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Paleotectonic Investigations of the
Pennsylvanian System in the United States

by

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Paleotectonic Investigations of the Pennsylvanian System in the United States

Chapter 8. Kansas[1/]

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Area A: Gray to buff sandstone overlying red and gray sandy or clayey mudstone of interval D

Area B: Gray sandy mudstone or locally, gray sandstone

Area C: Gray, red or variegated sandy, clayey mudstone

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Area C: Gray to buff, aphanitic to finely crystalline, locally chert-bearing, dolomitic or sandy limestone overlain by red and gray or variegated clayey mudstone, sandy clayey mudstone, or in some places sandstone or clayey mudstone containing thin beds of limestone------------------------------------

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.8-.9 Clayey mudstone. Marine or nonmarine.

.7 Algal limestone, locally oolitic or coquinoidal. Contains mollusks, brachiopods, bryozoans, crinoids. Marine.

.6 Sandy, clayey mudstone. Marine.

.5 Fusulinid-bearing limestone. May contain brachiopods, bryozoans, crinoids. Marine.

.4 Mollusk-bearing clayey mudstone. Marine.

.3 Pelecypod-bearing limestone. Also contains brachiopods and crinoids. Marine.

.2 Clayey mudstone bearing pelecypods, brachiopods, bryozoans. Marine.

.1 Coal, underlain by sandy, clayey mudstone. Nonmarine.

.0 Sandstone. May contain plant fossils. Nonmarine. (Adapted from Moore, 1936, p. 23, 25, 26; 1949b, p. 181; Zeller and others, 1967, pl. 1; Johnson and Wagner, 1957, pl. 3)------------

a

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ABSTRACT

Pennsylvanian strata of Kansas lie on eroded rocks ranging in age from Precambrian to Mississippian. Precambrian and early Paleozoic rocks underlie the Pennsylvanian on the Central Kansas uplift and Nemaha anticline. Mississippian rocks underlie the Pennsylvanian in the Forest City, Cherokee, Salina, and Sedgwick basins and in the Hugoton embayment of the Anadarko basin. These structural elements existed in Mississippian time; they were rejuvenated during Pennsylvanian time. They influenced kinds and thicknesses of Pennsylvanian sediment.

Pennsylvanian seas encroached mainly from the south. Sedimentation began in the Hugoton embayment during time of interval A (Morrow). Most of the Hugoton embayment and the Cherokee and Forest City basins were submergent during time of interval B (Atoka - lowermost Des Moines). All of Kansas except crests of the Nemaha anticline and Central Kansas uplift was covered by beds of interval C (Des Moines-lowermost Missouri). Strata of intervals D (Missouri) and E (Virgil) extended throughout the State. Pennsylvanian rocks are slightly thicker than 3,000 feet in the deepest part of the Hugoton embayment; they are thinner than 700 feet on crests of the Nemaha anticline and Cambridge arch.

The Pennsylvanian consists of thin but extensive limestones, marine and nonmarine mudstones and sandstones, and terrestrially deposited coals. The strata compose many cyclothems, especially in intervals C, D and E. Sediments were deposited almost entirely in shallow marine, paralic and terrestrial environments. Seas were mainly clear, warm, and moderately quiescent. Coastal regions were lowly emergent, swampy, thickly vegetated, and crossed by sluggish streams. Source area of terrigenous sediment during time of intervals A and B was mainly the terrane of early Paleozoic rocks in Kansas. Source areas of terrigenous sediment during times of intervals C, D and E were mainly the emergent Arbuckle Mountain region in Oklahoma and the Ozarks in Missouri.

Pennsylvanian strata were overlapped by Permian beds that probably extended entirely throughout Kansas. Permian beds were eroded from above the Pennsylvanian in eastern Kansas, perhaps mostly during the Triassic and Jurassic periods. This terrane may have been overstepped by Cretaceous strata. Pennsylvanian strata of eastern Kansas were eroded to peneplain-like topography during the Tertiary Epoch. Rivers of eastern Kansas have been superimposed into Pennsylvanian strata during post-Pliocene time.

Acknowledgements

My sincere appreciation is extended to Theodore E. Jacques, Sally Liggett Brown, Richard Schuman, Carl B. Kinnell, and Daniel F. Merriam, who helped in compiling the basic data for this paper. I express my appreciation to Daniel F. Merriam for providing the opportunity to undertake this work, and for his advice during the early stages of the project.

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REGION DEFINED

The region discussed in this chapter consists of the State of Kansas. Pennsylvanian rocks are exposed in the eastern part and occur in the subsurface throughout the State except in the extreme southeastern area (fig. GFS-1). Beds dip gently westward and the system attains a maximum

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Figure GFS-1. -- NEAR HERE.

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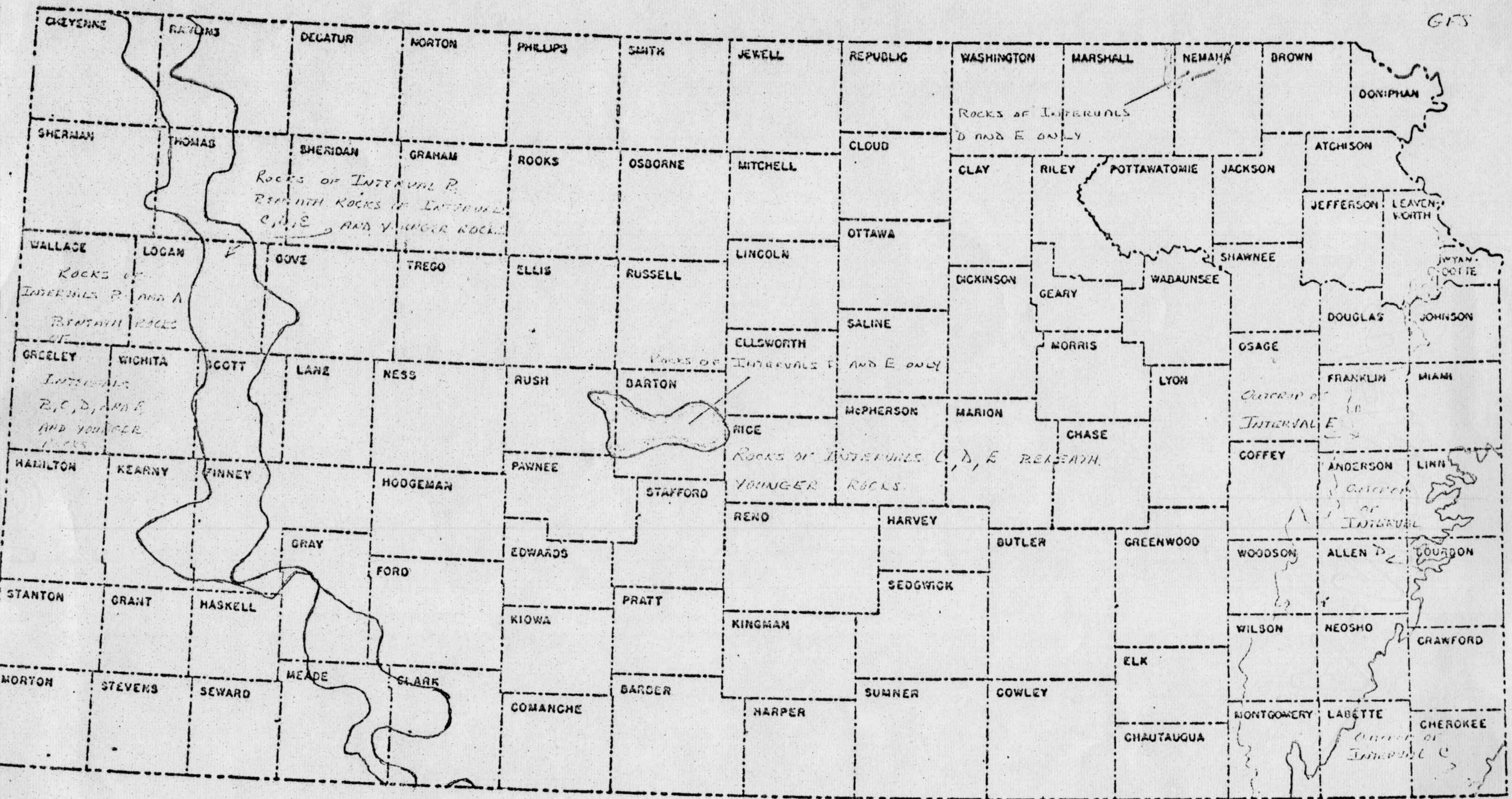
thickness of more than 3,000 feet in southwestern Kansas.

Figure GFS-1.--Distribution of Pennsylvanian rocks by intervals in Kansas. Also shown are counties, towns and geographic features referred to in text.

NOTE: TO BE REDUCED TO ABOUT 5.5 IN X 2.5 IN. COUNTY NAMES NOT REFERRED TO IN TEXT WILL BE DELETED. GEOGRAPHIC FEATURES REFERRED TO WILL BE ADDED.

GFS

~~FIG 1~~



675-1

Figure 1. – Distribution of Pennsylvanian rocks in Kansas. Also shown are counties, towns, and geographic features referred to in text.

Figure 675-1

PALEOGEOLOGY

Units underlying Pennsylvanian

Pennsylvanian rocks overlie Mississippian rocks throughout most of Kansas (pl. 2). In some areas on the Central Kansas uplift and Nemaha anticline (fig. GFS-2; pl. 2) rocks of Pennsylvanian

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Figure GFS-2.--NEAR HERE

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intervals C and D lie unconformably upon Paleozoic rocks older than Mississippian, and on some eroded anticlines they overlie rocks as old as Precambrian.

Rocks underlying the Pennsylvanian were not studied in detail during this investigation and they are differentiated only in a general manner on the paleogeologic map (pl. 2; table GFS-1). The Chattanooga Shale is mapped as a unit with rocks of the Hunton Group, in spite of the fact that the Chattanooga is of both Mississippian and Devonian age. The Hunton Group has been differentiated into Silurian and Devonian rocks only in a few places in Kansas. Similarly, the Arbuckle Group comprises rocks of Late Cambrian and Early Ordovician ages and these rocks have been differentiated only in eastern Kansas. The Reagan Sandstone is Late Cambrian in age but is mapped with Precambrian rocks because of the limited areal extent of the Reagan on higher parts of the Central Kansas uplift and Cambridge arch.

Table 1.--Major stratigraphic units underlying the Pennsylvanian in Kansas. Units shown only those included on paleogeologic map (Fig. 3).

SYSTEM	SERIES	GROUP	FORMATION
Mississippian	Chester		
	Meramec		
	Osage		
	Kinderhook		
Mississippian or Devonian			Chattanooga Shale
Devonian	Middle Devonian		
Silurian	Lower Silurian	Hunton Group	
Ordovician	Upper Ordovician		Maquoketa Shale
	Middle Ordovician		Viola Limestone
		Simpson Group	
	Lower Ordovician	"Arbuckle" Group	
Cambrian	Upper Cambrian		Reagan Sandstone
Precambrian Rocks			

Figure GFS-2.--Structural elements of Kansas in Late Mississippian and Early Pennsylvanian time (from evidence shown by Goebel, 1966, pl. 20; Merriam, 1962, p. 170; and Goebel and Stewart, 1971; manuscript in preparation.)

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GFS-2.
Figure 6. Structural elements of Kansas in Late Mississippian and Early Pennsylvanian time.
GFS

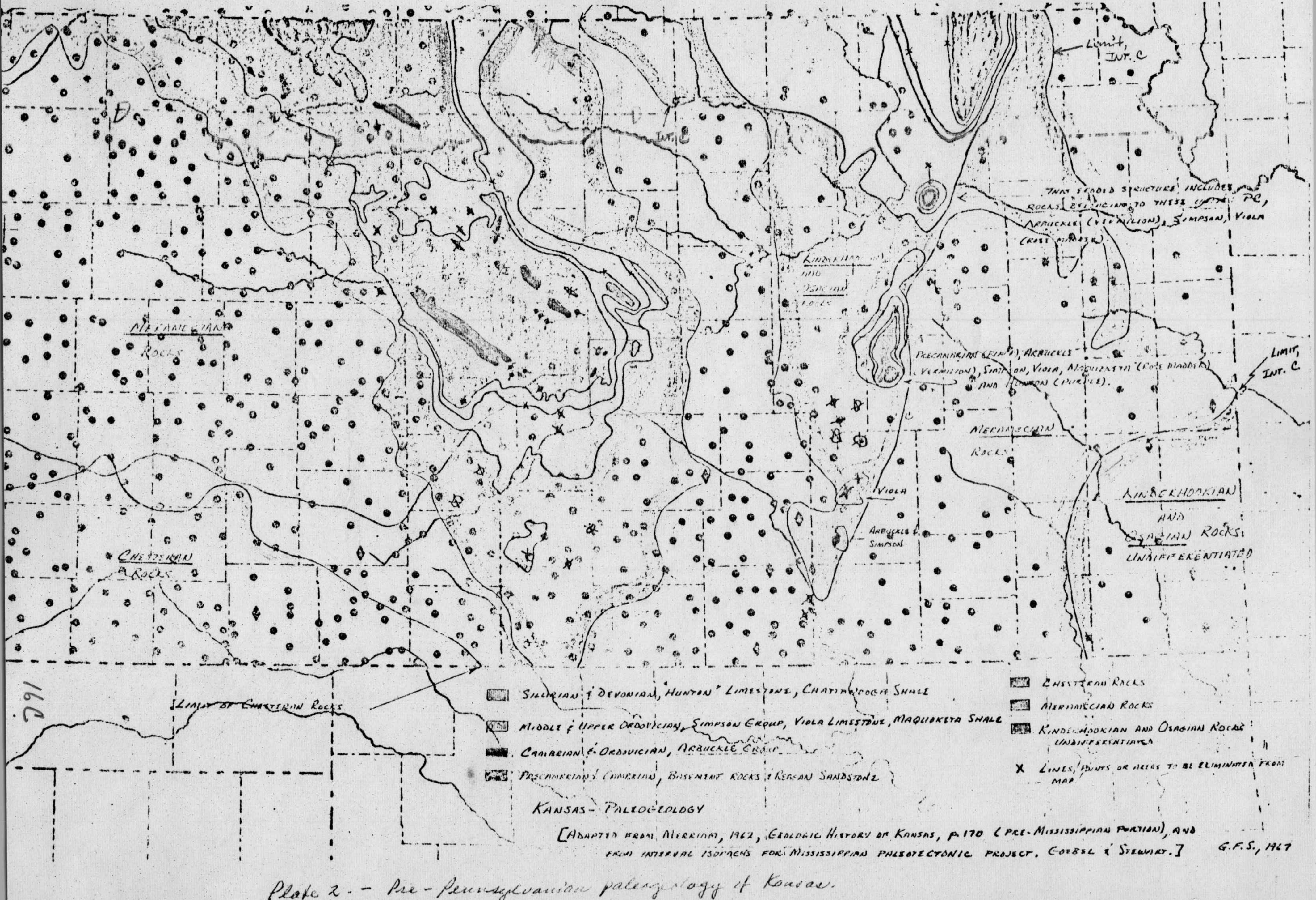

Plate 2. — Pre-Pennsylvanian paleogeology of Kansas.

Lower boundary of Pennsylvanian

Throughout Kansas, lowermost Pennsylvanian rocks generally are coarsely clastic and they lie unconformably upon deeply weathered and eroded rocks that are dominantly limestone and dolomite. In general, the terrane of older rocks is covered by a veneer of residual material and the reworked upper part of the residuum is accepted in Kansas as being the lowermost Pennsylvanian deposit. The boundary between reworked and residual material commonly is difficult to recognize in oil-well bit cuttings. Accordingly, the lower boundary of the Pennsylvanian is not precisely known in all parts of Kansas, in spite of the fact that an unconformity separates Pennsylvanian and older rocks throughout the state.

Residuum developed on Mississippian carbonate rocks commonly is composed of tripolitic chert that ranges in thickness from a few inches in southeastern Kansas (Howe, 1956, p. 31) to more than 100 feet further west in Sumner County (Lee, 1940, p. 76) (see fig. GFS-1). In central Kansas residual material developed upon weathered dolomite of the Arbuckle Formation consists mostly of chert, clay, silt and sand (Walters, 1946, p. 228).

In the part of Kansas generally east of the Nemaha anticline (fig. GFS-2) lowermost Pennsylvanian rocks dominantly are clayey mudstone, but sandstone that contains fragments of Mississippian chert is present in some places; in the Forest City basin (fig. GFS-2) basal Pennsylvanian rocks contain a small amount of arkose (Lee, 1943, p. 82). In a few places in Kansas, rocks representing the lowermost Pennsylvanian occur some tens of feet below the surface of the Mississippian or other Paleozoic carbonate rocks. In Jefferson and Leavenworth counties in northeastern Kansas (fig. GFS-1), black clayey mudstones that seem to be younger than Mississippian are fillings in pockets in Mississippian limestone (Lee, 1943, p. 78-79). These rocks were considered by Lee as being deposits in solution openings and caves; some of the constitutents of the mudstone were not recognized by him in other Mississippian or Pennsylvanian rocks. Lowermost Pennsylvanian rocks in the Joplin district of extreme southeastern Kansas and southwestern Missouri are described by Smith and Siebenthal (1907, p. 8) as having been deposited in caves in karst terrane.

In much of western Kansas, rock identified as lowermost Pennsylvanian commonly is a conglomerate or coarse sandstone and is called the Pennsylvanian basal conglomerate. It comprises variegated and locally oxidized mudstone, sandstone, and chert and ranges in thickness from a featheredge to more than 150 feet in some places (Ver Wiebe, 1941, p. 27). Pennsylvanian sandstone, limestone and mudstone overlie similar rocks of Chester age in southwestern Kansas (pl. 2) and in some places the unconformity at the base of the Pennsylvanian is obscure (McManus, 1959, p. 19).

Lowermost Pennsylvanian rocks are as old as Morrow in western Kansas and as young as Missouri in some parts of the Central Kansas uplift and Nemaha anticline (figs. GFS-1 and GFS-2).

Pre-Pennsylvanian topography

The paleogeomorphology of the surface beneath Pennsylvanian rocks is well known in only a few places in Kansas. Mississippian rocks are covered by a mantle of residual chert throughout much of the state. Features interpreted as caves in Mississippian rocks of northeastern Kansas that are filled with Pennsylvanian sediments are described by Lee (1943, p. 78-79). Sinkholes in exposed Mississippian rocks of southeastern Kansas were studied by Pierce and Courtier (1937), and by Saueracker (1965). The Cherokee Group in southeastern Kansas is considered to have been deposited upon a surface that was not replete with sinkholes and subterranean streams (Pierce and Courtier, 1937, p. 37; Saueracker, 1965, p. 26-27). However, the surface beneath this group in the Joplin district of extreme southeastern Kansas and southwestern Missouri is described as "karst topography of great detail" by Smith and Siebenthal (1907, p. 11).

Topographic features in Mississippian rocks that seem to be sinkholes have been discovered in Dickinson and Wabaunsee counties in east-central Kansas (fig. GFS-1) (Shenkel, 1955, p. 1; Smith and Anders, 1951, p. 29) and in Sumner County in south-central Kansas (Lee, 1940, p. 76-77). Isolated sinkholes that are less than 20 acres in area and solution valleys ranging from 20 to 80 feet deep, developed in rocks of the Arbuckle Group in oil fields in northeastern Barton County, were studied by Walters (1946); also, depressions believed to be sinkholes in karst terrane located in rocks of the Arbuckle Group in oil fields of Barton and Russell counties were described by Ver Wiebe (1941, p. 26-27, 82).

The widespread development and variable thickness of residual chert in the upper part of the Mississippian, according to Goebel (1966, p. 132), are evidence of karst topography throughout western Kansas. Thus, buried, moderately-developed karst topography is present in several places in Kansas and may be present in all areas where carbonate rocks underlie the Pennsylvanian, as indicated by the evidence compiled by authors cited above.

The amount of erosional relief on the surface beneath Pennsylvanian rocks is not well documented, but in some areas it may have ~~had a maximum of~~ been maximally only a few tens of feet. In northeastern Kansas the pre-Pennsylvanian surface is described as peneplain-like topography with broad, shallow valleys (Lee and Payne, 1944, p. 60-61). In southeastern Kansas relief on the surface of Mississippian rocks locally may have been as little as 20 feet (Pierce and Courtier, 1937, p. 37-38) and in Greenwood County (fig. GFS-1) it rarely exceeds 100 feet within a township (Bass, 1936, p. 21).

A pre-Pennsylvanian "mesa" in rocks of the Arbuckle Group is mapped by Ver Wiebe (1940, p. 82-84, pl. 1) in Barton and Russell counties (fig. GFS-1). This feature includes about 12 square miles of karst terrane, and in some areas slope of the surface is less than 10 feet per mile. Two pinnacles of Precambrian rocks that stand above the Arbuckle terrane are 30 and 60 feet high and less than 160 acres in area. Slope of the eroded surface of pre-Pennsylvanian rocks on the crest of the Cambridge arch (fig. GFS-2) locally was only about 20 feet per mile (Merriam and Atkinson, 1955, p. 20-21).

Initial folding of the Nemaha anticline (fig. GFS-2) began during Mississippian time according to Lee (1943, p. 115) and pronounced development of this feature occurred at the end of Mississippian sedimentation. The Central Kansas uplift was partly developed before deposition of Pennsylvanian rocks (Lee, 1953, p. 20). Erosional relief in parts of these two structural provinces probably was more than that in the other areas of Kansas; before deposition of Pennsylvanian sediments the Nemaha anticline and the Central Kansas uplift may have been ranges of low hills within vast plains of exceedingly low relief.

Paleotectonic implications

Most of the structural features that influenced deposition of Pennsylvanian sediments were present in part during Late Mississippian time. Initial movement of the Nemaha anticline may have taken place as early as Kinderhook time (Lee, 1943, p. 115), and minor anticlinal folding in the areas of the Central Kansas uplift and Cambridge arch took place before and during the Mississippian period (Lee, 1953, p. 20; Goebel, 1966, p. 46). Areas now included in the Forest City basin, Cherokee basin, Salina basin and the Hugoton embayment of the Anadarko basin (fig. GFS-2) were synclinal structures in Mississippian time (Lee, 1943, p. 120; Goebel, 1966, p. 142). These structures were rejuvenated and strongly folded during Late Mississippian time, and many smaller anticlines and synclines were formed. The present structural framework of Kansas was established before transgression of Pennsylvanian seas.

INTERVAL A

Formations included

Interval A is present in western Kansas only in the subsurface (pl. 3A) where it is comprises of the Kearny Formation. The Kearny occurs between the Mississippian System and the Atoka Series (table GFS-2). It is assigned a Morrow age on the basis of several species of Millerella (Thompson, 1944).

The type section of the Kearny Formation is in the Stanolind Oil and Gas Company Number 1 Patterson well, in Kearny County, Kansas (fig. GFS-3). This formation consists chiefly of clayey mudstone,

Figure GFS-3.--NEAR HERE

sandy mudstone and calcareous mudstone in most places, but limestone and sandstone are locally predominant in parts of Kansas. The formation includes two unnamed members; the lower is the thinner and is overlapped toward the eastern margin of the Hugoton embayment (fig. GFS-2).

SERIES	GROUP	INTERVAL	FORMATION
VIRGIL	WABAUNSEE GROUP	E	WOOD SIDING FORMATION
			ROOT SHALE
			STOTLER LIMESTONE
			PILLSBURY SHALE
			ZEANDALE LIMESTONE
			WILLARD SHALE
			EMPORIA LIMESTONE
			AUBURN SHALE
			BERN LIMESTONE
			SCRANTON SHALE
			HOWARD LIMESTONE
			SEVERY SHALE
	SHAWNEE GROUP		TOPEKA LIMESTONE
			CALHOUN SHALE
			DEER CREEK LIMESTONE
			TECUMSEH SHALE
			LECOMPTON LIMESTONE
			KANWAKA SHALE
			OREAD LIMESTONE
	DOUGLAS GROUP		LAWRENCE FORMATION
			STRANGER FORMATION
MISSOURI	LANSING GROUP		STANTON LIMESTONE
			VILAS SHALE
			PLATTSBURG LIMESTONE
	KANSAS CITY GROUP	D	BONNER SPRINGS SHALE
			WYANDOTTE LIMESTONE
			LANE SHALE
			IOLA LIMESTONE
			CHANUTE SHALE
			DRUM LIMESTONE
			CHERRYVALE SHALE
			DENNIS LIMESTONE
			GALESBURG SHALE
			SWOPE LIMESTONE
			LADORE SHALE
			HERTHA LIMESTONE
	PLEASANTON GROUP		TACKET FORMATION
			CHECKERBOARD LIMESTONE
			SEMINOLE FORMATION
DES MOINES	MARMATON GROUP	C	HOLDENVILLE SHALE
			LENAPAH SHALE
			NOWATA SHALE
			ALTAMONT LIMESTONE
			BANDERA SHALE
			PAWNEE LIMESTONE
			LABETTE SHALE
			FORT SCOTT LIMESTONE
	CHEROKEE GROUP		CABANISS FORMATION
			KREBS FORMATION
ATOKA	(UNDIFFER. GROUPS)	B	[illegible]
MORROW	(NO NAMED SERIES)	A	KEARNY FORMATION

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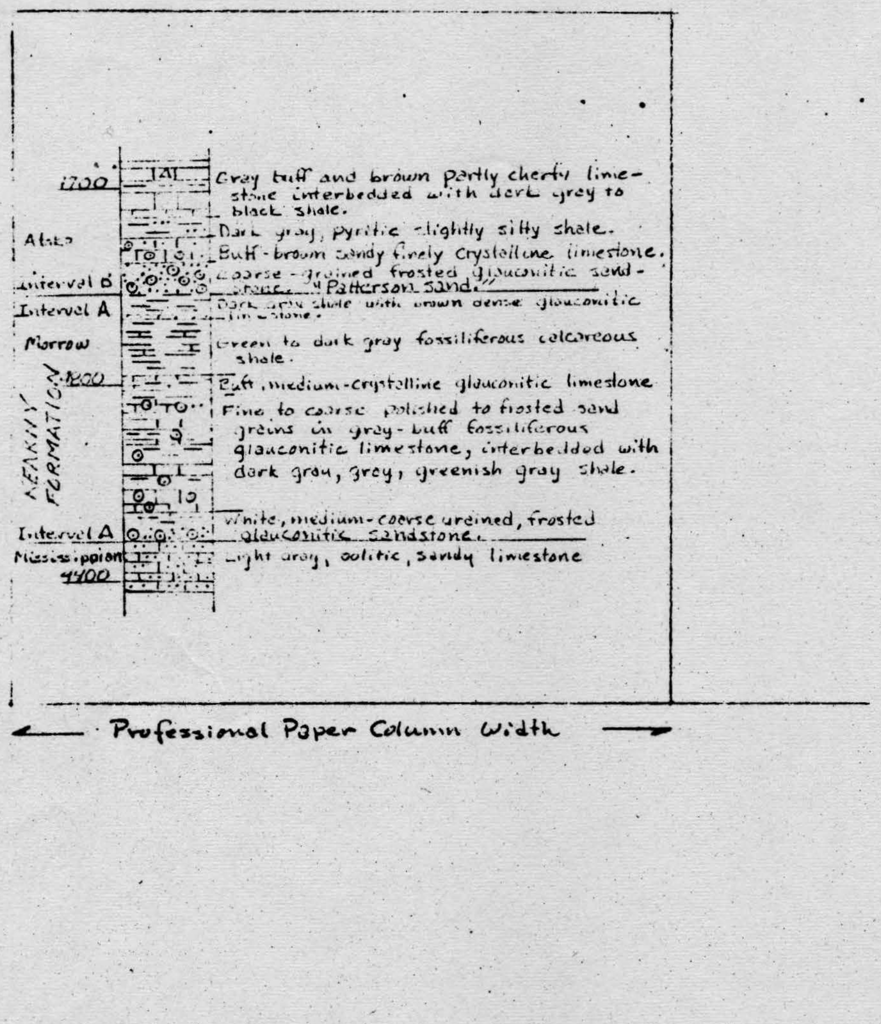
Figure GFS-3.--Type section of Kearny Formation, Stanolind Oil and Gas Company No. 1 Patterson well, Sec. 23, T. 22 S., R. 38 W., Kearny County, Kansas (after J. D. Davies, Kansas Sample Log Service Log. No. 9219).



