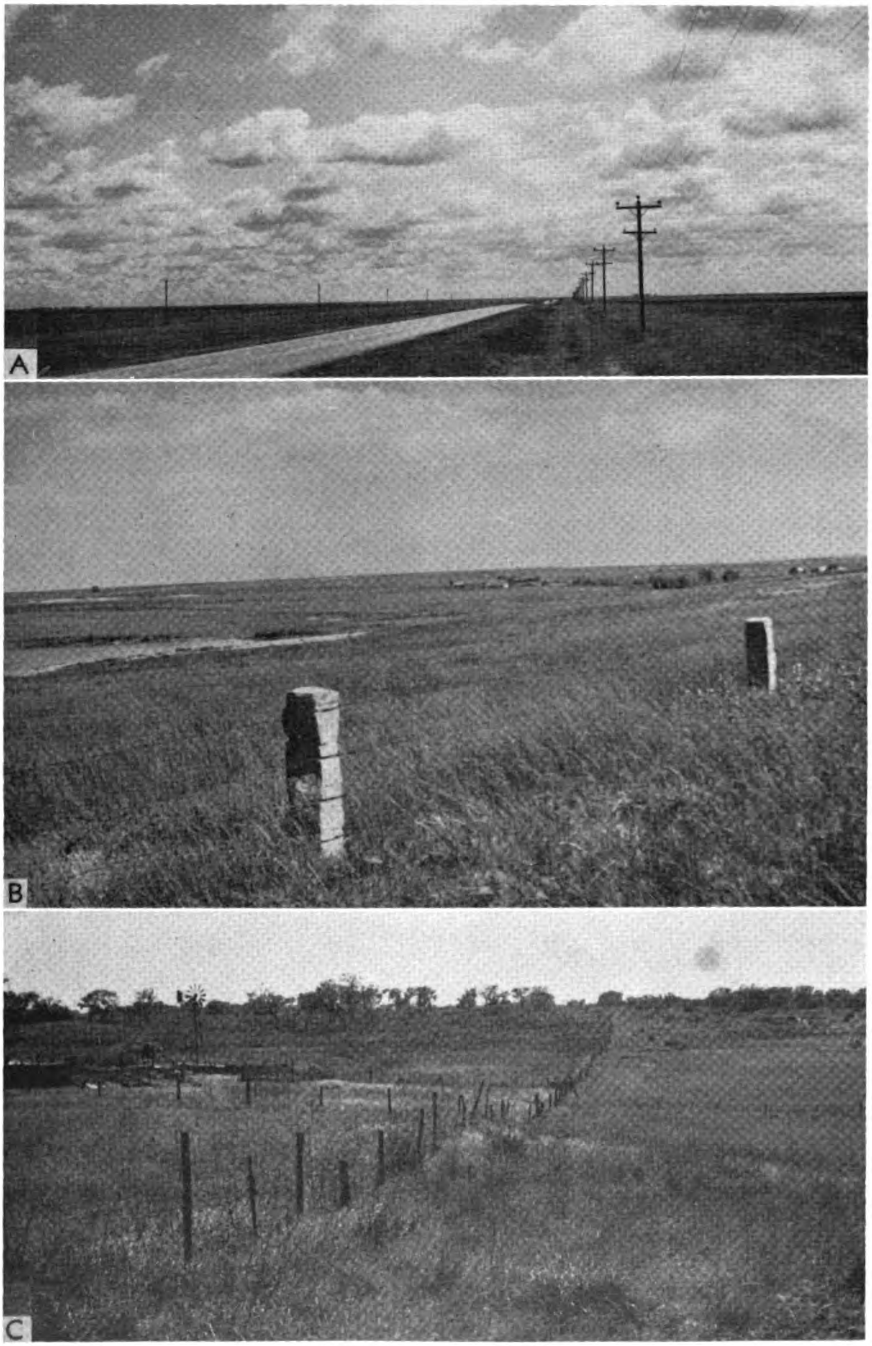


Plate 23.—A, View of High Plains about 7 miles west of Hoxie, Sheridan County. **B,** Fencepost Limestone fenceposts and rolling hills in Dissected High Plains of central Kansas. **C,** Sand dune topography in Great Bend Lowlands just northeast of Hutchinson **on Kansas Highway** 61, Reno County.

PLATE 24.—**A,** "Equus beds" in McPherson Lowland at southwest edge of McPherson, McPherson County. **B,** View of Flint Hills, Chase County. **C,** Kaw Valley in northwestern Douglas County; view from Mile 43 on the Kansas Turnpike. **D,** Osage Cuesta country along U.S. Highway 59, about 5 miles south of Garnett, Anderson County.

other places. For several miles west of the Flint Hills the situation is comparable, except that the direction of dip of Permian rocks is more westward (Pl. 24B).

The dip of beds away from the Ozark area in Missouri probably is the result of regional uplift centered in the Ozark area. Because of the monotonous westerly dip of beds, the name Prairie Plains Monocline (Prosser and Beede, 1904) has been applied to the structure of eastern Kansas, although it is more properly called the Prairie Plains Homocline. Most of the tilting developed after deposition of Permian sediments.

In eastern Kansas, remnants of three or more alluvial terraces that lie from a few feet to about 200 feet above the valley floors are common (Jewett and Merriam, 1959). Their histories are probably connected with glaciation. Alluvial terraces border the streams in southeastern Kansas, as well as those in and near glaciated northeastern Kansas.

Glacial till and outwash materials are present almost everywhere in the part of northeastern Kansas bounded roughly by Kansas River and Big Blue River; bedrock outcrops are scarce in the glaciated area (Pl. 24C). Thick deposits of loess border the Missouri and Kansas River valleys.

The eastern margin of Cretaceous deposits in Kansas has retreated farther west in southern Kansas than in the central and northern parts. Hence, along or near the southern boundary of Kansas, Permian rocks outcrop within 100 miles of the Colorado line (Fig. 90). These Permian beds are younger than those exposed farther east. The Blaine Formation, mentioned previously as a subsurface marker, crops out in Comanche and Barber Counties, and hills in Barber County carved in Nippewalla redbeds are capped with this gypsum formation. In the same area widespread slump topography has developed where the Blaine anhydrite and gypsum beds have been dissolved away.

The Smoky Hills, eroded from Dakota sandstone and clay, mark the approximate eastern edge of Cretaceous deposits. Comanchean beds are present in areas just east of the Dakota hills; in Clark, Comanche, and Kiowa Counties, Comanchean beds crop out in a sizable area. These deposits, Kiowa Shale and Cheyenne Sandstone, are exceptionally well exposed in the vicinity of Belvidere in Kiowa County. The Blue Hills are eroded Cretaceous deposits marking the eastern margin of the High Plains in north-central Kansas (Fig. 91).

The High Plains are developed on Pliocene beds and veneered with Pleistocene. This thick accumulation of mostly unconsolidated material makes up a great wedge of silt, sand, clay, and gravel in western Kansas. The outcrop pattern of the contact between Cretaceous (or very locally in southern Kansas, Permian beds) and overlying thick and extensive Tertiary deposits is very irregular because of recent erosion. In Wallace County the line of contact is within a few miles of the Colorado border. The High Plains are divided by the Arkansas River Lowland where large areas of unconsolidated Quaternary silt, sand, and gravel occur and hummocky sand dune tracts are widespread (Pl. 23C; McLaughlin, 1949). Just to the northeast are the "Equus beds," or so-called McPherson Lowland (Pl. 24A).

Pre-Tertiary Post-Cretaceous Surface

The pattern of sub-Cenozoic geology harmonizes with the regional surface geology of Kansas, as shown on the Geologic Map of Kansas (Moore and Landes, 1937), although the Permian has not been subdivided (Fig. 92). The Cheyenne, Kiowa, and Dakota are grouped together, as are the Greenhorn and Graneros, in keeping with the units shown on the geologic map. The Carlile, Niobrara, and Pierre are shown separately, and a small area of Dockum? (Triassic) is shown in the extreme southwestern corner of the state.

Boundaries of the various units are indicated in the position they now occupy, whether or not they are covered by Cenozoic deposits; therefore, the map is partly a subcrop map. Most of the Cretaceous formations have outliers east of the main outcrop belt, indicating, of course, that they formerly extended farther east than they do now. Because Upper Cretaceous units lithologically show no evidence of shoreline or near-shore features, it may be inferred that the Cretaceous extended farther east, but how far is a question; some of the units probably have extended to flanks of the Ozarks. Likewise, all units of the Pennsylvanian and Permian Systems must have extended farther eastward than they do now. Again, how far the resistant scarps of the Permian and Pennsylvanian deposits have retreated westward in Cenozoic time is questionable—probably not far.

Enormous quantities of rock material were removed from Kansas during Cenozoic time. Even if all the Cretaceous units thinned eastward and many were never deposited east of

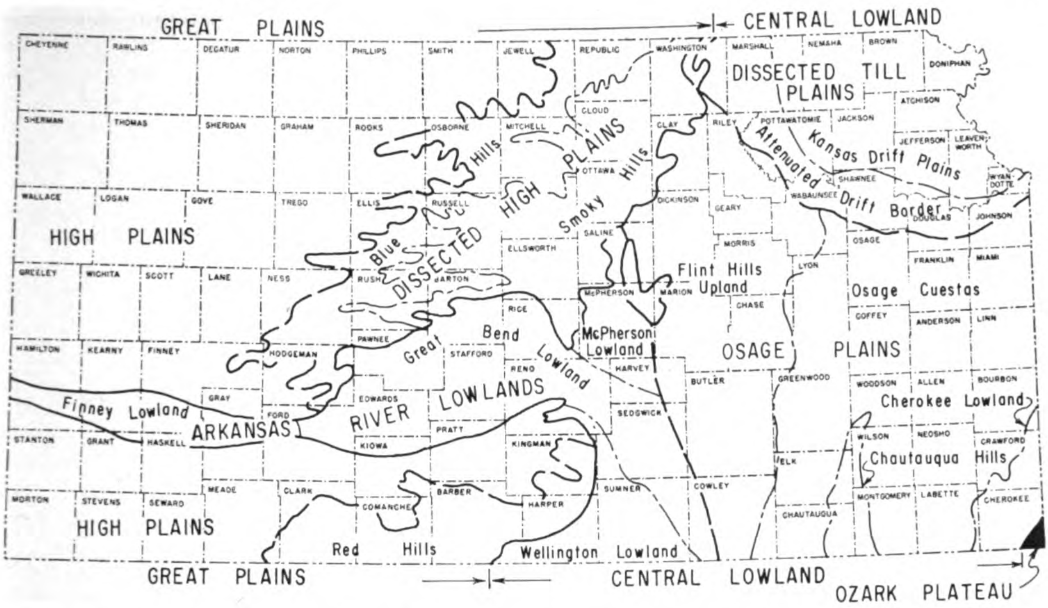


FIGURE 91.—Physiographic map of Kansas (from Schoewe, 1949).

the Kansas-Missouri boundary, the volume of this material now gone staggers the imagination. Much of it must now constitute part of Tertiary deposits of the Gulf Coast.

Pre-Cretaceous Post-Jurassic Surface

The inferred surface here considered, entirely or partly pre-Cretaceous and entirely or partly post-Jurassic in origin, is shown in Figure 93. It is essentially a subcrop map except for eastern Kansas, where Cretaceous deposits are absent. The Permian-Pennsylvanian contact was moved eastward and straightened to indicate that it undoubtedly has migrated downdip since Jurassic time.

The Triassic is represented to extend beneath Jurassic deposits in southwestern Kansas. The present southeastern extent shown for the formations probably is erosional, and the strata formerly extended farther to the southeast.

Pre-Triassic Post-Permian Surface

The approximately dated pre-Triassic post-Permian surface is one of major importance. Abrupt changes took place near the end of Permian time, some of which are reflected in the distribution of Paleozoic units. The sub-Mesozoic surface in western and central Kansas (where Mesozoic sediments are present) and an inferred pre-Mesozoic surface in eastern Kansas are shown on an areal geologic map (Fig. 94).*

Possible locations of different units in the Pennsylvanian and Permian are shown. In eastern Kansas, the outcrop lines trend approximately north-south and beds dip gently westward. The pattern reflects the structure of the Ozarks to the east and the downwarped Hugoton Embayment in southwestern Kansas, so that the lines in Kansas swing around the northern end of the embayment and strike northwestward, then northward, and finally northeastward. Levorsen (1960) figured the dip on the westward-dipping homocline in central Kansas to be about 7 feet per mile at the time of covering by Mesozoic deposits.

Pre-Pennsylvanian Post-Mississippian Surface

The pre-Pennsylvanian post-Mississippian surface in Kansas is probably the most important buried unconformity in the column, for structural features pictured by the subcrop pattern define the main structural and petroliferous provinces in Kansas. Some of these structural elements inherit attributes from earlier tectonic activity, but for the most part they seemingly

* Figures 94, 95, and 97 were prepared by me early in 1958 for this publication; however, they appeared in print prior to this time (Jewett and Merriam, 1959), and also in other publications. These maps, with some modifications, are reproduced here.

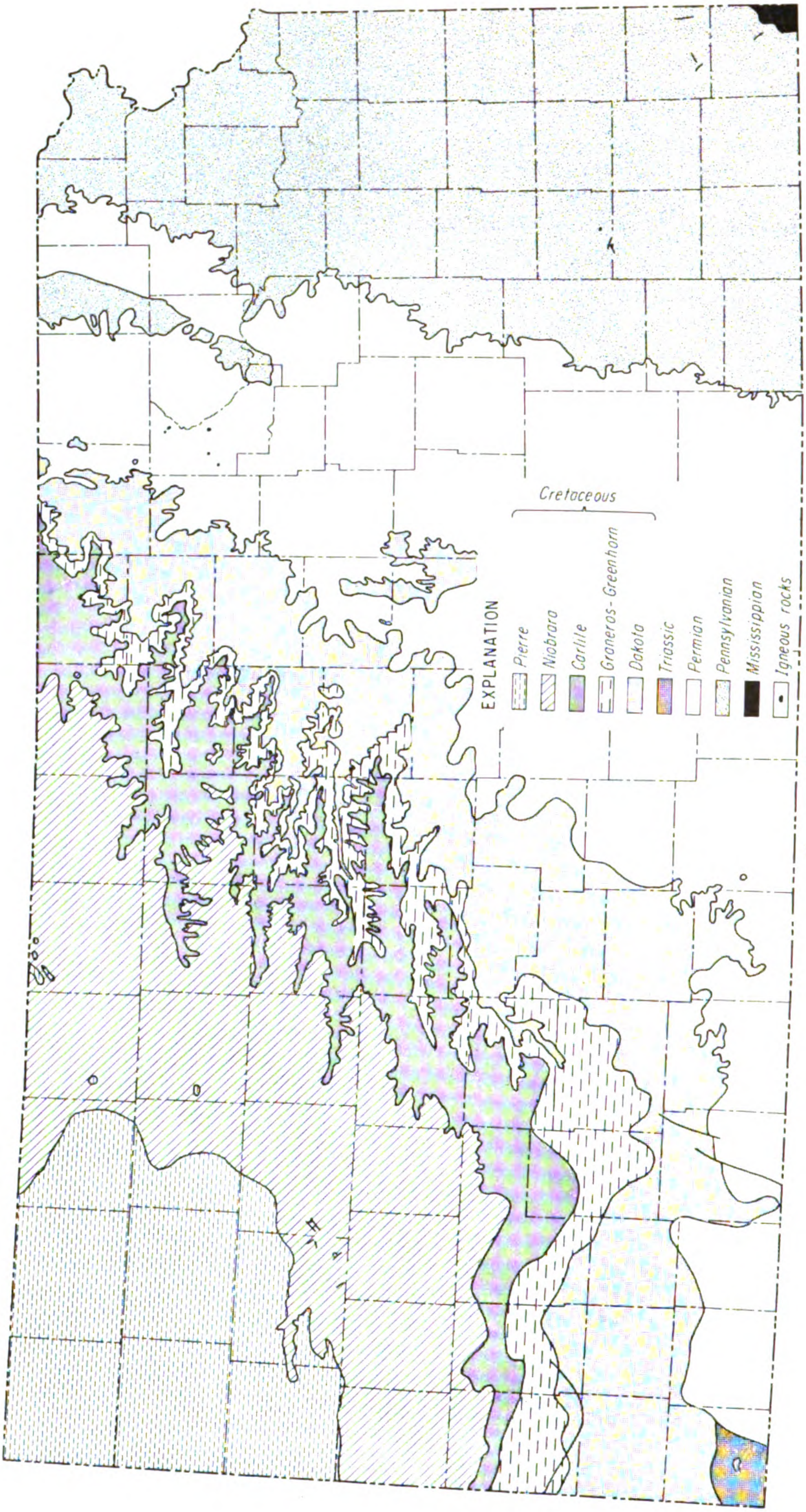


FIGURE 92.—Map of Kansas showing areal geology of surface below Cenozoic deposits (in part from Merriam and Frye, 1954).

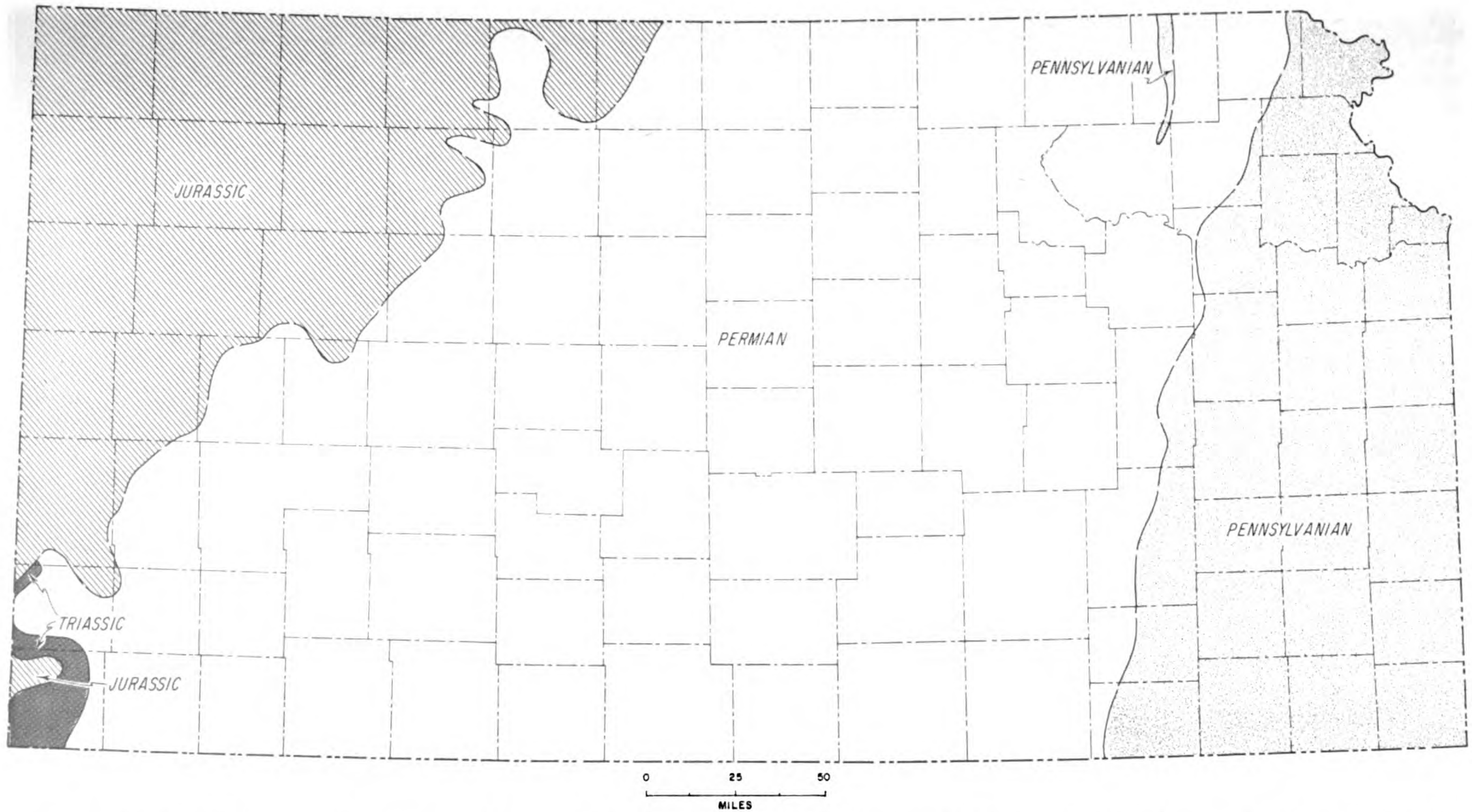


FIGURE 93.—Map of Kansas at pre-Cretaceous post-Jurassic time showing rocks underlying Cretaceous deposits in western part and inferred position of Pennsylvanian-Permian boundary in eastern part.

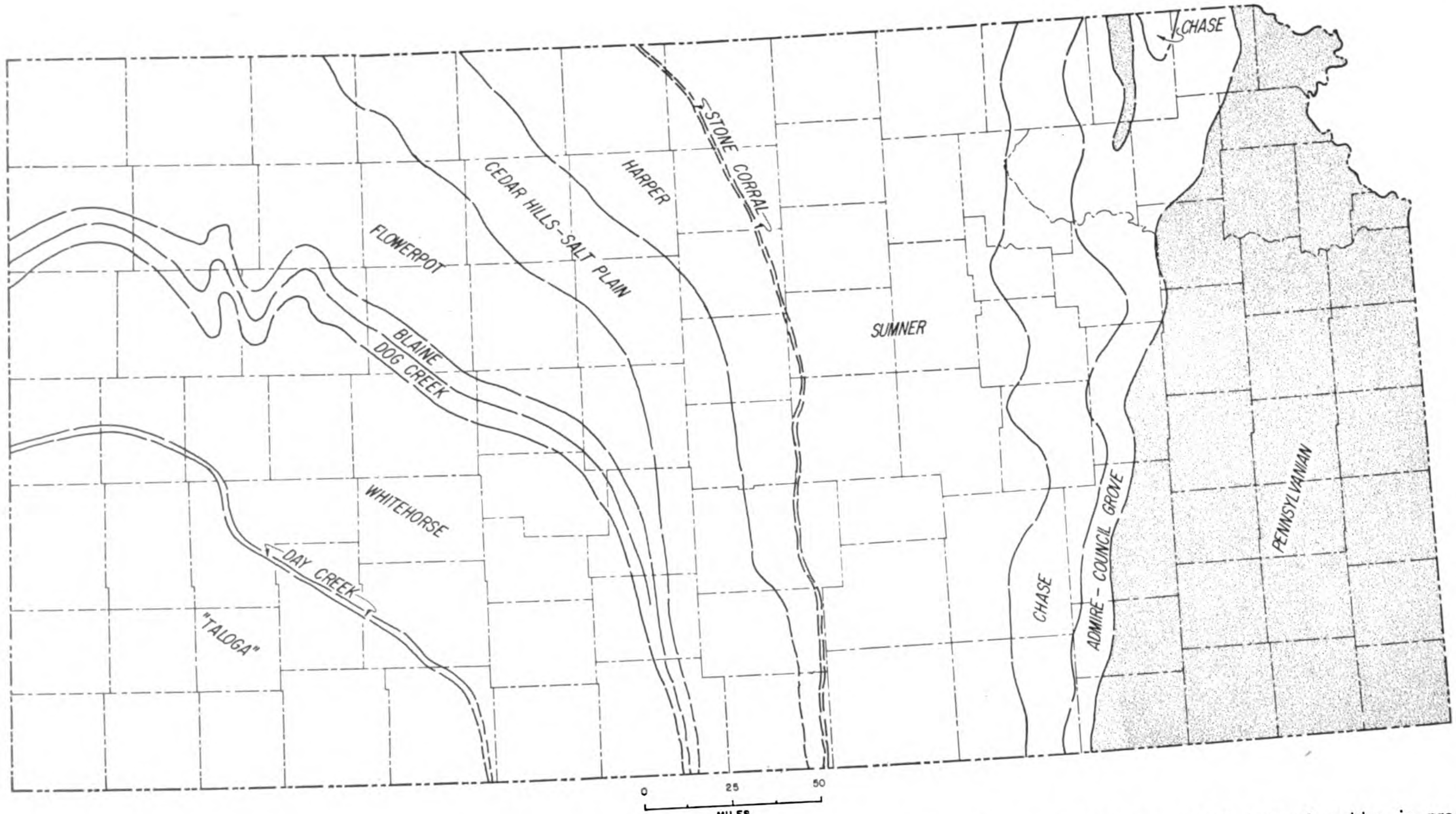


FIGURE 94.—Map of Kansas showing position of rock units immediately underlying Mesozoic beds or where Mesozoic cover is absent their inferred position in pre-Mesozoic time (in part from Merriam, 1957b). Outcrop pattern of Permian formations in western Kansas is controlled by configuration of Hugoton Embayment of Anadarko Basin.

originated in crustal disturbances that occurred between mid-Mississippian (probably post-Meramecian) and mid-Pennsylvanian (probably post-Morrowan pre-Desmoinesian) time.

It is possible to recognize and thus to locate inferred subcrops of the Mississippian, Devonian, Silurian, Maquoketa, Viola, Simpson, Arbuckle, and Precambrian on the pre-Pennsylvanian surface (Fig. 95). Mississippian rocks are the most widespread of the deposits beneath the Pennsylvanian, occurring everywhere except on upwarped areas of the Cambridge Arch, Central Kansas Uplift, Pratt Anticline, and Nemaha Anticline. Many areas of Precambrian underlie the Pennsylvanian in cores of uplifts. Some of these areas are bounded by faults. Younger units, chiefly Arbuckle, border the Precambrian; distribution of formations within the Arbuckle would indicate much of interest, but at present it is not possible to differentiate them on a usable scale.

Present distribution of Mississippian units under the Pennsylvanian indicates that they once covered the entire state and since have been eroded from the uplifts (Fig. 96). The youngest Mississippian rocks occur in the deepest portions of the basins, and successively older Mississippian beds are encountered proceeding outward from the basinal centers, until on the higher parts of the upwarped areas the Mississippian is completely missing. If all Mississippian units formerly extended across the uplifts, the amount of sediment derived by their removal is voluminous. This material undoubtedly went into forming lower Pennsylvanian strata in surrounding areas.

The youngest Mississippian in the Kansas portion of the Hugoton Embayment is Chesteran. Next below are the Ste. Genevieve, St. Louis, Salem, and Warsaw, of Meramecian age, underlain by Osagian and Kinderhookian units. On the Pratt Anticline, in Pratt and Barber Counties, the Osagian-Kinderhookian is undifferentiated. The youngest unit in the Salina and Sedgwick Basins is Salem, which is underlain by Warsaw, Osagian, and Kinderhookian rocks. Rocks of Kinderhookian age are next below Pennsylvanian deposits subparallel to the crest of the Nemaha Anticline. The Ste. Genevieve occurs in the Forest City Basin in northeastern Kansas, surrounded by St. Louis, Salem, and Warsaw. Several areas of Osagian rocks are present in eastern Kansas, including, in the northeast, rocks along the eastern flank of the Nemaha. The area of the controversial Cowley Formation is shown in southern Kansas (Fig. 96). Until the problem of its stratigraphic placement is decided, its position in time and space in relation to other beds remains problematical.

Pre-Mississippian Post-Devonian Surface

The age of the Chattanooga Shale in Kansas is variously identified as Devonian, Mississippian, or both. Because of the unconformity separating the Chattanooga from older rocks and the apparent conformable relation with overlying rocks, it is convenient to consider the Chattanooga with the Mississippian. Distribution of rocks on a surface directly below Chattanooga Shale, or, where Chattanooga (or Boice) Shale is absent, next below Mississippian limestone, is shown on Figure 97. No Mississippian or Chattanooga rocks remain on the northern part of the Nemaha Anticline, on isolated areas farther south along the crest of the uplift, or on the Central Kansas Uplift, structures that are post-Mississippian in age. The distribution of rocks on the pre-Mississippian surface in these areas is therefore inferential.

Crustal movements prior to deposition of Mississippian rocks, or, in eastern Kansas, before accumulation of Chattanooga Shale, had marked effects on Kansas geology. The main structural features recorded in the pattern of pre-Mississippian and pre-Chattanooga outcrops are: the Chautauqua Arch, ancestral Central Kansas Uplift (sometimes called Ellis Arch), North Kansas Basin, and Southwest Kansas Basin. Central Kansas Arch is a name sometimes used for the combined ancestral Central Kansas Uplift and Chautauqua Arch and the connecting, relatively lower, but nevertheless positive element between the arches.

Pre-Paleozoic Post-Precambrian Surface

Distribution of different Precambrian rock types below the Paleozoic-Precambrian unconformity in Kansas has been discussed previously and shown on Figure 87. The configuration of this surface is discussed under Present Structure.

Paleozoic formations resting on Precambrian rocks are shown in Figure 98. Arbuckle-Reagan (Cambrian-Ordovician), Simpson and Viola (Ordovician), and Cherokee, Marmaton, and Lansing-Kansas City (Pennsylvanian) rocks are found to overlie the Precambrian. Levorsen (1960, p. 18) called this type of map, which is a view of the surface from below the unconformity, a "worm's eye" or "lap-out" map. The Paleotectonic Map Project of the Federal Geological Survey uses "suprageologic" for such maps (E. D. McKee, personal communication).

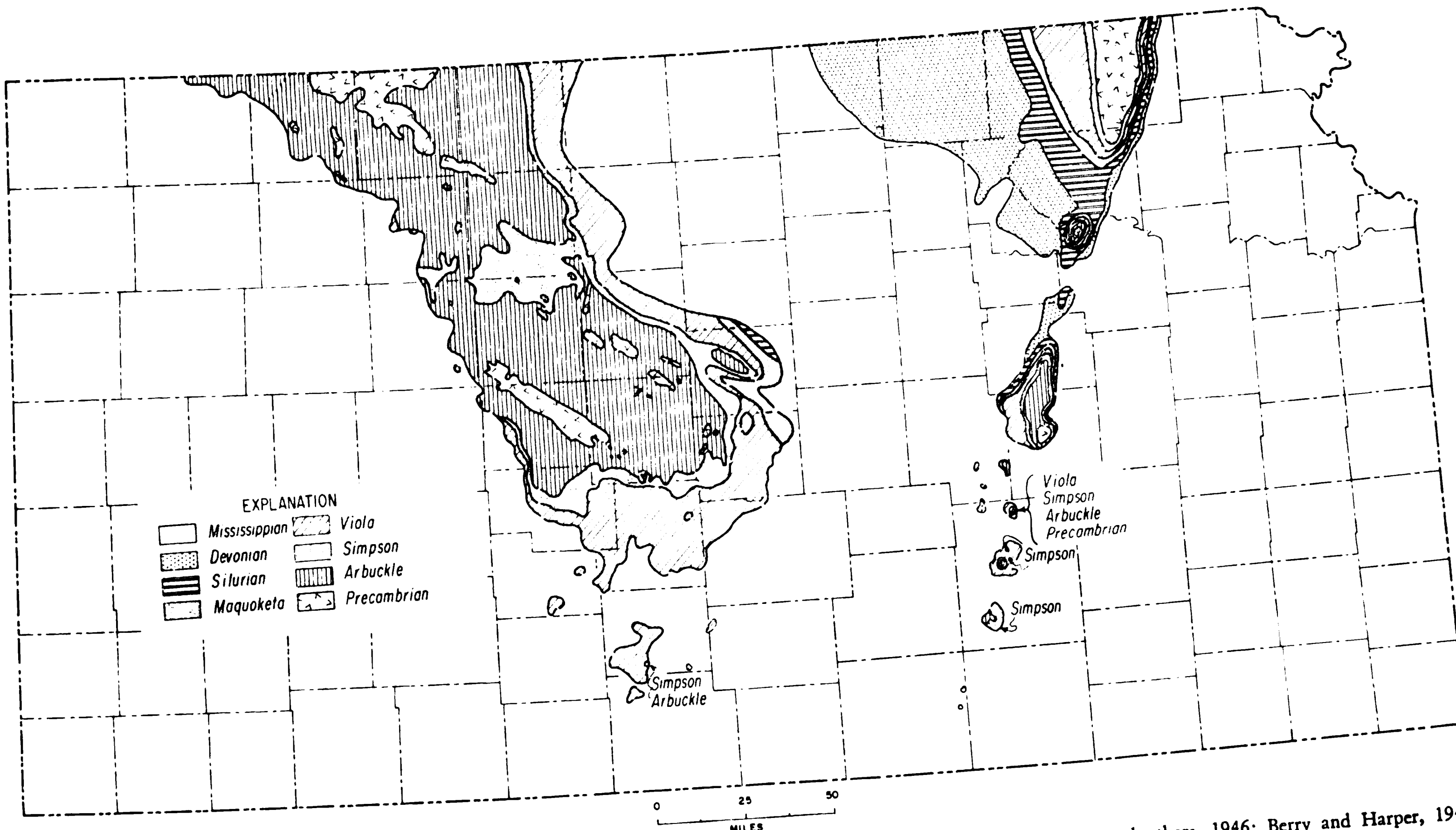


FIGURE 95.—Map of Kansas showing rocks underlying Pennsylvanian beds (in part from Lee, 1956; Merriam, 1955b; Lee and others, 1946; Berry and Harper, 1948; Hiestand, 1935). Mississippian rocks are present except on Nemaha Anticline, Central Kansas Uplift, Cambridge Arch, and Pratt Anticline, where rocks as old as Precambrian underlie Pennsylvanian.

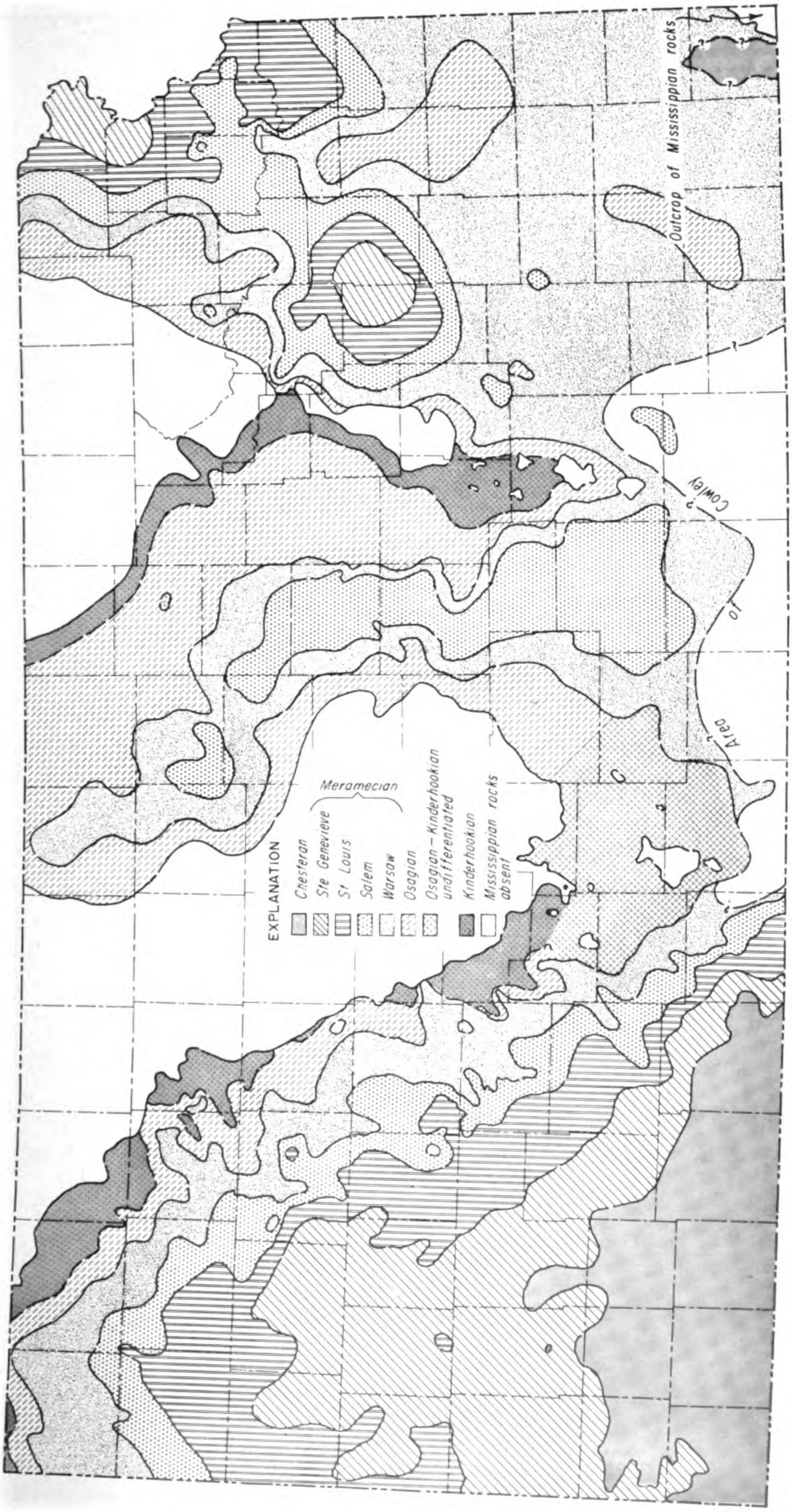


FIGURE 96.—Map of Kansas showing generalized distribution of Mississippian units below Pennsylvanian deposits (from Lee, 1956; Veroda, 1959; Beebe, 1957; Maher and Collins, 1949; Sloss, Dapples, and Krumbein, 1960). Area of controversial Cowley Formation is shown in south-central Kansas.

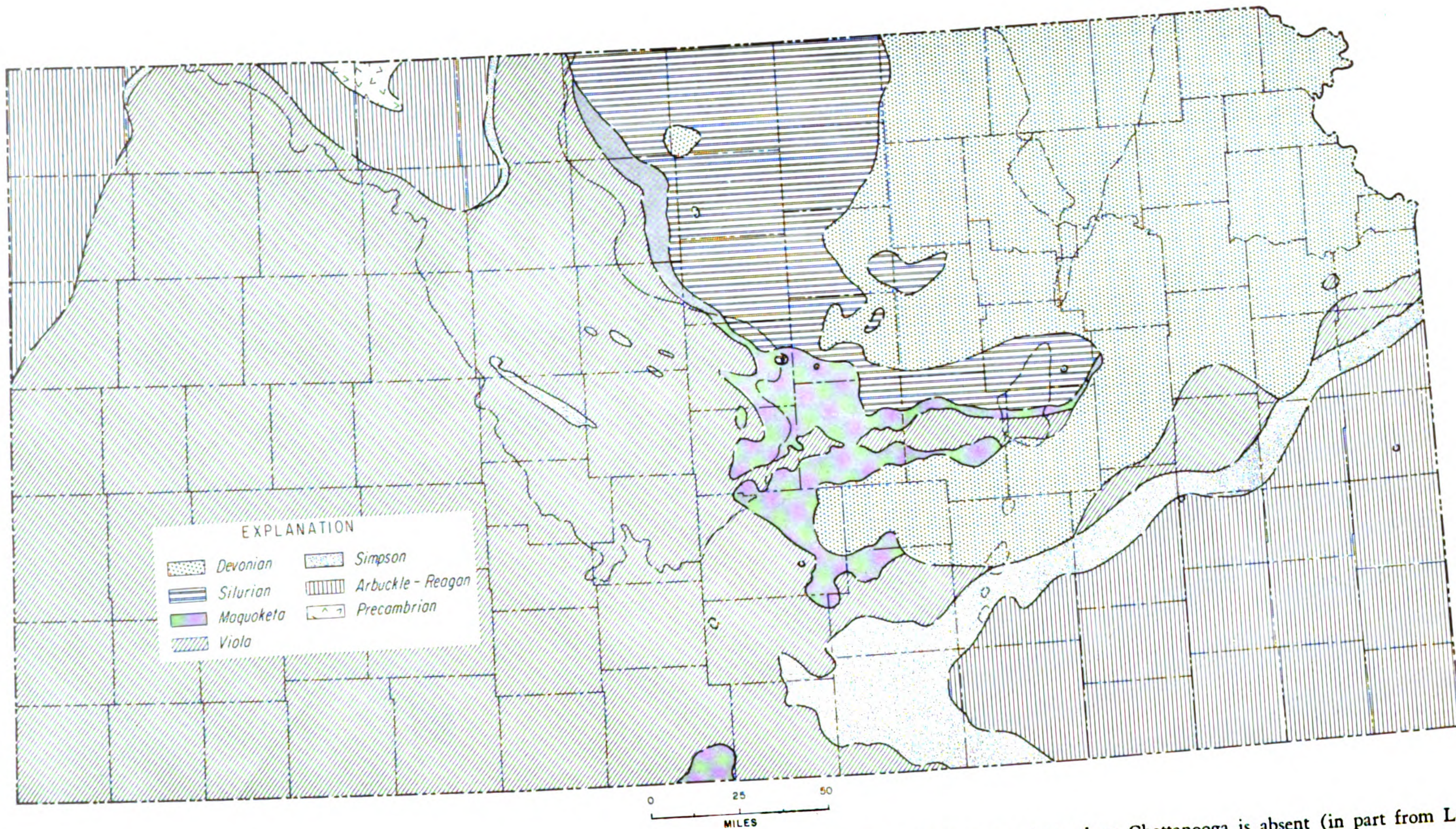


FIGURE 97.—Map of Kansas showing rocks underlying Chattanooga Shale or inferred position in pre-Chattanooga time where Chattanooga is absent (in part from Lee and Merriam, 1954b; Lee, 1956; Merriam, 1955b). Dashed line delimits areas lacking Mississippian cover.

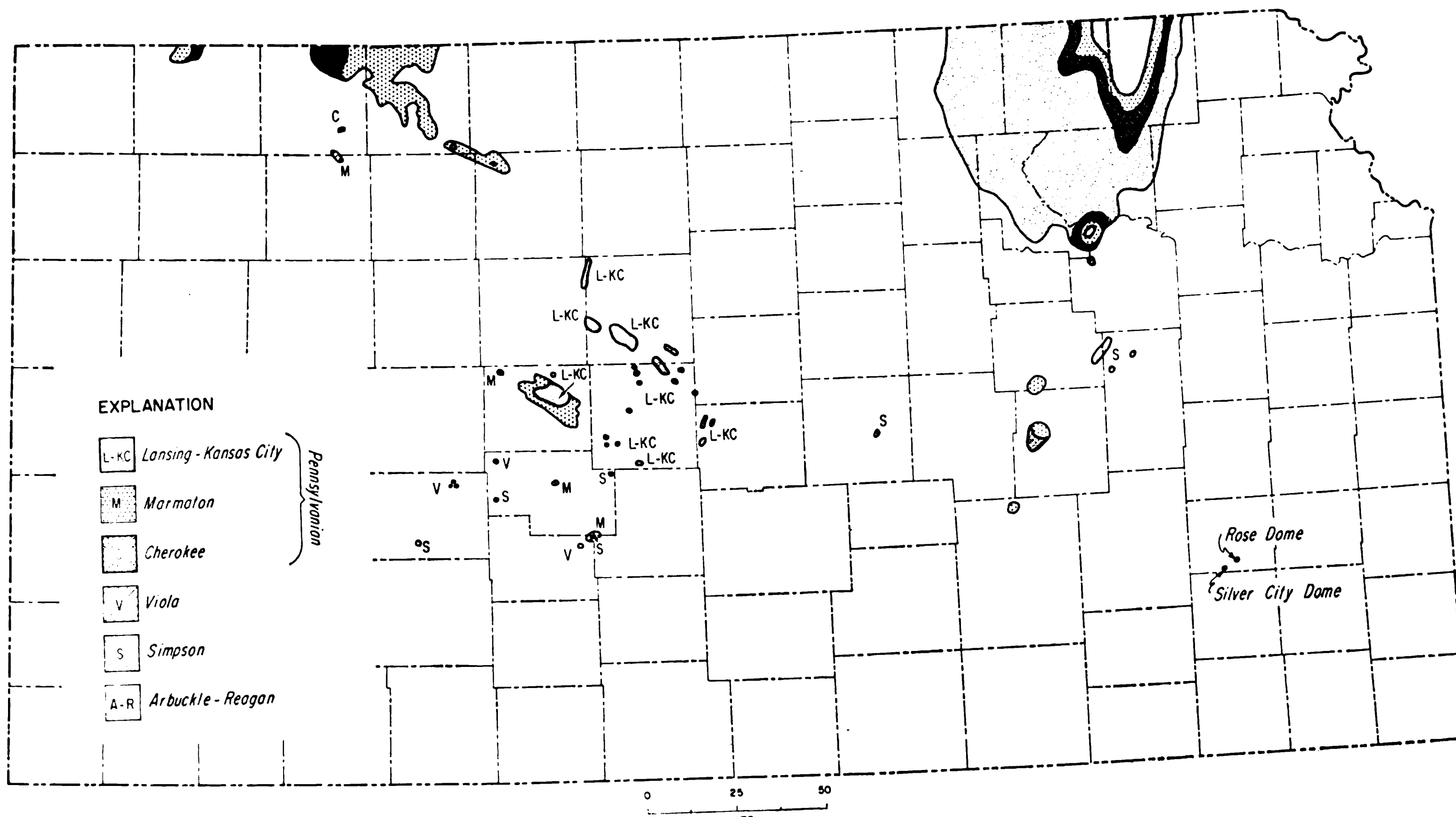


FIGURE 98.—Map of Kansas showing Paleozoic units that overlie Precambrian rocks. Only on structurally or topographically high areas do beds younger than Reagan Sandstone (Upper Cambrian) rest on basement.

Where formations younger than Arbuckle-Reagan are in contact with the Precambrian, indications are that Arbuckle-Reagan rocks were not deposited in the area or that these rocks were later uplifted and eroded from the area. Precambrian rocks were locally exposed in Kansas until Lansing-Kansas City time, when they were finally covered, and distribution of Paleozoic units indicates that upwarped areas were overstepped and buried. Walters (1946) in an excellent paper has related the history of some of the buried hills in central Kansas.

Incompleteness of the Kansas Geologic Record

The understanding of geologic history depends on preservation and interpretation of rocks, including the organic remains which they contain. In putting together past events in their proper sequence and perspective, one needs a complete rock record for a complete story. Desirable though this might be, however, it is not possible. Therefore the problem is one of continually gathering information and piecing it together.

By comparing the relative ages of rocks present in Kansas to the ages of rocks elsewhere in the world, it is possible to arrive at an estimate as to the amount of rock record that is missing in Kansas. Although preliminary work has been done and is being done now in determining the exact age of rocks, the precise age of different rock units in Kansas is essentially not known. The sequence of events, as interpreted from the rocks, is based on the relative position of rock units; in the absence of exact age determinations, the amount of the missing record can be, at best, only vaguely estimated. Intervals of geologic time that are completely unrepresented in this region can be demonstrated readily, and it is with these intervals that we are concerned here.

By tracing a persistent unit or other recognizable feature to areas where the geologic record is more nearly complete, it is possible to determine which rock units are missing. Where this is not possible, a study of the fossil record may reveal a break in the sequence.

Several sources, the most important of which are the geological correlation charts published by the Geological Society of America (Cobban and Reeside, 1952; Cooper and others, 1942; Dunbar and others, 1960; Howell and

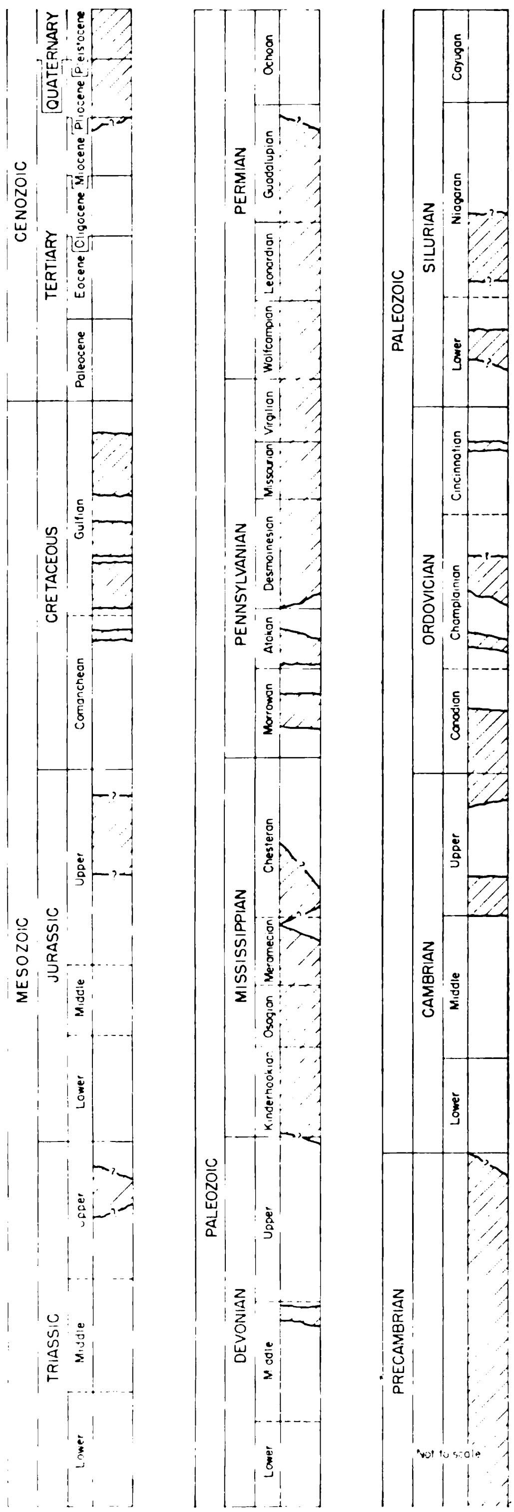


FIGURE 99.—Chart of geologic time divisions showing, by shading, units present in Kansas. Note that 12 series are completely absent, and five more are only very incompletely represented.

others, 1944; Imlay, 1952; Moore and others, 1944; Reeside and others, 1957; Swartz and others, 1942; Twenhofel and others, 1954; Weller and others, 1948; and Wood and others, 1941), were used in compiling data showing which geologic time divisions are represented in Kansas (Fig. 99). Because the chart illustrated here is not drawn to scale, the position of rock units is relative. A quick glance reveals that many series are very incompletely represented.

MISSING STRATIGRAPHIC UNITS

All major divisions of the rock systems are represented somewhere within Kansas, but several series are not represented. They are: Lower and Middle Cambrian, Cayugan (Upper Silurian), Lower Devonian, Ochoan (Upper Permian), Lower and Middle Triassic, Lower and Middle Jurassic, and Paleocene, Eocene, and Oligocene (Tertiary). Rocks of these ages, if they were ever present in Kansas, have been removed and are represented in the section only by unconformities.

Series that are only very incompletely represented are Cincinnatian (Upper Ordovician), Upper Devonian, Upper Triassic, Comanchean (Lower Cretaceous), and Miocene (Tertiary). Probably the most nearly complete rock section in Kansas extends from the base of the Cherokee Group (Desmoinesian) to top of the "Taloga Formation" (Guadalupian), and even this part of the column contains many disconformities representing time of erosion or nondeposition of sediments.

GEOLOGIC TIME AND MAXIMUM THICKNESS OF ROCKS

It is now possible by radioactivity to determine with reasonable accuracy the age of rocks. Although this is a slow and laborious process, many dates all over the world have now been determined. By using these dates, it is possible to estimate the duration of each geologic system and even of many series (Table 4). New and better procedures have recently made possible refinements in the geologic time scale (Kulp, 1961). However, few absolute dates for post-

TABLE 4.—Geologic time scale (from Holmes, 1959) and composite maximum thickness of rock units in the world

Era	*System or period*	*Series or epoch*	*Approx. number of million years ago*	*Approx. length, millions of years*	*Maximum known thickness of strata, feet*	*Maximum thickness of units in Kansas, feet*
CENOZOIC	Quaternary	Recent	0-1	1	6,000	1,000
		Pleistocene				
	Tertiary	Pliocene	1-13	12	15,000	800
		Miocene	13-25	12	21,000	....
		Oligocene	25-36	11	26,000	....
		Eocene	36-58	22	42,000	....
		Paleocene	58-63	5		
MESOZOIC	Cretaceous		63-135	72	51,000	3,000
	Jurassic		135-181	46	44,000	350
	Triassic		181-230	49	30,000	300
PALEOZOIC	Permian		230-280	50	19,000	3,000
	Pennsylvanian		280-310	30	46,000	4,700
	Mississippian		310-345	35		
	Devonian		345-405	60	38,000	325
	Silurian		405-425	20	34,000	435
	Ordovician		425-500	75	40,000	1,700
	Cambrian		500-600?	100	40,000	350
PRECAMBRIAN			600-2,500+	1,900+	Considerable	Considerable

Precambrian rocks in Kansas have been determined by radioactivity.

Holmes (1959) presented figures on composite maximum known thicknesses (Table 4): maximum thickness of the Quaternary is 6,000 feet, Tertiary 104,000 feet, Mesozoic 125,000 feet, and Paleozoic 217,000 feet. The total known thickness of all post-Precambrian rocks, then, is about 452,000 feet. The approximate thickness of rocks in Kansas is: Quaternary about 1,000 feet; Tertiary 800 feet; Mesozoic 3,650 feet; Paleozoic 10,500 feet; and the total about 16,000 feet. Of course, nowhere is there a complete column; the thickest known section in Kansas is about 9,500 feet, in the Hugoton Embayment in the southwestern part of Kansas.

DETERMINATION OF UNREPRESENTED TIME

Several methods may be used to estimate the amount of time that is not represented by the rock section in a given area; although it should be remembered that they provide only estimates. One method is to assume that each of the series represents approximately one-third of the duration of its system. Because of the complete absence of 12 of 39 post-Precambrian series, about 208 million years of geologic history is not represented in Kansas. By adding four very incompletely represented series, which comprise about 80 million years, approximately 290 million years or about one-half of post-Precambrian geologic time is unrepresented. This approximation is valid only if entire systems or series are absent and the remaining series are completely represented. Of course, none of the series are complete, hence even more time is unrepresented than estimated.

Another method used is to determine the amount of time represented by a given rock column, such as that of the Kansas region, which involves determining for each series the ratio of total known rock thickness to thickness in the area concerned. Certainly this is not a trustworthy basis for determination of time intervals, because sediment-accumulation rates differ enormously in different areas and because the total known rock thicknesses are aggregate sedimentary rock thicknesses of the world. Rock thickness per million years can be computed from time duration and maximum thickness of each series (Table 4). Ratio of the Quaternary is about 6,000 feet of rock per million years, whereas the ratio of the Cambrian is about 400 feet per million years. One possible explanation of this discrepancy is simply that more is known about the Quaternary because it is more readily available for study. Furthermore, erosion has not had enough time to strip away the younger rocks.

Kay (1955) concluded that rates of subsidence rarely were more than 1,000 feet in 1 million years and probably never more than 3,000 feet; these rates are undoubtedly much too high for Kansas. Because the subsidence rates are based on rock thicknesses, the results computed from rates of subsidence involve the same errors as the results obtained by using rock thicknesses.

Another method of computing the time represented is based on the rates of sedimentation of different rock types in Kansas. Such information, of course, is only an approximation, which may or may not be significant (see especially Barrell, 1917). Pettijohn (1949, p. 471) has stated:

> The rates of sedimentation have been of great interest to geologists for many years, primarily because if the rates were known, estimates of the length of time required for the deposition of any formation would be found readily by dividing its thickness by that of one year's deposit. Such an objective, however, rarely is attainable. Sedimentation seldom is continuous: it is subject to many interruptions. . . .

Pettijohn described several methods by which rates of sedimentation may be estimated: (1) by observing the thickness of annual layers (varves) of ancient sediments, (2) by dividing the thickness of beds of a given system by the length of the corresponding period as determined by radioactivity, (3) by observing present-day rates, and (4) by computing what the thickness of an annual layer should be if eroded material is redistributed over a known area. He concluded:

> The shales average about one half millimeter per year or 700 yr per ft. Data for other rock types are too meager to compute an average rate of deposition. Because shales are the dominant type of sediment and accumulate at rates greater than limestone but less than sandstones, their rate of accumulation may be somewhat near that of the average sediment.

If a constant sedimentation rate of 700 years per foot for the 16,000 feet aggregate maximum thickness of rocks in Kansas is assumed, other factors being negligible, the total time computed is far too few years to be realistic. A rate of 1,000 years per foot still gives too small a figure, and even at a rate of 5,000 years per foot of accumulation, approximately 85 percent of the record would be missing. This percentage is so great as to raise a question of how much trust, if any, can be placed in these methods.

It has long been recognized that the Pennsylvanian rocks, as well as the lower Permian rocks, in eastern Kansas exhibit well-defined cyclic characteristics. By comparing the number of cycles with the total section, it should be possible to calculate how much time, as an average, was required for each cycle to develop. If it is known what each cycle or cyclothem should include and what is represented in the rock record, it should be possible to determine what part and how much of the cycle (or cyclothem) was not developed or was developed and subsequently destroyed. Assuming that each unit of the cycle required the same amount of time for development, one can calculate the amount of time not represented. These assumptions are not strictly correct, because each unit did not take the same amount of time to develop and, of course, some—maybe even many—cyclothems were not recorded at all. From the base of Cherokee rocks to the top of the Brownville Limestone (top of the Pennsylvanian System) a total of about 85 cycles can be recognized; thus, each cycle was completed in about 350,000 years. Weller (1930) determined that an average cycle in Illinois was completed in about 400,000 years. By comparing the ideal cycle to what is actually present, it may be determined that about 35 percent of the sedimentary rocks in the upper part of the Pennsylvanian is not represented.

In Kansas, the downwarped basins are larger in areal extent than the uparched areas by a ratio of about 6:1, and likewise their volume of sediment is larger. The record is most nearly complete near the centers of the Forest City Basin, Cherokee Basin, Salina Basin, Sedgwick Basin, and the Hugoton Embayment. How much time is not represented by the rock record in each of these structural provinces will probably never be known, but it is estimated to be between 50 and 85 percent.

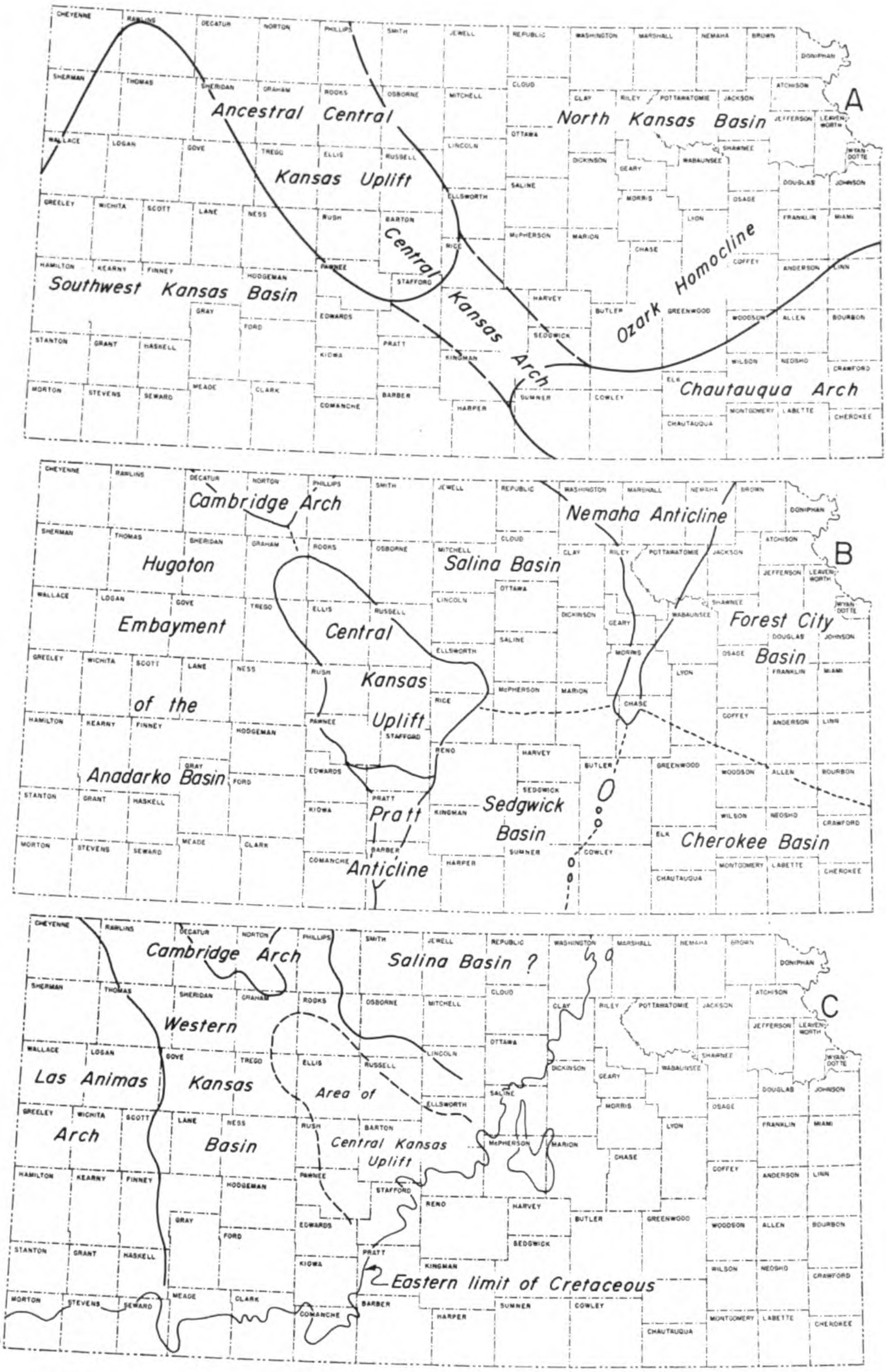


FIGURE 100.—Major structural features of Kansas: **A,** pre-Mississippian post-Devonian; **B,** pre-Desmoinesian post-Mississippian; **C,** Mesozoic.

TECTONIC FRAMEWORK

Compared with that in some parts of the world, the structural geology in Kansas is very simple. Kansas is located on a platformlike extension of a large, stable craton. Because this situation has prevailed since the end of the Precambrian, only a thin mantle of sedimentary rock covers the basement complex. This Precambrian basement complex is nothing but an extension of the large continental nucleus, the Canadian Shield, which is exposed farther north in Canada and in the north-central and northeastern United States. The sedimentary rocks, consisting of many thin units, rest nearly parallel on one another. This uncomplicated rock arrangement has simplified the task of exploring for valuable underground minerals in Kansas.

Pre-Mississippian structures are difficult to recognize because deformation subsequent to their original formation commonly has altered their shape and configuration considerably. The existing rock record, however, allows reconstruction with reasonable accuracy of the generalized pre-Mississippian Paleozoic tectonics (Fig. 100A).

A major change in structural development of the Kansas region took place near the end of Mississippian time. Many of the structures that began to develop near the end of the Mississippian or beginning of the Pennsylvanian now define the structural framework evident in Paleozoic beds. Post-Paleozoic movements did not materially alter these pre-Desmoinesian post-Mississippian structures (Fig. 100B).

Because Mesozoic deposits are absent in eastern Kansas, the interpretation of Mesozoic structures is restricted to those in western Kansas (Fig. 100C). Figure 100 shows the nearly complete change in structural development near the end of the Paleozoic.

After, and possibly during, deposition of a vast sheet of rock debris over eastern Colorado and western Kansas during Tertiary time, the area was tilted eastward. The structure forming the Great Plains is essentially an eastward-dipping homocline, with minor irregularities superimposed on the major structure.

The following are former or present major structural features in Kansas.

Ancestral Central Kansas Uplift.—The ancestral Central Kansas Uplift is a term sometimes used for the early Paleozoic development of the Central Kansas Uplift.

Barton Arch.—The names Barton Arch and Central Kansas Uplift are applied to the same pre-Desmoinesian post-Mississippian structure. Although Barton Arch has priority over Central Kansas Uplift, the latter name is most widely used and is accepted here.

Bourbon Arch.—This is a low, indistinct, seemingly uparched feature that trends almost east-west in eastern Kansas through parts of Bourbon, Allen, Anderson, Coffey, Woodson, Lyon, and Chase Counties, separating the Forest City Basin on the north from the Cherokee Basin on the south. It is supposedly pre-Desmoinesian post-Mississippian in age.

Although its limits are vague, this arch can be construed to cover about 3,000 square miles (Merriam and Goebel, 1956; Baker 1962). McMillan (1956) concluded that the arch exerted some influence on sedimentation as late as Late Pennsylvanian. Both Pennsylvanian and Permian beds crop out over the arch; subsurface strata are similar to the sequence in the Forest City Basin.

For a very brief time, then, the Bourbon Arch separated two areas, the Forest City and Cherokee Basins, that were accumulating sediments; but it should be remembered that in Middle and Late Pennsylvanian time sediments were being deposited over a vast area in middle North America, and it is misleading to place too much emphasis on an individual divide.

Cambridge Arch.—The southern end of the Cambridge Arch (sometimes called Darton's Arch) is located in Norton and Decatur Counties, so that this structure covers only about 1,000 square miles in western Kansas. It is a large, northwest-trending anticlinal feature that extends northward into Nebraska and is separated by a structural saddle from the Central Kansas Uplift to the southeast. Also on the same trend as the Cambridge Arch and Central Kansas Uplift are the Chadron Arch of Nebraska and the Chautauqua Arch in southeastern Kansas; all of them together form an arcuate trend of uparched features, which in plan view are convex toward the southwest. Structural movement occurred along the Cambridge Arch in pre-Mississippian and in pre-Desmoinesian post-Mississippian, as well as in Mesozoic time. The Salina Basin flanks the structure on the east, and the northern end of the Hugoton Embayment limits the western side.

Surface rocks along the Cambridge Arch are Tertiary and Cretaceous in age. On the crest of the structure in the subsurface, Precambrian rocks are overlain by strata of Pennsylvanian age; older Paleozoic rocks are upturned, truncated, and overstepped on the flanks. The Precambrian surface plunges southeastward and slopes both northeastward and southwestward. In southeastern Norton County the plunge is reversed to form a low, broad saddle that separates the Cambridge Arch proper from the Central Kansas Uplift. Distribution of Precambrian rock types gives a vague suggestion that the granite might have intruded into older preexisting sediments (Merriam and Atkinson, 1955, p. 3).

The arch is flanked by several smaller, parallel anticlinal and synclinal structures. The Stuttgart-Huffstutter Anticline on the east is separated from the Cambridge Arch by the northerly plunging Long Island Syncline. On the west side of the arch, the Jennings Anticline is a subsidiary feature which plunges southward.

Central Kansas Arch.—This term has been used to include the ancestral Central Kansas Uplift and the Chautauqua Arch.

Central Kansas Uplift.—The name Central Kansas Uplift (also called the Barton Arch or Russell Arch) has been used widely for a major pre-Desmoinesian post-Mississippian structural feature in central Kansas (Morgan, 1932). The northwest-trending uplift, outlined by the extent of Mississippian beds, separates the Hugoton Embayment on the west from the Salina and Sedgwick Basins on the east.

The Central Kansas Uplift is the largest positive feature in Kansas, occupying an area of about 5,700 square miles entirely within the state. Surface formations of Cretaceous, Tertiary, and Quaternary age mask the underlying structure of the deeper and older beds, inasmuch as structural development of the uplift was concluded before Mesozoic time. Near the southern end of the province a large area is covered with Pleistocene dune sand.

The section of sedimentary rocks over the structure is in most areas less than 5,000 feet thick. On the crest of the structure, Precambrian rocks are overlain by Pennsylvanian sediments; on the flanks of the uplift, pre-Pennsylvanian strata are upturned, truncated, and overstepped by Pennsylvanian beds. A fairly representative section of Permian rocks that extends across the structure includes evaporite deposits, especially the Hutchinson Salt. The Precambrian complex consists of a variety of igneous and metamorphic rocks. A great deal of subsurface information is available in this area because many wells have been drilled to the basement rocks.

Along the crest and flanks of the uplift are many subsidiary, although important, structures, including prominent anticlinal features known as the Ellsworth Anticline, Fairport Anticline, Pawnee Rib, Rush Rib, and Russell Rib. The Geneseo Uplift, located in parts of Rice, Ellsworth, and McPherson Counties, is a semi-detached, easternmost lobe of the Central Kansas Uplift (Clark, Arnett, and Royds, 1948).

Chautauqua Arch.—This is a pre-Mississippian anticlinal extension of an early phase of the Ozark Uplift into southeastern Kansas. It was a broad, uparched, westward-trending feature, and over its crest units as young as Pennsylvanian lie on rocks as old as Cambrian-Ordovician.

The arch began to rise at about the time the North Kansas Basin began to subside; but then Silurian rocks, and later Devonian rocks, were deposited, arched, and eroded, and rocks as old as Arbuckle were exposed, before deposition of the Chattanooga Shale. Mississippian strata were deposited over the area, and the post-Mississippian Cherokee Basin formed in the area of the Chautauqua Arch, indicating that structural development of the arch had been concluded by this time.

Cherokee Basin.—The shallow Cherokee Basin (infrequently called the Pryor Basin) developed on the older Chautauqua Arch in pre-Desmoinesian post-Mississippian time. It is an extension of the McAlester or Arkoma Basin of Oklahoma into southeastern Kansas. The northern part of the basin is separated from the Forest City Basin by the Bourbon Arch, and the western side is bounded by the Nemaha Anticline.

The Cherokee Basin is slightly smaller than the Forest City Basin, covering about 8,400 square miles. Surface rocks dip gently westward, except on small anticlines and near the Nemaha Anticline, where a slight reversal of dip reveals its presence. Mississippian rocks, the oldest exposed in Kansas, crop out in Cherokee County, in the extreme southeastern corner of the state. Pennsylvanian and Permian rocks are exposed over the rest of the basin. These sediments undergo facies changes southward into Oklahoma, making correlation of individual beds difficult. The maximum sedimentary sequence is about 3,500 feet thick.

Lower Pennsylvanian beds overlie Cambrian-Ordovician and Ordovician throughout most of the basin. Pre-Pennsylvanian history is that of the Chautauqua Arch. In Pennsylvanian time the Cherokee Basin was formed by mild downwarp. The Precambrian surface does not reflect this basinal structure.

Dodge City Basin.—The name Dodge City is occasionally used to differentiate a large structural feature in southwestern Kansas, better known as the Hugoton Embayment. Although the name Dodge City has priority, Hugoton has gained wide acceptance in recent years.

