State Geological Survey of Kansas, Bulletin 109
1954 Reports of Studies, Part 4, Pages 49-64, Plates 1-2
May 15, 1954

ADDITIONAL STUDIES OF THE CENOZOIC OF WESTERN KANSAS

By

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ABSTRACT

Subsurface data, obtained largely from ground-water test drilling, are utilized for the preparation of generalized areal geology and topography on the bedrock surface below the Cenozoic deposits of western Kansas. The geologic pattern is consistent with the regional pattern of areal geology shown on the State map of Kansas. The sub-Cenozoic topography reveals a recognizable pattern of bedrock valleys, developed in part during late Tertiary time and in part during Pleistocene time. Structure contours drawn on the "Algal limestone" at the top of the Ogallala formation are compared with structure contours drawn on the top of the Dakota formation. The Tertiary structural development of western Kansas is indicated by a map showing convergence between the Dakota and Ogallala formations.

INTRODUCTION

Much of western and south-central Kansas is covered by a relatively thin blanket of Cenozoic deposits of Pliocene and Pleistocene age. These surficial deposits, while containing the State's most extensive reservoirs of ground water and important deposits of sand, gravel, volcanic ash, and ceramic materials, nevertheless obscure the geology of the underlying rocks. Although subsurface studies have been reported in many county bulletins, a regional investigation of the surface below these deposits has not heretofore been made. Furthermore, these deposits contain at least one widespread stratigraphic datum—the "Algal limestone" at the top of the Ogallala formation—that can be used as a basis for structural contouring.

The purpose of this report is two fold: (1) to describe the generalized areal geology and topography of the surface below the Cenozoic deposits, and (2) to present, by use of structural data from the "Algal limestone," an analysis of Cenozoic regional structural movements in western Kansas. Thus we describe the concluding episode of structural history summarized recently by Lee and Merriam (1954) from studies of Paleozoic and Mesozoic rocks.

Subsurface data were obtained largely from the results of test drilling by the State and Federal cooperative ground-water division. Logs of test holes have been published for Stanton (Latta, 1941), Morton (McLaughlin, 1942), Ford (Waite, 1942), Meade (Frye, 1942), Hamilton and Kearny (McLaughlin, 1943), Finney and Gray (Latta, 1944), Thomas (Frye, 1945), Grant, Haskell, and Stevens (McLaughlin, 1946), Scott (Waite, 1947), Kiowa (Latta, 1948), Seward (Byrne and McLaughlin, 1948), McPherson, Harvey, and Sedgwick (Williams and Lohman, 1949), Pawnee and Edwards (McLaughlin, 1949), Norton (Frye and Leonard, 1949), Rice (Fent, 1950), Barton and Stafford (Latta, 1950), Lane (Prescott, 1951), Cheyenne (Prescott, 1953), and Sherman (Prescott, 1953a) Counties. Unpublished test hole data from the other counties of western Kansas were made available to us by the cooperative ground-water division.

Data for the preparation of the map showing structure of the "Algal limestone" (Pl. 2B) were obtained from published reports, our own field observations, and field notes of several members of the Geological Survey staff. M. K. Elias of the Nebraska Geological Survey generously furnished unpublished data on "Algal limestone" localities in western Kansas.

STRATIGRAPHY

The stratigraphic units used in the preparation of Plates 1 and 2 are listed in Table 1 and summarized in more detail by Moore and others (1951). The stratigraphic basis for the structural map on the top of the Dakota formation is described by Lee and Merriam (1954).

A discontinuous bed of distinctive lithology described as occurring stratigraphically at the top of the Ogallala formation has been

TABLE 1.—*Stratigraphic units utilized in preparation of Plates 1 and 2*

System	Formation	Member	Maximum thickness, feet	Character
Quaternary (Pleistocene)	(undifferentiated)		250+	Unconsolidated sand, gravel, and silt.
Tertiary (Pliocene)	Ogallala formation	Kimball, Ash Hollow, Valentine	300	Unconsolidated sand, gravel, and silt, and limestone.
Cretaceous	Pierre shale	(undifferentiated)	1,400	Dark shale.
	Niobrara formation	Smoky Hill chalk	700	Chalk and chalky shale.
		Ft. Hays limestone	65	Chalk.
	Carlile shale	(undifferentiated)	300	Dark shale.
	Greenhorn limestone	(undifferentiated	130	Alternating chalk and chalky shale.
	Graneros shale		65	Dark shale.
	Dakota formation	(undifferentiated)	300	Clay, siltstone, shale, and sandstone.

called the "Algal limestone" by Elias (1931) from the presence of the fossil algae *Chlorellopsis bradleyi*. Therefore the map showing the structure on the "Agal limestone" is intended to show the structural attitude of the top of the Kimball member of the Ogallala formation.