INTERVAL A.

KANSAS, ~~FIG 3~~, ROUGH COPY

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Figure 675-3

Upper boundary of interval A

In the deepest part of the Hugoton embayment, from Hamilton and Kearny Counties southward (fig. GFS-1), the boundary between intervals A and B generally is placed at the contact of clayey mudstone and sandstone of the Kearny Formation with the limestone above. Clayey mudstone of the uppermost parts of interval A is gray, greenish gray, black and, locally, variegated. Coal beds are present at or a short distance below the boundary. Near the eastern margin of the interval the clayey mudstone commonly is variegated and contains a relatively large proportion of sandstone.

Throughout southwestern Kansas, the lowermost limestone of interval B is gray or brown, dense, finely crystalline and chert-bearing; locally it is clayey or sandy. At some places the basal rocks of interval B consist of sandstone, as, for example, where the Patterson sand lies above the type section of the Kearny Formation in the Stanolind Number 1 Patterson well, Kearny County (fig. GFS-3).

From Hamilton and Kearny Counties northward, rocks of the uppermost part of interval A are composed chiefly of clayey mudstone, but in some places sandstone is present below the boundary. In deep parts of the Hugoton embayment mudstone, below the boundary, generally is dark gray, greenish gray or black, and locally is either sandy or calcareous, whereas near the eastern limit of interval A it is variegated and contains considerable amounts of sandstone.

In central western Kansas and in northwestern Kansas lowermost rocks of interval B consist mostly of limestone, but locally sandstone or mudstone is dominant. The limestone is gray to brown, finely crystalline, dense, chert-bearing, and is interbedded with clayey mudstone. Sandstone is white to gray, slightly glauconitic and is interbedded with clayey mudstone at some places.

Throughout western Kansas the upper part of interval A grades from dominantly grayish, coal-bearing, clayey mudstone in the deeper parts of the Hugoton embayment to variegated sandy or clayey mudstone near the eastern limit of the interval.

Thickness trends

Interval A thickens irregularly westward and southwestward from a beveled edge (pl. 3A) to at least 630 feet in eastern Morton County, Kansas (fig. GFS-1). It is less than 200 feet thick throughout most of its extent in Kansas, and is more than 500 feet thick only in a small part of southwesternmost Kansas. The interval thickens near the Anadarko basin of Oklahoma and Texas, but shows marked thinning across the Keyes dome (fig. GFS-2; pl. 3A). Irregularity in thickness in western Finney County and eastern central Kearny County probably is the result of both depositional thinning and erosion.

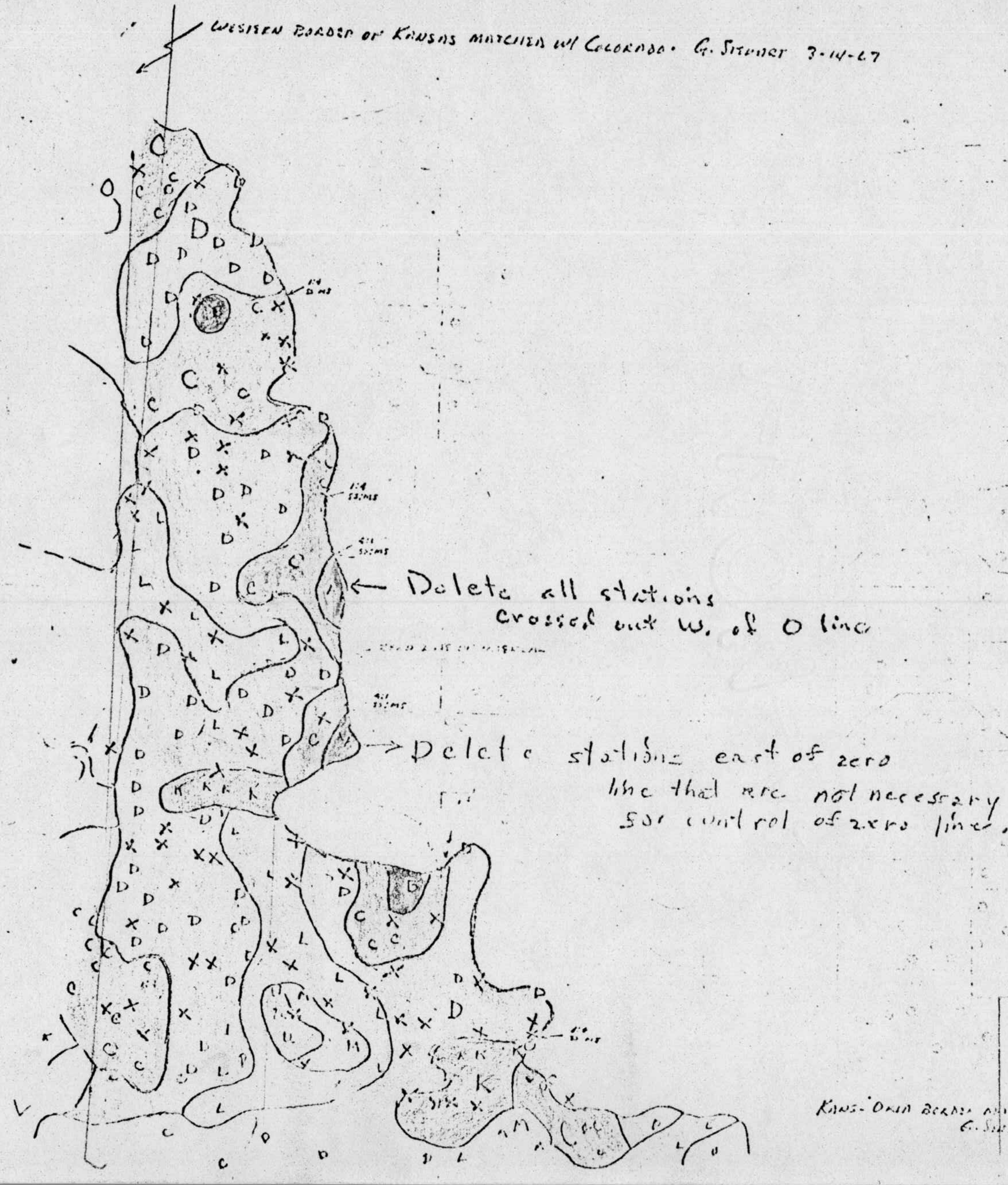
Lithofacies trends

Interval A, which includes only the Kearny Formation, is composed mainly of sandy mudstone, calcareous mudstone and clayey mudstone (pl. 3B). Sandstone and clayey sandstone are dominant in a few areas near the eastern limit of the interval, and these coarse-grained clastic rocks grade generally westward and southward into clayey and calcareous mudstone. The interval is composed predominantly of limestone in only a small area in Stevens and Seward Counties. Sandy mudstone is abundant in western Morton County (fig. GFS-1; pl. 3B).

Clayey mudstone of the lower member of the Kearny Formation is dark gray to black, thinly laminated or fissile. Sandstone ranges from white to light gray and is fine- to medium-grained, mostly lenticular, and contains granular glauconite in many places. Limestone is tan to light brown, arenaceous, and crinoidal. Fauna of the lower member includes crinoids, brachiopods and bryozoans.

Clayey mudstone of the upper member typically is dark gray or black. Locally some of it is variegated and in the upper part of the formation it is greenish to light gray in places. Sandstone of the upper member is mainly fine-grained; limestone is crystalline and arenaceous in the lower part but dense and argillaceous in the uppermost parts. The fauna includes brachiopods, horn corals, bryozoans, gastropods, crinoids, pelecypods, foraminifers and some ostracodes. Numerous thin coal beds are in the uppermost parts of the Kearny.

INTERVAL A



Symbols

A = ss.
B = clayey ss.
C = sndy mudstone
D = clayey mudstone (>80%)
K = sandy clayey ls
L = limy mudstone
M = clayey mudstone
U = ls (>80%)

Plate 675-3B. Lithofacies, int. A

~~FIG. 6~~

Sources and environments of deposition

During the time of interval A, the Hugoton embayment of Kansas was an open shelf bordering the Anadarko basin. Transgression of the sea across the shelf was not continuous, as shown by limestone, sandstone, and coal interbedded within interval A. Extensive units of silt- and sand-sized rock and of clastic carbonate rocks (McManus, 1959, p. 60-77) indicate that from time to time the sea maintained moderately high levels of energy.

Variegated clayey mudstone along the eastern margin of the interval, a local preponderance of sandstone and the abundance of frosted sand grains suggest that shorelines were not far removed from the present eastern boundary of interval A. Large amounts of sandy, clayey mudstone in northwestern Kansas indicate that the embayment may have extended only a short distance beyond into Nebraska and northeastern Colorado. Sandy clayey mudstone in western Morton County (pl. 3B), and minor amounts of arkosic sandstone in the interval in Morton, Hamilton, Stanton and Seward Counties (fig. GFS-1) imply that coarse detritus was brought into the Hugoton embayment of Kansas from areas of exposed basement rock in Colorado.

In western Kansas the sea in which interval A was deposited was bounded on the east by the western flanks of the Pratt anticline, the Central Kansas uplift, and the Cambridge arch (fig. GFS-2). During early stages of transgression, detrital materials were supplied from the western flank of this anticlinorium and from the Keyes dome (McManus, 1959, p. 134); also, residual materials on the pre-Pennsylvanian surface were reworked. Depositional landforms during early stages of accumulation of interval A, according to McManus (1959, p. 134-135), included alluvial channels, deltas, offshore bars, and mud-floored lagoons. These environments were succeeded gradually and with alternation by generally open-marine conditions, as shown by an increased percentage of limestone (McManus, 1959, p. 132) in the upper part of the lower member of the Kearny.

The fauna of the interval, although not abundant, includes brachiopods, horn corals, bryozoans, gastropods, crinoids, pelecypods, foraminifers and ostracodes (McManus, 1959). These forms are mainly indicative of littoral and shallow-water environments. During about medial time of interval A accumulation, shorelines and depositional landforms associated with them extended the maximal distance eastward. These shorelines may have reached lower parts of the western flanks of the Cambridge arch, the Central Kansas uplift and the Pratt anticline. The Keyes dome was buried by sediment and the western shoreline extended into Colorado. During latter stages of deposition of interval A the sea regressed into deeper parts of the Anadarko basin. The terrane of the Hugoton embayment probably consisted mostly of mudflats and extensive coal basins.

Paleotectonic implications

During the early part of Pennsylvanian time, the Hugoton embayment in southwestern Kansas was a broad, southward-plunging synclinal flexure that became slowly emergent. This syncline of regional extent was bounded on the east by the slightly uplifted, gentle anticlinorium comprising the Pratt anticline, Central Kansas uplift and Cambridge arch. The embayment extended northwestward into Colorado and was bounded on the southwest by the Keyes dome. The pre-interval A terrane consisted of exposed Meramec and Chester rocks (pl. ~~3B~~ 2). GFS

Subsidence of the Anadarko basin in Oklahoma during Springer and Morrow time may have been accompanied by progressive development of all the major flexures that were present in Kansas during the latter part of the Mississippian Period (fig. GFS-2). The Hugoton embayment probably subsided slowly and the regional anticlinal structures that bounded it presumably rose slightly. Subsidence of most of the embayment was less than 500 feet; maximum subsidence in Morton, Stanton, and Stevens Counties, probably did not exceed 750 feet.

Moderate erosion took place throughout the Kansas region after the accumulation of interval A. The easternmost boundary of the interval was eroded a short distance westward and small amounts of material probably were eroded from the top of the interval, locally even in central parts of the Hugoton embayment. Absence of the interval in western Finney County and eastern Kearny County is considered to be evidence that an anticlinal fold was present in that area during accumulation of interval A. Rocks of the interval probably were removed from the fold during the post-interval A emergence of the Hugoton embayment.

INTERVAL B

Formations included

Interval B is present in the subsurface of both western Kansas and eastern Kansas (fig. GFS-4). In western Kansas interval B

Figure GFS-4.--NEAR HERE

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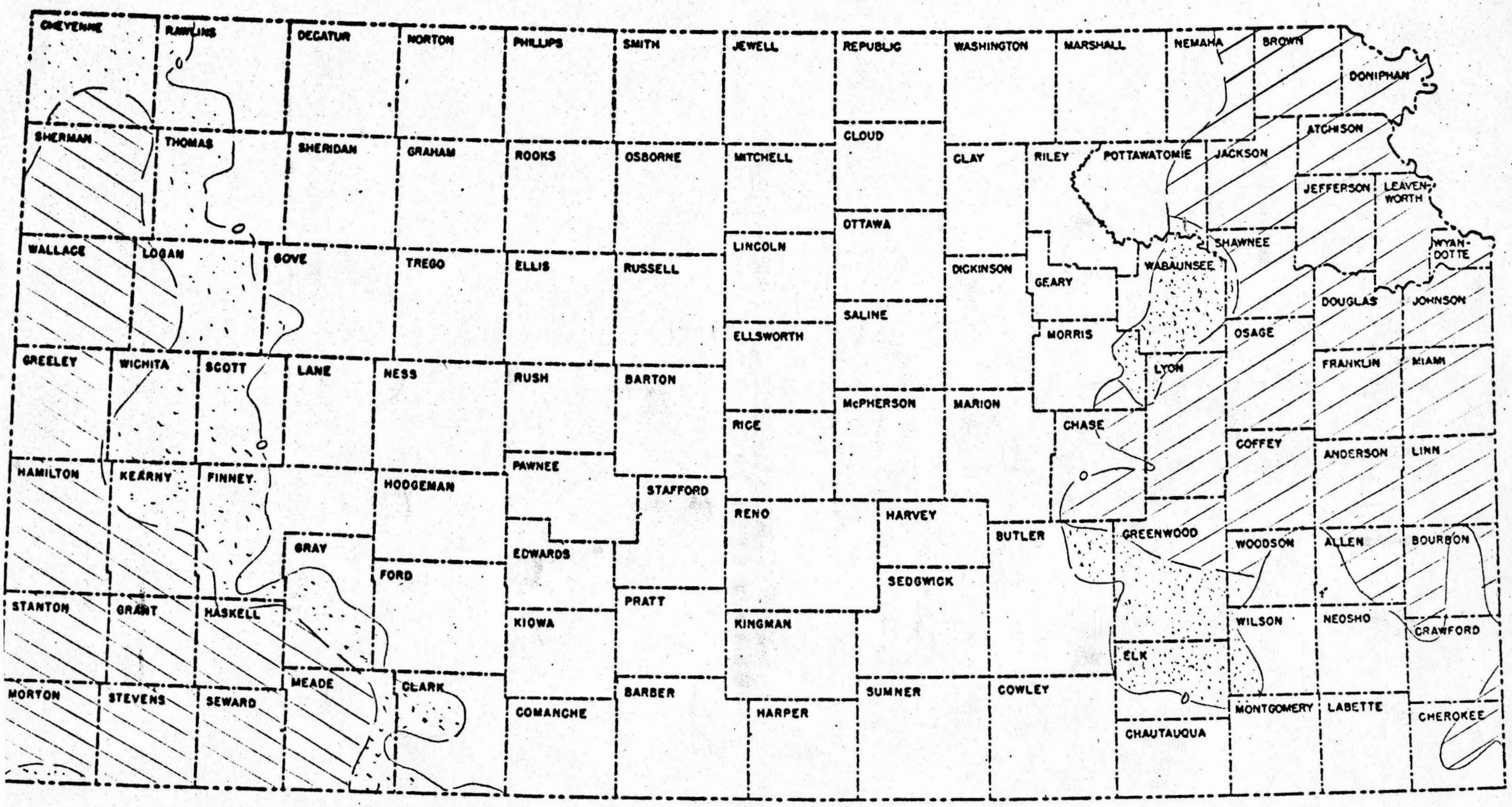
includes rocks that probably are of Atoka age. Accordingly, interval B occupies the stratigraphic position between the Kearny Formation and rocks of the Des Moines Series (interval C). Only a limited amount of research has been done on the paleontology of this interval in western Kansas, and therefore its age is not well established.

Figure GFS-4.--Generalized lithologic description of upper boundary of interval B in Kansas.



~~Figure 7.~~ General description of upper boundary of interval B.

Fig. 6 75-4

- Western Kansas - boundary between intervals B and C generally clayey mudstone below, limestone above; along featheredge boundary locally placed ' within "Pennsylvanian basal conglomerate."
- Western Kansas - boundary traceable within sequence of limestone and clayey mudstone.
- Eastern Kansas - boundary placed at contact of dark gray clayey mudstone below with varicolored sandy claye mudstone or grayish limestone above.

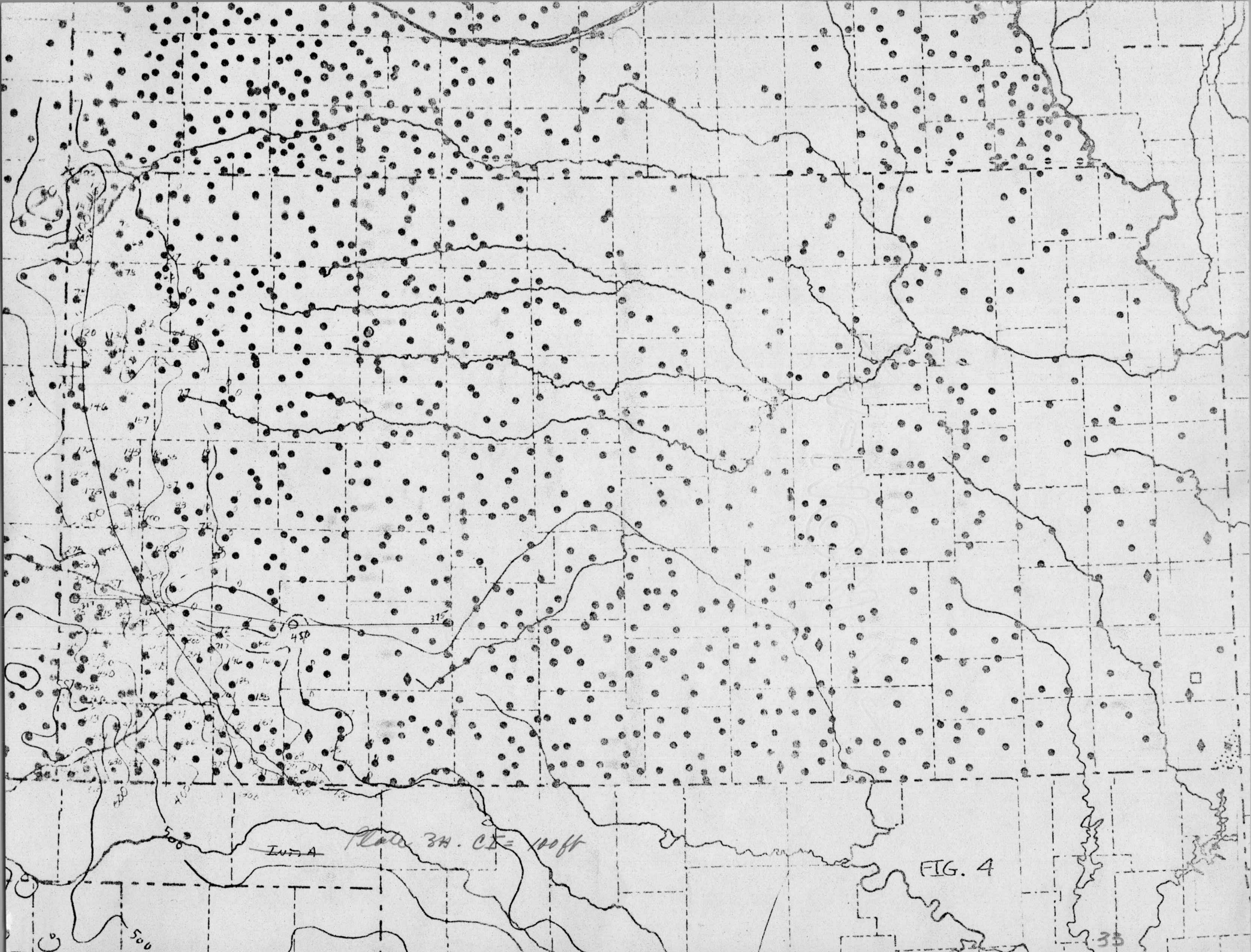


Plate 3H. CI = 100ft
IOWA
500
400
FIG. 4

In eastern Kansas interval B lies upon the Mississippian and includes rocks that have been classified in Kansas as Des Moines. These rocks are older than the Warner Sandstone Member of the Krebs Formation, Cherokee Group, throughout most of eastern Kansas. However, the top of interval B in southeasternmost Kansas is placed within the sequence below the Riverton coal (fig. GFS-5). Most of interval B of

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Figure GFS-5.--NEAR HERE

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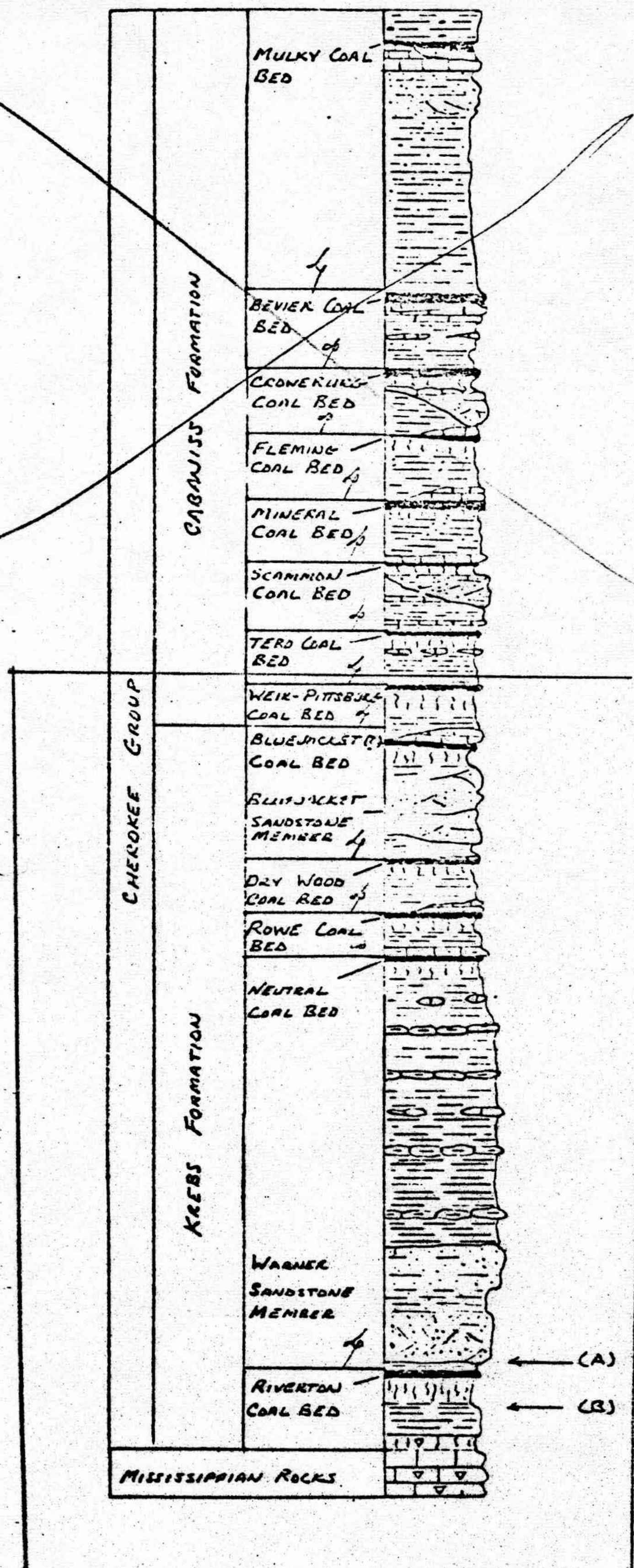
eastern Kansas may be considerably older than the Krebs Formation of northeastern Oklahoma (H. R. Wanless, 1967, personal commun.) and accordingly most of interval B probably is of Atoka age. The paleontology of Pennsylvanian rocks in deeper parts of the Forest City basin and of the Cherokee basin of Kansas (fig. GFS-2) has not been studied in detail, but regional stratigraphic relations between this part of the section and the Burgner, Riverton, and McLouth formations of Missouri (Searight and Howe, 1961, p. 79-81) support a tentative assignment to the Atoka and the lowermost part of the Des Moines.