Ellis Arch.—The pre-Mississippian structural development of the Central Kansas Uplift and Cambridge Arch has been designated the Ellis Arch. This anticlinal feature is a finger extending from the large Transcontinental Arch, which reached southwestward from Wisconsin through South Dakota and Nebraska (Eardley, 1951). Several periods of uplift affected the Ellis Arch; the strikes of anticlinal folds in pre-Pennsylvanian rocks differ about 20 degrees from the mid-line of the later uplift. These anticlinal folds are interpreted as pre-Mississippian in age, because they are aligned with folds on the Chautauqua Arch and because they seem to be related to features older than the Central Kansas Uplift (Moore and Jewett, 1942).

Forest City Basin.—Most of the Forest City Basin is located in Iowa, Missouri, and Nebraska; only the extreme southwestern corner lies in Kansas. The basin is the third largest in the Kansas region; its area slightly exceeds 9,500 square miles. It is bounded on the west by the Nemaha Anticline and on the southwest by the Bourbon Arch. The axis of the basin trends slightly east of north; it lies close to and parallels the axis of the Nemaha Anticline. The proximity of the basinal axis, the Brownville Syncline (Condra, 1927), to the Nemaha produces a relatively steep west flank, a gentle east flank, and an asymmetrical profile. The basin was a depositional area after Arbuckle time, first as part of the older North Kansas Basin and then as a separate feature.

Pennsylvanian and Permian strata, exposed at the surface along the southern side of the basin, have a gentle westward dip of 20 to 30 feet per mile, forming part of the Prairie Plains Homocline. Local anomalies are observed and mappable in surface beds. Numerous small faults, most of which have less than 50 feet of throw, have been mapped, especially in Franklin and Osage Counties. The northern part of the basin is mantled by loosely consolidated Pleistocene glacial deposits that obscure the bedrock.

The maximum section of sedimentary rocks in the Forest City Basin is about 4,000 feet thick and is encountered near the western flank. It includes rocks belonging to the Cambrian-Ordovician, Silurian-Devonian, Mississippian, Pennsylvanian, and Permian Systems. Along the western side of the basin, the lower Paleozoic strata have been upturned, truncated, and overstepped by Pennsylvanian sediments. The Precambrian rocks, which underlie the Paleozoic sedimentaries, include a large amount of metamorphics.

Hugoton Embayment.—The Hugoton Embayment is a large, shelflike extension into western Kansas of Oklahoma's Anadarko Basin (Maher and Collins, 1948). As a major structural unit, it occupies an area of about 28,600 square miles or one-third of Kansas. The eastern edge of the basin is limited by the Pratt Anticline, Central Kansas Uplift, and Cambridge Arch. The western side is formed by the Las Animas Arch of eastern Colorado. The structure plunges southward, and sediments thicken both toward the axis of the embayment and southward into the Anadarko Basin. Precambrian rocks are overlain by as much as 9,500 feet of younger rocks, making it the deepest structural basin in Kansas.

Extensive surface deposits of Cretaceous, Tertiary, and Pleistocene age mask the structure of the underlying Paleozoic beds. Inasmuch as the structural development of the embayment was concluded before the Mesozoic, the structure of the older beds is not reflected in the younger ones. Many small, normal, tension-type faults are known from surface exposures in the Cretaceous beds, especially in the Niobrara Formation. They are especially numerous in Logan County (Johnson, 1958). Prominent normal faults include the Crooked Creek and Fowler Faults in Meade County, which extend at least down to the Permian section, and the Syracuse Fault in Hamilton County. The column includes rocks of Cambrian-Ordovician, Mississippian, Pennsylvanian-Permian, Triassic, Jurassic, Cretaceous, Tertiary, and Pleistocene age. Many of the Paleozoic sedimentary units change facies southward into the Anadarko Basin and also westward into Colorado toward the Rocky Mountains. The Precambrian comprises mainly igneous but also some metamorphic rocks.

Las Animas Arch.—Only the easternmost edge of this major anticlinal feature extends into western Kansas; the arch is located mostly in eastern Colorado. It plunges northeastward and separates the Denver Basin from the Hugoton Embayment (and Western Kansas Basin).

Dips on the eastern flank of the Las Animas Arch in western Kansas can be recognized in beds as old as the Stone Corral. The northeasterly dip on the flank of the arch was accentuated after Dakota time; hence, the arch is mainly a post-Cretaceous structural feature in Kansas (Lee and Merriam, 1954a).

Nemaha Anticline.—The Nemaha Anticline, probably the most famous of all Kansas structures, is a major pre-Desmoinesian post-Mississippian element that crosses Kansas from Nemaha County on the north to Sumner County on the south and extends into Nebraska and Oklahoma. Since 1914, when oil was discovered along its trend in Butler County, the Nemaha has been subjected to intense exploration. It is recognizable in surface rocks of Permian and Pennsylvanian age along most of its length, but it is more pronounced in the subsurface. Dips as steep as 5 degrees are not uncommon in the surface beds. The anticline is faulted along the east side in several areas, and seemingly there are both high-angle reverse and normal faults. The relatively narrow Nemaha Anticline separates the Forest City and Cherokee Basins on the east from the Salina and Sedgwick Basins on the west. The Precambrian granite along the crest of the uplift lies within 600 feet of the surface near the Nebraska line but it plunges southward, so that at the Oklahoma border it is about 4,000 feet below the surface. The basement-rock core of the anticline is characterized by a series of knobs along the crest of the structure. Pre-Pennsylvanian strata are upturned, truncated, and overstepped by Pennsylvanian sediments along the flanks, and on the crest of the structure the Pennsylvanian beds rest on rocks as old as Precambrian. During the early part of Pennsylvanian time, the granite was exposed as a low ridge or chain of hills, which shed arkosic sediments into the adjoining basins.

North Kansas Basin.—The North Kansas Basin is a large, pre-Mississippian downwarped area north of the Chautauqua Arch and east of the ancestral Central Kansas Uplift. Ancestral North Kansas Basin is a term applied to pre-Devonian development of the same area.

The basin, in northeastern Kansas and adjoining states, began to develop after St. Peter time in the area of the Southeast Nebraska Arch (Lee, 1956). Differential downwarping allowed accumulation of Ordovician, Silurian, Devonian, and Mississippian strata. Several periods of structural movement are recorded in the sediments. A prolonged period of erosion near the end of Mississippian time is recognizable. The formation of the Nemaha Anticline in pre-Desmoinesian post-Mississippian time divided the North Kansas Basin into the Salina Basin and the Forest City Basin.

Northern Basin Shelf.—This term, or simply Northern Shelf, has been used to designate the shelf part of the Anadarko Basin in southern Kansas north of the "hinge line" (Jewett, 1951).

Ozark Homocline.—Ozark Homocline refers to a pre-Mississippian structural element in eastern Kansas (Rich, 1933). The homocline dipped gently westward and northwestward, broken only by local domings and downwarps. Actually, this structure was simply the northwestern flank of the Chautauqua Arch.

Prairie Plains Homocline.—In eastern Kansas, beds of Mississippian, Pennsylvanian, and Permian age dip gently toward the west at about 25 feet per mile. This monotonous feature has also been termed the Prairie Plains Monocline.

Pratt Anticline.—Deformation in early Paleozoic time and again in pre-Desmoinesian post-Mississippian time produced the Pratt Anticline. Because it occupies an area of only 1,000 square miles, mainly in Stafford, Pratt, and Barber Counties, it is regarded as the smallest major structure within Kansas. It is a broad, southward-plunging nose, which separates the Sedgwick Basin on the east from the Hugoton Embayment on the west. Farther south, in Oklahoma, the structure dies out and the Sedgwick Basin merges with the Hugoton Embayment on the northeast flank of the Anadarko Basin. Surface beds in Stafford and Pratt Counties, where a considerable area is covered by sand dunes, are mainly Tertiary and Pleistocene deposits. In Barber County, Permian redbeds crop out. The maximum section of sedimentary rock in this province is about 5,000 feet thick and includes those of Cambrian-Ordovician, Mississippian, and Pennsylvanian-Permian age. On the crest of the anticline is a large area where Mississippian rocks are absent and Pennsylvanian beds overlie Ordovician rocks.

Salina Basin.—The Salina Basin, or Central Nebraska Basin (Reed, 1954), is limited on the east by the Nemaha Anticline, on the west by the Cambridge Arch and Central Kansas Uplift, and on the south by an indistinct, unnamed saddle. The axis of this post-Mississippian syncline trends northwest and plunges northward into the deeper part of the basin in north-central Kansas. Prior to the end of Mississippian time, the basin formed part of the larger North Kansas Basin.

The Salina Basin is the second largest in Kansas, extending over an area of about 12,700 square miles. Cretaceous rocks cover the western part of the basin, whereas Permian beds are exposed on the eastern side. The basin is distinguishable in the Cretaceous rocks, although the axis is slightly east of the position indicated by the Pennsylvanian-Permian beds and slightly west of the position on the Precambrian surface. Sedimentary rocks present in the basin include units of Cambrian-Ordovician, Silurian-Devonian, Mississippian, Pennsylvanian-Permian, Jurassic, Cretaceous, and Tertiary age. The maximum section encountered is about 4,500 feet thick. Economically important minor structures in the basin include the Abilene Anticline, the northern part of the Voshell Anticline, and the Wilson-Burns Element.

Sedgwick Basin.—A shelflike, southerly plunging area in south-central Kansas, similar to the Hugoton Embayment but smaller (with an area of about 8,000 square miles), is called the Sedgwick Basin. It is a major pre-Desmoinesian post-Mississippian structural feature. The Nemaha Anticline bounds the basin on the east, the Pratt Anticline forms its west flank, and an indistinct saddle separates it from the Salina Basin on the north. The strata in the basin are characterized by facies change and by increased thickness southward from the shelf area into the deeper part of the Anadarko Basin proper.

Surface beds are Permian and Tertiary in age. The famous "Equus beds" of Pleistocene age form an extensive cover over the northern part of the basin, obscuring the bedrock. Sedimentary rocks of Cambrian-Ordovician, Silurian-Devonian, Mississippian, and Pennsylvanian-Permian age are as much as 5,500 feet thick in the deepest part of the basin.

Several minor structures, approximately parallel with the Nemaha Anticline, have been recognized in the basin. These include the Bluff City Anticline, Conway Syncline, Elbing Anticline, Halstead-Graber Anticline, and the southern end of the Voshell Anticline.

Southwest Kansas Basin.—The Southwest Kansas Basin is a major pre-Mississippian structural element that represents an early development of the Hugoton Embayment in southwestern Kansas. No distinction was made between the two terms by Merriam (1955b), and because Hugoton has gained wide usage it is used here. The extent of inundation and deposition in the basin was controlled by marginal positive areas and by conditions existing in the Anadarko Basin. The structural history of the feature consisted of a series of epeirogenic movements beginning in the Precambrian.

Western Kansas Basin.—This basin is a Mesozoic development in the area of the Hugoton Embayment. The downwarp plunges gently northward between the area of the Central Kansas Uplift and Cambridge Arch on the east and the Las Animas Arch on the west. The basin was a result of late Cretaceous? tilting to the northwest into the Denver Basin in eastern Colorado and southwestern Nebraska.

Several minor structures are evident in the basin. The shallow northward dip of the basin is reflected stratigraphically as low as the Stone Corral (Permian).

Smaller Structures.—In addition to the large structures mentioned, many smaller ones occur in the state, some of which have economic importance for their role in trapping petroleum. Locations of some of these features are shown in Figure 101.

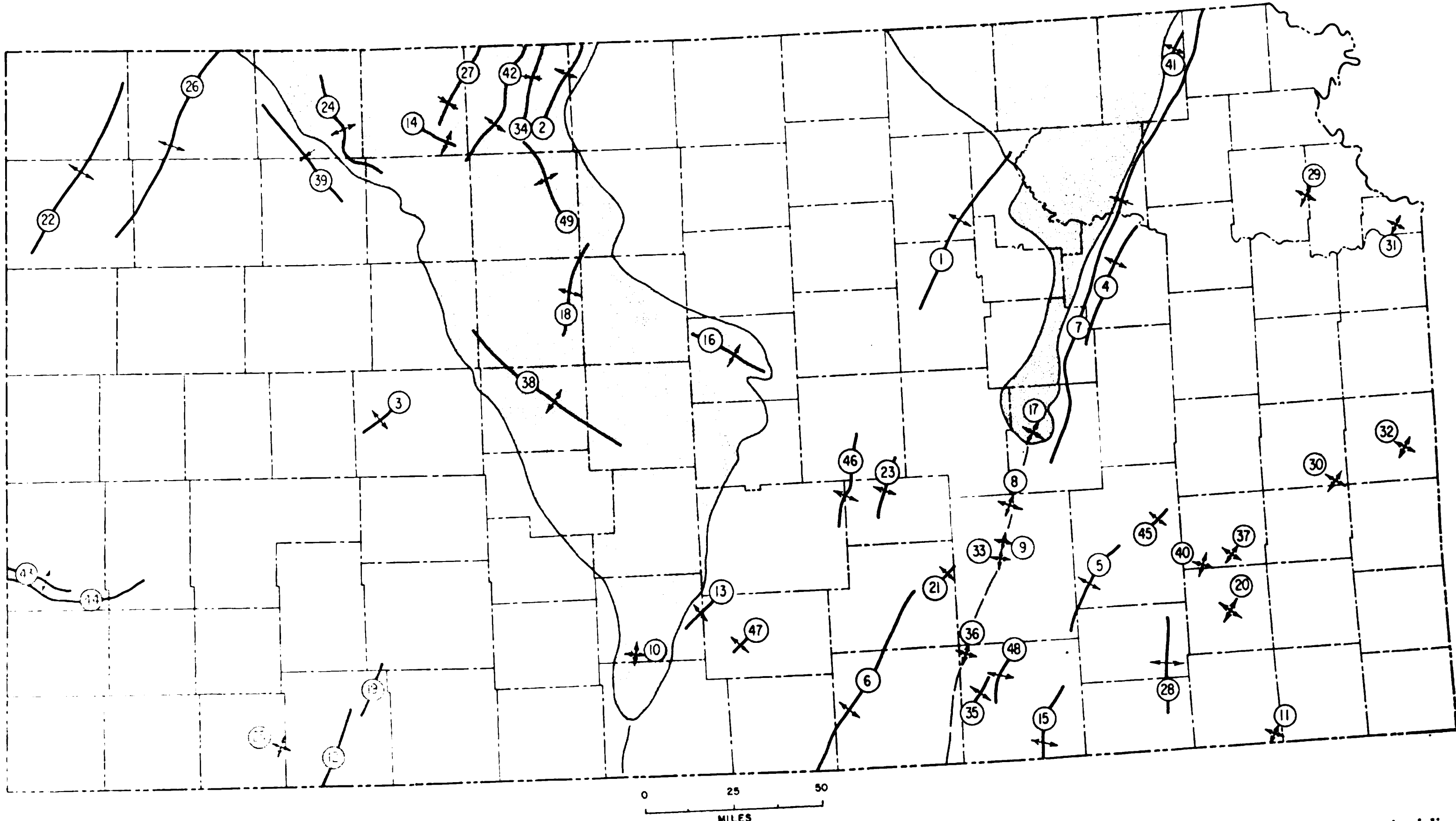


FIGURE 101.—Some minor structures in Kansas. 1, Abilene Anticline; 2, Agra Anticline; 3, Aldrich Anticline; 4, Alma-Davis Ranch Anticline; 5, Beaumont Anticline; 6, Bluff City-Valley Center-Elbing Anticline; 7, Brownville Syncline; 8, Burns Dome; 9, Chesney Dome; 10, Coats Anticline; 11, Coffeyville Dome; 12, Crooked Creek Fault; 13, Cunningham Anticline; 14, Densmore Anticline; 15, Dexter-Otto Anticline; 16, Ellsworth Anticline; 17, Elmdale Dome; 18, Fairport Anticline; 19, Fowler Fault; 20, Fredonia Dome; 21, Greenwich Anticline; 22, Goodland Anticline; 23, Halstead-Graber Anticline; 24, Jennings Anticline; 25, Kismet High; 26, Linda Anticline; 27, Long Island Syncline; 28, Longton Anticline; 29, McLouth Dome; 30, Mildred Dome; 31, Morris Anticline; 32, Mound City Dome; 33, Oil Hill Dome; 34, Phillipsburg Syncline; 35, Rainbow-Graham Anticline; 36, Redbud Dome; 37, Rose Dome; 38, Rush Rib; 39, Selden Syncline; 40, Silver City Dome; 41, Straham Anticline; 42, Stuttgart-Huffstutter Anticline; 43, Syracuse Anticline; 44, Syracuse Fault; 45, Virgil Anticline; 46, Voshell Anticline; 47, Willowdale Anticline; 48, Winfield Anticline; 49, Woodston Anticline (modified from Jewett and Merriam, 1959).

PRESENT STRUCTURE

Because of the need for structural maps in order to determine the regional tectonics of Kansas, the State Geological Survey began in 1957 to issue a series of such maps. Seven preliminary regional structural maps have been published on a scale of approximately 1:615,000, each showing the control that was used: (1) Dakota, Cretaceous (Merriam, 1957c); (2) Stone Corral, Permian (Merriam, 1958b); (3) Lansing, Pennsylvanian (Merriam, Winchell, and Atkinson, 1958); (4) Mississippian (Merriam, 1960b); (5) "Hunton," Silurian-Devonian (Merriam and Kelly, 1960); (6) Arbuckle, Cambrian-Ordovician (Merriam and Smith, 1961); and (7) Precambrian (Cole, 1962). It was not possible to show the control for each map on the copy reproduced here.

Because between 5,000 and 6,000 wells are drilled in Kansas each year (Goebel and others, 1961), detail on the maps may be, unavoidably, out of date before they are issued. The structural maps are therefore regarded as progress maps, and they are intended to show only regional structure. Areas such as the Central Kansas Uplift have been intensively drilled, and there, additional tests modify the mapping very little. In other areas, such as the Hugoton Embayment and Salina Basin, however, almost every well drilled adds significant information that may necessitate altering to some extent the configuration of the contours.

Publication of the map contoured on top of the Dakota (Cretaceous) suggested comparison with similar maps published previously during a span of 53 years (Merriam, 1958a). Five such structural maps, contoured on top of the Dakota rocks in Kansas (Fig. 102), have been published and are reproduced here: Darton (1905, 1918), Bass (1926), Lee and Merriam (1954a), and Merriam (1957c). The maps have been reduced to a common base for ease in visual comparison. They show at a glance the changing interpretation of structure on top of the Dakota in Kansas as an increasing number of wells steadily increased the control.

Shallow Structural Indicators

Generally speaking, in much of western Kansas, in contrast to the eastern part, surface mapping is unreliable for determining structure at depth, because the structural pattern of the Tertiary and Cretaceous rocks differs significantly from that of buried Permian, Pennsylvanian, and older rocks.

The Stone Corral Formation is the youngest stratigraphic unit that is both widely distributed and lithologically distinctive, and it is therefore a good marker. The Lansing Group, which lies 1,000 to 2,000 feet below the Stone Corral, is an important oil-producing zone, and because the Stone Corral occurs at shallower depth than the Lansing, it can be used as a datum horizon for geophysical (mainly seismograph, Beebe, 1959; Glover, 1953; Winchell, 1959) and core-drill exploration. Merriam (1955c) was able to demonstrate that the Stone Corral reliably reflects the structure of the older beds, and thus is a good indicator of the structure at depth of the Pennsylvanian rocks, especially the Lansing Group, in central and western Kansas (Fig. 103).

Two higher marker beds in the Permian, which very locally can be used satisfactorily in structural mapping, are the Blaine and Day Creek. They should be used with caution, however, because solution of salt beds below them may produce nontectonic structure.

Solution Features

Sinkholes are known to occur in beds as old as Cambrian-Ordovician (Arbuckle Group) and somewhere affect almost every rock formation of the geologic column in Kansas, including Recent deposits (Merriam and Mann, 1957). These features originated at various times, ranging from Ordovician to Recent.

Certain implications in the distribution and configuration of these features have economic significance, especially in locating oil and gas reservoirs (Ver Wiebe, 1947; Glover, 1953). Although surface sinkholes in Missouri have been found to contain important economic products, such as fire clay and pyrite, as yet no such deposits have been found in Kansas sinkholes. In the Tri-State District it has been recognized that the location of the lead and zinc ore is controlled, at least in part, by solution features in the Mississippian strata (Smith and Siebenthal, 1907).

Surface sinkholes, where numerous, affect ground-water conditions of the area. The likelihood of occurrence of sinkholes, as well as solution features and slumped blocks, is also important in structural geologic mapping, either in the subsurface or on the surface. Many other economically valuable data may be derived from study of these features.

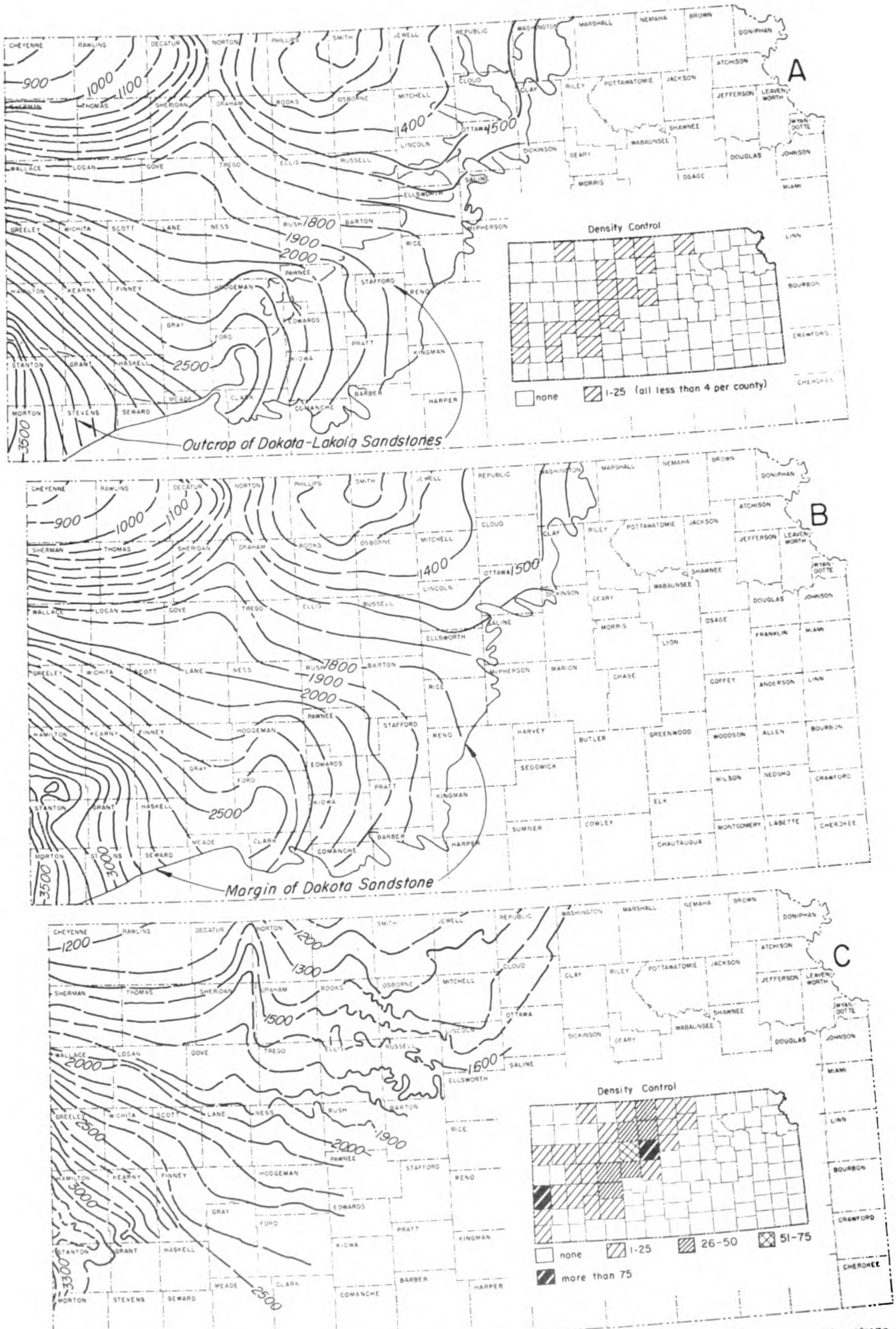


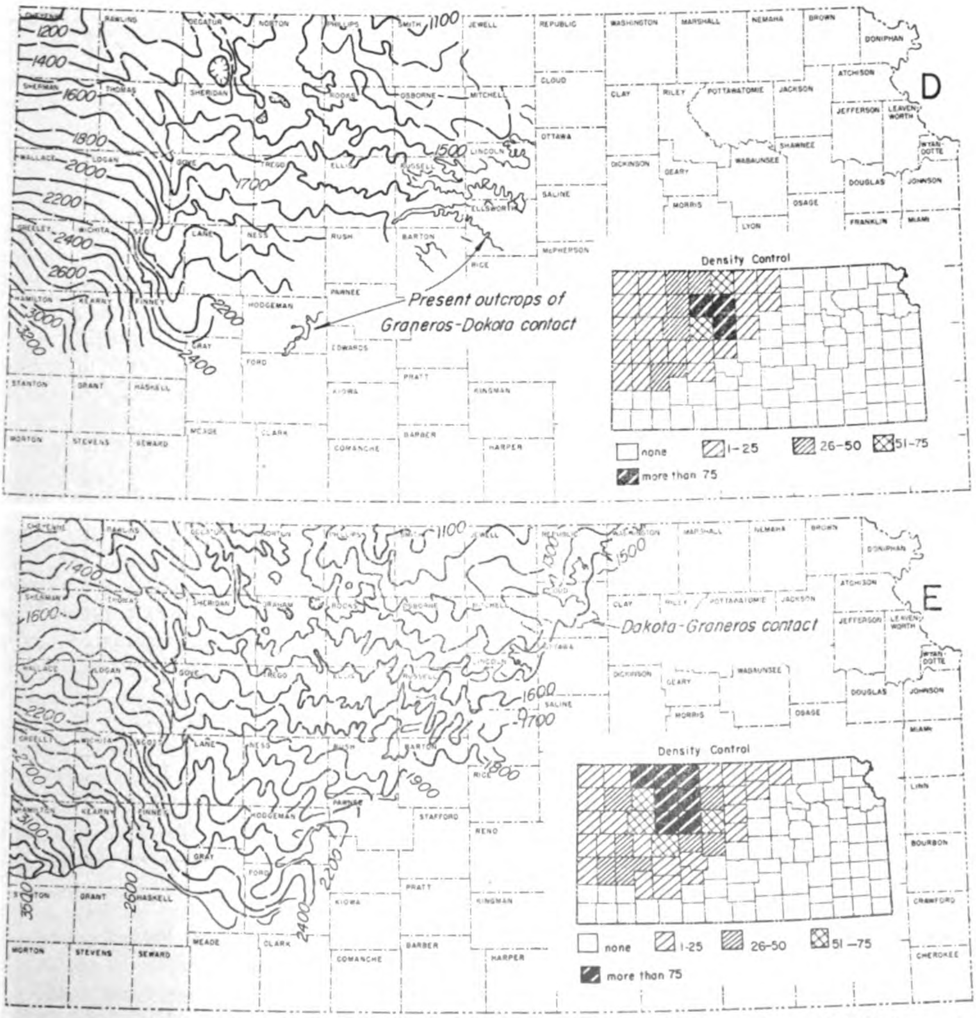
FIGURE 102.—Maps of Kansas showing progressive modification of ideas regarding Cretaceous structure Merriam, 1954; and **E**, Merriam, 1957 (from Merriam, 1958a). Contour interval 100 feet.

GEOGRAPHIC DISTRIBUTION AND ORIGIN OF SINKHOLES*

Sinkholes have been reported in 26 of the 105 Kansas counties. Of more than 50 counties that have been studied in some detail, sinkholes have been described in about one-third. A few noteworthy sinkholes in other counties, although not mapped, have received attention in geologic literature (Fig. 104).

The geographic distribution of many sinkholes, such as the series developed along the outcrop of the Fort Riley Limestone through Cowley, Butler, Chase, Morris, and Wabaunsee Counties, is controlled by the outcrop or subcrop pattern of a relatively soluble stratigraphic unit. Pierce and Courtier (1937) found that recent sinkholes on the Mississippian surface in southeastern Kansas are controlled to some extent by the location of old sinkholes; seemingly, these areas are more susceptible to recurrent slump. In McPherson, Harvey, and Sedgwick Counties the sinkholes (Pl. 25A) have formed near the eastern limit of the Wellington salt (Williams and Lohman, 1949). A reeflike expansion in the Red Eagle Formation (Permian) localizes sinkhole development in northern Lyon County (H. G. O'Connor, personal communication); the abnormally thick section of limestone seemingly is susceptible to the formation of sinkholes (Pl. 25B). Fent (1950b) found that sinkholes are especially numerous where late Pleistocene deposits overlie deep early Pleistocene channels.

* Individual sinkholes are described in **Appendix D.**



as control was increased through the years. **A**, Darton, 1905; **B**, Darton, 1918; **C**, Bass, 1926; **D**, Lee and

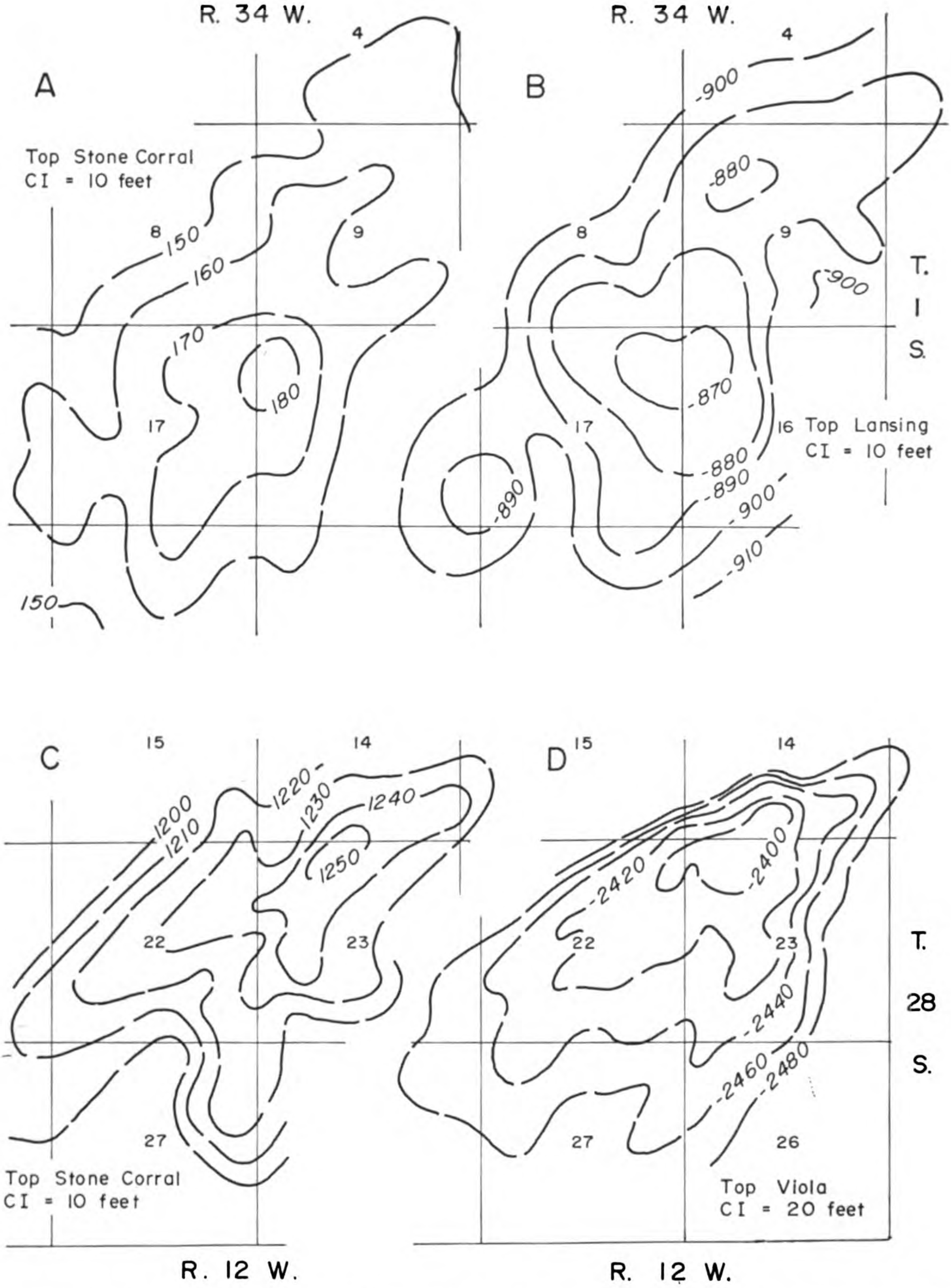


FIGURE 103.—Structure of the Cahoj field in Rawlins County on top of **A,** Stone Corral Formation, and **B,** Lansing Group; structure of Chitwood field in Pratt County on top of **C,** Stone Corral Formation, and **D,** Viola Limestone. Position and shape of structure on Stone Corral and lower units coincide nicely, but magnitude of structure on Stone Corral is less.

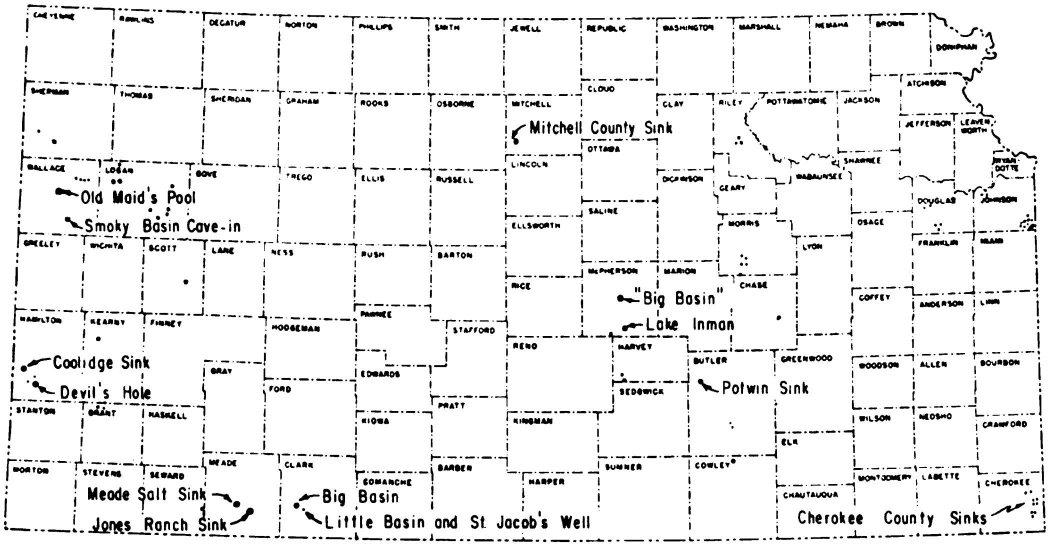


FIGURE 104.—Map showing locations of some better-known sinkholes in Kansas (from Merriam and Mann, 1957).

A sinkhole in Mississippian rocks in Dickinson County affects all overlying beds, including the surface Permian beds (Shenkel, 1955b; Rich, 1930), as does another sinkhole in Morris County.

A distinction should be made between depressions and sinkholes. Sinkholes are formed either by solution-subsidence or solution-collapse, whereas the High Plains depressions are formed by compaction, silt infiltration, or animal action. Frye (1950) gave an excellent summary of the origin of Great Plains depressions (in which he included sinkholes). He cited six causes of these depressions: (1) deep-seated solution, (2) solution of carbonate rocks, (3) eolian action, (4) differential silt infiltration, (5) animal action, and (6) faulting. Only deep-seated solution, solution of carbonate rocks (Pl. 25C), and faulting are factors involved in sinkhole development. The other factors affect development of the High Plains depressions, which are not true sinkholes.

The deep-seated solution features cited by Frye (1950) include Meade Salt Sink, Big Basin (Pl. 26A), Little Basin (Pl. 26B), Jones Ranch Sink, and Ashland-Englewood Basin. Examples of solution of carbonate rocks are the Coolidge Sink and Smoky Basin Cave-in in western Kansas.

Numerous examples can be cited of sinkholes controlled by faulting. C. R. Johnson (personal communication) states that probably all larger ones in Logan County are controlled by an intricate pattern of normal faults in the Niobrara Formation that results in horsts and grabens. Smith (1940) associated the Coolidge Sink in Hamilton County with a line of post-Ogallala faulting. Elias (1931) also cited several examples of linear trends of sinkholes in Wallace County, which he related to presumed faults. The sinks in the Stanton area near Bear Creek probably began to form at the time of folding and faulting of the Syracuse Anticline, and the process is still continuing (McLaughlin, 1946). According to Frye (1950), faulting has played a major role in sink development, especially in Meade County. Surface water has been allowed access to the deeply buried soluble rocks of the Permian via fault planes. Presumably this water circulation was essential to formation of cavities over which subsequent subsidence formed sinkholes. For example, the Meade Salt Sink is associated with and is located just east of the Crooked Creek Fault. Not enough information is available to make any more comparisons, but the correlation of structure to sinkholes is obvious.

Another unusual surface structure possibly controlled by faulting is one herein termed the Kanopolis Structure, which is located in sec. 21, T. 16 S., R. 7 W., in Ellsworth County (Pl. 25D). Beds of the Dakota are strongly deformed here, and the structure is most spectacular for Kansas. Ver Wiebe (1937) stated that

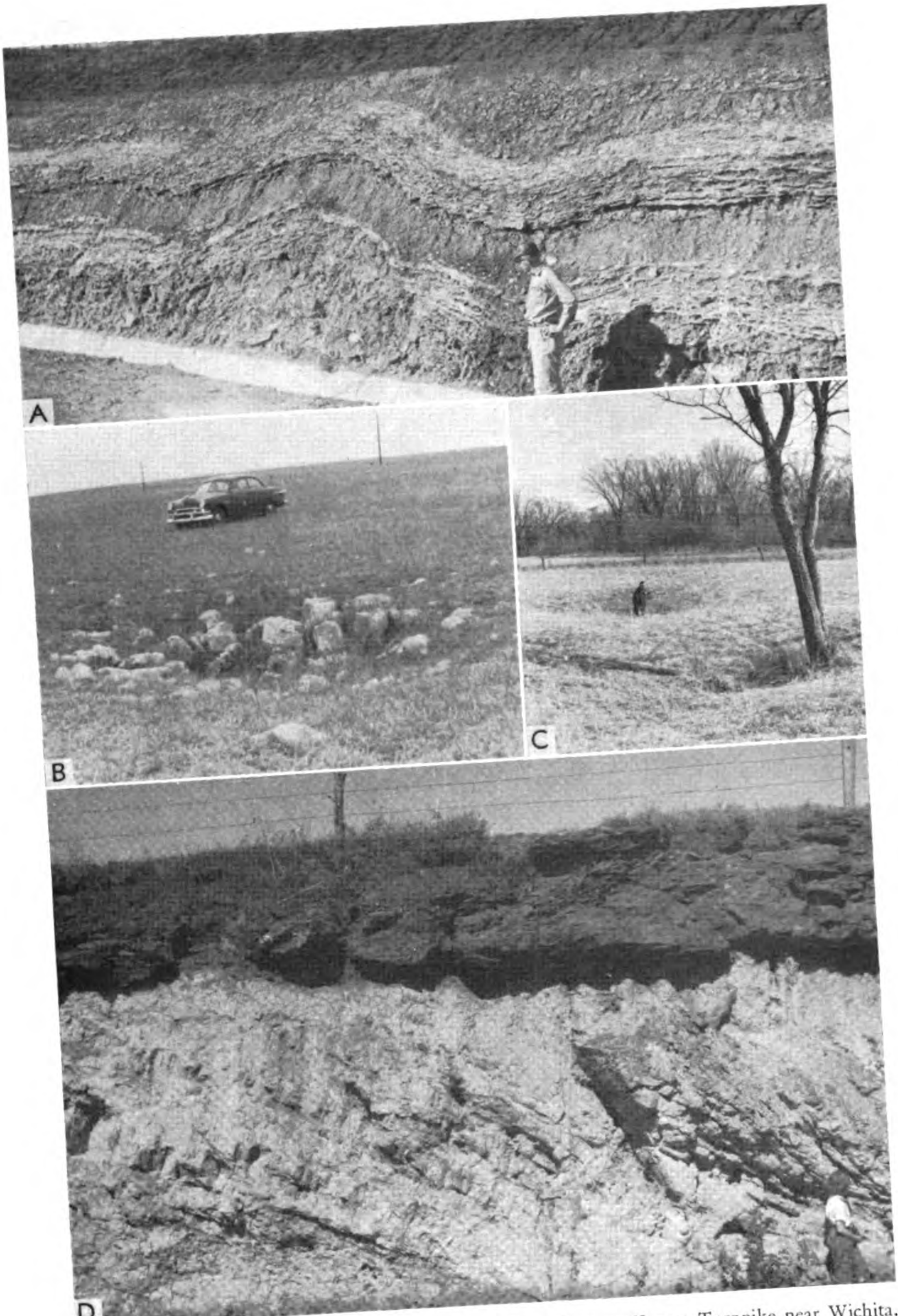


PLATE 25.—**A**, Slump structures in Wellington Formation on Kansas Turnpike near Wichita. Structures presumably were formed by solution of underlying salt at depth. **B**, Sinkhole in Red Eagle Limestone, Lyon County (sec. 23, T. 15 S., R. 11 E.). **C**, Two small sinkholes in Oread Limestone in southwestern Douglas County near Clinton (SE sec. 15, T. 13 S., R. 18 E.); photo by W. R. Atkinson. **D**, Kanopolis Structure in Ellsworth County (SE sec. 20, T. 16 S., R. 7 W.). Note highly disturbed beds below near-horizontal overlying sandstone unit.

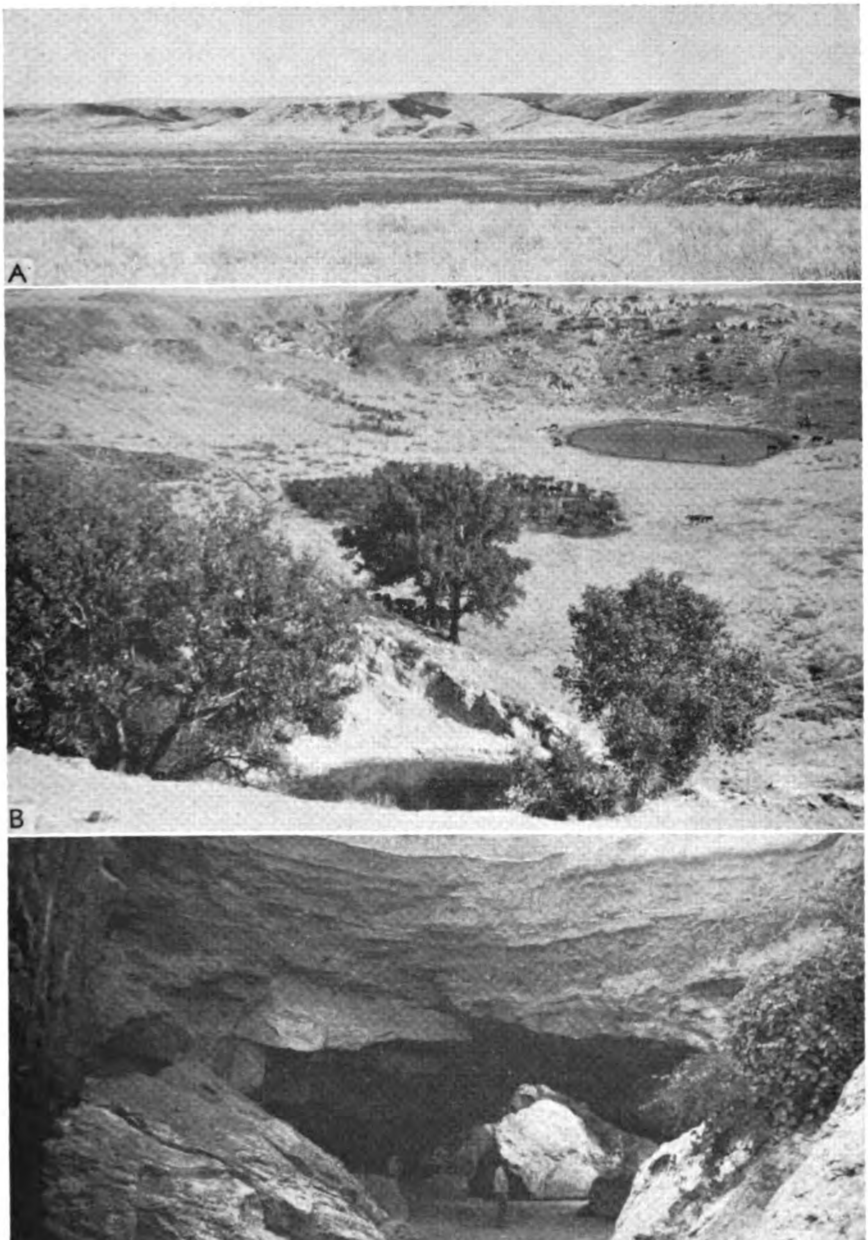


PLATE 26.—**A,** Big Basin, Clark County (sec. 25, T. 32 S., R. 25 W.); **photo by Ada Swineford. B,** St. Jacob's Well in Little Basin, Clark County (sec. 30, T. 32 S., R. 24 W.). **C,** Natural Bridge, which subsequently has collapsed, Barber County (SW sec. **25, T. 31 S., R. 15 W.).**

the explanation of the anomaly was not apparent, but he postulated that solution of rocks beneath the structure allowed the overlying beds to collapse, producing a fine example of a pseudo-angular unconformity.

SURFACE FAULTS IN NORTHWESTERN ELLIS COUNTY

In northwestern Ellis County, Bass (1926) mapped a total of 76 small faults in the Niobrara Formation (Cretaceous), which were assumed to be the surface expression of subsurface solution and subsequent slumping of overlying beds (Pl. 27A). The faults, commonly marked by veins of slickensided calcite as much as 6 inches thick, may be traced for several hundred feet. Because of the lack of closely spaced marker beds in the chalk, determination of the amount of displacement is difficult, but the greatest noted is about 80 feet. The faults show no preferential trend, dip steeply, and seemingly die out downward (Bass, 1926, p. 47). Twenhofel (1925) postulated four possible causes for these small faults: (1) differential settling of the brittle chalk; (2) surficial slumping along present stream valleys; (3) slumping into solution features formed within the chalk; and (4) faulting as a result of regional structural movement.

A cross section was constructed through the Texas No. 1 Hamburg (NE NE SW sec. 3, T. 12 S., R. 20 W.) and Transit No. 1 Hamburg (SE SE SW sec. 34, T. 11 S., R. 20 W.), within the disturbed area, and two wells located outside the disturbed area (Fig. 105, 106). The regularity of thickness of the units is most striking, and it may be noted that there is no evidence of solution of even the most soluble subsurface formations, for example, the Hutchinson Salt Member of the Wellington Formation. The irregularity of the Cretaceous-Permian unconformity is not sufficient to account for

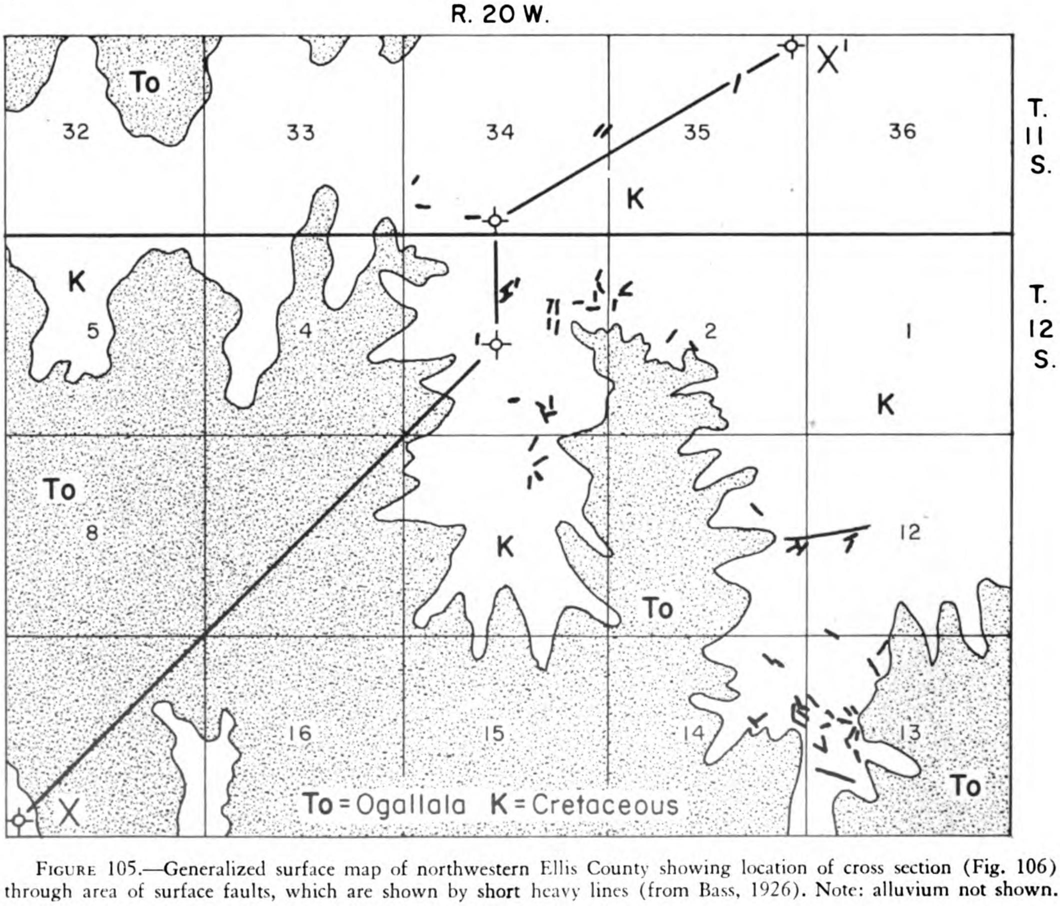


FIGURE 105.—Generalized surface map of northwestern Ellis County showing location of cross section (Fig. 106) through area of surface faults, which are shown by short heavy lines (from Bass, 1926). Note: alluvium not shown.

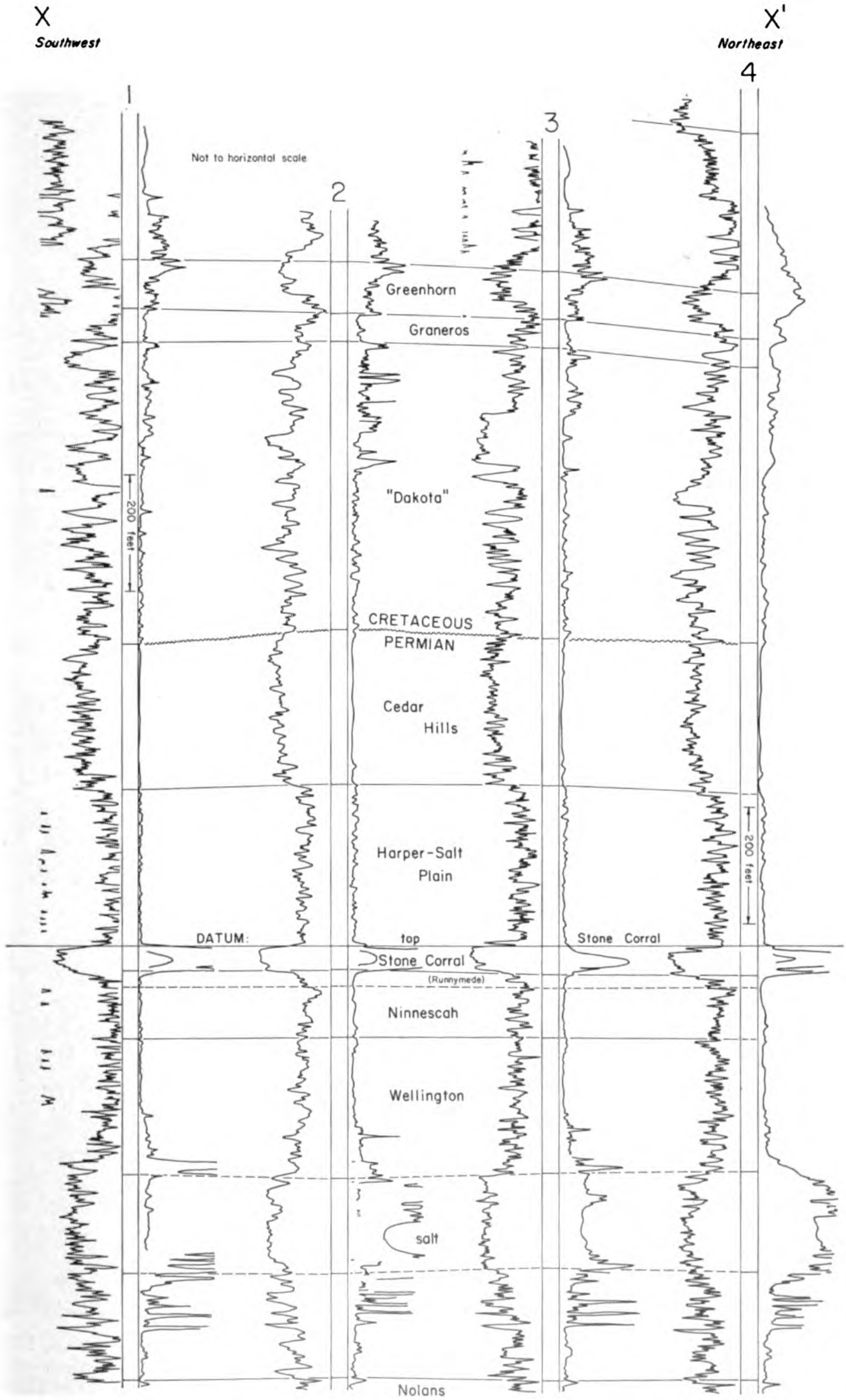


Figure 106.—Electric-log cross section in northwestern Ellis County across area of surface faulting in Niobrara Formation (Cretaceous). Location of cross section shown in Figure 105.

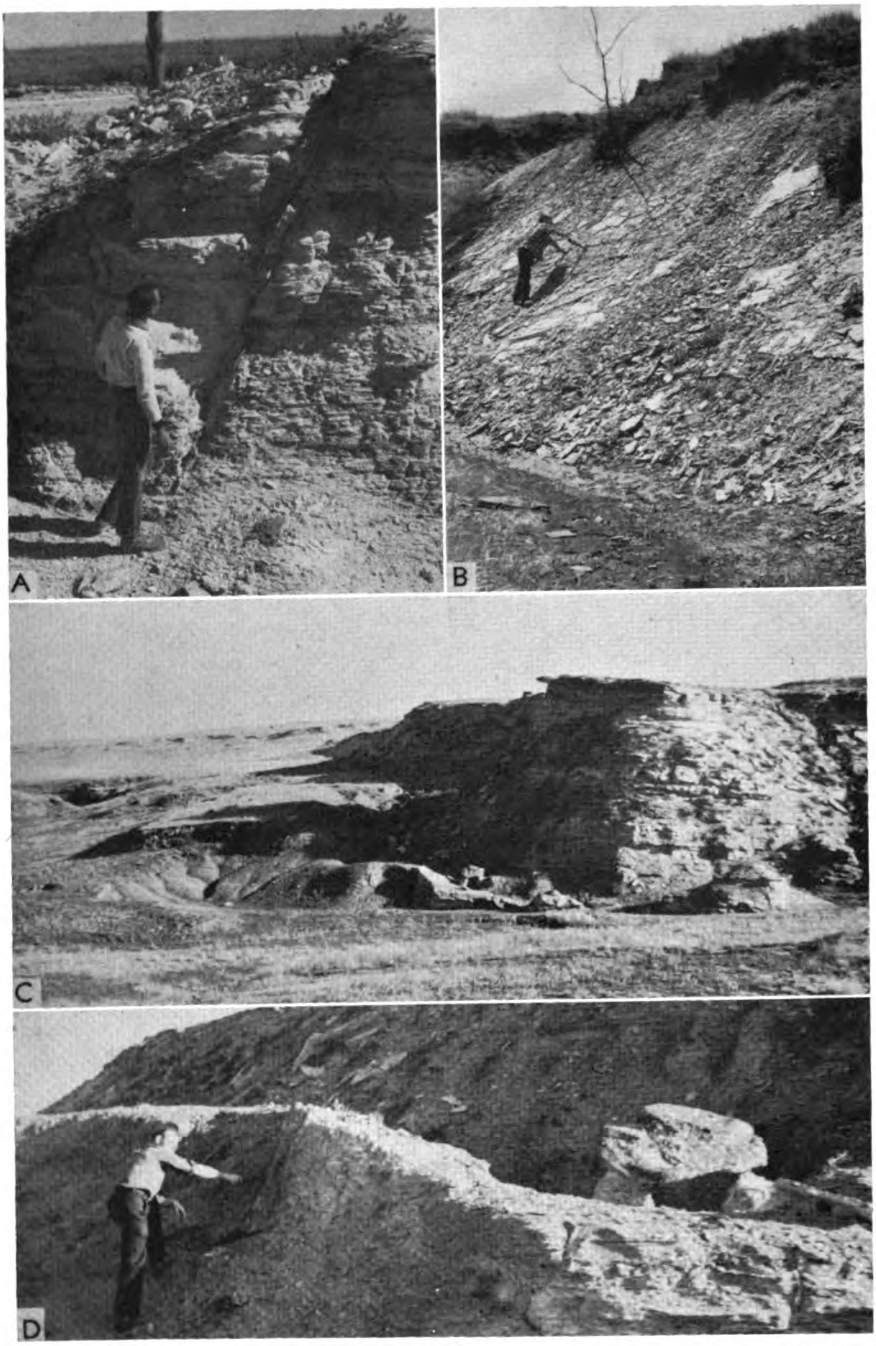


Plate 27.—A, Small fault with about 4 feet of displacement in Niobrara Formation, Ellis County (NE sec. 14, T. 12 S., R. 20 W.). **B,** Shale beds dipping 35°E in post-Stranger pre-Ireland fault block, Douglas County (NE SW sec. 33, T. 14 S., R. 21 E.). **C,** Pierre Shale (left) downfaulted against Niobrara Chalk (right) in Elkader Structure, Logan County (sec. 20, T. 15 S., R. 32 W.). **D,** Closeup of fault zone in Elkader Structure.

the faulting, nor is the irregular thickness of sandstones. Present stream valleys in Ellis County show no evidence of surficial slumping. Therefore, it seems most likely that the surficial faults were caused by differential settling of the brittle chalk beds over more plastic interbedded clayey, chalky shales and not by solution and collapse.

SUBSURFACE SINKHOLES

Some sinkholes preserved in the subsurface in central and eastern Kansas have been described, but none have yet been reported in the western part.

Buried hills and solution features have been recognized from subsurface data in several areas of the Midcontinent region. The Kraft-Prusa, Beaver, and Bloomer oil fields of northeastern Barton County were studied by Walters (1946). The oil occurs in the sedimentary strata surrounding and covering six buried Precambrian hills. The buried solution features were formed in dolomite of the Arbuckle (Cambrian-Ordovician) in early Pennsylvanian time preceding deposition of Pennsylvanian sediments. During this time the Precambrian hills were topographically higher than Cambrian-Ordovician rocks, which dip slightly away from the hills. The entire area was above sea level and was undergoing weathering and erosion, resulting in a youthful karst plain.

Each of the six buried hills is completely surrounded by a moat-type solution valley 20 to 80 feet deep having no known surface outlet. The inside wall of each valley, of course, is Precambrian rock and the outside valley wall is a low Arbuckle cuesta; hence, the profile is asymmetric. It is interesting to note that the wider and broader part of the asymmetrical valley formed adjacent to the most gentle hill slope, that the widest valley is around the largest hill, and that the narrowest valley surrounds the smallest hill.

Sinkholes on the plain surrounding the low hills are scattered and abundant but small. Many wells in the area were drilled on a 10-acre spacing; hence, some of the sinkholes are known to occupy less than 20 acres. The sinkholes are 10 to 60 feet deep. Valley sinks also found on the plain were attributed by Walters to coalescence of closely spaced sinkholes.

Walters emphasized the fact that although the physiographic features of the sinkholes and of the valleys surrounding the hills imply that these are solution phenomena, they do not prove such an origin. The proof is provided by the occurrence, in the lowest part of the depressions, of untransported residual weathered products from the dolomite. This residuum includes fragments of chert, clay, sand, silt, quartz crystals, and shale; the insoluble residues obtained in the laboratory by dissolving unweathered Cambrian-Ordovician dolomite core samples consist of the same materials.

A well in the Bemis pool, Ellis County, is judged to have penetrated a sinkhole in the Arbuckle, because it reached the Arbuckle 270 feet lower than did nearby wells on each side (Gordon, 1938). Another well in the same pool encountered weathered chert, derived from Mississippian rocks, in a cavern in the Arbuckle.

In the Silica pool, Barton County, karst topography is indicated by 36 known depressions in the Arbuckle, each filled with detrital material of early Pennsylvanian age (Ver Wiebe, 1941). The Lario No. 2 "A" Zohorsky well probably penetrated the deepest sink, because it encountered 163 feet of such conglomerate.

The Trapp pool, Russell and Barton Counties, has at least 12 subsurface depressions, which are believed to be ancient sinkholes in calcareous Arbuckle beds. The depressions are as much as 168 feet deep.

Sinkholes in Arbuckle rocks in the Ryan oil field, Rush and Pawnee Counties, on the southwestern flank of the Central Kansas Uplift, contain remnants of Simpson shale (Redman, 1947). Preservation of these remnants 20 miles from the main subcrop is attributable to their position in the bottom of sinkholes.

Sinkholes other than the previously described Simpson-filled ones are known in eastern Kansas. A sinkhole in Mississippian rocks in the Davis Ranch oil pool, Wabaunsee County, contains an abnormal thickness (420 feet) of Cherokee sediments (Smith and Anders, 1951). Lee (1940) mentioned a sinkhole on the buried Mississippian surface in Sumner County. Increased drilling for oil and gas will undoubtedly reveal other buried sinkholes. In general, the Arbuckle and Mississippian rocks are more susceptible to sinkhole formation than are other subsurface units.

Structure on Top of "Algal Limestone" (Pliocene)

The structure mapped on the "Algal limestone," defined as marking the top of the Ogallala Formation, reveals a monotonously uniform east dip, which reflects none of the major structural features of western Kansas

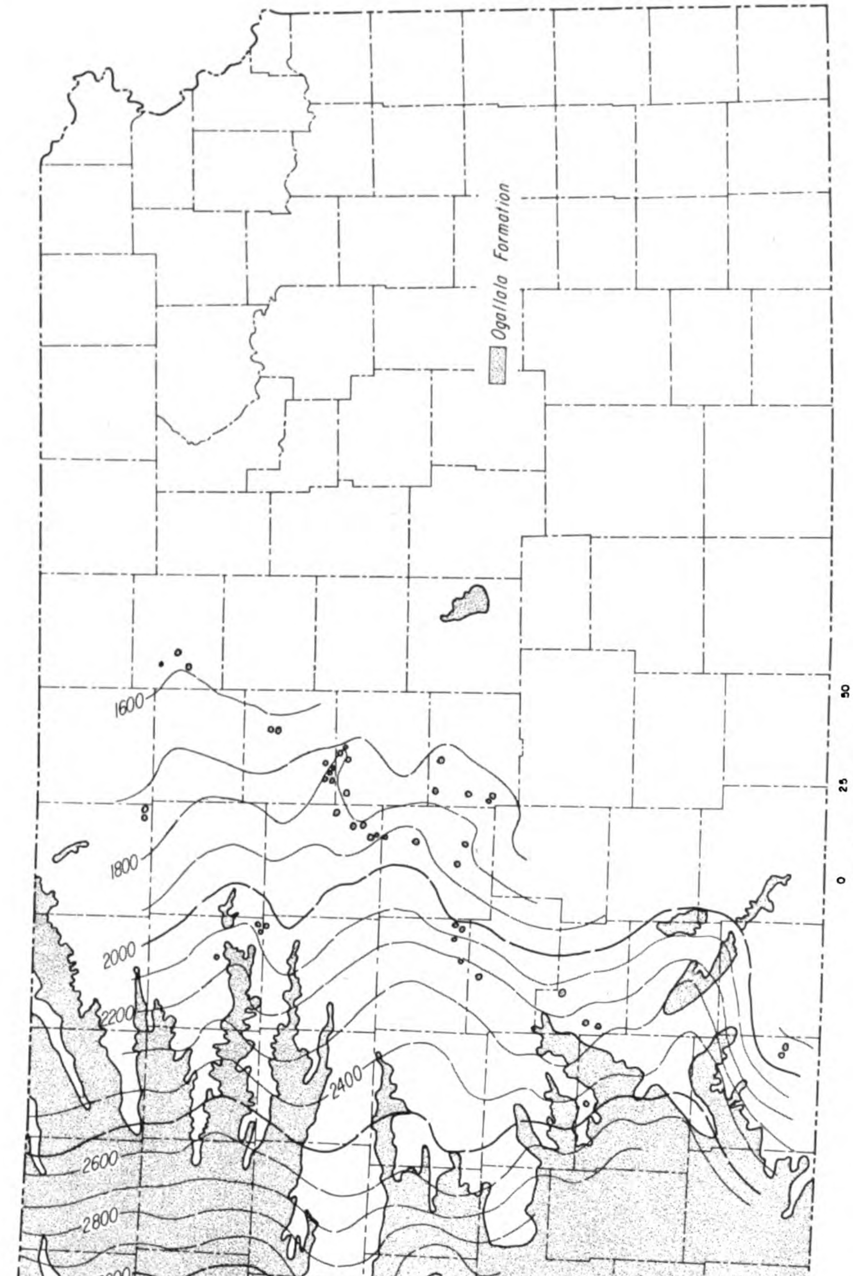


FIGURE 107.—Preliminary regional structural map contoured on top of "Algal limestone" (Ogallala Formation, Pliocene) in Kansas (adapted from Merriam and Frye, 1954). Contour interval 100 feet.

(Fig. 107). This is in strong contrast to structure displayed by other horizons and indicates absence of orogenic movement after deposition of the "Algal limestone." This bed overlies a sequence of alluvial sediments deposited by eastward-flowing streams, and it is judged that accentuation of an initial easterly dip can be attributed to epeirogenic eastward tilting of the Kansas-Colorado region. The dip of this surface, from an elevation of slightly more than 4,000 feet at the Colorado line to 1,600 feet in Mitchell and Lincoln Counties in central Kansas, averages only about 15 feet per mile.

Minor structural elements consist of eastward-trending, eastward-plunging noses. A small feature of this sort occurs in central Wallace County and another in southern Lincoln and northern Ellsworth Counties. Similar structural noses in Scott and Kiowa Counties are larger and more prominent.

In a large area—including Kearny, Grant, Haskell, Gray, Stevens, Seward, and Meade Counties—which is covered by post-Ogallala deposits, "Algal limestone" seems to be absent, but it may cover areas so small that it has not yet been found by drilling, or it may not have been recognized.

Structure on Base of Niobrara Formation (Cretaceous)

Although control is sparse, a structure map on the base of the Niobrara Formation (Fig. 108) shows features similar to those revealed on other Cretaceous horizons. Because of their likeness to this and the Dakota map, those prepared on top of the Niobrara and top of the Greenhorn Limestone are not reproduced here.

Owing to the restriction of the Niobrara to northwestern Kansas, the only major structural elements that can be recognized are the Cambridge Arch, part of the Western Kansas Basin, and the east flank of the Las Animas Arch. The same minor structural features as those on the Dakota are recognizable. The dominant structural feature is the long, linear, northerly plunging marginal syncline along the eastern border of the Las Animas Arch. The low regional dip, about 15 feet per mile, is northward. The greatest elevation above sea level is 3,400 feet, in Hamilton County, and the lowest is 1,450 feet, in Cheyenne and Phillips Counties.

Structure on Top of Dakota Group (Cretaceous)

A structure map (Fig. 109) shows the present attitude of the top of the Dakota Group (Gulfian Series). The 1,500 datum points used in making the map are limited to the western and central parts of Kansas, where Cretaceous deposits are present.

The structural conditions revealed by mapping the top of the Dakota indicate movements that occurred in Late Cretaceous and later time. Regional movements near the end of the Cretaceous and near the end of the Tertiary, which are most evident in the Rocky Mountains, affected most or all of Kansas and were closely connected with the subsidence of the Denver Basin. Three major structural features are indicated on the Dakota structure map. The average northerly dip in the central part of the area is about 7 feet per mile.

The north-dipping Western Kansas Basin probably was formed near the end of the Mesozoic. Several minor structures are evident in the basin.

The dip of beds on the eastern flank of the Las Animas Arch in western Kansas was accentuated after Dakota time, and in Kansas it was mainly a post-Cretaceous structural feature (Lee and Merriam, 1954a). The surface of the Dakota on the Las Animas Arch displays an average northeasterly dip of 20 feet per mile from Hamilton County to northeastern Gove County.

The Cambridge Arch is reflected in Cretaceous beds, indicating structural movement at least as late as post-Niobrara time. The arch separates the Western Kansas Basin on the west from the Salina Basin on the east and plunges southward, dying out in the vicinity of the northern end of the area of the Central Kansas Uplift. The arch was affected by adjustments in the Denver Basin and was subjected to northerly and northwesterly tilting.