The Ogallala formation of Pliocene age was deposited by eastward-flowing streams on an erosion surface of moderate relief. The contours in northwestern Kansas (Pl. 1) show a segment of this pre-Pliocene surface and the general eastward trend of the valleys that were filled by the deposition of the Ogallala formation. The oldest units of the formation were deposited in the lowest portions of these erosional valleys and successively younger sediments not only added to the thickness of the alluvium along the valley axes but overlapped on the bedrock along their flanks. This depositional history has resulted in (1) a complex stratigraphy within the formation, and (2) the absence of the lower member (Valentine) and in some places part or all the middle member (Ash Hollow) over high areas on the Cretaceous bedrock. The present easternmost outlier of the "Algal limestone" is in Cloud County. There, as in adjacent counties, it rests directly on Cretaceous rocks. In Sherman County, on the Kansas-Colorado line, this limestone caps almost 300 feet of Ogallala formation.

During the deposition of the uppermost member (Kimball) the sediments of the several eastward-trending valleys merged across the former bedrock divides to produce a coalescent plain of alluviation. This alluvial plain, which had an initial eastward slope, was marked by such depositional features as natural levees, abandoned channel segments, and "back swamp" depressions. It was on this surface that the "Algal limestone" formed.

The exact origin of the "Algal limestone" has been a subject of controversy since Elias (1931) first suggested its formation in an extensive lake that he considered to have covered a large part of the High Plains area of Kansas. Alternate hypotheses of origin have included development as soil caliche (denying the evidence of the fossil algae) on the alluvial plain, or 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). Even though the question of origin of this limestone bed is not as yet fully settled, it nevertheless serves as a moderately satisfactory structural datum as it occurs stratigraphically at the top of the Ogallala formation and therefore marks the position of a roughly uniform east-ward-sloping surface at the end of Tertiary time.

Pleistocene deposits occur as fillings of erosional valleys and eolian deposits on upland and intermediate levels. However, no stratigraphic datum in the Pleistocene sediments of western Kansas is known to possess sufficient continuity and uniformity to serve as a basis for structural mapping. The stratigraphy of the Pleistocene deposits of Kansas has been described recently by Frye and Leonard (1952) and is only incidental to the present study.

THE SUB-CENOZOIC SURFACE

The generalized topography and geology of the surface below the extensive Cenozoic deposits of western Kansas are shown on Plate 1. The subsurface control for the map is largely from test holes drilled by the cooperative State and Federal ground-water division. The distribution of these data, although not uniform throughout the region, is judged to be sufficient to permit the drawing of 100-foot contours.

The pattern of sub-Cenozoic geology harmonizes with the regional surface geology of Kansas as shown on the geologic map of the State (Moore and Landes, 1937) although the Permian has not been subdivided for this report. The Cheyenne sandstone, Kiowa shale, and Dakota formation are grouped together as are the Greenhorn limestone and Graneros shale in keeping with the units shown on the State map. The Carlile shale, Niobrara formation, and Pierre shale are shown separately. A small area of presumed Triassic is shown in the extreme southwestern corner of the State.

The contours drawn on the unconformity at the base of the Cenozoic deposits show a composite surface of several ages. 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 the close of Miocene time. As filling of the eastward-trending valleys proceeded throughout Pliocene time, continued erosion of the interfluves may have reduced somewhat the relief that existed at the beginning of Pliocene time. There are four major pre-Ogallala valleys shown by the contours on Plate 1. The northernmost (valley A) extends eastward from southern Cheyenne County through a broad and somewhat indistinct trough to western Phillips County. To the south valley B trends eastward from central Wallace County along the position of the present Smoky Hill Valley. The third valley (valley C) extends east-southeast from southeastern Wallace County, and the fourth (valley D) trends southeastward from the southeastern corner of Greeley County.