Figure GFS-5.--Graphic description of the lower part of interval C in Kansas, showing relative position of upper boundary of interval B in southeastern Kansas. Base of Warner Sandstone Member (A) is contact of intervals B and C throughout most of Eastern Kansas. In parts of southeastern Kansas, contact is located approximately at position (B).



G75-5

For Figure ~~8~~, please trim here, and use arrows (A) and (B) as shown below. Of course the words "Cherokee Group" must be shifted downward.
Thanks, G75 11/20/70

Figure G75-5

~~P. Bleelackonic, Kansas, Fig. 15~~

Upper boundary of interval B

Near the eastern margin of interval B in western Kansas (fig. GFS-4), the boundary between intervals B and C generally is placed at the upper surface of clayey mudstone that underlies limestone. In the region from Scott and Wichita Counties southeastward the clayey mudstone forming the uppermost part of interval B, commonly is medium gray to dark gray or black but locally is brown or red brown. At some places the mudstone is limy; elsewhere it contains considerable amounts of glauconitic sandstone. Northward from Scott and Wichita counties (fig. GFS-4) the clayey mudstones of uppermost interval B are mostly variegated or are brown and are sandy.

Limestones of lowermost interval C are chiefly gray to brown, aphanitic to finely crystalline, sandy and interbedded with dark-gray, clayey mudstone. Locally they are chert-bearing. In parts of Thomas and Rawlins counties and locally elsewhere along the margins of interval B, the contact of intervals B and C lies within the complex of detritus known as the Pennsylvanian basal conglomerate. This unit probably includes rocks ranging in age from post-Meramec to early Des Moines. In this terrane the boundary is difficult to determine because rocks above and below generally include variegated and greenish-gray, clayey mudstone and white to variegated, fine-grained sandstone. Conglomerate is present at some localities in uppermost interval B.

In the deepest part of the Hugoton embayment, the boundary of intervals B and C can be traced into a succession of brown to gray, cherty, aphanitic to finely crystalline limestone units interbedded with dark gray, clayey mudstone (fig. GFS-4). The contact seemingly is conformable, and beds above and below it are not markedly different in lithology.

Throughout most of eastern Kansas the boundary of intervals B and C is placed at the base of a sandstone unit that occupies the general stratigraphic position of the Warner Sandstone Member of the Krebs Formation (fig. GFS-4, GFS-5; table GFS-2). Where sandstone is not present in the lower part of the Cherokee Group, as in parts of Elk, Wilson, Woodson, Greenwood and Butler Counties, and in Wabaunsee, northwestern Lyon, and eastern Morris Counties, the boundary generally is placed at the contact of dark gray, clayey mudstone with overlying varicolored, sandy, clayey mudstone or gray limestone.

Throughout eastern Kansas, clayey mudstones near the upper boundary of interval B are gray to black, and locally are green, brown, or variegated. Minor amounts of sandstone are included in interval C in Chase and Lyon Counties, and traces of hematite, siderite, coal and clay occur in the mudstone. Sandstone near the base of interval C is predominantly white to gray and is fine- to medium-grained. Conglomeratic sandstone is present in a few places, as in parts of Morris and Jackson Counties. Near the base of interval C siderite is relatively common in the clayey mudstone.

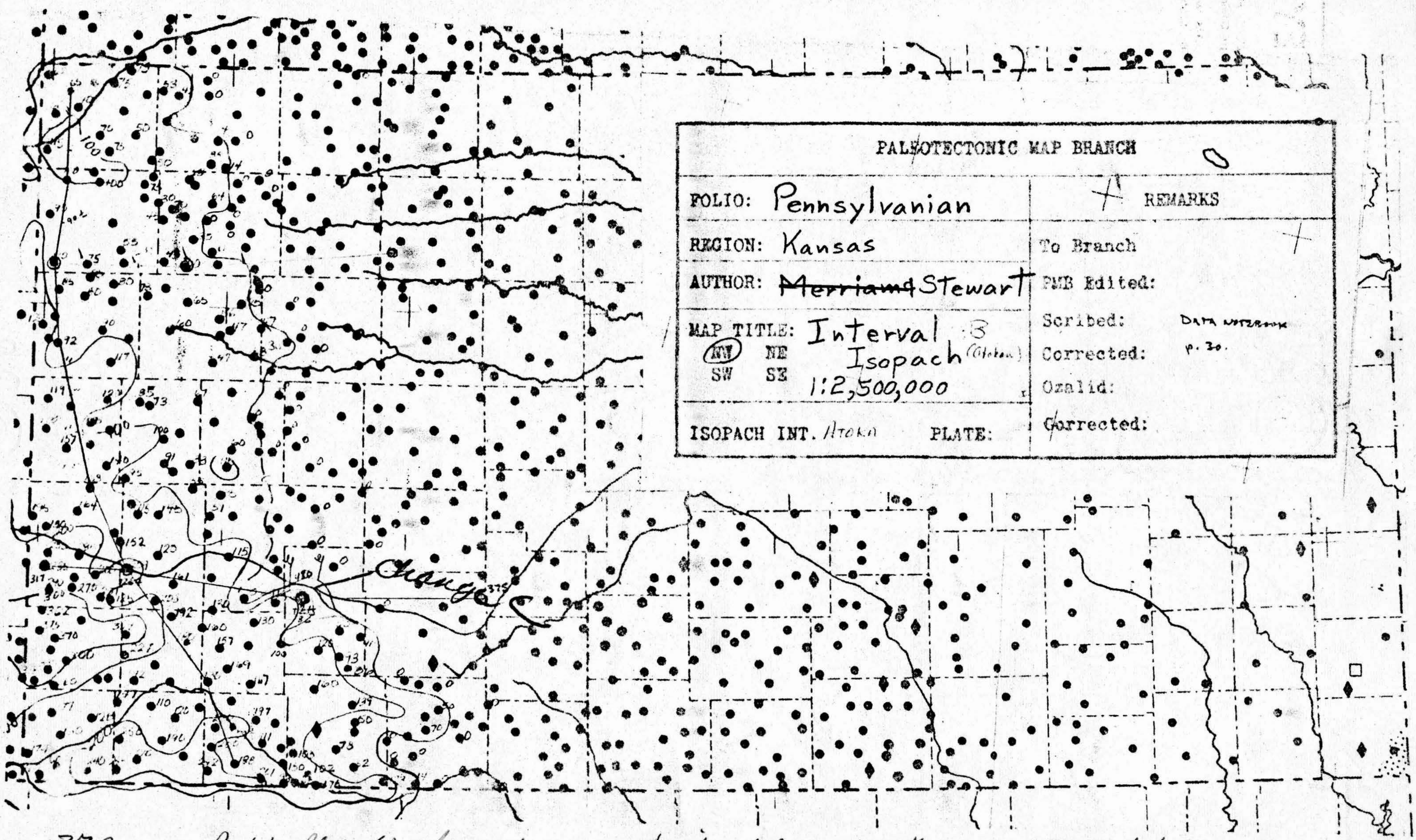
Thickness trends

Interval B in the Hugoton embayment thickens irregularly westward from a beveled edge to at least 375 feet in northwestern Stanton County, ~~Kansas~~ (pl. 6A; fig. GFS-5). The interval is less than 150 feet thick throughout

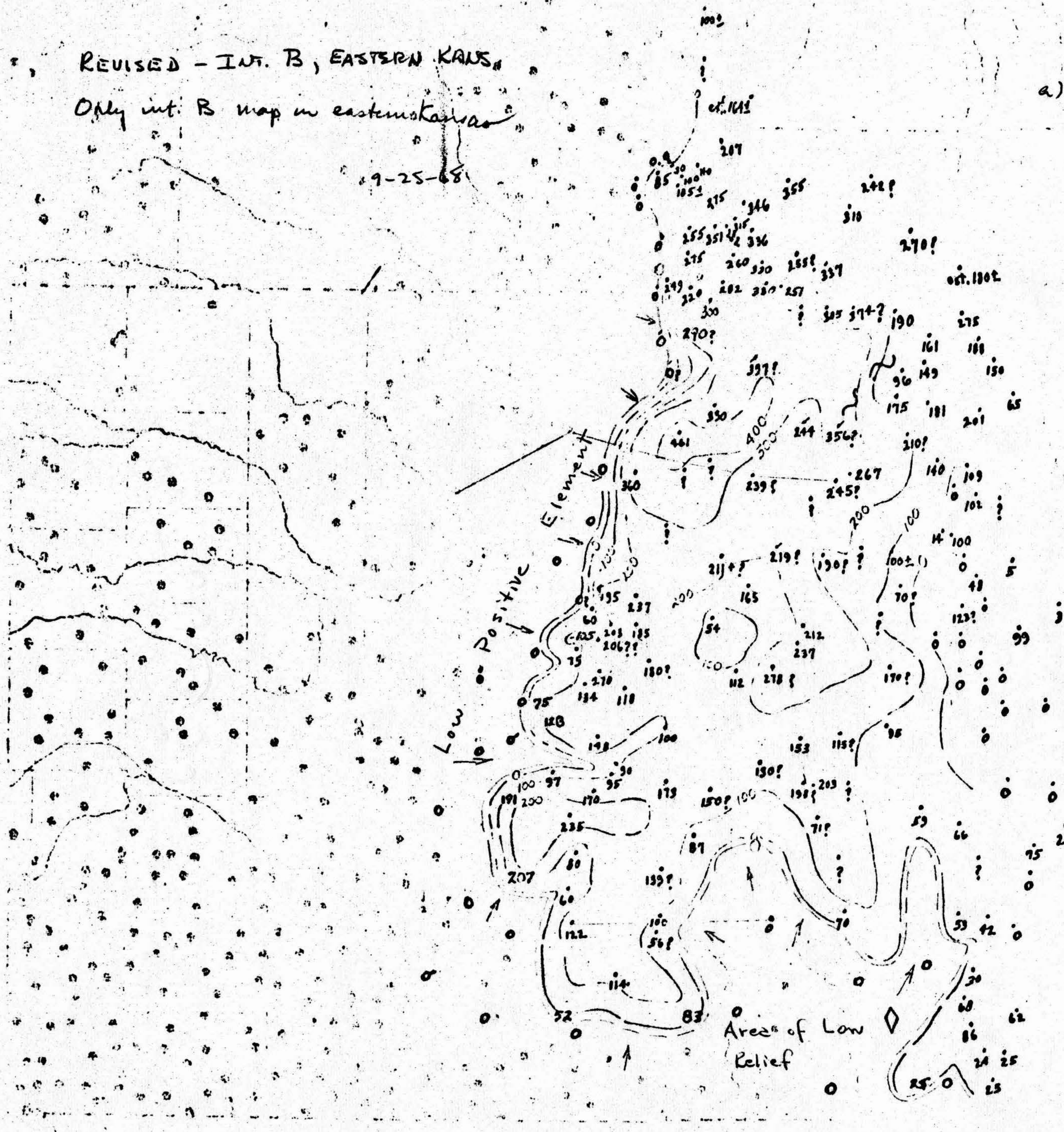
~~Figure GFS-5.--NEAR HERE~~

most of its extent in western Kansas and is more than 300 feet thick only in a small area in Stanton, Grant and Hamilton Counties. It thickens southward into the Anadarko basin of northwestern Oklahoma and Texas, but marked thinning occurs in a large area in the deeper part of the Hugoton embayment in Morton, Stevens and Grant Counties (fig. GFS-5). Small areas of pronounced thinning near the featheredge of the interval are present in Clark County and southern Finney County. Moreover, the interval is less than 100 feet thick throughout most of the northwestern six counties of Kansas.

In eastern Kansas, interval B is thickest in the deep parts of the Forest City basin. It is 450 feet thick in Jackson County, Kansas (fig. GFS-5). The western limit of the interval is located along a line generally parallel to the eastern flank of the Nemaha anticline. Lobes of interval B extend southward from the Forest City basin and thin to extinction in Chase, Butler, Greenwood and Elk Counties on the west and Cherokee and Crawford Counties on the east.



37B Part 1, Plate 6A - Isopachous map of interval B, western Kansas. CI = 100 feet.



→ = sand & mud, small volume.

Interval B, as mapped by Wanless, Prichard, Stewart says "[illegible] interval at time [illegible] the end of the interval." p. IV-8

Restored isopach, interval B eastern Kansas. Reasoning:

a) int. B ~ 100 ft thicker as restored - in keeping w/ restored int. B, western Kansas. Ham, p. 374 (1967) reports that Atokan probably extended over much of central states ("widespread 'distribution' before uplift and erosion by Desmoines tectonism. Int B contains ~~[illegible]~~ Desmoines and, (supposedly) Atokan rox; Atokan may well have been more extensive - but Atokan rocks would be buried beneath these Desm. rox! could have extended as far as red line shown here. This would have been "widespread" dep. as per Ham. To me, there's no evidence to show restored thicknesses liberally because who has a good hypothesis of

a) where the Atokan rox extended (if there are, in fact Atokan rocks in northeastern Kansas,) and

(b) how thick they might have been before paleo-Desm.

[illegible]

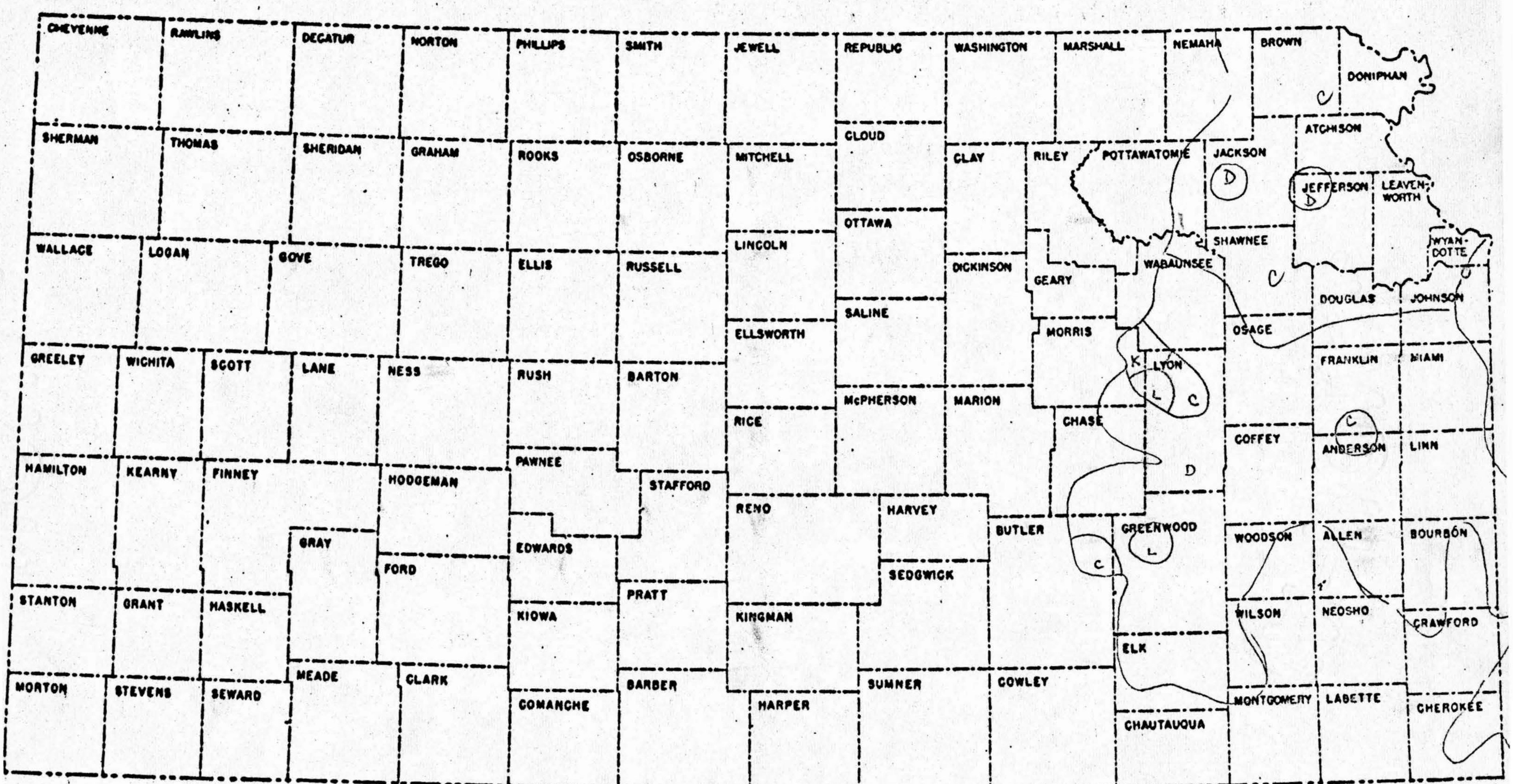
The interval is uncommonly thick in a moderately large area of northern Greenwood County, northeastern Butler County and southeastern Chase County and in a small area in Anderson County (fig. GFS-1). The eastern featheredge of interval B is located in eastern Johnson, Miami and Linn counties; the interval extends southward into southwestern Missouri and northward through Missouri into southwestern Iowa.

Lithofacies trends

The stratigraphic units within interval B of western Kansas are mainly thick limestone beds alternating with relatively thin beds of dark clayey mudstone. The limestone is gray or brown and chert-bearing; locally it is sandy. Variegated to greenish-gray clayey mudstone is predominant near the eastern margin of the interval, but locally the interval is comprised chiefly of white or gray glauconitic sandstone interbedded with variegated clayey mudstone. At some places, the dominantly detrital rocks of interval B lie upon a "basal conglomerate" of probable post-Meramec, pre-interval B age, and the contact is difficult to establish.


Newest Copy
3-15-67
Interval B
Western border of Kausas matches w/ Colo.
G. Stuart 3-15-67
Delete all stations crossed out W. of O line
Delete all stations E. of O line
Symbols
B = clayey ss.
C = sandy mudstone
D = clayey mudstone
K = sandy clayey limestone
L = limy mudstone
M = clayey limestone
U = limestone
Kausas - Okla border matched.
G. Stuart 3-15-67

FIG. 10



Lithofacies, interval B, eastern Kansas

~~FIG. 9~~

Facies of the entire interval B of western Kansas are mainly clayey limestone and limy, clayey mudstone. Limestone with only minor amounts of detrital material is present in a few small areas, chiefly in western Sherman and Wallace Counties and in western Cheyenne County. Detrital rocks are abundant near the featheredge of interval B throughout western Kansas. Clayey sandstone is predominant locally in Cheyenne County and northeastern Sherman County (fig. GFS-8). Large amounts of clayey mudstone and sandy clayey mudstone are present near the featheredge of the interval from Thomas County southward to Finney County. From Haskell County southeastward through Clark County to Oklahoma, interval B is mainly clayey limestone. In this region limy, sandy mudstone is dominant only in two small areas of Gray County and in northwestern Clark and northeastern Meade Counties.

Interval B of eastern Kansas (fig. GFS-4) is composed mostly of beds of clayey mudstone that locally are sandy or limy; it also contains numerous thin beds of coal. The mudstone is chiefly dark gray to black, but in western Elk and Greenwood Counties, in Butler, Chase and parts of Morris and Wabaunsee Counties and northward in the region of the eastern flank of the Nemaha anticline, variegated to green or gray, sandy, clayey mudstone is included locally; also there are siderite concretions and a seemingly greater amount of coal. The lowermost part of interval B lies upon eroded Mississippian rocks and contains relatively large amounts of sandstone, cherty sandstone or conglomerate at many places. In the basal part of the interval, these units range from only a few feet thick to 30 feet or more. At a few places in the Forest City basin, near the flank of the Nemaha anticline, interval B contains beds of conglomerate and of slightly arkosic sandstone.

North of Wabaunsee, Osage, southern Douglas and southern Johnson Counties, the entire interval is mostly sandy, clayey mudstone. South of this region and eastward into Missouri the interval is composed chiefly of clayey mudstone, although a small area in northwestern Lyon County and southeastern Morris County includes mostly sandy mudstone and limy sandy mudstone. Elsewhere in the southern part of eastern Kansas sandy mudstone is abundant in small, widely separated places.

Sources and environments of deposition

The Hugoton embayment of western Kansas was a relatively shallow, open shelf of the Anadarko basin during accumulation of interval B. After post-interval A emergence, subsidence of the embayments and transgression of the sea, was effectively continuous, interrupted only by episodes of minor restriction to deeper parts of the Anadarko Basin. Periodic retreat of the sea is indicated by detrital units, including sparse amounts of sandstone, within the interval in what must have been deeper parts of the embayment. Sea water probably maintained only moderate to low levels of energy, inasmuch as coarse-grained clastic and carbonate rocks are not widespread, and oolitic limestone is present sparingly.

From Finney County the farthest extent northward of shorelines during deposition of interval B probably was only a short distance beyond the present limits of the interval. The preponderance of detrital rocks in this region, the variegated coloring of mudstones, and the local occurrence of frosted sand grains and of conglomeratic sandstones support this conclusion. The northern limit of the Hugoton embayment, therefore, probably extended only a short distance into southwestern Nebraska.

Small amounts of arkosic sandstone in the interval at a few places in the westernmost counties of Kansas indicate that moderately coarse detrital material was transported from exposed basement rock in Colorado. A carbonate-and-clayey-mudstone composition of the interval is dominant in westernmost Kansas. From Finney County southward to Oklahoma, clayey limestone is the principal lithology, even as far as the featheredge of the interval at most places. In this region shorelines probably extended a few tens of miles eastward from the present limits of interval B.

Although rocks included in interval B of eastern Kansas have been studied closely only in a few places (Lee, 1943; Lee and Payne, 1944; and others) and are generally little known and poorly understood, a few salient facts lead to general and reasonably defensible conclusions. These facts include: (1) basal sand and conglomeratic sandstone are widespread on top of eroded Mississippian rocks; (2) interval B comprises mainly thick and extensive units of clayey mudstone; (3) lenticular bodies of sandstone are numerous; (4) the relatively minor amounts of marine limestone contain crinoid and brachiopod remains; linguloid brachiopod shells are included in black shale at some places (Lee and Payne, 1944, p. 120-121); (5) coal beds are comparatively common, and both these and coaly mudstones are interbedded within thin units of sandstone and fossiliferous limestone as well as mudstone (Lee, 1943, p. 84 and Lee and Payne, 1944, p. 101); and (6) clay ironstone is relatively abundant in the interval, and sideritic limestone is present in small amounts (Lee and Payne, 1944, p. 101).

On the basis of information in the preceding paragraph, it is evident that environments of deposition in the Forest City basin during accumulation of interval B ranged from terrestrial and marginal marine to shallow-water marine. Terrestrial conditions prevailed around the southern and western margins of the basin, but the rather large proportion of carbonate rocks in northwestern Lyon County and southeastern Morris County suggests that shallow marine conditions persisted in that area. Shorelines probably extended only a few miles beyond present limits of the interval, even during periods of maximum inundation. Subsidence of the basin was progressive, on the whole, but interbedding of sandstone, mudstone, limestone and coal is evidence of variations in depth of water that were frequent and widespread, so that depositional environments in the interior of the basin ranged repeatedly from shallow marine to swamp or other terrestrial types.

Although total accumulation of sediment exceeded 300 feet at some places, sea water in the basin probably never was as deep as 300 feet. Marine water apparently circulated freely, was of normal salinity, but mostly was turbid with clay-sized detritus. Basin margins probably bordered lagoonal bodies of brackish water, deltas and alluvial plains, lakes, and swamps with dense vegetation. Within these environments water circulation probably ranged from low energy, as indicated by abundant thick units of clayey mudstone, to moderate energy, as suggested by the comparatively small amounts of coarse-grained sandstone within the interval and by the local occurrence of such features as intraformational breccia (Lee and Payne, 1944, p. 102). In general, however, energy levels were low, a contention supported by the predominance of clayey mudstone. Landforms in the hinterlands of the basin probably were low-lying, except on the northern part of the Nemaha anticline where basement rocks were exposed and where some emergent surfaces may have been elevated as much as a few hundreds of feet. The prevailing climate probably was warm and humid, as shown by coal deposits.

Much clay and minor amounts of sand were transported eastward to the Forest City and Cherokee basins from the Nemaha anticline, south of Geary and Wabaunsee Counties. Erosion of a moderately large area of positive, but low-lying Mississippian carbonate-rock terrane in southeastern Kansas and the exposed Mississippian and Arbuckle carbonate rocks of the Ozark uplift apparently provided large amounts of clay. Most of the sand of the sandy clayey mudstone facies of interval B in eastern Kansas probably came from early Paleozoic rocks and Precambrian rocks that were exposed on the northern part of the Nemaha anticline of Kansas and Nebraska (pl. 2).

Paleotectonic implications

The Hugoton embayment was slightly emergent after accumulation of interval A but gradually subsided during deposition of interval B, and deposits of interval A were overlapped. Subsidence probably was accompanied by recurrent movement along the major flexures that bounded the embayment in Kansas, including the Pratt anticline, Central Kansas uplift and Cambridge arch (fig. GFS-2). Thinning of interval B in Morton, Hamilton, Stevens, Grant and Haskell Counties indicates that a small arch extended northeastward from the Keyes dome of the Oklahoma Panhandle at least to Finney County. Total subsidence of the embayment was about 400 feet.

Following accumulation of interval B, moderate erosion probably occurred near the eastern margin of the embayment. Sedimentation in the interior of the embayment was continuous from interval B into interval C.

During the time between deposition of Mississippian rocks and the beginning of deposition of interval B, the region that includes the Forest City basin, the northern part of the Cherokee basin and the Nemaha anticline was emergent and was eroded to very low relief; it then began to undergo slow structural deformation. The Forest City and Cherokee basins were formed in conjunction with elevation of the Nemaha anticline.