Many minor structures are revealed in western Kansas when the top of the Dakota rocks is contoured at an interval smaller than 50 feet (Merriam, 1957c). One of the more prominent of these structures is located in the southeastern part of the Western Kansas Basin and is called the Fairport Anticline. The anticline is asymmetrical, the west side being steeper, and it trends and plunges slightly east of north. The northeast-plunging Agra Anticline, on the west flank of the Salina Basin, extends from northern Rooks County across southeastern Phillips County and northwestern Smith County, Kansas, into Franklin County, Nebraska. Because information in this area is scanty, the exact geographic position of the structural axis is not known. Just west of the Agra Anticline and paralleling it is the Stuttgart-Huffstutter Anticline, which

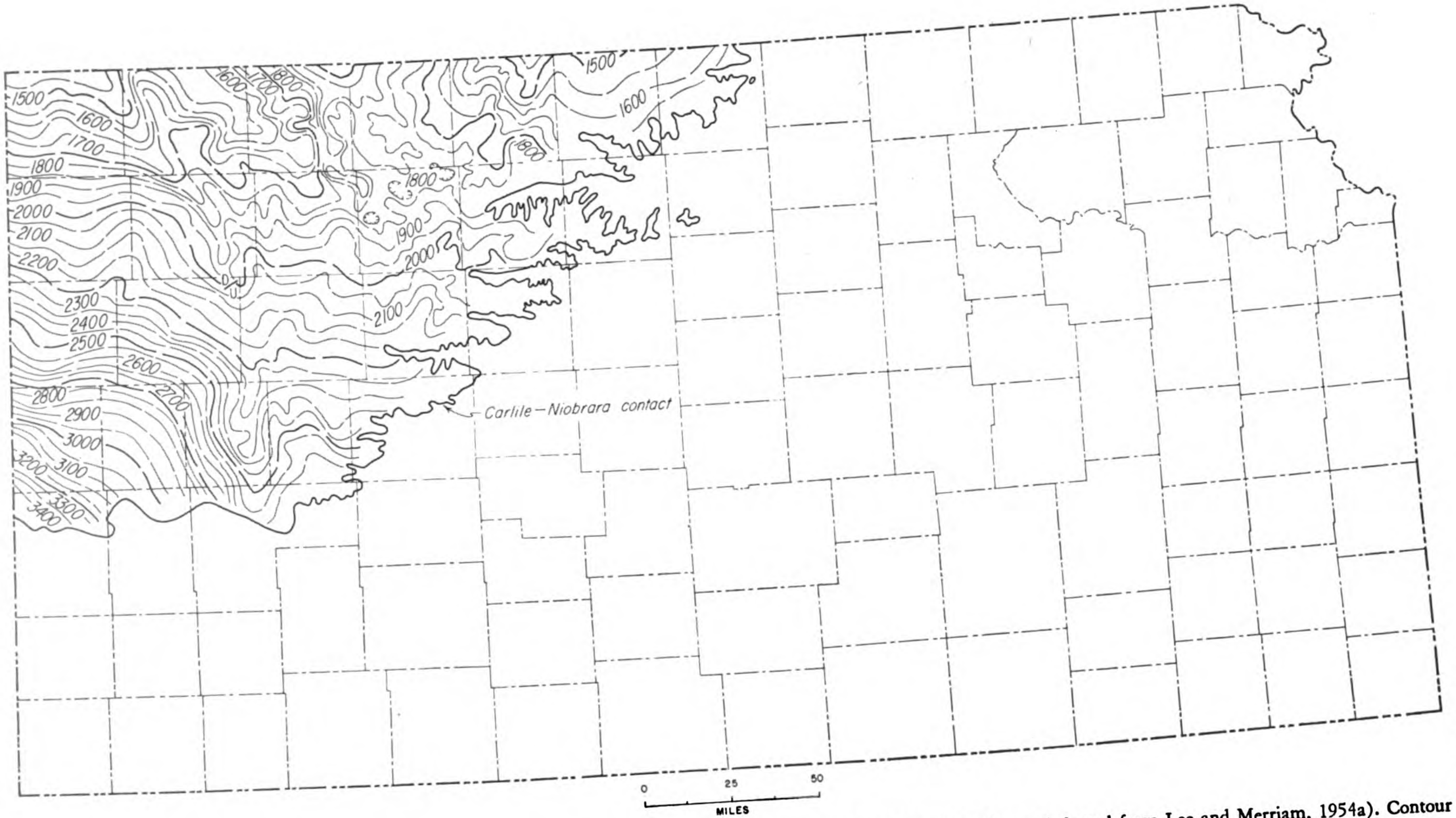


FIGURE 108.—Preliminary regional structural map contoured on base of Niobrara Formation (Cretaceous) in Kansas (adapted from Lee and Merriam, 1954a). Contour interval 50 feet.

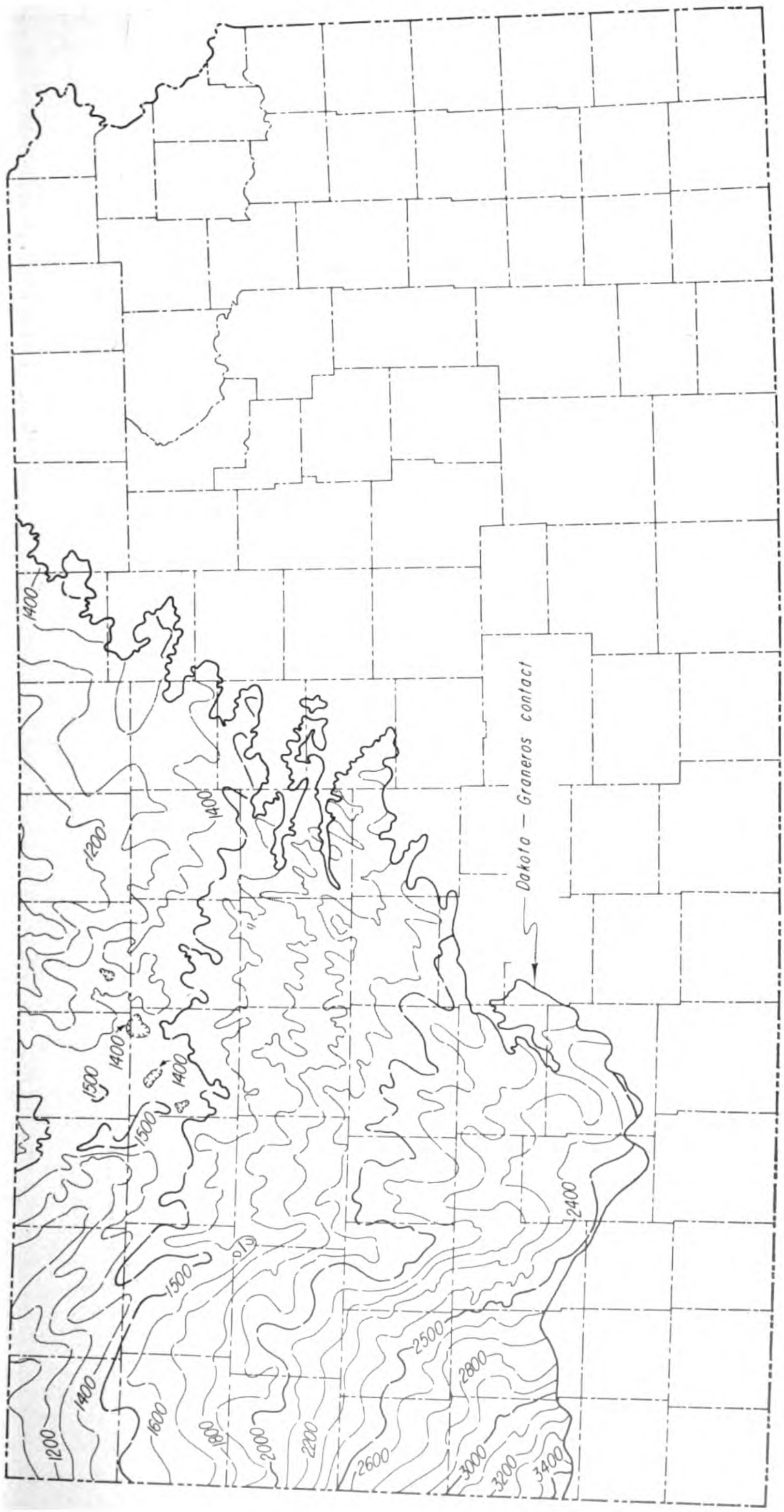


FIGURE 109.—Preliminary regional structural map contoured on top of Dakota Group (Cretaceous) in Kansas (adapted from Merriam, 1957c). Contour interval 100 feet.

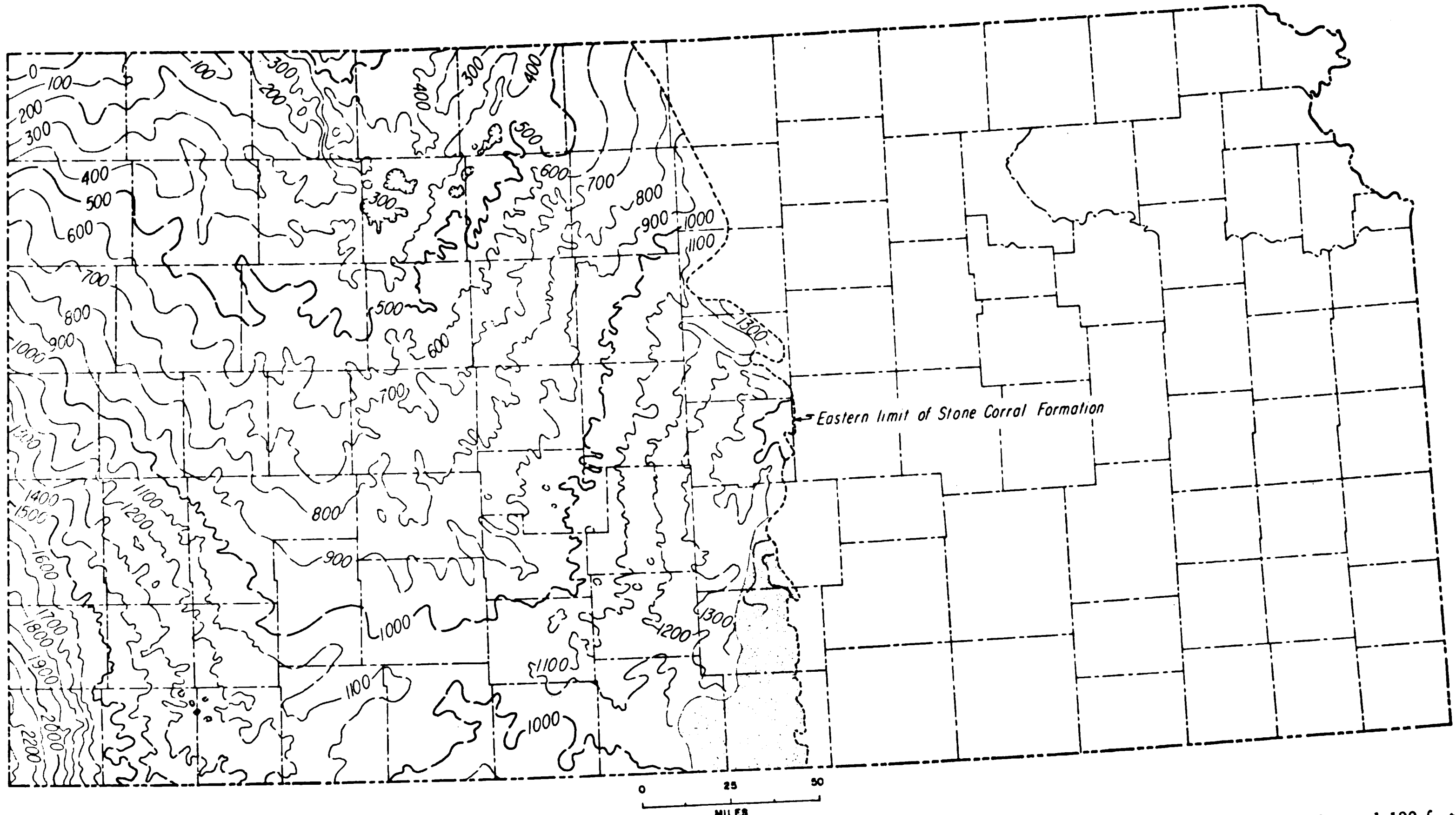


FIGURE 110.—Preliminary regional structural map contoured on top of Stone Corral Formation (Permian) in Kansas (from Merriam, 1958b). Contour interval 100 feet. Stone Corral could not be identified with certainty in well logs in shaded area.

extends from northeastern Graham County across Phillips County into Harlan County, Nebraska. Regionally, the structure plunges northeasterly, but several small closures are located along the axis. Between the Stuttgart-Huffstutter Anticline and the Cambridge Arch is a small northeast-plunging syncline, which has been termed the Long Island Syncline. This structure is a re-entrant of the Salina Basin.

A minor subsidiary structure of the Cambridge Arch in southeastern Decatur County, northeastern Sheridan County, and northwestern Graham County is called the Jennings Anticline. The axis of this structure approximately parallels that of the Cambridge Arch, and numerous small closures are located along the axis. To the west of the Cambridge Arch is the northwest-plunging Selden Syncline, a minor feature of the Western Kansas Basin. The paucity of data in this area makes it difficult to determine the location of the axis.

In southwestern Hamilton County, on the east flank of the Las Animas Arch, is a small east-trending structure termed the Syracuse Anticline, shown by McLaughlin (1943) to be faulted along the southern and southeastern flank. The lack of information makes it difficult to determine the exact position of the axis. The Bazine Anticline is discernible in Cretaceous rocks in the southern part of the Western Kansas Basin. The anticline extends from northwestern Ford County through Hodgeman County and southeastern Ness County to Rush County. The axis of the structure trends and plunges northeasterly.

Structure on Top of Stone Corral Formation (Permian)

The structure on top of the Stone Corral, shown on Figure 110, is the result of post-Stone Corral deformation. Although it does not everywhere reflect the regional structure of the older rocks with complete accuracy, Merriam (1955c) has shown that it is a good indicator of Pennsylvanian structure in local areas. About 4,950 wells were used in preparing this map.

Several major structural elements of western Kansas are evident on the map, including the southern end of the Cambridge Arch in Norton and Decatur Counties, the Western Kansas Basin, and the eastern flank of the Las Animas Arch, especially evident along the Colorado line. The average northerly regional dip in the central part of the area is about 5 feet per mile.

The Central Kansas Uplift is a broad, northwest-sloping surface flanked on the northeast and southwest by secondary synclines. The surface displays no regional arching, but many minor north- to northwest-plunging anticlines and synclines occur in the area (Lee and Merriam, 1954a). North-trending folds are represented by the Fairport Anticline in Russell County and Stuttgart-Huffstutter Anticline in Phillips County. Northwesterly folds are exemplified by the Wakeeney Anticline in Trego County.

A broad syncline, in the area of the Salina Basin, seems to border the northeastern margin of the Central Kansas Uplift in Osborne and Smith Counties and eastern Phillips County, but data are available from only a few wells. The syncline trends and plunges northwest, turning north on the east flank of the Stuttgart-Huffstutter Anticline.

The southeastern end of the asymmetrical Cambridge Arch is represented in Decatur and Norton Counties as a south-plunging arch. It is separated from the area of the Central Kansas Uplift by a saddle in which there are several closed synclinal basins. Secondary folds on this part of the Cambridge Arch resemble the northwest-trending folds in the area of the Central Kansas Uplift, except that they plunge to the southeast.

A dip of about 16 feet per mile on the northeastern flank of the Las Animas Arch in southwestern Kansas is modified by northeast-plunging anticlines and synclines.

The Western Kansas Basin, lying between the Las Animas Arch and the area of the Central Kansas Uplift, is limited on the south by the broad, west-trending Comanche Arch, which extends across southern Kiowa County and northern Clark County and south through eastern Meade County. It is bordered on the east by the northwest-sloping surface of the quiescent Central Kansas Uplift, with which it is roughly parallel, and on the west by the northeastern flank of the Las Animas Arch. The basin is a broad, north-plunging syncline roughly 100 miles wide and 200 miles long that extends an undetermined distance into Nebraska.

All the numerous secondary folds in the basin plunge northward. The structures on the eastern side of the basin are roughly parallel to the Central Kansas Uplift but those on the western flank trend northeast, then north, before paralleling the Central Kansas Uplift or the Cambridge Arch.

One conspicuous anticline is nearly 200 miles long. It originates in northern Finney County as a northeast-trending fold, swings north

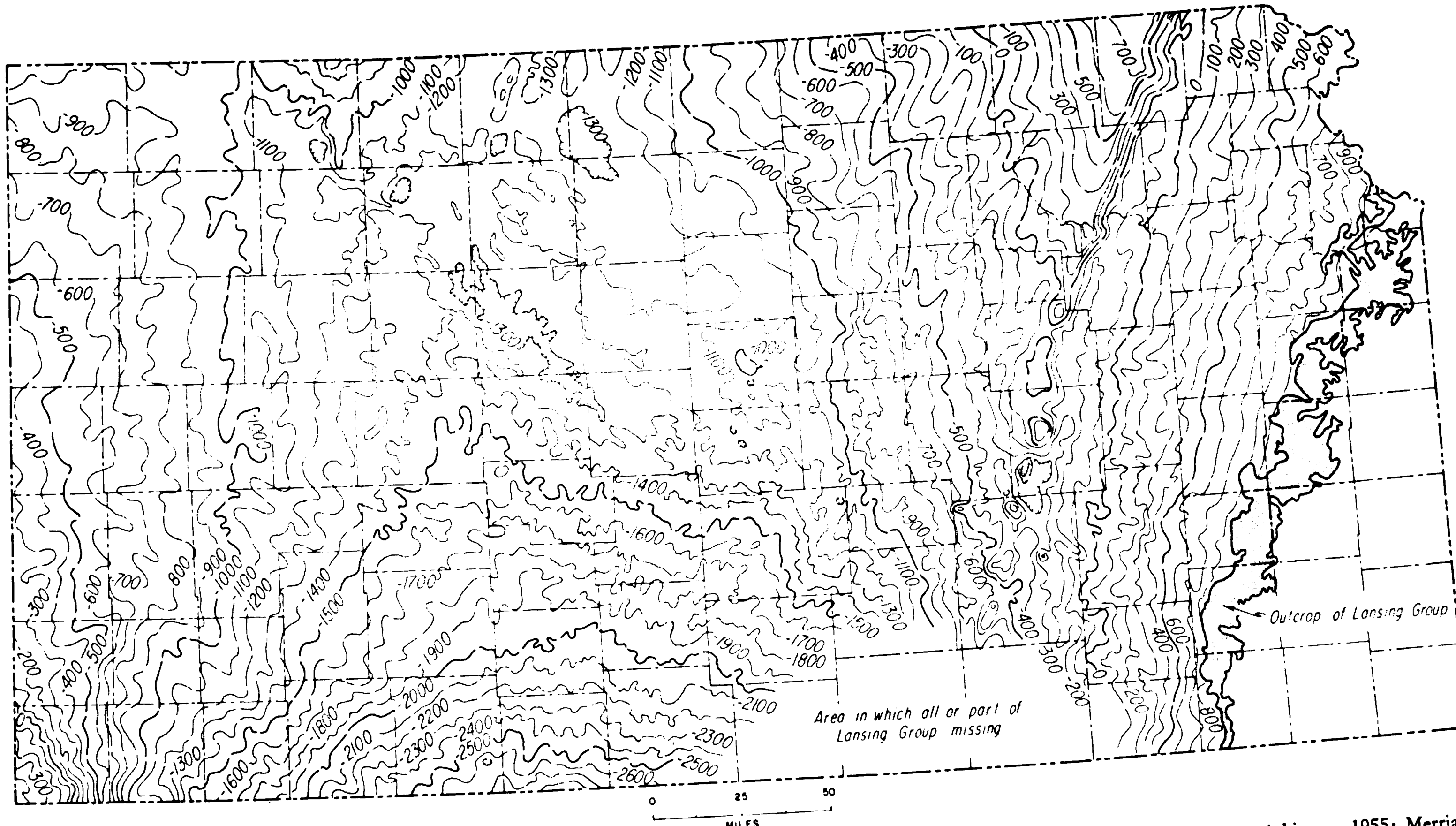


FIGURE 111.—Preliminary regional structural map contoured on top of Lansing Group (Missourian, Pennsylvanian) in Kansas (adapted from Atkinson, 1955; Merriam, Winchell, and Atkinson, 1958). Contour interval 100 feet.

through Lane and Gove Counties, thence northwest, paralleling the southern end of the Cambridge Arch. A syncline parallels this anticline on the west and is well defined in Scott and Logan Counties but less so in Thomas and Rawlins Counties. It is quite possible that these long linear features are actually interrupted, discontinuous, or ***en echelon*** folds, but control is not adequate for such interpretation.

Many other minor structures are revealed on the map, including the Jennings Anticline, Selden Syncline, Stuttgart-Huffstutter Anticline, and Long Island Syncline; Keyes Dome in extreme southwestern Kansas is evident.

Structure on Top of Lansing Group (Pennsylvanian)

The most pronounced feature revealed by structure on top of Lansing rocks is the south-plunging Nemaha Anticline (Fig. 111; Merriam, 1959a). The Nemaha, or so-called "granite ridge," is a major feature in the subsurface of the Midcontinent area, and it is important in controlling petroleum accumulation along its crest and flanks. It extends from Omaha, Nebraska, southwesterly across Kansas to Oklahoma City, Oklahoma. It is asymmetrical, having a steeper east flank, which locally is faulted.

Beds dip relatively steeply from the east flank of the Nemaha into the adjacent Brownville Syncline, the axis of which parallels that of the anticline. The syncline plunges southwesterly and is asymmetrical, the steep flank adjoining the Nemaha (Fig. 111). Eastward, the beds rise gradually toward the Ozark Dome in Missouri, forming the Prairie Plains Homocline on which are superposed many small structures, some of which trend northeast.

West of the Nemaha Anticline, the Lansing surface dips gently westward into the trough of the Salina Basin. Many minor structures are apparent on the east flank of the basin, the most prominent being the Abilene Anticline, which plunges southwestward across Riley and Dickinson Counties. The axis of the Salina Basin extends northwestward from southwestern Saline County into Nebraska. The Central Kansas Uplift limits the western flank of the basin.

Evidence of a structural divide between the Salina and Sedgwick Basins is a vaguely discernible saddle that extends eastward from the southwestern corner of Saline County through northern McPherson and Marion Counties. The axis of the Sedgwick Basin trends and plunges slightly west of south, and on the eastern flank of the basin are several minor but important northeast-trending anticlinal structures.

In parts of Barber, Harper, Kingman, Sumner, Sedgwick, Butler, Cowley, and Chautauqua Counties, part or all of the Lansing Group is absent (Winchell, 1957). A structural map contoured on the Haskell Limestone (a slightly higher datum often used for structural mapping) shows the Sedgwick Basin, Nemaha Anticline, Brownville Syncline, and Prairie Plains Homocline much as they would appear if the contours on the Lansing were extrapolated into the area.

The southern end of the southeast-trending Cambridge Arch and subsidiary structures are evident in parts of Decatur, Norton, Sheridan, and Graham Counties. The major northwest-trending Central Kansas Uplift forms the backbone of Kansas structure. On the broad, flat crest of the uplift, located mainly in Ellis County, is a shallow synclinal area (outlined by the minus 1300-foot contour). Numerous minor northwest-trending anticlines also are evident along the crest and flanks of the uplift. The Geneseo Uplift and Ellsworth Anticline, near the southeastern margin of the uplift in northern Rice and Ellsworth Counties, are outlined by the minus 1100-foot contour.

The Pratt Anticline is weakly reflected on Lansing structure. This northeast-trending, southwest-plunging anticline is located in southern Stafford County and parts of Pratt and Barber Counties. Where the structure dies out southward, the Sedgwick Basin merges into the southern part of the Hugoton Embayment as the Northern Shelf or Northern Basin Shelf of the Anadarko Basin.

The Hugoton Embayment of the Anadarko Basin, covering about one-third of Kansas, is limited on the eastern flank by the Cambridge Arch, Central Kansas Uplift, and Pratt Anticline, and on the western flank by the Las Animas Arch, which is located in Colorado. The shallow axis of the embayment extends from southeastern Clark County through Kiowa, Edwards, Pawnee, Rush, Trego, and Graham Counties to Sheridan County. North of Sheridan County the axis extends northwestward across Decatur and Rawlins Counties, and the feature is termed the Selden Syncline. Numerous subsidiary structures occur on both flanks of the embayment.

Structure on Top of Mississippian Rocks

The structure on top of Mississippian rocks is shown statewide on Figure 112. Mississippian rocks crop out in extreme southeastern Kansas. In the subsurface they have been re-

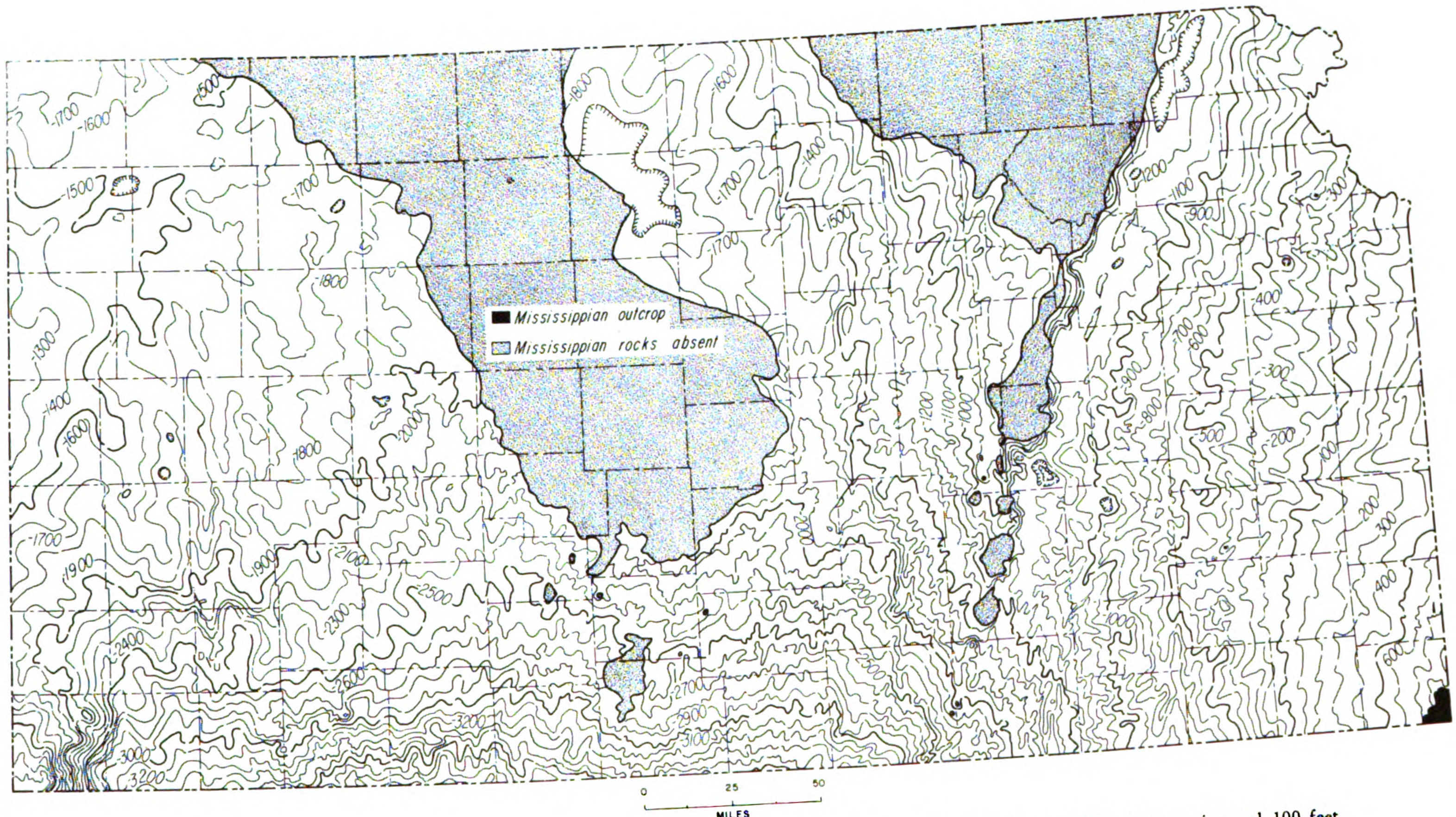


FIGURE 112.—Preliminary regional structural map contoured on top of Mississippian rocks in Kansas (from Merriam, 1960b). Contour interval 100 feet.

moved from higher parts of major uparched areas. Slightly more than 4,800 control points were used in preparing the map.

Published maps utilized in contouring the Mississippian surface include: northeastern Kansas by Lee and Payne (1944), Wilson County by Stryker (1925), Virgil field (T. 24 S., R. 12 E.) by Beekly (1929), southern Woodson and northern Wilson Counties by Hambleton and Merriam (1955), southwestern Crawford County by Dreyer (1947b), and parts of Cowley County by Bass (1929). Other information was obtained from Beebe (1957), Boughton (1920), Knight and Landes (1932), Maher and Collins (1949), Schrader (1908), Snow and Dean (1929), and Veroda (1959). The first known published map showing structure on top of the Mississippian in Kansas was by Moore and Haynes in 1917.

Regional dip of the Mississippian surface in southeastern Kansas is to the west or slightly north of west. This homoclinal surface is interrupted by numerous minor but economically important structures. In Chase, Butler, and Cowley Counties the homocline terminates in a narrow, sinuous syncline which parallels the east flank of the Nemaha Anticline. The dip on the east flank of the Nemaha is relatively steep, whereas that on the west flank is more gentle.

The slightly elongate Fredonia Dome, in Wilson County, is one of the more prominent minor structural features. The Longton Ridge, extending from eastern Chautauqua County through eastern Elk County, northwestern Wilson County, and southeastern Woodson County into Allen County, may be traced in surface Pennsylvanian rocks. In southern Woodson County, the Rose and Silver City intrusives occur on this trend. West of the Longton Ridge is another prominent, northeast-trending, south-plunging anticlinal structure, the Dexter-Otto Anticline. The northern part of this structure has also been called the Beaumont Anticline. The structure is traceable both on the Mississippian and in surface Pennsylvanian strata from eastern Cowley County through southeastern Butler County, Greenwood County, and northwestern Woodson County into southwestern Coffey County. West of the Dexter-Otto Anticline and parallel to it is the less pronounced Winfield Anticline, which extends across Cowley County and part of Butler County.

Although major structure trends northeast, several northwesterly trends are prominent. One extends diagonally across Lyon, Coffey, and Allen Counties; another trends northwest across southeastern Chase County, southwestern Lyon County, southwestern Coffey County, and Woodson County. A third extends from southeastern Chase County through northeastern Greenwood County to southwestern Woodson County. It is interesting to note that the two sets of structural trends intersect at Rose and Silver City Domes in Woodson County, where intrusives occur.

In northeastern Kansas the Mississippian surface, dipping gently to the northwest, forms the southeastern flank of the Forest City Basin. The structure is interrupted by small reversals such as the McLouth (Jefferson and Leavenworth Counties) and Alma Anticlines (Lee and Payne, 1944; Merriam, 1960a). The basinal axis, the Brownville Syncline, is prominent adjacent to the Nemaha Anticline and is traceable through parts of Morris, Wabaunsee, Pottawatomie, Jackson, Nemaha, and Brown Counties. The Mississippian surface rises relatively rapidly on the west limb of the Forest City Basin, giving the basin a decidedly asymmetrical aspect.

West of the Nemaha Anticline, dip of the surface is westward into the lower parts of the Salina and Sedgwick Basins. On this flank are several prominent anticlines, including the Abilene, Lindsborg, and Voshell. Shenkel (1959) described the geologic history of the Abilene Anticline, which is nearly parallel to the Nemaha and extends from Marshall County through Riley and southeastern Clay Counties to Dickinson County. The Irving Syncline is parallel to and east of the Abilene Anticline. The faulted, north-trending Voshell Anticline has several areas of closure along its crest. The west side of the feature is faulted and may have a throw of about 400 feet (Bunte and Fortier, 1941, p. 110). The Lindsborg structure is similar in size and shape to the Voshell, although no evidence of faulting has been found.

The Sedgwick Basin is reflected as a south-dipping surface having many minor, south-plunging structural noses and re-entrants. Many structures, especially on the eastern side of the basin, are semiparallel or parallel to the Nemaha Anticline. The west side of the basin is not readily discernible, although Shenkel (1955a) interpreted the Pratt Anticline as a broad, south-plunging anticlinal fold in Pratt and Barber Counties. The Cunningham structure (Rutledge and Bryant, 1937) is a prominent, northeast-trending anticlinal feature on the western side of the Sedgwick Basin in eastern Pratt County and northwestern Kingman County.

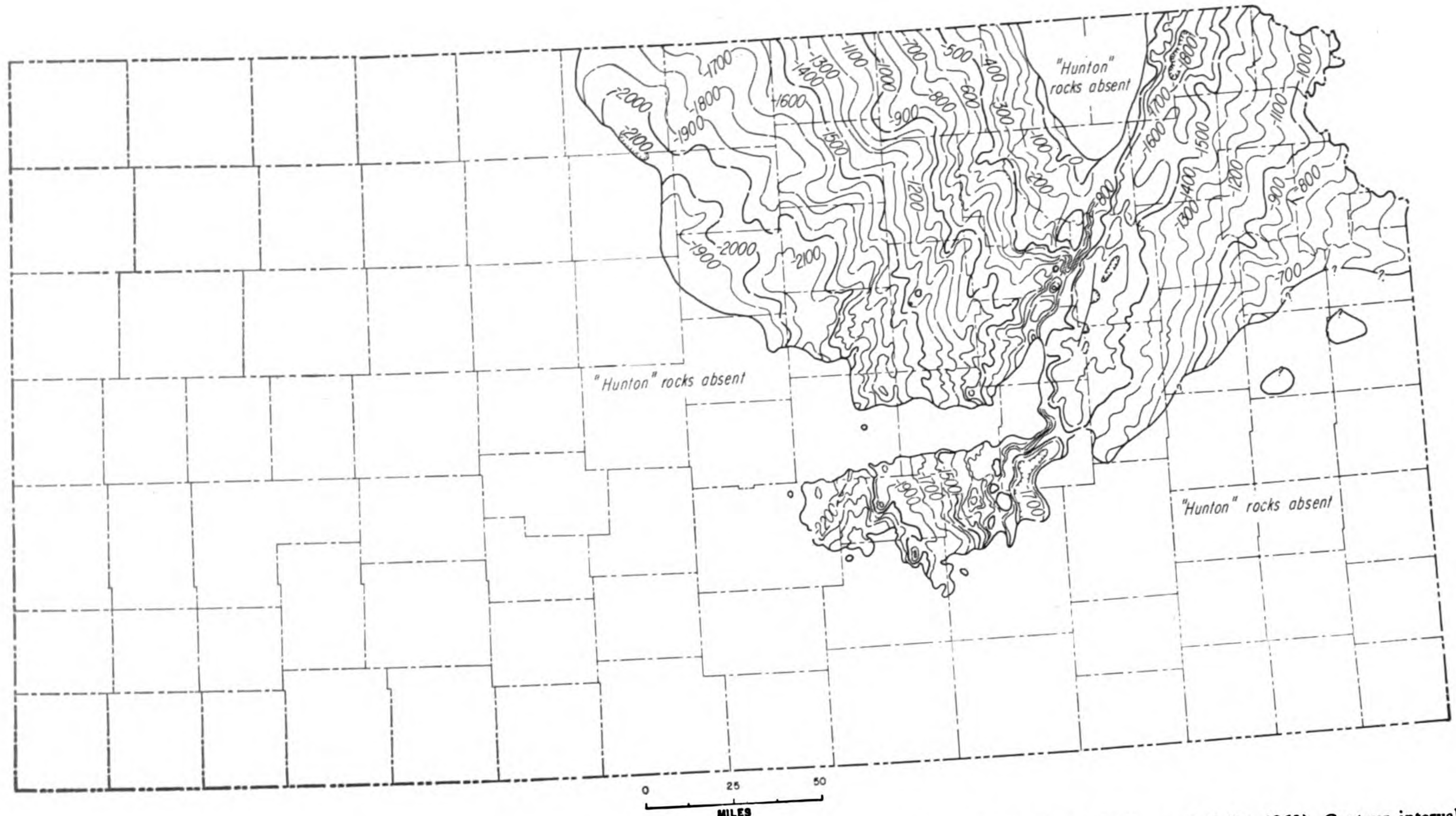


FIGURE 113.—Preliminary regional structural map contoured on top of "Hunton" rocks (Silurian-Devonian) in Kansas (from Merriam and Kelly, 1960). Contour interval 100 feet.

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West of the Central Kansas Uplift and Cambridge Arch is the large, shovel-shaped Hugoton Embayment. The eastern flank of the Las Animas Arch and many minor, north-plunging bifurcations are evident. In the embayment are long, narrow, south-plunging anticlinal structures; some, such as the Pleasant Prairie and Eubank, are faulted. Many small domal structures, such as Kismet in eastern Seward County, are evident, as is the northeast flank of the Keyes Dome in Morton County.

Structure on Top of "Hunton" Rocks (Silurian-Devonian)

The structure on top of "Hunton" rocks in Kansas (Fig. 113), almost identical to that revealed on top of the Mississippian, was interpreted from about 1,150 control points.

Numerous minor structures break the monotony of the homoclinal northwest dip of the southeast flank of the Forest City Basin. The Alma Anticline especially is evident just east of the basinal axis. The west flank of the basin is shown as an area of steep dip, because it was not possible to show all of the contours at this scale. West of the Nemaha the rocks dip gently westward into the Salina Basin.

The Salina Basin axis extends from Smith County through Mitchell, Lincoln, and Ottawa Counties to Saline County, where the "Hunton" is absent. The southwest-trending, south-plunging Abilene Anticline is a pronounced feature.

Structure on Top of Arbuckle Rocks (Cambrian-Ordovician)

Arbuckle rocks are present everywhere in the subsurface, except on the higher parts of positive structural features. Almost 5,800 wells were used in the construction of the map reproduced here (Merriam and Smith, 1962). Control for this map is adequate where the surface is shallow, for example, on upwarped areas; control is extremely inadequate in the basinal areas, especially in the Hugoton, where few tests have been drilled to the Arbuckle. Information also is lacking in eastern Kansas, where for years the lower limit of drilling has been the "Mississippi lime."

The regional dip of Arbuckle rocks in eastern Kansas is northwesterly (Fig. 114). The homocline terminates in the Brownville Syncline, which can be traced from Brown County, on the north, to Cowley County, on the south. North of central Chase County, the axis of the Brownville plunges northward, and south of this area it plunges southward. Several northeast-trending, south-plunging anticlines and synclines that roughly parallel the Nemaha Anticline are especially prominent in Cowley and Butler Counties.

Along the crest of the Nemaha Anticline are found many locally closed anticlinal structures, some of which are sizeable. The east flank of the Nemaha may be faulted like the Alma Anticline, which is located in south-central Wabaunsee County and northeastern Morris County.

West of the Nemaha many minor, south-plunging structural features interrupt the regional westward dip into the Salina and Sedgwick Basins, and, for the most part, they have a northeast trend which approximates the trend of the Nemaha. Some of the features, such as the Abilene and Voshell Anticlines, are very prominent. The Cunningham Anticline, trending northeast, is obvious in Pratt County and northwestern Kingman County. The axis of the Salina Basin extends from Smith County, on the north, southeastward to southwestern Saline County and northwestern McPherson County, where the plunge of the basinal axis is reversed, forming a structural saddle with the Sedgwick Basin to the south. The Salina Basin extends northward into Nebraska; the Sedgwick Basin is only an extension of a northern shelf area of the Anadarko Basin of Oklahoma (Bartram, Imbt, and Shea, 1950).

The broad, flat Central Kansas Uplift is a maze of small anticlinal and synclinal structures, many of which are faulted. Some, like the Fairport Anticline, trend northeast, and others, such as the Rush Rib, trend northwest. The Pratt Anticline, in Pratt and Barber Counties, is a broad, south-plunging southern extension of the Central Kansas Uplift. Northward from the Central Kansas Uplift is the Cambridge Arch and its many subsidiary features.

West of the Central Kansas-Cambridge-Pratt anticlinal complex is the immense Hugoton Embayment, a wide, flat, south-plunging, shelflike projection of the Anadarko Basin. In extreme southwestern Kansas is the northeastern flank of the Keyes Dome.

Configuration on Top of Precambrian Basement Complex

Precambrian rocks have been of interest for many years in the Midcontinent region because they form the "floor" for the overlying sedimentary rock sequence, and an understanding of them is necessary to the interpretation of the geologic history of the area.

The first well to the Precambrian, drilled at the Swift plant in Kansas City (sec. 15,

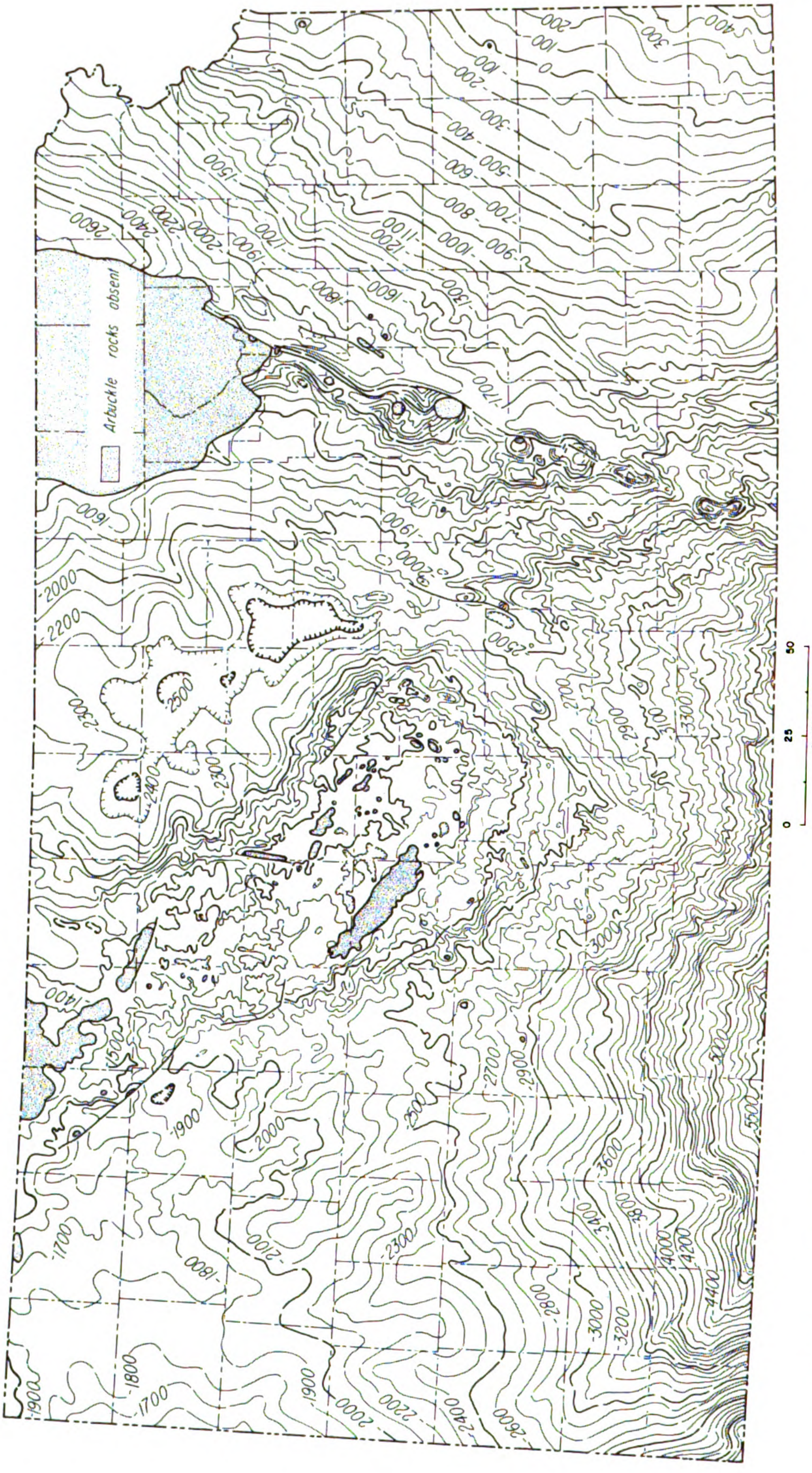


FIGURE 114.—Preliminary regional structural map contoured on top of Arbuckle rocks (Cambrian-Ordovician) in Kansas (from Merriam and Smith, 1961). Contour interval 100 feet.

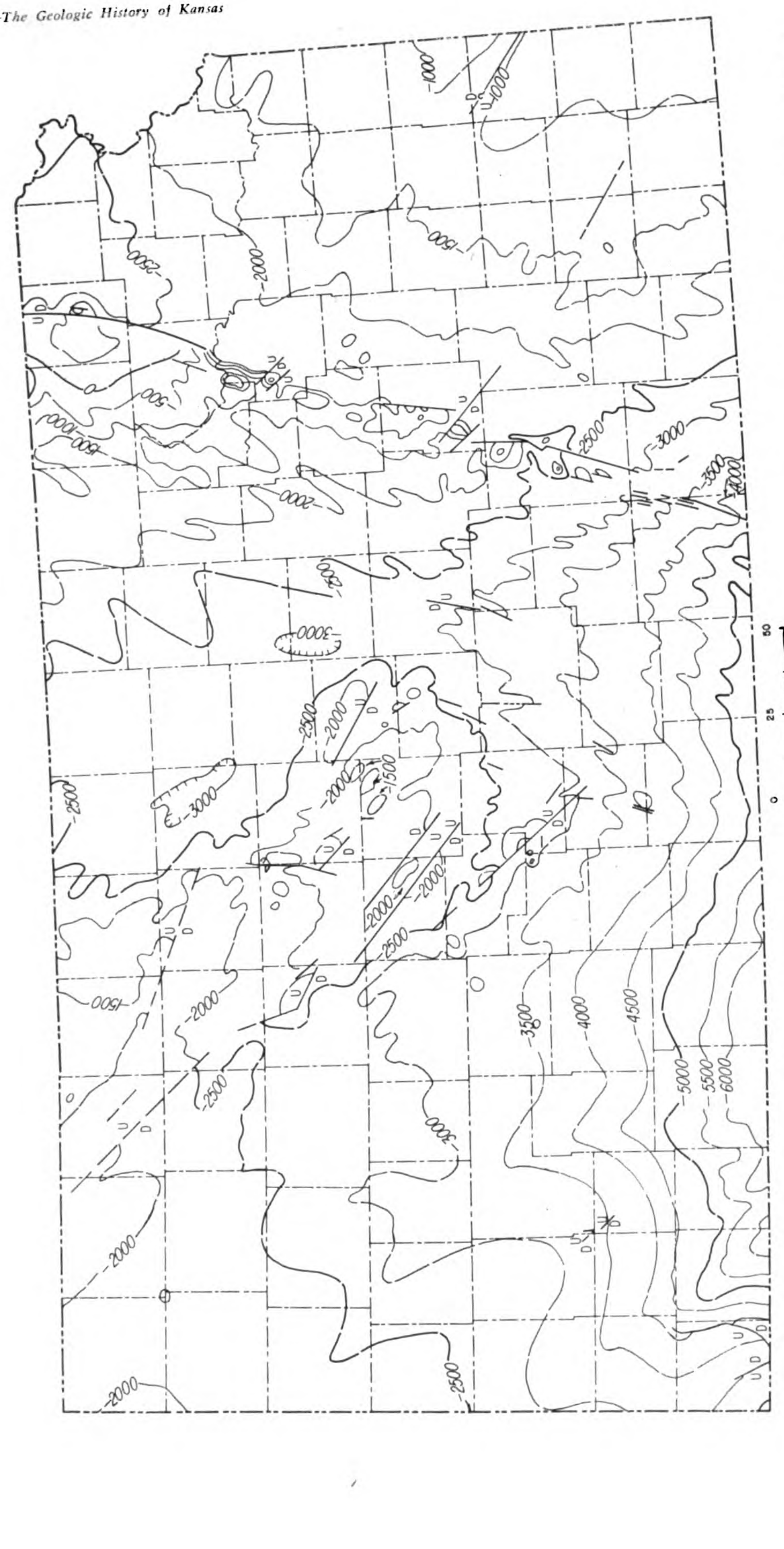


Figure 115.—Preliminary regional configuration map on top of Precambrian basement complex in Kansas (generalized from Cole, 1962). Contour interval 500 feet.

T. 11 S., R. 25 E.) in 1889, entered Precambrian arkose at 2,327 feet and was drilled to a total depth of 2,360 feet. The first known work dealing with Precambrian rocks in Kansas (Hay, 1893) noted the occurrence of granite at 2,100 feet, below all stratified rocks, in the Nickerson well near Paola in Miami County. This well (sec. 16, T. 17 S., R. 23 E.), drilled to a depth of 2,500 feet, was the deepest well in Kansas at that time. The Neodesha deep well was completed in 1897 and was abandoned in granite at a total depth of 2,412 feet. In 1905? and 1908 the Caney deep well and Iola deep well, respectively, were abandoned in the Precambrian. The Iola well is of interest because at a total depth of 3,434 feet it was then the deepest well in the Mississippi Valley west of St. Louis (Haworth, 1908). Granite was reported at shallow depths in the vicinity of Marysville and Seneca, in northeastern Kansas, and also in southeastern Nebraska near Lincoln and Dubois (or Bern).

Excitement heightened either late in 1914 or early in 1915 when granite was reported at a depth of only 958 feet in the first Zeandale test (Riley County); likewise, the No. 2 well recorded granite. Meanwhile, granite also was reported from a well on the Chase County Poor Farm, near Elmdale (Chase County); however, it was not verified at the time. Erasmus Haworth in 1915 reviewed in print the numerous reports of shallow granite. He published a short paper, *On crystalline rocks in Kansas*, in which he stated: ". . . this little report is prepared for the direct purpose of showing that the discoveries made [referring to the shallow granite] should in no way be used to lessen the prospective value of this part of the state as an oil and gas producer." His report must have served its purpose, because subsequently well after well was drilled, and although many of them encountered granite, exploration continued.

As the information accumulated, papers appeared in professional and trade journals. It is impossible to mention all of them, but the following are noteworthy: Gould (1923), Greene (1925), Landes (1927), Moore (1918, 1920), Moore and Haynes (1917), Powers (1917), Taylor (1917), and Wright (1918). There was lively discussion as to whether or not the "crystalline" rock was Precambrian basement or intrusive material of a later age; most agreed that evidence favored Precambrian.

Later, Landes and others (1960), Merriam (1962b), Merriam and Goebel (1954), Mettner (1935), and R. F. Walters (1946, 1953) emphasized various aspects of the Precambrian. In the middle 1950s O. C. Farquhar undertook a study of Precambrian rocks in Kansas (Farquhar, 1957).

The first known published map showing configuration on top of the buried Precambrian surface in eastern Kansas was prepared by Moore in 1920; he had only 28 tests that encountered the granite and 19 other deep tests on which to base his interpretation. Another map was published by Moore and Landes in 1927, which, because of increased control, showed considerably more detail than the earlier map. Mettner (1935) published a map showing topography of the Precambrian surface underlying the eastern two-thirds of Kansas; Moore and Jewett (1942) made the first statewide study; Farquhar's 1957 map included information for all but 29 of the 105 Kansas counties. Only five years after Farquhar's map was published, Cole (1962) prepared a map on a larger scale and incorporating much additional data (about 2,100 control points; Cole and others, 1961); this map is reproduced in Figure 115. Other maps of the Precambrian surface, but more local in nature, have been published—especially Moss (1936) and J. S. Porter (*in* Jewett, 1954).

The shape of the Precambrian surface is the result of a complex history. In addition to degradation of the surface prior to its being covered by Paleozoic rocks, Precambrian and post-Precambrian structural movements contributed to forming of the present shape. The shape of the surface is a composite result of erosional activity and structural deformation, greatly complicating interpretation of its history.

All pre-Middle Pennsylvanian post-Mississippian structures are discernible, including the Nemaha Anticline, Central Kansas Uplift, Cambridge Arch, and Pratt Anticline; the intervening Forest City, Cherokee, Salina, and Sedgwick Basins; and the Hugoton Embayment (Fig. 115). All major positive features have a southerly plunge, and in general the Precambrian surface slopes southward. Many minor structures also are shown.

DEVELOPMENT OF PRESENT STRUCTURE

Interpretation of the development of present structure is based on a study of isopachous maps, supplemented by structural development cross sections and a study of the stratigraphy. The incompleteness of the rock sequence, of course, makes it impossible to know the exact calendar of events; however, many valid assumptions can be drawn from the preserved record. It is unlikely, for instance, that any extraordinary catastrophic events in the interval of time not represented by rocks would fail to leave some identifying recognizable mark in the remaining rock record. Many events in geologic history doubtless have passed by unrecognized and unappreciated, but these happenings must have been of the same order of magnitude and development pattern as those that are known. As an extreme, for example, it is unthinkable that in post-Precambrian time Kansas was ever depressed to abyssal depths of the ocean, elevated sky high in mountains, or converted to a sizable volcanic terrain.

An isopachous, convergence, or thickness map shows in three dimensions thickness of rocks between any two selected horizons. If both surfaces were originally subhorizontal, an isopachous map would reveal the total structural movement of the lower surface when the upper surface was undisturbed. If one of the surfaces was an erosional surface of considerable relief, the isopachous map would show the topography of that surface. These principles have been set forth and elaborated on by Wallace Lee, whose summary is presented here (1954b, p. 69).

> A map depicting the thickness of a sequence of rocks between surfaces that were once flat or relatively flat records the structural movements that occurred between the development of the limiting surfaces. Such an isopachous map is essentially a structure map of the first surface at the time of the second. The accuracy with which such maps reveal the structural movements that took place during the interval depends on how closely the limiting surfaces approached a plane. The deformation is most accurately revealed where the confining surfaces were depositional. Erosional surfaces of low topographic relief may be used to reveal regional warping of broad areas. The relation of the sequence of rocks to underlying and overlying formations determines the time of movement. Isopachous maps that include sequences of formations whose thicknesses were separately controlled by conflicting patterns of folding express a composite of both movements and reveal neither.

As pointed out previously, the more nearly complete the rock record, the better may be interpretation of past events. The maximum post-Precambrian rock section in each province is listed on Table 5. The amount and age of rocks present in each province is significant and should be kept in mind in interpreting the structural history of that element.

For this study, regional convergence (or divergence) maps were constructed for rock divisions occurring between surfaces represented by each of the structural maps presented here. Additional information was obtained by preparing several developmental cross sections across the structurally positive areas. Structural development of individual major units is discussed in more detail later.

Table 5.—Maximum post-Precambrian rock thickness in areas indicated.

Pre-Desmoinesian post-Mississippian structural features	*Maximum post-Precambrian rock section, thickness in feet*
Nemaha Anticline	3,000
Cambridge Arch	4,500
Central Kansas Uplift	5,000
Pratt Anticline	5,000
Forest City Basin	4,000
Cherokee Basin	3,500
Salina Basin	4,500
Sedgwick Basin	5,500
Hugoton Embayment	9,500

Pattern of Deformation between Precambrian and Arbuckle Rocks

The pattern of deformation between top of Precambrian and top of Arbuckle (Cambrian-Ordovician) rocks is shown in Figure 116. The most obvious structure on the map is the Southeast Nebraska Arch, called Southeast Nebraska Uplift by Lee (1943), which developed in southeastern Nebraska and northeastern Kansas before Simpson deposition. In Kansas, the area of uplift includes all or parts of Marshall, Pottawatomie, Washington, Riley, Nemaha, and Jackson Counties. Data indicate pre-Simpson elevation of the area, beveling of uplifted formations, and deposition of Simpson rocks on Precambrian granite along the crest of the uplift. Part of the Precambrian area was re-exposed in pre-Pennsylvanian time, but the relative amount of erosion of the basement complex during these periods of exposure is not determinable. Preliminary studies on the configuration of Precambrian basement rock indicate that the arch probably began to form before deposition of Paleozoic sediments.

A pre-St. Peter syncline plunging southward from Russell and Barton Counties is revealed by the contours. The sequence thickens southward into the ancestral Anadarko or Oklahoma Basin,

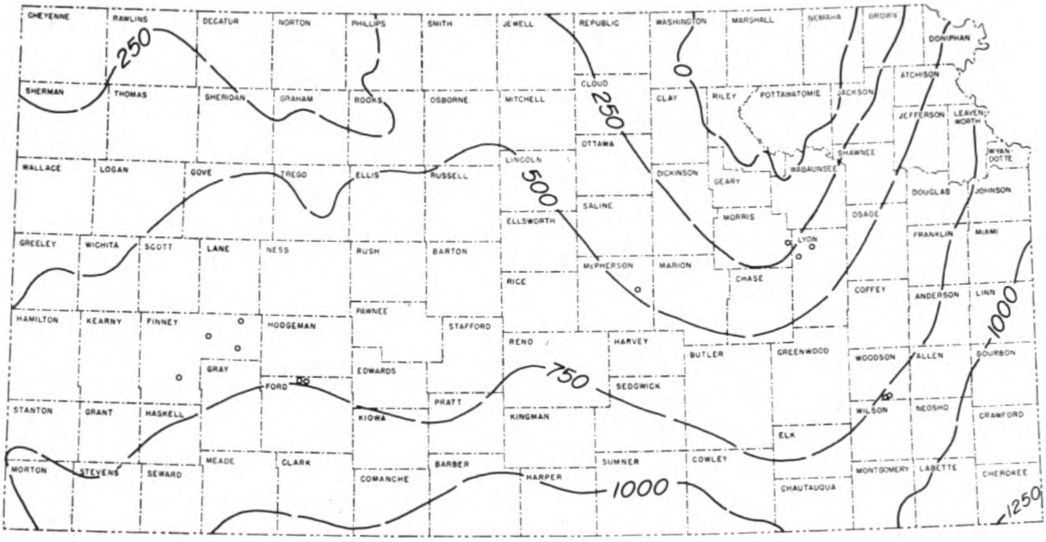


FIGURE 116.—Isopachous map showing convergence between top of Precambrian rocks and top of Arbuckle rocks. Southeast Nebraska Arch is shown by zero line in northeast, and rocks of interval thicken southwestward into Southwest Kansas Basin, and southeastward into Missouri. Rocks of this interval are missing in small areas in Lyon, Morris, Woodson, McPherson, Ford, and Finney Counties. Contour interval 250 feet.

reaching a maximum thickness of nearly 7,000 feet in Oklahoma (Huffman, 1960).

Northwesterly thinning to a featheredge reveals the presence of the Transcontinental Arch farther north in Nebraska. The early history of the Cambridge Arch is obscure, owing to lack of information as to where Pennsylvanian beds are in contact with the Precambrian around the arch, but evidence seems to indicate that the Cambridge Arch was present in Arbuckle time. The Central Kansas Uplift also was mildly active at this time. These two aligned structures represent a thumblike extension from the major northeastward-trending Transcontinental Arch.

Pattern of Deformation between Arbuckle and Mississippian Rocks

The pattern of deformation in the interval between top of Arbuckle and top of Mississippian rocks is revealed in Figure 117. Because the Mississippian (also Arbuckle, locally) is absent on higher parts of the Central Kansas Uplift, Cambridge Arch, and Nemaha Anticline, no attempt was made to extend the map into those areas. The pattern revealed by the contours is complicated because the tops of both the Mississippian and the Arbuckle are erosional, but it is believed that the erosional relief is considerably less than the regional structural relief.

The Nemaha Anticline is evident on the map because of thinning of strata in the interval, mainly Mississippian, and it is believed that the structure was developed near the end of Mississippian time. This conclusion is substantiated by other lines of evidence. At least 1,400 feet of rocks were removed by erosion where both the Mississippian and Arbuckle are missing in parts of Nemaha, Marshall, Washington, Pottawatomie, and Riley Counties, along the crest of the uparched Nemaha axis. In eastern Kansas, the regional dip was to the northwest, although many minor, northwesterly plunging noses and re-entrants were superposed on it. The Chesapeake Fault Zone developed during this time, possibly near the end of the Mississippian, and can be traced southeastward into Missouri. Other northwest-trending grabens also can be seen on the map, indicated by a thicker section.

In southeastern Kansas, the Chautauqua Arch is reflected as a broad, flat area elongated roughly east-west. Rocks in the sequence thicken both northward into the North Kansas Basin and southward into the Oklahoma Basin. Many northeast-trending structures semiparallel to the Nemaha Anticline are revealed, especially in the vicinity of Cowley County. They tend to "wrap around" the west-plunging Chautauqua

FIGURE 117.—Isopachous map showing convergence between top of Arbuckle rocks and top of Mississippian rocks. Rocks of interval thicken in northeast Kansas showing formation of North Kansas Basin during this time; in southwestern Kansas, rocks of interval thicken into Hugoton Embayment. Contour interval 100 feet.

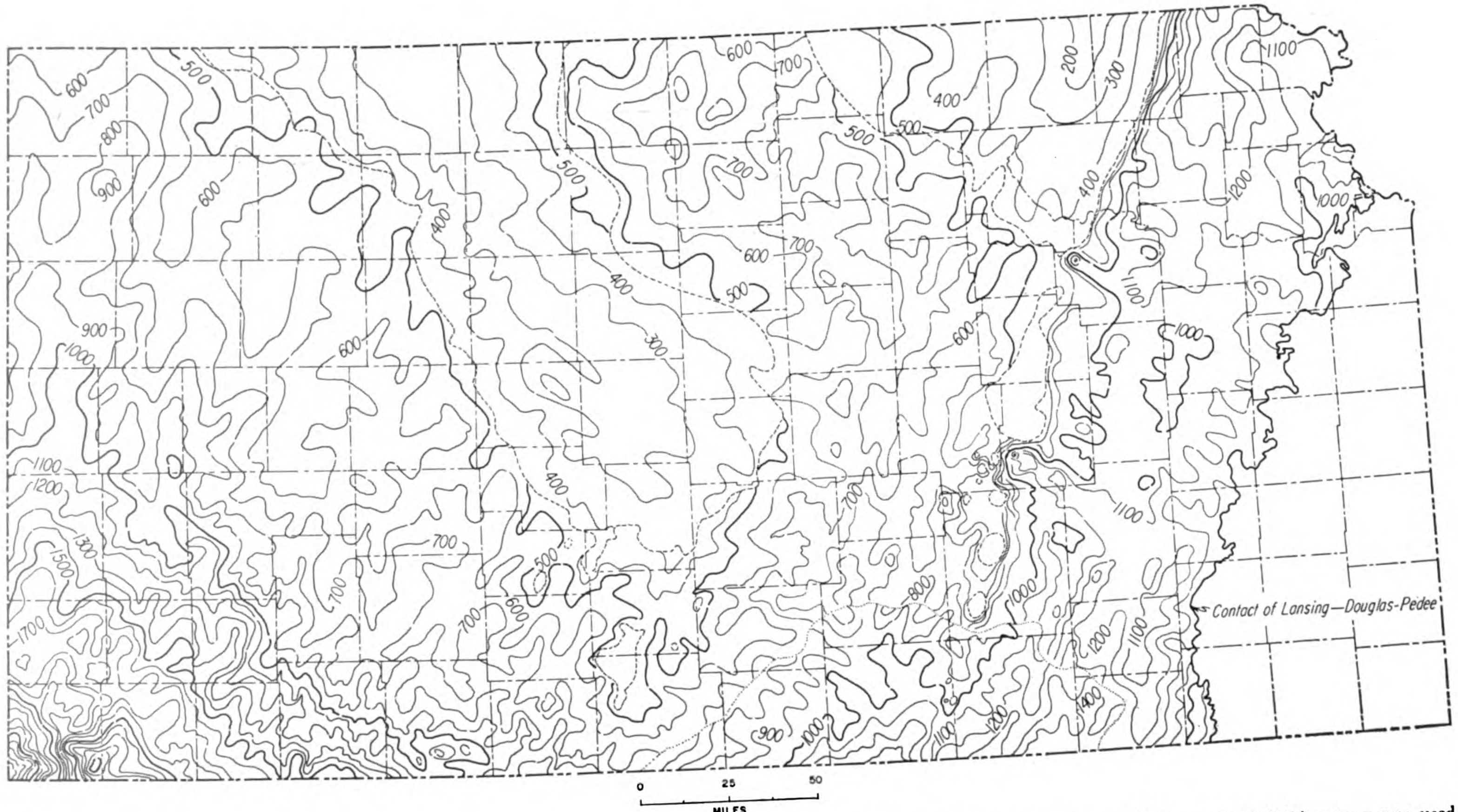


FIGURE 118.—Isopachous map showing convergence between top of Mississippian rocks and top of Lansing Group. In south-central Kansas, Haskell Limestone was used as upper horizon (dotted line); base of Pennsylvanian rocks was used as lower horizon on higher parts of uplifts where Mississippian rocks are missing (dashed line). Rocks of interval thicken into Hugoton trough, Salina Basin, and Sedgwick Basin. Contour interval 100 feet.

Arch; these structures are evident mainly because of the truncation of the Mississippian and represent features that developed near the end of Mississippian time.

In the area of the Salina Basin, northeast-trending noses plunge toward the central part of the North Kansas Basin. Structures such as the Abilene Anticline were developed, as well as many of the other northeast-trending features. In the area of the Sedgwick Basin, many northeast-trending elements also were developed. Gradual thickening of the section to the south into the deeper parts of the Sedgwick Basin is evident. The west side of the basin is delimited by the southward-plunging Pratt Anticline, which was smaller in area than now. Mississippian rocks were removed from the crest of the anticline and also from several other small areas along prominent anticlinal structures.

It is difficult to determine the sequence of events in the area of the Central Kansas Uplift because most of the pre-Mississippian record is missing; but from evidence obtained on flanks of the structure, it can be determined that Mississippian rocks, as well as older Paleozoic rocks, probably covered the uplift. These rocks were stripped from the higher part of the structure near the end of the Mississippian and in the early part of Pennsylvanian time, so that in some areas Pennsylvanian beds are in direct contact with the Precambrian basement. The southern end of the Ellsworth Anticline in Ellsworth County is shown, and thinning over the crest indicates structural movement during this interval.

The Hugoton Embayment continued to be downwarped. The axis of the northwest-trending narrow trough seemingly was located in Stevens and Stanton Counties, in extreme southwestern Kansas. The Keyes Dome also shows evidence of upward movement during this time. Many approximately north-trending structures in the embayment are shown on the map. In general, the section thickens toward the axis of the embayment and southward into Oklahoma.

Pattern of Deformation between Mississippian and Lansing Rocks

The convergence map (Fig. 118) is based on three different sets of information. In most of the area the interval mapped is from top of Mississippian rocks to top of the Lansing Group (Missourian, Pennsylvanian). On crests of uplifts—notably the Central Kansas Uplift, Cambridge Arch, and Nemaha Anticline—Mississippian rocks are absent and it was necessary to use the base of the Pennsylvanian rocks for the lower contact. In south-central Kansas, the Lansing is not present and thus the upper datum is top of the Haskell Limestone, which lies stratigraphically a few feet above the top of the Lansing Group. All pre-Desmoinesian post-Mississippian major structural features of Kansas are recognizable on this map.

The Nemaha Anticline is the most pronounced structural feature extending across Kansas. This northeasterly trending feature is shown to plunge southwestward at the horizon of the Mississippian while Lansing rocks were yet nearly horizontal and flat. This structural condition has merely been accentuated by subsequent movements. East of the Nemaha axis are the Forest City and Cherokee Basins. The axes of the basins, indicated by the thickest section of rocks, lie near and subparallel to the Nemaha; hence, these basins are decidedly asymmetrical. Information is lacking for most of the eastern flanks of the two basins, but it is believed that the section continues to thin toward the Ozark Uplift farther east, in Missouri (see Berger, 1918). Of prime structural importance is the development of the Chesapeake Fault Complex, trending northwesterly, and a parallel, similar complex farther northeast, in Wabaunsee County. These features are believed to be downdropped blocks or grabens of regional proportions.

West of the Nemaha Anticline, thick and thin areas represent development of several northeasterly trending, southwesterly plunging synclines and anticlines. The Abilene Anticline, for one, is very evident. Movement also occurred on the Voshell Anticline. The Salina Basin appears as a shallow, flat-bottomed synclinal area between the Nemaha Anticline and Central Kansas Uplift. The axis trends northwestward. A shallow saddle separates the southern end of the Salina Basin from the northern end of the Sedgwick Basin.

The Sedgwick Basin in south-central Kansas is distinguished as a northward extension of the Anadarko Basin of Oklahoma. The section thickens rapidly both toward the axis of the Sedgwick Basin and southward. Many minor structures are evident on the flanks of the basin. In the deepest part of the basin, slightly more than 1,300 feet of sediments accumulated during this interval and were preserved.

The backbone of Kansas, the Central Kansas Uplift, showed further structural movement during this interval. In general, the section thins over the crest of the uplift, and several

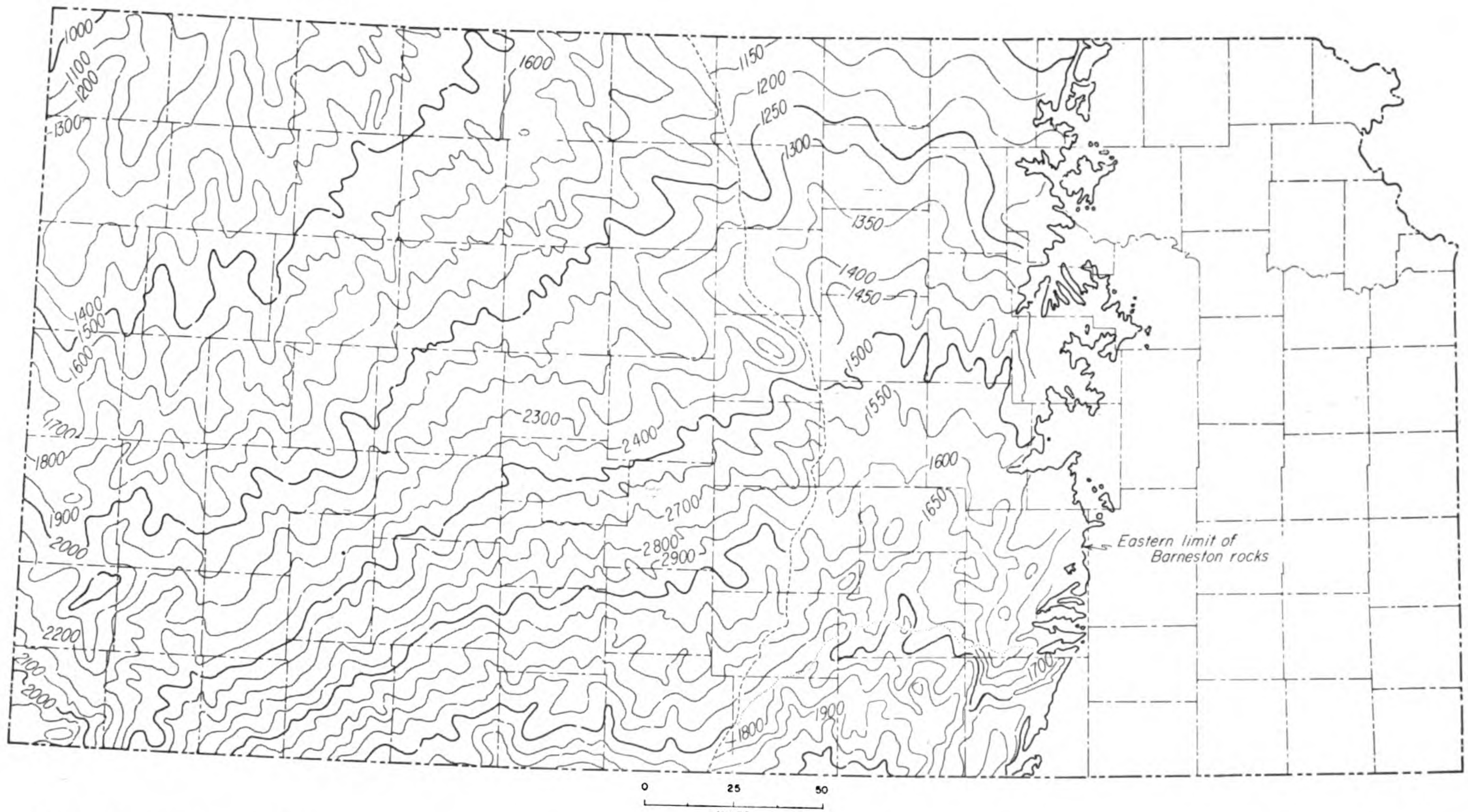


FIGURE 119.—Isopachous map showing convergence between top of Lansing Group and top of Stone Corral Formation. East of eastern limit of Stone Corral (dashed line), base of Barneston Limestone was used as upper horizon; in south-central Kansas, Haskell Limestone was used as lower horizon (south of dotted line). Rocks of interval generally thicken southward into Oklahoma. Contour interval 50 and 100 feet.

minor features associated with the uplift also showed movement at this time. The same is true for the Cambridge Arch, which is not distinctly separated from the Central Kansas Uplift. The Cambridge Arch-Central Kansas Uplift alignment is about 175 miles long in Kansas, and it extends northward an unmeasured distance into Nebraska.