Of these four recognizable pre-Ogallala valleys the northernmost (valley A) is the longest and least well defined. It is clearly separated from the second valley by a bedrock high along the north side of the present Smoky Hill River Valley. The second (valley B) is clearly defined by the contours only in Wallace County, and eastward from there is suggested by the relatively high bedrock beneath the featheredge of Ogallala on both the north and south sides of Smoky Hill Valley. In fact, removal of the Ogallala formation by Pleistocene erosion has produced an absence of data eastward along this trend which suggests the possibility that valley B may be a headwater bifurcation of the clearly defined adjacent trough (valley C) to the south. If this were true then the present Smoky Hill Valley is localized along a pre-Ogallala bedrock high. This alternate hypothesis has some credence because the Cretaceous Niobara formation and Pierre shale are distinctly less resistant to erosion than the Ogallala formation, and if covered only thinly or not at all by Pliocene sediments might have localized the present major valley.

The third valley (C) indicated by the contours is the sharpest and most distinct. It extends from southern Wallace County across northern Wichita, Scott, and Lane Counties to the eastern limit of the Ogallala cover in western Ness County. It is defined by pronounced bedrock highs on both the north and south sides. The fourth valley (D) is equally clear through the relatively short distance from southeastern Greeley County to the position of Arkansas River, south of which the pre-Ogallala topography merges with a surface cut in part by erosion during Pleistocene time.

South of Arkansas River the only surface that may safely be considered to be predominantly pre-Pleistocene in its development is in Morton, Stanton, and southern Hamilton Counties, and even here the suggested valleys coincide with the upper reaches of valleys farther east known to have been occupied in Pleistocene time. Therefore in this area there is either a fortuitous coincidence of Pliocene and Pleistocene valleys, or Pleistocene erosion removed the Ogallala formation and incised the bedrock as far west as the Colorado state line.

From Grant and Stevens Counties eastward to Kiowa County and south of Arkansas River the bedrock topography shown on Plate 1 is a complex consisting of the 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 pre-Ogallala surface southward from central Scott County and in central Haskell County 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 of Pleistocene age. Another major Pleistocene valley extends from eastern Gray County southeastward into northern Comanche County.

A prominent bedrock divide which trends southeastward from northern Ford County across Kiowa County into northwestern Barber County separates the early Pleistocene drainage systems of the southwestern part of the State from those of the south-central area, or the Great Bend Region. Eastward from Kiowa County the bedrock topography shown on Plate 1 was developed, essentially in its entirety, by Pleistocene erosion. In this area the bedrock valley systems were described by Fent (1950a); the present study in general confirms the drainage patterns he presented. An integrated system of bedrock valleys trending east-southeastward occurs under the region from central Kiowa County to central Reno County and is limited on the northeast by a distinct divide 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.

STRUCTURAL DEVELOPMENT AS SHOWN BY CENOZOIC DEPOSITS

Resume of Pre-Cenozoic Structural Developments

Structurally western Kansas was a northern extension of the Anadarko basin of Oklahoma and Texas throughout Paleozoic time. In Kansas this feature is called the Hugoton embayment. In pre-Pennsylvanian time this embayment was bordered on the southwest by the Sierra Grande uplift and on the north and northwest by the Siouxia uplift. Several times during the Paleozoic a low arch connected the Sierra Grande and Siouxia uplifts. The entire embayment plunged gently to the south, where the thickest accumulation of sediments occurred in the area of the Oklahoma-Texas panhandle (Maher and Collins, 1948; McCoy, 1953, pp. 1877-1883). The eastern extent of the embayment in pre-Pennsylvanian time is not known with certainty, but may have been limited in part by the western edge of the Chautauqua arch. In post-Mississippian time the Central Kansas uplift had its major development (Lee 1953, p. 20) and served to mark the eastern side of the embayment. During late Permian time or possibly earlier the long narrow north-south trending Oakley anticline (Lee and Merriam, 1954, pl. 3A) divided the Hugoton embayment into the Syracuse and Cimarron basins.

An erosional period of considerable duration following Permian time resulted in the truncation of the southerly dipping Permian beds, and major southerly flowing streams produced an erosional relief of more than 400 feet on the pre-Cretaceous surface.

The close of the Permian Period was marked by a complete change in both structural pattern and geological conditions. Marine sedimentation ceased and subaerial erosion was accompanied by continental sedimentation in the extreme southwestern part of the State. The Hugoton embayment, which had persisted from Cambrian time, was destroyed by slight northwestward tilting into the Denver basin in eastern Colorado as shown by a northwestward thickening of Triassic (McCoy, 1953, p. 1887) and Jurassic deposits (Lee and Merriam, 1954, fig. 10). Little movement took place during Cretaceous time except for the development of a marginal syncline along the eastern side of the Las Animas arch. The Cretaceous deposits that accumulated on a shelf area of the Denver basin were uniform in thickness and had a slight southerly dip. Major regional tilting which accentuated the prevailing northwestward dip began in post-Niobrara time. Orogenic movement accompanied this tilting during late Mesozoic or early Cenozoic time as is shown by the present structure of the Cretaceous deposits. Subsequent subaerial erosion followed this major structural orogeny until the deposition of the Ogallala formation of Pliocene age.