The most pronounced deformation of rocks in Kansas took place as faulting and monoclinal folding along the eastern flank of the Nemaha anticline (Lee, 1943, p. 116). The Forest City and Cherokee basins seem to have subsided differentially, producing the Bourbon arch, a broad structure with little closure and low topographic relief that probably formed an indistinct and temporary barrier between the basins. This poorly defined arch trended northwestward from Bourbon County through Allen, Anderson, Coffey, and Lyon Counties to Chase County (fig. GFS-1, GFS-2). Its presence is indicated by an area of thinning of interval B (pl. 6A). Northward the interval thickens to more than 450 feet in Jackson County and southward it thickens to more than 200 feet in northern Butler, southern Chase, and northern Greenwood Counties.

The absence of interval B in the southeasternmost counties of Kansas (~~fig. GFS-5~~ pl. 6A) and in parts of northeastern Oklahoma, the presence of very thick Atoka rocks in eastern Oklahoma and the presence of rocks of Atoka age in southwestern Missouri (Searight and Palmer, 1957) indicate that when marine sediments were deposited in interval B, the waters transgressed northward from Oklahoma through southwestern Missouri to the Forest City basin, thence southward across the Bourbon arch to the Cherokee basin of Kansas. The emergent terrane of southeastern Kansas probably was a low platform that extended westward to the Nemaha anticline and southward into central Oklahoma.

Little definitive evidence exists to show that interval B rocks of eastern Kansas were long emergent or markedly eroded before deposition of interval C. Rather, the regional stratigraphy indicates continued sedimentation with alternation between marine and nonmarine deposition. The Nemaha anticline, Forest City basin, and Cherokee basin developed progressively, but by the end of accumulation of interval B the Bourbon arch ceased to have conspicuous influence on regional sedimentation.

INTERVAL C

Formations included

Interval C is exposed at the surface in eastern Kansas, and is present throughout the State except in the southeasternmost part of Cherokee County, and in two general areas in the subsurface. The interval was never deposited on high-standing parts of the Nemaha anticline in northern Nemaha and northeastern Marshall Counties, nor was it deposited on higher parts of the Central Kansas uplift, as in Rush and Barton Counties (pl. 7A).

In ascending order, interval C includes the Cherokee Group of Des Moines age, except the lowermost units of the Krebs Formation (fig. GFS-5), the Marmaton Group of Des Moines age, and the Pleasanton Group of Missouri age (table GFS-2).

Upper boundary of interval C

The upper boundary of interval C is placed at the base of the Hertha Limestone of the Kansas City Group (table GFS-2), a stratigraphic marker that can be traced throughout Kansas. The Pleasanton Group might have been placed in interval D rather than C, but its correlation throughout Kansas involves considerable difficulty and a great risk of inaccuracy. For these reasons it is included in interval C with the underlying Des Moines rocks.

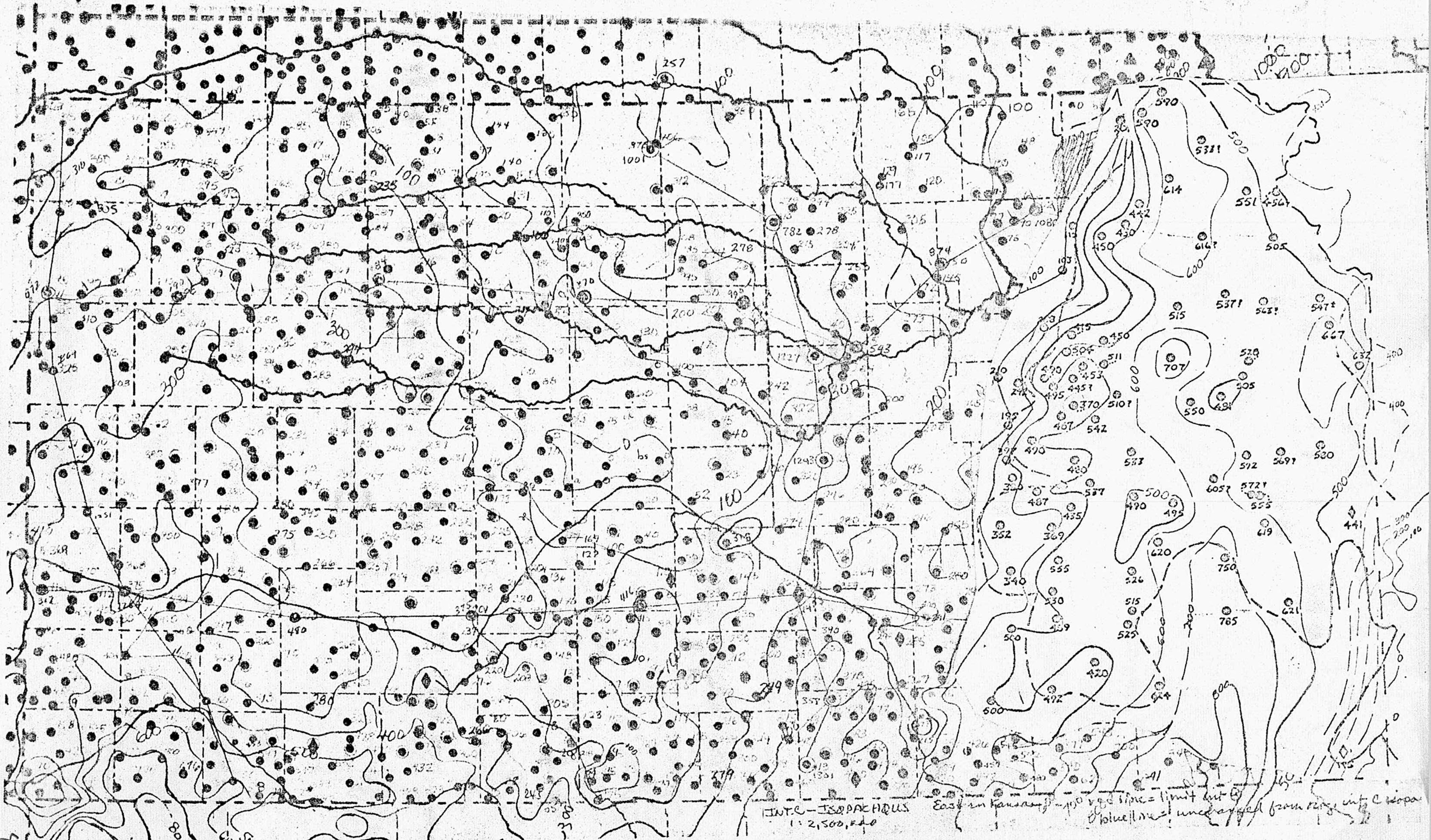


Plate 675-7A Isopachous map of interval C.

Throughout Kansas the boundary between intervals C and D is placed at the contact of clayey mudstone below with limestone above (fig. GFS-6). The mudstone is mostly gray, red, or variegated and

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Figure GFS-6.--NEAR HERE

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is carboniferous at some places. On the higher parts of the Central Kansas uplift the clayey mudstone locally contains much chert and is included in the unit discussed previously as the "Pennsylvanian basal conglomerate." Limestone overlying interval C is aphanitic to finely crystalline and locally contains chert.

Thickness trends

In eastern Kansas, interval C thickens westward from an erosional edge in Cherokee County to more than 800 feet (pl. 7A) in the deepest part of the Cherokee basin in Labette, southern Montgomery, and southeastern Chautauqua Counties, where the section is complete. The interval is 615 or more feet thick in the deepest parts of the Forest City basin in Brown, Atchison, northwestern Jefferson, and eastern Jackson Counties.

A short distance westward from the Forest City basin, interval C thins markedly, forming a feather edge on the crest of the Nemaha anticline in northern Nemaha and northeastern Marshall Counties. The interval thins westward from more than 800 feet in the Cherokee basin to less than 100 feet above local anticlines in the southern part of the Nemaha anticline (pl. 7A). Interval C thickens to as much as 320 feet along the strike of the plunging Nemaha anticline from Nemaha County southwestward to Sumner County.

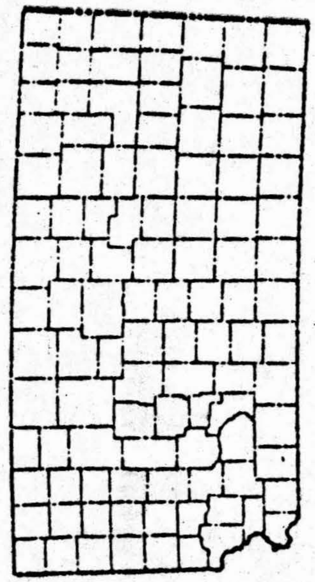
Figure GFS-6.--Generalized lithologic description of upper boundary of interval C in Kansas.

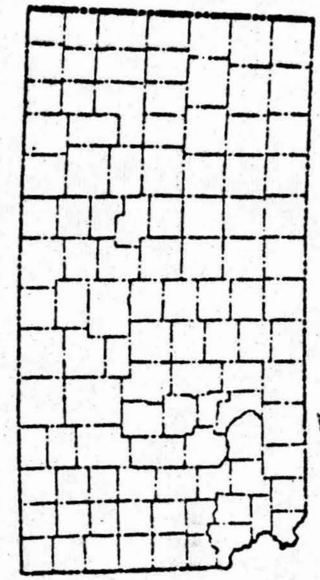
Area A: Chiefly buff to gray or white, aphanitic or finely crystalline limestone overlying gray to black, locally carboniferous or sandy, clayey mudstone.

Area B: Gray, buff, or locally white, aphanitic to finely crystalline, locally chert-bearing limestone overlying red and gray, locally variegated, locally grayish green, clayey or sandy~~, clayey~~ mudstone.

Area C: Gray to buff, mainly chert-bearing, aphanitic to finely crystalline limestone overlying gray, dark gray, black, or, rarely, variegated clayey mudstone.

Area D: Buff to gray, locally chert-bearing limestone overlying gray mudstone.





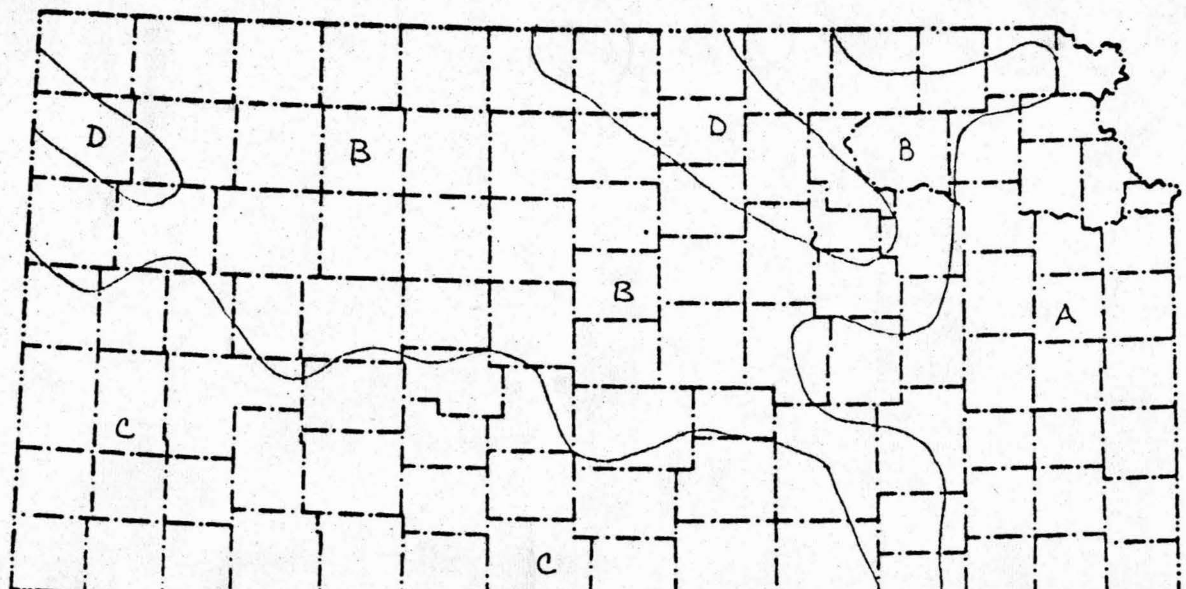


Fig. GTS-6

~~Figure 11.~~ General description of upper boundary of interval C in Kansas.

Westward from the Nemaha anticline, interval C thins into the Salina basin to the northwest and into the Sedgwick basin to the southwest. Rocks of this interval are slightly thicker than 400 feet in northwestern Jewell and northeastern Smith Counties, where is located the deepest part of the Salina basin of Kansas. The interval thickens to as much as 460 feet in southwestern Sumner County, site of the deepest part of the Sedgwick basin. Small areas in which the interval is very thin are in southern McPherson County and northern Saline County, between the Salina and Sedgwick basins.

Rocks of interval C are absent from the crest of the Central Kansas uplift in Rush and Barton Counties. They are less than 100 feet thick throughout a large area of central Kansas and northwestward along the crest of the Cambridge arch into Nebraska. The interval also is thinner than 100 feet over much of the Pratt anticline (fig. GFS-2; pl. 7A) in southern Stafford County, eastern Pratt County and in northern and southwestern Barber County.

Interval C thickens gradually westward and southwestward into the Hugoton embayment from the anticlinorium of the Cambridge arch, Central Kansas uplift, and Pratt anticline, and has a maximum thickness of 770 feet on the axis of the embayment, in southwestern Stevens County. Pronounced local thinning is present above the Keyes dome in southwestern Morton County, and marked regional thinning takes place northward from Keyes dome through Stanton and Hamilton Counties, eastern Greeley and western Wichita Counties to eastern Wallace and western Logan Counties. Throughout an uncommonly large, five-county area of central western Kansas, centering upon southwestern Ness County, interval C is in general uniformly thick.

Lithofacies trends

Interval C is composed mainly of interbedded clayey mudstone, sandstone, limestone, and coal. The Cherokee Group, for instance, contains much clayey mudstone, appreciable amounts of sandstone and at least 13 thin coal beds of large areal extent. Limestone beds are thin, some are lenticular and, on the whole, they are sparse in the Cherokee Group. The Marmaton Group, in contrast, includes four widespread limestone and three mudstone formations. In addition, it includes relatively minor amounts of sandstone and coal. The Pleasanton Group is chiefly clayey mudstone but contains sandstone, one widespread limestone unit, and small amounts of coal.

Several limestone units, some coal beds, and a few sandstone beds of interval C are widely distributed at the surface in eastern Kansas. Facies changes occurring westward in the subsurface, however, involve the addition of limestone and mudstone units in basinal areas. Farther west, a decrease in the number of these units across the Nemaha anticline, the Cambridge arch, the Central Kansas uplift, and the Pratt anticline (fig. GFS-7), results in difficulties in recognizing more than a few of

Figure GFS-7. NEAR HERE

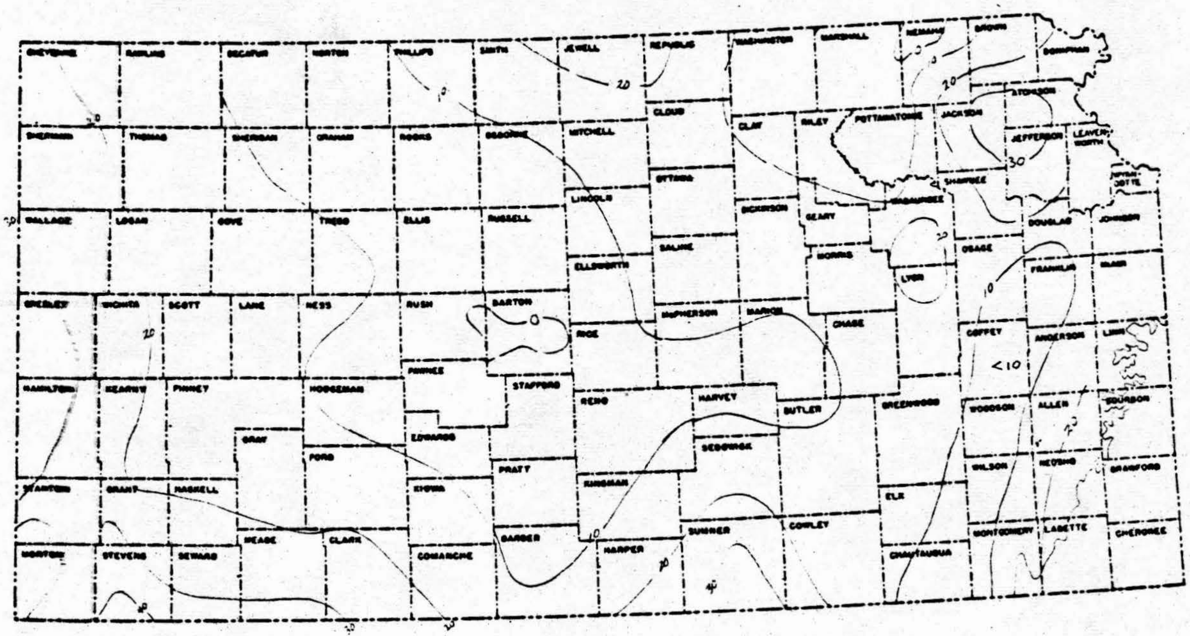
them. The recognizable units are predominantly limestones, and correlation of all but the most distinct and persistent is tenuous in western Kansas.

In the Forest City and Cherokee basins, interval C consists mainly of clayey mudstone. This rock makes up the interval in southern Shawnee County, northern and western Osage County and eastern Lyon County, and it is abundant locally elsewhere in eastern Kansas. In this region, the clayey mudstone dominantly is gray, black, green, red, or variegated. It contains buff to red sandstone lenses and minor amounts of buff to gray, dense to finely crystalline limestone. A few coal beds are present and siderite concretions are in the lower beds at some places.

Figure GFS-7.--(a) Approximate number of distinct limestone units in interval C. Forest City, Cherokee, Salina and Sedgwick basins contain large numbers of limestone units, and accordingly, large numbers of detrital units, whereas a lesser number of units lap onto the Cambridge Arch-Central Kansas Uplift-Pratt Anticline and Nemaha anticlinoria.

(b) Approximate average thickness of limestone units in interval C, showing slight increase in average thickness of units into basinal areas. Changes of facies of interval C westward from dominantly clayey limestone (~~fig. 14~~ pl. 7B) is due, in general, to moderate thickening of large numbers of limestone units relative to detrital units, rather than great thickening of only a few limestone units.

(a)



Approximate Number of Distinct Limestone Units in Interval C. Kansas

(b)

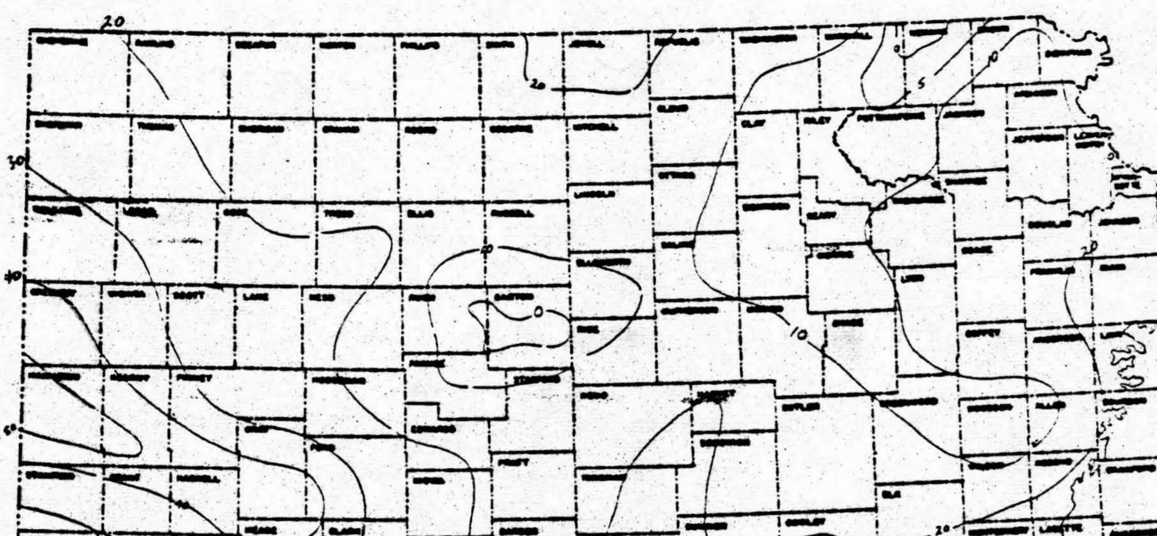


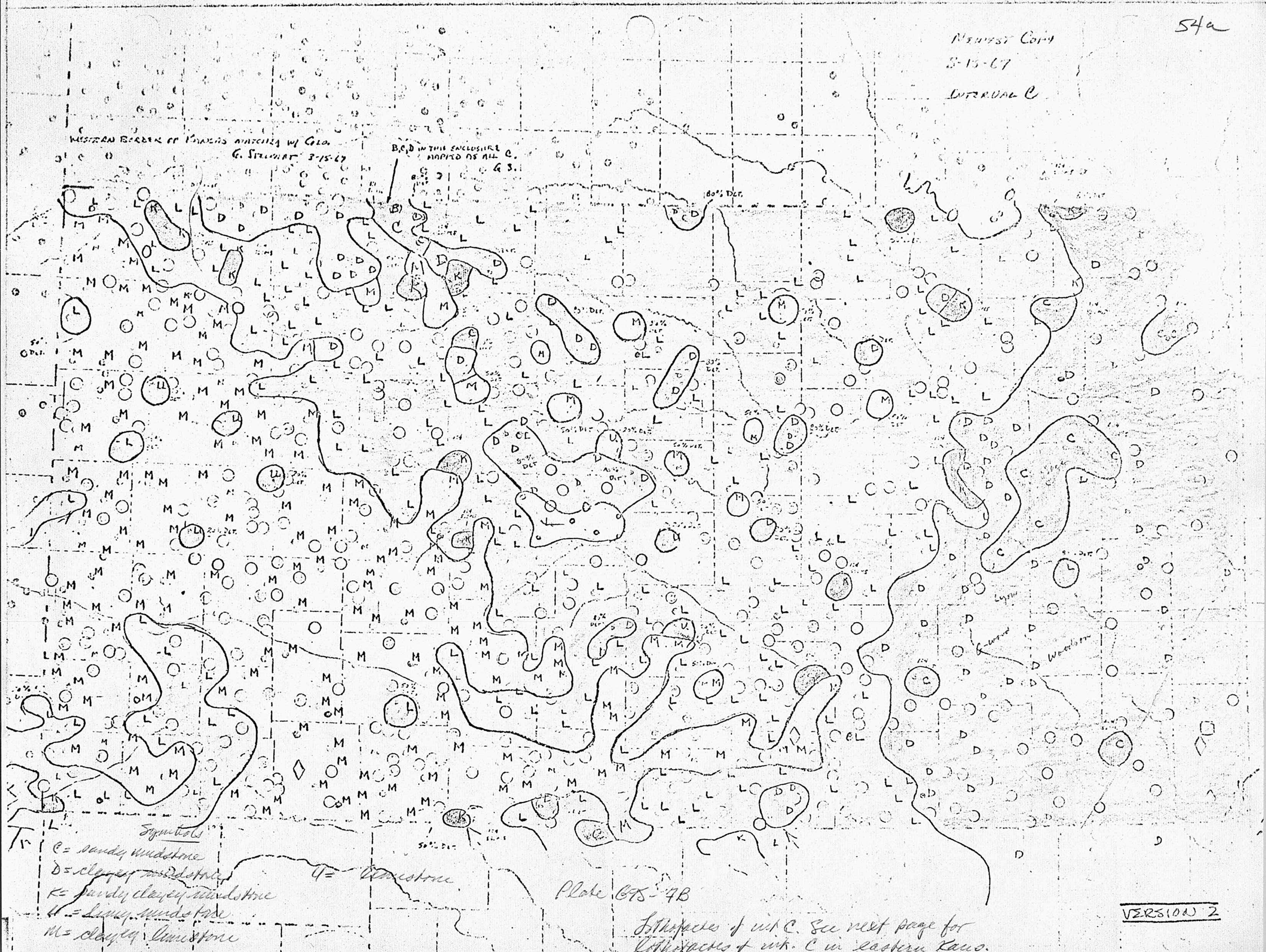
Figure G75-7

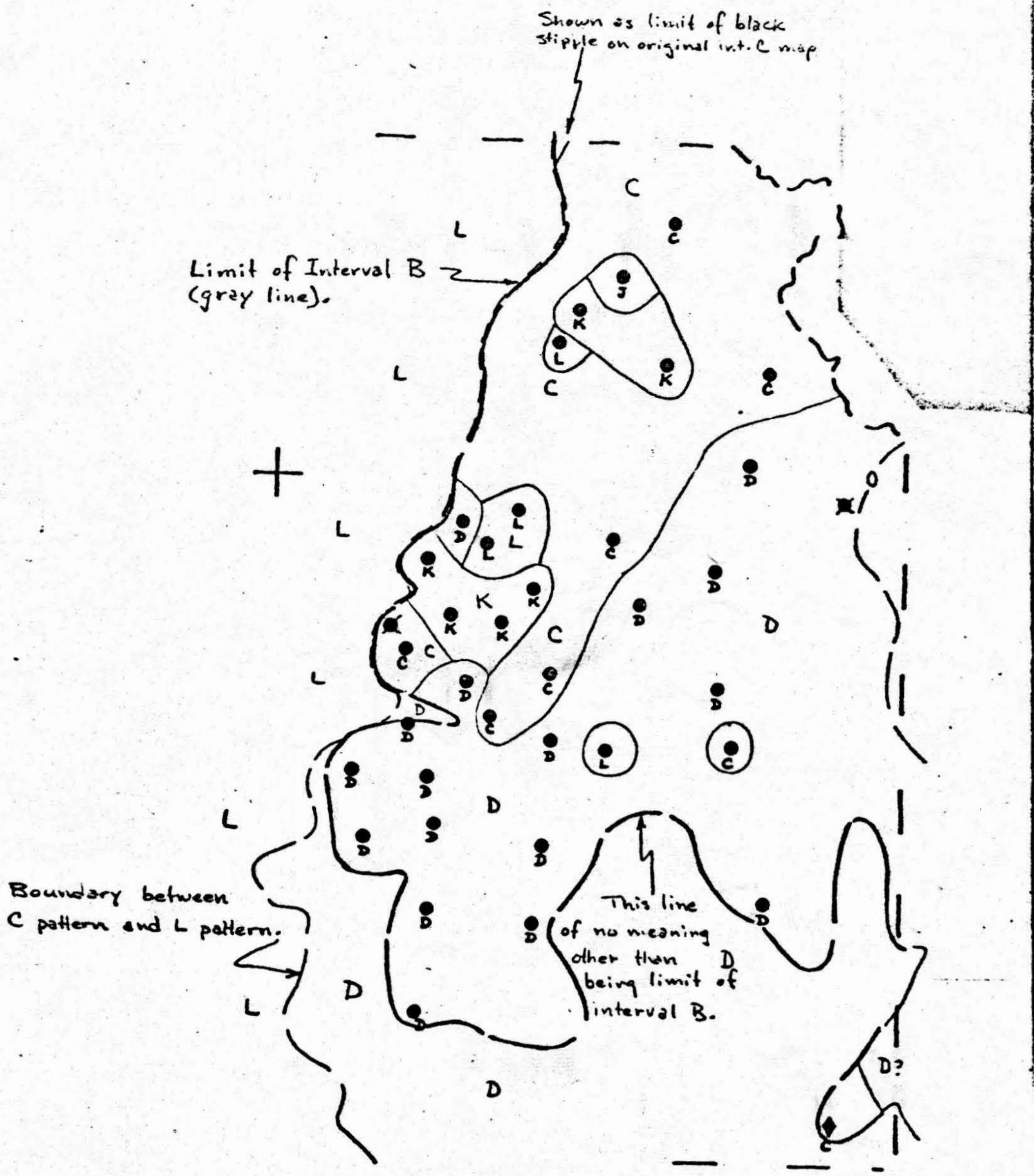
Throughout central southern Kansas and most of northern Kansas, interval C is chiefly limy mudstone (pl. 7B). Large amounts of this rock are on the Central Kansas uplift in northern Barton County, western Ellsworth County, southern Russell County, and southeastern Ellis County. It also forms most of the interval on the Cambridge arch in northern Rawlins County and in Decatur County. Both mudstone and muddy limestone constitute interval C on the Cambridge arch in parts of Norton, Phillips and Graham Counties. Small, widely scattered areas in which the interval is composed mostly of various types of mudstone and of clayey limestone occur throughout this region.