Extending southwesterly from the southern tip of the Central Kansas Uplift is the Pratt Anticline, which shows structural development at this time. The section thins over the crest of the southerly plunging structure, and Mississippian beds are absent on its crest. This anticline serves to separate the Sedgwick Basin on the east from the huge, sprawling Hugoton Embayment on the west.

The Hugoton Embayment was structurally active during this time. The section thickens toward the southwest into the Hugoton trough in extreme southwestern Kansas. Numerous thinnings and thickenings reveal many minor features on the northeastern flank of the embayment. Most of them plunge southwesterly. At the Kansas-Colorado line, in the northern end of the embayment, the section thins to the west. Although information is lacking, this thinning may represent movement of the Las Animas Arch, which is present farther west, in eastern Colorado.

The Keyes Dome, in Morton County in extreme southwestern Kansas, is a sharp structural feature that limits the Hugoton trough on the southwest. It was actively rising during this interval.

Pattern of Deformation between Lansing and Stone Corral Rocks

Information regarding structural development between Lansing and Stone Corral rocks (Fig. 119) is also derived from three sets of data. For central and western Kansas, west of a line extending from Smith County on the north to Barber County on the south, the contours represent convergence between top of the Stone Corral Formation (Leonardian, Permian) and top of the Lansing Group (Missourian, Pennsylvanian). East of the eastern limit of the Stone Corral Formation and west of the outcrop of the Florence Limestone, contours show thickness of the section between base of the Florence Limestone (Wolfcampian, Permian) and top of the Lansing Group, except in the southern part of the area in parts of Harper, Sumner, Cowley, Butler, Sedgwick, and Kingman Counties. Here the top of the Lansing is not recognized and thus the bottom datum is top of the Haskell Limestone, which occurs stratigraphically a few feet above the Lansing Group but in the lower part of the Douglas Group (Virgilian, Pennsylvanian).

Movement on all major and many minor structural features seemingly continued during this interval, although less actively than earlier in the Paleozoic. The Hugoton Embayment continued to be downwarped, and in southern Clark and Comanche Counties at least 3,600 feet of sediments accumulated. A different structural pattern began to develop during this interval and it eventually ended development of the Hugoton Embayment, which had persisted from the Precambrian. In the northern part of the embayment, in eastern Rawlins, Scott, Thomas, and Logan Counties and western Gove County, movement commenced along the Oakley Anticline, a north-trending, southerly plunging structure, which divided the Hugoton Embayment into the Syracuse Syncline on the west and the Cimarron Syncline on the east. The Oakley Anticline must have been active in pre-Hutchinson (Leonardian) time because it seemingly controlled the depositional western limit of the Hutchinson Salt Member of the Wellington Formation (Fig. 37A).

Movement had all but ceased on the Cambridge Arch and Central Kansas Uplift. The configuration of the contours in southwestern Russell and Ellsworth Counties and south-central Rooks County suggests that minor movement occurred on the Central Kansas Uplift, possibly in pre-Hutchinson time. Subsidiary features along the crest and flanks of the Central Kansas Uplift were subject to slight accentuating movement.

The Pratt Anticline, located in Pratt, Barber, and Comanche Counties, shows some suggestion of movement during this time. Although the axis of the Pratt Anticline is approximately parallel to that of the Nemaha Anticline, structural development of this feature is closely connected with the Central Kansas Uplift.

One of the minor subsidiary structural features of the Central Kansas Uplift which showed pronounced movement during this time is the Ellsworth Anticline. This structure is located in west-central Ellsworth County and is especially prominent on the pre-Pennsylvanian areal geologic map where the Simpson rings the structure cored with Arbuckle rocks.

The axis of the Salina Basin is evident, extending from Jewell County through northeast-

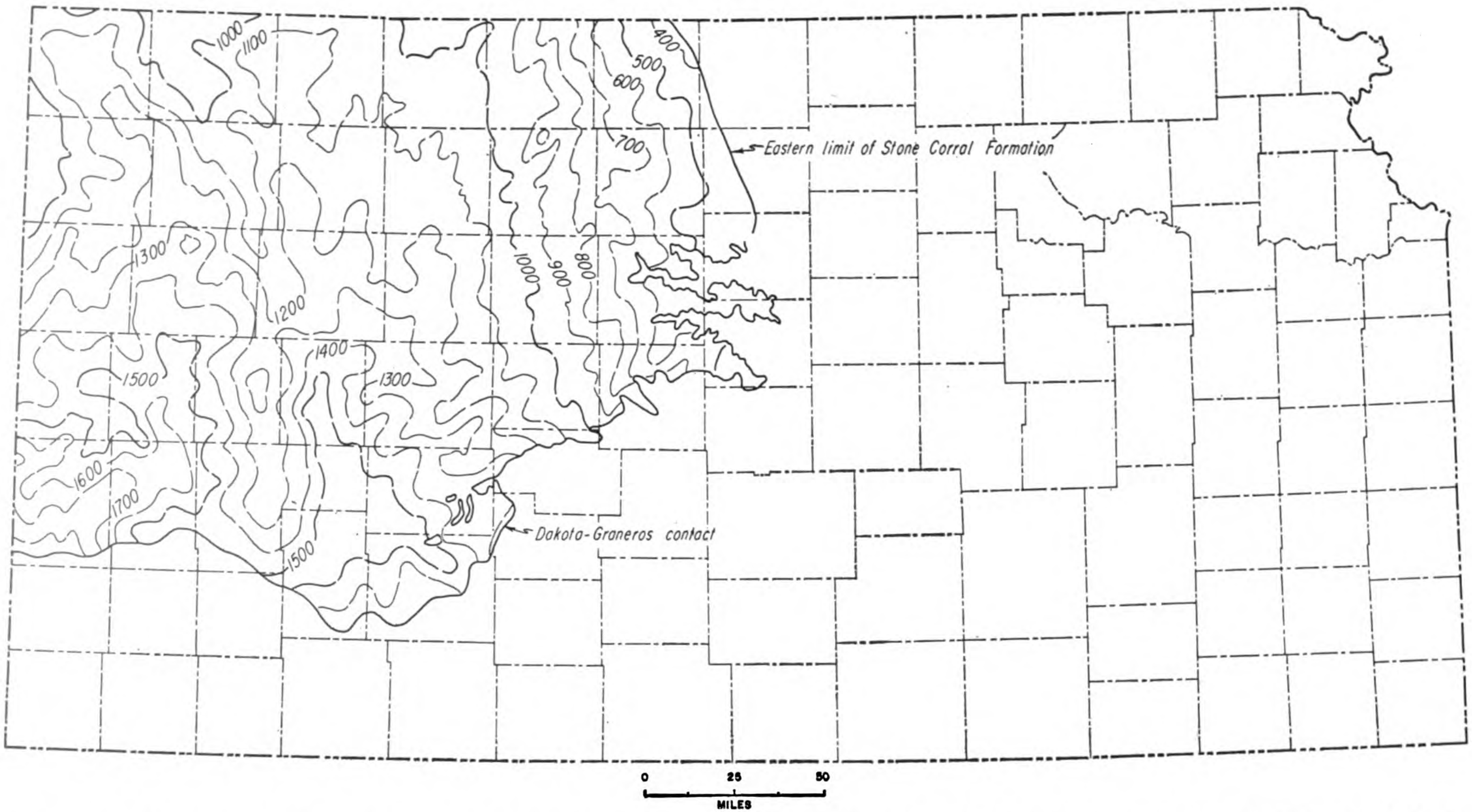


FIGURE 120.—Isopachous map showing convergence between top of Stone Corral Formation and top of Dakota Group. Map reveals that Oakley Anticline, a south-plunging structure, and associated Syracuse and Cimarron Basins were formed during this interval. Thinning over crest of Cambridge Arch suggests movement on that structure during this time. Contour interval 100 feet.

ern Mitchell County and southwestern Cloud, Ottawa, and Saline Counties into northwestern McPherson County. Several minor structures are evident on the flanks of the basin, the most prominent being the Abilene Anticline, which extends from northwestern Riley County through Clay and Dickinson Counties into northeastern Saline County, and the Voshell Anticline, which extends across McPherson County into northeastern Reno County. Both of these anticlinal features are roughly parallel to the Nemaha Anticline.

The Sedgwick Basin axis seemingly is located in south-central Kansas in Harper, Kingman, and Reno Counties. The basin trends approximately south and plunges southward toward Oklahoma. Variation in thickness of the section between top of the Haskell Limestone and base of the Florence Limestone in the Sedgwick Basin is more pronounced than in other basinal areas, possibly because of nearness to the hingeline between the shelflike area and the geosynclinal area to the south.

The Nemaha Anticline is most evident from Chase County through Butler County into southeastern Sumner County. It trends roughly northeastward and plunges southwestward. If the upper datum bed were present farther east, so that it would be possible to map the interval, undoubtedly the presence of the Nemaha Anticline would be reflected by the contours, showing, of course, that the Nemaha was tectonically active at this time. It is also possible that the Forest City and Cherokee Basins would be revealed.

Pattern of Deformation between Stone Corral and Dakota Rocks

Inasmuch as the Stone Corral (Leonardian, Permian) is an evaporite and the Dakota (Cretaceous) is overlain by the Graneros Shale, which has a variation in thickness of not more than 30 feet in 200 miles, the upper surfaces of both the Stone Corral and Dakota must originally have been essentially flat (Lee and Merriam, 1954a). Thickness of the section, therefore, reveals structural movements that occurred between the deposition of the Stone Corral and the Dakota (Fig. 120). Data for depicting thickness of the section between these two surfaces are even more sparse than for the previous thickness maps.

The map shows no arching of the Central Kansas Uplift as a major structural feature during this time, but only tilting of the area toward the southwest (toward the Hugoton Embayment). Upward movement of the southeastern end of the Cambridge Arch is suggested by a bulge in the 1,000-foot isopach in Norton County.

The Las Animas Arch is west of the area of the map, but it grades into the western limb of the Hugoton Embayment. Uplift on the northeastern flank of the Las Animas Arch in Kansas was imposed upon the Stone Corral after Permian time.

The general pattern of the Hugoton Embayment shown by the contours is subsidence. The most striking and unexpected structural feature is the prominence of the Oakley Anticline, a southerly plunging anticline extending southward from Thomas to Finney County. Although it began to form earlier, its structural relief (on the Stone Corral) exceeded 200 feet in Dakota time. It is flanked by structural basins: that on the west, in Kearny and Wichita Counties, is the Syracuse Basin; that on the east, in Lane and Finney Counties, is the Cimarron Basin.

The northern end of the post-Stone Corral salt beds of the Nippewalla Group (Fig. 37B) seems to have been confined by the west flank of the rising Oakley Anticline, although farther south the salt beds cross the projected axis of the fold.

It is probable that many secondary structures were developed during this period, but only a few are clearly revealed by available data. Local thinning of the sequence on the Stuttgart-Huffstutter Anticline and on the Sunny Slope Anticline indicates their pre-Cretaceous, or, strictly speaking, pre-Dakota origin. More detailed contouring of the thickness will probably reveal other areas of pre-Cretaceous structure.

Pattern of Deformation between Dakota and Ogallala Rocks

At the end of the Cretaceous Period, Mesozoic deposits in Kansas dipped northwestward into the Denver Basin. This pattern was maintained and possibly accentuated during Cenozoic time (Merriam and Frye, 1954, p. 61). Because the structural pattern was about the same from Dakota to the end of Niobrara time, it can be assumed that the convergence map (Fig. 121) represents the movement that took place after deposition of the Niobrara Formation and before formation of the "Algal limestone." The contours reveal a general northwestward dip of the Dakota into the Denver Basin by Pliocene time.

An exception to the prevailing regional dip is found in the Shallow Water Basin of Scott County, which has at least 100 feet of closure.

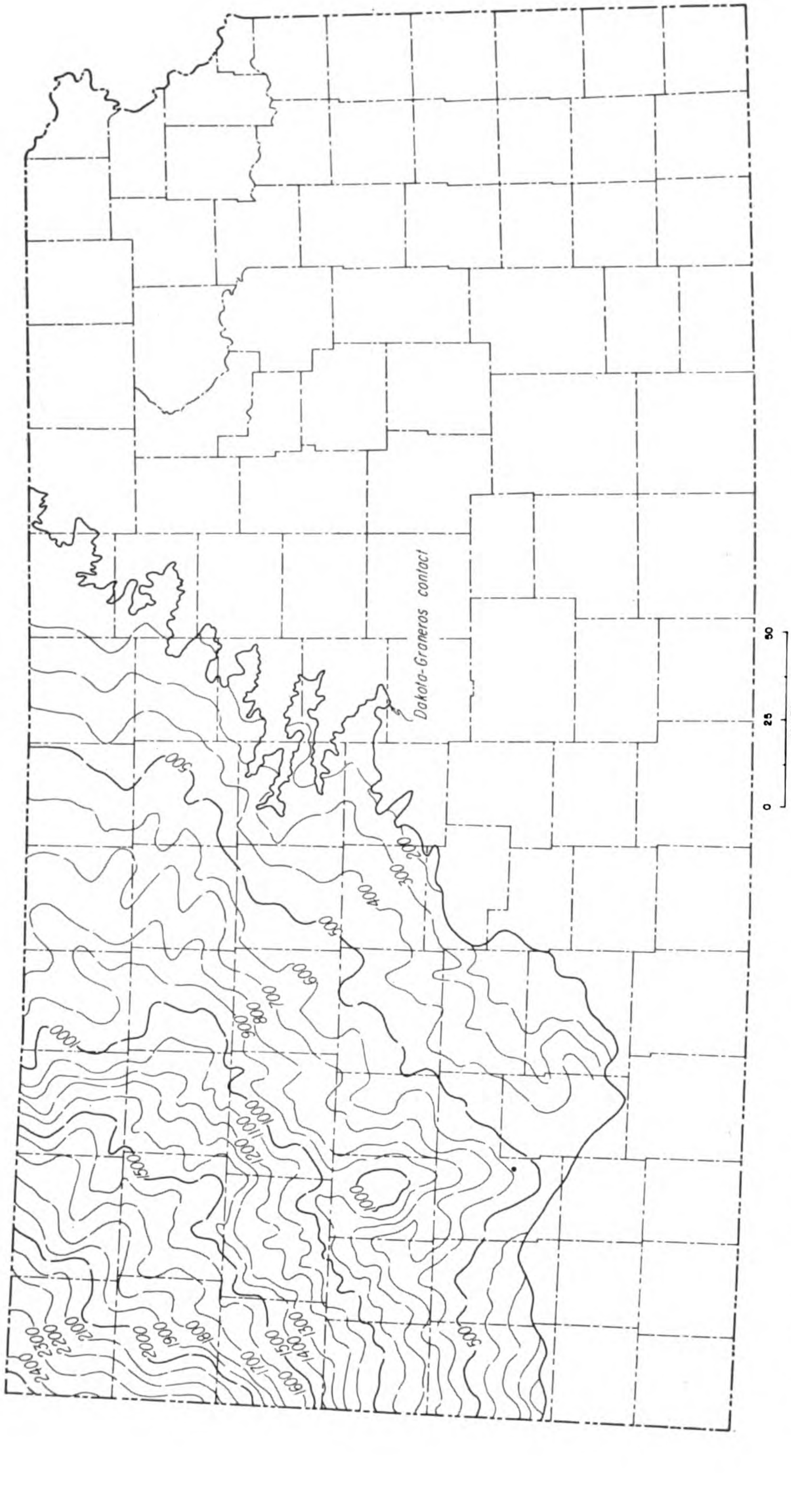


FIGURE 121.—Isopachous map showing convergence between top of Dakota Group and top of "Algal limestone." Rocks of interval thicken northwestward into Colorado. Shallow Water Basin is evident as a depressed area in Scott County. Contour interval 100 feet.

A faint suggestion of a syncline plunging northward is observed in western Gove County and eastern Thomas County and is judged to be the marginal syncline that developed chiefly in Late Cretaceous time (Lee and Merriam, 1954a). It may have developed further during Cenozoic time. Several other minor anticlines and synclines are recognizable on the map. They have a northwestward trend and plunge to the northwest into the Denver Basin.

As the present regional dip of the Dakota is to the north rather than to the northwest, it is judged that this area was tilted toward the east, both before and after deposition of the "Algal limestone." The latter is assumed to have been deposited on a uniform slope having somewhat less eastward dip than it does at present.

Minor and local structural movements may have taken place during the Cenozoic Era, but major Kansas structural features—the Central Kansas Uplift, Cambridge Arch, and Western Kansas Basin—show no evidence of movement then. Epeirogenic movements predominated in the Cenozoic in western Kansas.

Recent Structural Development

Earthquakes are the only perceptible means for man, in his short life span, to determine which structural features are active; therefore, a correlation between earthquakes and structure should indicate which structures, if any, are continuing to develop (Merriam, 1956).

History indicates that earthquakes in Kansas have not been numerous, frequent, or intense, although 41* have been recorded since 1811 (a list of earthquakes is given in Appendix E). Of these, 24 had epicenters within Kansas; the others were located in adjacent areas—eastern Nebraska, western Missouri, Oklahoma, and the Panhandle of Texas. Most of the earthquakes having epicenters in Kansas are clustered in two areas in the eastern part—in eastern Riley County, western Pottawatomie County, and Geary County; and in Sedgwick County in the vicinity of Wichita (Fig. 122).

EARTHQUAKE FREQUENCY

The time-intensity relation of earthquakes that had epicentral areas in Kansas is shown in Figure 123, where time is plotted as the abscissa and intensity as the ordinate. The plot reveals moderately intense earthquakes, about VIII, in 1867 and 1906.

Since the total time involved is short, the periodicity, or seeming regularity, of the earthquakes may give an erroneous impression. If

* Two additional shocks were felt in northwestern Missouri and northeastern Kansas on December 25, 1961 (Dellwig and Gerhard, 1962).

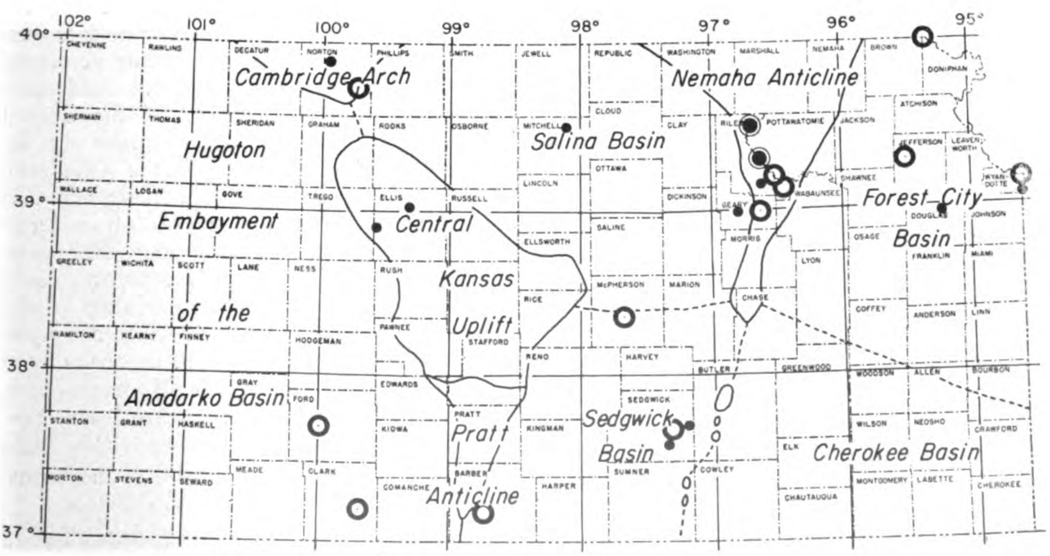


FIGURE 122.—Map showing relationship in Kansas of earthquake epicenters to major pre-Desmoinesian post-Mississippian structural features. Twenty-four earthquakes have been recorded since 1867; frequency of earthquakes along Nemaha Anticline suggests that it is mildly tectonically active (adapted from Merriam, 1956).

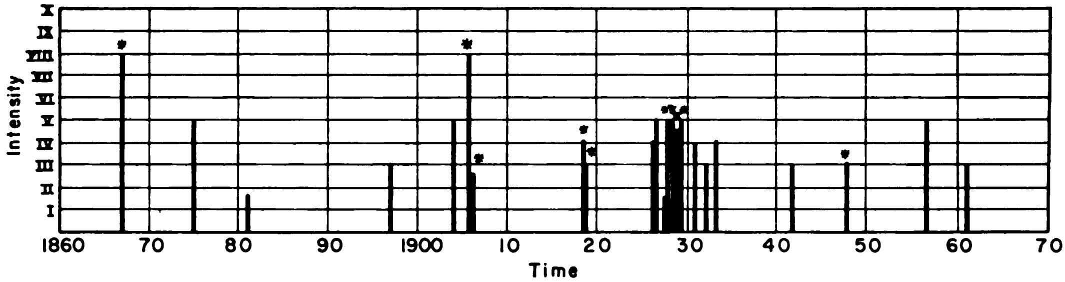


FIGURE 123.—Time-intensity relation of earthquakes that had epicenters in Kansas. Columns with a star indicate earthquakes occurring along trend of Nemaha Anticline (adapted from Merriam, 1956).

stronger earthquakes occur with the regularity suggested by the frequency plot, there should have been one in 1825 and another in about 1950, but no earthquakes were reported at either time. Nevertheless, the fact that a quake was not recorded in the early 1800s in Kansas is not surprising, because few people inhabited the area at that time, and records were poor. It is also possible that the frequency rate is decreasing, so that the time interval between stronger shocks is increasing. If this is true, then it will be a good many decades before any evaluation as to frequency can be made.

RELATION OF EARTHQUAKES TO STRUCTURAL FEATURES

As part of the Central Stable Region, Kansas probably was never subjected to intense earthquakes, such as are now known in the mobile belts of the world. The tectonic history has been one of gentle uparching and downwarping of structural elements.

The most obvious correlation of earthquakes to structure is along the Nemaha Anticline, where at least 10 of the earthquakes (in Riley, Pottawatomie, Geary, Sedgwick, and Sumner Counties) occurred in reasonable proximity to the axis of the anticline (Fig. 122). It is also noteworthy that the strongest earthquakes (1867 and January 7, 1906) have occurred along this structure. This relation of seismic activity to the Nemaha Anticline has been noted previously by Lee (1954a) in regard to the earthquake on April 9, 1952, which had its epicentral area in Oklahoma. The area affected by the earthquake corresponds almost perfectly with the Nemaha Anticline. Lee concluded that because there was no observable displacement of the surface rocks, the quake was the result of minor adjustments in the deep-seated rocks and that similar movements probably have occurred intermittently since Permian time. It is curious that the epicenters of all 10 earthquakes should be located west of the anticlinal axis. One explanation for this may be that the earthquakes occurred along a series of reverse faults that dip westward along the east side of the structure. Evidence of reverse faulting has been found in east-central Nemaha County by Wallace Lee (personal communication), in Wabaunsee County by Smith and Anders (1951), and in Richardson, Nemaha, and Otoe Counties, Nebraska, by E. C. Reed (personal communication). Faults are also known at various other places along the Nemaha Anticline in Kansas and Oklahoma. It may be concluded, then, that active tectonic development by faulting is taking place at the present time along parts of the Nemaha Anticline.

The relation of other earthquakes to structural features in Kansas is not easy to interpret. Two earthquakes of moderate intensity occurred on the Cambridge Arch, and two small ones occurred at the northern end of the Central Kansas Uplift. One small earthquake also occurred in the Salina Basin, as well as a moderate one in the area between the Sedgwick and Salina Basins. Two earthquakes of moderate intensity have occurred in the southern part of the Hugoton Embayment; these possibly could be related to minor adjustments in areas adjoining the Amarillo Uplift. Recently an earthquake of moderate size occurred in south-central Kansas on the Pratt Anticline. No earthquakes have been recorded in the Cherokee Basin. Several that have occurred in the Forest City Basin could be adjustments to the uplift of the Nemaha Anticline or the result of other factors.

The focal depths of earthquakes affecting Kansas are relatively shallow, ranging from approximately 16 to 38 miles. These depths would indicate that the hypocenters are located above the Mohorovicic discontinuity and within the

TABLE 6.—Approximate focal depths of some earthquakes affecting Kansas in recent years. Depth of focus computed from Gutenberg's formula (Gutenberg and Richter, 1942, p. 174) $r/h=\sqrt{10(I_o/3-\frac{1}{2})}-1$, where r is radius of perceptibility, I_o is maximum intensity, and h is depth of focus. These figures should be regarded only as relative magnitudes of depth.

Date	*Location of epicenter*	*Hypocenter*
September 23, 1929	Manhattan, Kansas	23 miles
October 21, 1929	Junction City, Kansas	22 miles
March 1, 1935	near Tecumseh, Nebraska	29 miles
June 19, 1936	Texas Panhandle	38 miles
March 11, 1948	northwest of Amarillo, Texas	27 miles
April 9, 1952	near Oklahoma City, Oklahoma	19 to 37 miles
January 6, 1956	Barber County, Kansas	32 km (20 miles)[1]
April 13, 1961	northwest of Norton, Kansas	20 to 50 miles[2]
December 25, 1961	near Excelsior Springs, Missouri (2)	35 km (22 miles); 25 km (16 miles)[3]

[1] Dellwig (1956).
[2] J. A. Peoples, personal communication.
[3] Dellwig and Gerhard (1962).

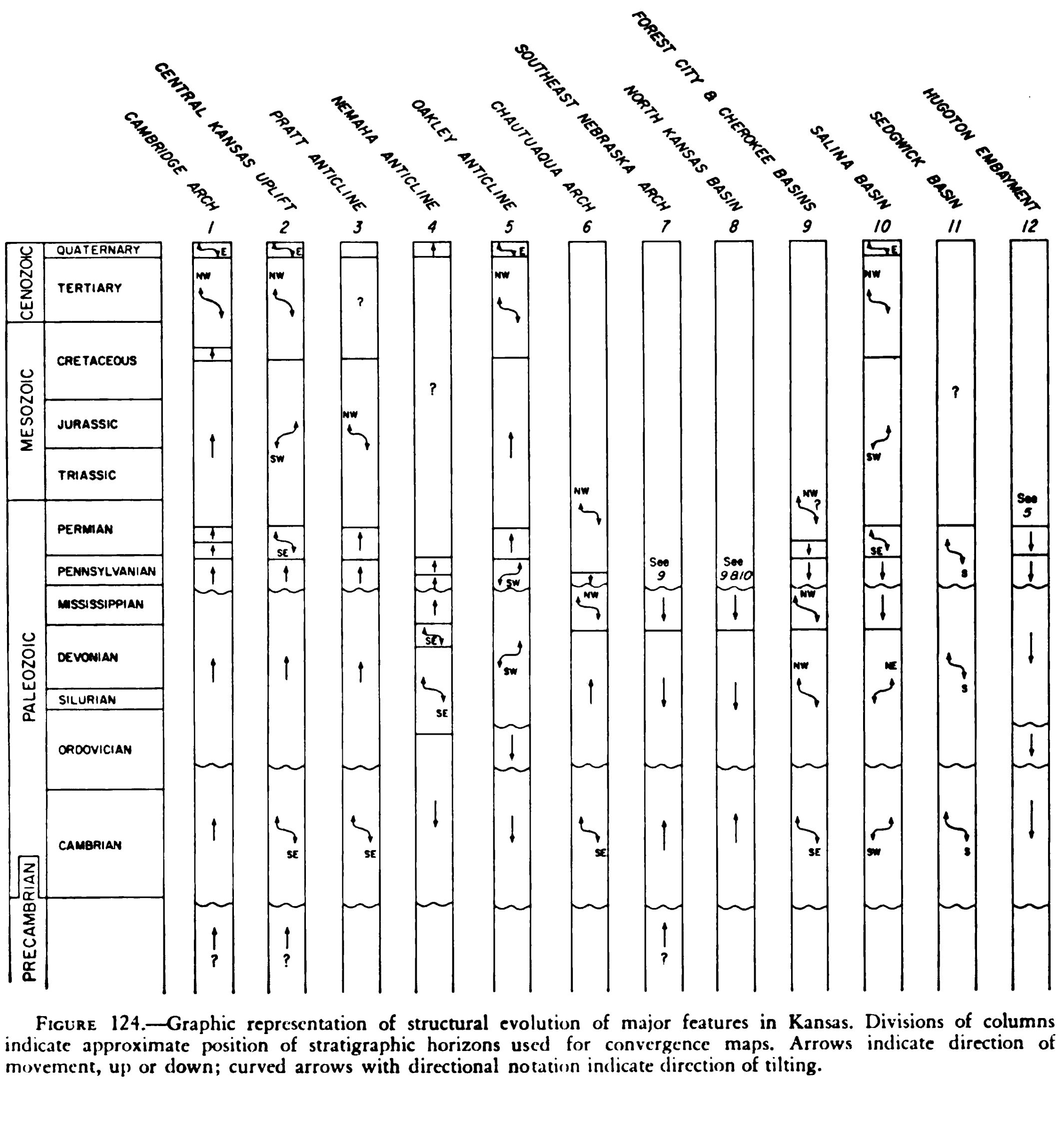


FIGURE 124.—Graphic representation of structural evolution of major features in Kansas. Divisions of columns indicate approximate position of stratigraphic horizons used for convergence maps. Arrows indicate direction of movement, up or down; curved arrows with directional notation indicate direction of tilting.

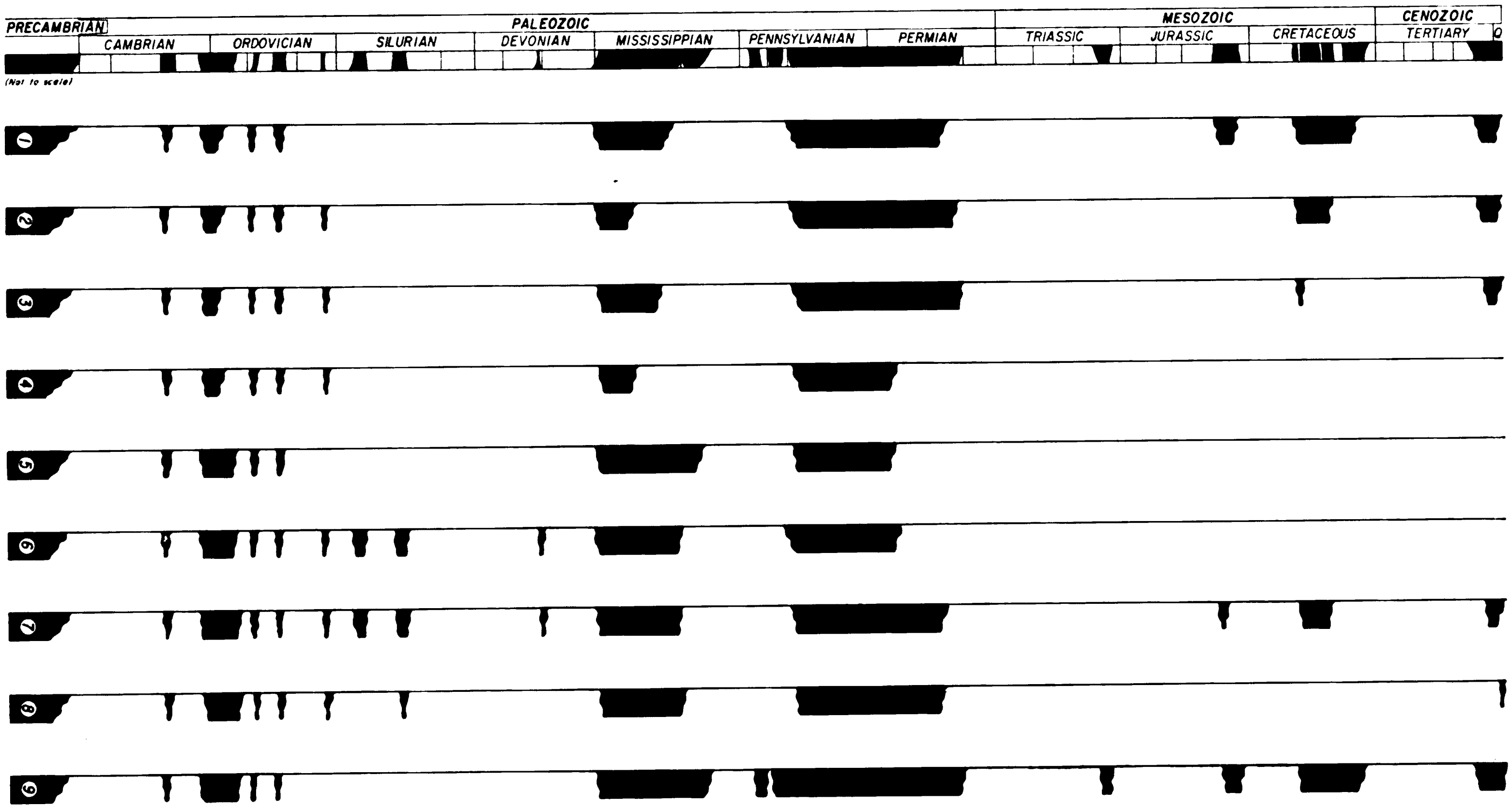


FIGURE 125.—Beds present in major pre-Desmoinesian post-Mississippian structural elements. 1, Cambridge Arch; 2, Central Kansas Uplift; 3, Pratt Anticline; 4, Nemaha Anticline; 5, Cherokee Basin; 6, Forest City Basin; 7, Salina Basin; 8, Sedgwick Basin; and 9, Hugoton Embayment.

granitic crust (J. A. Peoples, personal communication, June 22, 1962). Table 6 gives approximate focal depths of some earthquakes in the Midcontinent. The figures are relative, not absolute, depths.

Because of the paucity of destructive earthquakes in Kansas, it can be concluded that the area is a relatively stable one; however, the relation of earthquakes to the Nemaha Anticline shows that the anticline is tectonically active at present. The other structural features in Kansas may be regarded as stable.

Development of Major Structural Features

Gross aspects of structural development of each of the major structural features are shown graphically in Figure 124. Information for this generalized chart was obtained, at least in part, from: Merriam and Atkinson (1955) and Parkhurst (1959a) on the Cambridge Arch; Lee (1953) on the Central Kansas Uplift; McCoy (1953), Merriam (1955b), Mehl (1959), and Hays (1961) on the Hugoton Embayment and Pratt Anticline; Lee (1956) on the Salina Basin; Kelly (1961) on the Sedgwick Basin; Lee (1943) and Lee and others (1946) on the Forest City Basin; Lee and Merriam (1954b) on the Nemaha Anticline; and Goebel and Merriam (1959) on the Cherokee Basin. This chart, although generalized and greatly simplified, gives a graphic comparison of the movements of different structural elements through time. Post-Paleozoic movements in eastern Kansas can only be assumed, owing to lack of Mesozoic and Cenozoic deposits in this region. Even in western Kansas incompleteness of the rock record seriously hampers interpretation. The extent of this hindrance may be estimated by noting the large gaps in the column in Figure 125.

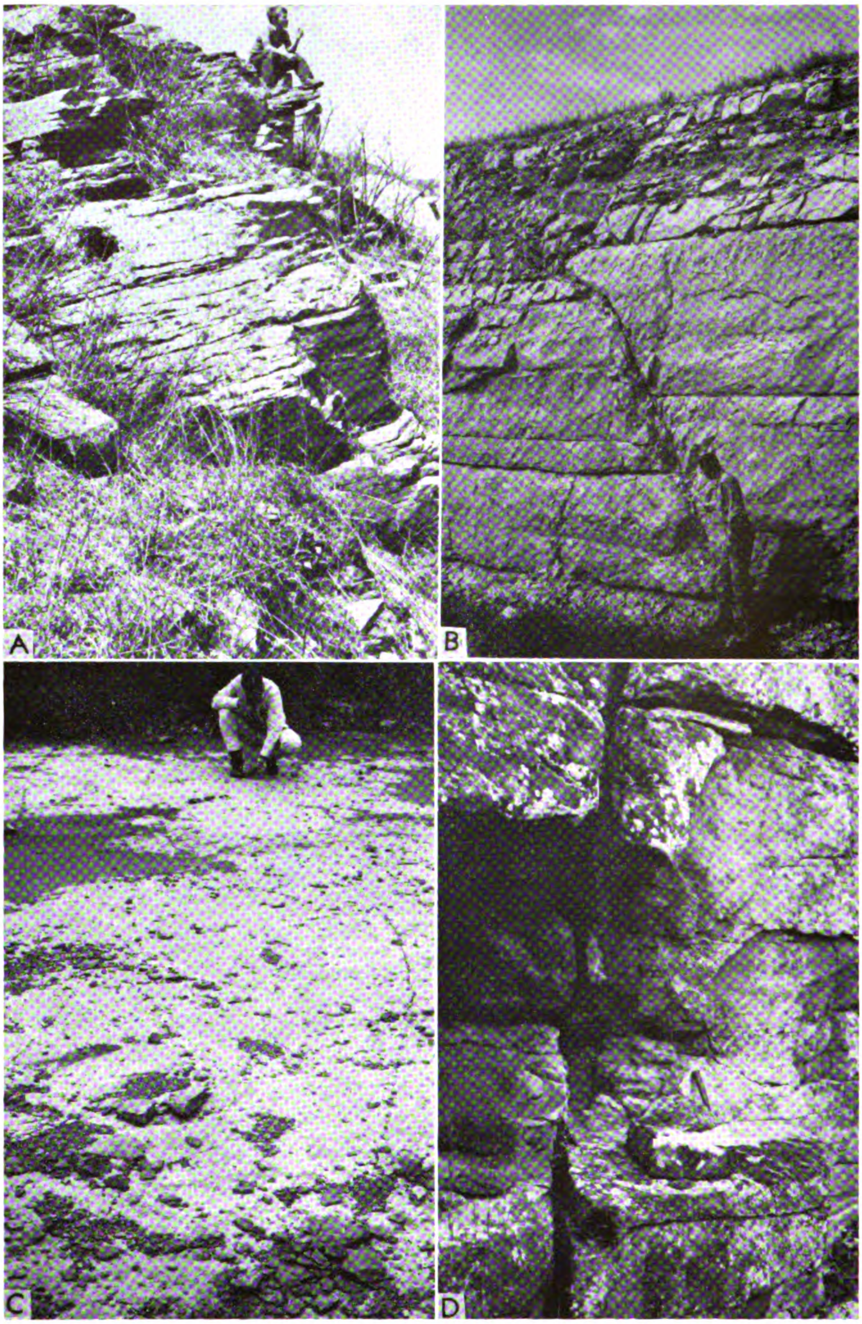


PLATE 28.—**A,** Dipping beds along north side of fault on Silver City Dome, Woodson County (NE sec. 32, T. 26 S., R. 15 E.). **B,** Small normal fault in Fort Hays Limestone in road cut on U.S. Highway 36, Jewell County (SW SE sec. 16, T. 3 S., R. 7 W.). **C,** Joints in South Bend Limestone, Allen County (NE sec. 27, T. 23 S., R. 18 E.). **D,** Joints in Elgin Sandstone, Chautauqua County (sec. 15, T. 35 S., R. 10 E.).

STRUCTURAL PATTERNS

In considering size of structural elements and their relation in space, it is convenient to classify them. The largest structural elements of the earth's crust are the continents and ocean basins, which are of first-order magnitude. Subcontinental regions constituting structural entities, such as the Midcontinent, Rocky Mountains, and Colorado Plateau, may be classified as second-order structures. Regional structures, such as the Central Kansas Uplift, Salina Basin, and Nemaha Anticline, are third order; small structures, such as the Stuttgart-Huffstutter Anticline, Long Island Syncline, and Alma Anticline, then, are fourth order. Local closed "highs" are the smallest or fifth-order structures. This classification is useful in that it brings together, for comparison, structures of the same magnitude. It is the small structures and their relations to larger elements that are of concern here.

Locations of the small structures (fourth order) in relation to the major structural features (third order) are shown in Figure 126. Insofar as possible, a random selection of structures was made in order to obtain representative ones in different structural regions, but unfortunately only along oil-producing anticlines is detailed information for structural studies available. It is not possible to obtain sufficient data in synclines or along barren anticlines. All structures studied in detail are shown in Figures 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, and 136, and information from them is listed in Table 7.

The fields were contoured on top of Lansing, Mississippian, "Hunton," or Viola rocks, at 10-foot intervals. Of course, the figures given in Table 7 are only representative of magnitude because not all fields are completely exploited. More or less closure might be shown if older or younger datum horizons were used for contouring.

Major pre-Desmoinesian post-Mississippian structural elements exhibit two sets of trends—one approximately northeast (N 20° E), as shown by the Nemaha Anticline, and the other northwesterly (N 45° W), exemplified by the Central Kansas Uplift. Smaller structures superimposed on these uplifts or adjacent to them are either parallel (subparallel) or perpendicular to the larger structures. About 8 percent of the structures studied are domes and thus show no preferential trend.

Fifth-order structures likewise exhibit cross trends, but a study of these structures reveals three sets of trends at approximately N 12° E, N 40° E, and N 42° W (Fig. 137). The faults in Kansas also reveal much the same pattern, although northeast-trending ones seemingly are not so plentiful.

TABLE 7.—Data on some oil- and gas-producing anticlinal and domal structures in Kansas.

Field	*Structural feature*	*Contour mapping horizon*	*Depth to mapping horizon in discovery well, feet*	*Direction of axis*	*Amount of closure, feet*	*Area of closure, square inches*[1]	*Length/width ratio*
Nunn	Hugoton	Lansing	3905	N 25° E	13	17.5	2.6
Law	Central Kansas Uplift	Lansing	3741	N 26° W	16	13.7	2.7
Shallow Water	Hugoton	Lansing	3940	N 32° W	28	16.0	2.8
Hardesty	Cambridge	Lansing	3643	N 38° E	20	9.0	1.3
Arnold	Hugoton	Lansing	3945	N 58° W	11	5.0	2.0
Nana	Cambridge	Lansing	3581	N 33° W	33	9.0	2.0
Clara	Pratt	Lansing	3949	N 30° E	36	7.0	2.1
Ruggles	Salina	Lansing	3019	N 33° W	20	8.0	1.6
Frey	Central Kansas Uplift	Lansing	3378	N 30° E	23	11.5	3.1
Rutherford	Central Kansas Uplift	Lansing	3493	N 20° E	13	9.5	2.4
Stuttgart	Cambridge	Lansing	3128	N 12° E	28	9.0	2.8
Lake City	Pratt	Lansing	3745	N 19° E	28	10.3	1.7
Hayden	Central Kansas Uplift	Lansing	3267	N 54° W	20	7.5	1.8
Logan	Cambridge	Lansing	3083	N 26° W	17	10.5	1.5
Hickman	Central Kansas Uplift	Lansing	3402	N 42° W	20	14.2	1.5
Grover	Salina	Lansing	3126	N 34° E	15	8.4	2.7
Moore	Pratt	Lansing	3778	dome	39	4.5	1.0
Brock	Central Kansas Uplift	Lansing	3307	N 39° E	27	12.6	1.2
Adell	Cambridge	Lansing	3630	N 53° W	61	17.6	2.3
Oro	Hugoton	Lansing	3723	dome	33	5.7	1.0

[1] As measured by planimetry on scale of 4 inches=1 mile. To convert square inches to square miles multiply by 24.89×10^{11}.

Table 7.—Data on some oil- and gas-producing anticlinal and domal structures in Kansas (concluded).

Field	Structural feature	Contour mapping horizon	Depth to mapping horizon in discovery well, feet	Direction of axis	Amount of closure, feet	Area of closure, square inches	Length/width ratio
Groff	Central Kansas Uplift	Lansing	3416	N 20° W	22	11.2	2.2
Warner	Cambridge	Lansing	3147	N 34° E	29	10.2	2.7
Webs	Hugoton	Lansing	3732	dome	23	3.9	1.0
Sunny Slope	Central Kansas Uplift	Lansing	3451	N 60° W	12	8.0	2.2
Sawlog Creek	Hugoton	Lansing	3910	N 37° W	22	6.3	1.8
Walz	Central Kansas Uplift	Lansing	3371	N 36° E	20	7.1	1.8
Studley	Hugoton	Lansing	3687	N 53° W	26	15.0	3.0
Adell NW	Cambridge	Lansing	3633	N 3° W	49	10.8	1.5
Wessel	Hugoton	Lansing	3944	N 3° W	14	6.8	1.7
Llanos	Hugoton	Lansing	4290	N 13° E	26	10.8	2.2
Purdyville	Hugoton	Lansing	4010	N 25° W	31	6.2	1.8
Hortonville	Cambridge	Lansing	3736	N 45° W	16	3.0	1.2
Coats	Pratt	Lansing	3920	dome	104	9.0	1.0
Jennings	Cambridge	Lansing	3403	N — S	14	9.9	1.2
Asburn	Forest City	Viola	3254	N 13° E	29	8.5	2.7
Comiskey	Forest City	Viola	2929	N 22° E	30	12.0	3.0
Sabetha	Forest City	"Hunton"	2825	N 46° E	63	6.1	1.8
Alta Vista	Nemaha	Cottonwood		N 16° E	30	13.0	3.5
Fairplay	Sedgwick	Mississippian	2250	dome	20	10.6	1.0
Davenport	Hugoton	Lansing	3596	N 75° E	14	7.5	1.2
Kismet	Hugoton	Lansing	4314	N 15° W	21	15.7	3.2
Shiley East	Hugoton	Lansing	3703	dome	34	8.7	1.0
Blazier	Hugoton	Lansing	3666	N 52° W	34	7.2	2.5
Aldrich NE	Hugoton	Lansing	3810	N 54° E	40	26.7	1.4
Eagle Creek	Central Kansas Uplift	Lansing	3317	N 46° E	19	5.3	1.6
Wieland N	Hugoton	Lansing	3756	dome	56	13.1	1.0
Gish	Sedgwick	Mississippian	4318	N 42° E	22	10.5	1.6
Rosedale	Sedgwick	Lansing	3234	N 28° W	18	6.3	1.7
Interstate	Hugoton	Lansing	2925	N 32° E	38	71.2	2.6
Graber	Sedgwick	"Hunton"	3300	N 9° E	70	63.5	3.4
Bitter Creek	Sedgwick	Mississippian	3498	N 32° E	19	9.1	2.2
Hunter	Salina	Mississippian	2676	N 20° E	32	24.9	2.5
John Creek	Forest City	Viola	3088	N 19° E	85	60.2	3.3
Mill Creek	Forest City	Mississippian	2195	N 15° E	20	9.4	2.2
Davis Ranch	Forest City	Viola	3199	N 2° E	53	17.5	3.0
Newbury	Forest City	Mississippian	2156	N 21° E	30	9.4	2.5
Weathered	Cherokee	Mississippian	3057	N 14° E	60	12.3	2.8
Posey	Cherokee	Mississippian	3164	N — S	24	12.0	1.7
Box	Cherokee	Mississippian	2840	dome	27	5.1	1.0
Hannah	Cherokee	Kansas City	1959	N 12° W	23	6.8	2.0
Countryman	Cherokee	Mississippian	2825	N 12° E	37	8.7	2.3
				N 40° E	35	7.0	3.3
Webb	Cherokee	Mississippian	1931	N 21° E	43	8.7	1.6
Wilmington	Forest City	Viola	2994	dome	20	5.3	1.0
Ogallah	Central Kansas Uplift	Arbuckle	3961	N 64° W	49	62.4	3.6
Dunes	Central Kansas Uplift	Arbuckle	3956	N 38° E	47	5.4	2.4
Alloway	Cherokee	Arbuckle	——	dome	35	6.2	1.0
Norton	Cambridge	Arbuckle	3778	N 52° E	26	57.7	3.0
Aldrich NE	Hugoton	Mississippian	4398	N 50° E	33	20.4	1.4
Purdyville	Hugoton	Mississippian	4663	N 50° E	42	11.9	1.9
Graber	Sedgwick	"Hunton"	3274	N 12° E	60	51.0	3.3
North Star	Central Kansas Uplift	Viola	4063	N 10° E	30	8.5	2.2
Gish	Sedgwick	Simpson	4700	N 40° E	28	9.3	1.5
Fall Creek	Sedgwick	Simpson	4746	N 34° E	78	13.2	1.6
Asmusson	Nemaha	Arbuckle	2695	N 13° E	272	10.7	2.4
Ames	Central Kansas Uplift	Arbuckle	3348	N 53° W	31	15.6	2.9

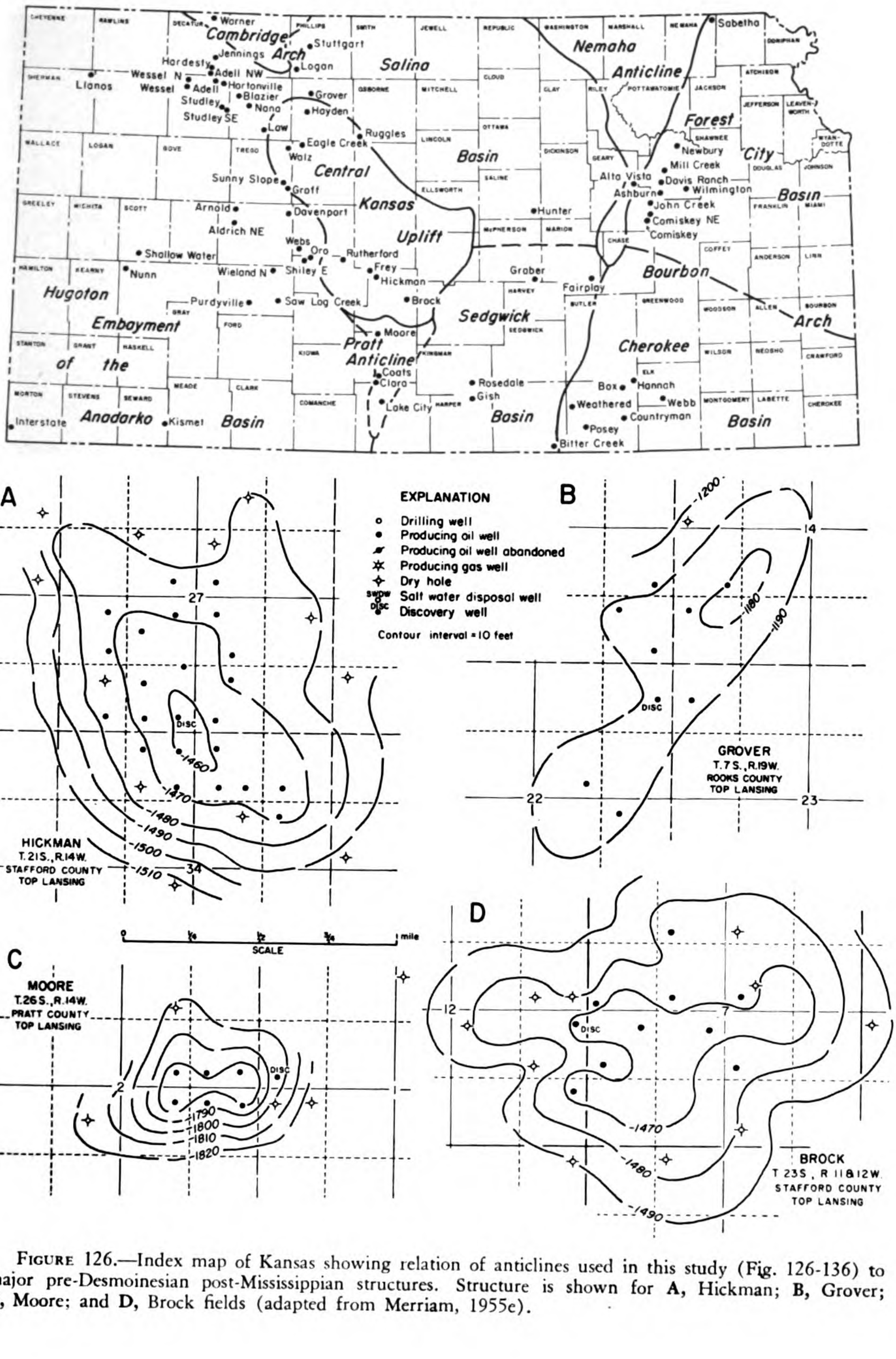


Figure 126.—Index map of Kansas showing relation of anticlines used in this study (Fig. 126-136) to major pre-Desmoinesian post-Mississippian structures. Structure is shown for **A**, Hickman; **B**, Grover; **C**, Moore; and **D**, Brock fields (adapted from Merriam, 1955e).

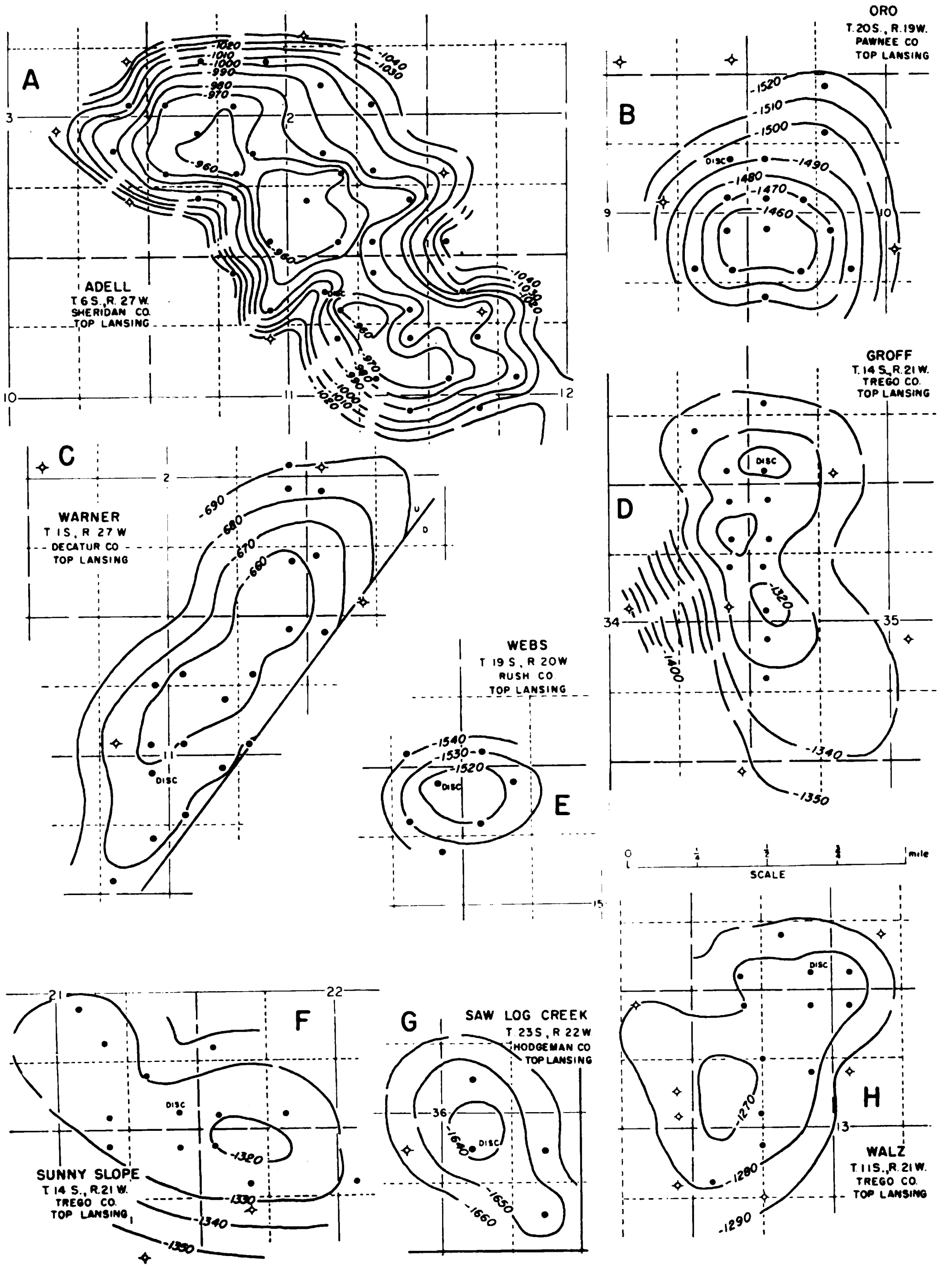


FIGURE 127.—Structure of A, Adell; B, Oro; C, Warner; D, Groff; E, Webs; F, Sunny Slope; G, Saw Log Creek; and H, Walz fields (adapted from Merriam, 1955e).

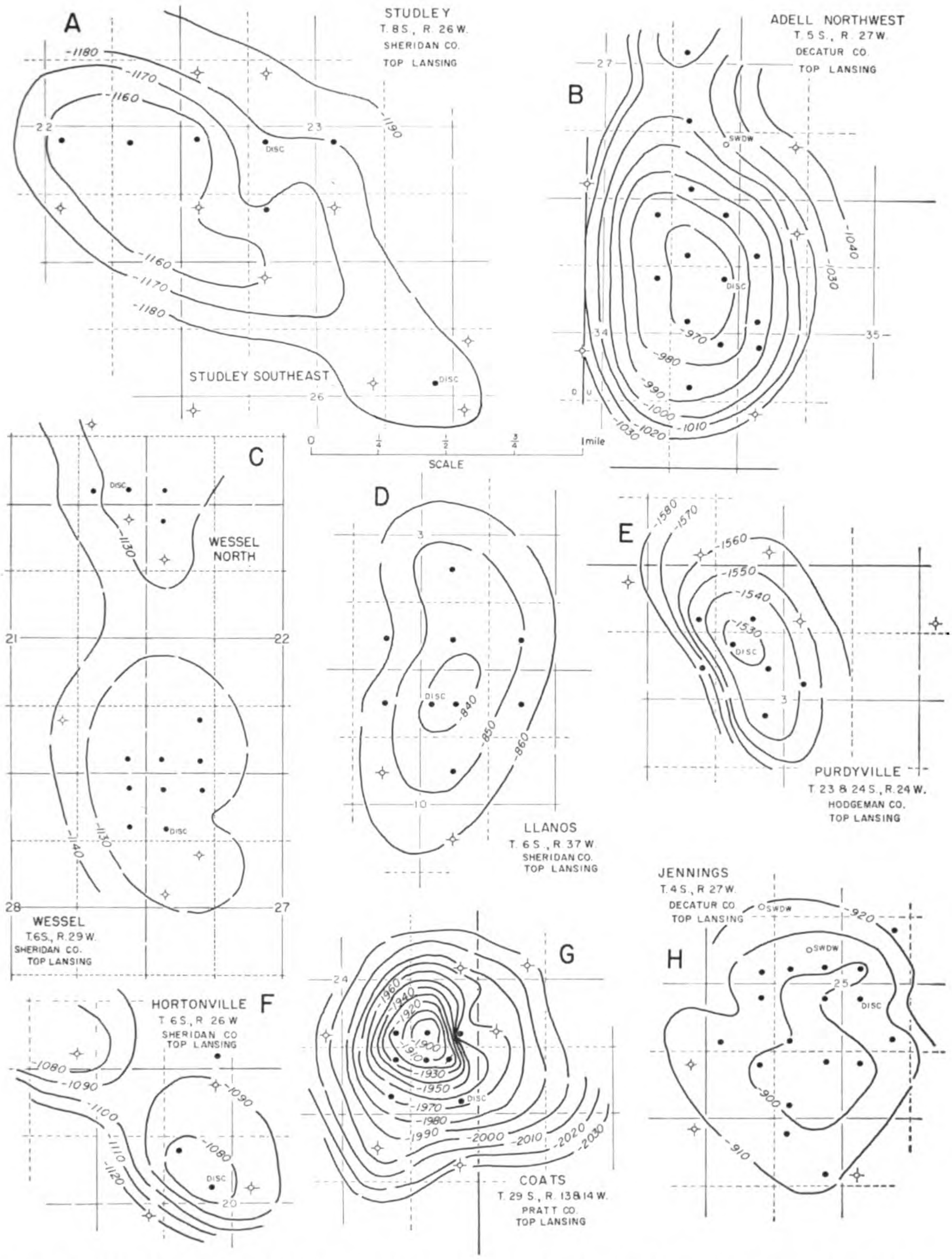


FIGURE 128.—Structure of **A,** Studley and Studley Southeast; **B,** Adell Northwest; **C,** Wessel and Wessel North; **D,** Llanos; **E,** Purdyville; **F,** Hortonville; **G,** Coats; and **H,** Jennings fields (adapted from Merriam, 1955e).

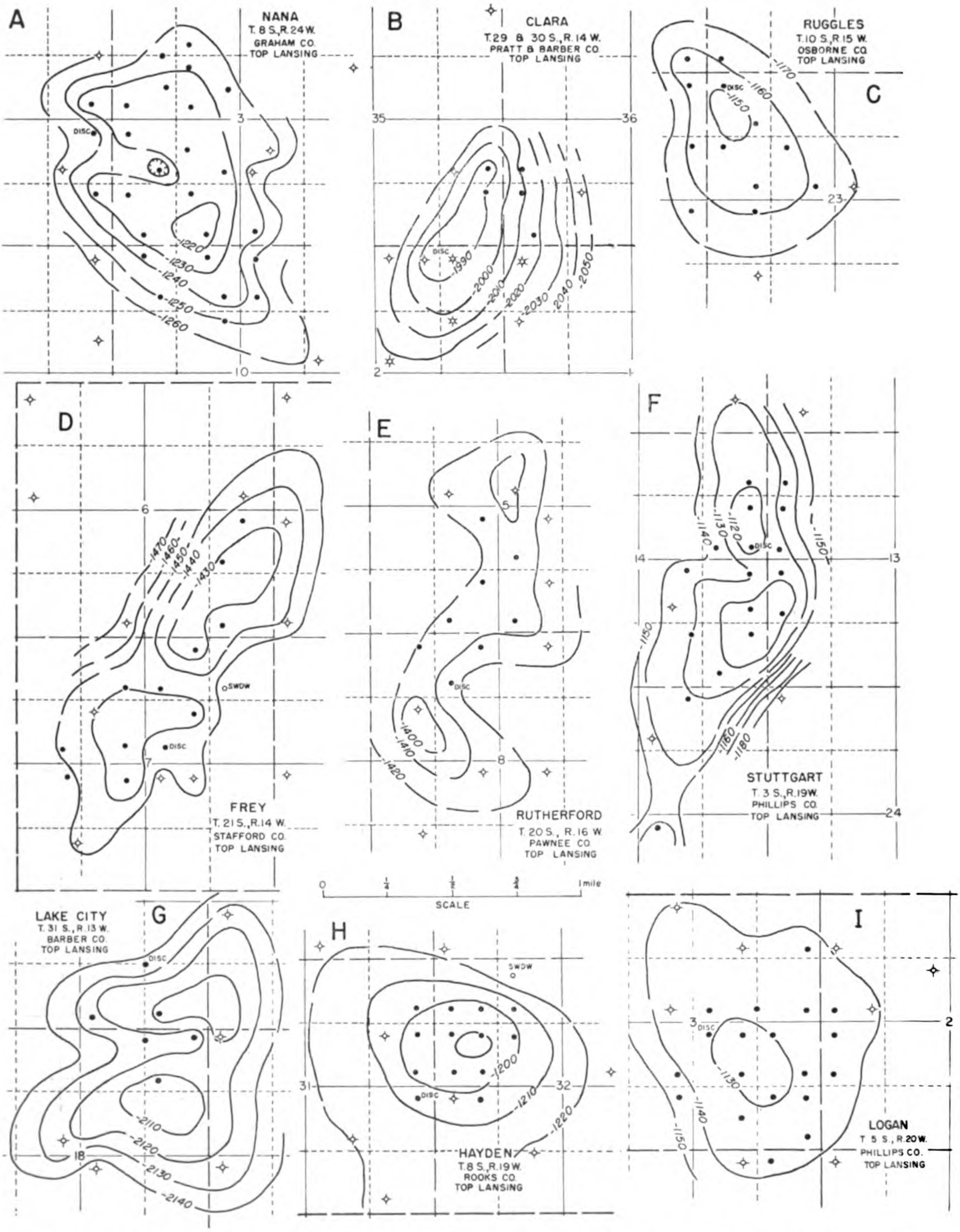


FIGURE 129.—Structure of **A,** Nana; **B,** Clara; **C,** Ruggles; **D,** Frey; **E,** Rutherford; **F,** Stuttgart; **G,** Lake City; **H,** Hayden; and **I,** Logan fields (adapted from Merriam, 1955e).

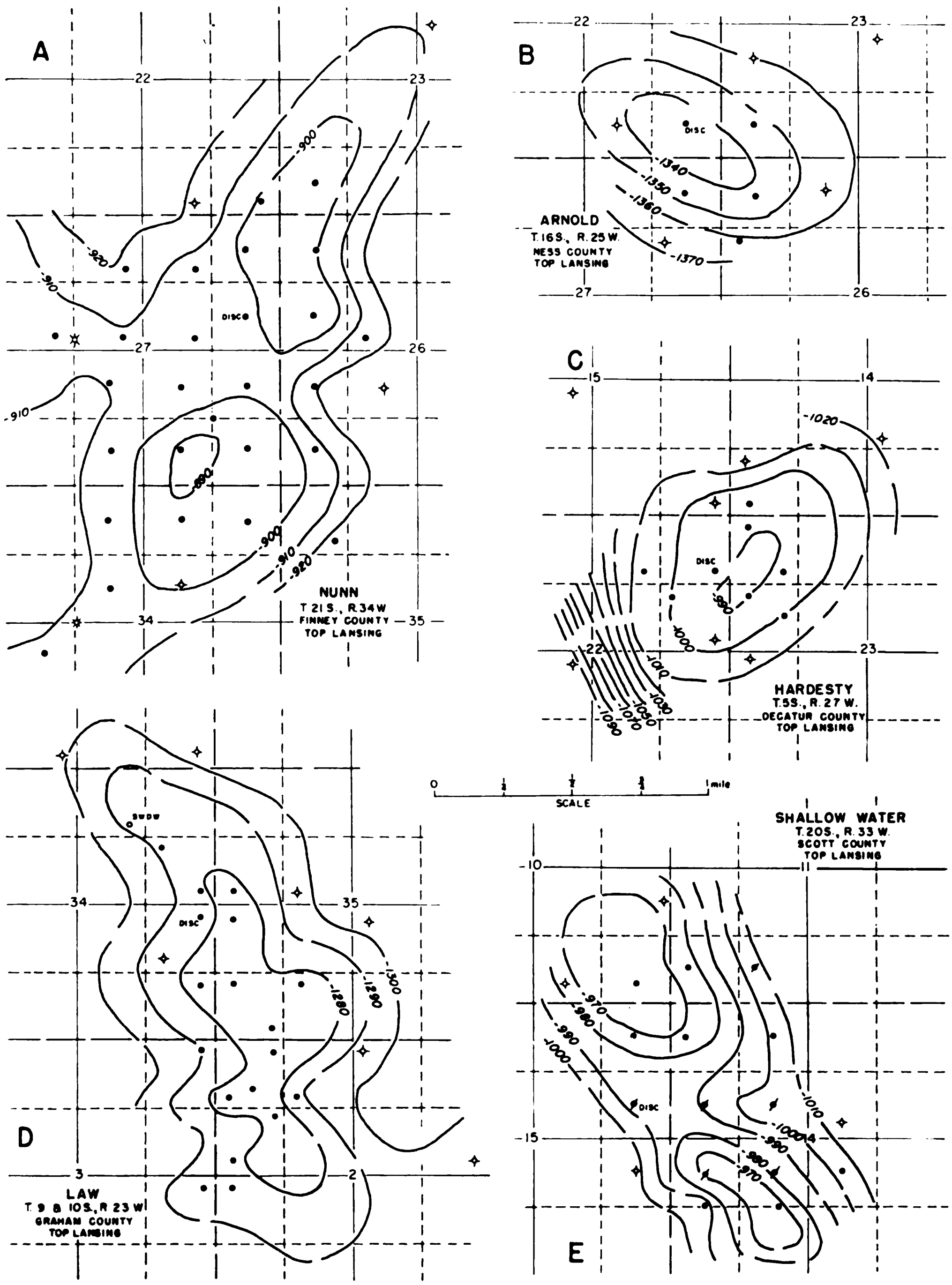


FIGURE 130.—Structure of A, Nunn; B, Arnold; C, Hardesty; D, Law; and E, Shallow Water fields (adapted from Merriam, 1955e).