Structure on the Dakota Formation

The structure map of the top of the Dakota formation in western Kansas (Lee and Merriam, 1954) (Pl. 2A) shows several major features; these include the Salina basin, the Cambridge arch, the Las Animas arch, and the Western Kansas basin. The present regional dip on the Dakota formation is to the north.

A syncline in eastern Osborne and central Smith Counties trends in a northwest-southeast direction and plunges to the northwest. This syncline is judged to be a younger structural feature superimposed on the older Salina basin (Lee, Leatherock, and Botinelly, 1948, pl. 8). Minor anticlines and synclines also trending northwest-southeast and plunging to the northwest parallel the basin axis.

The southeastern end of the Cambridge arch is reflected in the structure on the Dakota formation in Decatur and Norton Counties. This major structural feature has a northwest-southeast trend and plunges to the southeast. Several minor anticlines and synclines on the flanks of this arch have parallel trends and plunge to the southeast.

The east flank of the Las Animas arch is marked by a narrow, linear, north-plunging synclinal trough which is located in Scott, Gove, Thomas, and Cheyenne Counties. The northerly dip on the east flank of the arch is uniform with few irregularities.

The Western Kansas basin plunges gently to the north and is restricted by the Las Animas arch on the west and the Cambridge arch and the area of the Central Kansas uplift on the east. The area of the Central Kansas uplift is reflected in the top of the Dakota only vaguely. This broad low arch has many secondary anticlinal and synclinal trends on its flanks which also plunge to the north.

The southern and eastern limit of control on the Dakota map is the Dakota-Graneros contact. A westerly trending anticline in Kiowa and Clark Counties separates the Western Kansas basin from the Anadarko basin of Oklahoma (Lee and Merriam, 1954, pl. 1). This structural high may have been developed in post-Permian time when the Hugoton embayment was destroyed by northwestward tilting.

Structure on the Top of the Ogallala Formation ("Algal Limestone")

The structure on top of the "Algal limestone," in strong contrast to that displayed by the Dakota formation, reflects none of the major structural features of western Kansas. The structure on the Ogallala formation has a rather monotonously uniform east dip (Pl. 2B). Although part of the seeming uniformity may be due to lack of control, it is clear that the structure shown on Plate 2B indicates absence of orogenic movement since the deposition of the "Algal limestone." This bed occurs, for the most part, as the uppermost unit of a sequence of alluvial sediments deposited by eastward-flowing streams and it is judged that an accentuation of this initial easterly dip can be attributed to epeirogenic movements to the west of Kansas.

The minor structural elements consist of eastward-plunging noses. A small structural nose occurs in central Wallace County and another in southern Lincoln and northern Ellsworth Counties. In Scott and Kiowa Counties these features are larger and more prominent. In all cases the noses have an east-west trend and plunge to the east.

A large area, including Kearny, Grant, Haskell, Gray, Stevens, Seward, and Meade Counties, which is covered by post-Ogallala deposits seems to lack "Algal limestone." This may be explained by its absence in this area, or because its areal extent is so small that it has not yet been found by drilling in the subsurface. In general the structure as shown on the top of the "Algal limestone" does not reflect the structure of the older rocks.

Cenozoic Structural Movements

At the end of the Cretaceous Period the Mesozoic deposits in Kansas dipped to the northwest into the Denver basin. This pattern was maintained and possibly accentuated during Cenozoic time as shown by Plate 2C. Convergence maps, like other isopachous maps, show by lines of equal interval the convergence or divergence of two surfaces. The variations in the interval between the selected surfaces show a composite of the total movement during the period of time that separates them. Thus, since the structural pattern was about the same from Dakota time to the end of Niobrara time, it can be assumed that the convergence map (Pl. 2C) represents the movement that took place after the deposition of the Niobrara formation and before the formation of the "Algal limestone." If we assume both of these planes to have been initially horizontal, the contours reveal a general northwestward dip of the Dakota formation into the Denver basin.