The detrital rocks, chiefly the clayey mudstones, are predominantly variegated, red and gray, or black, but, locally, they are green. Clayey mudstone in the lowermost parts of the interval includes beds of basal conglomerate at some places on the Central Kansas uplift, Cambridge arch, and Nemaha anticline. Limestone units mostly are gray to buff, aphanitic to finely crystalline and locally are chert-bearing or oolitic.

In most of the southwestern quarter of Kansas, interval C is clayey limestone (fig. GFS-7). The limestone is buff or gray, and oolitic or chert-bearing at some places. Clayey mudstone is red and gray and locally sandy.

In southwestern Morton County, on the Keyes dome, mudstone is the dominant rock in interval C (pl. 7B). Mudstone extends along the ~~borders~~ the Keyes dome on the north and east and continues northeastward into the Hugoton embayment, westward into Colorado, and southward into the Oklahoma panhandle. Most of the clayey mudstone is red and gray and locally contains moderate amounts of sand. Limestone units in this region are buff to gray, aphanitic to finely crystalline and locally are oolitic.


Newest Copy
3-15-67
Interval C
Western Border of Kansas matching w/ Colo.
G. Stewart 3-15-67
B, C, D in this enclosure mapped as all C.
G S.
Symbols
C = sandy mudstone
D = clayey mudstone
K = sandy clayey mudstone
U = limy mudstone
M = clayey limestone
T = limestone
Plate GS-7B
Lithofacies of unit C. See next page for
lithofacies of unit C in eastern Kans.
VERSION 2



PENNSYLVANIAN PALEOTECTONIC PROJECT, KANSAS
LITHOFACIES, INTERVAL C, REVISED IN AREA WHERE INTERVAL B IS MAPPED. (INTENDED TO BE USED FOR REVISION OF ORIGINAL ISOPACH OF INTERVAL C.) GFS 9-2-68

Sources and environments of deposition

Lack of evidence of erosion between intervals B and C in the deep parts of the Hugoton embayment and in the Forest City and Cherokee basins suggests that subsidence was continuous in these regions from Atoka into Des Moines time. Marine deposition and transgression through interval C time were interrupted only by brief episodes of partial regression. Folding of anticlinal structures continued during deposition of interval C. All of Kansas became a region of comparatively shallow basins and open shelves, separated by regional anticlinal folds.

The Nemaha anticline was uplifted and the basins flanking it to the east and west subsided recurrently during deposition of interval C. The Nemaha was faulted at several places along its eastern flank and both normal and reverse faults seem to be present. Precambrian igneous rocks were exposed in northern Kansas and locally elsewhere along the crest of the anticline; they were surrounded mostly by Paleozoic carbonate rocks but in some small areas by clayey mudstone and sandstone. The dominantly clayey rock of interval C in the Forest City and Cherokee basins was derived from the progressively less emergent terrain of the Nemaha anticline and from emergent regions to the northeast and east of Kansas.

Progressive encroachment of the seas is indicated by overlapping of units from the Forest City and Cherokee basins onto the Nemaha anticline. Likewise, deposits of the Sedgwick basin and the Hugoton embayment transgressed onto the Pratt anticline, Central Kansas uplift and Cambridge arch, and those from the Salina basin onto the Nemaha anticline, Central Kansas uplift, and Cambridge arch (pl. 7B). Periodic retreat of these seas is indicated rocks of terrestrial and marginal-marine environments interbedded with rocks of marine environments.

The shallow interior seaways probably maintained only low to moderate levels of energy and were prevailingly turbid, for interval C is composed predominantly of clayey mudstone; the few sandstones are mostly fine- to medium-grained and clayey (Lee, 1943, p. 81-84; Howe, 1956). Along the eastern flank of the northern part of the Nemaha anticline, however, interval C locally contains small amounts of conglomerate and arkosic sandstone, suggesting occasional strong currents in that area. Also, some limestones are locally conglomeratic or brecciated, indicating wave or current action (Howe, 1956, p. 24).

In the outcrop region of the Cherokee basin, the Cherokee Group contains about 13 cyclothems (GFS-8) that show alternation of marine

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Figure GFS-8.--NEAR HERE

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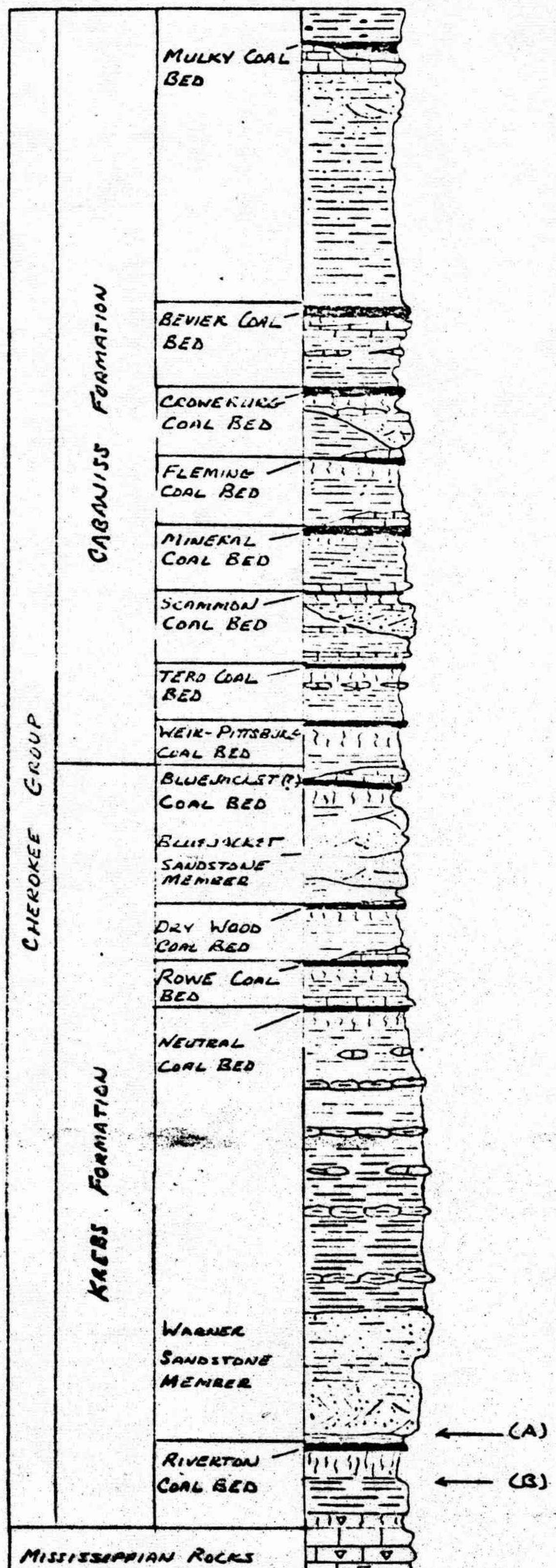
and non-marine conditions near the eastern margin of the Cherokee basin (Abernathy, 1937, p. 18-23; Moore, 1950; Howe, 1956). The cyclothems comprise five units, including dark mudstone and irregularly bedded limestone at the base, overlain in turn by gray mudstone, a unit of sandstone or limestone facies, an underclay, and a coal.

Figure GFS-8.--Generalized section of the Cherokee Group of southeastern Kansas. Each coal-bearing unit constitutes a cyclothem. (Adapted from Howe, 1956, pl. 2, and Zeller and others, 1968).



For Figure ~~8~~ 5, please trim here, and use arrows (A) and (B) as shown below. Of course the words "Cherokee Group" must be shifted downward.

Thanks, GTS 11/20/70

Figure G75-8

IP Paleotectonic, Kansas,

The basal dark mudstone and irregularly bedded limestone contain a variety of marine fossils including mostly brachiopods, corals, conodonts, scattered fish remains and macerated plant material (Howe, 1956; Moore, 1950, p. 8; Williams, 1938). They overlie coal beds. The mudstone and limestone are interpreted as representing marginal-marine to shallow marine conditions, and the beginning stages of transgression of the sea. Gray, evenly bedded, clayey, sparsely fossiliferous mudstone units overlie the basal dark mudstone and are the thickest units within each cyclothem (Howe, 1956, p. 24). Probably they were deposited under conditions of continued subsidence and transgression, and the establishment of a shallow marine environment.

Sandstone or limestone, or a mixture of these facies, lies above the gray mudstone and beneath underclay. The sandstone normally ranges from massive to thin bedded and is fine grained. Both sandstone and limestone contain marine fossils. Good sorting of the sandstone and the local conglomeratic and brecciated facies of the limestone are considered evidence of shallow marine to lagoonal conditions (Howe, 1956, p. 24). These rocks seem to represent conditions of general regression of the seas. Underclays contain parts of fossil root systems, stigmarian remains, and carbonized plant material (Howe, 1956), and together with the overlying coal beds are evidence of non-marine depositional environments.

The preceding description of cyclothems in the Cherokee Group is simplified. The position of the sandstone and clayey mudstone beds in a sequence differs somewhat from place to place, and the environments of deposition were not everywhere the same. Not all sandstone beds in the Cherokee outcrop area are of marine origin; some locally contain stigmarian roots and root casts, other plant material, and the tracks of land animals (Howe, 1956, p. 33, 57; Moore, 1950, p. 8).

The evidence indicates ~~that~~ alternation from terrestrial to shallow marine depositional environments for the lower part of interval C in southeastern Kansas. Fusulinids, which are sparingly present in outcropping Cherokee rocks, ~~probably~~ may indicate the deepest marine conditions during deposition of Pennsylvanian cyclothems (see McCrone, 1964, p. 275 for a summary discussion of this problem). If so, maximum water depths recorded by the outcropping Cherokee rocks of Kansas were about 50 to 75 feet.

Rocks of the Cherokee Group are more clayey and contain lesser amounts of limestone in the interior of the Forest City and Cherokee basins than on the margins. Numerous sandstone bodies are present; some are extensive, but most are lenticular and local. Some of these sandstones in Greenwood, Butler, and neighboring counties of the Cherokee basin probably were offshore bars deposited on the northern and western margins of shallow bays in the Cherokee sea (Bass, 1936).

Numerous thin coal beds are included in Cherokee rocks in the interior and western parts of the Forest City and Cherokee basins (Johnson and Adkison, 1967, p. 9; Johnson and Wagner, 1967, p. 132; Bass, 1936; Mudge and Burton, 1959, p. 122). These interbedded coal beds as well as the shoestring sands, limestones containing marine fossils, and the fossil plants (Bass, 1936, p. 26) are evidence that alternating shallow marine and non-marine conditions prevailed across the Forest City and Cherokee basins and onto the flanks of the low-standing Nemaha anticline during deposition of the Cherokee Group.

Rocks of the overlying Marmaton Group east of the Nemaha anticline consist of clayey mudstone beds, interlayered with limestone beds, channel sandstones, and thin beds of coal (Jewett, 1945; Lee, 1943). Corals and algae are contained in some limestone beds, and fusulinids are present sparingly. The coral genus Chaetetes is especially abundant, locally producing great increases in thickness of the Fort Scott Limestone (table GFS-2) (Moore, 1949a). Clayey mudstone beds, some of which are black and carbonaceous, contain mainly marine fossils including brachiopods, bryozoans, crinoids, mollusks and corals (Jewett, 1945, p. 13).

In the subsurface of the Forest City basin, limestone beds are thin and indistinct, and the Marmaton comprises progressively greater proportions of detrital rocks as it overlaps the Cherokee Group westward onto the Nemaha anticline. Coal beds are present in the Marmaton at least as far west as Shawnee County on the eastern flank of the Nemaha anticline (Johnson and Adkison, 1967, p. 10; Johnson and Wagner, 1967, p. 133).

In most places, the Marmaton overlies the Cherokee Group conformably, but a regional disconformity is present between the Marmaton and the Pleasanton Group above. In many outcrops of interval C in eastern Kansas, a sandstone unit is present at the base of the Seminole Formation (table GFS-2), and the contact of this sandstone with Marmaton beds beneath is regarded as the boundary between the Missouri and Des Moines Series (Jewett, Emery, and Hatcher, 1965). This disconformity extends a short distance westward into the subsurface of the Forest City and Cherokee basins. No conclusive evidence is known of a widespread disconformity at the top of the Des Moines stage west of the Nemaha anticline (Jewett, Emery, and Hatcher, 1965, p. 5; McMurray, 1962, p. 23).

In the area of outcrop, clayey mudstone of the Pleasanton Group contains a variety of fossils (Jewett, Emery, and Hatcher, 1965) including land plants, brachiopods, crinoids, bryozoa, and pelecypods. The Checkerboard Formation (table GFS-2), which consists of fine-grained nodular or cross-bedded, coquinoid limestone, contains arenaceous foraminifers and other marine fossils. Associated sandstones may contain marine fossils, land plants, or a mixture of both. In the interior of the Forest City basin and westward onto the Nemaha anticline, the Pleasanton consists chiefly of clayey mudstone, siltstone, and fine-grained sandstone, with minor amounts of limestone (Johnson and Adkison, 1967, p. 10; Johnson and Wagner, 1967, p. 133; Lee, 1956, p. 91, 92).

From the Nemaha anticline eastward, the general pattern of alternating marine and non-marine conditions established during deposition of the Cherokee Group continued into Marmaton and Pleasanton times. Throughout deposition of interval C, the depth of marine water probably did not greatly exceed 100 feet in this area. During periods when the region was emergent, the coastal relief may have ranged from a few feet to only a few tens of feet. Maximal relief on the surface at the Missouri-Des Moines contact, where topographic relief probably was at its greatest for interval C, is about 50 feet (Lee, 1943, p. 88).

Westward from the Nemaha anticline, the Cherokee, Marmaton and Pleasanton groups are increasingly difficult to differentiate. Cyclothems as developed in the Cherokee Group of eastern Kansas are not in this region, coal beds are few and seemingly are discontinuous laterally, and sandstone is present only in minor amounts (Adkison, 1963). Clayey mudstone beds in the Salina and Sedgwick basins and on the Central Kansas uplift are predominantly red and gray. They are present where the Cherokee Group overlaps onto the Central Kansas uplift (Lee, 1956, p. 87).

Westward from the Cambridge arch-Central Kansas uplift and the Pratt anticline, limestone beds are chert-bearing and abundantly oolitic; they are fossiliferous, containing fusulines, brachiopods, corals, crinoids and algae. Beds of arkosic sandstone, some of which are 15 to 20 feet thick, occur at several places in Hamilton, Stanton, and Morton Counties. Arkosic sandstone and coarse-grained quartz sandstone with well-rounded, frosted grains are present in Cheyenne and Rawlins Counties. Frosted sand grains also are in parts of interval C elsewhere in western Kansas, especially where the interval overlaps the "Pennsylvanian basal conglomerate."

Rocks of interval C west of the Nemaha anticline are believed to have accumulated under generally transgressive marine conditions, including shallow shelf to littoral and, locally, subaerial environments, where beds of interval C overlap onto the western flank of the Nemaha anticline, and onto the Cambridge arch, Pratt anticline, and Central Kansas uplift. At times moderately high energy prevailed in the sea, as is shown by the abundance of oolitic limestone in the interval. The water was turbid periodically, but seemingly was clear enough at other times to allow corals and algae to flourish. The gently emergent regional anticlinoria of Kansas were the sources of much fine detritus, but arkosic sandstones of southwestern and northwestern Kansas suggest the proximity of exposed basement rocks on the ~~Las Animas arch~~ Sierra Grande - Apishapa Uplift and associated structural features in eastern Colorado.

Paleotectonic implications

In the interior of the Forest City and Cherokee basins and the Hugoton embayment, sedimentation continued without significant interruption from the time of interval B into the time of interval C. Deepening of basins and moderate uplifting of anticlines accompanied transgression of seas from the south. The Sedgwick and Salina basins were inundated and all rocks of interval B were overlapped northward. All of Kansas except crests of the Central Kansas uplift and Nemaha anticline were covered by marine waters at one time or another during accumulation of interval C. Transgression caused by progressive subsidence of the entire region was interrupted periodically by minor episodes of regression, caused by uplift of the anticlinoria and the region east of the Nemaha anticline. By the end of interval C time only small areas in Rush, Barton, northern Nemaha, and northeastern Marshall Counties were emergent.

Structural deformation of all major folds in Kansas probably continued intermittently throughout deposition of interval C. In the deeper parts of the Hugoton embayment, where interval C overlies interval B, thinning of interval C occurred across and northeastward from the Keyes dome in Morton County, and thickening took place toward the axis of the embayment in Stevens and Stanton Counties (pl. 7A). These events are evidence of continued movement of folds active during and since the time of interval A (pl. 3A). Thickening of interval C rocks in the Forest City and Cherokee basins shows that downwarping continued during accumulation of the Cherokee, Marmaton, and Pleasanton Groups; total subsidence probably was on the order of 800 feet (pl. 7A). Folding of local anticlines and synclines accompanied uplift of the Nemaha anticline and the Central Kansas uplift (Lee, 1956, p. 149-150). Although rocks of interval C are more than 400 feet thick in the Salina and Sedgwick basins, these regions had been downwarped to some extent before interval C time. Accordingly, total subsidence of these basins during accumulation of interval C probably was somewhat less than 400 feet.

INTERVAL D

Formations included

Interval D is exposed at the surface in eastern Kansas and is present throughout the State except in the southeasternmost few counties (pl. 8A). The interval includes the Kansas City Group in the lower part and the Lansing Group in the upper part (table GFS-2).

Upper boundary of interval D

The upper boundary of interval D is placed at the contact of the Stanton Limestone of the Lansing Group (below) with the Stranger Formation of the Douglas Group above; this is the Missouri-Virgil boundary in Kansas. Throughout most of Kansas uppermost rocks of interval D are limestone and lowermost rocks of interval E are mudstone (fig. GFS-9).

Figure GFS-9.--NEAR HERE

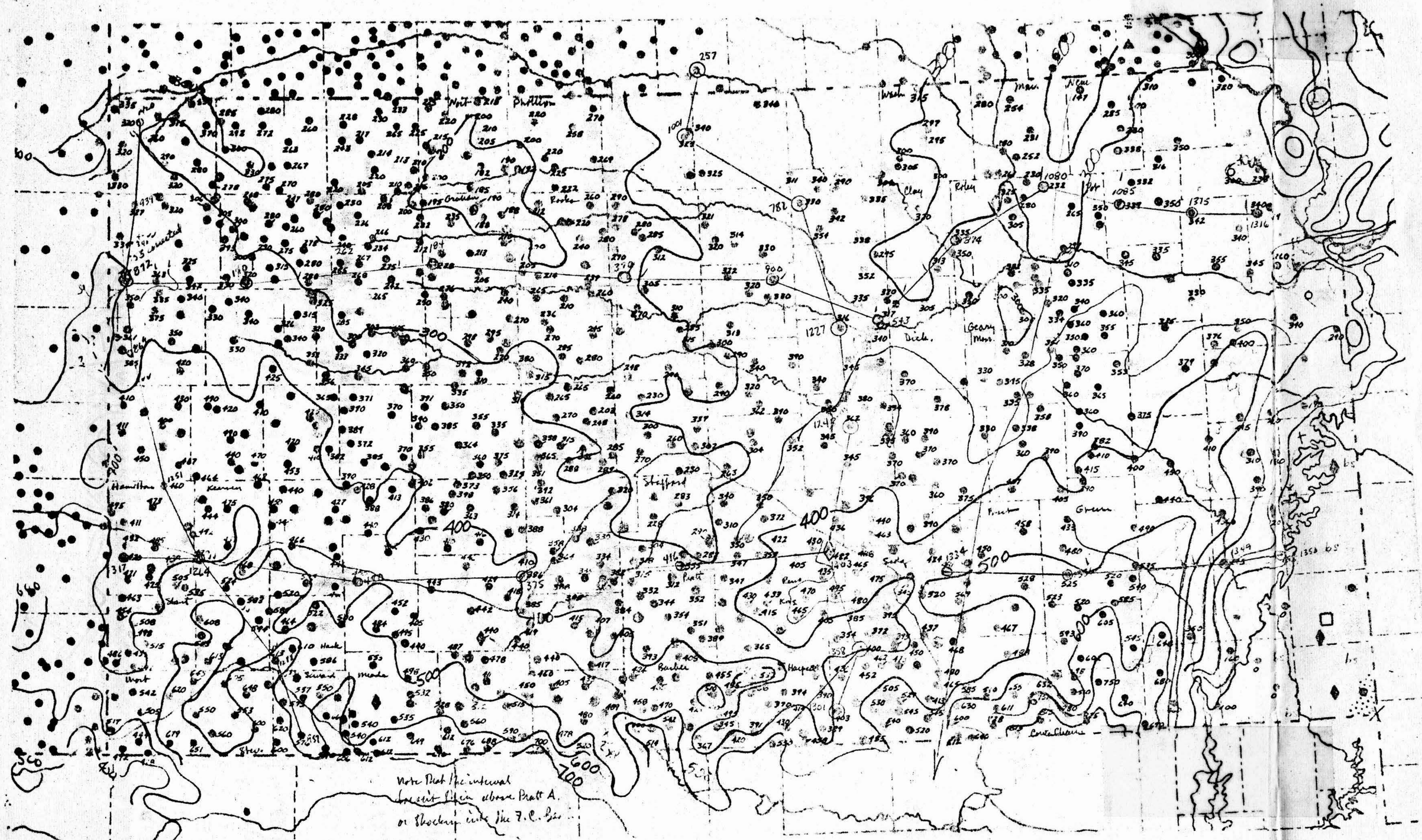


Plate 9A - Isopachous map of interval D in Kansas.
Contour interval is 100 feet.

Figure GFS-9.--Generalized lithologic description of upper boundary of interval D in Kansas. Throughout all of Kansas but area A, as described below, uppermost rocks of interval D are buff, gray or locally white limestones. They are aphanitic to finely crystalline, locally chert-bearing, oolitic or dolomitic. Lowermost rocks of interval E include:

Area A: Gray to buff sandstone overlying red and gray sandy or clayey mudstone of interval D.

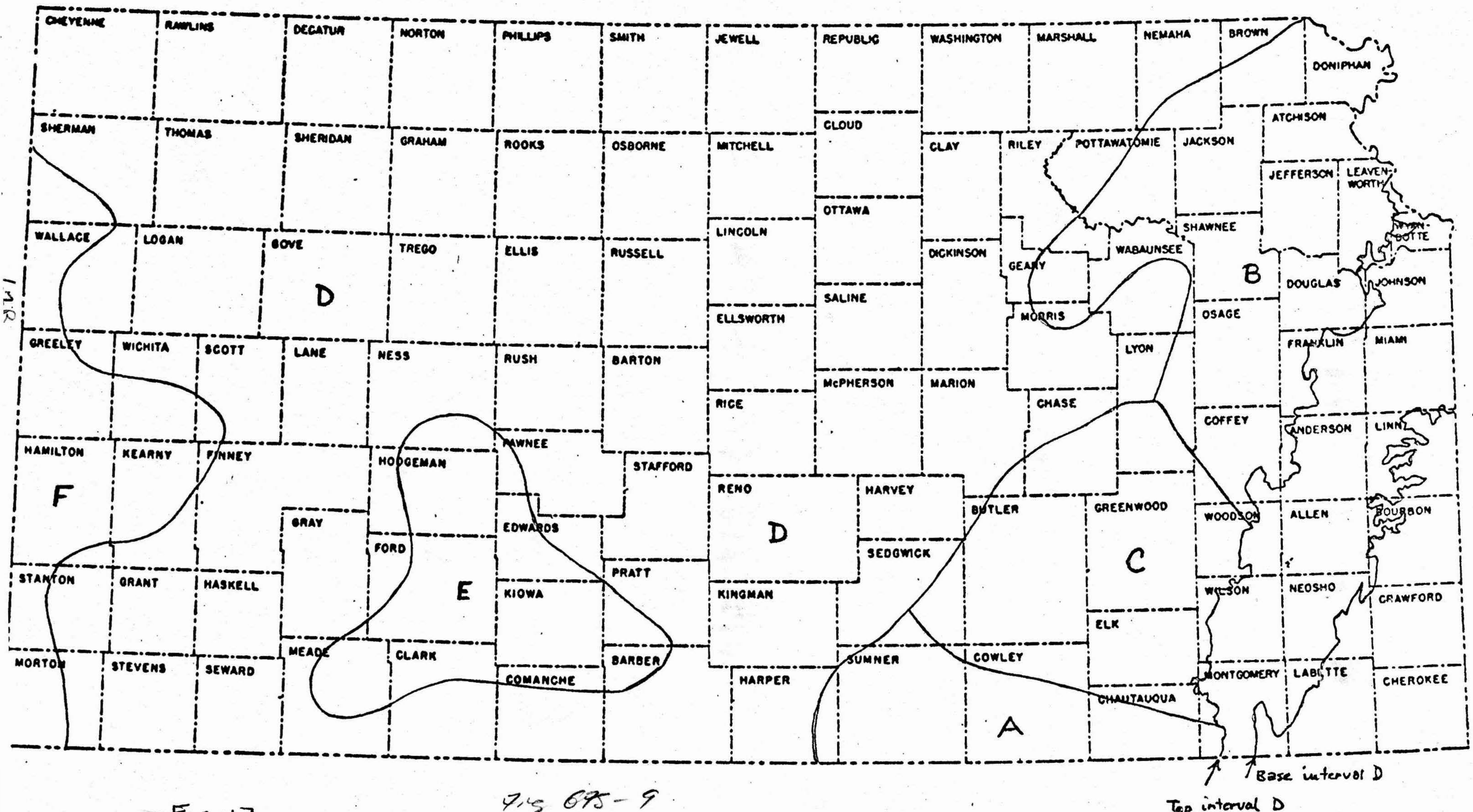
B: Gray sandy mudstone or locally, gray sandstone.