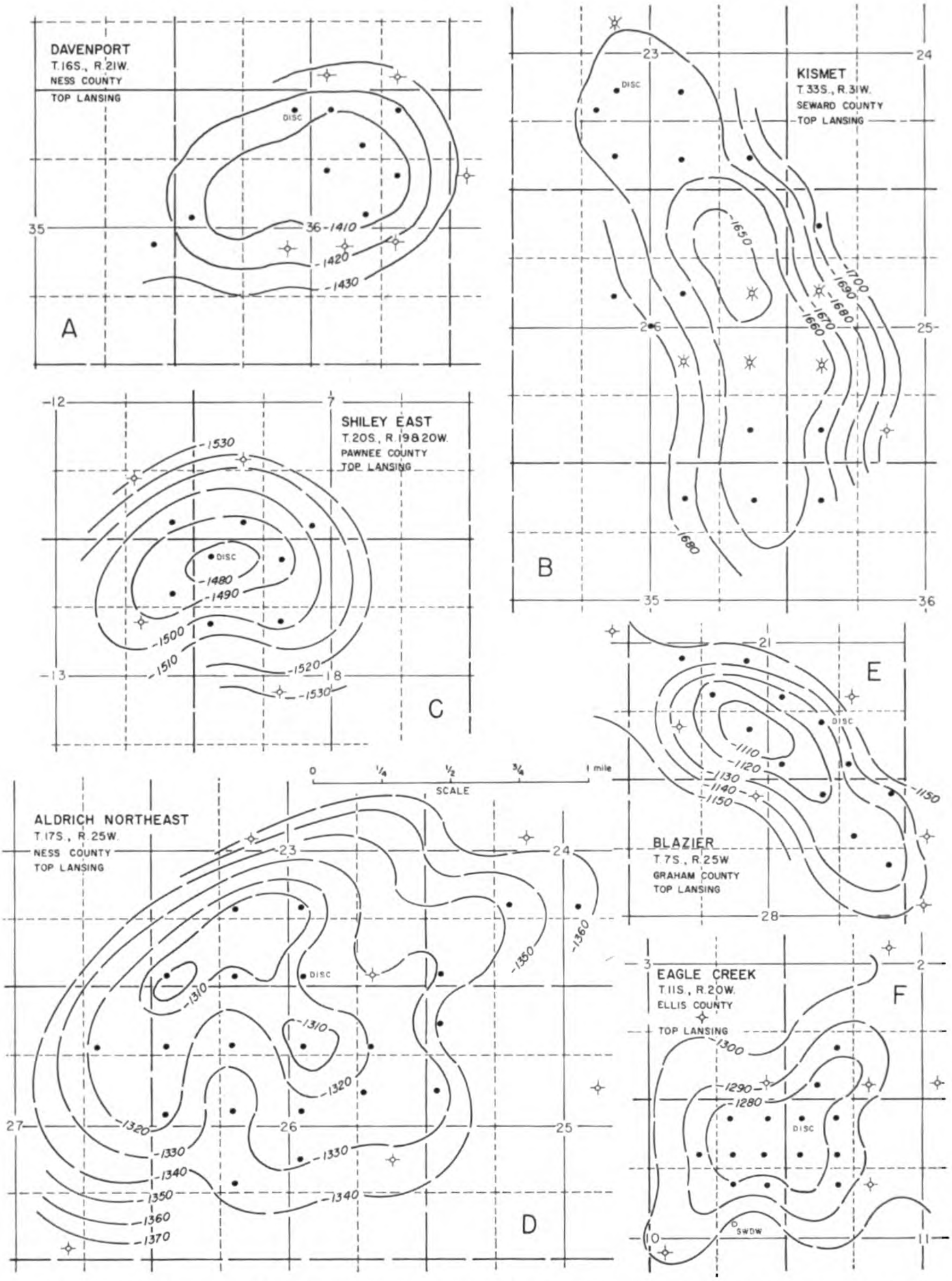


FIGURE 131.—Structure of **A,** Davenport; **B,** Kismet; **C,** Shiley East; **D,** Aldrich Northeast; **E,** Blazier; and **F,** Eagle Creek fields.

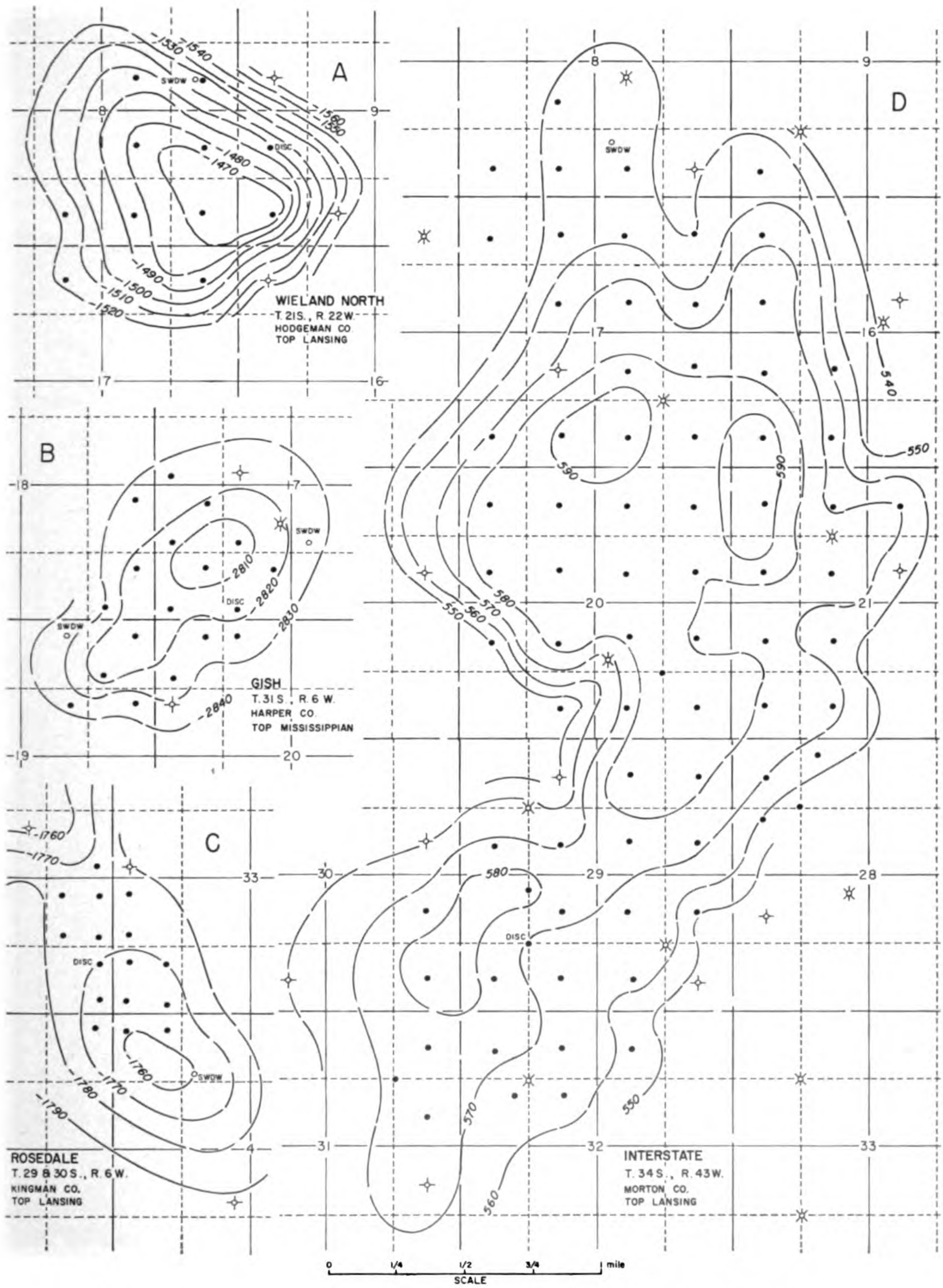


FIGURE 132.—Structure of **A,** Wieland North; **B,** Gish; **C,** Rosedale; and **D,** Interstate fields.

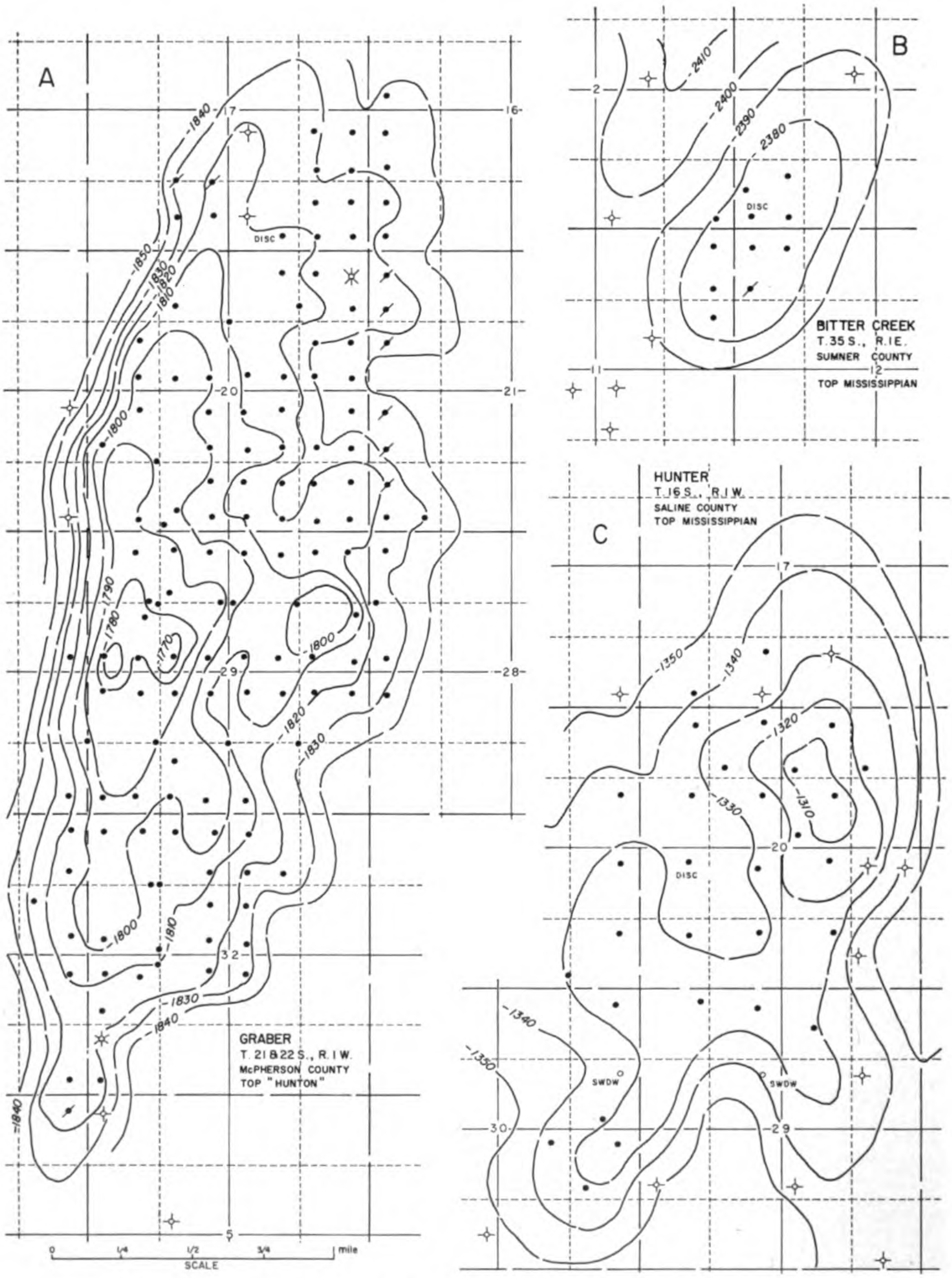


FIGURE 133.—Structure of **A,** Graber; **B,** Bitter Creek; and **C,** Hunter fields.

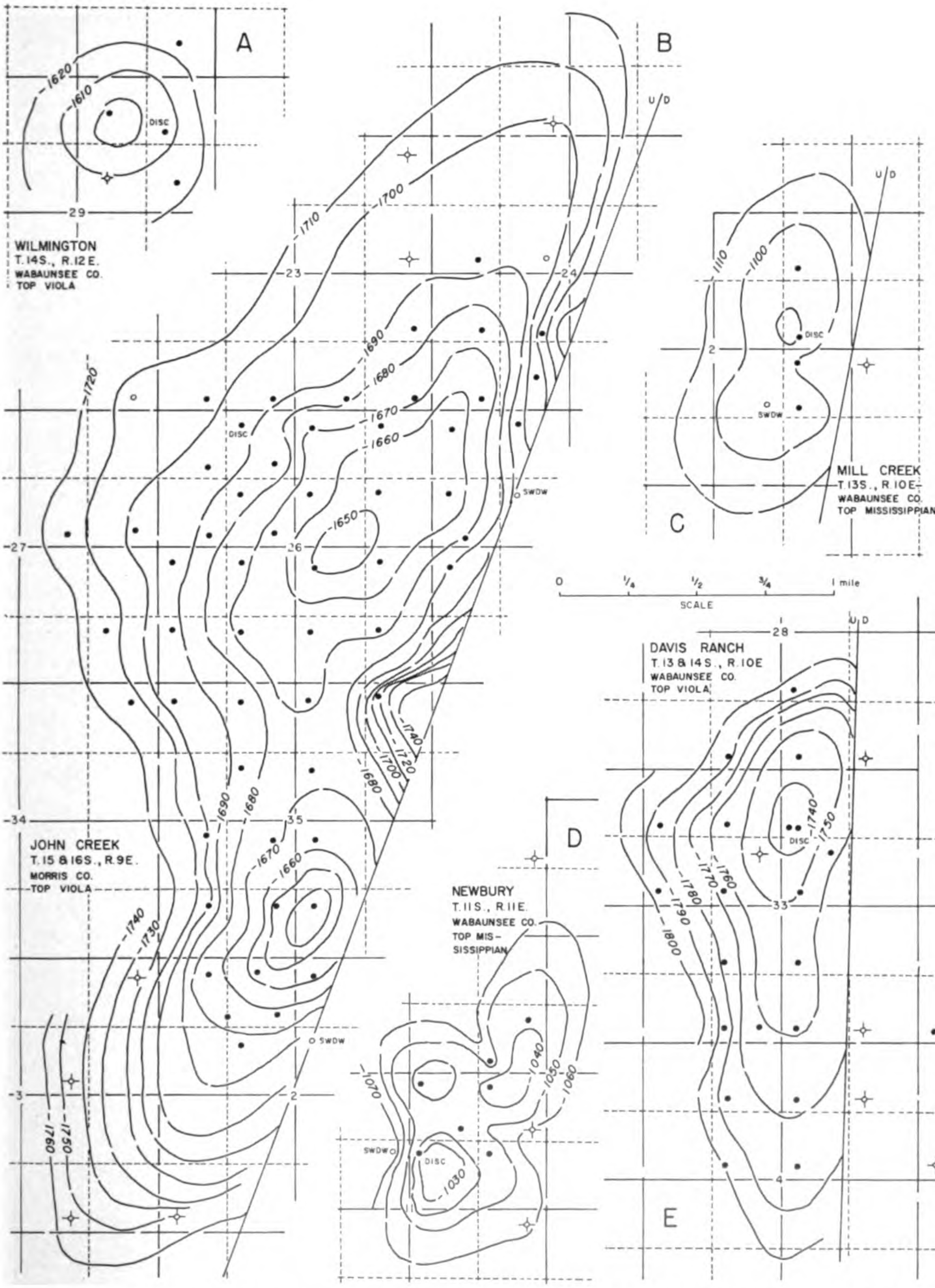


Figure 134.—Structure of **A,** Wilmington; **B,** John Creek; **C,** Mill Creek; **D,** Newbury; and **E,** Davis Ranch fields.

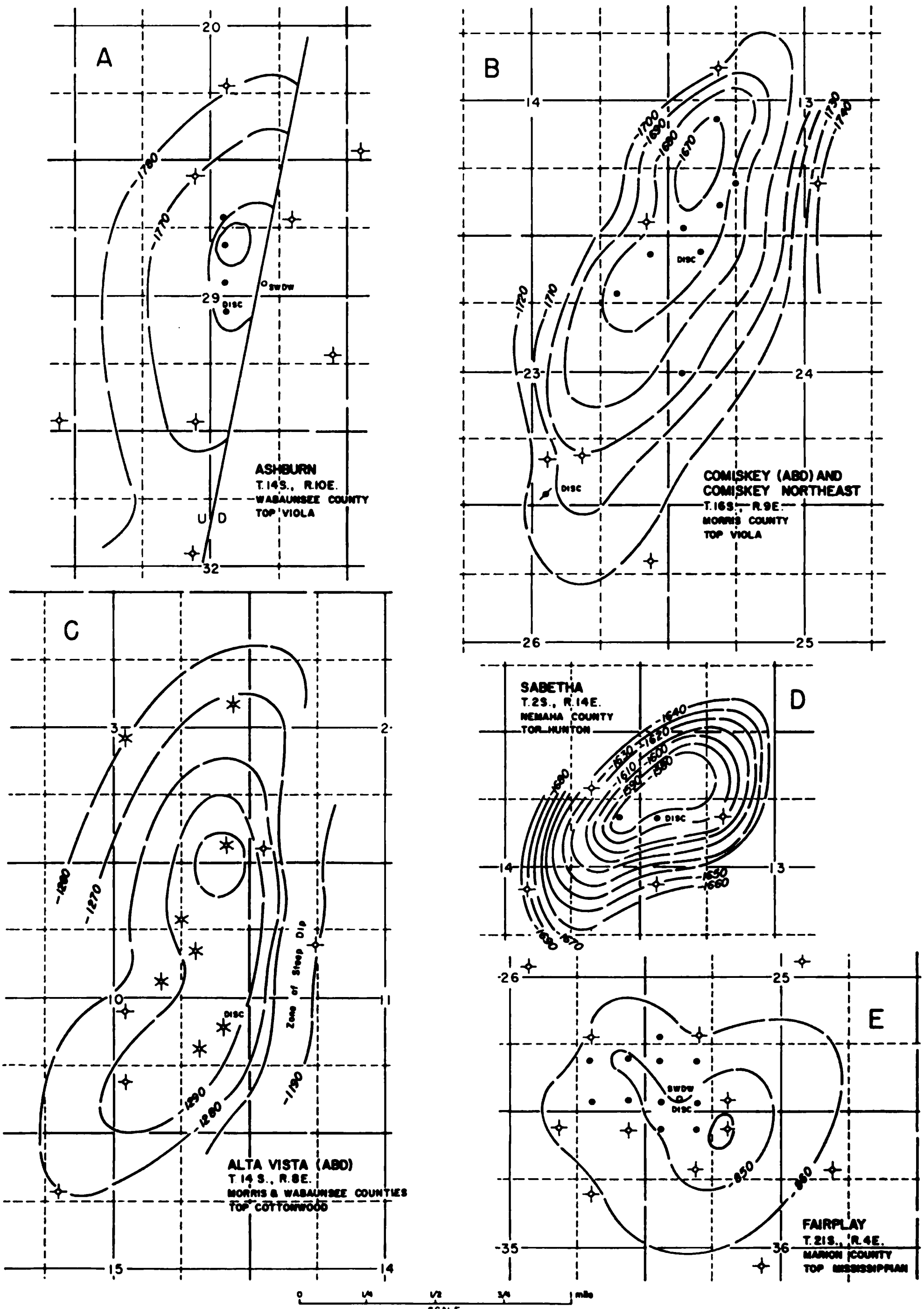


FIGURE 135.—Structure of **A**, Ashburn; **B**, Comiskey and Comiskey Northeast; **C**, Alta Vista; **D**, Sabetha; and **E**, Fairplay fields.

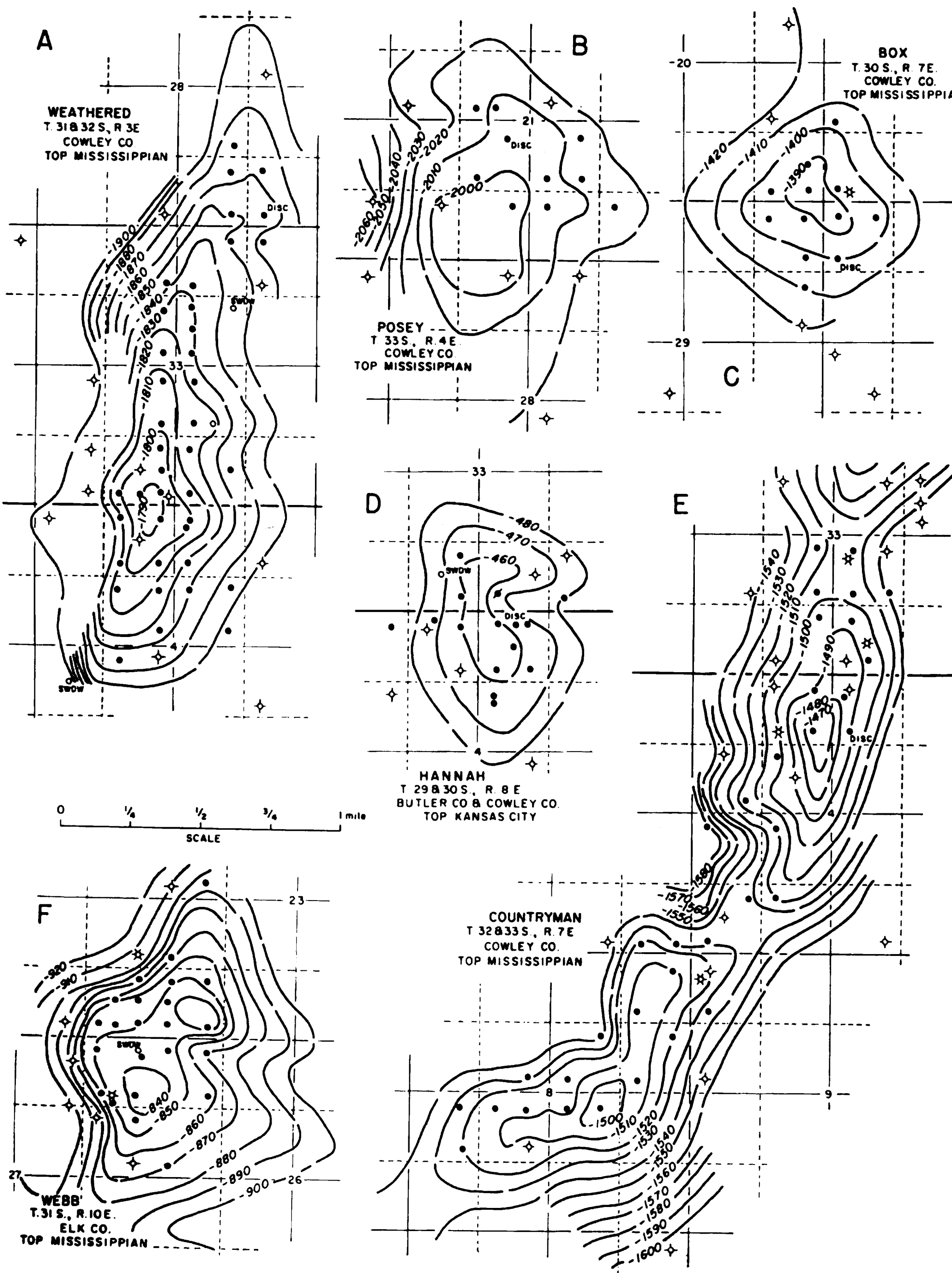
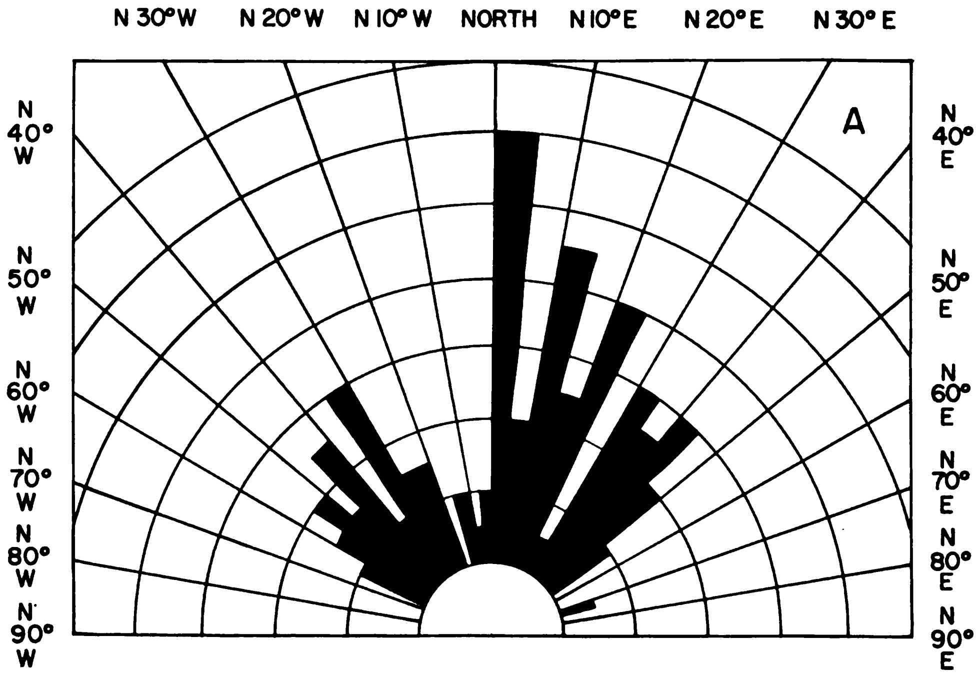


FIGURE 136.—Structure of **A,** Weathered; **B,** Posey; **C,** Box; **D,** Hannah; **E,** Countryman; and **F,** Webb fields.



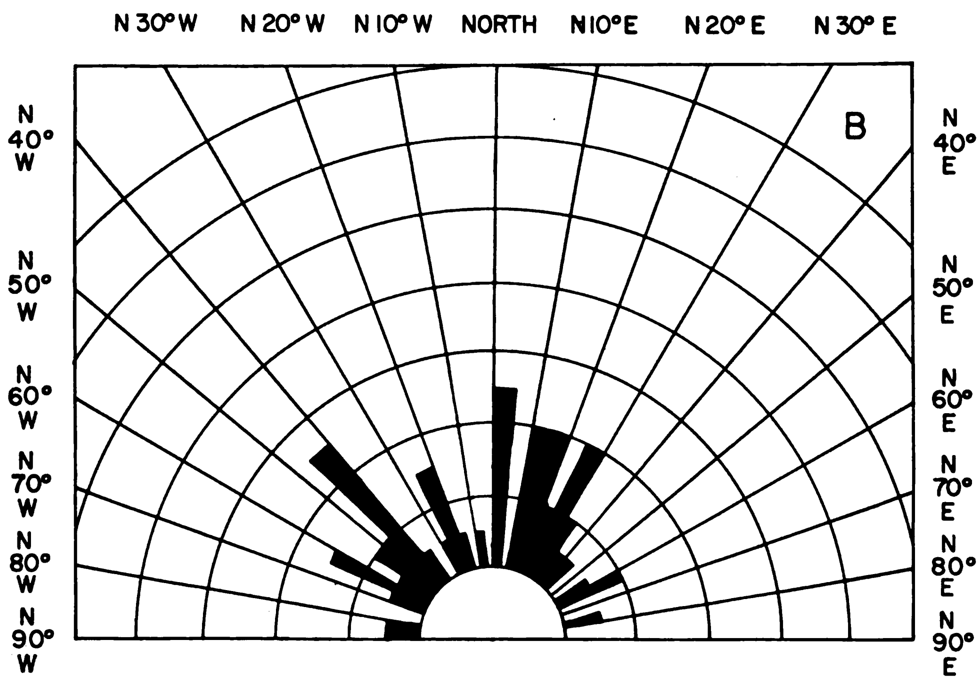


FIGURE 137.—Direction of **A**, structural axes, and **B**, fault trends. Three sets of structural trends approximately N 12° E, N 40° E, and N 42° W are evident.

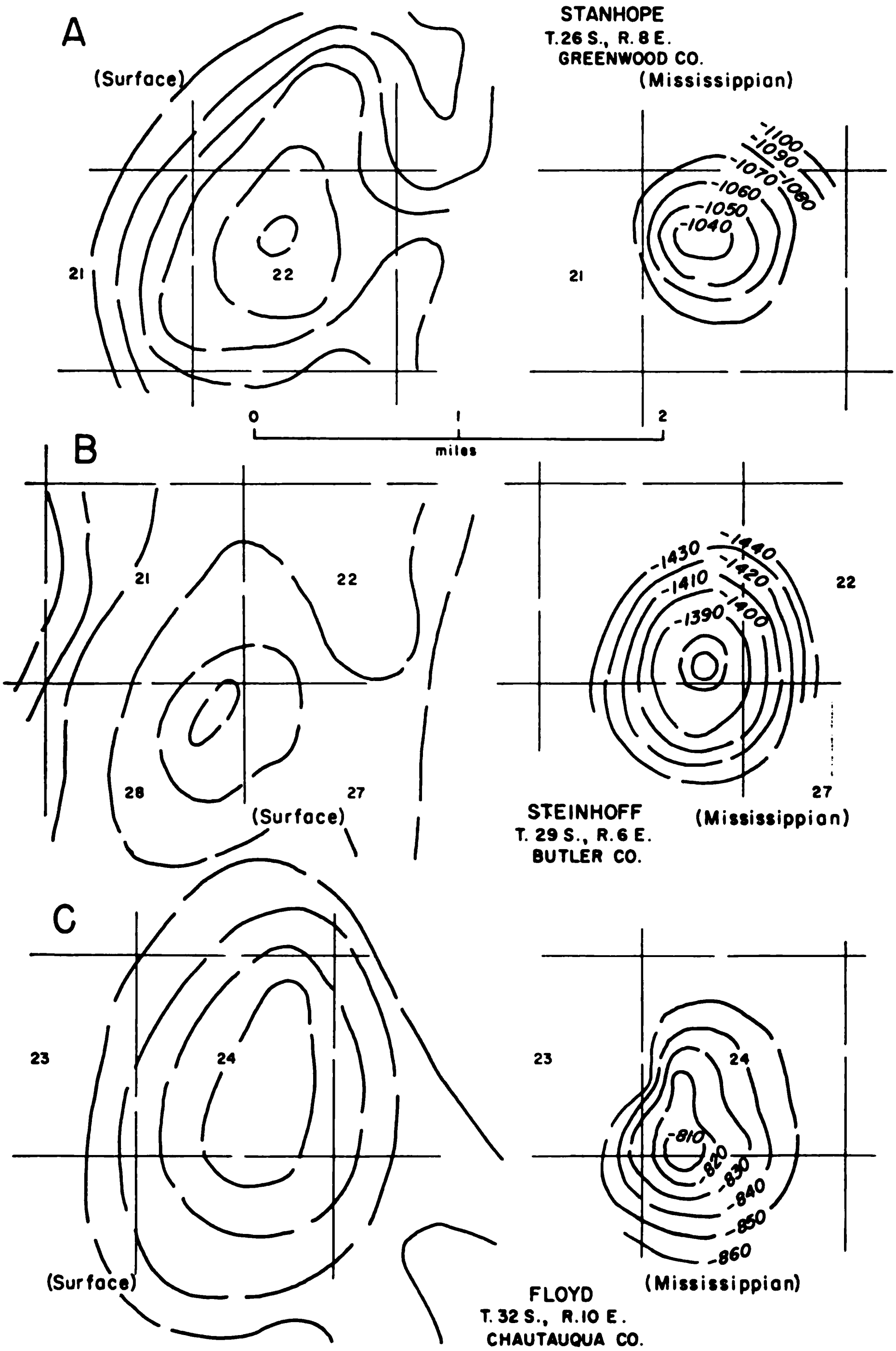


FIGURE 138.—Three anticlinal areas in southeastern Kansas showing relation of configuration of structure in surface beds to top of Mississippian rocks: A, Stanhope field; B, Steinhoff field; and C, Floyd field.

Magnitude of Features

The amount of closure ranges from 11 feet at Arnold (Fig. 130) to 104 feet at Coats (Fig. 128). Average closure of the fields contoured is 27 feet on the Lansing, 30 feet on the Mississippian, and 43 feet on the Viola. Because only two fields were contoured on the "Hunton," the average closure is not significant. In general, it may be stated that the amount of closure increases with depth. Merriam (1955c) found that in eight of ten fields in central and western Kansas the structural relief on the Stone Corral is less than on the Lansing. Many areas in southeastern Kansas show a well-defined relationship between surface structure and structure at depth (Merriam and Goebel, 1959c). This is not a new idea; it was pointed out 34 years ago by Bass (1929) and 39 years ago by Ley (1924). In many places, surface structure in Pennsylvanian or Permian beds may provide clues to the attitude of the Mississippian or older surfaces; however, in other fields there is no coincidence.

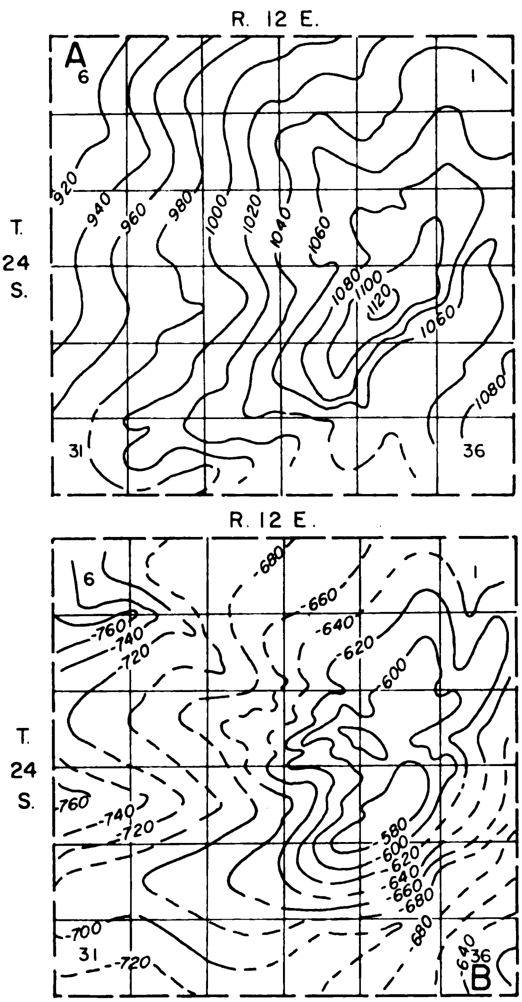


FIGURE 139.—Virgil Anticline. **A**, structural map contoured at 20-foot intervals on top of Lecompton Limestone; **B**, structural map contoured at 20-foot intervals on top of "Mississippi lime." Both maps from Beekly (1929).

Because structural relief in surface rocks is small, anticlines at depth are not all indicated by closure at the surface. Many northeast-trending anticlines as mapped on top of Mississippian rocks are revealed on the surface by southwest-plunging structural noses.

Three areas of surface closure and their corresponding subsurface structures are shown in Figure 138. Structure in outcropping rocks is revealed as northeast-trending anticlines with the structural saddle located on the southeast, which regionally is updip. Beneath these areas of low closure, 10 to 30 feet, are more pronounced structures on the Mississippian surface that exhibit at least 40 feet of closure.

The position of the structural axis also may shift with depth. According to Ley (1924, p. 449):

> Folding generally shifts with depth, sometimes to the west-southwest as in the Red Bank pool at Coffeyville in Montgomery County, or to the south, as in the Rose dome area of southern Woodson County. There seems to be no hard and fast rule which can be applied; better practice would be to apply the direction of shifting which subsurface studies establish for the area in question.

Part of this shift in position with depth may be due to westerly regional dip and part to convergence of the two mapped horizons. Other factors also may influence the shift.

VIRGIL ANTICLINE.—Beekly (1929) has shown the relation of surface structure to structure on top of the Mississippian in the Virgil Anticline in Greenwood County (Fig. 139). Concerning this structure he wrote (1929, p. 145):

> The Virgil pool is located on a surface structure having more than 60 feet of closure . . . the surface structure [is] mapped on the top of the LeCompton limestone and on intervals between this datum bed and the Deer Creek and Topeka limestones. . . . The subsurface structure . . . is contoured on the top of the "Mississippi lime." Although not recognized as a satisfactory marker in many localities in Kansas, it was used in this field for the reasons that it happens to conform very closely with the surface structure . . . available well logs show such remarkable regularity of section and intervals that the subsurface structure as mapped on the top of the "Mississippi" cannot differ in any essential respect from that of any higher bed or that mapped at the surface.

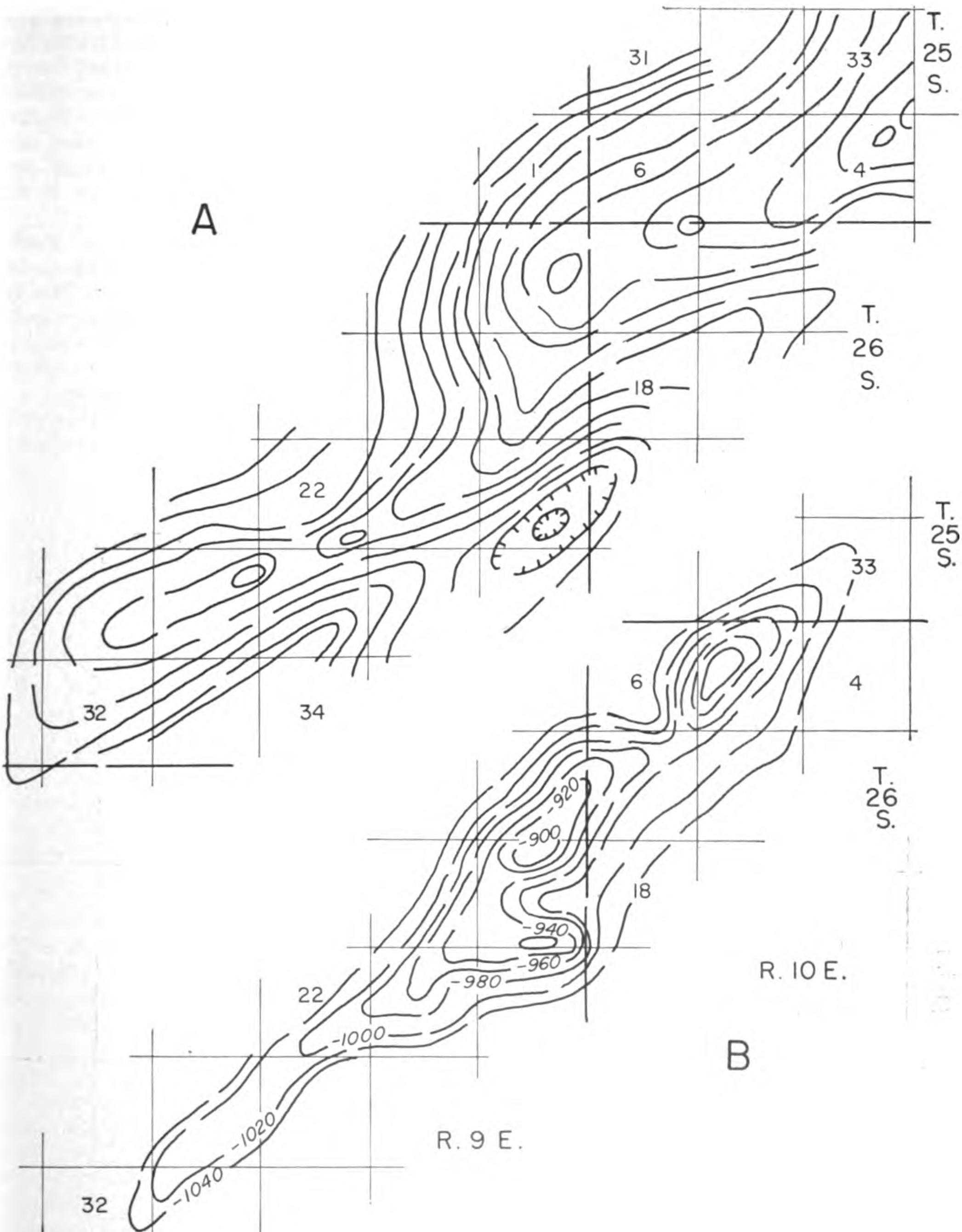


FIGURE 140.—Reese Anticline. **A**, Structural map contoured at 10-foot? intervals on outcropping rocks (from Kansas Blue Print Company, Wichita); **B**, structural map contoured at 20-foot intervals on top of Mississippian rocks (from Merriam and Goebel, 1959c).

The Mississippian structural map (Fig. 139B) shows approximately 100 feet of closure, and there is negligible offset of the structural axis at greater depth.

REESE ANTICLINE.—The Reese Anticline is a long, narrow, northeast-trending feature located in Greenwood County (Fig. 140). Structure on top of the Mississippian reveals a northeast-trending, double-plunging anticline having 100 to 120 feet of closure. Control available suggests that the anticline is slightly asymmetrical, the northwest flank being steeper.

The surface structure (Fig. 140A) was taken from a map supplied by the Kansas Blue Print Co. of Wichita. The contour interval is not known, but it seems to be 10 feet. The Reese Anticline as outlined by surface structure is mainly a southwest-plunging nose; small areas of closure are located along the crest. Maximum closure of these areas seems to be about 20 feet. Although the surface and subsurface areas of closure do not coincide, the position and trend of the axis are the same on both maps.

COUNTRYMAN ANTICLINE.—The Countryman Anticline is a northerly trending feature located in Cowley County (Fig. 141). The surface structure (Fig. 141A) was taken from a Federal Geological Survey open-file report. Some subsurface control is available along the crest, but is inadequate to delineate the structure in the subsurface.

Structure on top of the Mississippian reveals three areas of closure on the crest of the Countryman. The maximum local closure is 30 to 50 feet, but closure for the entire structure is probably somewhat larger. Because well control is sparse on the flanks, it is not possible to determine symmetrical expression of structure.

The surface trend is closely coincident with the trend on top of the Mississippian; however,

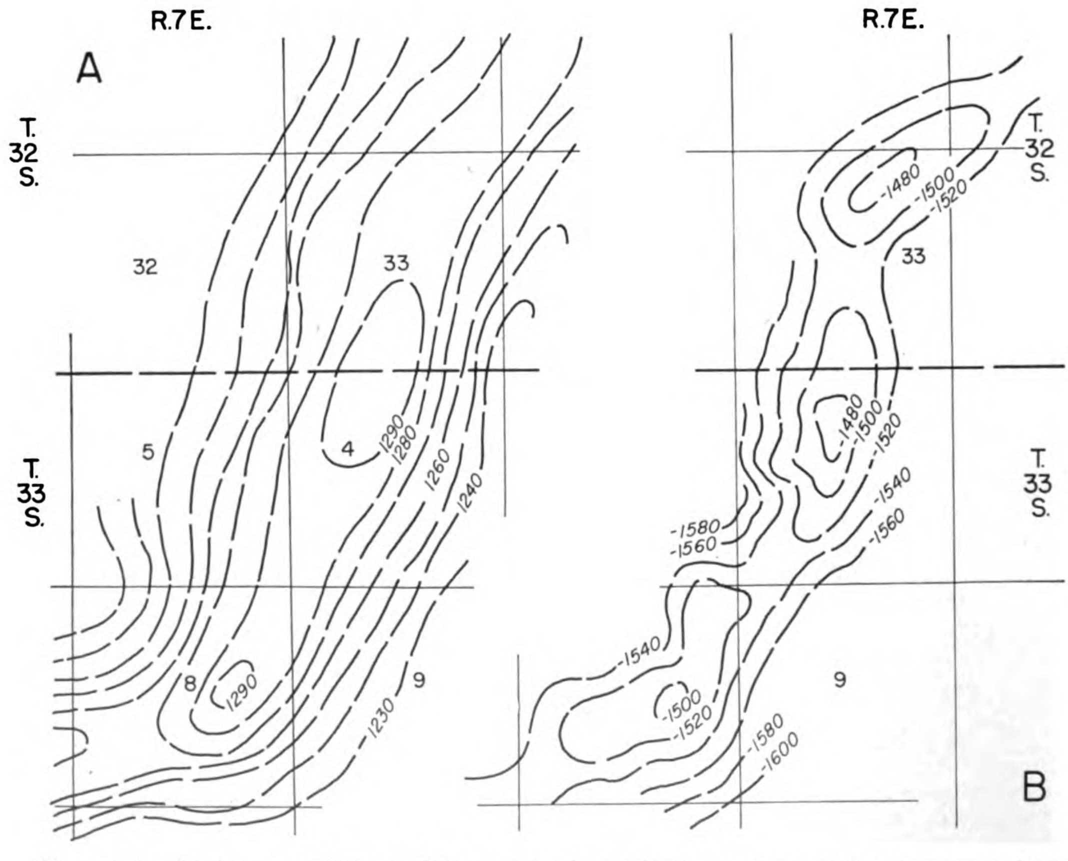


FIGURE 141.—Countryman Anticline. **A,** Surface structural map showing northeast trend of Countryman (from Bass, 1942); **B,** structure on Mississippian rocks closely resembles surface structure, although local closures along crest of structure do not coincide (from Merriam and Goebel, 1959c).

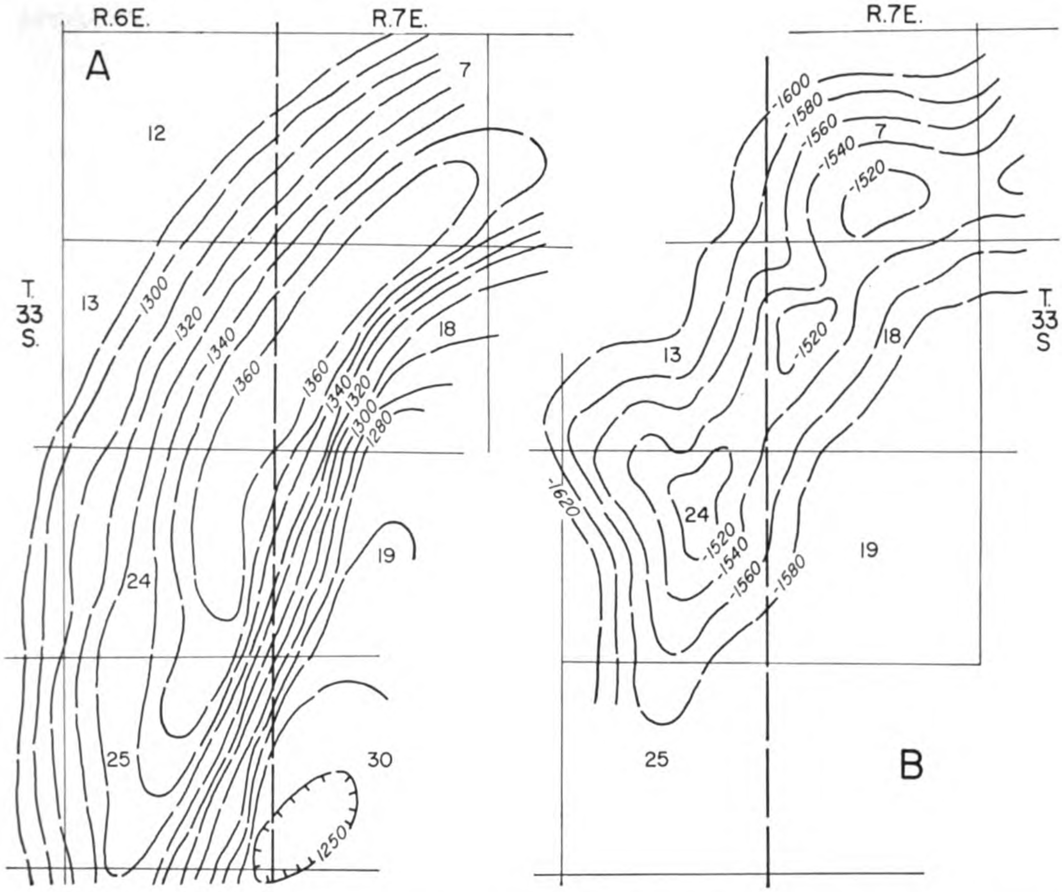


FIGURE 142.—Dexter Anticline. **A**, Structural map contoured at 10-foot intervals on outcropping beds (from Bass, 1929); **B**, subsurface structural map contoured at 20-foot intervals on top of Mississippian rocks (from Merriam and Goebel, 1959c).

maximum closure is less at the surface. Seemingly only about 20 feet of closure is evident in outcropping beds. If either flank is steeper, it is the southeast one.

DEXTER ANTICLINE.—The Dexter Anticline is located in Cowley County just southwest of the Countryman Anticline and on the same general structural trend (Fig. 142). Few wells have been drilled to the Mississippian, but enough control is available to give a reasonably accurate picture of the general nature of the structure. The surface map reproduced here is from Bass (1929).

Structure on top of the Mississippian is a north- to northeast-trending anticline showing three local areas having 20 to 40 feet of closure; the overall closure of the structure is probably greater. Lack of well control on the flanks makes it difficult to judge the symmetry of the structure, but it seems to be slightly steeper on the southeast side.

Surface structure (Fig. 142A) reveals only one large area of closure of about 20 feet. The position of the crest of the surface structure corresponds well to the position of the crest on the Mississippian. Both maps indicate that the structure continues to the northeast and to the south.

STRUCTURAL RELATIONS

The four cited examples showing relation of surface to subsurface structure in southeastern Kansas are unfortunately all along the same structural trend. The structural relief along this trend and other parallel elements (Longton Ridge and Winfield Anticline) is greater than in intervening areas; therefore, structural relations may be different in these intervening areas because of the lesser magnitude of structure.

From limited information, then, the following generalizations can be made, but they may not hold true for all of Kansas (Merriam and Goebel, 1959c): (1) Structural relief seems to increase with depth (Fig. 143). Structural noses in surface rocks may reveal the presence of closed anticlinal structures in older beds; if closure is evident at the surface, it should increase downward. Many surface structures do not persist at depth, however. It may perhaps be safely assumed that the sharper and more pronounced features will carry down. (2) Crests of structure shift with depth. In general, the greater the depth to the top of the Mississippian, the greater the shift; commonly the shift is westward. (3) In general the southeast flank of northeast-trending structures has steeper dip than the northwest flank. McCoy and Keyte (1934, p. 300) found a steep east flank on the Beaumont Anticline and postulated that it was faulted.

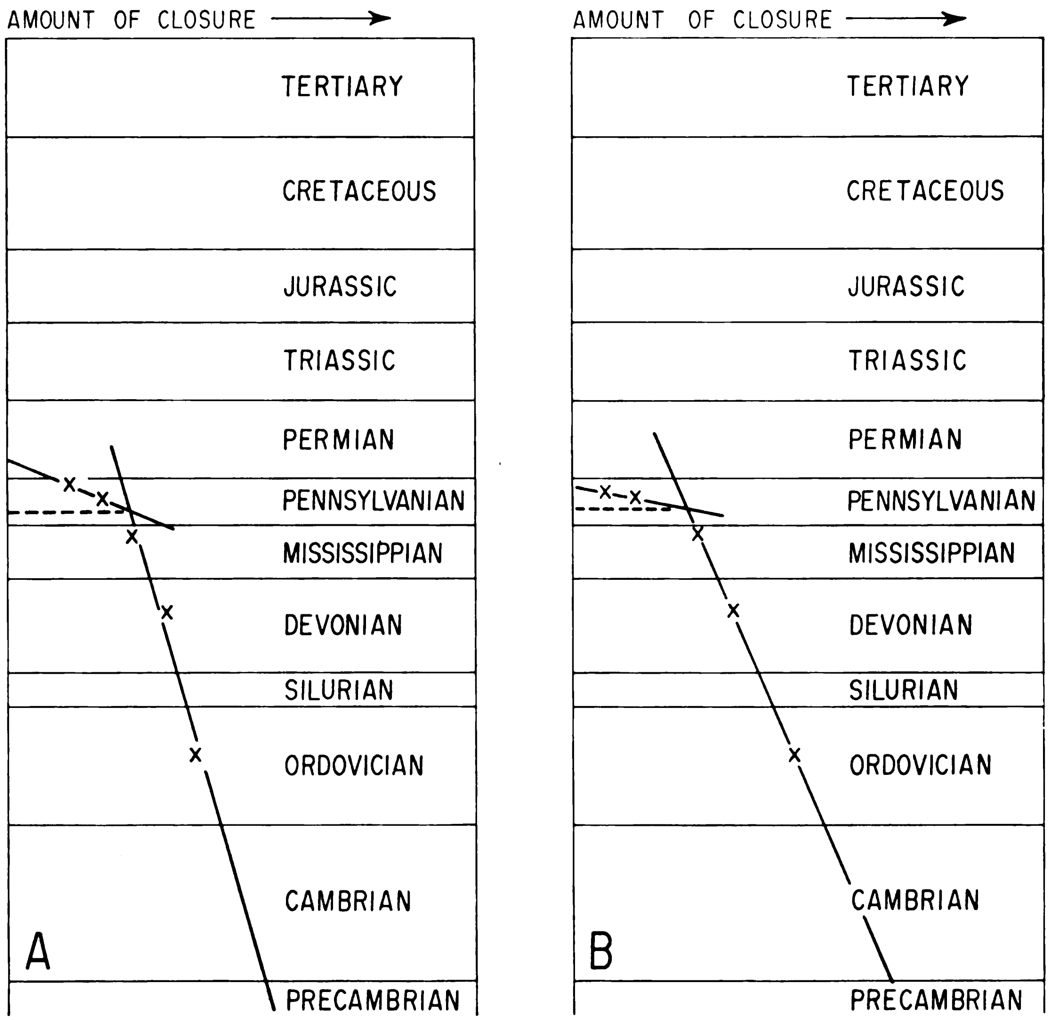


FIGURE 143.—Chart showing increase of structural closure with depth for **A**, Mill Creek, and **B**, Ashburn, fields in Wabaunsee County. Preliminary studies indicate that amount of closure (or area under closure, or cumulative of either) plotted against age (or depth) of contoured horizon may reveal interesting information regarding development of structure. An abrupt change in slope of line should indicate time of structural deformation. In addition, amount of closure at depth should be predictable knowing that of shallower horizons.

Shape of Structures

Structural shapes range from domes to sharp elongated anticlines. Examples of domes are Moore (Fig. 126) and Oro (Fig. 127). Examples of anticlines are many, but those having a length/width ratio greater than 3 include: Frey (Fig. 129) and Studley (Fig. 128). Some fields, such as Countryman (Fig. 136) and Aldrich Northeast (Fig. 131), have multiple areas of closure. Some structures have one steeper flank, giving them an asymmetrical aspect, such as Adell (Fig. 127) and Groff (Fig. 127). Many of the fields having steep flanks show faulting in the lower beds, indicating that the steep dip is the result of draping over a fault block. Some fields, such as Davis Ranch (Fig. 134) and John Creek (Fig. 134), are known to be faulted at the level of contouring, and therefore the fault traces are shown. Lack of information makes it difficult to determine the precise direction and magnitude of faults.

The area under closure differs considerably among the structures studied. Hortonville has the least closure, only 0.2 square mile (Fig. 128). The largest structure is Interstate (Fig. 132), which has about 4.5 square miles of closure; other large structures include Graber (Fig. 133) and John Creek (Fig. 134).

Structures contoured on top of Arbuckle rocks are shown in Figure 144. The shapes and sizes of these structures are as varied as those shown on younger horizons (Table 7). The structure on top of Arbuckle rocks in the Norton field is similar to that on the higher horizons (Merriam and Goebel, 1954). The Norton feature is an elongated, northeast-trending anticline of low relief with the southeast flank steeper than the northwest. The anticline plunges both northeastward and southwestward about 20 feet per mile. The structure is irregular and has four small areas of closure, the maximum being about 10 feet. Minor irregularities of the structure are believed to be the result of erosion. Because the Arbuckle is absent on the northwest flank, it is not possible to determine the original extent of the structure. On the Central Kansas Uplift many of the structures are large, broad, anastomosing features that are difficult to delineate. In other areas, structures at the horizon of the Arbuckle are sharp and many, such as Asmusson (Fig. 144), may be faulted.

It has been noted from this study that small anticlines in Kansas can be classified into two types, depending on the location of the structural saddle, or spill point, on the structure. In one type, the spill point is on the side that is updip regionally, and normally that side is the critical flank. Two examples of this side-opening type are shown in Figure 145. In the Willowdale structure (Fig. 145A) the regional dip on the Viola is to the southeast, and the structure is elongate parallel to the regional strike. In shallower beds, this type of structure would be represented by a southeastward-plunging nose. Levorsen (1927) has shown the effect of convergence on the closure of structure and the shift of structural axes with depth. He demonstrated how a structural nose on surface beds becomes a closed anticline on a deeper horizon because the two horizons converge updip regionally. These principles apply here. The Wakeeney structure (Fig. 145B) is mapped on the Stone Corral, which has a regional dip to the northwest.

The other type of structure is one in which the structural saddle is located at the end of the feature and which could therefore be termed an open-end type. Most of these are situated along larger elongate structures; in fact, several closed areas may be found on trends, such as the Abilene Anticline, that exhibit an open-end spill point. Examples given here are the Hockett structure (Fig. 145C), which plunges southeastward, and the Buhler structure, which plunges southward (Fig. 145D).

Plains-Type Folding

Although for individual structures neither the type of folding nor the originating force, whether compressional, vertical, or compactional, is known, it is significant that local anticlines fit into a regional pattern. This certainly implies some common factor in their origin. Because structures are present in older beds, it is assumed that they are tectonic or are related to tectonic rather than surficial movements. In addition, relation of the structure at one horizon to that at another, as well as the position and arrangement of strata, strongly suggest vertical structural movement—such as upwarping and downwarping combined with differential compaction and draping of beds over fault blocks—rather than horizontal movement. This is so-called "plains-type folding."

Gardner (1917) was perhaps the first to champion vertical uplift in explaining plains-type folding of the Midcontinent area. He reasoned that lateral stresses could not be transmitted through weak sediments for any great distance and therefore could not account for the folds. Because the local structures are small, they must have been produced by pressures that

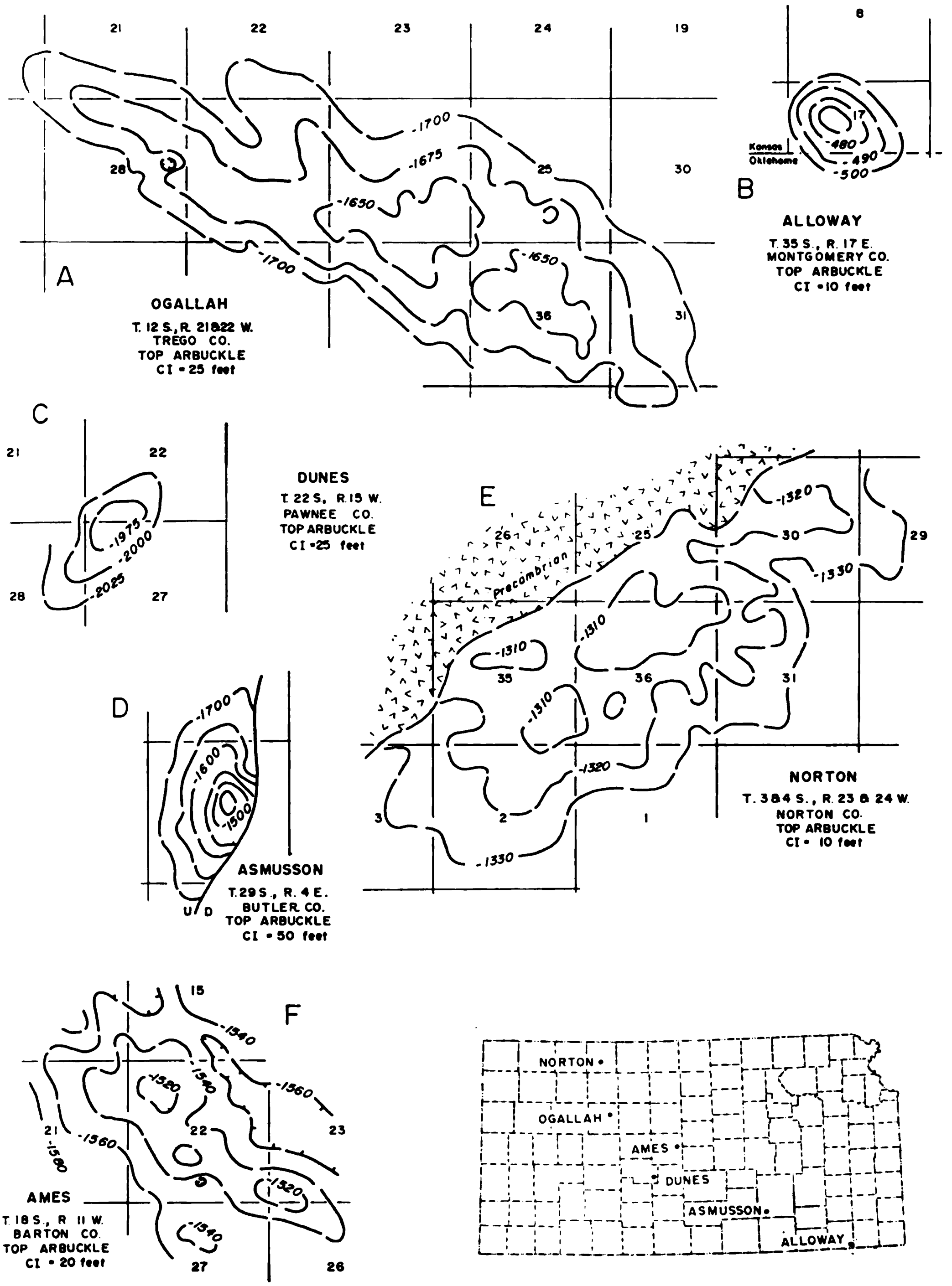


FIGURE 144.—Structure of Ogallah, Alloway, Dunes, Asmusson, Norton, and Ames fields (in part from Merriam and Goebel, 1954; Merriam and Smith, 1962).

acted mainly vertically. Blackwelder (1920) reviewed the suggested explanations for the formation of Midcontinent structure—tangential compression, vertical readjustment due to deep-seated rock flowage, and differential settling of sediments—and concluded that the last of these hypotheses is the most probable.

Fath (1920), in his classic paper on Midcontinent structure, postulated that horizontal forces are transmitted through the rigid crystalline basement. If displacements along faults in the basement were horizontal, the results were tension faults in the surface beds; if displacements were vertical, anticlinal folds developed. Configuration of the resulting structure at the surface would depend on the incompetency (or competency) of the units overlying the basement. Fath concluded further that an extensive series of essentially parallel fault zones had to be present in the basement complex to account for the geographic distribution of structure. The complex of faults was the result of orogenesis, which probably took place in Precambrian time, since no deformation of great magnitude is known to have occurred in the Midcontinent in the Paleozoic. Later, intermittent movement along these Precambrian lines of weakness resulted in the present structural features. By his keen insight into the problem, Fath was therefore able to demonstrate that the belts of faults

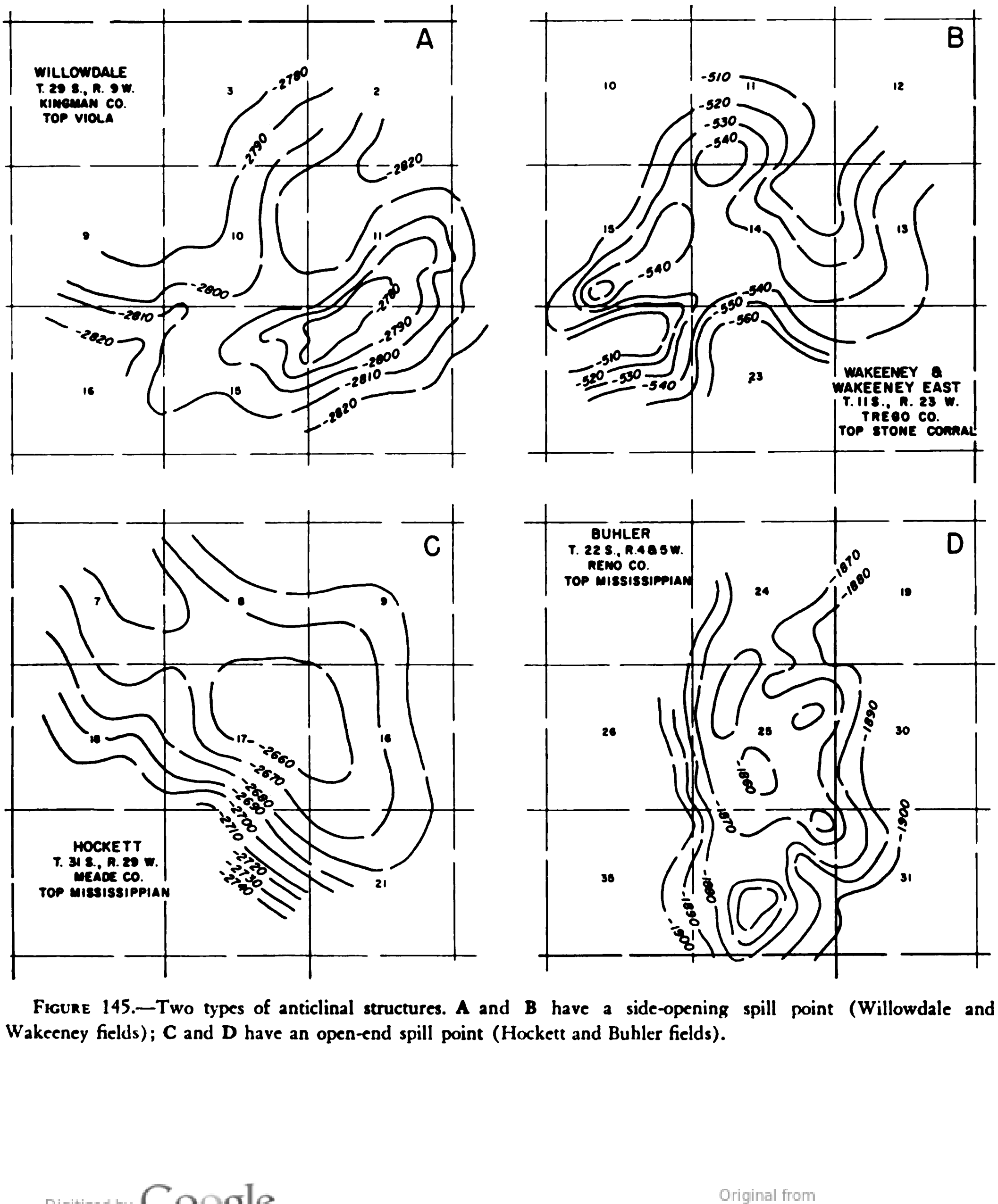


FIGURE 145.—Two types of anticlinal structures. A and B have a side-opening spill point (Willowdale and Wakeeney fields); C and D have an open-end spill point (Hockett and Buhler fields).

in northeastern Oklahoma, the anticlinal folds, and the Nemaha granite ridge were related in origin. He expressed similar ideas in 1921.

McCoy (1921) sought to explain the fault zones in northeastern Oklahoma as the result of tensile stresses developed in a settling basin. Monnett (1922) thought that the magnitude and arrangement of structures could have been produced by differential settling of sediments, and suggested a relation between folding and lithologic composition. Powers (1922) discussed five hypotheses for the origin of Midcontinent structure: (1) tangential compression, (2) rock flowage, (3) warping during deposition, (4) torsional faulting, and (5) condensation of sediments. He thought that compaction of sediments was most important. Rubey (Rubey and Bass, 1925) discussed all theories regarding the formation of Midcontinent structure and analyzed them with respect to the structure as shown in Cretaceous beds in Russell County. After reviewing each method of origin he concluded (1925, p. 84):

> Block faulting or differential movements between blocks of rigid pre-Cambrian rocks capped by Ordovician or Mississippian sediments took place along preexistent fault lines or sheer [*sic*] zones and exposed to erosion a surface of gentle slopes and steep fault scarps. The displacement along the faults varied from place to place, ranging from several hundred feet . . . to nearly nothing . . . . Streams flowing on this land surface cut deeper the original depressions at the base of the fault scarps, and probably shifted backward, but did not eradicate the cliffs . . . . The sea later encroached on this old land surface and covered it with sediment . . . . With the increase in the thickness of the sediments, the lower mud deposits were continuously squeezed to a smaller volume, but the old hard rocks below the plain of unconformity underwent little or no corresponding compression.

From the foregoing statement, he obviously regarded the draping of sediments over old fault blocks as important.

In 1925, Powers summarized information concerning the structural geology of the Midcontinent. In general he found that: (1) structural noses are the dominant structure, (2) surface folds are reflected or surficial, (3) most folds are small, (4) closure increases downward from as little as 5 feet in Pennsylvanian beds to 400 feet in the Ordovician, (5) the amount of closure is proportional to size in many structures, and (6) the number of folds is inversely proportional to size, and in addition they are irregularly disposed.

In contrast to Appalachian and Rocky Mountain structure, Powers coined the term "plains-type folding" for the small, irregularly distributed, periodically rejuvenated Midcontinent folds. He concluded that plains-type folding is complex and deserved further study.

Twenhofel in 1925 ascribed the amoeboid-type structure in Russell County to settling of Cretaceous sediments over irregularities of the eroded, buried Permian surface. Foley (1926), using information gained from working with models, postulated that a westward thrust of the Ozarks was opposed by the Nemaha granite ridge, causing rotational stresses in the formations between them. This, then, he thought would account for the *en echelon* faults in northeastern Oklahoma. Bass (1929) stated that many characteristics of the folds in Cowley County indicated that the theory of tangential compression was correct for that part of the country.

Clark (1932) made a quantitative study of the origin of plains-type folds and concluded (p. 46):

> The characteristic features of these folds all suggest vertically acting forces rather than horizontal compression, and an analysis of the stresses developed in the overlying sediments by vertical displacement, due to movement along an old fault plane in the basement rocks, indicates that that hypothesis offers a satisfactory explanation of the type of folding developed, and of the normal faulting in connection with the folding.

Clark also pointed out that the plains-type fold is characterized by: (1) local uplift without a corresponding depression, (2) prominence increasing with depth as sediments thin over the crest, (3) asymmetrical aspects, and (4) association with normal faulting.

In discussing the origin of domes in central Kansas, Landes and Ockerman (1933) proposed that domes similar to the ones in Mitchell and Lincoln Counties might have been produced by any one of five forces: (1) injected igneous plugs, (2) injected salt plugs, (3) differential settling caused by leaching of salt, (4) depositional dips on the flanks of ancient hills, and (5) differential compaction over buried hills and valleys or lenses of sandstone. They concluded that the structures were caused by deposition conformable to the surface of Permian hills. Although it was once thought that the Cretaceous of western Kansas reflected deeper structure (Lupton, Lee, and Van Burgh, 1922), it was later found to do so only locally, depending on whether the structure was the result of slumping or of tectonic movement (Stoner, 1934).