An exception to the regional dip is the Shallow Water basin in Scott County which is closed structurally. This basin has more than 100 feet of closure. A faint suggestion of a syncline plunging toward the north is present in western Gove and eastern Thomas Counties. This trend occupies about the same position as the marginal syncline which developed in late Cretaceous time. Since it is roughly in the same position, it is judged that the marginal syncline continued to develop during Cenozoic time. Several other minor anticlines and synclines are recognized on the map (Pl. 2C). They have a northwest-southeast trend and plunge to the northwest into the Denver basin.

Assuming that the "Algal limestone" was deposited on a uniformly eastward-dipping slope, and that the slope of the surface was less than the present dip of the bed, the convergence map represents the attitude of the top of the Dakota formation at the end of "Algal limestone" deposition. Thus, since the present regional dip of the Dakota is to the north rather than to the northwest, it is judged that this horizon was tilted toward the east after the deposition of the "Algal limestone."

Minor and local structural movements may have taken place during the Cenozoic Period. However, in Kansas, movements on the major structural features—the Las Animas arch, the Cambridge arch, and the Western Kansas basin—show no evidence of movement during the Tertiary Period. Epeirogenic rather than orogenic movements predominated in the Cenozoic in western Kansas.

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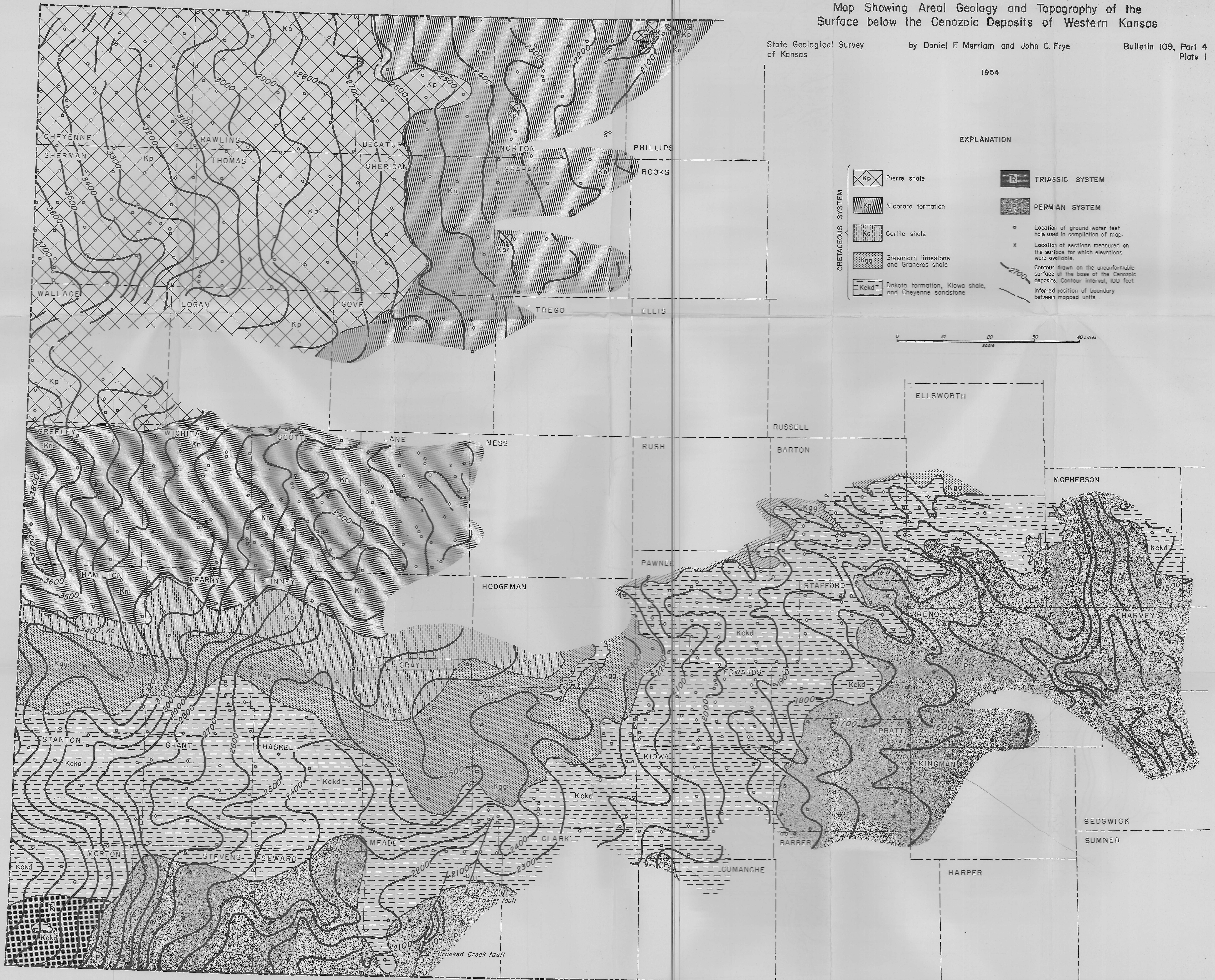
Map Showing Areal Geology and Topography of the Surface below the Cenozoic Deposits of Western Kansas