C: Gray, red or variegated sandy, clayey mudstone.

D: Red and gray or variegated clayey mudstone.

E: Red and gray or variegated sandy clayey mudstone or, locally, sandstone.

F: Gray clayey mudstone.



~~FIG 17~~

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Thickness trends

In much of Kansas east of the Nemaha anticline (fig. GFS-2) interval D thickens westward from an erosional edge to more than 800 feet in the deeper part of the Cherokee basin in Chautauqua and Cowley Counties (pl. 8A). An elongate area of thickening extends southwestward from Douglas County to Chautauqua County, wherein the interval increases from about 400 to more than 800 feet. Rocks of interval D are almost 500 feet thick in the Sedgwick basin in parts of Harvey, Sedgwick, Reno, and Kingman Counties, and more than 500 feet in the Cherokee basin, but they are relatively thin in most places across the Nemaha anticline.

Interval D thins markedly across the northern part of the Nemaha anticline in northeastern Kansas and is less than 150 feet thick in northwestern Nemaha County. A large region in which the interval ranges from 300 to 400 feet thick extends from the area of the Forest City basin, across the central part of the Nemaha anticline and northward into the Salina basin (pl. 8A). Rocks of interval D are less than 300 feet thick throughout the region of the Cambridge arch-Central Kansas uplift. They are less than 200 feet thick on the crest of the anticline in parts of Norton, Phillips, Graham, and Rooks Counties (fig. GFS-1), from where they thicken gradually eastward into the Salina basin and southwestward into the axis of the Hugoton embayment.

Rocks of interval D show marked local thickening and thinning at several places in Kansas, notably in the Hugoton embayment. The interval thins across the Keyes dome in southwestern Morton County, thickens abruptly in northern and eastern Morton County, and thins across much of western Stanton County and Hamilton County. Pronounced thinning of the interval occurs southwestward from southern Finney County through northwestern Haskell County, southeastern Grant County and into central Seward County. Rocks of interval D are less than 400 feet thick southeastward from the crest of the Central Kansas uplift through eastern Pratt County and southwestern Kingman County to northeastern Harper County, thence northeastward and southwestward for a long distance into Sedgwick and Barber Counties.

Lithofacies trends

Interval D is composed mainly of limestone, clayey mudstone, comparatively minor amounts of sandstone, and, in the Kansas City Group, small amounts of coal. Fifteen formations are included in the interval, most of which are continuous laterally, traceable at the surface, and recognizable in the subsurface; some units can be identified in the subsurface as far as westernmost Kansas (Merriam, 1963; Parkhurst, 1959). Limestone units thicken generally westward and southward in the subsurface; at some places on the surface they thicken abruptly into algal-mound complexes and in the subsurface, locally are as much as four times the normal thickness (Merriam, 1963; Heckel and Cocke, 1969).

Interval D consists mostly of limy, clayey mudstone in southeastern and easternmost Kansas (pl. 8B), but is largely clayey limestone in southern Greenwood and northern Elk Counties, and both clayey mudstone and sandy clayey mudstone in parts of Chautauqua, Cowley, and Sumner Counties. Most of the clayey mudstone is gray and red, but locally contains thin beds that are black and carbonaceous. Beds of buff or tan sandstone at some places are more than 10 feet thick. Limestone units are mostly buff to gray, chert-bearing, and oolitic.

Rock of interval D is chiefly clayey limestone from the Forest City basin across the Nemaha anticline into the Salina basin, thence southward into the Sedgwick basin, and westward across the Cambridge arch into Colorado (pl. 8B). Limestone and sandy clayey limestone are abundant at several scattered localities. Limestone makes up the interval across the Cambridge arch, mostly in Decatur, Sheridan and Graham Counties. In extreme northwestern Kansas, interval D consists of limy mudstone.

Limestone beds of interval D are buff to gray or locally white, some are chert-bearing, oolitic, or dolomitic, and most are aphanitic to finely crystalline. In the clayey limestone facies, clayey mudstone is interbedded with the limestone and is red, gray, grayish-green, or black in the area of the Nemaha anticline and Forest City basin and locally contains beds of carbonaceous clayey mudstone. In the Salina basin and westward to Colorado, the clayey mudstone is red and gray or variegated, and includes black clayey mudstone at several places. Beds of sandstone are present in the clayey mudstone across some parts of the Cambridge arch and in Cheyenne, Sherman, Wallace and Greeley Counties in northwesternmost Kansas.

Symbols

J = sandy ls.
K = sandy clayey ls.
L = limy mudstone
M = clayey ls.
U = ls.

Plane 8B - Lithofacies map.

Interval D is predominantly limestone in southwestern and central Kansas, in the region of the eastern flank of the Hugoton embayment and the Central Kansas uplift and Pratt anticline. Facies of sandy, clayey limestone, limy mudstone, and clayey limestone overlie the Keyes dome and border it to the northeast. Large isolated areas of clayey limestone compose the interval in southern Finney County and vicinity and in a large, irregularly shaped area extending from Kiowa County southward to Barber County and eastward to Harper County. Clayey limestone makes up interval D in southern Clark County and southward into Oklahoma.

Limestone beds of southwestern and central Kansas are aphanitic to finely crystalline, dominantly buff or gray, locally white, and dolomitic at many places. The interval contains chert-bearing or oolitic limestone almost throughout the region. Clayey mudstone beds are mostly gray or red, but are black at several places. They are sandy or silty locally and contain beds of white to gray, fine-grained, limy sandstone on the Keyes dome.

Sources and environments of deposition

Sedimentation apparently was uninterrupted from interval C into interval D time in Kansas. Soon after the onset of interval D sedimentation, the crests of the Nemaha anticline and Central Kansas uplift were submerged, and shallow marine to paralic conditions prevailed across the state. Subsidence of basinal areas continued throughout the interval, interrupted by periods of relative standstill when regression of the sea took place and a terrestrial environment developed locally. The major anticlinal structures continued to be folded, but less intensively than during interval C time.

Terrigenous detritus in rocks of interval D came from outside Kansas, probably from the Arbuckle Mountains region to the south, the Ozarks to the east, and to some extent, from the north and northeast (Heckel and Cocke, 1969; Crowley, 1969; Walton, 1960; Ball, 1964). Coarse clastic carbonate rock and an abundance of oolitic limestone in parts of the interval indicate some moderate to high energy in marine waters of Kansas; these waters ranged from turbid, as shown by the presence of clayey mudstone beds, to clear, as shown, for example, by beds rich in algae, whose habitat presumably was well-lighted and reasonably free of fine suspended mud.

In the outcrop region, interval D consists of formations made up chiefly of (a) limestone members interbedded with relatively thin clayey mudstone members, alternating with (b) thick formations of clayey mudstone (fig. GFS-10). Several cyclothems are recognized within the

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Figure GFS-10.--NEAR HERE

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interval. Neither the order of occurrence of beds nor their ~~, nor the~~ faunal content is the same among different cyclothems. This complexity seems to be due to partial development of simple cyclothems, each of which is developed differently from the others, and all of which are contained in a single large, complex cyclothem, termed a megacyclothem (fig. GFS-11)

Figure GFS-11.--NEAR HERE

(Moore, 1936, p. 29; 1950, p. 11).

Figure GFS-10.--Generalized section of interval D in eastern Kansas. The interval is composed basically of formations that include thick limestone members interbedded with thin mudstone members, alternating with formations that include thick mudstone members, sandstone, coal, and thin limestone units. (After Zeller and others, 1968, pl. 1).

(TP Paleotectonic, Kansas, Fig. 10)
G Stewart, 12/7/70

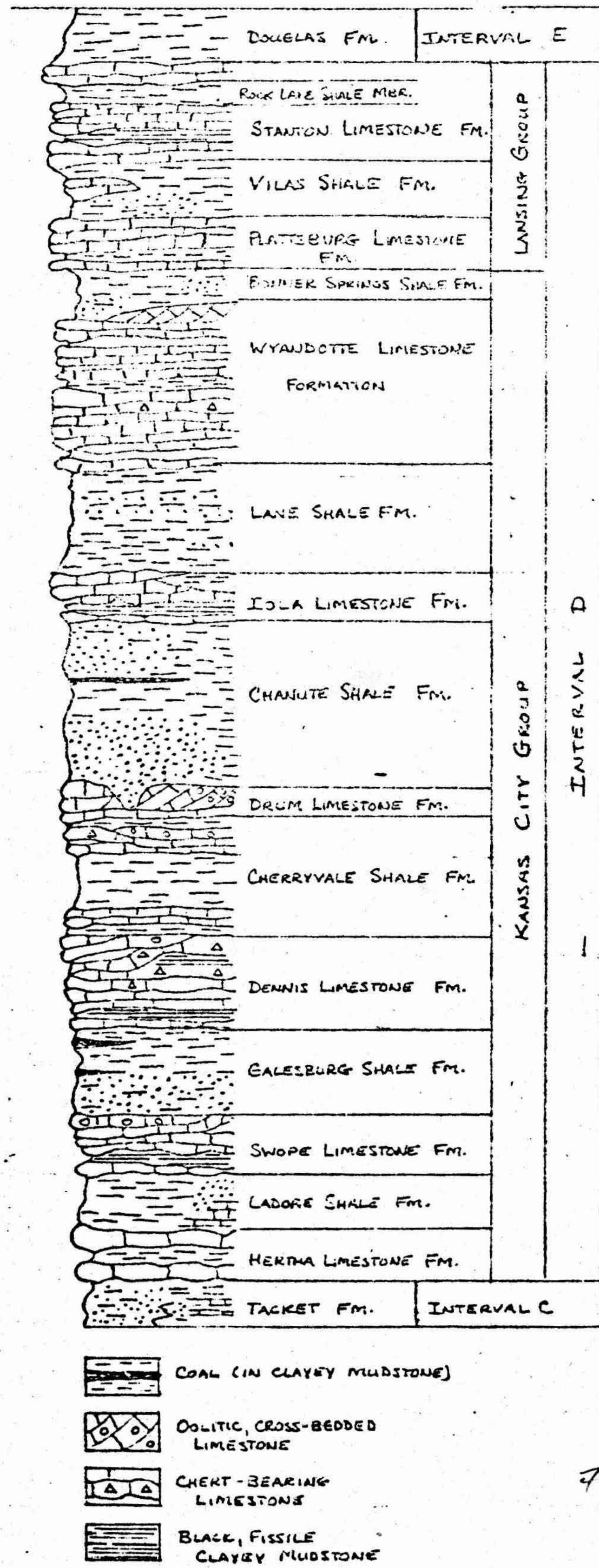

Fig. G75-10

74B

Figure GFS-11.--Diagrammatic and representative section of interval D rocks, eastern Kansas, showing a megacyclothem that contains three cyclothems (A,B,C). (Adapted from Moore, 1949b, p. 78).

BY G. Stewart DATE 12/9/70 SUBJECT TP Paleotectonic, Kansas, SHEET NO. ____ OF ____

CHKD. BY ____ DATE ____ FIG. 20 11 JOB NO. ____

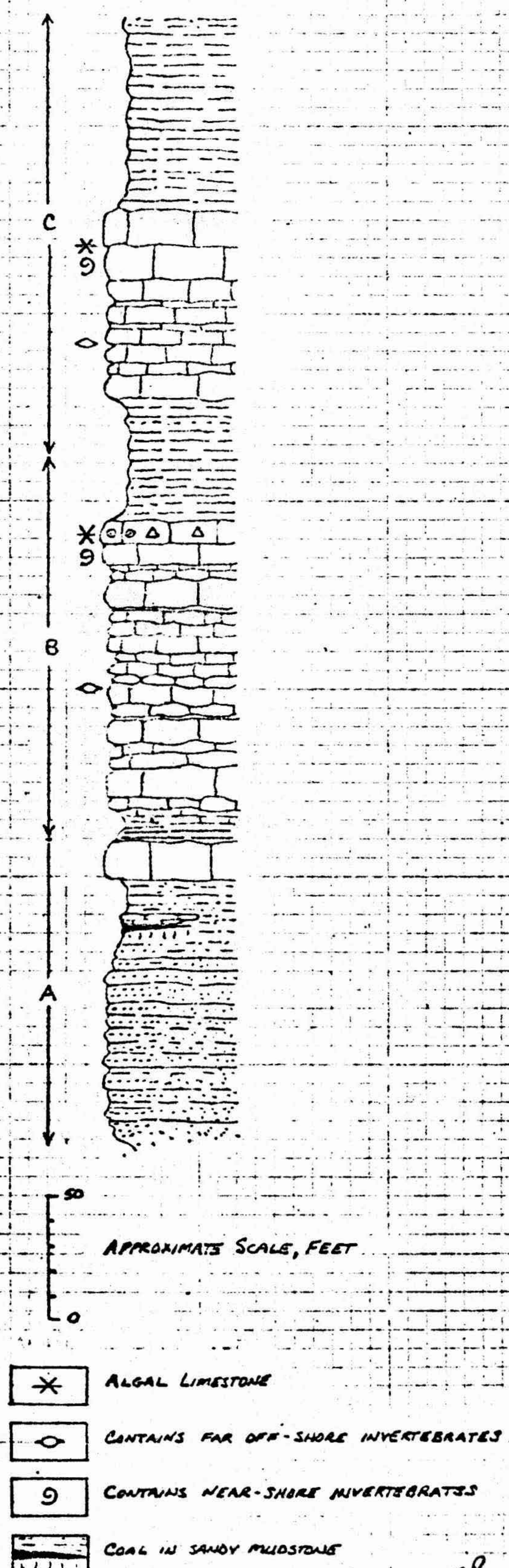

Fig. GTS-11

75B

Three basic types of partially developed cyclothems can be distinguished; they are included repeatedly in megacyclothems of interval D (fig. GFS-11). Cyclothems shown by the letter "A" generally include sandstone overlain by beds of shaley, clayey mudstone or locally by coal and limestone--the latter containing mollusks, fusulinids, or brachiopods. Cyclothems designated by the letter "B" comprise (1) a dark, carbonaceous, fissile, clayey mudstone, overlain by light-colored clayey mudstone, both of which contain thinly scattered conodonts, brachiopods, pelecypods, or phosphatic concretions with marine fossils; (2) thick units of thin- to medium-bedded limestone containing in its upper part fusulinids and oolites, nodular chert, abundant algae, and some mollusks and brachiopods; and (3) sandy, clayey, shaley mudstone that generally is unfossiliferous. A cyclothem shown by the letter "C" may include in its lower part a sandy unit bearing plant fossils, overlain by sandy, shaley, clayey mudstone with mollusks, and limestone that includes in its upper part fusulinids, mollusks, and algae (Moore, 1949; 1950).

In eastern Kansas all of the limestone formations of interval D locally contain thick and extensive algal mounds. These reef-like masses have been subjects of much study in recent years (Wilson, 1957; Davis, 1959; Harbaugh, 1959, 1960, 1962, 1964; Wray, 1964, 1965; Harbaugh and others, 1965; Crowley, 1966; Frost, 1968; Heckel and Cocke, 1969). In the central parts of the mounds leaflike algae are especially abundant. The mounds are chiefly massive to thick-bedded calcilutite and carbonate spar (Heckel and Cocke, 1969, p. 1061); in some of them the core areas contain invertebrate fossils, including brachiopods, bryozoans, crinoid remains, horn corals, fusulinids, encrusting algae, gastropods, tubiform foraminifers, or sponges (Crowley, 1966; Wray, 1964; Davis, 1959; Harbaugh, 1962.

Cross-bedded calcarenitic limestone, including both fragmental skeletal material and thick oolitic deposits, commonly overlies the central parts as well as the flanks of the mounds. Some of these mounds are exceedingly thick in comparison with the thickness of the units within which they are developed; also they cover large areas. For example, a large algal mound in the Spring Hill Limestone Member of the Plattsburg Formation (table GFS-2) in Wilson County is 88 feet thick, whereas the Spring Hill normally is about three feet thick. This bank complex covers an area of about 140 square miles (Harbaugh, 1962, p. 43).

Algal mounds within interval D mostly occur near the southern extremities of limestone units, at relatively short distances from places where carbonate beds of interval D grade into terrigenous rocks. Moreover, in some areas, the mounds occur in several different units of interval D. For example, algal mounds are in the Hertha Limestone Formation (table GFS-2) in southeastern Kansas, and also in the Bethany Falls Member of the Swope Limestone and the Winterset Member of the Dennis Limestone in the same area (Heckel and Cocke, 1969, p. 1063).

Algal mounds seem to have formed mostly on high areas on the floors of shallow seas, including mud bars (Harbaugh, 1964) or, as in the Wyandotte Limestone Formation, on submerged deltaic platforms (Crowley, 1966, p. 47). Their growth probably kept pace with subsidence (Heckel and Cocke, 1969, p. 1067). At times the upper parts of the mounds were barely awash, perhaps even slightly emergent (Harbaugh, 1960, p. 233), and strong currents deposited calcarenites as spits and bars; the calcilutites probably formed in quiet lagoons.

The facies of algal-mound limestones and associated rocks of interval D, as represented in the outcrop area of eastern Kansas, graded northward and westward into open-marine facies and southward and southwestward into the terrigenous facies of south-central Kansas and Oklahoma. The basic kinds of environments described above were represented repeatedly in interval D but were displaced laterally by other facies as a result of periodic advances and retreats of the sea.

All environmental implications of cyclothems in interval D are not yet clear, and considerable work remains to be done before the algal-mound complexes are understood thoroughly. Nonetheless, during the time of interval D, the depositional environment intermittently ranged from shallow marine to terrestrial in eastern Kansas.

Most beds of interval D contain abundant marine fossils, but at a locality in Anderson County a mixed assemblage of marine invertebrates, land plants, coelacanth fishes, terrestrial arthropods, and reptiles has been recovered from the Rock Lake Shale Member of the Stanton Limestone (fig. GFS-10) (Moore and others, 1936; Peabody, 1952, 1957, 1958; Eaton and Stewart, 1960; Cridland and others, 1963). These fossils are judged to have been buried in a lagoonal environment (Peabody, 1952; Eaton and Stewart, 1960; Cridland and others, 1963; Moore, 1964), and the member containing them probably was deposited in an area that was gradational northwestward, through east-central Kansas, from terrestrial to marine (Ball, 1964, p. 231-232).

Tracks probably of amphibians have been reported from the Kansas City Group at Kansas City, Missouri (Branson and Mehl, 1932, p. 391-393). In addition, a few coal beds, sandstone beds and clayey mudstone beds that contain plant fossils, as well as other features indicative of a littoral environment, (Gentile, 1969; Ball, 1964) suggest that periodically during the time of interval D, eastern Kansas was a slightly emergent region of low-lying, swampy, coastal plains crossed by sluggish streams and bordering a shallow, clear and warm sea.

In the subsurface of Kansas, cyclothems of interval D, including algal mounds and terrestrial deposits in some beds, extend an unknown but considerable distance westward. Algal mounds may be as far west as Butler and Cowley Counties (Merriam, 1963, p. 124; Ball, 1964, p. 196-197); one coal bed occurs in Butler County (Adkison, 1963, p. 10), and coaly, clayey mudstone occurs in Shawnee County (Johnson and Wagner, 1967, p. 133-134).

Other salient evidence from subsurface records of depositional environments includes the almost ubiquitous occurrence of oolitic limestone in some of the beds. This rock is considered indicative of shallow water and moderately strong currents. Secondly, the persistence of black, fissile, carbonaceous and clayey mudstone beds and some limestones that extend far westward in Kansas suggest areas of quiet water accumulation. Finally, the presence of small amounts of algal-encrusted shell fragments, crinoid stem fragments, and fusulinids in Rawlins County (Harbaugh and Davie, 1964) indicate places of shallow water deposition.

Distribution of distinctive fossils believed to be environmental indicators has been recorded as follows: gastropods, corals, bryozoans, fusulinids, crinoid stem fragments, and small amounts of algal-encrusted shell fragments in Stafford County (Harbaugh and Davie, 1964); crinoids, fusulinids, brachiopods, bryozoans, ostracodes, gastropods, and pelecypods in the Sedgwick basin (Adkison, 1963); fusulinids in many other places and algal and crinoidal limestone in parts of Morton, Seward, and Stanton Counties.

Distinctive rock types, other than those cited above, useful in environmental interpretation of interval D strata include red, gray, or variegated clayey mudstone at many places, and sandy, clayey mudstones in Morton County, near the Keyes dome, and in Cheyenne County in northwesternmost Kansas.

These data are considered representative of the evidence bearing upon depositional conditions of interval D in Kansas. On the whole, they suggest that a cyclic, shallow-marine to locally terrestrial environment prevailed throughout most of the region during the time of this interval.

The limestone and clayey limestone that are dominant in interval D of central Kansas grade southward into limy mudstone, clayey mudstone, and sandy mudstone of south-central Kansas, in the general area of Wilson, Montgomery, Chautauqua, Elk, Cowley, and Sumner Counties. Comparable changes take place in beds exposed at the surface in southern Kansas. The change in lithology of the interval in this region is probably more the result of contemporaneous changes of facies than of erosion of limestone followed by deposition of sandstone and mudstone. Evidence exists both for facies changes and disconformities, however, and the relative importance of the two is still open to question (Lukert, 1949, p. 145-151; Pate, 1959, p. 44-48; Rascoe, 1962; Merriam, 1963, p. 125; and especially Winchell, 1957; Schulte, 1958; and Ball, 1964, p. 196-200).

In general, carbonate units of the Kansas City Group persist farther southward than do those of the Lansing Group (Lukert, 1949, p. 146, cross-section A-B; Merriam, 1963, p. 124), indicating a progressive northward influx of terrigenous detritus into south-central Kansas through interval D time.

Paleotectonic implications

Sedimentation was continuous from interval C into interval D time throughout all of Kansas except on the highest parts of the Central Kansas uplift in Barton and Rush Counties and the Nemaha anticline (fig. GFS-2) in Marshall and Nemaha Counties (fig. GFS-1). These positive areas were inundated shortly after onset of interval D sedimentation and were covered by rocks representing most of the lower part of the interval.

The central portions of the Cherokee basin and the Hugoton embayment continued to subside during interval D. Total subsidence exceeded 700 feet in the deepest part of the Hugoton embayment in southwestern Comanche County, and 900 feet in the Cherokee basin in southern Chautauqua County. However, during periods of maximal submergence, marine waters probably were only a few tens of feet deep.

Regressions of the sea produced several episodes in which terrestrial conditions prevailed in parts of eastern Kansas, and paralic depositional environments may at times have existed as far westward as the Nemaha anticline and the Sedgwick and Salina basins.

Rocks of interval D are no thicker in the central parts of the Forest City and Salina basins than on the flanks of these basins, showing that no differential subsidence occurred within them during interval D time. The Forest City and Salina basins were filled by sediment of interval C and, during the deposition of interval D, they subsided as shelves that extended northward from the Cherokee and Sedgwick basins. Large structural embayments extended from the deep part of the Cherokee basin northeastward into the southern part of the Forest City basin and northwestward across the southern part of the Nemaha anticline into the Sedgwick basin.

The northern part of the Nemaha anticline was uplifted moderately during interval D time, but only slight uplift took place within the southern two-thirds of the anticlinorium. The Cambridge arch and Central Kansas uplift continued to be elevated and together composed a large anticlinorium that extended throughout most of northwestern Kansas. The crest of the structure was located on the Cambridge arch in Norton, Graham, and western Phillips and Rooks Counties, where interval D is thinner than 200 feet. Thinning of interval D in Barber, Harper and Sedgwick Counties indicates that a large northeast-trending anticline extended from the northeastern flank of the Hugoton embayment to the Sedgwick basin, and lay directly across the southeastward-plunging part of the Central Kansas uplift.

The Keyes dome was actively folded and therefore influenced sedimentation during interval D time. The interval thins across the dome's northern and eastern flanks and its strata include considerable amounts of sandstone and mudstone in proximity to the dome. Several large anticlinal flextures in the Hugoton embayment were uplifted slightly during the time of this interval; most of them plunged southward and southwestward from the northeastern shelf toward the axis of the embayment and the Keyes dome.

By the end of interval D time, all of Kansas was submergent except perhaps a part of south-central Kansas including Montgomery, Wilson, Cowley and Sumner Counties where uppermost rocks of interval D may have undergone intermittent subaerial erosion.

INTERVAL E

Formations included .