For any factor that can be found to support one of the several explanations offered by the various authors as to the origin of plains-type folds, another can be found to refute it. The suggested hypotheses may be grouped under

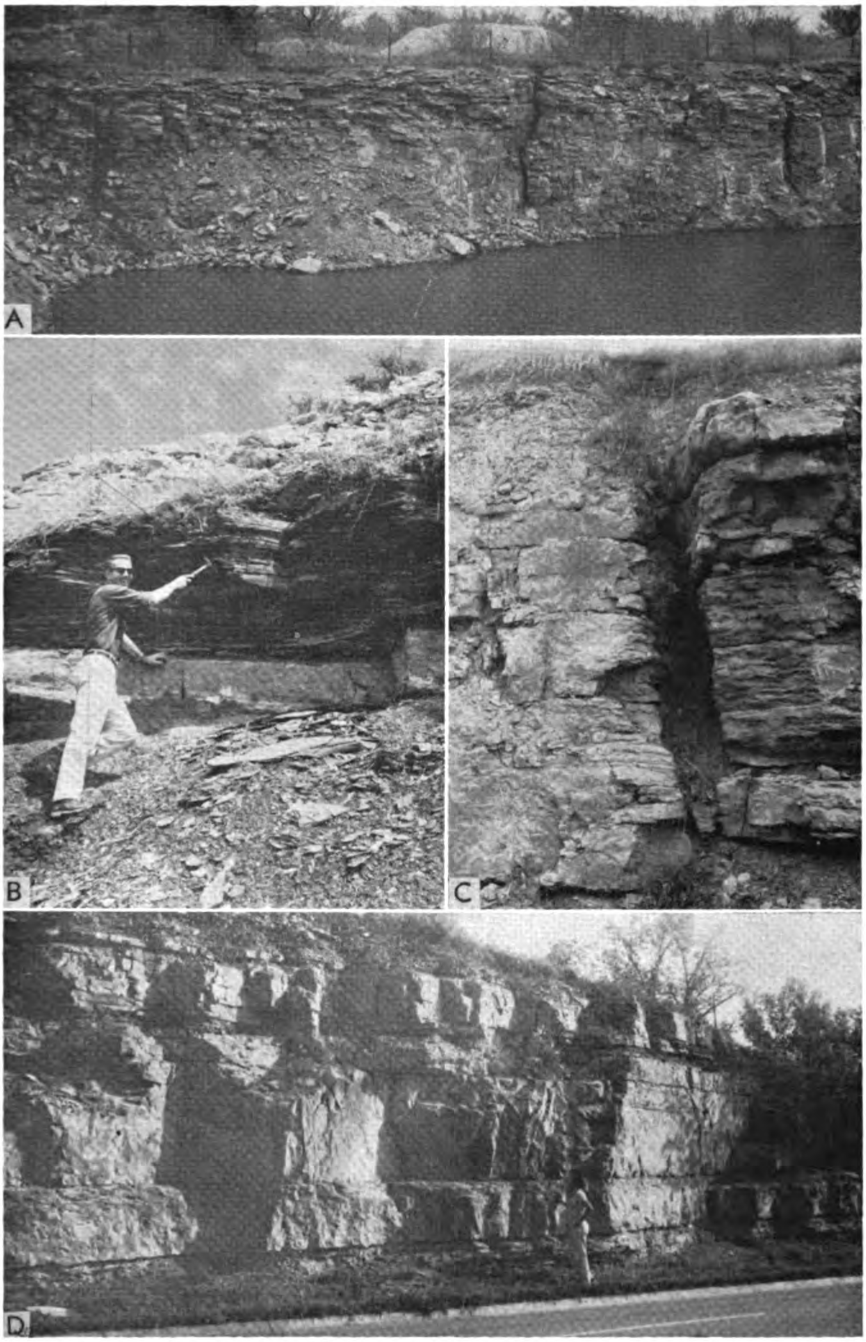


PLATE 29.—**A**, Joints in Drum? Limestone buildup in Montgomery County just southeast of Independence (NW sec. 5, T. 33 S., R. 16 E.). **B**, Note direction of joints in Leavenworth Limestone is different from that in overlying black Heebner Shale; on Kansas Turnpike about 3 miles west of West Lawrence Interchange, Douglas County. **C**, Small fault with approximately 1 foot of displacement in Stoner Limestone; on Kansas Turnpike at Mile 14, Wyandotte County. **D**, Well-jointed Fort Riley Limestone exposed on Kansas Highway 18 at west edge of Junction City, Geary County.

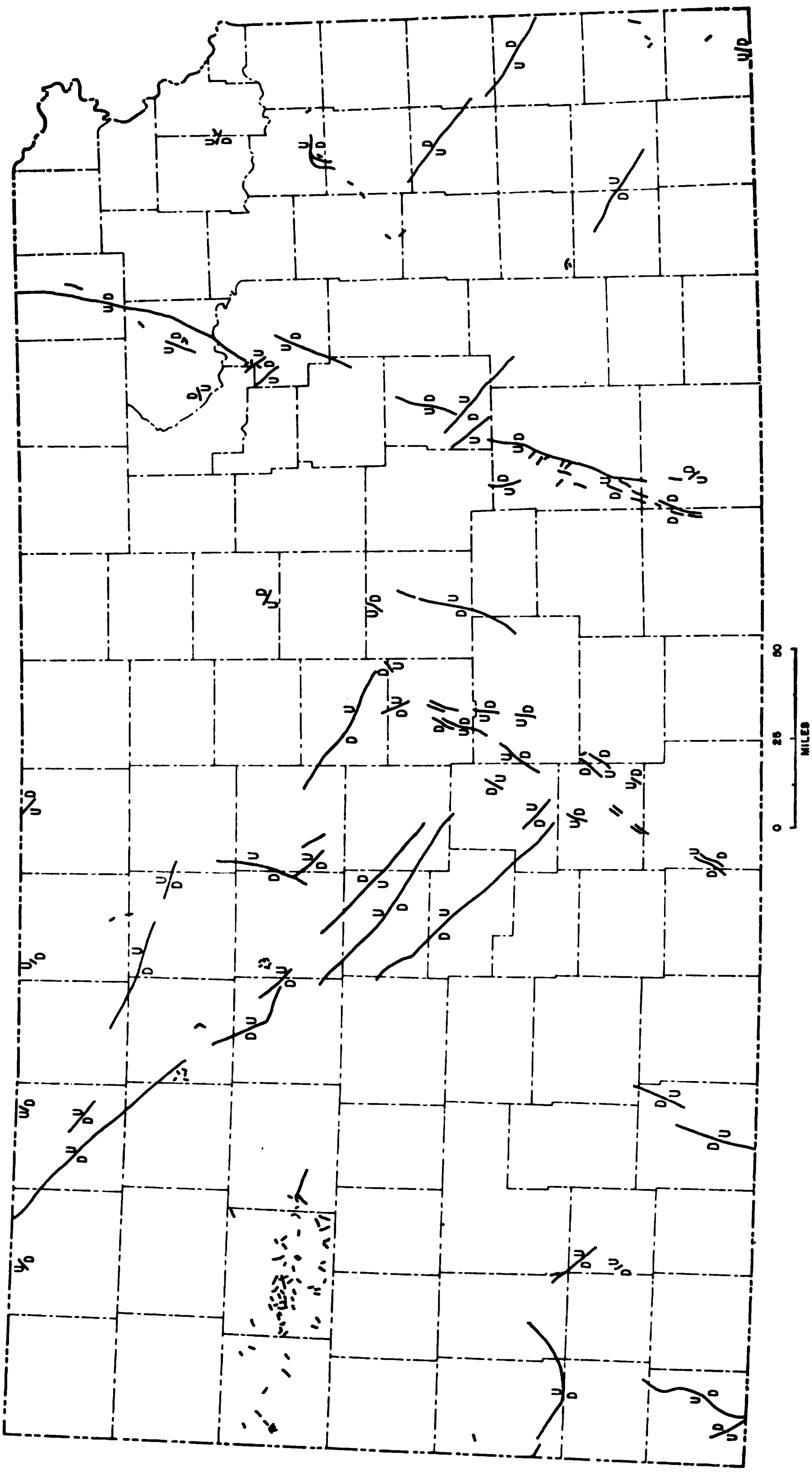


FIGURE 146.—Map showing location of some faults in Kansas. Information taken from State and Federal Survey and Kansas Geological Society publications. Summary of direction of elongation of faults shown in Figure 137.

four major headings, which have been summarized by McCoy (1934): (1) tangential compression, (2) torsional stress, (3) differential settling of sediments, and (4) local vertical uplift. McCoy favored the last mentioned as the most plausible explanation. He further concluded that the same results (as those by uplift) may be obtained by differential downwarp with lag over local areas. The controlling forces seemingly act through the basement, because the area affected and the magnitude of adjustment depend mainly on the vertical distance between the surface and basement. Rich in 1935 expressed the idea that the pattern revealed by removal of regional dip in the sedimentary beds suggests readjustments in a fractured Precambrian basement. He suggested a post-Pennsylvanian date for readjustments. Nevin wrote (1942, p. 61):

> It should be remembered that all the effects of actual uplift could be given by a regional subsidence, during which local areas lagged behind. The greater part of these relative uplifts took place when the general area was being buried by hundreds of feet of sediment.

Nevin emphasized that plains-type structure seemingly is the result of vertical rather than horizontal stresses, and that the resultant fold is classified as supratenuous.

Little has been published about the problem of plains-type folding in the last 20 years, although much data has been accumulated. Crucial information, however, is lacking concerning the basement, which holds the key to the problem. Means are being sought to get detailed data on the basement, but until this data is forthcoming, study of plains-type folding is at a standstill.

From data at hand, it seems that any and all of the explanations have merit in certain circumstances, and that each may hold a partial answer to the origin of Midcontinent structures. In summary, then, forces seem to be transmitted through the rigid basement, and the structure seen in the overlying beds is the local result of the vertical relief of these stresses. Differential compaction of sediments over "buried hills" perhaps is accelerated by earth movements. It seems reasonable to assume that these anticlinal structures were formed as local areas were left behind during regional subsidence. The configuration and magnitude of the features are determined by the original form of the basement. It also seems reasonable to conclude that the zones of weakness in the basement which are now revealed by anomalies in overlying sediments were inherent onward from Precambrian time.

Fault Patterns

Recognition of faulting is extremely important in mineral exploration; however, only in recent years has it received deserving attention. This is because criteria for detecting faults in Kansas are subtle and therefore delineation of faults is difficult. Faulting as now recognized has played a much greater role in the development of Kansas structure than was heretofore understood (see Brewer, 1959).

Location of known faults in the state is shown in Figure 146. Information on the location of these faults was taken from material published by the Kansas Survey, Kansas Geological Society, and Federal Geological Survey. Several faults have been named, including the Chesapeake Fault Zone (in Bourbon, Anderson, and Wabaunsee Counties), Crooked Creek and Fowler Faults (in Meade County), Humboldt Fault (in Nemaha and Pottawatomie Counties), Syracuse Fault (in Hamilton County), and Worden Fault (in Douglas County).

Few faults in Permian and Pennsylvanian rocks in eastern Kansas have been noted (Pl. 27B). Those described are local in nature and of small displacement, usually less than 25 feet. Along the northeastern side of the Silver City Dome, in Woodson County, strata have been displaced as much as 200 feet in a fault associated with intrusive material. The Worden Fault in Douglas County (O'Connor, 1960) is the longest recognized on the surface in eastern Kansas. The Worden and minor faults in southeastern Osage County and northwestern Franklin County occur along a northeast-trending disturbed zone extending for at least 50 miles. The cause of this disturbance is not known.

Evidence of extension of the Chesapeake Fault Zone from Missouri into Kansas has recently been recognized. Although it is not continuous, the northwest-trending disturbed zone is traceable for a distance of almost 600 miles in Missouri, Kansas, and Nebraska. The structure is essentially a graben 6 to 10 miles wide with the floor downdropped as much as 1,000 feet. In Wabaunsee County the Nemaha Anticline is cut by the feature. Several similar, parallel structures are discernible, but at present it is not possible to outline them.

A major zone of faulting occurs along the length of the Nemaha Anticline. In Kansas the Humboldt Fault borders the eastern flank of the Nemaha in its northern part. On the surface, displacement may be up to 100 feet (Condra, 1927). The Humboldt and associated faults are known to cut Precambrian and lower Paleozoic rocks discontinuously along the eastern flank of the Nemaha for the entire length of the state. To the south, in Cowley and Sumner Counties, oil is produced from fields located on small horsts on the crest of the Nemaha Anticline.

Many faults are known or believed to cut Precambrian and lower Paleozoic rocks on and adjacent to the Central Kansas Uplift. The Rush Rib, bounded by faults, is a large horst. Other features such as the Ellsworth, Fairport, and Voshell Anticlines are faulted. None of these faults are known to reach the surface.

Throughout western Kansas there are numerous small faults in Cretaceous beds, especially in the Niobrara Formation, although they are not usually mapped. Several disturbed areas similar to the one in northwestern Ellis County are known (Pl. 27C, 27D). Faults are profusely displayed along Smoky Hill River, where the Cretaceous strata are well exposed. In southwestern Kansas, faults are difficult to recognize on the surface in an area lacking traceable marker beds; however, the Crooked Creek, Fowler, and Syracuse Faults have been verified by test-hole drilling.

Little work has been done on jointing in Kansas, although the joints are extensively developed (Pl. 28, 29). In regard to northeastern Wilson County, Wagner (1961) reported:

> A system of joints is well developed in the [Altoona] quadrangle. The joints fall into two general groups that trend about N 55° E and N 35° W. Observations taken at the outcrop established their major trends and vertical dips, but most of the trends . . . were taken directly from aerial photographs . . . . The joints are well developed and clearest on the photographs in limestone units 15 to 30 feet thick; they are obscure but detectable in sandstone units.

In Franklin County (NE sec. 24, T. 18 S., R. 18 E.), S. M. Ball (personal communication) measured a joint system developed in the Haskell Limestone with trends of N 58° W, N 20° W, and N 23° E. In the Reading Limestone in the spillway of the Atchison State Lake, C. K. Bayne (personal communication) noted a joint system having northwest, northeast, and east-northeast trends.

It has long been recognized that some of the drainage in Kansas is controlled by a fracture pattern. Merriam (1955e, p. 82) stated:

> Some of the drainage in western Kansas gives the impression of being affected in some way by this structural pattern. It is especially noticeable where the Arkansas River flows in a zig-zag manner, first northeast, then southeast, etc.

In northwestern Kansas, drainage patterns trend approximately N 55° E, N 25° W, and N 45° W and are probably controlled by a fracture pattern in bedrock. This pattern is evident on topographic maps and is visible from the air, especially in early morning or late afternoon.

Further work on fracture patterns in Kansas is warranted.

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APPENDICES

Appendix A—Known "Algal Limestone" Occurrences in Kansas†

BARTON
NE NE 11-16-12W[1]
NW 21-17-12W[2]
CEL 20-17-13W[2]
NW NW 28-19-12W[3]
NE 15-19-13W[3]
2 miles SW of Alberta[4]

CHEYENNE
SW 27-1-37W[5]
SE 21-1-42W[3]
NW NW 22-1-42W[6]
SW 22-1-42W[3, 5]
SE NW 23-1-42W[3]
NW 24-1-42W[3]
NW 27-1-42W[7]
SW 5-2-37W[8]
NW 9-2-42W[8]
•NW NW NW 4-3-38W[5]
Cen. 29-3-39W[8]
31-4-37W[3]
•SW SW SW 33-4-38W[5]
•SE NW 15-5-37W[5]
NE 32-5-39W[3]
NW 33-5-39W[3]
NW 31-5-40W[5]

CLARK
NW SE 25-30-23W[3]
NW SW 25-30-23W[3, 9]
N2 25-32-25W[10]
SW NW 29-33-21W[11]
NW 34-33-21W[11]

CLOUD
SE SE 7-6-4W[12]
SE SE 34-6-4W[12]
SW SW 18-7-4W[12]

DECATUR
SW NW 25-1-27W[13]
NE SW 29-4-26W[13]

EDWARDS
SW NE 2-24-19W[3, 14]
SE 21-25-20W[3, 14]
NE 28-25-20W[3, 14]

ELLIS
3-11-16W[3]
10-11-16W[3]
CWL 3-12-20W[6]
NW SW 17-12-20W[15, 16]

ELLSWORTH
CSL 8-14-8W[17]
CEL 10-14-8W[17]
SW 12-14-8W[17]
CWL SW 14-14-8W[17]
NW 19-14-8W[1]
CNL NW 4-14-9W[17]
CNL NE 11-14-9W[17]
SW NW 15-14-9W[3]
SW SW 10-14-10W[17]
SE SE 15-14-10W[17]

FINNEY
SW 12-23-28W[18]

FORD
NE 1-25-26W[19]
NW SW 11-25-26W[19]
NW SW 12-25-26W[19]
Cen. 34-26-22W[19]
SE NE NE 10-26-23W[19, 20]
NE NE NE 10-26-23W[19, 20]
SE SE SE 15-26-23W[19, 20]
SW SW SW 28-27-22W[19]

GRAHAM
SE NE 34-6-24W[22]
NW NE 4-6-25W[23]
¼ mile west of SE 1-7-22W(?)[22]

GREELEY
NE 8-16-40W[3]
SE NW 6-16-42W[3]
•NW 19-16-42W[21]
North of Tribune at
Kansas Highway 27[3]

HAMILTON
Cen. 7-25-42W[3, 7]
CEL NE 8-25-42W[7, 10]

HODGEMAN
NW 19-23-23W[7]

LANE
SE 20-18-26W[8]
24-18-26W, on
Kansas Highway 96[3, 4]
SW SW 19-18-28W[6]
NW NW 30-18-28W[6]
SE SE 24-18-29W[1]
3 miles NW of Alamota[4]

LINCOLN
NW SE 8-11-7W[24]
NW NW NW 20-11-7W[24]
SW SW 20-13-9W[17, 24]
CSL SE 23-13-9W[24]
CWL SW 24-13-9W[17, 24]
CWL SW 28-13-9W[17, 24]
SE SE SE 30-13-9W[24]
CSL S2 32-13-9W[24]

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† Locations are given in section, township, and range, respectively, according to the General Land Office classification.
• Test well.
1 Frye, Leonard, and Leonard (1951).
2 Latta (1950).
3 List of localities compiled by M. K. Elias and obtained from J. C. Frye.
4 Elias (1931).
5 Prescott (1953a).
6 Frye, Leonard, and Swineford (1956).
7 Swineford, Leonard, and Frye (1958).
8 M. K. Elias, unpublished cross section.
9 From H. T. U. Smith.
10 Smith (1940).
11 J. C. Frye, personal communication.
12 Buck, Van Horn, and Young (1951).
13 Byrne, Beck, Bearman, and Matthews (1950).
14 Described by W. H. Courtier.
15 Byrne, Coombs, and Bearman (1949).
16 Byrne, Coombs, and Bearman (1947).
17 Frye (1945a).
18 Latta (1944).
19 Unpublished map, author unknown.
20 Locality found by R. C. Moore and verified by J. C. Frye.
21 Prescott, Branch, and Wilson (1954).
22 Prescott (1955).
23 Byrne, Coombs, and Matthews (1951).
24 Berry (1952).
25 Byrne, Beck, and Bearman (1949).
26 M. K. Elias (?), unpublished reconnaissance map.
27 Beck and McCormack (1951).
28 Fent (1950a).
29 Waite (1947).
30 Prescott (1953b).
31 H. T. U. Smith, personal communication.
32 M. K. Elias, a Wallace County geologic map.
33 Byrne, Houston, and Mudge (1948).
34 Latta (1941).
35 Frye (1945b).

SE SE SE 33-13-9W[24]
CSL S2 33-13-9W[24]
NW NW SW 24-13-10W[24]

LOGAN
NE NE 23-12-32W[6]

NESS
CNL NE 28-16-21W[7]
NE SE 31-16-23W[16]
19-18-26W on Kansas Highway 96[3]
CWL NW 30-18-26W[7]

NORTON
NE NW 21-2-21W(?)[25]
NW 33-5-24W[25]
35-5-24W (Lenora section)[6]

PAWNEE
Cen. 15-20-18W[11]

RAWLINS
NE 22-2-35W[8]
E2 19-3-35W[3]
SW 27-3-35W[8]
NE 19-4-33W[26]
SW 16-4-36W[8]
NW 8-5-34W[26]
NW SW 4-5-35W[27]

RICE
NW SW 19-18-8W[28]
SW SE 10-18-10W[28]
N2 27-19-10W[7, 28]
*SE 10-20-10W[28]

ROOKS
S2 10-9-16W[8]
W2 13-9-17W[8]
E2 14-9-17W[8]
W2 16-9-17W[8]
E2 17-9-17W[8]
NE 20-9-17W[8]
N2 32-10-16W[8]
NE SW 35-10-16W[8]
CEL 23-10-17W[8]
CWL 24-10-17W[8]
Cen. 26-10-17W[8]
SW NE 16-10-18W[8]
SE 18-10-18W[8]
Cen. 21-10-18W[8]
Cen. 20-10-19W[8]
SW 21-10-19W[8]
E2 28-10-19W[8]
Cen. 29-10-19W[8]
CNL 30-10-19W[8]
E2 25-10-20W[8]

RUSH
SW 8-19-16W[3]
SW? 9-19-16W[3]
NW 13-19-16W[3]
N2 16-19-16W[3]
CNL 17-19-16W[3]
SW 23-19-16W[3]
SE 30-19-17W[11]

RUSSELL
CEL 3-14-11W[7, 17]
Cen. SE 31-14-11W[1]
SE SE SE 23-15-12W[1]

SCOTT
SW 20-18-33W[29]
NW SE 16-19-34W[29]
SW SE 5-20-31W[29]
SW SE 12-20-32W[29]

SHERMAN
*NE NE NE 1-6-40W[5, 30]
*SE 36-6-40W[30]
SW NE 27-6-41W[30]
*SE 31-6-42W[30]
16-7-40W[31]
*NE 1-8-39W[30]
NW 3-8-41W[30]
SE 23-8-42W[4, 30]
N2 28-8-42W[3]
*NE 1-9-39W[30]
*NE 6-9-42W[30]
NW 1-10-41W[30]
31-10-41W[32]

SMITH
NE 21-5-11W[33]
SW 23-5-11W[33]

STANTON
Near middle of 30-43W[34]

THOMAS
NW 19-7-36W[30]
SW 7-8-36W[35]

WALLACE
NE NW SE 4-11-40W[3, 32]
NW SE 4-11-42W[3, 32]
SE SW 31-11-42W[32]
S2 36-11-43W[3]
SW SE NW 2-12-40W[32]
NE 3-12-40W[3, 4]
NW SW 2-12-42W[4]
SE NE SW 4-12-42W[3, 32]
5-12-42W[3]
31-12-42W[3]
35-12-42W[3]
12-12-43W[3]
2-13-42W[3]
3-13-42W[3]
8-13-42W[3]
9-13-42W[3]
SE 10-13-42W[3, 4]
SE 11-13-42W[3, 6]
15-13-42W[3]
34-13-42W[3]
NW NW 35-13-42W[3, 32]
NE NW 36-13-42W[32]
24-13-43W[3]
NW SW 7-14-38W[4, 6]
SW SW 7-14-38W[6, 32]
SE 8-14-38W[3, 4, 6]
9-14-38W[3]
10-14-38W[3]
NE NE 11-14-38W[32]
SW SW 11-14-38W[32]
NE SW 11-14-38W[32]
SE NE 12-14-38W[4]
SE NE SW 12-14-38W[32]
16-14-38W[3]
17-14-38W[3]
18-14-38W[3]
12-14-39W[3, 7]
13-14-39W[3]
14-14-39W[3]
15-14-39W[3]
NW NW SW 21-14-39W[32]
22-14-39W[3]
23-14-39W[3]
24-14-39W[3]
NW SW 28-14-39W[32]
29-14-39W[3]
30-14-39W[3]
NE NW 16-14-40W[3, 32]
SW SE NW 17-14-40W[3, 32]
NE SE 31-14-40W[3, 32]
NE SW 32-14-40W[32]
SE NW 4-14-41W[32]
NW SW 26-14-42W[3, 32]
34-14-42W[3]
NW NW 35-14-42W[3, 6, 32]
NW NW SW 35-14-42W[3, 32]
36-14-42W[3]
28-15-38W[3]
29-15-38W[3]
SW SE SE 29-15-39W[4, 32]

WICHITA
NW 23-18-38W[21]
*SE 1-20-35W[21]
*SE 29-20-38W[21]

Appendix B—Catalog of Mesozoic Nomenclature for Kansas[1]

*Arickaree Shale. F. W. Cragin, 1896[2]
Comment: Rejected because of similarity with the established name Arikaree.

‡Barberian series. C. R. Keyes, 1940[3]
Comment: Term proposed by Keyes; included Kiowa and Cheyenne.

Beecher Island Shale. M. K. Elias, 1931
Age and position: Gulfian, Campanian, uppermost of six members of Pierre Shale, Montana Group.
Description: Light-gray with greenish tinge, concretionary shale containing thin streaks of bentonite in lower part.
Thickness: About 100 feet.
Type locality: Beecher Island, Yuma County, northeastern Colorado.

*Belvidere Shale. R. T. Hill, 1895
Comment: Rejected term for the earlier proposed Kiowa; also proposed to include Kiowa and Cheyenne although not used.

Benton Shale. F. B. Meek and F. V. Hayden, 1862
Comment: Informally used in Kansas to include Graneros, Greenhorn, and Carlile.

†Bentonite marker bed.
Comment: Informal stratigraphic term for a recognizable bentonite bed in the Graneros Shale.

‡Bituminous shale. W. N. Logan, 1897
Comment: Rejected term for the earlier proposed Graneros.

Black Hill Shale. F. W. Cragin, 1885
Comment: Proposed name for part of the Kiowa, but not now used.

Blue Cut Shale. F. W. Cragin, 1895
Comment: Proposed name for part of the Kiowa, but not now used.

Blue Hill Shale. W. N. Logan, 1897
Age and position: Gulfian, Turonian, middle of three members of the Carlile Shale, Colorado Group.
Description: Dark-gray noncalcareous concretionary shale.
Thickness: From 50 to 160 feet.
Type locality: Blue Hills in Mitchell, Russell, and Republic Counties and Blue Hill Township, Mitchell County, Kansas.

Bridge Creek Limestone. N. W. Bass, 1926
Age and position: Gulfian, Turonian, upper member of Greenhorn where Pfeifer and Jetmore can not be distinguished, Colorado Group.
Description: Alternating limy shale and thin chalky limestone.
Thickness: About 74 feet.
Type locality: Bridge Creek, northwest of Medway, Hamilton County, Kansas.

Brookville terrane. C. R. Keyes, 1915
Comment: Not an accepted term.

Buckskinian series. C. R. Keyes, 1941
Comment: Not an accepted term.

†Cannon-ball zone. F. W. Cragin, 1896
Comment: Informal zone recognized in the Victoria Clay (same as Blue Hill Shale).

Carlile Shale. G. K. Gilbert, 1896
Age and position: Gulfian, Turonian, one of four formations composing the Colorado Group, subdivided into three members (Fairport, Blue Hill, and Codell).
Description: Chalky, bentonitic shale near base; black fissile concretionary shale in upper part containing a very fine grained sandstone at top.
Thickness: About 300 feet.
Type locality: Carlile Spring and Carlile Station about 21 miles west of Pueblo, Colorado.

Cawker terrane. C. R. Keyes, 1915
Comment: Not an accepted term.

†Champion shell bed. F. W. Cragin, 1895
Comment: An informal term applied to a prominent thin shell bed at base of the Kiowa.

Cheyenne Sandstone. F. W. Cragin, 1889
Age and position: Comanchean, Albian, lowest Cretaceous unit in Kansas; where present it is between Kiowa and Permian, Triassic, or Jurassic.
Description: Varicolored fine- to coarse-grained crossbedded sandstone and dark-gray silty shale; conglomeratic zone at base.
Thickness: About 75 feet on the outcrop and a maximum of 300 feet in the subsurface.
Type locality: Cheyenne Rock, Belvidere, Kiowa County, Kansas.

Cockrum Sandstone. B. F. Latta, 1941
Age and position: Gulfian?, Cenomanian or Albian, used in southwestern Kansas instead of Dakota.
Description: Varicolored ferruginous sandstone and light-colored shale.
Thickness: About 100 feet.
Type locality: Cockrum Branch of Bear Creek in southwestern Stanton County, Kansas.

Codell Sandstone. N. W. Bass, 1926
Age and position: Gulfian, Turonian, uppermost member of the Carlile Shale.
Description: Light-colored fine-grained silty sandstone.
Thickness: Ranges from 0 to 40 feet, but averages about 25.
Type locality: Bluffs along Saline Valley in Ellis County, Kansas, about 5 miles south and west of Codell.

Colorado Group. F. V. Hayden, 1876
Age and position: Gulfian, Cenomanian, Turonian, Coniacian, and early Stantonian; includes the Benton and Niobrara.
Description: Dark-gray shale, chalky limestone, bentonite, and silty sandstone.
Thickness: About 1,050 feet.
Type locality: Exposures along east side of Front Range in Colorado.

Comanchean Series. R. T. Hill, 1887
Age and position: Early Cretaceous including late Aptian, Albian, and earliest Cenomanian (earliest Late Cretaceous).
Description: Provincial series of nonmarine sandstone and marine shale.
Thickness: Average thickness about 250 feet.
Type locality: Comanche, Comanche County, Texas.

Comanche Peak. R. T. Hill, 1889
Comment: Texas term overextended into Kansas.

*Corral Sandstone. F. W. Cragin, 1895
Comment: Rejected as a local facies of the Cheyenne.

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[1] Boldface—accepted by the Kansas Geological Survey (see Kansas Geological Survey Bulletin 89, 1951).
Unmarked lightface—names not used or yet recognized by the Kansas Geological Survey.
* Names abandoned or rejected by the Federal and Kansas Geological Surveys.
† Informal names, not acceptable for formal stratigraphic classification.
‡ Informal names not recognized by the Federal or Kansas Geological Surveys, therefore not listed in the Federal Geological Survey Lexicons: Bulletins 769 (Wilmarth, 1925), 896 (Wilmarth, 1938), 1056-A (Wilson, Sando, and Kopf, 1957), and 1056-B (Wilson, Keroher, and Hansen, 1959).

[2] For references regarding names and dates see Wilmarth (1938).

[3] It was impossible and impractical to list all of C. R. Keyes' proposed nomenclatural terms; a few are given as examples.

†Cruise Sandstone. C. W. Sternberg and A. J. Crowley, 1954 (first proposed in a paper given at the 1952 American Association of Petroleum Geologists annual meeting and shown in chart form by Boreing, 1953)
Comment: Subsurface term used for "J" sand or lower member of the Omadi Formation.

†"D" sand.
Comment: Informal subsurface letter designation for upper sand in the Gurley Member of the Omadi Formation.

*Dacotah beds. Robert Hay, 1885
Comment: Spelling rejected in favor of Dakota.

Dakota Formation. F. B. Meek and F. V. Hayden, 1862
Age and position: Gulfian?, Cenomanian?, includes beds between the Comanchean Kiowa Shale and Gulfian Graneros Shale. May be either Comanchean or Gulfian or both. Subdivided into Janssen and Terra Cotta Members. Originally proposed as a group term.
Description: Varicolored clay, silt, and shale containing lenticular sandstone layers and ironstone concretions.
Thickness: Between 100 and 300 feet.
Type locality: In hills back of Dakota, Dakota County, Nebraska.

Dakota Group. See Dakota Formation.

Dakota Sandstone. See Dakota Formation.

Dakotan series. See Dakota Formation.
Comment: A generally nonaccepted term of C. R. Keyes.

Dockum? Group. W. F. Cummins, 1890
Age and position: Upper Triassic, Panhandle of Texas and southeastern New Mexico, subdivided into Tecovas and Trujillo Formations.
Description: Redbeds.
Thickness: About 40 feet on the outcrop and maximum of 320 feet in the subsurface.
Type locality: Dockum, Dickens County, Texas.

*Downs Limestone. F. W. Cragin, 1896
Comment: Now called Fencepost Limestone.

*Elk Creek beds. F. W. Cragin, 1895
Comment: Discarded as being a local name for a major part of the Cheyenne.

*Elk River beds. See Elk Creek beds.
Comment: Name mentioned by Moore, Frye, and Jewett (1944), probably referring to Elk Creek beds; name not acceptable, as it is preempted.

Ellsworth Formation. R. C. Moore, 1935
Comment: Name appears on a chart (Moore, 1935a) with no explanation except that classification of Dakota beds is in doubt awaiting completion of studies by A. C. Tester; later the name appeared on the Geologic Map of Kansas (Moore and Landes, 1937); Plummer and Romary (1942) credit the name to Tester as appearing on Moore's chart.

Fairport [Chalky] Shale. W. W. Rubey and N. W. Bass, 1925[4]
Age and position: Gulfian, Turonian, lowest of three members of the Carlile Shale.
Description: Light-gray calcareous shale and thin chalk beds and thin bentonite seams.
Thickness: Averages about 125 feet.
Type locality: Exposures a few miles south and west of Fairport, Russell County, Kansas.

Fencepost Limestone. W. N. Logan, 1897
Comment: Name given to a thin limestone bed at top of Greenhorn, quarried for fence posts; also called "post limestone."

‡Ferruginous group. W. N. Logan, 1897
Comment: An informal term for the lower part of the Dakota, not acceptable for stratigraphic nomenclature.

‡Flagstone horizon. W. N. Logan, 1897
Comment: One of five units of the lower part of the Benton, now recognized as upper part of the Lincoln Limestone.

*Fort Benton Group. F. B. Meek and F. V. Hayden, 1862
Comment: A term used in early reports for what is now generally called Benton, see Benton Shale.

Fort Hays Limestone. S. W. Williston, 1893
Age and position: Gulfian, Coniacian, lower of two members of the Niobrara Formation, Colorado Group. Also has been called Hays Limestone.
Description: Light-gray thin to massive chalk or chalky limestone.
Thickness: Ranges from 40 to 90 feet.
Type locality: Fort Hays, Ellis County, Kansas.

*Fort Pierre Group. F. B. Meek and F. V. Hayden, 1862
Comment: Now termed simply Pierre.

Fullington Shale. F. W. Cragin, 1895
Comment: Term used for lower part of Kiowa, in turn subdivided into Black Hill and Blue Cut Shales.

Fuson Shale. N. H. Darton, 1901
Comment: Lower Cretaceous term used farther north and west and not applicable to Kansas.

†"G" sand.
Comment: Subsurface informal letter designation for lower sand in the Gurley Member of the Omadi.

Gove Chalk. C. R. Keyes, 1941
Comment: Nonaccepted term for Niobrara.

Graham jasper. F. W. Cragin, 1896
Comment: Bed of jasper near top of Niobrara Formation.

Graneros Shale. G. K. Gilbert, 1896
Age and position: Gulfian, Cenomanian, lowest formation of Colorado Group, overlies Dakota and underlies Greenhorn.
Description: Dark-gray clayey fissile noncalcareous shale.
Thickness: About 45 feet.
Type locality: Name suggested by R. C. Hills; named for Graneros Creek, Pueblo County, Colorado.

Greenhorn Limestone. G. K. Gilbert, 1896
Age and position: Gulfian, Cenomanian and Turonian, one of four formations of Colorado Group, subdivided into four members, contains Fencepost Limestone, sugar sand, and shell-rock limestone.
Description: Light-gray interbedded chalky limestone and calcareous shale and some thin bentonite beds.
Thickness: About 100 feet.
Type locality: Greenhorn Station, 14 miles south of Pueblo, Colorado, and Greenhorn Creek.

*Greenleaf Sandstone. C. N. Gould, 1898
Comment: Local bed in the Kiowa.

Gulfian Series. R. T. Hill, 1887
Age and position: Late Cretaceous including late Cenomanian, Turonian, and Senonian. The boundaries between Early and Late and between Comanchean and Gulfian do not coincide exactly, but term is used more or less synonymously with Late Cretaceous.
Description: Provincial series of predominantly marine deposits.
Thickness: About 2,500 feet.
Type locality: Gulf Plain of the Gulf of Mexico.

[4] The new stratigraphic code (American Commission on Stratigraphic Nomenclature, 1961) does not permit using adjectives in formal stratigraphic terms; the Kansas Survey uses Fairport Chalk.

†Gurley Sandstone. G. W. Sternberg and A. J. Crowley, 1954 (see Cruise Sandstone)
Comment: Subsurface term used for upper member ("D" and "G" sands) of the Omadi Formation.

‡Gypsiferous horizon. W. N. Logan, 1897
Comment: Upper of three units of the upper part (Saliferous group) of the Dakota.

Hartland Shale. N. W. Bass, 1926
Age and position: Gulfian, late Cenomanian, one of four members of the Greenhorn.
Description: Gray chalky bentonitic shale.
Thickness: About 30 feet.
Type locality: Exposures along Arkansas River a short distance west of Hartland, Kearny County, to Kendall, Hamilton County, Kansas.

*Hays Limestone. See Fort Hays Limestone.

‡Hesperornis beds. S. W. Williston, 1897
Comment: Paleontological zone in the Niobrara, not applicable as a stratigraphic name.

‡Hodgeman Shale. R. C. Moore, 1935
Comment: Name appears on a rock chart with no explanation but is indicated to apply to the lower unit of Solomon Formation.

†Huntsman Shale. C. W. Sternberg and A. J. Crowley, 1954 (see Cruise Sandstone)
Comment: A subsurface term for the shale unit between the "D" and "G" sands and the "J" sand.

*Inoceramus beds. C. A. White, 1870
Comment: Paleontological name applied to the Niobrara.

‡Inoceramus horizon. W. N. Logan, 1897
Comment: Paleontological name for one of five units recognized in the lower Benton, also known as the shell rock; part of Greenhorn.

†"J" sand.
Comment: Letter designation informally used for a subsurface unit known as Cruise Member of the Omadi.

Janssen Clay. Norman Plummer and J. F. Romary, 1942
Age and position: Age is questionably Gulfian or Comanchean. It occurs beneath Graneros and above Terra Cotta (lower member of the Dakota Formation).
Description: Clay, silt, and fissile shale containing lenticular sandstone and lignite.
Thickness: From 30 to 80 feet.
Type locality: Janssen Station, Ellsworth County, Kansas.

Jetmore Chalk. W. W. Rubey and N. W. Bass, 1925
Age and position: Gulfian, Turonian, one of four members of the Greenhorn, Colorado Group.
Description: Light-gray chalky shale and chalky limestone.
Thickness: About 22 feet.
Type locality: Exposures south and east of Jetmore along south side of Buckner Creek, Hodgeman County, Kansas.

Kent bed. F. W. Cragin, 1895
Comment: A once-used name for a local bed.

Kiowa Shale. F. W. Cragin, 1894
Age and position: Comanchean, Albian, upper of two Lower Cretaceous formations, contains Champion shell bed.
Description: Light-gray to black fissile fossiliferous shale.
Thickness: Typically from 60 to 150 feet.
Type locality: Kiowa County, Kansas.

*Kirby clay. C. N. Gould, 1898
Comment: One of four members of the Medicine beds, now part of the Kiowa and Dakota.

Lake Creek Shale. M. K. Elias, 1931
Age and position: Gulfian, Campanian, one of six members of the Pierre, Montana Group.
Description: Dark-gray concretionary shale.
Thickness: About 200 feet.
Type locality: Lake Creek in northwestern Wallace County, Kansas.

Lakota Sandstone. N. H. Darton, 1899
Comment: A term for Lower Cretaceous beds used north and west of Kansas.

*Lanphier beds. F. W. Cragin, 1895
Comment: Discarded as being a local facies of the Cheyenne.

‡Lignite horizon. W. N. Logan, 1897
Comment: Lowest of three units of the Saliferous (upper) Dakota.

Lincoln Limestone. W. N. Logan, 1897, emend. W. W. Rubey and N. W. Bass, 1925
Age and position: Gulfian, Cenomanian, lowest of four members of the Greenhorn, Colorado Group.
Description: Light-gray chalky shale and chalky limestone.
Thickness: Average 28 feet.
Type locality: Lincoln, Lincoln County, Kansas.

*Lincoln Marble. See Lincoln Limestone.

*Lisbon Shale. F. W. Cragin, 1896
Comment: Preoccupied and same as the older name, Pierre.

‡Lower group. W. N. Logan, 1897
Comment: A nonusable name including Graneros and Greenhorn.

†Lucina limestone. M. K. Elias, 1931
Comment: Informal paleontological name for local zone in Pierre.

†"M" sand.
Comment: An informal subsurface letter designation for one of many sand bodies in the Lakota or Cloverly or Cheyenne.

Marquette Member. W. H. Twenhofel, 1924
Comment: Upper of three units of the Belvidere designating an occurrence of fossils.

*Medicine beds. C. N. Gould, 1898
Comment: Includes upper Kiowa and lower Dakota, divided into three units; discarded as a name for a local facies without stratigraphic value.

Mentor Formation. F. W. Cragin, 1895
Comment: Corresponds to different stratigraphic sections depending on different definitions and restrictions; Lower Cretaceous.

Montana Group. G. H. Eldridge, 1888
Age and position: Gulfian, Senonian, contains two, three, or four formations depending on area; only lower unit present in Kansas.
Description: Composed mainly of shale and sandstone.
Thickness: Ranges from 1,000 to 1,600 feet.
Type locality: Extensive development in Montana, especially in upper Missouri River region.

Morrison Formation. G. H. Eldridge *in* Emmons, Cross, and Eldridge, 1896; emend. Waldschmidt and LeRoy, 1944
Age and position: Late Jurassic, present in Kansas subsurface only between overlying Cretaceous and underlying Permian or Triassic.
Description: Varicolored, predominantly greenish, shale and some sandstone, anhydrite, and pink chert.
Thickness: Ranges to 350 feet.
Type locality: Just north of Morrison, Colorado.

Natural Corral Member. W. H. Twenhofel, 1924
Comment: Lower of three units of the Belvidere designating a fossil occurrence.
Niobrara Chalk. See Niobrara Formation.
Niobrara Formation. F. B. Meek and F. V. Hayden, 1862
Age and position: Gulfian, Coniacian and Santonian, upper formation of four in the Colorado Group, subdivided into two members. Once it had group status, but was deemed more appropriate as a formation.
Description: Light-gray soft calcareous shale and chalk.
Thickness: Averages about 600 feet.
Type locality: Along Missouri River near mouth of Niobrara River, Knox County, Nebraska.
Niobrara Group. See Niobrara Formation.
Niobrara Limestone. See Niobrara Formation.
•Norton zone. F. W. Cragin, 1896
Comment: Middle part of the Smoky Hill.
†"O" sand.
Comment: Informal letter designation for one of the many sands in the Lakota or Cloverly or Cheyenne.
Omadi Formation. G. E. Condra and E. C. Reed, 1943
Comment: The Omadi Formation (or Sandstone) is approximately equivalent to the Dakota Formation; overlain by Graneros and underlain by Kiowa or Skull Creek; subdivided into the Gurley, Huntsman, and Cruise (or "D," "G," and "J" sands). The term has not been generally accepted, although applicable, especially in the subsurface of central and western Kansas.
‡Ornithostoma beds. S. W. Williston, 1897
Comment: Proposed new name for Pteranodon beds as *Pteranodon* is a synonym for *Ornithostoma*; this is a good example of the impracticability of applying paleontological names to stratigraphic units.
•Osborne Limestone. F. W. Cragin, 1896
Comment: Same as Fort Hays, a better-established name.
•Ostrea shales. W. N. Logan, 1897
Comment: Paleontological name applied in early reports to beds now known as Fairport.
Pete terrane. C. R. Keyes, 1915
Comment: An inept name for part of the Dakota.
Pfeifer Shale. N. W. Bass, 1926
Age and position: Gulfian, Turonian, upper member of the Greenhorn, contains the Fencepost Limestone bed at top.
Description: Light-gray interbedded calcareous shale and chalky limestone.
Thickness: About 20 feet.
Type locality: Exposures 2½ miles northwest of Pfeifer, Ellis County, Kansas.
Pierre Shale. F. B. Meek and F. V. Hayden, 1862
Age and position: Gulfian, Campanian and Maestrichtian, Montana Group, subdivided into six members.
Description: Dark-gray to black concretionary shale.
Thickness: Ranges to about 1,600 feet.
Type locality: Exposures at old Fort Pierre in either Stanley or Hughes County, South Dakota.
†Post limestone. See Fencepost Limestone.
•Pteranodon beds. W. N. Logan, 1897
Comment: Paleontological name formerly applied to Smoky Hill.
Purgatoire Formation. G. W. Stose, 1912
Comment: Includes Kiowa and Cheyenne; more appropriately used south and west of Kansas.
†"R" sand.
Comment: One of many sands in the Lakota or Cloverly or Cheyenne referred to by informal letter designation.
Rawlinsian series. C. R. Keyes, 1941
Comment: A nonused term.
•Reeder Sandstone. F. W. Cragin, 1895
Comment: Term used for part of the Dakota.
Rocktown [channel] Sandstone. W. W. Rubey and N. W. Bass, 1925
Comment: A discontinuous sandstone body in the Dakota.
‡Rudistes beds. S. W. Williston, 1897
Comment: Paleontological name applied to the upper Pteranodon (Smoky Hill beds).
•Russell Formation. F. W. Cragin, 1896
Comment: Old term including Greenhorn and Fairport.
‡Saliferous shale group. W. N. Logan, 1897
Comment: Upper of two parts of the Dakota.
Saline Valley Shale. D. E. Hattin, 1962
Comment: Hattin proposed the following changes in classification of the Carlile: (1) Fairport be elevated to formation, (2) Blue Hill be redefined to include all beds between Fairport and Fort Hays and elevated to formational status, (3) Codell be retained as a member of the Blue Hill, (4) Saline Valley be applied to the lower division of the Blue Hill, and (5) Carlile be elevated to subgroup rank.
Salt Grass Shale. M. K. Elias, 1931
Age and position: Gulfian, Campanian, one of six members of the Pierre.
Description: Gray clayey shale.
Thickness: About 60 feet.
Type locality: Salt Grass Canyon, southern tributary of Goose Creek, Wallace County, Kansas.
‡Salt Marsh horizon. W. N. Logan, 1897
Comment: Middle of three units of the Saliferous (upper Dakota).
Sharon Springs Shale. M. K. Elias, 1931
Age and position: Gulfian, Campanian, lowest of six members of the Pierre, Montana Group.
Description: Black flaky shale.
Thickness: About 155 feet.
Type locality: Sharon Springs, Wallace County, Kansas.
†Shell-rock limestone. See Greenhorn Limestone.
Comment: An informal name for limestone bed at top of Jetmore.
Skull Creek Shale. A. J. Collier, 1922
Comment: Lithologic equivalent to the Kiowa farther north and west of Kansas.
Smoky Hill Chalk. F. W. Cragin, 1896
Age and position: Gulfian, Coniacian and Santonian, upper member of the Niobrara, Colorado Group.
Description: Gray chalky shale containing limonitic concretions and bentonite; locally forms massive chalk beds.
Thickness: About 550 feet.
Type locality: Smoky Hill River, Kansas.
‡Solomon Formation. R. C. Moore, 1935
Comment: Shown on chart as upper formation, containing two members, of Dakota Group.
•Spring Creek Clays. C. N. Gould, 1898
Comment: Basal unit of the Medicine beds.
•Stokes Sandstone. F. W. Cragin, 1895
Comment: Upper unit of Elk Creek beds, which were upper unit of Cheyenne; discarded name for local beds in Cheyenne.

Stokes Hill Sandstone. W. H. Twenhofel, 1924
Comment: Stokes Hill used instead of Cragin's term Stokes.

†Sugar sand. See Greenhorn Limestone.
Comment: Informal reference to a granular bed in Greenhorn (Pfeifer).

Sundance Formation. N. H. Darton, 1899
Comment: Term used mainly north and west of Kansas; part of Jurassic beds in Kansas may be equivalent to part of Sundance.

†"T" sand.
Comment: One of many subsurface sands informally referred to the Lakota or Cloverly or Cheyenne.

Terra Cotta Clay. R. C. Moore, 1935; def. Norman Plummer and J. F. Romary, 1942
Age and position: Age is questionably Gulfian or Comanchean. It occurs beneath the Janssen (upper member of the Dakota) and above the Kiowa. Moore also showed the name on charts in 1935 and 1940.
Description: Varicolored interbedded clay, shale, and siltstone, and lenticular sandstone.
Thickness: Ranges from 70 to 220 feet.
Type locality: Terra Cotta school district, north of the abandoned village of Terra Cotta, Ellsworth County, Kansas.

*Trego zone. F. W. Cragin, 1896
Comment: Lower part of the Smoky Hill.

Trinity Sandstone. R. T. Hill, 1888
Comment: A Texas term that was extended into Kansas.

*Tucumcari beds. W. F. Cummins, 1892
Comment: Correlated with upper part of the Belvidere, which corresponds to upper part of Kiowa and lower part of Dakota.

Unnamed Member. M. K. Elias, 1931
Comment: One of six members of the Pierre, Montana Group, composed of gray to black shale 500 to 600 feet thick. Needs proper stratigraphic designation for recognition.

‡Upper group. W. N. Logan, 1897
Comment: A nonusable name for Carlile.

*Victoria Clay. F. W. Cragin, 1896
Comment: An abandoned term for Blue Hill and Codell.

*Victoria Formation. See Victoria Clay.

*Wafer Shale. F. W. Cragin, 1895
Comment: Another term for Black Hill.

*Walker beds. F. W. Cragin, 1895
Comment: Substitute for Belvidere, which included Cheyenne and Kiowa.

Wallace Shale. C. R. Keyes, 1941
Comment: A nonused term.

Weskan Shale. M. K. Elias, 1931
Age and position: Gulfian, Campanian, one of six members of the Pierre, Montana Group.
Description: Gray clayey shale.
Thickness: About 170 feet.
Type locality: Five miles north of Weskan, Wallace County, Kansas.

Windom Member. W. H. Twenhofel, 1924
Comment: Middle of three units of the Belvidere designating occurrence of fossils.

Wiskanian series. C. R. Keyes, 1941
Comment: A nonused term.

†"X" bentonite bed.
Comment: Same bed as the Bentonite marker bed.

Appendix C—Supplement to Structural Nomenclature in Kansas*

Agra Anticline.—The Agra Anticline was named by Parkhurst (1959a). The structure is a generally northeast-trending anticline which extends from southeastern Phillips County to northwestern Smith County. The Phillipsburg Syncline separates the Agra from the Stuttgart-Huffstutter Anticline, farther to the west. To the east of the Agra Anticline is the axis of the Salina Basin.

Alta Vista Anticline.—The Alta Vista Anticline was shown by Merriam (1960c) to trend north and to have a steep east flank. Closure in surface beds amounts to about 30 feet. This small anticlinal structure is one of many located along the north-northeast-trending, south-plunging Nemaha Anticline, and is located in northeastern Morris County in sec. 3 and 10, T. 14 S., R. 8 E. The abandoned Alta Vista gas field is located on this structure.

Ashburn Anticline.—The Ashburn Anticline is a north-northeast-trending structure located in southwestern Morris County in sec. 29, T. 14 S., R. 10 E. Merriam (1960a) showed the structure as one of several along the prominent Alma Anticline, which is just east of and parallel to the Brownville Syncline. The eastern limit of the anticline is probably a high-angle reverse fault. Closure is about 35 feet on the Viola and progressively less in younger beds. Brinegar (1960) was able to demonstrate that part of the Mississippian section on the southeastern flank of this structure is repeated in one of the wells on the east side of the Ashburn oil field.

Cambridge Arch.—The name for the Arch comes from the town of Cambridge, Furnas County, Nebraska. Merriam and Atkinson (1955) modified the concept of the Cambridge Arch in Kansas as shown by Bass in 1926 and reproduced by Jewett in 1951. Even now, there is some doubt as to whether the structure is a series of northwest-trending anticlines as shown by Merriam (1958c) or whether there is a prominent bend in the axis of the feature as shown by Reed (1955).

Chesapeake Fault Zone.—This fault zone is recognizable on several published maps (Merriam, 1960b). The name, previously applied in southwestern Missouri, is hereby applied to the extension of the fault zone in Kansas. Branson (1944) reported that the Chesapeake Fault extends for a known distance of about 80 miles from Stone County to Dade County, Missouri. Many minor faults are associated with the main one, which is nearly parallel to the Ste. Genevieve and Cap-au-Gres Faults.

Cimarron Syncline.—The Cimarron Syncline is located in Lane, Gove, Trego, Ness, Hodgeman, and Finney Counties. It is a large synclinal area just east of the Oakley Anticline. Lee and Merriam (1954a) showed this north-trending, south-plunging syncline on an isopachous map from top of the Stone Corral (Permian) to top of the Dakota (Cretaceous). The basin was formed when the Oakley Anticline developed, dividing the Hugoton Embayment.

Coats Anticline.—The Coats Anticline is located in sec. 24, T. 29 S., R. 14 W., in Pratt County, Kansas. Curtis (1956) described the field as a small anticline on which Simpson, Viola, and part of the Mississippian formations have been truncated on a pre-Pennsylvanian uplift. More than 150 feet of closure is evident at the horizon of the top of the Arbuckle. The Coats oil field is located on the structure. Brewer (1959) interpreted the structure as faulted.

Comanche Arch.—The Comanche Arch, hereby named for Comanche County, is a large, broad, east-trending anticlinal feature located in parts of Barber, Pratt, Kiowa, Comanche, Clark, Ford, and Meade Counties, Kansas. Merriam (1957b) called attention to this feature and noted that it limits the southern end of the Western Kansas Basin. This arch is especially evident at the horizon of the Stone Corral. To the south of its crest, beds dip rapidly southward into the Anadarko Basin of Oklahoma.

Countryman Anticline.—The Countryman Anticline (Merriam and Goebel, 1959c) is a north-trending structure located in Cowley County. Structure at the horizon of the top of the Mississippian reveals three areas of closure on the crest of the Countryman; the maximum local closure is 50 feet. Closure for the entire structure probably is somewhat larger, however. The surface trend is closely coincident with the trend on top of the Mississippian. Surface closure is less, because seemingly only about 20 feet of closure is evident in outcropping beds.

Densmore Anticline.—The Densmore Anticline is a low, elongate anticline trending nearly normal to the Stuttgart-Huffstutter Anticline. It extends from the southeastern part of the Cambridge Arch southeastward to the southern extremity of the Stuttgart-Huffstutter Anticline. Parkhurst (1959a) named this structure for the town of Densmore, in southeastern Norton County. It separates the Long Island Syncline on the north from a closed synclinal area on the south.

Denver Basin.—The axis of the Denver Basin closely parallels the front of the mountain ranges in eastern Colorado and trends approximately north-south. The basin is asymmetrical, the west flank being steeper than the east. The southeast flank of the Denver Basin extends into extreme northwestern Kansas, in Cheyenne County. Regional dip in Cretaceous beds is to the northwest, about 20 feet per mile. The Denver Basin is also known as the Denver-Julesburg Basin or Julesburg Basin.

Goodland Anticline.—The Goodland Anticline is a northeasterly plunging anticlinal structure that parallels the Las Animas Arch and is separated from it by a shallow syncline. Mehl (1959, p. 36) said of the structure, ". . . the Goodland Anticline, herein named, is a large subsidiary structure of the Las Animas Arch that parallels the Las Animas structure on post-Mississippian structural datums, but converges with it on pre-Pennsylvanian structural datums." This same feature also has been called the Sherman Arch.

Greenwich Anticline.—The Greenwich Anticline is located in the northeast part of T. 26 S., R. 2 E., in Sedgwick County. Cole (1960) showed the structure as a northeast-trending anticline which approximately parallels the Nemaha Anticline. It plunges to the southwest, and closure at the horizon of the top of the "Hunton" is approximately 50 feet.

Jennings Anticline.—The Jennings Anticline is defined as a north-trending, southerly plunging structure located in T. 3, 4, 5, and 6 S., R. 26 and 27 W., in eastern Decatur County and northeastern Sheridan County, Kansas. Merriam and Atkinson (1955) named the structure for the town of Jennings, which is located along the crest of the anticline in southeastern Decatur County.

Jetmore Syncline.—This prominent syncline is located on the eastern flank of the Hugoton Embayment in western Kansas. Hays (1961, p. 11) said the following concerning the syncline: "Centered in Ness and

* This list is a supplement to "Geologic Structures in Kansas," Kansas Geological Survey Bulletin 90, pt. 6 (Jewett, 1951).

Hodgeman Counties is the Jetmore Syncline, bounded on the east by the southwest flank of the Central Kansas Uplift. Since this high in the eastern part of the [thesis] area is believed to be in part pre-Mississippian (possibly even contemporaneous with the deposition of the Arbuckle Group), it might best be referred to as part of the Ellis Arch. West of the Jetmore Syncline there is only a suggestion of a bounding structural high."

John Creek Anticline.—The John Creek Anticline is located in sec. 23, 24, 25, 26, 27, 34, and 35, T. 15 S., R. 9 E., and sec. 2, T. 16 S., R. 9 E., in extreme northeastern Morris County. Merriam (1960a) showed this local structure to be one of several along the larger Alma Anticline east of the Brownville Syncline in the Forest City Basin. The anticline trends north-northeast, is 4 to 5 miles long, and has a maximum width of about 2 miles. Closure on top of the Viola Limestone is approximately 70 feet. The east flank is faulted, giving the structure a decidedly asymmetrical aspect (Kansas Geological Society, 1960).

Kaneb Basin.—Kaneb Basin is an informal term proposed by F. J. Gardner (personal communication) for a petroliferous province in northwestern Kansas and southwestern Nebraska, which has been called the Southwest Nebraska-Northwest Kansas Basin. It includes part of the northern end of the Hugoton Embayment.

Kanopolis Structure.—The Kanopolis Structure is located southeast of Kanopolis along the north side of Thompson Creek (SW sec. 21, T. 16 S., R. 7 W.) in Ellsworth County. The structure, as reported by Ver Wiebe (1937), may have been formed by solution of rocks beneath the structure, allowing the overlying beds to collapse. Beds exposed in the road cut are contorted and faulted. Because of the scarcity of outcrops in the vicinity of the structure, it is not possible to determine its extent; however, it is probably local.

Kismet High.—The Kismet High is located in eastern Seward County in southwestern Kansas. The structure was first named in print by King (1956) for a minor but sharp domal feature within the Hugoton Embayment. The Kismet oil field is located on this structure.

Las Animas Arch.—The Las Animas Arch is a broad anticline, which trends and plunges northeast. It extends from northern Las Animas County through Bent, Kiowa, Cheyenne, and Kit Carson Counties, and into southeastern Yuma County, Colorado. Only the eastern flank of this arch is present in western Kansas. Dip on the east flank is northeasterly about 20 feet per mile into a well-developed syncline that follows the margin of the arch and hence is referred to as the marginal syncline. The structural development of the arch was shown by Maher (1945).

Linda Anticline.—The term Linda is used for a prominent northeast-trending anticlinal feature in northwestern Kansas. The anticline was named by Walton (1960) for the town of Linda, located in Rawlins County. This anticline lies southeast of the Goodland Anticline, which in turn is southeast of the Las Animas Arch. It extends from southeastern Sherman County north-northeast across Rawlins County, Kansas, and dies out in extreme southern Hitchcock County, Nebraska. The name appears in print on a map prepared by Walton for an article by Goebel and Merriam (1960).

Lindsborg Anticline.—A prominent anticlinal feature in central Saline County and north-central McPherson County is here named the Lindsborg Anticline. The structure trends approximately north and on the horizon of the top of the Mississippian it plunges southward. The structure is the first anticlinal fold east of the Salina-Sedgwick Basin axis, and on it is located the Lindsborg oil field.

Long Island Syncline.—The Long Island Syncline is a broad, northeasterly plunging syncline in eastern Norton County and northwestern Phillips County. The structure was named by Merriam and Atkinson (1955) for the town of Long Island in Phillips County, which is near the axis of the syncline. This feature marks the eastern edge of the Cambridge Arch and separates it from the prominent Stuttgart-Huffstutter Anticline.

Marginal Syncline.—The northeasterly slope on top of the Dakota on the eastern flank of the Las Animas Arch is terminated by a well-developed unnamed syncline that follows the margin of the arch and is referred to informally as the marginal syncline. Lee and Merriam (1954a) defined the nature of this feature. The narrow syncline trends north from central Finney County to Thomas County, but its extension northwest into Cheyenne County is without adequate control. The marginal syncline conforms in part to a similar syncline at the horizon of the Stone Corral. It was formed about in the position of the older Oakley Anticline, almost completely destroying it.

Mill Creek Anticline.—The Mill Creek Anticline is a local feature in western Wabaunsee County, Kansas, in sec. 2, T. 13 S., R. 10 E., on the Alma Anticline (Merriam, 1960a). The anticline has only about 30 feet of closure. It trends slightly east of north and the east flank is faulted (Lewis, 1960a).

Newbury Anticline.—The Newbury Anticline, in northeastern Wabaunsee County, is located along the Alma Anticline. This structure is the northernmost oil-producing feature along the Alma trend. The anticline is elongate in a northeast direction and has about 20 feet of closure on top of the Viola; apparently the east flank of the structure is not faulted (Lewis, 1960b).

Norton Anticline.—The Norton Anticline, on which the Norton oil field is located, is in Norton County. Merriam and Goebel (1954) applied this name to an anticline of low relief having a steeper southeast than northwest flank and trending northeast. At the horizon of the top of the Arbuckle, the structure is irregular and has four small areas of closure, the maximum being about 10 feet. The minor irregularities of the structure seem to be the result of erosion. Arbuckle is absent on the extreme northwest flank of the structure.

Oakley Anticline.—The Oakley is a pre-Dakota, long, narrow, north-trending southerly plunging anticline extending from Thomas County to Finney County. This anticline had a structural relief on the Stone Corral of more than 200 feet in Dakota time. This large feature essentially divides the Hugoton Embayment. The fact that salt beds extend to the flank of the Oakley Anticline but do not cross it implies that it was active before deposition of the Stone Corral. The pre-Dakota expression of the Oakley Anticline at the horizon of the Stone Corral was canceled by post-Dakota development of the marginal syncline; in the areas where the two structural features were in conflict, the structural relief of the Oakley was obliterated.

Phillipsburg Syncline.—The Phillipsburg Syncline was named by Parkhurst (1959a) for the town of Phillipsburg, Phillips County, located near the southern end of the structure. It is an elongate shallow syncline trending north-northeast and extending into Nebraska. The structure separates the Agra Anticline on the east from the Stuttgart-Huffstutter Anticline on the west.

Pratt Anticline.—The Pratt Anticline was first shown as a major pre-Desmoinesian post-Mississippian structural province in Kansas by Merriam (1955e). The structure is a southern extension of the Central Kansas

Uplift in Stafford, Pratt, and Barber Counties, Kansas. It is a large, broad, southerly plunging anticlinal feature which separates the Hugoton Embayment from the Sedgwick Basin. The structure is named for Pratt County.

Reese Anticline.—The Reese Anticline is a long, narrow, northeast-trending anticline located in Greenwood County. Merriam and Goebel (1959c) named the structure for the town of Reese. The structure is fairly well outlined and is mappable on the surface. At the horizon of the top of the Mississippian, the doubly plunging anticline has a closure of 100 to 120 feet. The anticline is slightly asymmetrical, being steeper to the northwest.

Selden Syncline.—The northwesterly plunging Selden Syncline is located in southeastern Decatur County and northeastern Sheridan County, and is named for the town of Selden in Sheridan County. This large synclinal feature, which flanks the Jennings Anticline on the west, is, according to Merriam and Atkinson (1955), a northern extension of the axis of the Hugoton Embayment. There is some indication that the northeast flank of the structure is faulted.

Sherman Arch.—The term Sherman Arch was first used by Gardner (1959) in the same sense that Goodland Anticline is used; the latter has gained wider acceptance.

Southwest Nebraska-Northwest Kansas Basin.—This term was proposed by Monahan and Rutledge (1959) for the northern part of the Hugoton Embayment between the Las Animas Arch and the Cambridge Arch. Other names have gained wider acceptance, and thus this term has not been generally used.

Strahm Anticline.—The Strahm Anticline in Nemaha County in northeastern Kansas was shown by Jewett and Merriam (1959). At the horizon of the top of the "Hunton" the anticline trends northeast and includes two prominent areas of closure. On this structure are located the Strahm, Strahm East, and Sabetha oil fields. The structure, located in T. 2 S., R. 14 E., is just east of the Nemaha Anticline but west of the Brownville Syncline.

Stuttgart-Huffstutter Anticline.—The Stuttgart-Huffstutter Anticline is located in Phillips County in northwestern Kansas. This prominent north-northeast-trending anticline was named by Lee and Merriam (1954a). It is separated from the Cambridge Arch proper by the north-northeast-plunging Long Island Syncline. Along the crest are located numerous oil fields, including Stuttgart, Stuttgart South, Dayton, Huffstutter Southwest, and Huffstutter.

Sunny Slope Anticline.—The Sunny Slope Anticline is located in T. 14 S., R. 21 W., in southeastern Trego County in western Kansas. The Sunny Slope oil field is located on this anticline. Lee and Merriam (1954a) mentioned that this feature probably had some structural movement in late Paleozoic time.

Syracuse Fault.—Primarily on the basis of physiographic evidence, Smith (1940) recognized the possibility of a fault on the south side of the Syracuse Anticline, previously named and delineated by Darton. The fault was later found by a test drilling (McLaughlin, 1943). Jewett and Merriam (1959) showed the position of this structure in western Kansas. It is essentially an east-trending fault, located in southern Hamilton and Kearny Counties.

Syracuse Syncline.—The Syracuse Syncline is located in Wichita and Kearny Counties just west of the Oakley Anticline. Lee and Merriam (1954a) named this basinal feature, which corresponds to the Cimarron Syncline to the east of the Oakley Anticline.

Transcontinental Arch.—Only a small part of the Transcontinental Arch is located in Kansas and that is an extension from the main arch. Eardley (1949, 1951) and Reed (1948) showed the location of this major feature—the backbone of the continent—and discussed its history. The arch and its subsidiary features exerted a considerable influence on the geologic history of the area adjacent to it.

Wakeeney Anticline.—The Wakeeney Anticline is a northeast-trending structure near the center of T. 11 S., R. 23 W., in Trego County. Lee and Merriam (1954a) mentioned this prominent anticline, on which the Wakeeney oil field is located.

Willowdale Anticline.—The Willowdale Anticline is located in sec. 10, 11, 14, and 15, T. 29 S., R. 9 W., in Kingman County. Cruce (1956) showed this to be a steep anticlinal structure elongated northeast and plunging southwest. At the horizon of the top of the Viola the structure has about 30 feet of closure.

Woodston Anticline.—The Woodston Anticline is a narrow, elongate, northerly plunging structure extending from east-central Rooks County to south-central Phillips County. The anticline was named by Parkhurst (1959a) for the town of Woodston in eastern Rooks County. It is separated from the Stuttgart-Huffstutter Anticline on the north by a low saddle, and it is probably closely associated with the Central Kansas Uplift. Oil is produced from Lansing and Kansas City rocks in a part of the structure in the Faubion, Low Creek, Stockton, Medicine Creek, Clayton, and Lone Star fields.

Worden Fault.—The Worden Fault, named by O'Connor (1960), is located in southern Douglas County. The fault extends approximately east-west from Baldwin to just northwest of Worden, where it curves southward and apparently continues into Franklin County. The north and west side is upthrown. Several minor faults are associated with the feature. According to O'Connor (1960) the fault is post-Toronto pre-Leavenworth (Virgilian) in age, and does not affect the underlying Stanton rocks. He concluded that the fault is nontectonic.

Appendix D—Surface Sinkholes and Other Solution Features*

Ashland Basin (Ashland-Englewood Basin).—The Ashland Basin in southern Clark County, southwestern Kansas, forms a large topographic depression. It is a coalescing sinkhole (Frye, 1942). The depression probably was caused by solution of Permian salt and gypsum, which occur less than 1,000 feet below the surface (Frye, 1950; Jewett, 1951; Smith, 1940).

This large sinkhole is as much as 12 miles wide and 500 feet below the general level of the High Plains (Schoewe, 1949). The walls are Permian redbeds capped by Ogallala (Pliocene). The basin is dissected and drained by Cimarron River. As much as 100 feet of late Pleistocene fill has been deposited in the depression. Frye (1950) dated its subsidence as mid-Pleistocene to late Pleistocene and believed that solution is directly related to faults that formed in Pleistocene time in the area.

Big Basin and Little Basin.—Two sinkholes in western Clark County are well known; the larger, Big Basin (Pl. 26A), is located just west of the smaller, Little Basin, which contains within its boundaries a picturesque and smaller sinkhole known as St. Jacob's Well (Pl. 26B).

Big Basin is situated in sec. 24 and 25, T. 32 S., R. 25 W. The sinkhole is subcircular and approximately one mile in diameter. The floor is relatively flat and 125 to 150 feet below the rim. Small depressions or sags, often retaining water, occur on the floor of the basin. The wall of the sinkhole is still essentially vertical although slightly dissected. Permian, Cretaceous, and Tertiary rocks crop out in the wall of the basin. Its formation probably occurred from several hundred to a few thousand years ago (Smith, 1940).

Little Basin is about one-third mile east of Big Basin. The floor is 35 feet below the rim level. Although Little Basin is shallower than Big Basin, the two sinkholes are believed to be the same age. St. Jacob's Well, a relatively recent sinkhole, is on the floor of Little Basin. The water which is retained in this smaller sinkhole forms an "oasis" in the semiarid country.

Both Big and Little Basins are believed to be due to solution of the underlying soluble Permian beds.

Cherokee County Sinkholes.—Sinkholes are observable where rocks of Mississippian age crop out in some areas of southeastern Kansas. All known sinkholes in Cherokee County are attributed to solution of the thick Mississippian limestone in post-Cherokee time, as well as recently. Howe (1956) reported that Pennsylvanian strata are commonly faulted in older sinkholes because the collapse of caverns in the Mississippian limestone occurred after consolidation of overlying sediments. Some faults have a throw of as much as 6 feet. Pyrite and marcasite are common along fault planes.

Nine recent sinkholes were described by Pierce and Courtier (1937). Old sinkholes dated as post-lower Cherokee are exposed in four of the recent sinkholes.

Two of the recent sinkholes subsided about 1905. One is located in the SW sec. 34, T. 32 S., R. 25 E.; the other is in the NW sec. 28, T. 33 S., R. 25 E. Both sinkholes are elliptical, 75 to 125 feet across, and 30 or more feet deep. Their walls are nearly vertical.

Two more sinkholes are in the W2 sec. 34, T. 32 S., R. 25 E. The earlier sinkhole was formed in 1911. A few years prior to 1911 a sag, about 14 feet in diameter, appeared in a corn field, but no water was retained in the depression. In 1911 a larger hole suddenly appeared in the area of the former sag. The wall was vertical and extended down 72 feet; water was present in the bottom. In 1933 the north rim sank approximately 20 feet. The second sinkhole in sec. 34 formed in 1922 and was a shallow depression about 10 feet in diameter.