State Geological Survey of Kansas

by Daniel F. Merriam and John C. Frye

Bulletin 109, Part 4
Plate 1

1954



Structure and Convergence Maps; Dakota and Ogallala Formations in Western Kansas

State Geological Survey of Kansas

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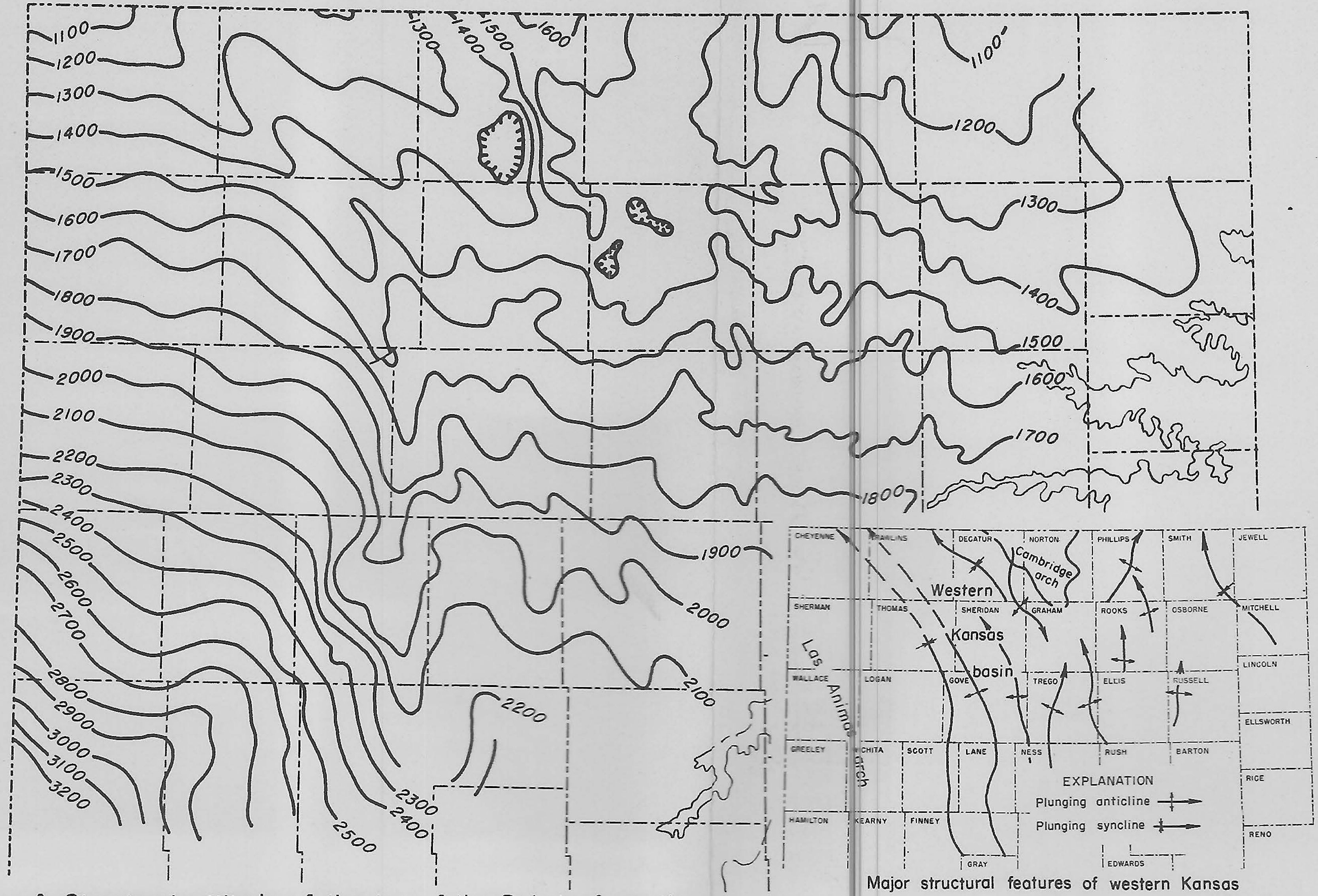
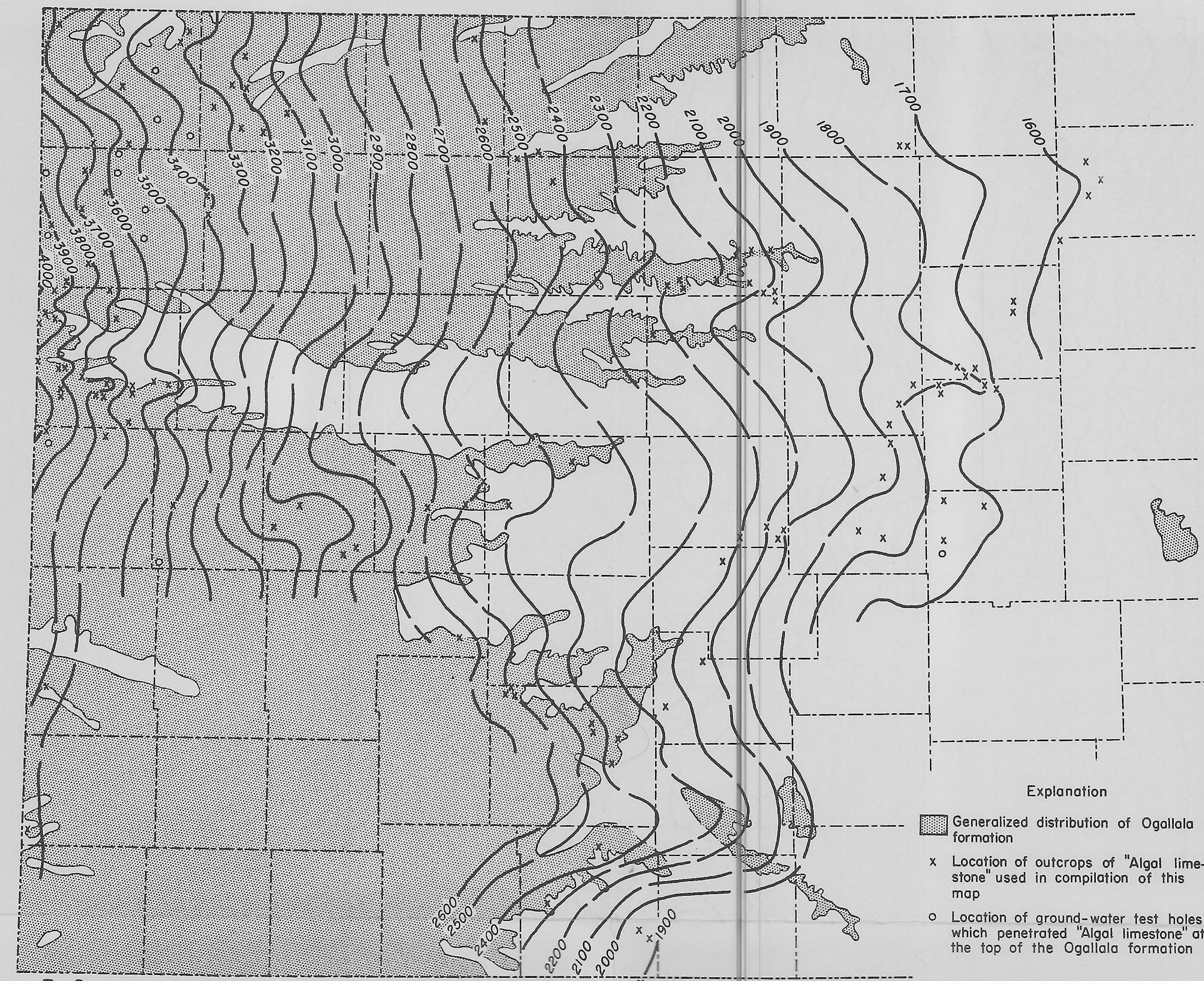
1954