Interval E crops out in eastern Kansas and is present in all of the State except a few counties near the eastern border. The interval includes the Douglas, Shawnee and Wabaunsee groups, in ascending order (table GFS-2).

Upper boundary of interval E

No widespread, clear-cut physical difference exists between the uppermost beds of the Pennsylvanian and the lowermost beds of the Permian in Kansas. Pennsylvanian rocks are conformably overlain by Permian rocks at most places both at the surface and in the subsurface. In the outcrop belt in Kansas, the upper boundary of the interval is placed arbitrarily at the contact of the Brownville Limestone Member of the Wood Siding Formation, Pennsylvanian, below, with the Towle Shale Member of the Onaga Shale, Permian, above (fig. GFS-12). Several clayey mudstone units in the upper part of

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Figure GFS-12.--NEAR HERE

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the Wabaunsee Group, Pennsylvanian, and lower part of the Admire Group, Permian, contain channel or sheet sandstones, however (for further discussion see Mudge, 1956; Mudge and Yochelson, 1962, p. 19-21, and 119-120). Some of the channel sandstones cut deeply into underlying beds; for example, sandstone-filled channels of the Towle Shale Member have cut into Pennsylvanian rocks as deeply as to the Zeandale Limestone (table GFS-2) (Johnson and Wagner, 1967, p. 175-180, pl. 3). Although channel sandstones are numerous in this part of the stratigraphic section and are important to interpretation of environments of deposition, no single rock unit that contains channel sandstone beds is taken to be evidence of an extensive disconformity that separates the Pennsylvanian and Permian systems.

Figure GFS-12.--Generalized section of uppermost Pennsylvanian and lowermost Permian rocks in the outcrop of interval E in Kansas (after Zeller and others, 1968, pl. 1, and Johnson and Wagner, 1967, pl. 3).

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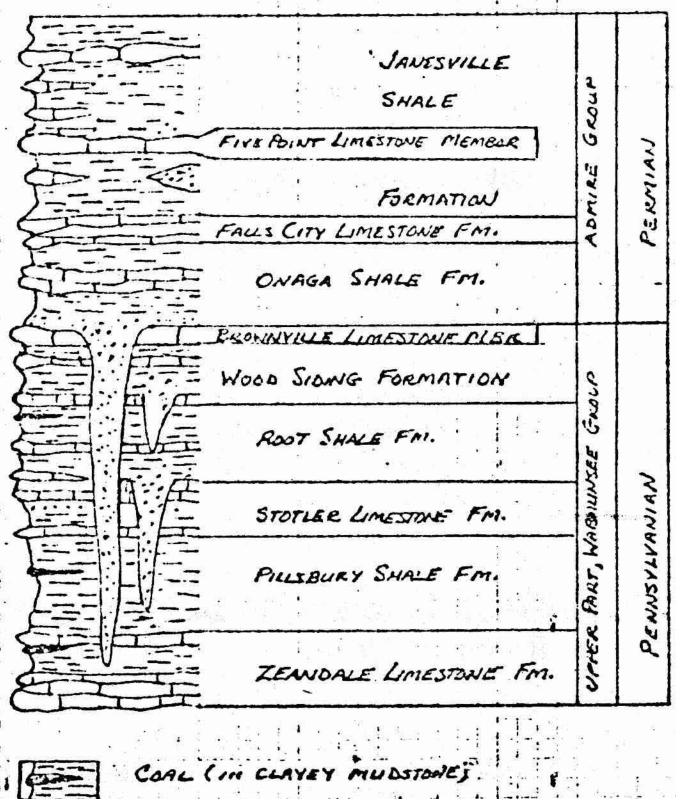

Fig. 6?5-12

Because of the lithic similarity of uppermost Pennsylvanian and lowermost Permian rocks, the lack of an exhaustive study of fossils contained in them, and the absence of a definite and extensive unconformity in the stratigraphic section, the boundary between the systems in Kansas was placed at several different positions within the section during the period from 1859 to 1936 (Moore, 1940, p. 300; Mudge and Yochelson, 1962, p. 118). All positions were higher stratigraphically than the present still-arbitrary boundary, the top of the Brownville Limestone Member, first established by Moore (1936, p. 14).

Difficulty in exact placement of the boundary on the basis of stratigraphic paleontology is caused by (a) limited confusion as to the exact base of the Permian throughout the North American standard sequence of western Texas (Douglas, 1962, p. 120-122; Oriel, Meyers and Crosby, 1967, p. 26-27), which of course makes precise definition of the Pennsylvanian-Permian boundary in Kansas a somewhat subjective matter; (b) uncertainty concerning validity of defining the base of the Pseudoschwagerina zone as the base of the Permian System (Douglas, 1962, p. 121); (c) the fact that the lowermost occurrence of Pseudofusulina, taken to be diagnostic of the Pseudoschwagerina zone, is in the Five Point Limestone Member of the Janesville Shale (fig. GFS-12), about 60 feet above the base of the Permian in Kansas, as defined since 1936; and (d) lack of distinct breaks in the evolutionary sequence of the closely studied fossils from the uppermost Pennsylvanian and lowermost Permian rocks of Kansas.

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The fauna of the Pennsylvanian-Permian boundary section includes fusulinids, corals, echinoids, crinoids, brachiopods, pelecypods, gastropods, both nautiloid and ammonoid cephalopods, and ostracodes (Douglas, 1962, p. 120-122; Duncan, 1962, p. 122-123; and Gordon, 1962, p. 123 and 126). ~~Accordingly,~~ arbitrary assignment of the top of the Brownville Limestone Member as the top of the Pennsylvanian System in Kansas is as logical on the basis of present knowledge as assignment of any other horizon in this part of the section. It is perhaps as well justified by practicality and long-time usage as by stratigraphic evidence. (See Mudge and Yochelson, 1962, p. 116-127 for a thorough discussion of this matter).

The Wood Siding Formation can be traced into the subsurface west of the outcrop area (Merriam, 1963, fig. 43), but is not sufficiently lithologically distinctive and persistent to be easily recognizable throughout central and western Kansas. In shallow subsurface sections near the outcrop (area A, fig. GFS-13), the

Figure GFS-13.--NEAR HERE

uppermost beds of interval E are chiefly gray to buff, aphanitic to finely crystalline limestone, overlain by gray or greenish-gray clayey mudstone, sandy clayey mudstone or, locally, sandstone. In southwestern Kansas (area B, fig. GFS-13) rocks below the boundary are gray to buff, aphanitic to finely crystalline, locally oolitic limestone overlain by gray, clayey mudstone or sandy clayey mudstone. Throughout the remainder of Kansas (area C, fig. GFS-13) the youngest Pennsylvanian rocks are mainly gray to buff, aphanitic to finely crystalline, locally chert-bearing, dolomitic or sandy limestone overlain by red and gray or variegated clayey mudstone, sandy clayey mudstone or, at a few places, sandstone or clayey mudstone containing thin beds of limestone. At several places, uppermost rocks of interval E are sandy clayey mudstone or sandstone.

Figure GFS-13.--Generalized description of upper boundary of interval E in Kansas.

Area A: Gray to buff, aphanitic to finely crystalline limestone overlain by gray or greenish gray clayey mudstone, sandy clayey mudstone, or in some places, sandstone.

Area B: Gray to buff, aphanitic to finely crystalline, locally oolitic limestone overlain by gray, clayey mudstone or sandy clayey mudstone.

Area C: Gray to buff, aphanitic to finely crystalline, locally chert-bearing, dolomitic or sandy limestone overlain by red and gray or variegated clayey mudstone, sandy clayey mudstone, or in some places sandstone or clayey mudstone containing thin beds of limestone.

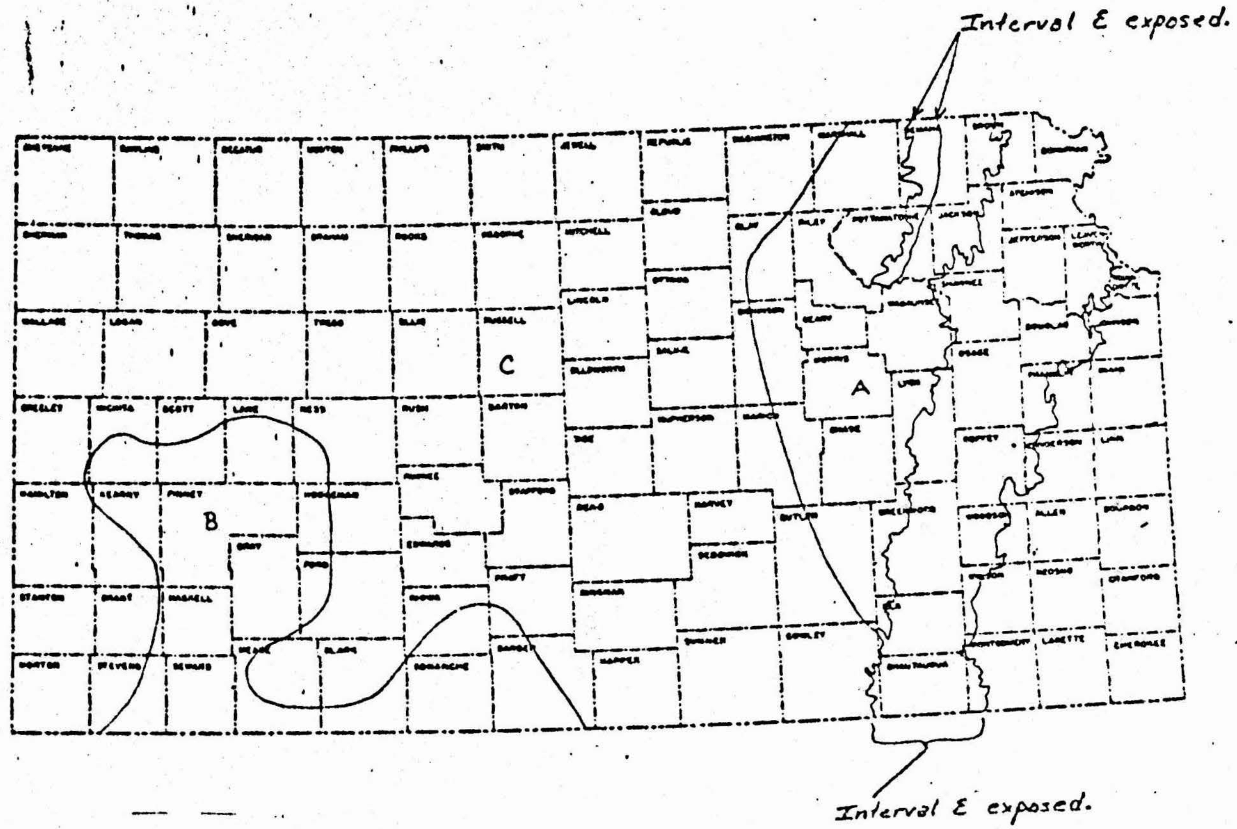

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Figure 13.

Here, plate 9A refers to isopach of interval E.

Thickness trends

In eastern Kansas, interval E thickens westward from an erosional thin edge into a trough that flanks the Nemaha anticline on the east, plunges southward, and extends from southeasternmost Nebraska to Oklahoma (pl. 9A). The interval thins markedly across the southern and central parts of the Nemaha anticline. A slight amount of thinning occurs over the northern end of the anticline in Nemaha, Marshall, Pottawatomie, Riley and Geary Counties (fig. GFS-1). Rocks of interval E are more than 700 feet thick in the central part of the Salina basin and thicken southward along the western flank of the Nemaha anticline to more than 1500 feet in southeastern Harper County and southwestern Sumner County. The interval thins northwestward from this locality across a broad region underlain by the Pratt anticline-Central Kansas uplift-Cambridge arch anticlinorium, and is less than 400 feet thick in the northwesternmost counties of Kansas. Rocks of interval E are thinner than 600 feet in the vicinity of the Keyes dome in Morton County, thicken generally eastward to more than 1100 feet in Clark County, and thence are progressively thicker southward into Oklahoma.

Lithofacies trends

At the surface in Kansas, interval E is made up chiefly of beds of clayey mudstone, limestone, sandstone, and minor amounts of coal (pl. 9B). The Douglas Group includes two formations made up predominantly of thick units of mudstone with sandstone and a few beds of coal, limestone, and conglomerate. The Shawnee Group comprises four limestone and three shale formations, within which members are arranged in distinctive cyclic sequences. The Wabaunsee Group consists chiefly of mudstone, sandstone, thin limestone units, and a few thin beds of coal. Channel sandstones are common in the upper part of the Wabaunsee Group. All three groups of interval E definitely can be recognized in shallow subsurface sections and a few of the marker beds can be traced for long distances into central and western Kansas.

Interval E includes mostly clayey mudstone and sandy clayey mudstone in the part of Kansas eastward from the Nemaha anticline. The interval is composed mostly of limy, sandy, and clayey mudstone at localities in proximity to the Nemaha anticline, especially in parts of Nemaha and Pottawatomie Counties, Jackson County, Wabaunsee, Geary and Morris Counties and in south-central Cowley County (fig. GFS-1). Clayey mudstone is mostly red and gray or greenish gray; beds of black, fissile clayey mudstone are well developed and widespread, especially in formations of the Shawnee Group. At some places clayey mudstone units contain sandstone that is several tens of feet thick. Limestone beds in the interval are buff to gray, aphanitic to finely crystalline; locally some of them are dolomitic or chert-bearing.

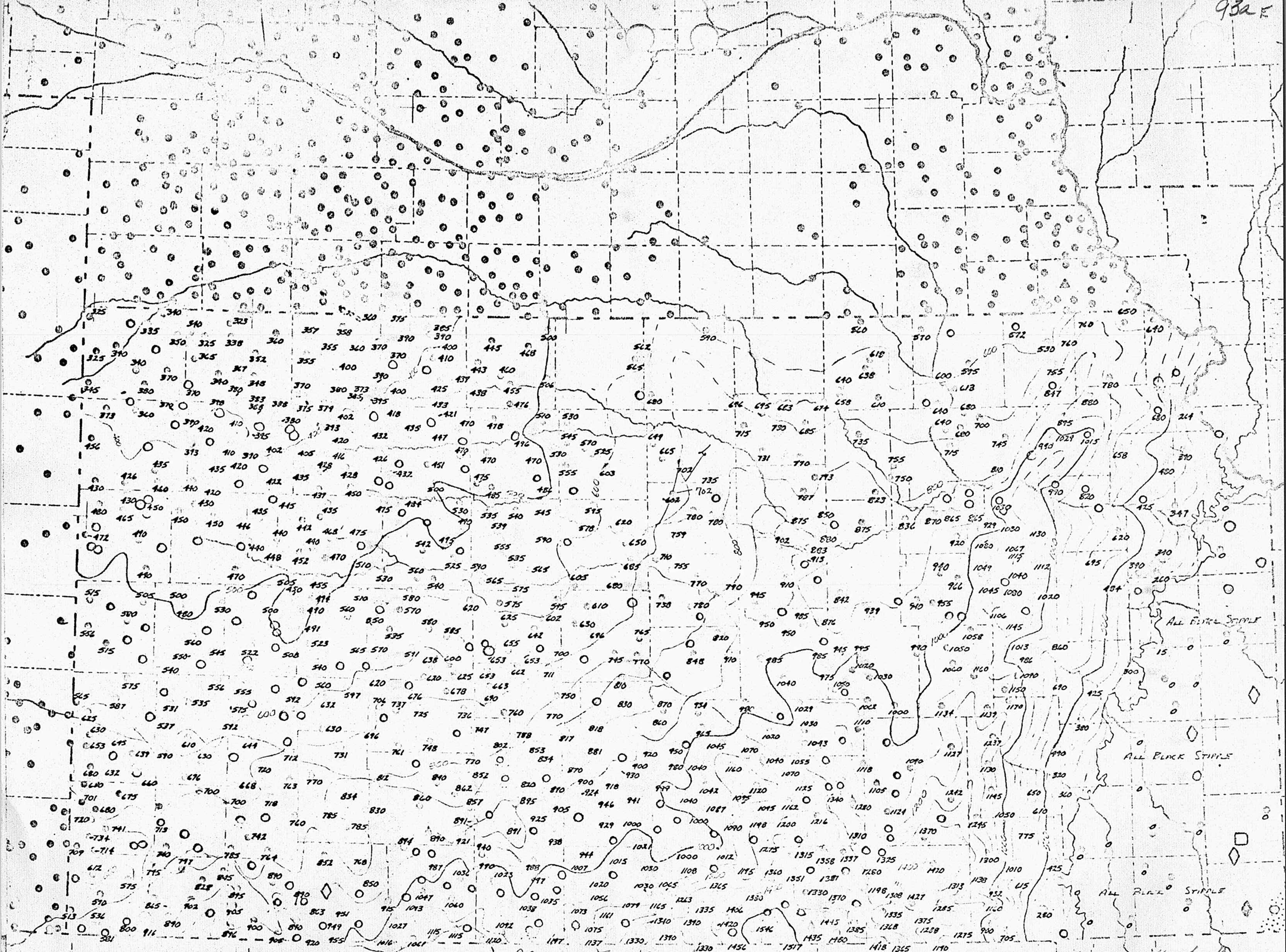

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Plate - G75 - 4A Isopachous map, interval E. Contour interval 100 feet.

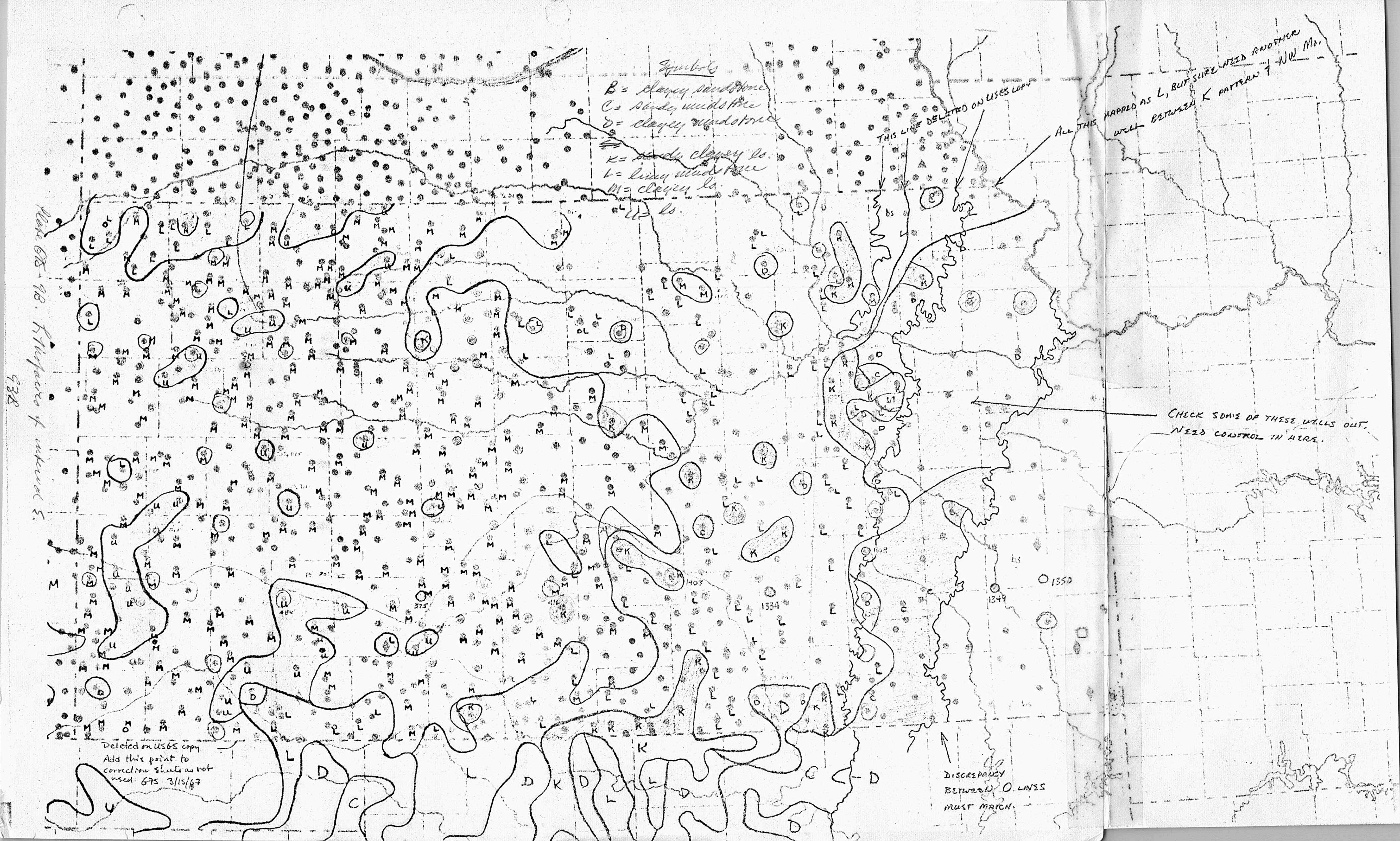
Plate 68-98. Lithofacies of interval 5.
538
Symbols
B = clayey sandstone
C = sandy mudstone
D = clayey mudstone
K = sandy clayey ls.
L = limy mudstone
M = clayey ls.
U = ls.
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ALL THIS MAPPED AS L, BUT SURE NEED ANOTHER WELL BETWEEN K PATTERN & NW MO.
CHECK SOME OF THESE WELLS OUT. NEED CONTROL IN HERE.
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Throughout most of north-central, east-central and south-central Kansas, including the Salina and Sedgwick basins, interval E is composed primarily of limy, clayey mudstone. Furthermore, limy, sandy and clayey mudstone is predominant in a few scattered localities, notably in western Sumner, southern Harper, and southeastern Barber Counties (fig. GFS-1). Mudstone beds are red and gray, locally greenish gray, variegated, and a few are thin, black and carbonaceous. Limestone is gray or buff, aphanitic to finely crystalline, and some chert-bearing or dolomitic beds are present throughout the region.

Clayey limestone or limestone constitutes interval E throughout almost all of western Kansas. Limy, clayey mudstone is the dominant facies in parts of Cheyenne and Rawlins Counties in northwesternmost Kansas and in parts of Seward, Meade and Clark Counties in southwestern Kansas. Limestone beds are generally gray to buff and aphanitic to finely crystalline, and some of the units are both dolomitic and chert-bearing in all parts of the region. Oolitic limestone is present in some parts of the interval in most parts of western Kansas. Clayey mudstone is mainly red and gray and is silty or sandy at some places. A few thin beds, locally a single bed, of dark gray or black, clayey mudstone is present within most of western Kansas.

Sources and environments of deposition

Sedimentation apparently was continuous from interval D time into interval E time throughout all of Kansas except perhaps the south-central part (area A, fig. GFS-9). Depositional environments were controlled, in part, by continued subsidence of basinal areas and moderate uplift of anticlinoria throughout the time of interval E. Regression of the sea occurred periodically and, in eastern Kansas, terrestrial environments developed at many places.

Source areas of terrigenous detritus deposited in eastern and southern Kansas were mainly the Arbuckle and Ozark mountains; the Ouachita Mountains probably contributed a limited amount. In youngest beds part of the detritus probably came from the north and northwest (Mudge, 1956, p. 676), and thin beds of arkosic sandstone in southwestern Kansas suggest the proximity of exposed basement rocks on the ~~Las Animas arch~~ Sierra Grande-Apishapa uplift and associated structural features in eastern Colorado.

Comparisons of lithofacies and faunas suggest remarkably little variation in depositional environments of interval E throughout Kansas. The general similarity of faunas in subsurface limestones to those in correlative beds on the outcrop suggests that all the limestones were deposited on shallow, open-marine shelves. The seas probably persisted longer in central and western Kansas than in the east, but coal beds in south-central Kansas, and the plant fossils and lignitic beds of southwestern Kansas indicate that the strand line fluctuated widely. Probably even short-lived emergences of most of Kansas occurred during parts of interval E. Thus, Kansas seems to have been a region of gentle relief, periodically exposed as broad coastal plains.

Certain fossil groups and rock types have proved especially useful in interpreting depositional environments of subsurface rocks of interval E. Limestone beds of interval E contain crinoids, ostracodes, bryozoans, brachiopods, algae and abundant fusulinids (Adkison, 1963, p. 8-9; Collins, 1947, p. 4; Maher, 1947, p. 6). Some of the fusulinids are weathered (Collins, 1947, p. 8). Thin discontinuous coal beds are in interval E in Butler, Sedgwick, and Reno Counties (Adkison, 1963, pl. 1); plant fossils and lignitic beds are present in the southernmost townships of Seward and Meade Counties. Beds of oolitic limestone are numerous throughout the subsurface. Thin beds of arkosic sandstone are in the subsurface in Hamilton and Clark Counties.

Because interval E in Kansas is composed of three distinct groups of strata -- the Douglas, Shawnee and Wabaunsee Groups -- that are exposed in the eastern part of the State and are clearly traceable in the subsurface of central Kansas, the environments of deposition as interpreted for each of these groups will be discussed separately in the following paragraphs. In western Kansas where interval E is predominantly clayey limestone and normal limestone, mudstone marker beds are largely lacking. The groups in this area can not be accurately distinguished. Therefore only generalized conclusions concerning environments are proposed.

Douglas Group:--In the area of outcrop the Douglas Group (table GFS-2) is mostly a thick section of clayey mudstone and sandstone containing a few thin limestones and small amounts of conglomerate and coal (fig. GFS-14). It thickens southward and grades almost entirely into mudstones and sandstones in northern Oklahoma (Ball, 1964).

Figure GFS-14.--NEAR HERE

Figure GFS-14.--Generalized section of Douglas Group in outcrop area of eastern Kansas. (After Zeller and others, 1968, pl. 1; Moore, 1949b, p. 144-145).