Two other shallow sinkholes, about 10 feet in diameter, are located in the NE sec. 9, T. 32 S., R. 25 E.; one formed about 1921 and the other in 1929. Another sinkhole in the NE sec. 34, T. 32 S., R. 25 E., was reported to have formed in 1911 or 1912; it was filled prior to 1937, and no further data on it are available. In 1924 cracks appeared in the soil in the E2 sec. 9, T. 32 S., R. 25 E. The area of soil cracks subsided in 1929 to form a vertical-walled, elliptical sinkhole, 75 to 125 feet across and 30 feet deep.

Coolidge Sink.—On December 18, 1926, a hole suddenly appeared in the ground 15 miles south of Coolidge, Hamilton County (NE sec. 22, T. 25 S., R. 43 W.). On July 1, 1930, the sinkhole was reported to be about 60 feet in diameter and 40 feet deep (Bass, 1931). It was circular with a steep and undercut wall; the floor sloped at a low angle toward the center of the depression. Three sets of crevices encircled the structure.

By August 8, 1930, the sinkhole had enlarged to a diameter of 104 feet and increased in depth to 68 feet (Bass, 1931). The material in which the sinkhole was formed was homogeneous silt; no stratified rock could be seen in the hole. Smith reported that in 1940 water filled the hole to within 10 feet of the surface and that the wall had slumped so that no overhang was visible. The depression had increased in size to 150 by 200 feet in 1941 and had elongated from its original circular shape, engulfing a nearby country road. It also had filled with water to within 15 feet of the rim (McLaughlin, 1943).

Bass attributed the sinkhole to solution and formation of a cavern with subsequent collapse of the roof. He reported that bedrock dips at 5° toward the sinkhole, indicating that the entire area of recent subsidence may be part of a larger and older sinkhole. Landes (1931) studied the area and determined that Graneros Shale was exposed below the rim. From this, Landes decided that the original cavern must have been formed in either salt or gypsum in the Permian section. Smith found that this sinkhole is but one of a linear series and suggested that they occur along a post-Ogallala fault.

Meade Salt Sink.—Sudden sinking of a circular area 150 to 200 feet across took place sometime between the 3rd and 18th of March 1879, in Meade County, 1½ miles southeast of Meade. The sinkhole is on the east side of Crooked Creek, just east of the Crooked Creek Fault. The Great Salt Well, as it was called at the time of formation, engulfed a portion of the "Jones and Plummer Trail," an often-used wagon road and cattle trail (Cragin, 1884). Mudge (1879) stated that by the 18th of March it was 60 feet deep and had a circumference of 610 feet; it was nearly circular with a perpendicular wall. Saline water filled the hole to within 17 feet of the land surface. The depth of the water ranged from 15 to 27 feet at the edge to 42 feet at the center. Water finally rose to within 14 feet of the ground surface.

Sod cracks formed on the rim around the sinkhole. They were 5 to 15 feet deep and 1 to 10 inches wide. The more distant cracks were 126 feet from the hole.

Mudge (1879) stated that 1 bushel of salt was recovered for every 43 gallons of water, about a 7 percent

* From Merriam and Mann, 1957.

concentration. At one time salt was produced commercially from the well.

Presently the sinkhole is filling with sediment. In the last few years the sinkhole has been completely dry (W. H. Schoewe, personal communication).

Mudge (1879) thought that a cavern had been formed in the Dakota Formation, softer material having been washed out by subterranean water, causing subsequent caving. Johnson (1901), Smith (1940), and Frye (1942) suggested that the cavern formed in underlying Permian salt beds and that overlying rocks collapsed. Frye (1942) pointed out that the shallowest soluble rock is in Permian redbeds several hundred feet below the present water table. He believed that Pliocene faulting provided the necessary openings for water to have access to soluble beds in the Permian and the faulting therefore controlled development of solution caverns; the period of sinkhole formation thus has been limited to post-Pliocene time.

Mitchell County Sink.—An unusual type of sinkhole developed in Mitchell County in 1927. Subsidence in the form of a trench in loess, 200 feet long, 75 feet wide, and 18 feet deep, necessitated moving a farm house. Landes (1932) reported that flat discoidal pebbles of the Fort Hays Limestone, derived from nearby outcrops, are found in loess at the level of the trench floor. He believed that solution of limestone pebbles formed a small cave in the loess, that erosion by circulating ground water enlarged the cave, and that the result was collapse of the overlying loess and formation of a sinkhole. A second collapsed cave 40 feet long was formed in 1931 at right angles to the main trench.

Jones Ranch Sink.—The Jones Ranch Sink, 8 miles southeast of Meade, forms a large topographic depression in Meade County (T. 32 and 33 S., R. 27 W.). The sinkhole is subcircular, 3 miles in diameter, and controls a centripetal drainage pattern. It is dissected and partly filled with sediment. Exposed bedrock dips slightly into the sinkhole. Its origin is attributed to solution and collapse (Smith, 1940; Frye, 1942; Jewett, 1951). From the molluscan fauna which it contains, Frye and Leonard (1952) dated the fill as early Wisconsinan. They pointed out that isolated features such as this are dated either by fossils or by intersection of lines of dissection.

Old Maid's Pool.—This sinkhole is northwest of Sharon Springs in Wallace County (sec. 30, T. 12 S., R. 40 W.). Moore (1926b) described it as 80 feet in maximum depth and three-eighths of a mile in diameter. It holds a small lake 300 feet wide, although in 1962 it was dry. The hole is circular, and the wall is moderately dissected. Pierre Shale is exposed on the south side of the basin (Elias, 1931).

Potwin Sink.—A sinkhole which occurred suddenly near Potwin has been described by Gordon (1938). The hole, located in the SE sec. 24, T. 24 S., R. 3 E., Butler County, was formed on the afternoon of September 22, 1937. It was 90 feet by 150 feet, elongated in an east-west direction, and about 45 feet deep. Water filled the hole to within 15 feet of the rim. The unstratified loam of the wall of the sinkhole was perpendicular. It was estimated that approximately 500,000 cubic feet of material was involved in the subsidence. The rim was estimated to be about 35 feet below base of the Herington Limestone. Gordon believed that solution had taken place in the Fort Riley Limestone about 75 feet below base of the sinkhole and that sudden collapse of the cavern roof resulted in the sinkhole.

Two older partly filled sinkholes are found in the vicinity of the Potwin Sink.

Smoky Basin Cave-in.—A sudden subsidence which took place near Smoky Hill River about 5 miles east of Sharon Springs on March 9, 1926, attracted nation-wide attention. The sinkhole (sec. 33 and 34, T. 13 S., R. 39 W., Wallace County) had a diameter of about 50 feet. By March 11 it had increased in size to about 125 by 250 feet, giving it an irregular elliptical shape (Moore, 1926b). By April 13 its dimensions had increased to 150 by 290 feet, and still later to about 250 feet north-south by 350 feet east-west. The wall was vertical down to the water level, 165 to 170 feet below the lip. Water was 50 feet deep in the center of the hole. Moore (1926a) estimated the total depth of the sinkhole to be 300 to 350 feet and the amount of material involved to be approximately 1½ million cubic feet. Pierre Shale is exposed in the wall of the sinkhole, and the Niobrara Formation is exposed a short distance east of the area.

Moore (1926a) suggested that because of its size and the large amount of material involved, the sinkhole was due to roof collapse into a cavity of considerable size in chalk in the upper part of the Niobrara. Chalk was dissolved by eastward-moving ground water, which entered the formation at the outcrop farther west.

Russell (1929) discarded Moore's idea of solution of the Niobrara and postulated instead that the sinkhole was the indirect result of structural deformation. He thought there was too much shale in the Niobrara to be dissolved for cavern formation, and he found no evidence that the formation carried water. The clue to the origin of the sinkhole, he believed, lies in the structure of the region, because in nearby counties there are many faults which were formed during pre-Ogallala and post-Ogallala deformation. He believed that cavities, strong enough to resist pressures for a long time, occurred along faults, ultimately collapsing as did the Smoky Basin Cave-in. Many previously formed sinkholes probably have been obliterated by erosion and deposition so that only recent ones are evident. Russell reported a fault having a throw of 50 feet in the north wall of the cave-in.

Elias (1930) was of the opinion that the theory of collapse or subsidence along fault voids is unsound. He suggested that the fault may have aided indirectly in the cave-in by permitting surface water to descend underground and gain access to underlying chalk, causing subsequent solution in the Niobrara Formation.

Flint Hills Sinkholes.—Hay (1896) described numerous sinkholes on upland areas of the Flint Hills in the Fort Riley Military Reservation, Riley County. Although not large, deep, nor spectacular, they are described here because they are representative of the common upland type in Kansas.

These sinkholes range in diameter from 30 to 50 feet and in depth from 8 to 10 feet. All are roughly circular or oval in shape. Hay counted as many as 42 individual sinkholes in 1 square mile. Most individual sinkholes do not retain water. One of the larger sinkholes in the area contains five smaller ones in its floor. Upland sinkholes on the Fort Riley Reservation have been formed by solution and subsidence of the Fort Riley Limestone, which lies near the surface in the region. The Fort Riley is readily soluble and exhibits well-defined jointing.

Similar sinkholes have been reported in Wabaunsee County by Savage (1881) and in Morris County by W. R. Atkinson (personal communication), Hay (1896), and Schoewe (1949). Small, circular, shallow sinkholes due to solution of the Fort Riley Limestone also occur in Cowley County (Bass, 1929) and Butler County (Fath, 1921).

Other Solution Features.—Commonly associated with sinkhole development in Kansas are caves, natural bridges, underground drainage, and soil cracks. These related features are prominent mainly in the western part of the state. For the most part they are small and do not form a major part of the physiography.

Lee and Payne (1944) described an interesting occurrence of cave deposits in Mississippian rocks found in the subsurface of the McLouth gas and oil field, in Jefferson and Leavenworth Counties. Pennsylvanian deposits occur in the caves, which were found at depths of as much as 150 feet below the top of the Mississippian.

Davis (1955) described in detail three small caves in the Stanton Limestone (Pennsylvanian) in Wilson and Montgomery Counties.

Caves, presumably in the Fort Riley Limestone (Permian), have been mentioned by Savage (1881) as occurring in Wabaunsee County. Stalactites and stalagmites occur in the caves. W. R. Atkinson (personal communication) reported the occurrence of caves in the Fort Riley Limestone in southwestern Morris County. Caves in this part of the geologic section are usually low and narrow but long.

Solution of gypsum in the Blaine Formation (Permian) has resulted in many small sinks, caves, and natural bridges in Barber and Comanche Counties. Caves in this area and adjoining portion of Oklahoma are commonly called "The Bat Caves." These caverns have been described in detail by Twente (1955). Grimsley and Bailey (1899) described a gypsum cave on Cave Creek, 4 miles west of Evansville, known as Big Gypsum cave. A stream entered from the west of the 100-foot cave and left by an east opening.

The largest and best known natural bridge in Kansas spanned Bear Creek at a point 7 miles south of Sun City in Barber County (Pl. 26C). The bridge, 12 feet high, 55 feet long, and 35 feet wide, collapsed late in 1961 (D. J. Malone, personal communication). Many other small natural bridges occur in this part of the state, but they are not as well known as the Sun City Natural Bridge. Such bridges have also formed by solution of Permian gypsum.

The absence of surface drainage courses may indicate subterranean water courses in soluble rocks. In the Bird City area in Cheyenne County, there is an absence of drainage channels. In western Kansas, White Woman Creek offers an excellent example of subsurface water drainage. The stream enters the state in Greeley County and flows east across Wichita County into western Scott County, where the surface water course disappears. No re-entry to the surface is known. The point at which the stream disappears is a short distance west of the Modoc Basin.

McLaughlin (1946) mentioned the area of the Bear Creek depression, where Bear Creek crosses the northwestern corner of Grant County. In places, drainage consists of a series of sinkholes and short intermittent streams, indicating underground water channels. In southern Kearny County, surface expression of the Bear Creek drainage ends abruptly. Many other small streams, especially in Wichita, Scott, Kearny, Finney, Grant, and Haskell Counties, flow for short distances on the surface and then disappear underground.

Appendix E—Earthquakes in Kansas

The following list of earthquakes is chronological and includes the location of the epicenter, wherever possible, by latitude and longitude. Intensities are based on the Modified Mercalli Intensity Scale of 1931, the scale used by the U.S. Coast and Geodetic Survey. If the intensity was given in another scale, the value has been converted to Mercalli units of I to XII; if no value was given in a reference, one is estimated. The sources of information are listed at the end of this appendix and are cited in the descriptions by number. An asterisk indicates that the epicenter was in Kansas.

1811, December 16.—(36.6° N, 89.6° W; X.) The epicenter was near New Madrid, Missouri, and the earthquake affected at least 2,000,000 square miles. This was the first of three severe shocks and numerous minor ones in the area. The three earthquakes were probably the most catastrophic ever recorded in the central region of the United States. (4, 7)

1812, January 23.—Same as December 16, 1811. (4, 7)

1812, February 7.—Same as December 16, 1811, and January 23, 1812. (4, 7)

•*1867, April 24.*—(39.5° N, 96.7° W; VIII.) The epicenter was located near Manhattan, Kansas. It was felt over an area of 300,000 square miles in Kansas, Nebraska, Missouri, Illinois, Indiana, and possibly Ohio. Several persons were injured, though not seriously. People rushed into the streets; buildings swayed; clocks stopped; animals were alarmed in the fields; a heavy wave about 2 feet high was observed in Kansas River at Manhattan; stones from buildings were loosened; the walls of many buildings cracked; windows and glassware were shaken; objects were thrown from shelves; a train stopped and the engineer and fireman got out, thinking the boiler was going to blow up. A low rumbling sound accompanied the vibrations. At different places there seemed to be either one or two ground waves. The shock, which occurred at about 2:45 p.m., lasted 10 to 30 seconds. Topeka, Manhattan, Lawrence, Junction City, Atchison, and Solomon, in Kansas; Omaha, Nebraska; St. Louis, Missouri, reported effects of the earthquake; and it may have been felt in Carthage, Ohio. (4, 7, 8, 18, 19, 20, 21, 31, 32)

•*1875, November 8.*—(39.3° N, 95.5° W; V.) The epicenter was near Valley Falls, Kansas, and the earthquake was felt over an area of about 8,000 square miles. Dishes rattled; windows shook; people were awakened; some buildings rocked or quivered; the shock was felt in the Capitol at Topeka. Two shocks, which lasted about one minute each, were felt in Lawrence, Kansas, between 4:30 and 5:00 a.m. The earthquake was also felt in Leavenworth, Manhattan, and Burlingame, Kansas, and in western Missouri. (4, 7, 21, 23)

1877, November 15.—(41° N, 97° W; VII.) The epicenter was in eastern Nebraska but the shock was also felt in Iowa, Kansas, the Dakotas, and northwestern Missouri; the total area affected was about 140,000 square miles. There were two shocks, one at 11:45 a.m. and the other at 12:30 p.m., causing buildings to sway and people to run into the streets at Atchison, Kansas. The earthquake was also felt in the Kansas communities of Lawrence, Topeka, and Kansas City. (4, 7, 21, 31; *Topeka Journal*, July 6, 1927; *Arkansas City Traveler*, May 1, 1925)

1878, November 18.—(36.7° N, 90.4° W; VII.) The epicenter was located in southeast Missouri and the disturbance was felt over an area of 150,000 square miles. At 11:15 p.m. a slight shock was felt at Leavenworth, Kansas. (4, 9)

•*1881, May 19.*—(I or II.) A slight shock was felt at Lawrence, Kansas, about 9:00 a.m. (24)

1882, October 22.—(35° N, 94° W; VII-VIII.) The epicenter was in Arkansas but the earthquake was felt over an area of 135,000 square miles, including eastern Kansas, at about 4:15 p.m. (4, 7)

1895, October 31.—(37° N, 89.4° W; VIII-IX.) Charleston, Missouri, was in the epicentral area of an earthquake that affected about 1,000,000 square miles and was felt in 23 states. People were awakened and houses shook in Topeka, Kansas. It was also felt in the Kansas communities of Pittsburg, Emporia, Florence, Clay Center, Lawrence, Wamego, Manhattan, Holton, Fort Scott, Leavenworth, Hiawatha, and Kansas City. Dishes and windows rattled; buildings rocked and trembled; and water spilled from vessels. There were three shocks, accompanied by rumbling, at about 5:15 a.m. (4, 7, 21; *Arkansas City Traveler*, May 1, 1925)

•*1897, December 2.*—(III.) Windows, doors, and dishes rattled in Kansas City, Missouri, at 1:10 p.m. The earthquake was most noticeable in Westport, Missouri. (7)

1902, January 24.—(38.6° N, 90.3° W; VI-VII.) The epicenter was in Missouri. The earthquake, which affected about 40,000 square miles, was felt at about 4:48 a.m. at Leavenworth, Kansas, at Beverly, Missouri, and in the Kansas City area. (4, 7)

•*1904, October 27.*—(37.7° N, 100° W; V.) The earthquake was felt over 2,700 square miles. Three shocks awakened sleeping persons and rattled dishes at Meade and Dodge City, in Kansas. (4)

•*1906, January 7.*—(39.3° N, 96.6° W; VII-VIII.) The epicenter was at Manhattan, Kansas, and the shock affected about 10,000 square miles. At about 6:20 p.m. the earthquake, accompanied by a roaring sound, shook Topeka, Kansas. Houses and buildings vibrated; dishes and windows rattled; water in glasses showed motion. Two shocks occurred at Wamego, Oskaloosa, and Herington, in Kansas; three shocks were felt at the Union Pacific Hotel in Topeka. Auburn and Dover were also affected. Ground motion was observed at Manhattan, where chimneys toppled, people fled their houses, and plaster cracked; Abilene and Marysville rocked; a slight shock was felt at Wichita, Emporia, Junction City, Alma, Beloit, and Kansas City. Other areas affected included Nebraska and western Missouri. The shock lasted about 23 seconds. (4, 7, 21; *Topeka Journal* [?]; *Arkansas City Traveler*, May 1, 1925)

•*1906, January 23.*—(II-III.) A slight shock occurred at Manhattan, Kansas, at about 8:00 a.m. This was one of a series of small aftershocks of the January 7 earthquake. (7)

1909, September 27.—(39° N, 87.7° W; VIII.) The earthquake's epicenter was in Indiana but it was felt in Kansas City, Missouri, and possibly a little farther west, in Kansas. (4)

1917, April 9.—(38.1° N, 90.6° W; VI.) The epicentral area was in eastern Missouri, but the earthquake affected more than 200,000 square miles, including eastern Kansas; it occurred at about 2:52 p.m. One shock was felt in Lawrence, Kansas, where it was recorded on the seismograph as having an intensity of II. (4, 7, 10)

•*1919, May 26.*—(IV.) A shock that lasted for 4 seconds was felt in Wichita, Kansas, at 9:06 p.m. (7; *Arkansas City Traveler*, May 1, 1925)

•*1919, July 26.*—(37.7° N, 97.3° W; III.) At Wichita one shock was felt at 5:00 a.m. and another at 7:55 a.m. The second was stronger and was preceded by a loud rumbling. (7, 11; *Arkansas City Traveler*, May 1, 1925)

1925, July 30.—(35.4° N, 101.3° W; VI.) Southwestern Kansas was affected by an earthquake, the epicenter of which was in the Panhandle of Texas. There was a tremor for 3 minutes at Pratt, Kansas, at 6:15 a.m.; at Liberal, Kansas, bells on locomotives rang and heavy furniture moved slightly; at Medicine Lodge, Kansas, windows shook for 15 minutes. It was also felt at Wichita, Elkhart, and Leavenworth, in Kansas, and was recorded on the seismograph at Lawrence, Kansas. (4, 7, 25; *Kansas City Star*, July 30, 1925)

**1927, January 7.*—(IV.) The epicenter seemingly was at McPherson, Kansas, where a shock was felt at about 3:30 a.m. Some sleepers were awakened; dishes rattled; and the keystone in the frame of a bank window fell out. There were deep rumbling sounds. (7)

**1927, March 19.*—(40° N, 95.3° W;V.) The shock was centered at White Cloud, Kansas, where people ran out of houses that rocked. The shock was felt over approximately 300 square miles, at about 11:25 a.m. (4)

**1928, November 8.*—(39.5° N, 98.1° W; I or II?) At Beloit, Kansas, dishes and windows rattled at the Industrial School. The earthquake was not reported elsewhere. (5)

**1929, September 23.*—(39° N, 96.6° W; V.) The epicenter was in the vicinity of Manhattan, Kansas; there were two shocks, the second of which was the stronger. Over an area of 3,500 square miles houses shook and windows and dishes rattled. The trembling was felt in an area of 15,000 square miles, including Wakefield, Wheaton, Eskridge, Concordia, and LeRoy, in Kansas. The shocks occurred at about 4:00 and 5:00 a.m. (4, 6, 7, 26)

**1929, October 21.*—(39.2° N, 96.5° W; V.) The epicenter was near Junction City, Kansas. There was no damage, but windows and cooking utensils rattled, to an accompaniment of sounds like thunder. The earthquake was felt about 3:30 p.m., over an area of about 8,000 square miles, including Manhattan, McFarland, Council Grove, Concordia, Chapman, Clay Center, Emmett, Wamego, and St. George, in Kansas. It was also recorded by the seismograph at Lawrence, Kansas. (4, 6, 7, 27)

**1929, October 23.*—(39° N, 96.8° W; II or III?) A slight tremor was felt at Junction City, Kansas. (6, 7)

**1929, November 26.*—(37.2° N, 99.7° W; IV or V.) A shock was felt at Ashland, Kansas, about 10:20 p.m. (6, 7)

**1929, December 7.*—(39.2° N, 96.5° W; V.) The earthquake was felt in the central area of the October 21 shock, over about 1,000 square miles. At Manhattan, Kansas, windows rattled and buildings shook; many people were awakened, but there was no damage. Elsewhere in Kansas it was felt at Council Grove, Wamego, McFarland, Junction City, and it was recorded at Florissant at 2:02 a.m. (4, 6, 7)

**1931, August 9.*—(IV?) Three shocks occurred in Kansas City, Missouri; the epicenter was probably near Turner, Kansas. The shocks were at 12:18 a.m., 1:07 a.m., and 1:15 a.m. At Kansas City dishes rattled and pictures swung. The earthquake was also felt at Overland Park, Merriam, and Bonner Springs, in Kansas, and at Leeds, Missouri. (7, 14, 28)

**1932, January 28.*—(III?) An earthquake shook Ellis and Trego Counties in Kansas at 6:15 p.m. Windows were shattered in farmhouses 15 miles north of Ellis, Kansas. (*Topeka Capital*, January 29, 1932)

**1933, February 20.*—(39.8° N, 99.8° W; V.) A shock was felt over about 6,000 square miles in Norton and Decatur Counties, in Kansas, and Furnas and Harlan Counties, in Nebraska, at about 11:00 a.m. Buildings and houses swayed; dishes and windows rattled; people ran out of their houses; no damage was reported. The earthquake was also felt at Oronoque and Norcatur, in Kansas. (4, 15)

1935, March 1.—(40.3° N, 96.2° W; VI to VII.) There were two shocks about 4 minutes apart at 5:00 a.m., the first strong and the second weak. They were felt in Nebraska, Iowa, Kansas, and Missouri, in an area of about 50,000 square miles. The epicenter was near Tecumseh, Nebraska, where some windows were broken; chimneys cracked and some toppled; plaster and stone walls cracked. (4, 7, 16)

1936, June 19.—(35.8° N, 101.3° W; VI.) The earthquake was felt at about 9:24 p.m. over an area of about 40,000 square miles and was centered northeast of Amarillo, in the Texas Panhandle. In Elkhart, Kansas, objects were displaced and there was slight damage to buildings. It was also felt in Liberal, Sublette, and Ulysses, in Kansas. (4, 17)

1939, November 23.—(38.2° N, 90.1° W; V.) The epicenter was near Griggs, Illinois, but the earthquake was felt about 9:15 a.m., over an area of 150,000 square miles, including Chanute, Fort Riley, Junction City, Ottawa, and Pittsburg, in Kansas. (1, 4)

**1942, September 10.*—(III?) A slight tremor was felt about 4:00 a.m. at Hays, Stockton, and Plainville, in Kansas. It was strong enough to awaken some sleepers in Hays. (2, 29)

1948, March 11.—(36° N, 102.5° W; VI.) An earthquake centered northwest of Amarillo, Texas, was felt over about 50,000 square miles in Colorado, Kansas, Oklahoma, New Mexico, and Texas. It was felt in Kansas at Elkhart and Larned (intensity V), and also, but with less intensity, in Satanta, Syracuse, Johnson, and Rolla. (13)

**1948, April 2.*—(III.) Six tremors were felt in the Beechwood area about 5 miles east of Wichita, Kansas, between 9:00 and 10:00 p.m. There were ripples of water in goldfish bowls, and walls in a housing project trembled. (13)

1952, April 9.—(35.4° N, 97.8° W; VII.) The epicenter was about 5 miles southwest of Oklahoma City, Oklahoma. The earthquake was felt over an area of 140,000 square miles. At Kansas City and Medicine Lodge, in Kansas, the intensity was V; it was also strongly felt at Concordia, Hutchinson, Iola, Junction City, Lawrence, Lindsborg, McPherson, Topeka, Wichita, and Winfield, in Kansas; most of eastern Kansas was affected. (12)

**1956, January 6.*—(37.15° N, 98.45° W; V.) The epicenter was in Barber County near Coats, Kansas. It occurred a few minutes before 6:00 a.m. and was felt over an area of about 18,500 square miles. Its estimated duration was about 9 seconds; a noise was reported by most people to be accompanying the quake. Several walls were damaged in Coats, and desks rattled violently. Windows and dishes shook in Pratt, Kansas, and people were awakened. The tremor was also reported in Coldwater, Hardtner, and Kiowa, in Kansas, and in Alva, Oklahoma. (3, 30)

**1961, April 13.*—(northwest of Norton; III or IV.) The mild quake occurred at 3:15 p.m. It was felt over an area about 35 miles in diameter—including Norton, Norcatur, and Almena, in Kansas, and Arapahoe and Beaver City, in Nebraska. Eleven miles north of Norton it was felt at the Dry Creek School. A rumbling noise was reported with the shock; windows and buildings shook, and desks rattled, but no damage was reported. The depth to hypocenter was estimated to be 20 to 50 miles. (22)

1961, December 25.—(approximately 39.3° N, 94.2° W; IV; and 39.1° N, 94.6° W, and 39.4° N, 94.2° W; V.) Two shocks, at 6:20 a.m. and 7:00 a.m., were felt in northwestern Missouri and northeastern Kansas in an area with a radius of about 70 miles. The first shock was perceptible over approximately 8,300 square miles and strongest in Ray and Clay Counties, Missouri. The second shock was felt over an area of about 9,745 square miles; there were two small areas of maximum intensity, one centered around Kansas City and the other around Lawson, Missouri. Noises were associated with the earthquakes and were described as jets crashing the sound barrier, explosions, roars, thunder, blasting, etc. People were awakened in Lawson, Liberty, Kearney, Excelsior Springs, and Kansas City, in Missouri, as well as in Kansas City, Kansas. There were reports that plaster cracked, dishes and windows rattled, Christmas tree ornaments shook, furniture vibrated, and a 4-inch water main broke. Depth of focus was 20 to 30 km; no relation to a major geologic structure was established. (Information from Dellwig and Gerhard, 1962.)

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Appendix F—Wells Used in Construction of Cross Sections

Figure 3

1.	Deep Rock No. 1 Clark	SW	SW	SW	sec. 23,	T. 1 S.,	R. 42 W.
2.	Ohio No. 1 Rose	NE	NE	NE	sec. 35,	T. 1 S.,	R. 40 W.
3.	Brack No. 1 "B" Judy	NW	SE	NW	sec. 26,	T. 1 S.,	R. 39 W.
4.	Ashland No. 1 Kacirek	NE	SE	SW	sec. 8,	T. 2 S.,	R. 36 W.
5.	Stanolind No. 1 Cahoj		SW	NE	sec. 20,	T. 1 S.,	R. 34 W.
6.	Musgrove No. 1 Mines	SE	SE	SW	sec. 11,	T. 2 S.,	R. 30 W.
7.	Helmerich & Payne No. 1 Sauvage	NE	NE	NE	sec. 3,	T. 1 S.,	R. 27 W.
8.	Empire No. 1 Tansill	NW	NE	NE	sec. 26,	T. 1 S.,	R. 24 W.
9.	Jones, Shelbourne, & Farmer No. 1 Gramzow	NE	NE	SW	sec. 10,	T. 1 S.,	R. 22 W.
10.	B & R No. 1 Richards	NW	NW	SW	sec. 24,	T. 1 S.,	R. 19 W.
11.	Black Cat No. 1 Bjurstram	SE	SE	SE	sec. 7,	T. 1 S.,	R. 18 W.
12.	Musgrove No. 1 Jackson	SW	SW	NE	sec. 21,	T. 1 S.,	R. 16 W.
13.	Snowden No. 1 Lull	C	SW	NW	sec. 5,	T. 3 S.,	R. 11 W.
14.	National Assoc. No. 1 Roe	NE	NE	NE	sec. 19,	T. 1 S.,	R. 7 W.
15.	Gulf No. 1 Baker	NW	SE	SE	sec. 1,	T. 1 S.,	R. 2 E.
16.	Davon No. 1 Schaeffer	NW	NW	SW	sec. 20,	T. 1 S.,	R. 6 E.
17.	Groge No. 1 Suggett?	NW	SW	NW	sec. 34,	T. 2 S.,	R. 8 E.
18.	Texas No. 1 Murdock	SE	SE	SW	sec. 16,	T. 2 S.,	R. 13 E.
19.	Carter No. 1 Strahm	NW	SW	NW	sec. 13,	T. 2 S.,	R. 14 E.
20.	Davon No. 1 Yost	SE	SW	NE	sec. 33,	T. 1 S.,	R. 16 E.
21.	Curtis et al. No. 1 Fraser	NW	NW	NW	sec. 14,	T. 2 S.,	R. 19 E.
22.	Plymate-Barnholdt No. 1 Elliot	CSL	SE	SW	sec. 31,	T. 3 S.,	R. 20 E.

Figure 4

1.	Van Grisso No. 1 Golden	SE	SE	SE	sec. 24,	T. 10 S.,	R. 42 W.
2.	Kingwood & Aurora No. 1 Rauckmann	SE	SE	NE	sec. 11,	T. 8 S.,	R. 40 W.
3.	Texas No. 1 McArthur	SE	NE	SW	sec. 18,	T. 8 S.,	R. 36 W.
4.	Derby & Van Grisso No. 1 Schielke	NW	NW	NW	sec. 17,	T. 8 S.,	R. 34 W.
5.	Virginia No. 1 Cooper	NE	NE	NE	sec. 12,	T. 7 S.,	R. 33 W.
6.	Ashland No. 1 Misner	NE	NE	NE	sec. 33,	T. 8 S.,	R. 32 W.
7.	Anderson & Strain No. 1 Moss	SW	SW	NE	sec. 2,	T. 8 S.,	R. 30 W.
8.	Pratt No. 1 Cooper	SW	SW	SE	sec. 25,	T. 8 S.,	R. 29 W.
9.	Heathman-Seeligson No. 1 "A" Brown	NW	NW	NW	sec. 26,	T. 8 S.,	R. 27 W.
10.	NCRA No. 1 Teagarden	NE	NW	SE	sec. 10,	T. 7 S.,	R. 26 W.
11.	Herndon No. 1 Clubb	NW	NW	NE	sec. 32,	T. 7 S.,	R. 24 W.
12.	Keating No. 1 School	SE	SE	SE	sec. 33,	T. 7 S.,	R. 21 W.
13.	Deep Rock No. 1 Schoeller	NE	SE	NW	sec. 32,	T. 7 S.,	R. 19 W.
14.	Lindas No. 1 Maddy	NE	NW	SW	sec. 36,	T. 7 S.,	R. 18 W.
15.	Anderson-Prichard No. 1 Stephanson	NE	NE	SE	sec. 32,	T. 7 S.,	R. 15 W.
16.	Mid-Kan No. 1 Boyce	SE	SE	NW	sec. 18,	T. 6 S.,	R. 13 W.
17.	Texas Pacific No. 1 Gasper	SW	NW	SW	sec. 31,	T. 7 S.,	R. 10 W.
18.	Murfin No. 1 Wessling	SE	SE	NE	sec. 35,	T. 6 S.,	R. 7 W.
19.	Murfin No. 1 Stillwell	NW	SW	NW	sec. 12,	T. 6 S.,	R. 6 W.
20.	Shawver-Armour No. 1 Daniels	NE	NE	NE	sec. 32,	T. 6 S.,	R. 5 W.
21.	Stanolind No. 1 Campbell	SW	NW	NW	sec. 26,	T. 6 S.,	R. 2 W.
22.	Brack No. 1 Erickson	NE	NE	NW	sec. 15,	T. 7 S.,	R. 5 E.
23.	Allman et al. No. 1 Fredrich	NW	NW	NW	sec. 20,	T. 9 S.,	R. 8 E.
24.	Amerada No. 1 Mertz	SW	SW	NE	sec. 6,	T. 11 S.,	R. 10 E.
25.	Adkins & Appleman No. 1 McLaughlin	SE	SE	SE	sec. 26,	T. 10 S.,	R. 11 E.
26.	Skelly No. 1 St. Mary's	NE	SW	NE	sec. 11,	T. 10 S.,	R. 12 E.
27.	McKnab No. 1 Fritz	SW	SE	NW	sec. 4,	T. 12 S.,	R. 14 E.
28.	Smith No. 1 Smith	SW	SW	SE	sec. 28,	T. 12 S.,	R. 19 E.
29.	Kasper No. 1 James	CNL	NE	NW	sec. 8,	T. 13 S.,	R. 25 E.

Figure 5

1.	Cities Service No. 1 "B" Greenwood	NE	NE	NW	sec. 14,	T. 33 S.,	R. 42 W.
2.	Hugoton Prod. No. 2-12 Panoma	NE	NW	SE	sec. 12,	T. 31 S.,	R. 38 W.
3.	Socony-Mobil No. 1 Cutter	C	SW	SE	sec. 1,	T. 31 S.,	R. 35 W.
4.	Columbian Fuel No. 1 Novinger	C	NW	NW	sec. 26,	T. 33 S.,	R. 30 W.
5.	Northern Natural No. 1 Collingwood	SW	SW	NE	sec. 8,	T. 32 S.,	R. 27 W.
6.	Shell No. 1 Statton	SE	SE	NW	sec. 12,	T. 30 S.,	R. 25 W.
7.	Texas No. 1 Moore	NW	NW	SW	sec. 25,	T. 31 S.,	R. 22 W.
8.	Aladdin No. 1 Herd	C	SW	NE	sec. 25,	T. 32 S.,	R. 19 W.
9.	Huber No. 1 Einsel	SW	NW	NW	sec. 11,	T. 33 S.,	R. 17 W.
10.	Anschutz No. 1 Mills	C	NE	SE	sec. 5,	T. 33 S.,	R. 14 W.
11.	Skelly No. 1 "E" Boggs	NW	NW	SW	sec. 2,	T. 33 S.,	R. 12 W.
12.	Shaw No. 1 McReynolds	NW	NE	SW	sec. 29,	T. 31 S.,	R. 10 W.

13. Phillips No. 1 Rago	NW	NW	NW	sec. 15, T. 30 S., R. 7 W.
14. Aladdin No. 1 John	NE	NE	SW	sec. 34, T. 31 S., R. 4 W.
15. Brack & NCRA No. 1 Dennison	S2	S2	SE	sec. 10, T. 31 S., R. 2 W.
16. Alpine No. 1 Lonnberg	SW	SW	NW	sec. 14, T. 31 S., R. 1 W.
17. Aladdin No. 1 Bellman	NE	NE	SW	sec. 15, T. 30 S., R. 1 E.
18. Wixson et al. No. 1 Newton	SE	SE	SE	sec. 21, T. 30 S., R. 2 E.
19. Vickers No. 1 Daniels	NE	NE	NW	sec. 33, T. 30 S., R. 3 E.
20. Champlin No. 1 Bevis	SE	SE	SW	sec. 13, T. 30 S., R. 3 E.
21. Brinn No. 1 Hughes	NW	NW	SW	sec. 20, T. 31 S., R. 4 E.
22. Vickers No. 1 Swoyer	NE	SE	SE	sec. 3, T. 31 S., R. 5 E.
23. Hull-Elmerdale No. 1 Fuller		C	N2	sec. 32, T. 31 S., R. 7 E.
24. Marland No. 1 Hiatt	SW	SW	NE	sec. 8, T. 31 S., R. 8 E.
25. Smith and Ash No. 1 Miller	SE	SW	NE	sec. 16, T. 31 S., R. 9 E.
26. Diller No. 2 Hull	NE	NE	SE	sec. 26, T. 31 S., R. 10 E.
27. Gas No. 2 McBee				sec. 29, T. 31 S., R. 13 E.
28. New England No. 1 Evans	SW	SW	SE	sec. 27, T. 31 S., R. 16 E.
29. Finley No. 1 Gill	NE	NW	NE	sec. 14, T. 31 S., R. 18 E.
30. Labette No. 1 Bradford	SW	SW	NE	sec. 5, T. 31 S., R. 19 E.
31. Glore No. 1 Wert	C	NE	SE	sec. 17, T. 31 S., R. 21 E.
32. Kaney No. 4 Herrington	NW	NW	NW	sec. 20, T. 30 S., R. 22 E.
33. Lasalle No. 1 Gobl	SE	SE	NW	sec. 20, T. 28 S., R. 25 E.

Figure 8

1.		SE	SW	sec. 32, T. 20 S., R. 34 W.	(Waite, 1947, p. 187)
2.	NW	NW	NW	sec. 26, T. 20 S., R. 36 W.	(Prescott, Branch, and Wilson, 1954, p. 124)
3.	SE	SE	SE	sec. 29, T. 20 S., R. 38 W.	(Prescott, Branch, and Wilson, 1954, p. 125)
4.	NW	NW	NW	sec. 30, T. 19 S., R. 39 W.	(Prescott, Branch, and Wilson, 1954, p. 119)
5.	NW	SW	NW	sec. 21, T. 18 S., R. 40 W.	(Prescott, Branch, and Wilson, 1954, p. 113)
6.		NW	cor.	sec. 22, T. 17 S., R. 41 W.	(Prescott, Branch, and Wilson, 1954, p. 102)
7.		NW	cor.	sec. 19, T. 16 S., R. 42 W.	(Prescott, Branch, and Wilson, 1954, p. 98)
8.		SE	SE	sec. 23, T. 15 S., R. 41 W.	(Drilled by Federal and State Geological Surveys, Ground-Water Division)
9.	NE	NW	NW	sec. 11, T. 15 S., R. 40 W.	(Drilled by Federal and State Geological Surveys, Ground-Water Division)
10.		SE	SE	sec. 8, T. 14 S., R. 38 W.	Surface section measured by M. K. Elias (1931, pl. 32)
11.		SE	SE	sec. 10, T. 13 S., R. 42 W.	Surface section measured by M. K. Elias (1931, pl. 32)
12.	SW	SW	SW	sec. 36, T. 10 S., R. 42 W.	(Prescott, 1953b, p. 124)
13.	SW	SW	SW	sec. 31, T. 9 S., R. 39 W.	(Prescott, 1953b, p. 114)
14.	NE	NE	NE	sec. 1, T. 9 S., R. 39 W.	(Prescott, 1953b, p. 113)
15.	NE	NE	NE	sec. 1, T. 8 S., R. 39 W.	(Prescott, 1953b, p. 103)
16.	SE	SE	SE	sec. 36, T. 6 S., R. 40 W.	(Prescott, 1953b, p. 92)
17.	NE	NE	NE	sec. 1, T. 6 S., R. 40 W.	(Prescott, 1953b, p. 91)
18.	SW	SW	SW	sec. 33, T. 4 S., R. 38 W.	(Prescott, 1953a, p. 91)
19.	SE	SE	SE	sec. 32, T. 3 S., R. 38 W.	(Prescott, 1953a, p. 87)
20.	NW	NW	NW	sec. 4, T. 3 S., R. 38 W.	(Prescott, 1953a, p. 86)

Figure 12

1. Ohio No. 1 Rose	NE	NE	NE	sec. 35, T. 1 S., R. 40 W.
2. Ashland No. 1 Kacirek	NE	SE	SW	sec. 8, T. 2 S., R. 36 W.
3. Natural and Ashland No. 1 Lewis	SW	NW	NE	sec. 21, T. 3 S., R. 32 W.
4. Musgrove No. 1 Mines	SE	SE	SW	sec. 11, T. 2 S., R. 30 W.
5. Strain and Hall No. 1 Odle	NW	NW	SE	sec. 14, T. 2 S., R. 26 W.
6. Empire No. 1 Atens Estate	SE	SE	SW	sec. 6, T. 1 S., R. 22 W.
7. Texas No. 1 Baynes	SW	SW	NW	sec. 8, T. 2 S., R. 19 W.
8. Flynn No. 1 Willis	NE	NE	NE	sec. 8, T. 4 S., R. 16 W.
9. Snowden No. 1 Lull	C	SW	NW	sec. 5, T. 3 S., R. 11 W.
10. National Assoc. No. 1 Roe	NE	NE	NE	sec. 19, T. 1 S., R. 7 W.

11. Surface section measured by Plummer and Romary (1942, p. 331).

Figure 13

1. Ohio No. 1 Rose	NE	NE	NE	sec. 35, T. 1 S., R. 40 W.
2. Service No. 1 Beeson	NE	NE	NW	sec. 8, T. 3 S., R. 38 W.
3. Sinclair-Prairie No. 1 Robbins	SW	SW	NE	sec. 32, T. 4 S., R. 35 W.
4. Kelly and Weissbeck No. 1 Thomas	NE	NE	NW	sec. 30, T. 7 S., R. 32 W.
5. Anschutz No. 1 Gassman	SE	SE	SE	sec. 28, T. 10 S., R. 29 W.
6. Globe No. 1 Snyder	SE	SE	SE	sec. 8, T. 14 S., R. 29 W.
7. Cooperative No. 1 "A" McKinley	NE	NE	NE	sec. 19, T. 17 S., R. 24 W.
8. Chalmette No. 2 Bowman	SE	SW	SE	sec. 30, T. 19 S., R. 25 W.
9. Phillips No. 1 Houseman	NW	NE	NE	sec. 30, T. 22 S., R. 22 W.
10. Northern Natural No. 1 Bierwagen	C	SE	NW	sec. 10, T. 26 S., R. 21 W.

11. Surface section measured by Bruce F. Latta (1948).

Figure 14

1.	Ohio No. 1 Rose	NE	NE	NE	sec. 35,	T. 1 S.,	R. 40 W.
2.	Falcon-Seaboard No. 1 Zweygardt	SE	SE	SW	sec. 1,	T. 3 S.,	R. 41 W.
3.	Texas No. 1 Walz	SW	NW	NE	sec. 3,	T. 5 S.,	R. 42 W.
4.	Bigsby and McKubbin No. 1 Hill	C	SW	SE	sec. 36,	T. 11 S.,	R. 42 W.
5.	United Producing No. 1 Hiebert	C	NW	NW	sec. 5,	T. 17 S.,	R. 42 W.
6.	B & R No. 1 Darbro	SW	SW	NE	sec. 32,	T. 20 S.,	R. 38 W.
7.	Woodward No. 1 Buck	SE	SE	NW	sec. 15,	T. 23 S.,	R. 39 W.
8.	Superior No. 1 "A" Tucker	SE	SW	SE	sec. 4,	T. 29 S.,	R. 42 W.
9.	Cities Service No. 1 "A" Boehm	NE	NE	NW	sec. 11,	T. 33 S.,	R. 42 W.

Figure 20

1.	Ohio No. 1 Cruise	NW	SW	SE	sec. 7,	T. 14 N.,	R. 49 W.
2.	Ohio No. 1 Fender	NW	NW	SW	sec. 2,	T. 14 N.,	R. 48 W.
3.	Cope et al. No. 1 Schwartz	NE	NE	NW	sec. 32,	T. 13 N.,	R. 44 W.
4.	Ohio No. 1 Sejkora	NW	NW	SE	sec. 23,	T. 10 N.,	R. 39 W.
5.	Lion No. 1 Earl	C	NE	NE	sec. 1,	T. 4 N.,	R. 41 W.
6.	Ohio No. 1 Rose	NE	NE	NE	sec. 35,	T. 1 S.,	R. 40 W.
7.	Sinclair-Prairie No. 1 Robbins	SW	SW	NE	sec. 32,	T. 4 S.,	R. 35 W.
8.	Kelly & Weissbeck No. 1 Thomas	NE	NE	NW	sec. 30,	T. 7 S.,	R. 32 W.

Figure 28

1.	Ohio No. 1 Rose	NE	NE	NE	sec. 35,	T. 1 S.,	R. 40 W.
2.	Service No. 1 Beeson	NE	NE	NW	sec. 8,	T. 3 S.,	R. 38 W.
3.	Stanolind No. 1 Mullen		SW	SE	sec. 14,	T. 4 S.,	R. 35 W.
4.	Texas No. 1 Federal Land	SW	NE	SW	sec. 7,	T. 8 S.,	R. 35 W.
5.	Wycoff No. 1 Chase	NE	NE	SE	sec. 1,	T. 9 S.,	R. 33 W.
6.	Texas No. 1 Meeks	SE	SE	SW	sec. 36,	T. 8 S.,	R. 31 W.
7.	Prime No. 1 Fallow	SE	SE	NE	sec. 19,	T. 10 S.,	R. 27 W.
8.	Anschutz No. 1 Bollig	SW	SW	SW	sec. 28,	T. 9 S.,	R. 25 W.
9.	Shields No. 1 Belveal	E2	SE	NE	sec. 9,	T. 8 S.,	R. 24 W.
10.	Keating No. 1 Kirtley	NE	NW	SW	sec. 4,	T. 8 S.,	R. 21 W.
11.	Keating No. 1 School	SE	SE	SE	sec. 33,	T. 7 S.,	R. 21 W.

Figure 33

1.	Ohio No. 1 Rose	NE	NE	NE	sec. 35,	T. 1 S.,	R. 40 W.
2.	Natural No. 1 Lewis	SW	NW	NE	sec. 21,	T. 3 S.,	R. 32 W.
3.	Sinclair-Prairie No. 1 Bremer	NW	NW	SE	sec. 28,	T. 4 S.,	R. 28 W.
4.	Kornfeld No. 1 Zohner	SW	SW	SW	sec. 10,	T. 7 S.,	R. 24 W.
5.	Keating No. 1 School	SE	SE	SE	sec. 33,	T. 7 S.,	R. 21 W.
6.	Lewis No. 1 Moore	SE	SE	NE	sec. 10,	T. 7 S.,	R. 17 W.
7.	Westgate-Greenland No. 1 Dean	SW	SW	SW	sec. 5,	T. 8 S.,	R. 14 W.
8.	Texas Pacific No. 1 Gasper	SW	NW	SW	sec. 31,	T. 7 S.,	R. 10 W.
9.	Carter No. 2 Exploration	SE	SE	SW	sec. 20,	T. 9 S.,	R. 7 W.
10.	Stanolind No. 1 Equitable Life	NE	NW	SE	sec. 17,	T. 12 S.,	R. 1 E.

Figure 34

1.	Sinclair-Prairie No. 1 Bremer	NW	NW	SE	sec. 28,	T. 4 S.,	R. 28 W.
2.	Union No. 1 Pratt	NW	NE	SW	sec. 23,	T. 8 S.,	R. 26 W.
3.	Empire & NCRA No. 1 Knoll	NE	NE	NE	sec. 16,	T. 10 S.,	R. 25 W.
4.	Deep Rock No. 1 Nicholson	SW	SW	SW	sec. 29,	T. 13 S.,	R. 22 W.
5.	Bay No. 2 Everett	SE	SE	NE	sec. 7,	T. 18 S.,	R. 25 W.
6.	Metropolitan No. 1 O'Brien	C	NW	NE	sec. 18,	T. 21 S.,	R. 25 W.
7.	Atlantic No. 1 Hall	C	NW	SE	sec. 36,	T. 23 S.,	R. 22 W.
8.	Broderick & Gorden No. 1 Smith	C	NE	SE	sec. 17,	T. 24 S.,	R. 20 W.

Figure 36

1.	Cities Service No. 1 "A" Boehm	NE	NE	NW	sec. 11,	T. 33 S.,	R. 42 W.
2.	Huber No. 1 Sparks		C	NE	sec. 34,	T. 30 S.,	R. 42 W.
3.	Huber No. 1 Hoopingarner		C	NE	sec. 21,	T. 30 S.,	R. 42 W.
4.	Huber No. 1 Kilgore	C	NE	NW	sec. 5,	T. 30 S.,	R. 42 W.
5.	Superior No. 1 "A" Tucker	SE	SW	SE	sec. 4,	T. 29 S.,	R. 42 W.
6.	Huber No. 1 Walkemeyer	C	NE	SW	sec. 22,	T. 28 S.,	R. 42 W.
7.	Musgrove No. 1 Bray	NW	NW	NW	sec. 26,	T. 25 S.,	R. 41 W.
8.	Carter No. 1 Overton	NE	NE	SW	sec. 24,	T. 24 S.,	R. 41 W.
9.	United Producing No. 1 Staerkel	C	SE	SE	sec. 14,	T. 22 S.,	R. 41 W.
10.	B & R No. 1 Darbro	SW	SW	NE	sec. 32,	T. 20 S.,	R. 38 W.
11.	Van Grisso No. 1 Clift	C	SW	SW	sec. 9,	T. 19 S.,	R. 40 W.
12.	Caulker No. 1 Brunswig	C	NW	SW	sec. 6,	T. 18 S.,	R. 39 W.

Figure 38

1. United Producing No. 1 Helfrich .... C SE SE sec. 6, T. 25 S., R. 42 W.
2. Carter No. 1 Overton .... NE NE SW sec. 24, T. 24 S., R. 41 W.
3. Woodward No. 1 Buck .... SE SE NW sec. 15, T. 23 S., R. 39 W.
4. Trans-Era No. 1 "C" Miller .... NE NE NE sec. 23, T. 22 S., R. 37 W.
5. Hartman No. 1 Damme .... SE SE NW sec. 21, T. 22 S., R. 33 W.
6. Carter No. 1 Russell .... NE NW NW sec. 22, T. 22 S., R. 31 W.
7. Texaco No. 1 Davis .... C SW NE sec. 3, T. 23 S., R. 30 W.

Figure 39

MEASURED SURFACE SECTIONS (from Merriam, 1957a)

1. SW cor. sec. 21, T. 27 S., R. 6 W.
2. SE SW sec. 21, T. 25 S., R. 6 W.
3. NW cor. sec. 22, T. 25 S., R. 7 W.
4. SW SE sec. 9, T. 22 S., R. 6 W.
5. SW NW sec. 11, T. 20 S., R. 6 W.

Figure 41

1. Superior No. 1 "A" Tucker .... SE SW SE sec. 4, T. 29 S., R. 42 W.
2. Stanolind No. 1 Toohey .... C sec. 24, T. 29 S., R. 40 W.
3. Sinclair-Prairie No. 1 Bittiker-Keller .... SW SW NE sec. 18, T. 29 S., R. 36 W.
4. Texas No. 1 Tanner .... C sec. 36, T. 29 S., R. 34 W.
5. Skelly No. 1 Hull .... SW SW NE sec. 1, T. 29 S., R. 32 W.
6. Texas No. 1 Weatherbee .... SW SW SW sec. 17, T. 29 S., R. 26 W.
7. Texas No. 1 Andrews .... NW NW SW sec. 17, T. 29 S., R. 23 W.
8. Rine-Roberts-Murphy No. 1 Hertlein .... SE SE NW sec. 5, T. 29 S., R. 13 W.

Figure 44

1. Stanolind No. 1 Equitable Life .... NE NW SE sec. 17, T. 12 S., R. 1 E.
2. Continental No. 1 Howie .... SW SW NE sec. 10, T. 15 S., R. 1 E.
3. Rex and Morris No. 1 Rock .... SE SE NE sec. 22, T. 15 S., R. 3 E.
4. Sohio No. 1 Hopwaning .... SW SW NW sec. 29, T. 15 S., R. 5 E.
5. Gold No. 1 Nelson .... C SE SW sec. 6, T. 15 S., R. 7 E.
6. Champlin No. 1 Schruben .... NW SW SW sec. 5, T. 15 S., R. 9 E.
7. Carter No. 1 Wheat .... NW SE NE sec. 10, T. 15 S., R. 11 E.
8. White and Ellis No. 1 Miller .... SW SW NE sec. 1, T. 16 S., R. 12 E.
9. Smith and Cameron No. 1 Vanderslice .... NW NW SW sec. 31, T. 17 S., R. 16 E.
10. Schermerhorn No. 2 Johanning .... E2 NW NE sec. 17, T. 15 S., R. 19 E.

Figure 47

1. Ohio No. 1 Rose .... NE NE NE sec. 35, T. 1 S., R. 40 W.
2. Brack No. 1 "B" Judy .... NW SE NW sec. 26, T. 1 S., R. 39 W.
3. Ashland No. 1 Kacirek .... NE SE SW sec. 8, T. 2 S., R. 36 W.
4. Stanolind No. 1 Cahoj .... SW NE sec. 20, T. 1 S., R. 34 W.
5. Skelly No. 1 Wicke .... C SW SW sec. 16, T. 1 S., R. 32 W.
6. Musgrove No. 1 Mines .... SE SE SW sec. 11, T. 2 S., R. 30 W.
7. Great Basins No. 1 Huff .... SE SE NE sec. 15, T. 1 S., R. 27 W.
8. Great Lakes Carbon No. 1 Minshall .... SE SE SE sec. 35, T. 1 S., R. 23 W.
9. Peters No. 1 Skelton .... NW NE NW sec. 20, T. 1 S., R. 19 W.
10. Musgrove No. 1 Jackson .... SW SW NE sec. 21, T. 1 S., R. 16 W.
11. Lasky No. 1 Habiger .... SE SE SW sec. 34, T. 2 S., R. 11 W.
12. National Associated No. 1 Roe .... NE NE NE sec. 19, T. 1 S., R. 7 W.

Figure 52

1. Sinclair-Prairie No. 1 Mercer .... NE NE NW sec. 28, T. 10 S., R. 40 W.
2. Texas No. 1 Dougherty .... NW SW SW sec. 23, T. 6 S., R. 33 W.
3. Musgrove No. 1 Mines .... SE SE SW sec. 11, T. 2 S., R. 30 W.
4. H & T Drilling No. 1 Harold .... SW SW SW sec. 11, T. 6 S., R. 28 W.
5. Cities Service No. 1 Blazier .... NE SW SE sec. 21, T. 7 S., R. 25 W.
6. Davis & Child No. 1 Scott .... NE NE NW sec. 7, T. 7 S., R. 22 W.
7. Lewis No. 1 Moore .... SE SE NE sec. 10, T. 7 S., R. 17 W.
8. Westgate-Greenland No. 1 Dean .... SW SW SW sec. 5, T. 8 S., R. 14 W.
9. Carter No. 2 Exploration .... SE SE SW sec. 20, T. 9 S., R. 7 W.
10. Stanolind No. 1 Equitable Life .... NE NW SE sec. 17, T. 12 S., R. 1 E.

Figure 53

1. Rine No. 1 Crissman .... NW NW NE sec. 34, T. 12 S., R. 18 W.
2. Sohio No. 5 "A" Rusch .... SE SW SW sec. 19, T. 12 S., R. 15 W.
3. Northern Ordnance No. 1 Colliver .... C NE NE sec. 29, T. 12 S., R. 12 W.
4. National Associated No. 1 Pistoria .... SE NW SW sec. 22, T. 13 S., R. 5 W.
5. Auto Ordnance No. 1 Gekler .... NW NW NW sec. 20, T. 12 S., R. 2 W.
6. Stanolind No. 1 Equitable Life .... NE NW SE sec. 17, T. 12 S., R. 1 E.

7.	Carter No. 1 Meseke	SE	SE	NE	sec. 29, T. 12 S., R. 9 E.
8.	Landon and Waugh No. 1 Martin	SE	SE	NE	sec. 34, T. 13 S., R. 12 E.

9. Composite surface sections from central Douglas County.

Figure 54

1.		SE	sec. 3, T. 24 S., R. 13 E.
2.	SE	NE	sec. 25, T. 20 S., R. 14 E.
3.		C	sec. 31, T. 18 S., R. 16 E.
4.		NW	sec. 6, T. 18 S., R. 16 E.
5.		SW	sec. 11, T. 17 S., R. 16 E.
6.		NW	sec. 4, T. 14 S., R. 17 E.
7.	SW	NW	sec. 36, T. 11 S., R. 17 E.

Figure 56

1.	Shell No. 1 Johnson	SE	NE	NE	sec. 15, T. 20 S., R. 11 E.
2.	Cities Service No. 1 Baldwin	SE	SE	SE	sec. 11, T. 19 S., R. 10 E.
3.	Huber No. 1 Ball	NW	SW	NW	sec. 23, T. 18 S., R. 10 E.
4.	Shell No. 1 Hagins	SE	NW	NE	sec. 13, T. 17 S., R. 11 E.
5.	White and Ellis No. 1 Miller	SW	SW	NE	sec. 1, T. 16 S., R. 12 E.
6.	Phillips et al. No. 1 McKnight	NE	NE	SW	sec. 16, T. 14 S., R. 12 E.
7.	Woods No. 1 Oberle	SW	SW	NW	sec. 14, T. 14 S., R. 15 E.
8.	Lynn No. 1 Blake	SE	SE	NW	sec. 15, T. 13 S., R. 16 E.
9.	Lynn No. 1 Warner	SW	SE	NW	sec. 5, T. 13 S., R. 17 E.
10.	Skelly No. 1 Middlekauff	SW	NE	NE	sec. 21, T. 13 S., R. 19 E.

Figure 59

MEASURED SURFACE SECTIONS (Kansas Geological Survey files).

1.			SE	sec. 30, T. 34 S., R. 15 E.
2.			NE	sec. 5, T. 33 S., R. 15 E.
3.			SE	sec. 15, T. 32 S., R. 14 E.
			SW	sec. 26, T. 32 S., R. 14 E.
4.			N2	sec. 26, T. 30 S., R. 15 E.
5.			E2	sec. 24, T. 29 S., R. 14 E.
6.			SE	sec. 12, T. 29 S., R. 15 E.
7.			SW	sec. 14, T. 28 S., R. 16 E.
8.	SE	SW	NE	sec. 14, T. 28 S., R. 16 E.
			W2	sec. 8, T. 28 S., R. 17 E.
9.			N2	sec. 7, T. 20 S., R. 19 E.
			SE	sec. 12, T. 20 S., R. 18 E.
10.			N2	sec. 24, T. 17 S., R. 20 E.
11.		NE	SE	sec. 28, T. 14 S., R. 20 E.
			SW	sec. 26, T. 16 S., R. 21 E.
12.		SW	NW	sec. 12, T. 14 S., R. 22 E.
13.			SE	sec. 3, T. 13 S., R. 21 E.
14.			NE	sec. 28, T. 11 S., R. 23 E.
15.			C	sec. 6, T. 11 S., R. 23 E.
16.			NE	sec. 36, T. 10 S., R. 23 E.
17.			NW	sec. 31, T. 9 S., R. 23 E.

Figure 61

1.	Yarnell No. 1 Lyon	NW	NW	SW	sec. 30, T. 34 S., R. 5 E.
2.	Bishop and Atlantic No. 1 Cook	SW	SW	SE	sec. 27, T. 32 S., R. 5 E.
3.	Adair and Lee Phillips No. 1 Sandstrum	NW	SE	SW	sec. 15, T. 30 S., R. 5 E.
4.	Magnolia No. 3 North Fox Bush	SE	NE	SE	sec. 23, T. 28 S., R. 5 E.
5.	National Associated No. 1 "A" Falkenburg	SE	SE	NW	sec. 18, T. 26 S., R. 6 E.
6.	Allied Materials No. 1 Ruckert	SE	SW	NE	sec. 15, T. 24 S., R. 6 E.
7.	Amerada No. 1 Lostutter	NE	NE	NE	sec. 1, T. 20 S., R. 7 E.
8.	Sohio No. 1 Hopwaning	SW	SW	NW	sec. 29, T. 15 S., R. 5 E.
9.	Stanolind No. 1 Equitable Life	NE	NW	SE	sec. 17, T. 12 S., R. 1 E.

Figure 67

MEASURED SURFACE SECTIONS

1.		SW	sec. 5, T. 35 S., R. 20 E.
2.	NE	SW	sec. 9, T. 34 S., R. 20 E.
3.		NW	sec. 19, T. 33 S., R. 21 E.
4.	NW	NE	sec. 13, T. 32 S., R. 21 E.
5.		SE	sec. 24, T. 30 S., R. 22 E.
6.		N2	sec. 19, T. 29 S., R. 24 E.
7.		NW	sec. 11, T. 28 S., R. 25 E.
	NW	SW	sec. 5, T. 28 S., R. 25 E.
8.		N2	sec. 20, T. 25 S., R. 25 E.
9.	NW	NE	sec. 33, T. 23 S., R. 25 E.

Figure 69

CROSS SECTION A-A′

1.	? No. 1 McFadden	—	—	—	sec. 12, T. 34 S., R. 14 E.
2.	Cavert No. 9 Dobson			NE	sec. 5, T. 34 S., R. 15 E.
3.	? No. 3 Clark		SW	NE	sec. 33, T. 33 S., R. 15 E.
4.	Empire ?	—	—	—	sec. 24, T. 33 S., R. 15 E.
5.	Cardwell et al. No. 1 Pennington	NW	SW	SE	sec. 3, T. 33 S., R. 16 E.
6.	? No. 1 Hopkins		SE	NE	sec. 29, T. 32 S., R. 17 E.
7.	? No. 1 Dodds	—	—	—	sec. 19, T. 32 S., R. 17 E.

CROSS SECTION B-B′

1.	? No. 1 Gadle	—	—	—	sec. 14, T. 26 S., R. 18 E.
2.	? No. 14 Diamond	—	—	—	sec. 16, T. 26 S., R. 19 E.
3.	Speelman No. 1? Olson	—	—	—	sec. 7, T. 26 S., R. 20 E.
4.	Prairie Western et al. No. 4 Fry	NW	SW	NW	sec. 8, T. 26 S., R. 20 E.
5.	Iola Portland Cement No. 1 Nelson	—	—	—	sec. 5, T. 26 S., R. 21 E.
6.	Fees & Hoyt No. 19 Brandenburg	SW	SW	SW	sec. 10, T. 26 S., R. 21 E.
7.	? No. 1 Daniels	C	NE	NW	sec. 18, T. 26 S., R. 22 E.

Figure 70

1.	Stanolind No. 1 Patterson	CEL	SE	SE	sec. 23, T. 22 S., R. 38 W.
2.	Atlantic No. 1 Thornbrough	NW	SE	NW	sec. 16, T. 21 S., R. 35 W.
3.	Shallow Water No. 1 Lockman	SE	SE	SE	sec. 22, T. 21 S., R. 34 W.
4.	Alpine No. 1 Landgraf	SW	SW	SE	sec. 27, T. 21 S., R. 32 W.
5.	B & R No. 1 Drees	NW	NW	SE	sec. 31, T. 21 S., R. 30 W.
6.	Cities Service No. 1 "B" Murphy	NE	NE	SE	sec. 16, T. 20 S., R. 28 W.
7.	Wedell and Levan No. 1 Pemeler	SE	SE	SE	sec. 3, T. 19 S., R. 26 W.
8.	Franco-Central No. 1 "A" Weeks	NE	NE	NW	sec. 31, T. 17 S., R. 24 W.
9.	Welch & Olsson No. 1 Turner	NW	NW	NE	sec. 12, T. 16 S., R. 23 W.
10.	Sunray Midcontinent No. 2 McMamee	SE	NW	NE	sec. 36, T. 16 S., R. 21 W.
11.	Anschutz No. 1 Seelye	NW	SW	SE	sec. 3, T. 16 S., R. 19 W.
12.	Flynn No. 1 Klaus	NE	NE	SW	sec. 19, T. 15 S., R. 18 W.

Figure 71

1.	Sunray Midcontinent No. 2 McMamee	SE	NW	NE	sec. 36, T. 16 S., R. 21 W.
2.	B & R No. 1 Bott	SW	SW	NE	sec. 11, T. 18 S., R. 20 W.
3.	Cities Service No. 2 Jennings	SE	SE	SE	sec. 12, T. 20 S., R. 20 W.
4.	Continental No. 1 Osgood	NE	NE	NE	sec. 14, T. 22 S., R. 19 W.
5.	Bay No. 1 Fischer	NW	NE	NW	sec. 26, T. 23 S., R. 17 W.
6.	Lauck No. 1 Johnson	NE	NE	SW	sec. 1, T. 25 S., R. 17 W.
7.	Texas No. 1 Mitchell	NW	NE	NE	sec. 2, T. 27 S., R. 18 W.
8.	Huber et al. No. 1 Cullins	NW	NW	SE	sec. 20, T. 28 S., R. 17 W.
9.	GMR No. 1 Piester	SW	SW	NW	sec. 24, T. 29 S., R. 16 W.
10.	Johnson No. 1 Robbins Ranch	NW	NW	SE	sec. 15, T. 31 S., R. 16 W.
11.	Sohio and Musgrove No. 1 Angell	SE	SE	SE	sec. 11, T. 33 S., R. 14 W.
12.	Atlantic No. 1 "A" Cook	NE	NW	SW	sec. 17, T. 34 S., R. 12 W.
13.	Aurora No. 1 Platt	C	NE	SE	sec. 6, T. 35 S., R. 12 W.

Figure 77

CROSS SECTION X-X′

1.	Texas No. 1 Schmidt	NE	SW	SW	sec. 31, T. 20 S., R. 3 E.
2.	Prairie No. 1 McLinden	SE	NW	NW	sec. 25, T. 20 S., R. 5 E.
3.	Martin No. 1 Winsor	SW	SW	NW	sec. 2, T. 20 S., R. 6 E.
4.	Forrester No. 1 Prather	NE	SE	NE	sec. 7, T. 20 S., R. 7 E.
5.	Vickers No. 1 Nicoll	SW	SW	NW	sec. 16, T. 20 S., R. 7 E.
6.	Aladdin et al. No. 1 Drummond	SE	SE	SW	sec. 15, T. 20 S., R. 7 E.
7.	Security No. 1 Allison	SW	SW	NW	sec. 20, T. 20 S., R. 8 E.
8.	Morrison et al. No. 1 Norton	SW	SW	SE	sec. 36, T. 20 S., R. 8 E.
9.	Shell No. 1 Johnson	SE	NE	NE	sec. 15, T. 20 S., R. 11 E.
10.	Stanolind No. 1 Butler	SE	SE	SW	sec. 1, T. 21 S., R. 13 E.
11.	Cramm et al. No. 1 Allen	SE	NE	SE	sec. 13, T. 21 S., R. 15 E.
12.	Orlando No. 1 Snider		NW	NW	sec. 21, T. 21 S., R. 16 E.
13.	Brundred No. 1 Louk	NE	NE	NW	sec. 2, T. 21 S., R. 19 E.
14.	Brundred No. 1 Bowman disposal			NE	sec. 6, T. 21 S., R. 20 E.
15.	? No. 1 Cook	SE	SE	NW	sec. 4, T. 22 S., R. 24 E.

CROSS SECTION Y-Y′

1.	Wixson et al. No. 1 Newton	SE	SE	SE	sec. 21, T. 30 S., R. 2 E.
2.	Vickers No. 1 Daniels	NE	NE	NW	sec. 3, T. 30 S., R. 3 E.
3.	Champlin No. 1 Bevis	SE	SE	SW	sec. 13, T. 30 S., R. 3 E.
4.	Brinn No. 1 Hughes	NW	NW	SW	sec. 20, T. 31 S., R. 4 E.
5.	Vickers No. 1 Swoyer	NE	SE	SE	sec. 3, T. 31 S., R. 5 E.

6.	Hull-Elmerdale No. 1 Fuller		C	N2	sec. 32, T. 31 S., R. 7 E.
7.	Marland No. 1 Hiatt	SW	SW	NE	sec. 8, T. 31 S., R. 8 E.
8.	Smith and Ash No. 1 Miller	SE	SW	NE	sec. 16, T. 31 S., R. 9 E.
9.	Diller No. 2 Hull	NE	NE	SE	sec. 26, T. 31 S., R. 10 E.
10.	Gas No. 2 McBee	—	—	—	sec. 29, T. 31 S., R. 13 E.
11.	New England No. 1 Evans	SW	SW	SE	sec. 27, T. 31 S., R. 16 E.
12.	Finley No. 1 Gill	NE	NW	NE	sec. 14, T. 31 S., R. 18 E.
13.	Labette No. 1 Bradford		SW	NE	sec. 5, T. 31 S., R. 19 E.
14.	Glore No. 1 Wert	C	NE	SE	sec. 16, T. 31 S., R. 21 E.
15.	Kaney No. 4 Herrington	NW	NW	NW	sec. 20, T. 30 S., R. 22 E.

CROSS SECTION Z-Z′

1.	Anderson No. 1 Gramse		SE	SE	sec. 4, T. 11 S., R. 18 E.
2.	Smith et al. No. 1 Smith	SW	SW	SE	sec. 28, T. 12 S., R. 19 E.
3.	Landsprecht and Baker No. 1 Griffin	C	NW	SE	sec. 4, T. 14 S., R. 18 E.
4.	Cities Service No. 1 Dilworth	NW	NW	SW	sec. 7, T. 15 S., R. 17 E.
5.	Smith & Cameron No. 1 Vanderslice	NW	NW	SW	sec. 31, T. 17 S., R. 16 E.
6.	? No. 1 Warren			S2?	sec. 32, T. 19 S., R. 17 E.
7.	Brundred (Harrington & Cooper No. 2) No. 1 Louk	NE	NE	NW	sec. 2, T. 21 S., R. 19 E.
8.	? No. 1 Brecheisen	SE	NW	SW	sec. 14, T. 22 S., R. 19 E.
9.	? No. 2 O'Hara	NE	SW	SE	sec. 5, T. 23 S., R. 19 E.
10.	? No. 1 Anderson		SW	SW	sec. 23, T. 25 S., R. 20 E.
11.	Wangler et al. No. 1 Dahl			NW	sec. 25, T. 26 S., R. 20 E.
12.	Missionary Institute No. 1 St. Francis Pass		S2	SE	sec. 13, T. 29 S., R. 20 E.
13.	Kaney No. 4 Herrington	NW	NW	NW	sec. 20, T. 30 S., R. 22 E.