Bulletin 109, Part 4
Plate 2



Major structural features of western Kansas

A. Structural attitude of the top of the Dakota formation
(From Lee and Merriam, 1954)

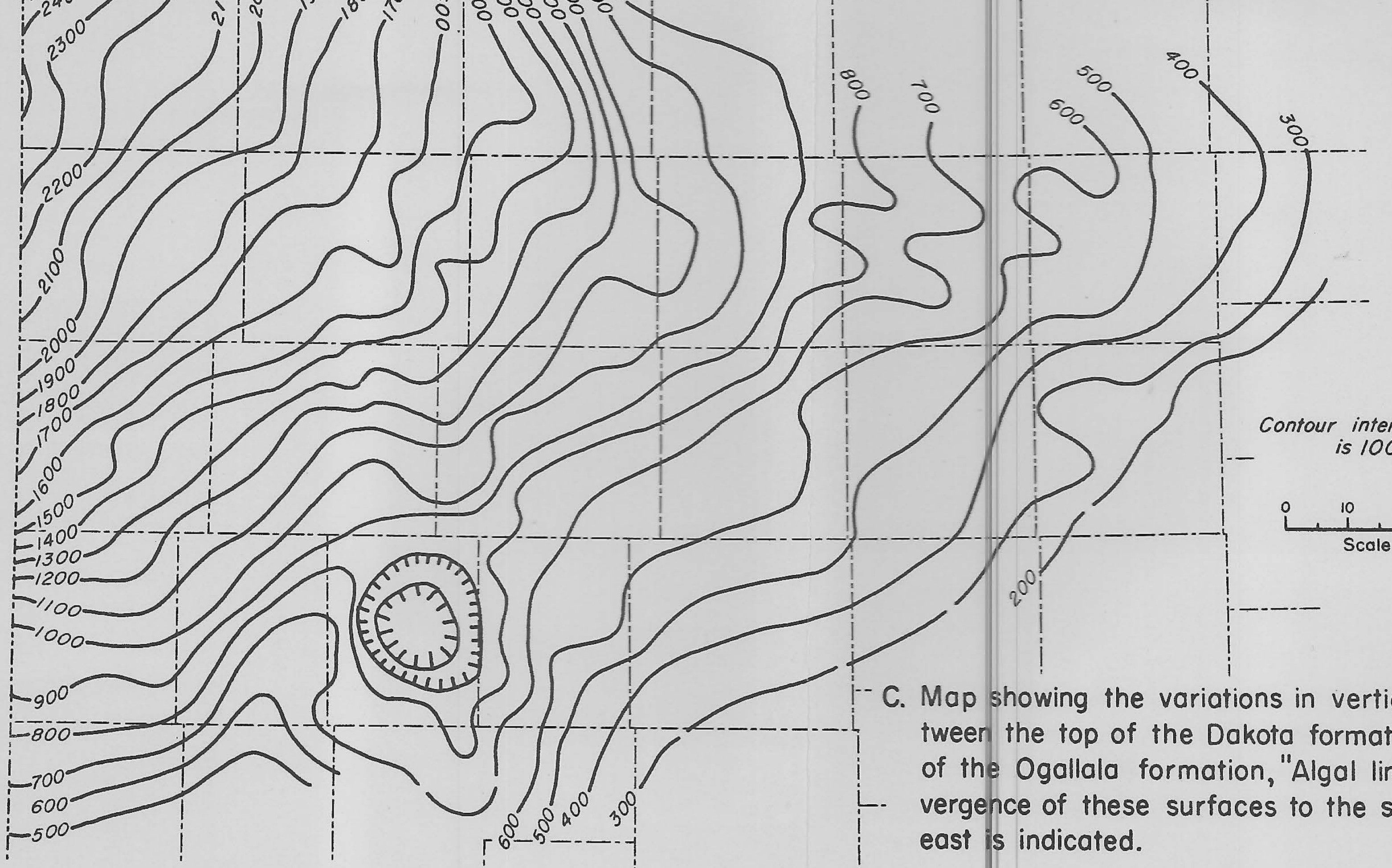


Explanation

- Generalized distribution of Ogallala formation
- x Location of outcrops of "Algal limestone" used in compilation of this map
- o Location of ground-water test holes which penetrated "Algal limestone" at the top of the Ogallala formation

B. Structural attitude of the top of the Ogallala formation ("Algal limestone")

(Elevations were in part taken from U.S.G.S. quadrangle maps.)



Contour interval for all maps is 100 feet

0 10 20 30 40
Scale in miles

C. Map showing the variations in vertical interval between the top of the Dakota formation and the top of the Ogallala formation, "Algal limestone". Convergence of these surfaces to the south and southeast is indicated.