Figure 83

1.	Empire No. 1 Gray	SW	SE	SE	sec. 27, T. 3 S., R. 25 W.
2.	Trans-Era No. 1 Humphry	N2	NE	NE	sec. 25, T. 3 S., R. 25 W.
3.	Jones, Shelburne, & Farmer No. 1 Ankenman	SW	SW	SE	sec. 29, T. 3 S., R. 24 W.
4.	Jones, Shelburne, & Farmer No. 1 Brown	SW	SW	SW	sec. 27, T. 3 S., R. 24 W.
5.	Empire No. 1 Davis	SE	SE	SW	sec. 26, T. 3 S., R. 24 W.
6.	Jones, Shelburne, & Farmer No. 1 Gooder	NE	NE	NE	sec. 23, T. 3 S., R. 24 W.
7.	Gore No. 1 Snyder	NE	NE	NW	sec. 9, T. 3 S., R. 23 W.
8.	Great Lakes Carbon No. 1 Muir	NW	NW	SW	sec. 12, T. 3 S., R. 23 W.

Figure 86

1.	Kimmel No. 3 George	C	SE	NW	sec. 5, T. 24 S., R. 17 E.
2.	Brant-Sarber No. 1 Trout	SW	NW	SW	sec. 4, T. 24 S., R. 17 E.
3.	? No. 1 Murphy	SW	SW	SE	sec. 8, T. 24 S., R. 17 E.
4.	Southern Kansas No. 8 Harris	SW	SW	SW	sec. 8, T. 24 S., R. 17 E.
5.	? No. 4 Jackson	C	NE	NE	sec. 18, T. 24 S., R. 17 E.
6.	McLoud No. 1 Habinger	C	SE	NE	sec. 19, T. 24 S., R. 17 E.

Figure 106

1.	Amerada No. 1 Reitmeyer	SW	SW	SW	sec. 17, T. 12 S., R. 20 W.
2.	Texas No. 1 Hamburg	NE	SE	SW	sec. 3, T. 12 S., R. 20 W.
3.	Transit No. 1 Hamburg	SE	SE	SW	sec. 34, T. 11 S., R. 20 W.
4.	C & G No. 1 Waldschmidt	NE	NE	NE	sec. 35, T. 11 S., R. 20 W.

Appendix G—Road Logs

Road logs are available for various parts of Kansas, especially from the Kansas Geological Society. The following logs (Fig. 147), most of which were prepared for Kansas Geological Society field conferences, are in many ways general enough that they can be used along with a geologic map of the state as a guide for the traveler. Mr. C. K. Bayne, Dr. L. F. Dellwig, Dr. J. M. Jewett, Mr. W. S. Johns, Mr. W. D. Johnson Jr., Mr. Charles Lane, Mr. B. F. Latta, Dr. R. C. Moore, Mr. H. G. O'Connor, Mr. G. F. Stewart, and Dr. Ada Swineford helped prepare and check the logs.

Kansas Turnpike—Kansas City to South Haven

Milepost	*Tenths*	
0		18th Street Expressway, Kansas City, Kansas
	0.2	Drum Limestone underlain by Cherryvale Shale
1		
	0.2	K 32 overpass
	0.4	Loess on Lane Shale on north
	0.9	Lane Shale-Iola Limestone on both sides of road
2		
	0.4	Wyandotte Limestone on Lane Shale
	0.7	View of Kansas River
3		Iola Limestone on both sides of road
	0.1	Drum Limestone on north
	0.4	Overpass
	0.8	Loess on both sides of road
	0.9	61st Street underpass (Bridge 303)
4		
	0.4	65th Street underpass
	0.5	Pleistocene on Lane Shale
	0.7	Loess on both sides of road
5		US 40 Interchange underpass (Bridge 300-A)
	0.3	Argentine Limestone on north
	0.4	72nd Street underpass (Bridge 300)
	0.5	Farley Limestone on north
	0.6	Farley Limestone on both sides of road
	0.7	Kansas City Toll Station
6		
	0.1	Overpass
	0.7	Loess on Argentine Limestone below road on north
7		
	0.1	86th Street underpass
	0.2	Pleistocene on Bonner Springs Shale
	0.8	Plattsburg Limestone on Bonner Springs Shale
8		Vilas Shale to Stoner Limestone
	0.1	Bridge
	0.2	Bonner Springs Shale and Plattsburg Limestone
	0.4	Wyandotte Limestone to Plattsburg Limestone
	0.6	Overpass
	0.7	Farley Limestone on north
9		
	0.2	Plattsburg Limestone to Stoner Limestone on both sides of road
	0.3	Pleistocene on South Bend Limestone (Stanton Formation)
10		
	0.1	110th Street (K 107) underpass (Bridge 294)
	0.5	Tonganoxie Sandstone on north
	0.7	Pleistocene on Tonganoxie Sandstone
	0.8	Tonganoxie Sandstone on both sides of road

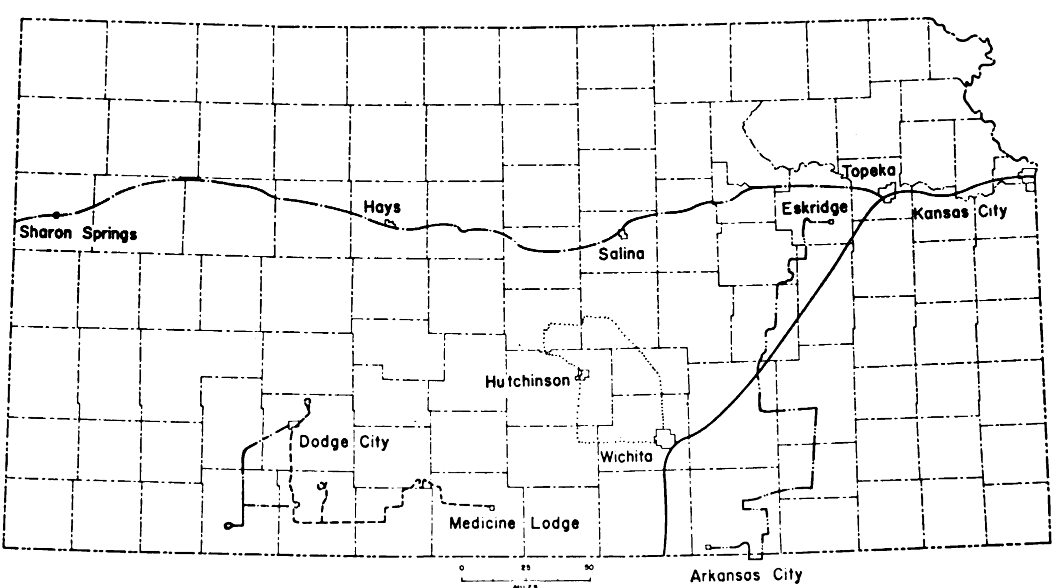

Figure 147.—Map of Kansas showing locations of selected road logs given in Appendix G.

11
0.1 Tonganoxie Sandstone on north
0.2 Overpass
0.3 Pleistocene on both sides of road
0.5 Tonganoxie Sandstone on both sides of road
0.8 Riverview Road underpass (Bridge 291)

12 South Bend Limestone in ditch on right
0.5 Bonner Springs Interchange (Bridge 290-A)
0.7 K 7 underpass (Bridge 290)

13
0.3 Overpass
0.4 Tonganoxie Sandstone on north
0.8 South Bend Limestone to Wyandotte Limestone

14
0.3 142nd Street underpass (Bridge 288)
0.6 Santa Fe Railroad overpass
0.7 Wolf Creek overpass

15
0.1 Kansas Avenue underpass
0.2 Bonner Springs Shale and Plattsburg Limestone
0.3 Bonner Springs Shale and Plattsburg Limestone
0.9 Tonganoxie Sandstone on both sides of road

16 Tonganoxie Sandstone on north
0.3 De Soto Road underpass (Bridge 284)

17
0.4 Underpass (Bridge 283)

18
0.4 Underpass (Bridge 282)

19
0.1 Pleistocene on Tonganoxie Sandstone
0.3 Underpass (Bridge 281)

20
0.2 Underpass (Bridge 279)
0.7 Stranger Creek overpass

21
0.7 Stoner Limestone on both sides of road
0.8 Tonganoxie Sandstone

22
0.3 Glacial drift
0.6 Underpass (Bridge 277)
0.7 Stranger Formation on north
0.9 Stranger Formation

23
0.2 Stranger Formation
0.5 Haskell Limestone Member on north
0.7 Underpass (Bridge 276)

24 Stranger Formation
0.6 Pleistocene on Stranger Formation
0.8 Eudora Road underpass (Bridge 275)

25 Sandstone in Stranger Formation
0.1 Massive sandstone in Stranger Formation
0.9 Bridge

26
0.3 Pleistocene on north
0.6 Sandy shale in Stranger Formation
0.9 Tonganoxie Sandstone

27
0.1 Haskell Limestone on north
0.3 Underpass
0.6 Lawrence Service Area

28
0.2 Underpass (Bridge 272)
0.7 Pleistocene on both sides of road

29
0.1 Stranger Formation
0.5 Stranger Formation on both sides of road

30
0.3 K 32 underpass (Bridge 270)
0.6 Mud Creek overpass
0.9 Union Pacific Railroad overpass

31 River floodplain and low terraces
0.8 Overpass

32
0.1 Sand pit on south
0.8 East Lawrence Interchange

33
0.3 US 40 and US 24 overpass
0.5 East end of Kansas River bridge
0.9 West end of Kansas River bridge

34
0.2 Union Pacific Railroad overpass
0.4 Michigan Street underpass
0.7 West Lawrence Interchange underpass (Bridge 261)
0.9 Country Club Road underpass (Bridge 260)

35
0.1 Oread Limestone scarp on south and ahead
0.9 Lakeview Alternate Road underpass (Bridge 259)

36
0.5 Road on Menoken terrace
0.9 Baldwin Creek bridge

37
0.7 Lawrence Shale and Oread Limestone on both sides of road. East end of exposure of Lawrence to Plattsmouth

38 Harrison Well Road underpass
0.1 Kereford Limestone
0.5 Oread Limestone
0.7 Plattsmouth Limestone

39
0.8 Lecompton Limestone

40 Kanwaka Road underpass (Bridge 256)
0.1 Lecompton Limestone
0.3 Lecompton Limestone on both sides of road
0.7 Lecompton Limestone

41
0.5 Tecumseh Shale and base of Deer Creek Limestone
0.7 Sandstone in Tecumseh Shale

42
0.1 Robert Steel Highway overpass
0.7 Upper part Tecumseh Shale and Deer Creek Limestone

43
0.1 Overpass
0.4 Upper Tecumseh Shale and lower Deer Creek Limestone
0.9 Deer Creek Limestone

44
0.1 Ervine Creek Limestone
0.2 Rock Bluff Limestone and Queen Hill Shale

45
0.1 Lecompton Alternate Road underpass (Bridge 250)

46
0.1 Topeka Limestone
0.4 Topeka Limestone

	0.6	Big Springs Road underpass (Bridge 249)
	0.8	Calhoun Shale
47		
	0.1	Bridge
	0.2	Upper Calhoun Shale and Topeka Limestone
	0.6	Pleistocene deposits on north
48		
	0.1	Upper Calhoun Shale and Topeka Limestone
	0.2	US 40 overpass
	0.7	Upper Calhoun Shale and Topeka Limestone
49		
	0.2	Miliken Road underpass (Bridge 246)
	0.3	Topeka Limestone
	0.6	Topeka Limestone
50		Calhoun Shale
	0.3	Ozawkie Limestone to Ervine Creek Limestone
	0.8	Rock Bluff Limestone to Ervine Creek Limestone
51		
	0.1	Calhoun Shale and Topeka Limestone
	0.2	Earl Hall Road underpass (Bridge 243)
	0.4	Ervine Creek Limestone
	0.7	Rock Bluff Limestone to Ervine Creek Limestone
52		
	0.1	Deer Creek Limestone
	0.3	Calhoun Shale on both sides of road
	0.4	Sandstone in Calhoun Shale
	0.7	Topeka Limestone on both sides of road
	0.8	Tecumseh Road underpass (Bridge 242)
	0.9	Calhoun Shale and Hartford Limestone
53		
	0.3	Ervine Creek Limestone
	0.7	Calhoun Shale and Topeka Limestone
	0.8	Topeka Service Area
54		
	0.3	Croco Road underpass (Bridge 241)
	0.9	East Topeka Interchange underpass (Bridge 240)
55		Topeka Limestone and upper Calhoun Shale
	0.1	Calhoun Shale
	0.4	Wittenberg Road underpass (Bridge 239)
56		
	0.1	29th Street underpass (Bridge 238)
	0.2	Topeka Limestone and Calhoun Shale
	0.4	Topeka Limestone
	0.6	Topeka Limestone
	0.9	Overpass
57		
	0.6	Overpass
58		
	0.1	Sandstone in White Cloud Shale
	0.3	Overpass
	0.7	Howard Limestone
59		Nodaway coal and Church Limestone
	0.2	US 75 and Santa Fe and Missouri Pacific Railroad overpass
	0.5	South Topeka Interchange underpass (Bridge 230)
60		
	0.1	White Cloud Shale
	0.2	Church Limestone
	0.5	Howard Limestone
	0.7	Glacial deposits
	0.8	Overpass (Bridge 228)
61		Nodaway coal to Utopia Limestone
	0.7	Burlingame Road underpass (Bridge 227)
62		
	0.1	White Cloud Shale
	0.6	White Cloud Shale
	0.8	Burlingame Limestone on both sides of road
63		Pauline Road overpass (Bridge 226)
	0.1	Burlingame Limestone
	0.4	Burlingame Limestone
	0.8	Happy Hollow Limestone to Rulo Limestone
64		
	0.1	Clark Road underpass (Bridge 224)
	0.3	White Cloud Shale
	0.9	Happy Hollow Limestone?
65		
	0.3	Wanamaker Road underpass (Bridge 223)
66		
	0.5	Burlingame Limestone
67		
	0.1	Auburn Road underpass (Bridge 220)
	0.8	Burlingame Limestone
68		
	0.3	Wakarusa Road underpass (Bridge 218)
	0.8	Wakarusa Creek overpass (Bridge 217)
69		
	0.2	Burlingame Limestone and Soldier Creek Shale
	0.5	Auburn-Osage Road underpass (Bridge 216)
	0.6	Limestone in Soldier Creek Shale
	0.7	Limestone in Soldier Creek Shale
70		
	0.6	Poor exposure of Reading Limestone
71		
	0.1	Elmont Limestone
	0.5	Elmont Limestone and Willard Shale
	0.8	Willard Shale to Maple Hill Limestone
72		Tarkio Limestone to Maple Hill Limestone
	0.4	Sandstone in Pillsbury Shale
	0.5	Sandstone in Pillsbury Shale (Bridge 215)
	0.8	Maple Hill Limestone
	0.9	Tarkio Limestone
73		
	0.1	Tarkio Limestone
	0.9	Prairie Center Road underpass (Bridge 213)
75		
	0.6	Tabor Road underpass (Bridge 211)
76		
	0.5	Switzler Road underpass (Bridge 210)
	0.7	Sandstone in Pillsbury Shale
77		Sandstone in Pillsbury Shale
	0.7	Underpass (Bridge 209)
	0.9	Dover Limestone
78		
	0.8	Dover Limestone overlying Pillsbury Shale
79		
	0.5	Santa Fe Railroad overpass (Bridge 207)
	0.6	Dragoon Creek bridge
	0.9	Dover Limestone and underlying shale
80		
	0.1	Underpass (Bridge 205)
	0.2	Dover Limestone
81		
	0.1	K 31 underpass (Bridge 204)
	0.3	Soldier Creek bridge
	0.7	Underpass (Bridge 202)

82
0.3 Underpass (Bridge 201)
83
0.3 Pillsbury Shale and Dover Limestone
0.5 Underpass (Bridge 200); sandstone in Pillsbury Shale
0.7 Sandstone in Pillsbury Shale overlain by Dover Limestone
84
0.9 Harveyville Road underpass (Bridge 197)
86
0.1 Underpass (Bridge 196)
88
0.1 Underpass (Bridge 194)
0.7 Marais des Cygnes River bridge; Maple Hill Limestone under bridge
89 Pillsbury Shale to Jim Creek Limestone
0.6 US 56 underpass (Bridge 192)
0.8 Admire Interchange (Bridge 192-A)
90
0.4 French Creek Shale and Grayhorse Limestone
91 Underpass (Bridge 190)
0.4 Missouri Pacific Railroad overpass
0.7 Dover Limestone
0.9 Underpass (Bridge 188)
92
0.5 Hundred and Fortytwo Mile Creek bridge
0.7 Dover Limestone and Pillsbury Shale
93
0.2 Underpass (Bridge 184)
0.5 Hill Creek bridge
0.7 Dry Shale and Grandhaven Limestone
94
0.5 Underpass (Bridge 182)
95
0.2 Nebraska City Limestone and underlying beds
0.9 Brownville Limestone and Grayhorse Limestone
96
0.3 K 99 underpass (Bridge 178)
97
0.1 Underpass (Bridge 177)
0.7 Falls City Limestone?
98
0.4 Underpass (Bridge 176)
99
0.1 Falls City Limestone
0.6 Underpass (Bridge 174)
100
0.9 Dows Creek bridge
101
0.7 K 99 underpass (Bridge 170)
103
0.7 K 99 underpass (Bridge 168)
104
0.4 Underpass (Bridge 167)
105 Emporia Service Area
0.5 Underpass (Bridge 166)
106
0.3 Allen Creek bridge
0.5 Missouri, Kansas, and Texas Railroad overpass (Bridge 163)
0.7 Troublesome Creek bridge
0.9 Underpass (Bridge 161)
107
0.5 Neosho River bridge
0.8 Nebraska City Limestone and adjacent beds

108
0.2 Underpass (Bridge 159)
0.5 Americus Road underpass (Bridge 158)
109
0.3 Underpass (Bridge 157)
0.7 Emporia Interchange underpass (Bridge 156)
0.9 US 50 overpass (Bridge 155)
110
0.5 Overpass
0.8 Santa Fe Railroad overpass
112 Cottonwood River bridge
113
0.5 Bridge
0.9 Wood Siding Formation
114
0.1 Bridge 146
0.2 Brownville Limestone
116
0.2 Pipe Township Road (Bridge 144)
0.4 Hamlin Shale
0.7 Hamlin Shale
117
0.1 Americus Limestone
0.2 Hughes Creek Shale
0.5 Red Eagle Limestone
0.7 Grenola Limestone
118
0.1 Red Eagle Limestone
0.2 Johnson Shale
0.4 Johnson Shale
0.7 Johnson Shale
0.8 Center Township Road (Bridge 140)
119
0.1 Upper Johnson Shale and lower Red Eagle Limestone
0.2 Howe Limestone
0.3 Lower Grenola Limestone
0.8 Burr Limestone
0.9 Legion Shale and Sallyards Limestone
120 Roca Shale
0.2 Red Eagle Limestone
0.7 Johnson Shale to Grenola Limestone
121
0.1 Neva Limestone
0.5 Cottonwood Limestone overlain by Florena Shale
0.9 Easly Creek Shale overlain by Crouse Limestone
122 Tea Pot Mound Road underpass (Bridge 138); Crouse Limestone overlain by Blue Rapids Shale
0.2 Blue Rapids Shale
0.6 Speiser Shale and Threemile Limestone
0.9 Funston Limestone and underlying Blue Rapids Shale
123
0.1 Crouse Limestone
0.5 Crouse Limestone
0.9 Bader Limestone and overlying Easly Creek Shale
124
0.3 Bader Limestone
0.7 Bader Limestone
0.9 Blue Rapids Shale to Speiser Shale on east side of road
125
0.2 Speiser Shale and Threemile Limestone
0.5 Threemile Limestone and Havensville Shale

	0.7	Havensville Shale and Schroyer Limestone
	0.8	Bazaar cattle crossing (Bridge 137)
126		
	0.1	Havensville Shale and Schroyer Limestone
	0.4	Havensville Shale
	0.6	Threemile Limestone
	0.8	Havensville Shale and Schroyer Limestone
127		
	0.7	Wymore Shale and overlying Kinney Limestone
128		
	0.4	Schroyer Limestone
	0.9	Schroyer Limestone
129		Schroyer Limestone
	0.6	Kinney Limestone
130		Florence Limestone
	0.2	Kinney Limestone
	0.6	Threemile Limestone and Speiser Shale
131		Funston Limestone
	0.3	Funston Limestone and Blue Rapids Shale
	0.4	Sharps Creek bridge
	0.7	Funston Limestone
132		Speiser Shale and overlying Threemile Limestone
	0.4	Matfield Green cattle crossing; Wymore Shale
	0.6	Schroyer Limestone
	0.8	Threemile Limestone and Speiser Shale
133		
	0.2	Funston Limestone and Speiser Shale
	0.4	Funston Limestone and Speiser Shale
134		
	0.4	Shaw Creek Road
	0.9	Little Cedar Creek Road underpass (Bridge 133)
135		Blue Rapids Shale
	0.3	Overpass
	0.5	Funston Limestone and Speiser Shale
	0.8	Wreford Limestone
136		
	0.1	Speiser Shale and Funston Limestone
	0.3	Funston Limestone
	0.4	Crouse Limestone
	0.6	Overpass
137		
	0.1	Underpass (Bridge 130)
	0.3	Blue Rapids Shale and Funston Limestone
	0.7	Speiser Shale and Threemile Limestone
138		
	0.2	Kinney Limestone
	0.3	Florence Limestone and underlying Matfield Shale
	0.7	Florence Limestone
	0.9	Florence Limestone
139		
	0.7	Matfield Green Service Area
140		
	0.8	Quarry in Fort Riley Limestone on west
141		
	0.3	Lower part of the Doyle Shale
142		
	0.6	Santa Fe Railroad overpass
144		
	0.3	K 13 underpass (Cassoday)
	0.8	Underpass
146		
	0.1	Harsh Road underpass
147		
	0.4	Oakdale Road underpass (Bridge 122)
148		
	0.1	Towanda Limestone
	0.8	Hursh Road underpass (Bridge 121)
149		
	0.5	Towanda Limestone
150		
	0.1	Underpass (Bridge 120)
	0.5	Fort Riley Limestone
151		
	0.4	Fort Riley Limestone
	0.5	Fort Riley Limestone
152		Fort Riley Limestone
	0.1	Ellis Road underpass (Bridge 119)
	0.4	Fort Riley Limestone
	0.6	Benson Road underpass (Bridge 118)
153		Upper part of Fort Riley Limestone
	0.3	Upper part of Fort Riley Limestone
	0.6	Quarry in Fort Riley Limestone on west
154		
	0.3	Fort Riley Limestone
	0.6	Holmesville Shale and Towanda Limestone
	0.9	Fort Riley Limestone
155		
	0.1	Bridge
	0.5	Chelsea Road underpass (Bridge 117)
	0.9	Bridge
156		
	0.5	Towanda Limestone
157		
	0.5	Putnam Road underpass (Bridge 114)
161		
	0.2	Upper part of Doyle Shale
	0.3	US 77 underpass (Bridge 112)
	0.5	Towanda Limestone
	0.7	Bridge
162		
	0.3	Bridge
	0.8	Winfield Limestone
163		
	0.1	Winfield Limestone
	0.5	Winfield Limestone
164		
	0.1	Oil Hill Road
	0.4	Bridge
165		Cresswell Limestone
	0.3	Bridge
	0.6	El Dorado Township Road underpass (Bridge 106)
166		
	0.1	El Dorado Interchange underpass (Bridge 104)
	0.3	K 196 underpass
	0.9	Underpass (Bridge 102)
168		
	0.2	Florence Limestone
	0.4	Kechi Road underpass (Bridge 100)
169		
	0.5	Cresswell Limestone
	0.8	Cresswell Limestone
	0.9	Underpass (Bridge 98)
171		
	0.1	Ohio Street underpass (Bridge 97)
	0.7	Cresswell Limestone
	0.8	Towanda Service Area
172		Cresswell Limestone
	0.2	Cresswell Limestone

	0.7	Lower part of Winfield Limestone and Gage Shale
	0.8	Towanda Road underpass (Bridge 95)
173		
	0.2	Whitewater River bridge
	0.9	Underpass (Bridge 92)
174		
	0.5	Winfield Limestone
175		
	0.1	Odell Shale
	0.4	Santa Fe Lake Road underpass (Bridge 90)
	0.7	Herington Limestone
176		
	0.6	29th Street underpass (Bridge 88)
177		
	0.4	Indianola Road underpass (Bridge 87)
178		
	0.3	Bridge
179		
	0.2	21st Street underpass
	0.9	162nd Street underpass (Bridge 84)
180		
	0.7	Bridge
181		
	0.1	160th Street underpass (Bridge 82)
	0.2	Main Street underpass (Bridge 81); Wellington Shale
	0.3	13th Street underpass; Wellington Shale
	0.4	Wellington Shale
182		
	0.2	159th Street underpass (Bridge 79)
183		
	0.2	Bridge
	0.4	143rd Street underpass (Bridge 76)
184		
	0.6	Wellington Shale
	0.7	127th Street underpass; Wellington Shale
	0.8	US 54 and Kellogg Road underpass (Bridge 74)
	0.9	Wellington Shale
185		
	0.8	Bridge
186		
	0.8	Webb Road underpass (Bridge 72)
187		
	0.1	East Wichita Interchange underpass (Bridge 71)
	0.9	Bridge
188		
	0.4	Bridge
189		Wellington Shale
	0.3	Bridge
	0.9	Bridge
190		
	0.6	Bridge
	0.8	Fees Avenue underpass (Bridge 61)
191		
	0.3	Hamilton Road underpass (Bridge 60)
	0.9	K 15 Interchange underpass (Bridge 59)
192		
	0.1	K 15 overpass
	0.2	Santa Fe Railroad overpass
	0.3	Arkansas River bridge
	0.5	Bridge
193		
	0.8	Bridge
194		
	0.2	Bridge
	0.6	South Wichita Interchange overpass
195		
	0.2	Bridge
196		
	0.2	Bridge
	0.6	Bridge
197		
	0.2	Haysville Road underpass (Bridge 45)
198		
	0.2	Derby Road underpass (Bridge 43)
199		
	0.2	Underpass (Bridge 42)
200		
	0.2	Waco Road underpass (Bridge 41)
201		
	0.2	Clearwater Road underpass (Bridge 40)
202		
	0.1	Bridge
	0.3	Underpass (Bridge 39)
203		
	0.3	Bridge
204		
	0.1	Underpass (Bridge 37)
205		
	0.1	Underpass (Bridge 36)
206		
	0.1	Underpass (Bridge 35)
	0.7	Terrace deposits
207		
	0.1	Underpass (Bridge 34)
	0.6	Bridge
208		
	0.1	Underpass (Bridge 32)
209		
	0.1	Bridge
	0.6	Sand dunes
	0.8	Ninnescah River bridge
210		
	0.1	Underpass (Bridge 30)
	0.3	Bridge
211		Wellington Service Area
	0.1	Underpass (Bridge 28)
	0.6	Wellington Shale
	0.9	Bridge
213		
	0.3	Underpass (Bridge 26)
214		
	0.4	Underpass (Bridge 25)
215		
	0.5	Underpass (Bridge 24)
216		
	0.5	Underpass (Bridge 23)
217		
	0.3	Wellington Shale
	0.5	South Haven Toll Station (Bridge 22)
	0.8	Wellington Shale
218		
	0.2	Bridge
	0.5	Bridge
219		
	0.5	Underpass (Bridge 19)
220		
	0.5	Underpass (Bridge 18)
221		
	0.6	Bridge
222		
	0.4	Wellington Shale
	0.5	Underpass (Bridge 16)
223		
	0.5	Underpass (Bridge 15)

225		
	0.5	Underpass (Bridge 13)
226		
	0.5	Underpass (Bridge 12)
227		
	0.2	Wellington Shale
228		
	0.5	Underpass (Bridge 10)
	0.9	Wellington Shale
230		
	0.5	Underpass (Bridge 8)
	0.6	Wellington Shale
231		
	0.4	Bridge
232		
	0.4	Bridge
	0.9	Wellington Shale
233		
	0.4	Wellington Shale
	0.6	Underpass (Bridge 4)
234		
	0.6	Underpass (Bridge 3)
235		
	0.6	Underpass (Bridge 2)
	0.7	Wellington Shale
	0.9	Wellington Shale
236		
	0.7	Oklahoma state line and underpass (Bridge 1)

I 70 and US 40—Topeka to Sharon Springs

Cumulative mileage	Mileage	
0.0	0.0	South Topeka Interchange, Kansas Turnpike, and I 470 and US 75 bypass
0.9	0.9	Burlingame overpass; Howard Limestone and Nodaway coal
2.5	1.6	Gage underpass
2.8	0.3	White Cloud Shale
3.3	0.5	29th Street underpass
4.4	1.1	Sandstone in White Cloud Shale
4.6	0.2	21st Street underpass
5.7	1.1	Wanamaker Road overpass
6.1	0.4	Bern Limestone underlain by Scranton Shale
7.2	1.1	I 70 and US 40 overpass
7.8	0.6	Silver Lake Shale overlain by Burlingame Limestone
8.8	1.0	Underpass
9.1	0.3	Auburn Road underpass
9.4	0.3	Auburn Shale and Emporia Limestone
10.0	0.6	Emporia Limestone
10.4	0.4	Bern Limestone overlying Scranton Shale
10.8	0.4	Blacksmith Creek bridge
11.0	0.2	Scranton Shale and overlying Bern Limestone
11.4	0.4	Mission Creek bridge
12.2	0.8	Valencia Road underpass
12.7	0.5	Auburn Shale
13.1	0.4	Zeandale Limestone and Willard Shale (below)
13.4	0.3	Tarkio Limestone on both sides of road
13.7	0.3	Tarkio Limestone underlain by Willard Shale
14.0	0.3	Upper part of Emporia Formation
14.1	0.1	Emporia Limestone and Auburn Shale on left
14.5	0.4	West Union Road underpass
14.8	0.3	Willard Shale overlain by Tarkio Limestone
15.5	0.7	Buffalo Mound ahead on skyline
16.0	0.5	Willard-Dover Road underpass
16.5	0.5	Zeandale Limestone
16.7	0.2	Tarkio Limestone
17.1	0.4	Dover Limestone on north side of road
17.3	0.2	Dover Limestone underlain by Pillsbury Shale
17.6	0.3	Dover Limestone on both sides of road
17.8	0.2	Dover Limestone on both sides of road
19.3	1.5	Stotler Limestone
19.9	0.6	Stotler Limestone
20.0	0.1	Stotler Limestone and Pillsbury Shale on both sides of road
20.4	0.4	Bridge
21.1	0.7	K 30 underpass
21.7	0.6	Brownville Limestone (Pennsylvanian) overlain by Towle Shale (Permian)
22.9	1.2	Falls City Limestone overlain by West Branch Shale
23.8	0.9	Aspinwall Limestone
24.1	0.3	Vera Road underpass
26.9	2.8	Bridge
27.5	0.6	Roadside park
28.3	0.8	Hughes Creek Shale exposure with Long Creek Limestone at top
28.5	0.2	Hamlin Shale overlain by Foraker Limestone
28.7	0.2	Mill Creek bridge
29.0	0.3	Rock Island Railroad overpass
29.2	0.2	K 138 overpass
29.6	0.4	Bridge
29.9	0.3	Chert gravel hills (buried Pleistocene valley) on north
31.8	1.9	Bridge
32.0	0.2	K 185 underpass
33.3	1.3	Rock Island Railroad overpass
33.5	0.2	Bridge
34.0	0.5	Grenola Limestone to Cottonwood Limestone
34.3	0.3	Cottonwood Limestone
34.5	0.2	K 99 overpass; Florena Shale and Morrill Limestone
35.4	0.9	Bader Limestone
35.9	0.5	Threemile Limestone and underlying Speiser Shale
36.3	0.4	Wreford Limestone and underlying Speiser Shale
36.5	0.2	Funston Limestone on south side of road
36.8	0.3	Funston Limestone, Blue Rapids Shale, Crouse Limestone, and Easly Creek Shale (below)
37.1	0.3	Crouse Limestone on both sides of road
37.3	0.2	Bader Limestone
37.5	0.2	Beattie Limestone
37.8	0.3	Cottonwood Limestone
38.3	0.5	Bridge
40.3	2.0	Funston Limestone on south
40.5	0.2	Wreford Limestone
40.9	0.4	Schroyer Limestone
42.3	1.4	Limestone in Havensville Shale above Threemile Limestone
42.9	0.6	Bader Limestone
43.6	0.7	Eskridge Shale
43.9	0.3	Bridge; Neva Limestone
45.0	1.1	Eskridge Shale overlain by Beattie Limestone
45.6	0.6	Eskridge Shale to Bader Limestone

45.8	0.2	Bridge
46.0	0.2	Bader Limestone
46.3	0.3	Funston Limestone, Speiser Shale, and lower part of Wreford Limestone
46.5	0.2	Wreford Limestone
46.7	0.2	Schroyer Limestone
46.9	0.2	Schroyer Limestone
47.4	0.5	Florence Limestone and underlying Matfield Shale
47.8	0.4	Florence Limestone
48.1	0.3	K 13 overpass
48.3	0.2	Florence Limestone and Matfield Shale
49.0	0.7	Florence Limestone
49.7	0.7	Wreford Limestone
50.4	0.7	Florence Limestone
51.9	1.5	Wreford Limestone
52.6	0.7	Kinney Limestone
53.0	0.4	McDowell Creek
54.5	1.5	Florence Limestone and Matfield Shale
55.2	0.7	Ft. Riley Limestone
56.2	1.0	Florence Limestone
57.1	0.9	Kinney Limestone?
57.7	0.6	Clark Creek
58.8	1.1	Ft. Riley Military Reservation; Wreford Limestone
59.1	0.3	Funston Limestone
60.4	1.3	Marshall Field underpass
62.2	1.8	Florence Limestone and underlying units
62.7	0.5	Smoky Hill River
63.5	0.8	Junction City; K 207 overpass
64.9	1.4	US 77 overpass
65.9	1.0	Roadside park
69.5	3.6	Ft. Riley-Milford Road bridge
70.6	1.1	Dickinson County
73.2	2.6	K 206 overpass
73.5	0.3	Winfield Limestone
77.6	4.1	Nolans Limestone
78.5	0.9	K 43 overpass
81.9	3.4	Buckeye Road underpass
83.4	1.5	Wellington Shale (poorly exposed)
84.4	1.0	K 15 overpass
87.1	2.7	Talmage underpass
93.3	6.2	K 221 underpass
93.8	0.5	Saline County
94.6	0.8	Roadside park
99.9	5.3	New Cambria (K 220) underpass
100.4	0.5	Dakota Group (poorly exposed)
103.7	3.3	Dakota rocks poorly exposed
106.4	2.7	Camp Webster Road
107.5	1.1	US 81 overpass, turn left (south) on US 40 and 81
109.8	2.3	Turn right on US 40
111.3	1.5	US 81 bypass
118.0	6.7	Bavaria
124.2	6.2	Brookville
128.5	4.3	Ellsworth County
129.8	1.3	Sandstone in Dakota at left (south) capping small hill
131.1	1.3	K 141 intersection
131.3	0.2	Dakota sandstone on both sides of road
134.5	3.2	Carneiro
135.6	1.1	Dakota sandstone on both sides of road
141.2	5.6	K 111 intersection
144.8	3.6	K 45 intersection
145.3	0.5	K 14 intersection
145.5	0.2	Ellsworth
151.1	5.6	Cross-bedded sandstone in the Dakota Group
160.8	9.7	Wilson
161.8	1.0	Russell County
167.5	5.7	Dorrance
174.3	6.8	Greenhorn Limestone (poor exposure)
183.0	8.7	Russell
192.6	9.6	Gorham
193.7	1.1	Ellis County
195.8	2.1	Walker
199.7	3.9	Victoria
208.8	9.1	Stay left on bypass US 40
209.0	0.2	Hays
210.5	1.5	Roadside park
210.8	0.3	US 183 intersection
211.0	0.2	Old Fort Hays
212.8	1.8	Business US 40 intersection
217.1	4.3	Upper part of Carlile Shale overlain by Fort Hays Limestone
222.8	5.7	Abandoned quarry in Fort Hays Limestone (south side)
223.0	0.2	Fort Hays Limestone on left (south)
224.4	1.4	Ellis
226.7	2.3	Trego County
229.9	3.2	I 70; keep left
231.0	1.1	Ogallala Formation in road cut
231.5	0.5	Ogallala Formation in road cut
231.8	0.3	K 147 overpass
234.5	2.7	Rest area north side of road
235.4	0.9	Rest area south side of road
239.2	3.8	US 283 north
240.2	1.0	US 283 south
252.4	12.2	Voda underpass
257.4	5.0	K 198 overpass
259.5	2.1	Gove County
265.2	5.7	K 212 overpass
273.0	7.8	K 211 overpass
276.2	3.2	Rest area
279.1	2.9	K 23
279.5	0.4	US 40 keep right
287.4	7.9	Grinnell
297.5	10.1	Logan County
297.7	0.2	Roadside park
299.4	1.7	Oakley
299.6	0.2	US 383 and US 83
308.3	8.7	Monument
310.8	2.5	K 25 (north)
318.2	7.4	K 25 (south)
321.7	3.5	Winona
328.1	6.4	Pierre Shale overlain by Pleistocene deposits
328.6	0.5	North Fork Smoky Hill River
330.1	1.5	McAllaster Buttes, Pierre Shale exposures
331.0	0.9	McAllaster
335.4	4.4	Turtle Creek
337.2	1.8	Wallace County
339.7	2.5	Fort Wallace museum and park
340.2	0.5	Wallace
349.8	9.6	Sharon Springs
350.0	0.2	K 27 (north)
350.1	0.1	K 27 (south)
362.4	12.3	Weskan
366.9	4.5	Colorado state line

US 166, K 38, US 160, K 99, US 54, US 56, K 4, and county roads—Arkansas City to Eskridge (from Kansas Geological Society 24th Field Conference Guidebook)

Cumulative mileage	*Mileage*	
0.0	0.0	Arkansas City, east side of town on south side US 166 (Madison Avenue) just east of Santa Fe Railroad underpass

0.1	0.1	Walnut River
0.5	0.4	Winfield Limestone in road cut
0.8	0.3	Loess overlying Odell Shale
3.2	2.4	Winfield Limestone capping hill on left. Leave US 166; go straight ahead, curve right on old US 166
3.4	0.2	Intermediate (Illinoisian) terrace
3.8	0.4	Lower (Wisconsinan) terrace
4.8	1.0	Winfield Limestone overlain by loess
5.6	0.8	Winfield Limestone scarp
6.9	1.3	Poor exposure of Ft. Riley Limestone
7.2	0.3	Silverdale Road
7.3	0.1	Ft. Riley Limestone
7.5	0.2	Upland (Early Pleistocene) chert gravels on Ft. Riley Limestone
8.0	0.5	Grouse Creek. Kinney Limestone exposed on left in creek bank
8.5	0.5	Kinney Limestone
9.2	0.7	Florence Limestone (about 12 feet thick in this area)
10.0	0.8	Upland capped with Ft. Riley Limestone; note numerous quarries in Ft. Riley Limestone
14.2	4.2	Base of Barneston Limestone
15.3	1.1	Maple City
16.2	0.9	Curve right (east)
19.2	3.0	Otto; turn right (south)
20.3	1.1	Wreford Limestone
20.9	0.6	Wreford Limestone scarp
21.7	0.8	Wreford Limestone scarp
24.1	2.4	Crouse Limestone on left in creek bank
24.6	0.5	Oklahoma state line
26.6	2.0	Spring Creek
27.0	0.4	Turn left (east)
27.3	0.3	Cattle guard
27.6	0.3	Cattle guard
28.1	0.5	Turn right (south)
28.7	0.6	Morrill Limestone bench
29.1	0.4	Bader Limestone outlier
30.4	1.3	Turn right (west)
32.2	1.8	Beaver Creek
32.9	0.7	Pass over cattle guard and turn around to head east
33.1	0.2	Beattie Limestone exposure in gully just west of unimproved road on Murphy Ranch
33.6	0.5	Beaver Creek
34.0	0.4	Sandstone in Eskridge Shale
34.6	0.6	Morrill Limestone
37.4	2.8	Oklahoma 18 intersection, turn left (north); Grainola to right (south)
41.4	4.0	Kansas state line (Cowley County Road 7)
43.4	2.0	Grenola Limestone
45.9	2.5	Cottonwood Limestone
46.6	0.7	Intersection Cowley County Road 6, continue straight ahead
49.4	2.8	Intersection US 166, turn right; Funston Limestone
49.8	0.4	Crouse Limestone on right
50.0	0.2	Crouse Limestone
50.3	0.3	Bader Limestone
50.8	0.5	Cross railroad and turn left on Cowley County Road 7
53.0	2.2	Hooser; Beattie Limestone in stream gully northeast of road
57.1	4.1	Wreford Limestone in road cut
57.8	0.7	Wreford Limestone in road cut
58.2	0.4	Basal part of Wreford Limestone
60.1	1.9	Intersection Kansas 38, turn left (west)
62.3	2.2	Wreford Limestone
62.7	0.4	Crouse Limestone
63.2	0.5	Wreford Limestone and Speiser Shale
63.5	0.3	Top of Wreford Limestone
64.0	0.5	Turn right (north) on gravel road
65.3	1.3	Grouse Creek
69.2	3.9	Intersection of US 160, turn right (east)
69.4	0.2	Grouse Creek
70.4	1.0	Cambridge
73.3	2.9	Crouse Limestone
74.0	0.7	Crouse Limestone
78.0	4.0	Crouse Limestone
79.0	1.0	Crouse Limestone
79.2	0.2	Morrill Limestone in road ditch on right
79.4	0.2	Elk County
79.5	0.1	Grenola Limestone
81.2	1.7	Foraker Limestone
81.6	0.4	Brownville Limestone on north in road ditch
82.5	0.9	Nebraska City Limestone and sandstone in French Creek Shale in road ditch on right
82.6	0.1	Caney River
83.6	1.0	Intersection road to Grenola
88.3	4.7	Emporia Limestone
91.4	3.1	Moline; stay on US 160
92.8	1.4	Topeka Limestone
93.0	0.2	Junction Kansas 99 and US 160, continue straight ahead
93.5	0.5	Elk Creek; Deer Creek Limestone in creek bank
93.6	0.1	Topeka Limestone
93.7	0.1	Turn left (north) on Kansas 99
97.3	3.6	Topeka Limestone
99.6	2.3	Elk River
100.3	0.7	Howard
103.7	3.4	Howard Limestone
104.9	1.2	Howard Limestone
109.7	4.8	White Cloud Shale in road cut at top of hill
110.0	0.3	Greenwood County
112.0	2.0	Severy road, continue on Kansas 99
113.0	1.0	Intersection Kansas 96
113.1	0.1	Howard Limestone
116.2	3.1	White Cloud Shale
117.6	1.4	Howard Limestone
118.3	0.7	Otter Creek
119.3	1.0	Climax Road
120.4	1.1	Howard Limestone on hill to left, Severy Shale in road cut, and upper Topeka Limestone
122.8	2.4	Severy Shale
123.6	0.8	Fall River
125.0	1.4	Howard Limestone
126.4	1.4	Junction US 54, curve left (west)
129.1	2.7	Eureka
130.2	1.1	Leave US 54, continue straight ahead (south)
130.3	0.1	City park
130.6	0.3	Junction US 54, turn left on River Street (west)
130.8	0.2	Fall River
131.6	0.8	Happy Hollow Limestone
132.3	0.7	Silver Lake Shale
132.6	0.3	Wakarusa Limestone, Soldier Creek Shale, and Burlingame Limestone
132.8	0.2	Emporia Limestone and Auburn Shale
133.6	0.8	Reece oil field
137.4	3.8	Brownville Limestone, Pony Creek Shale, and Wood Siding Formation
138.5	1.1	Admire Group

139.2	0.7	Brownville Limestone and Pony Creek Shale
139.9	0.7	Spring Creek
140.4	0.5	Foraker Limestone
141.0	0.6	Roca Shale
141.4	0.4	Lower Grenola Limestone and upper Roca Shale. Note folded and truncated beds in upper Roca Shale in south road cut
142.2	0.8	Sallyards oil field. Grenola Limestone; note oil-saturated zone near middle
142.5	0.3	Eskridge Shale
142.8	0.3	Cottonwood Limestone and upper Eskridge Shale
143.0	0.2	Beattie Limestone in road cut
143.2	0.2	Turn left (south) across field to old US 54
143.3	0.1	Turn right (west) on old US 54; Butler County
144.0	0.7	Wreford Limestone, Kinney Limestone blocks on hillside
144.4	0.4	Florence Limestone
148.4	4.0	Turn right (north) into Rosalia, stay on blacktop next 16 miles
164.7	16.3	Cassoday
165.1	0.4	Intersection Kansas 13 (straight ahead)
165.7	0.6	Kansas Turnpike overpass
169.3	3.6	Chase County
172.0	2.7	Florence Limestone, Kinney Limestone blocks on hill ahead
172.4	0.4	Wreford Limestone
175.5	3.1	Matfield Green
183.3	7.8	Rock Creek
183.7	0.4	Turn right (east) to Bazaar
184.1	0.4	Bazaar
184.5	0.4	Turn right (south)
185.1	0.6	Cross South Fork Cottonwood River, and turn left
188.4	3.3	Turn around at road corner
188.6	0.2	Beattie Limestone in stream bank
191.2	2.6	Beattie Limestone in stream bank
192.2	1.0	Straight ahead (north)
193.5	1.3	Turn right (east)
194.0	0.5	Turn left (north)
197.0	3.0	Turn right (east)
200.9	3.9	Turn left (west) and cross Cottonwood River
201.2	0.3	Turn right (east) at intersection
201.5	0.3	Turn left (north)
202.1	0.6	Cross railroad and old US 50, continue straight ahead
202.8	0.7	Turn north
203.3	0.5	Neva Limestone
203.6	0.3	Neva Limestone
203.8	0.2	Cross US Highway 50, continue north
208.2	4.4	Wreford Limestone on hilltop
210.1	1.9	Florence Limestone
211.6	1.5	Wreford Limestone at creek
212.2	0.6	Turn right (east)
212.7	0.5	Jog right
213.5	0.8	Cattle guard
213.9	0.4	Cattle guard; Morris County
216.1	2.2	Straight ahead
216.3	0.2	Cottonwood Limestone and underlying Eskridge Shale in spillway of Lake Kahola dam
217.1	0.8	Turn right (east)
219.1	2.0	Turn left (north)
220.1	1.0	Grenola Limestone
220.3	0.2	Neosho River
221.8	1.5	Dunlap
221.9	0.1	Intersection with blacktop, continue north
222.3	0.4	Rock Creek
222.8	0.5	Cross abandoned railroad, continue north on gravel road
225.0	2.2	Grenola Limestone
227.6	2.6	Comiskey NE oil field
228.7	1.1	Intersect US 56, turn right (east)
229.4	0.7	Rock Creek
229.6	0.2	Crouse Limestone
229.7	0.1	Lyon County
229.9	0.2	Funston Limestone and Speiser Shale
230.3	0.4	Funston Limestone
231.1	0.8	Crouse Limestone
232.3	1.2	Rock Creek; Cottonwood Limestone in creek bank
232.8	0.5	Crouse Limestone
233.1	0.3	Upper part of Funston Limestone and Speiser Shale
233.4	0.3	Wreford Limestone
233.7	0.3	Turn left (north)
234.4	0.7	Speiser Shale
234.7	0.3	Crouse Limestone
238.9	4.2	Wabaunsee County
239.9	1.0	Wreford Limestone
240.4	0.5	Wreford Limestone
240.9	0.5	Turn left (west)
241.8	0.9	Turn right (north)
243.8	2.0	Intersection, continue straight ahead
246.7	2.9	Florence Limestone bench
247.7	1.0	Wreford Limestone
247.9	0.2	Speiser Shale and Funston Limestone
248.9	1.0	Junction Kansas 4; Funston Limestone in cut
249.3	0.4	Funston Limestone
250.3	1.0	Crouse Limestone
250.7	0.4	Middle Branch of Mill Creek
252.4	1.7	Crouse Limestone and Easly Creek Shale
253.4	1.0	Speiser Shale and Threemile Limestone
253.6	0.2	Schroyer Limestone
254.0	0.4	Threemile Limestone
255.1	1.1	Beattie Limestone, Eskridge Shale, and Grenola Limestone
255.3	0.2	Bridge
255.9	0.6	Entrance to Lake Wabaunsee
256.4	0.5	Wreford Limestone
257.8	1.4	Eskridge

US 81, US 56, K 14, K 96, K 61, K 17, US 54, and county roads—Wichita to Lyons and Hutchinson and return (from Kansas Geological Society 24th Field Conference Guidebook)

Cumulative mileage	*Mileage*	
0.0	0.0	Intersection US 81 and Kechi Road
0.1	0.1	Low (Wisconsinan) terrace of Little Arkansas River
1.3	1.2	Wellington Formation (Permian) with thin Pleistocene cover
2.8	1.5	Division Headquarters, Kansas Highway Patrol on right (east)
3.0	0.2	Valley Center Road
5.0	2.0	Goodrich oil field on right (east)
8.0	3.0	Harvey County
11.0	3.0	Kansas 196
15.5	4.5	Stay left on US 81 to Newton
15.9	0.4	Newton; stay on US 81 through town
18.6	2.7	Continue left on US 81

19.4	0.8	"Equus beds." Highway is along eastern edge of "Equus beds" to Conway
22.2	2.8	Zimmerdale
25.3	3.1	Hesston
29.1	3.8	McPherson County
31.6	2.5	Moundridge
40.2	8.6	Elyria
41.0	0.8	Voshell oil field
44.0	3.0	Crossroads; continue on US 81
44.8	0.8	NCRA refinery
47.0	2.2	Intersection US 81 and US 56 at west edge of McPherson. Turn left (west) on US 56
49.0	2.0	McPherson channel, "Equus beds." Approximately 260 feet to bedrock
51.5	2.5	Ninnescah Shale (Permian)
51.7	0.2	Propane storage in Hutchinson Salt Member of Wellington Formation to left (Security Underground Storage)
52.4	0.7	LPG storage in Hutchinson Salt to right (NCRA)
52.5	0.1	Conway. Thin Pleistocene cover on Ninnescah Shale
53.5	1.0	LPG storage to left (Skelly)
56.5	3.0	Kiowa Shale
59.2	2.7	Windom Junction. Windom oil field
60.2	1.0	Turn left (south) on Rice County line
62.2	2.0	Turn right (west)
62.6	0.4	Welch-Bornholdt oil field
63.2	0.6	Stone Corral Formation in road ditch on north
63.3	0.1	Ninnescah Shale
64.9	1.6	Little Arkansas River
65.2	0.3	Crossroads
65.6	0.4	Kiowa Shale
67.2	1.6	Intersection US 56 Detour
76.1	8.9	Turn left (south)
77.1	1.0	Turn right (west)
77.5	0.4	Turn left (south)
77.8	0.3	American Salt Company mine
78.1	0.3	Turn left (west)
78.7	0.6	Turn left (south) on Kansas 14 and 96
79.0	0.3	Late Pleistocene terraces
86.3	7.3	Sterling
87.6	1.3	Turn left (east) on E. Garfield
88.0	0.4	Rest stop, turn around
88.3	0.3	Turn left (south) on Kansas 14 and 96
90.5	2.2	Arkansas River
91.3	0.8	Reno County
91.7	0.4	Stabilized sand dunes. Sterling oil field
95.9	4.2	Wisconsinan terraces
97.1	1.2	Arkansas River
98.2	1.1	Nickerson; stay on Kansas 96
110.2	12.0	Hutchinson
110.9	0.7	Turn right (south) on Adams Street
111.0	0.1	Intersection US 50 and Kansas 96; continue straight ahead
111.5	0.5	Turn left (east) on Avenue B
113.2	1.7	Turn right (south) on Laramie Street
113.3	0.1	Turn left (east) on Carey Road
114.2	0.9	Halstead Avenue; continue straight ahead on Carey Road
115.0	0.8	Carey Salt Company mine
115.9	0.9	Turn left (south) on Halstead Avenue
116.3	0.4	Turn right (west) on Avenue G
116.6	0.3	Carey wells to right
117.7	1.1	State Reformatory on right
118.1	0.4	Barton Salt Company to left. All production from wells
118.9	0.8	Turn left (south) on Main Street
119.2	0.3	Arkansas River, South Hutchinson
119.7	0.5	Stay right
120.0	0.3	Intersection Kansas 17 and 61; turn left (south)
120.1	0.1	Turn right (west) on Kansas 61
122.0	1.9	Leave highway and continue straight ahead on gravel
122.1	0.1	Turn right (north) and cross railroad tracks
122.2	0.1	Cities Service Hutchinson LPG terminal
122.4	0.2	Railroad crossing; turn left (east)
122.5	0.1	Intersection with Kansas 61
123.7	1.2	Hutchinson
124.3	0.6	Turn right (south) on Kansas 17
126.1	1.8	Cross early Pleistocene channel containing 140 to 150 feet of fill
126.9	0.8	Kansas sheet deposit about 60 feet thick
127.3	0.4	U.S. Naval Air Station
129.0	1.7	Ninnescah Shale
130.3	1.3	Haven Road
132.3	2.0	Castleton Road
134.8	2.5	Thin Pleistocene on Ninnescah Shale
136.1	1.3	Ninnescah Shale in valley on left
136.8	0.7	Pleistocene over Ninnescah Shale
137.6	0.8	Andale Road
138.0	0.4	Ninnescah Shale exposed to left
138.6	0.6	Pretty Prairie Road
139.1	0.5	Pleistocene on Ninnescah Shale
141.6	2.5	Kingman County
142.6	1.0	Mt. Vernon Road
143.4	0.8	Thick Pleistocene fill
145.6	2.2	Waterloo Road
146.3	0.7	Smoots Creek
146.5	0.2	Junction US 54 and Kansas 17; turn left (east) on US 54
146.8	0.3	Smoots Creek. Pleistocene on Ninnescah Shale to county line
153.6	6.8	Sedgwick County, Ninnescah Shale
153.9	0.3	Bartholomew oil field
155.1	1.2	Cheney Road
155.7	0.6	Pleistocene terraces
156.3	0.6	Ninnescah River
156.7	0.4	Ninnescah Shale. Uplands capped with Pleistocene deposits
160.0	3.3	Garden Plain
161.5	1.5	Approximate contact Ninnescah Shale and Wellington Formation (covered)
162.5	1.0	Viola Road
166.0	3.5	Goddard
168.3	2.3	Colwich Road
170.7	2.4	"Equus beds"
172.5	1.8	Cowskin Creek
174.6	2.1	Airport Road. Pleistocene fill at airport approximately 180 feet thick
174.9	0.3	Wichita

US 50, US 283, US 160, US 183, and county roads—Dodge City to Medicine Lodge (from Kansas Geological Society 18th Field Conference Guidebook)

Cumulative mileage	*Mileage*	
0.0	0.0	Head east on south side of highway at east limit of Dodge City on US 50, US 283, and K 45
0.6	0.6	Arkansas River valley to right
0.8	0.2	Ogallala Formation in road cuts for next few miles
4.3	3.5	Junction US 50 bypass; continue ahead (east) on US 50

5.4	1.1	Five Mile Creek
6.1	0.7	Junction US 283; turn left (north) on US 283
7.4	1.3	High Plains surface. Thickness of the Ogallala Formation in this vicinity is about 100 feet
10.7	3.3	Valley of Sawlog Creek straight ahead
13.6	2.9	Ogallala Formation (Pliocene) and Graneros Shale (Cretaceous) on right. Dakota-Graneros contact exposed on left
14.0	0.4	Sawlog Creek. Turn left (west) on section road
15.0	1.0	Turn left (south) on section road
15.3	0.3	Sawlog Creek
15.4	0.1	"Turtle back," capped by Ogallala Formation which in turn is underlain by Graneros and Dakota rocks
15.6	0.2	Ogallala Formation in road ditch on left
16.4	0.8	Good Ogallala crops on right in valley side
17.1	0.7	Turn left (east) on section road
18.1	1.0	Junction US 283; turn right (south) on US 283
19.2	1.1	Ogallala and Dakota exposures
19.4	0.2	Five Mile Creek
21.1	1.7	Building on left is made of Dakota siltstone
24.6	3.5	Junction US 50 and K 45; turn right (west) on US 50, US 283, and K 45
26.3	1.7	Junction US 50 bypass; keep left on US 50, US 283, and K 45
27.5	1.2	Dodge City municipal airport to southwest
30.7	3.2	Dodge City
31.9	1.2	Turn left (south) at Second Avenue and W. Chestnut on US 283 and K 45
32.0	0.1	Santa Fe Railroad
32.3	0.3	Arkansas River
32.7	0.4	Rock Island Railroad
33.1	0.4	Junction US 283 and K 45; stay left on US 283
42.5	9.4	Mulberry Creek
47.4	4.9	Kansas Power and Light Service installation on left. The surface in this area is underlain by the Pleistocene Kingsdown silt
49.7	2.3	Dodge Experiment Field of Kansas State University on right
51.2	1.5	Clark County
51.5	0.3	Large natural undrained depression
53.0	1.5	Minneola
53.2	0.2	Rock Island Railroad
53.3	0.1	Junction US 283 and US 54; continue straight ahead (south) on US 283
53.9	0.6	Undrained depression
55.5	1.6	Large undrained depression
60.6	5.1	Large undrained depression to left
62.2	1.6	Ogallala Formation in stream valley to left
63.6	1.4	Ogallala Formation in road cut
65.2	1.6	Junction US 160; continue straight ahead (south) on US 283 and US 160
67.5	2.3	North rim of Big Basin. Ogallala Formation in road cut
67.8	0.3	Contact of Ogallala Formation with Permian "Taloga Formation" in road cut
68.1	0.3	Note the slump structure in the Ogallala beds around the edge of Big Basin
69.0	0.9	Turn left (west) at top of south rim of basin; go through gate
70.1	1.1	Lower Cretaceous Cheyenne Sandstone overlying "Taloga Formation" in draw on right
70.3	0.2	Cross creek bottom
70.7	0.4	Turn around in field. St. Jacob's Well. On the far side of Little Basin (southeast side) is the Cheyenne Sandstone (yellow) overlain by Kiowa Shale (dark gray) and Ogallala rimrock
71.1	0.4	Cross creek bottom
71.3	0.2	Southeast side of Big Basin
72.4	1.1	Turn left (south) on US 283 and US 160
74.5	2.1	Antelope Creek
75.2	0.7	Junction US 160 and US 283; stay left (east) on US 160
77.8	2.6	Whitehorse Formation (Permian)
78.6	0.8	Slump structure in upper Whitehorse Formation
78.9	0.3	Kiger Creek
80.6	1.7	Little Sandy Creek
83.6	3.0	Whitehorse Sandstone
84.4	0.8	Redhole Creek
86.4	2.0	Ashland oil field on left
86.8	0.4	Ashland
87.5	0.7	Intersection Main and E. 4th
87.8	0.3	Bridge
87.9	0.1	Turn left (north) to Clark County State Park
88.5	0.6	West Branch Bear Creek
89.0	0.5	Whitehorse Formation on right and left
89.8	0.8	Ashland oil field to left
90.4	0.6	Day Creek Dolomite capping knoll to right
91.8	1.4	Cattle guard
92.2	0.4	Ahead and to the right is Kiowa Shale overlying Permian redbeds
92.8	0.6	Ogallala Formation to the right and ahead
93.0	0.2	Ogallala Formation on both sides of road
93.2	0.2	Cattle guard
94.6	1.4	Cattle guard
95.6	1.0	Cattle guard
95.8	0.2	Bluff Creek valley ahead
97.1	1.3	Cattle guard
97.3	0.2	Day Creek Dolomite on both sides of road
97.5	0.2	Kiowa Shale exposed to right of road
97.8	0.3	Kiowa Shale in road cut
98.0	0.2	Kiowa Shale on right side of road; "Taloga Formation" on left
98.6	0.6	Day Creek Dolomite in road
98.9	0.3	Bluff Creek
99.1	0.2	Cattle guard
99.4	0.3	Cattle guard
99.7	0.3	Road crosses Day Creek Dolomite
100.7	1.0	Ogallala Formation in road cut on the right
101.4	0.7	Cattle guard
103.4	2.0	Cattle guard
103.9	0.5	Cattle guard
104.3	0.4	Cattle guard
104.4	0.1	Turn left (west) at the State Park sign
105.6	1.2	Stay left (south)
105.7	0.1	Clark County State Park and lake on right
106.4	0.7	Turn right (west)
106.7	0.3	Turn left
106.8	0.1	Stay left at edge of lake

106.9	0.1	Pavilion. Turn around and proceed back on same route to US 160 at east edge of Ashland
125.8	18.9	Turn left (east) on US 160
126.2	0.4	Bear Creek
130.8	4.6	Day Creek
132.0	1.2	Junction US 183 and K 34; continue ahead (east) on US 160, US 183, and K 34
132.1	0.1	Whitehorse Sandstone in road cuts
134.3	2.2	Whitehorse Sandstone in road cuts
137.4	3.1	Santa Fe Railroad
138.1	0.7	Comanche County
140.3	2.2	Bluff Creek
141.4	1.1	Junction US 160, US 183, and K 34; straight ahead (east) on US 160 and US 183. Protection is ¼ mile to the left (north)
142.3	0.9	Kiowa Creek
142.8	0.5	Cavalry Creek
147.0	4.2	Whitehorse Sandstone
147.5	0.5	Sand dune topography
150.2	2.7	Junction K 1; turn left (north) on US 160 and US 183
154.8	4.6	Coldwater
155.4	0.6	Santa Fe Railroad
156.3	0.9	Junction US 160 and US 183; turn right (east) on US 160
157.6	1.2	Santa Fe Railroad
158.0	0.5	Old stabilized sand dunes
162.4	4.4	Turn left (north) on old US 160 to Wilmore
166.2	3.8	Turn right (east). "Meade Formation" (Pleistocene) in road cut on the right
166.6	0.4	Wilmore
166.8	0.2	Turn left (north) and cross Santa Fe Railroad
167.1	0.3	Turn right (east)
167.3	0.2	Mule Creek. Cross bridge and turn left (north)
169.7	2.4	Turn left (north)
171.3	1.6	Turn right (east)
172.7	1.4	"Meade Formation" in the road cuts
173.7	1.0	Turn left (north) before railroad crossing. Kiowa County
174.6	0.9	Slow; dangerous corner
174.9	0.3	"Meade Formation" underlain by Kiowa Shale in road cut
175.5	0.6	Kiowa Shale outcrops
176.4	0.9	Cheyenne Sandstone on left and Kiowa Shale on right
177.0	0.6	Mephistopheles Quarter Acre. Cheyenne Sandstone on left and Kiowa-Cheyenne contact on right
179.0	2.0	Good exposures of Cheyenne Sandstone on far side of valley to the left
179.9	0.9	Belvidere
180.3	0.4	Turn right (south) on private road immediately east of railroad section house and cross railroad track
180.6	0.3	Cattle guard
180.8	0.2	Turn off road and stay right on faint old trail in pasture. A small grove of trees is on the right along Cheyenne Sandstone outcrops
181.0	0.2	Kiowa Shale outcrops in the flat on the left
182.2	1.2	Turn right (east) on the Belvidere road
182.7	0.5	Marlow Member of the Whitehorse Formation on the right
182.9	0.2	Medicine Lodge River
183.6	0.7	Turn right (south) and cross Santa Fe Railroad; stay right on main road
185.9	2.3	Bridge. Medicine Lodge Gypsum and Dog Creek Shale on the left
186.0	0.1	Dog Creek Shale
186.4	0.4	Dog Creek Shale
186.7	0.3	"Meade Formation" on small hill
187.1	0.4	Barber County
187.8	0.7	Old gypsum quarry to the left
188.9	1.1	Turkey Creek oil field
189.6	0.7	Flowerpot Shale exposed along bluff to the left
191.0	1.4	Sun City oil field on the left. Cross Santa Fe Railroad
191.2	0.2	Medicine Lodge River
191.9	0.7	Flowerpot Shale on the right
192.3	0.4	Turn left (east)
192.6	0.3	Sun City oil field to left (north)
193.1	0.5	Medicine Lodge River
193.5	0.4	Santa Fe Railroad
193.7	0.2	Turkey Creek
194.0	0.3	Turn right (south)
194.3	0.3	Sun City
194.4	0.1	Santa Fe Railroad. Turn left (east) and cross railroad track again
194.5	0.1	Turn right (south) at service station and cross railroad track
195.2	0.7	Medicine Lodge River
195.5	0.3	Gypsum-capped hills
195.7	0.2	Flowerpot Shale with gypsum on right in road cut
196.4	0.7	Stay left. Road to right leads to Pioneer gypsum mine
196.6	0.2	Cattle guard
196.7	0.1	View of gypsum-capped hills
196.8	0.1	Cattle guard
197.2	0.4	Stay right
197.7	0.5	Cattle guard
197.8	0.1	Bear Creek
198.0	0.2	Gypsum-capped Flowerpot Shale on left
200.0	2.0	Turn left (east), cross cattle guard into field
200.7	0.7	Former Natural Bridge. Turn cars around and proceed back to Sun City road
201.4	0.7	Turn left (south) on Sun City road
203.8	2.4	Junction US 160; turn left (east) on US 160
204.9	1.1	Junction with the Deerhead road; continue straight ahead (east) on US 160
207.1	2.2	Flowerpot Shale
207.3	0.2	Medicine Lodge Gypsum for the next 0.7 mile
208.6	1.3	Dog Creek-Marlow contact on left
210.1	1.5	Junction Lake City road; continue straight ahead (east) on US 160
210.2	0.1	Flowerpot Shale
211.1	0.9	Little Bear Creek gas field on right
211.2	0.1	Little Bear Creek
211.5	0.3	Flowerpot Shale with the Medicine Lodge Gypsum on top
212.2	0.7	Medicine Lodge Gypsum
212.9	0.7	Flowerpot Shale
213.7	0.8	Bitter Creek
215.2	1.5	View of Twin Buttes (in Flowerpot Shale) on right ahead
218.6	3.4	Cedar Creek
219.0	0.4	Cedar Hills Sandstone on right
219.3	0.3	Cedar Hills Sandstone

220.9	1.6	Cedar Hills Sandstone
221.3	0.4	National Gypsum Company plant ahead on left
222.7	1.4	Junction US 160 and US 281; continue straight (east) on US 160 and US 281
223.0	0.3	Medicine Lodge River
223.2	0.2	Gypsum plant on left
223.5	0.3	Medicine Lodge

K 45, K 23, K 98, and US 160—Dodge City to junction of US 160 and US 283 (from Kansas Geological Society 18th Field Conference Guidebook)

Cumulative mileage	*Mileage*	
0.0	0.0	Junction US 283 and K 45 at southern city limits of Dodge City. Stay right on **K 45**
0.2	0.2	Hummocky sand dune topography to left
2.6	2.4	Driving through sand dune area
3.2	0.6	Bridge
12.6	9.4	Gray County
13.3	0.7	Ensign
17.4	4.1	High Plains undrained depression
18.4	1.0	Haggard
19.9	1.5	Junction K 23; turn left (south) on K 23. Undrained depression at junction
20.9	1.0	Two undrained depressions
30.7	9.8	Meade County
32.6	1.9	Crooked Creek
32.9	0.3	Kingsdown silt on both sides of the road
34.1	1.2	Meade Artesian Basin to left (east) in distance
35.7	1.6	Sappa Formation silt
36.9	1.2	Junction K 98; continue straight ahead on **K 23**
37.0	0.1	Purex volcanic ash pit on left
37.9	0.9	Turn left (east) on section road
38.5	0.6	Turn left (north) on access road
39.1	0.6	Purex, Ltd., volcanic ash mine. Pearlette Ash bed of the Sappa Formation
40.3	1.2	Turn left (south) on K 23
40.8	0.5	Sappa Formation silt in road cut
43.2	2.4	Sappa Formation silt in road cut
45.9	2.7	Meade, Rock Island Railroad
46.4	0.5	Junction K 23, US 54, and US 160; continue straight ahead (south) on K 23
49.2	2.8	Crooked Creek
49.8	0.6	Mid-Co Products Company volcanic ash pit (abandoned) on skyline to left
54.3	4.5	Undrained depression
54.8	0.5	Turn right (west) on K 98
55.9	1.1	View of Crooked Creek valley ahead
57.2	1.3	Turn around at bridge that crosses Crooked Creek. Ogallala gravel (pit to south) overlain by Ogallala sandy silt (fossiliferous Ash Hollow Member). Crooked Creek Fault (200 feet displacement in Permian) between Crooked Creek channel and Ogallala bluffs. Ogallala sand and sandy silt (Ash Hollow) overlain by Grand Island gravel in road cut
58.0	0.8	"Meade Formation" type locality as designated by Frye and Hibbard in 1941 in canyons to south and in road cut
59.6	1.6	Junction K 23; turn left (north) on K 23
62.5	2.9	Slow; sharp turn ahead
62.7	0.2	Turn right (east) on country road
63.7	1.0	Turn left (north) on country road
65.1	1.4	Mid-Co Products volcanic ash pit (abandoned) on left
65.5	0.4	"Meade Formation" in road cuts
65.7	0.2	Stay left
66.6	0.9	Pearlette Ash bed in road cut and in small pit on left
67.2	0.6	Meade Salt Sink ¼ mile to the southwest. This sinkhole developed suddenly in March 1879 and is just east of Crooked Creek Fault
67.9	0.7	Crooked Creek
68.9	1.0	Junction US 160. Meade city park on left. Turn right (east) on US 160.
69.0	0.1	Crooked Creek
69.1	0.1	"Meade Formation"
69.5	0.4	Junction US 54; turn right (east) on US 160
75.5	6.0	Large undrained depression elongated east-west on the right
79.2	3.7	Ogallala Formation on right
79.5	0.3	Ogallala Formation exposed along unnamed tributary to North Branch of Sand Creek
80.8	1.3	North Branch of Sand Creek. Ogallala well exposed on both sides of the stream and for the next few draws to the east
82.1	1.3	Clark County
83.1	1.0	Johnson Creek. Ogallala Formation exposed in valley sides
85.2	2.1	"Taloga Formation" (uppermost formation of Permian redbeds) in valley wall of Indian Creek on right
87.2	2.0	Junction US 283 and US 160

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Boldface type indicates a more important reference; *italic* type indicates reference to a plate.