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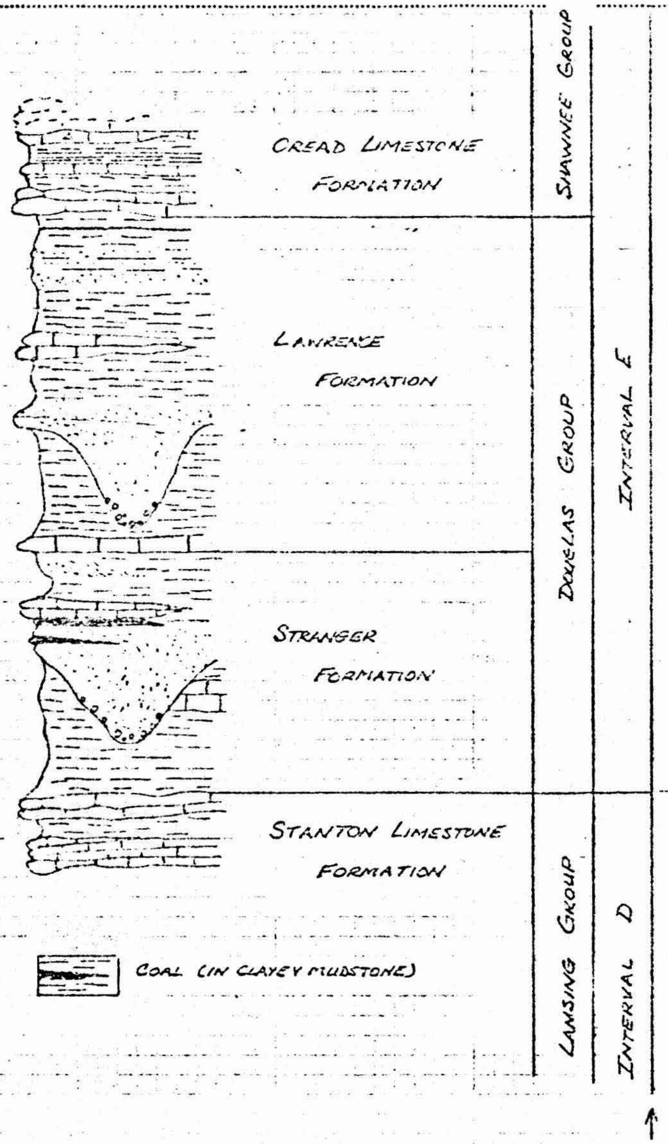

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97B.

Mudstones of the Douglas Group are predominantly clayey. They are mostly gray or geeenish gray; a few beds are reddish brown. Fauna of the mudstone beds includes gastropods, arenaceous foraminifers, ostracodes, nautiloid and ammonoid cephalopods, conodonts, bryozoans, worm tracks and abundant pelecypods (Ball, 1964; Wagner, 1954). Silty and sandy mudstones locally contain remains of land plants.

In general, the pelecypod-bearing sandy, clayey mudstone beds of this group grade northward into brachiopod-bearing clayey mudstones in Nebraska. This change in lithology and fauna is evidence that near-shore depositional environments of the Douglas Group of eastern Kansas graded northward into deeper marine waters (Ball, 1964, p. 278).

Lenses of fine-grained tan to brown quartzose sandstone and siltstone occur within mudstones of the Douglas Group at many places in the outcrop area. Some units of sandstone are as thick as 65 feet (Lins, 1950, p. 124). Channel sandstones of the Douglas Group extend through parts of several counties in eastern Kansas and thicken generally southward. The sandstone commonly is thin-bedded or cross-bedded and locally contains ripple marks, contorted bedding, flow casts and related sedimentary structures (Lins, 1950; O'Connor, 1960; Ball, 1964, p. 90-91). Some of the sandstone beds include flakes of muscovite mica, a few percent of feldspar grains, and plant fossils. Sandstones of the Group probably were deposited in mixed terrestrial and marine environments, mostly near the shores of the sea (Ball, 1964, p. 306-311).

All limestones in the Douglas Group apparently are marine. They are only a few feet thick and wedge out southward in southern Kansas and northern Oklahoma. Fossils contained in the limestone commonly include algae, brachiopods, corals, bryozoans, crinoids, gastropods, fusulinids, and pelecypods (Ball, 1964). Remains of fish occur locally in the lower part of the Lawrence Formation (table GFS-2) (Miller and Swineford, 1957; Twenhofel and Dunbar, 1914). One limestone member in north-eastern Kansas contains streaks and disseminated bits of coal. Some of the limestones are cross-bedded locally (Ball, 1964, p. 105-109; p. 262).

All limestone beds in this group probably were deposited in shallow marine waters, perhaps less than ~~about~~ 100 feet deep. Some of them originated as calcareous sands or lime muds in near-shore environments (Ball, 1964, p. 272-273).

Conglomerates are common in the Douglas Group, occurring chiefly in the lower parts of thick sandstone units (fig. GFS-14). Pebbles in the conglomerates are mostly limestone and mudstone derived from beds of the Lansing and Douglas groups (Ball, 1964, p. 283-284; O'Connor, 1960, p. 29; Lins, 1950, p. 119-120). The matrixes include quartz sand and silt. These beds contain invertebrate fossils, mostly reworked, and plant fossils (Ball, 1964, p. 293; Lins, 1950, p. 120-121).

Coal beds of the Douglas Group generally are thin and lenticular. Many coal lenses occur within mudstones or limestones bearing marine fossils. Plant material probably was transported to the sites of deposition and accumulated in littoral environments (Bowsher and Jewett, 1943, p. 38; Ball, 1964, p. 304); however, at least one coal lens contains stumps and trunks of trees in growth positions, and twigs that cut across bedding planes of the overlying mudstone and sandstone (Bowsher and Jewett, 1943, p. 28; Ball and others, 1963, p. 25). This coal bed obviously is autochthonous.

Numerous disconformities are recorded from the outcrop area of this Group, especially in the southern part of eastern Kansas. None of them extends throughout the entire eastern Kansas region. They probably are evidence of erosion by currents near the shores of the sea and by subelevation in shallow marine water (Ball, 1964, p. 41-42; 255-263).

The Douglas Group thins northward and northwestward in the subsurface. It persists throughout much of the State as a dominantly mudstone unit at the base of interval E, but it grades westward from chiefly clayey mudstone and sandstone to limestone and clayey mudstone (see also Ball, 1964, p. 72; Rascoe, 1962, p. 1363). Coal beds of the Douglas Group extend only a short distance into the subsurface of eastern Kansas (Ball, 1964, p. 235).

In summary, the Douglas Group thins northward and northwestward in eastern Kansas. The outcropping parts of the Douglas includes mostly terrigenous detrital rocks deposited in marine environments, but some of the sediments were accumulated in marine-border and swampy terrestrial environments. Topography of the sea bottom and the coastal region was gentle, and during times of maximal submergence, marine waters probably were less than about 100 feet deep. The prevailing climate is believed to have been warm and humid (Miller and Swineford, 1957).

Shawnee Group:--The Shawnee Group includes two complete megacyclothems and parts of two others (fig. 15) (Moore, 1949b, p. 143-145; 1950, p. 10-11). The megacyclothems are "cycles of cyclothems" each including four or five completely or partly developed cyclothems (Moore, 1936, p. 29). The sequence of cyclothems, the lithologies of beds that compose them, and the faunas that they contain are generally repeated from megacyclothem to megacyclothem (fig. 15; table 3).

The Shawnee Group thickens southward. Limestone beds grade into mudstones and sandstones in southern Kansas and northern Oklahoma.

In the subsurface the Shawnee, like the Douglas Group, thins northward and northwestward and grades into gray and tan limestones interbedded with red and gray clayey mudstones (Rascoe, 1962, p. 1364-1365). In northwestern Cheyenne and Rawlins counties the interval is chiefly red and gray sandy, clayey mudstone.

Some formations can be correlated for long distances in the subsurface (Adkison, 1963, pl. 1). A few rock units of some cyclothems, especially the single-bedded limestones and overlying black fissile mudstones (units "B" 2 and "C" 1, fig. 15) are traceable throughout vast areas. The black fissile mudstone of the Oread formation (fig. 15), for example, extends throughout 150,000 square miles with consistent lithology (Evans, 1966, fig. 3, p. 60-61).

Figure GFS-15.--NEAR HERE

Figure GFS-15.--Megacyclothems of the Shawnee Group (1-4, right column), each containing five completely or partly developed cyclothems (A-E, left column). Megacyclothems 1 and 4 include uppermost part of Douglas Group and lowermost part of Wabaunsee Group, respectively. (After Moore, 1922, p. 26-34; 1949b, p. 144-145; Zeller and others, 1968, pl. 1).

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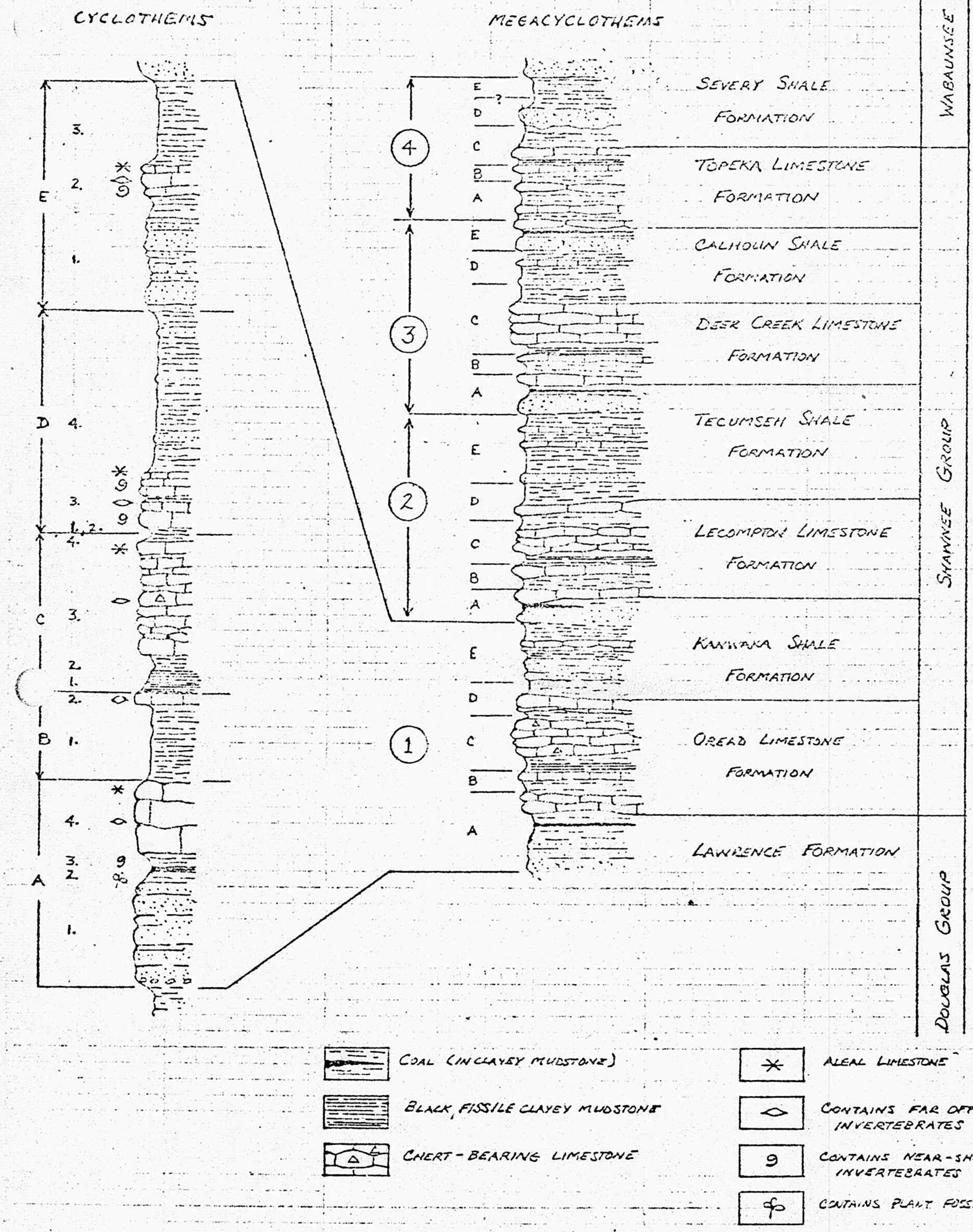

Fig. 678-15

102B

CYCLOTHEM		GENERAL LITHOLOGY AND FAUNA
E	3.	Clayey mudstone containing marine invertebrates in lower part and plant fossils in upper part.
	2.	Limestone, partly oolitic, containing fusulinids, mollusks, algae and crinoid fragments.
	1.	Sandstone containing mollusks.
D	4.	Clayey mudstone containing mollusks in lower part, land plants in upper part.
	3.	Fusulinid-bearing limestone, locally oolitic or cross-bedded, containing bryozoans, mollusks, brachiopods, fusulinids, crinoid fragments, and locally sponges.
	2.	Clayey mudstone containing mollusks.
	1.	Sandstone and clayey mudstone locally containing land plants.
C	4.	Clayey mudstone containing marine mollusks.
	3.	Wavy-bedded, chert-bearing limestone containing fusulinids, brachiopods, bryozoans, algae, corals, crinoid and echinoid fragments, and other marine fossils.
	2.	Gray, calcareous clayey mudstone containing brachiopods, crinoid columnals, bryozoans, mollusks, and foraminifera.
	1.	Thin, black, fissile, carbonaceous clayey mudstone containing phosphatic concretions, conodonts, orbiculoid brachiopods, scolecodonts, pectinoid mollusks, and fish spines.
B	2.	A single thin, but very extensive bed of uniformly fine-grained limestone containing abundant foraminifera, including arenaceous forms and fusulinids, and other marine fossils, mainly brachiopods, gastropods, and pelecypods.
	1.	Thick clayey mudstone locally containing abundant brachiopods, bryozoans, pelecypods, and a thin coaly bed in the lower part.
A	4.	Thick limestone, locally oolitic, containing fusulinids, mollusks, brachiopods, crinoids, echinoids, bryozoans, algae, corals, and foraminifera.
	3.	Clayey mudstone containing near-shore invertebrate fossils, especially pelecypods and brachiopods.
	2.	Clayey mudstone containing plant fossils and locally, a thin coal bed.
	1.	Sandstone, locally conglomeratic and locally containing plant fossils.

Table GFS-3.-General rock types and fauna of cyclothems in a megacyclothem of the Shawnee Group. (After Moore, 1936, 1949b, 1964; Troell, 1969; Toomey, 1966; Evans, 1966.)

See also figure 15.

Rocks of the Shawnee Group were deposited in alternating marine and nonmarine environments. Limestones and most of the mudstones accumulated in marine waters; thin coal beds and some of the sandstones accumulated in terrestrial and marine-border environments. The remarkable uniformity of some units across wide areas suggests little variation in relief of the emergent coastal regions and the sea bottoms and in other factors that controlled sedimentation.

A summary description of depositional environments, based on similarity of the five megacyclothems of the Shawnee Group, follows. Members of a few cyclothems have been studied closely, and conditions of their deposition are reasonably well known. This knowledge has been extended to make general statements about corresponding beds in other cyclothems.

The genesis of sandstones that form the basal units of megacyclothems (type "A" cyclothem, unit 1, fig. 15) is difficult to interpret. These sandstones generally contain plant fossils but no marine fossils (Johnson and Adkison, 1967, p. 83; O'Connor, 1960, p. 42, 45-47). They are judged to be non-marine and are, perhaps, accumulated as detritus on the flood plains of coastal rivers. Clayey mudstone and coal that overlie the sandstone (type "A" cyclothem, unit 2, fig. 15) represent deposition in swamps, probably located near the margins of the seas (Troell, 1969, p. 21). Clayey mudstones that overlie the coal beds (unit "A" 3, fig. 15) were deposited near shore lines of transgressing seas. Thick limestones of type "A" cyclothems (unit "A" 4, fig. 15) probably were laid down during episodes of rapid marine transgression followed by stillstands and the onset of regressions (Troell, 1969; Johnson and Adkison, 1967, p. 83). The limestones were deposited in shallow marine environments that ranged in position from strand lines and tidal flats to open marine waters averaging perhaps 50 feet deep (Troell, 1969).

The lower parts of the clayey mudstones in type "B" cyclothems (fig. 15) are mostly nonmarine. They probably were deposited in coastal swamps and estuaries during periods of regression of the seas (Troell, 1969, p. 23; Johnson and Adkison, 1967, p. 81-84; Moore, 1936, p. 148, 163). The upper parts of the clayey mudstones record the onset of an episode of transgression; the topmost beds probably accumulated in shallow water near the shore lines (Moore, 1964, p. 311; Johnson and Adkison, 1967, p. 81-83; Troell, 1969, p. 23). With deepening of the seas exceptionally uniform, single-bedded limestones of type "B" cyclothems (unit "B" 2, fig. 15) were deposited conformably upon the clayey mudstones. They accumulated on extensive platforms, probably in quiescent, relatively shallow, open-marine water (Toomey, 1966).

Depositional environment of the basal black, fissile, clayey mudstones of "C"-type cyclothems, (unit "C" 1, fig. 15) is problematic. The environment has been judged to have been perhaps (a) a marine swamp (Moore, 1950, p. 11); (b) a vast expanse of open marine water only a few meters deep (Moore, 1964, p. 344); (c) shallow marine water with low circulation caused by exceedingly dense seaweed (Wagner, 1964, p. 583, 584, 590); and (d) deep marine water with restricted circulation in the central part of a basin (Evans, 1966, p. 120-126). Theories (a), (b) and (c) suggest that this mudstone was deposited during periods of regression of the sea; theory (d) indicates that it was deposited far from shore during maximal transgressions that followed deposition of the limestones of "B"-type cyclothems (fig. 15). The evidence compiled by Evans (1966; theory (d) above is formidable. If Evans' conclusions are correct ~~Paleogeographic evidence indicates that these mudstones were deposited during maximal stages of transgression (theory (d) above); if this is correct,~~ cyclothems B and C (fig. 15) seem to record a single cycle of transgression and regression and megacyclothems of the Shawnee Group may be composed of only four cyclothems.

Gray clayey mudstones overlying the black fissile mudstone (unit "C" 2, fig. 15) are believed to have been deposited in shallower marine waters. They may record an episode of short-lived, partial regression. The overlying limestones (unit "C" 3, fig. 15) probably accumulated in clear marine water less than about 60 feet deep, but 50 miles or more from shore (Moore, 1964, p. 318). Uppermost beds of "C"-type cyclothems are clayey mudstones deposited near shore during regression of the seas (Johnson and Adkison, 1967, p. 81-82).

The basal deposits of "D"-type cyclothems are sandstones and mudstones (unit "D" 1, fig. 15) that may be partly terrestrial deposits, overlain by mudstones deposited near shore in shallow marine water (unit "D" 2, fig. 15) (Johnson and Adkison, 1967, p. 81-82).

Mudstones of "D"-type cyclothems are overlain by limestones (unit "D" 3, fig. 15) probably deposited in shallow, clear marine water. Regression of the seas apparently began during deposition of the limestones and their upper parts may have accumulated above wave base (Johnson and Adkison, 1967, p. 81-82). These limestones grade upward successively into near-shore, perhaps estuarine, clayey mudstones and nonmarine clayey mudstones (unit "D" 4, fig. 15) (Johnson and Adkison, 1967, p. 82-83).

The lower parts of type "E" cyclothems are composed of mudstones and sandstones, some deposited in flood plains and swamps of emergent terrain (unit "E" 1, fig. 15) (Johnson and Adkison, 1967, p. 82-83). The mudstones grade upward into argillaceous limestones (unit "E" 2, fig. 15) probably deposited near shore in shallow marine waters. Uppermost beds of "E"-type cyclothems are near-shore marine clayey mudstones.

Wabaunsee Group:--The Wabaunsee Group includes several cyclothems (fig. GFS 16), but they do not compose megacyclothems (Moore, 1949b, p. 167-169). The Wabaunsee contains much sandstone and sandy and clayey mudstone; also many thin but extensive limestones. The group thickens southward. Limestone beds grade into mudstones and sandstones in southern Kansas and northern Oklahoma. ~~Likewise~~ they thin northward and northwestward in the subsurface.

Mudstones of the Wabaunsee Group are mostly bluish gray to yellowish gray although, in the upper part of the group, some beds are red, green, or maroon. Fossils are not abundant in the mudstone, but include brachiopods, pelecypods, gastropods, crinoid columnals, bryozoans, ostracodes, a few corals, and rare fucoidal markings (Moore, 1949b; Mudge and Yochelson, 1962; Mudge and Burton, 1959; Johnson and Wagner, 1967, p. 141-142). Fossilized wood and plant fragments, at least some of which came from land plants, are in several mudstone members of the Wabaunsee Group, generally in association with sandstone lenses (Moore, 1949b; Mudge and Yochelson, 1962, p. 11, 13; Johnson and Wagner, 1967). Several thin coals are in the mudstone, which probably is nonmarine (Moore, 1936, p. 25; 1964, p. 289).

Fine-grained, gray quartzose sandstone composes much of the Wabaunsee Group, occurring mostly as lenses and channel fillings within mudstone members (fig. GFS 16). The channel fillings range in size from a few feet wide and deep to one channel as wide as 3.5 miles and another as deep as 105 feet (Mudge, 1956). (See discussion of upper boundary, interval E, p.63-64).

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Figure GFS-16.--NEAR HERE

Figure GFS-16.--Generalized section of Wabaunsee Group in outcrop area of eastern Kansas. Stratigraphic positions of about 12 cyclothems are shown (right column). The 10 units that compose a Wabaunsee-type cyclothem are (left column):

.8-.9 Clayey mudstone. Marine or nonmarine.

.7 Algal limestone, locally oolitic or coquinoidal. Contains mollusks, brachiopods, bryozoans, crinoids. Marine.

.6 Sandy, clayey mudstone. Marine.

.5 Fusulinid-bearing limestone. May contain brachiopods, bryozoans, crinoids. Marine.

.4 Mollusk-bearing clayey mudstone. Marine.

.3 Pelecypod-bearing limestone. Also contains brachiopods and crinoids. Marine.

.2 Clayey mudstone-bearing pelecypods, brachiopods, bryozoans. Marine.

.1 Coal, underlain by sandy, clayey mudstone. Nonmarine.

.0 Sandstone. May contain plant fossils. Nonmarine.

(Adapted from Moore, 1936, p. 23, 25, 26; 1949b, p. 181; Zeller and others, 1967, pl. 1; Johnson and Wagner, 1957, pl. 3).

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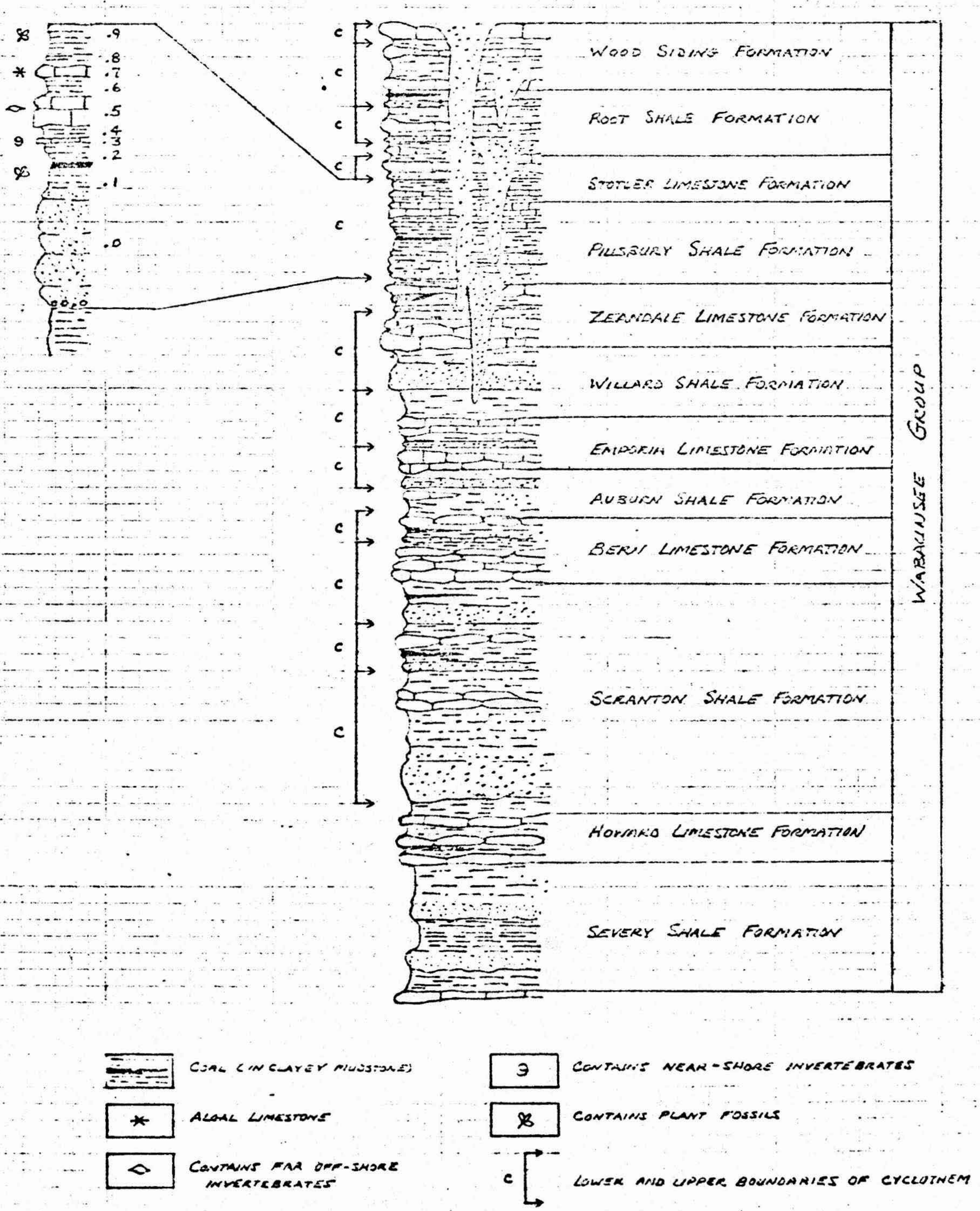

The channel sandstones commonly contain muscovite and chlorite mica, and some beds have minor amounts of frosted quartz grains, feldspar, garnet, tourmaline, and opaque heavy minerals (Mudge, 1956; Mudge and Burton, 1959, p. 26; Mudge and Yochelson, 1962, p. 11). Many sandstones contain macerated plant fragments, fossilized wood, and locally, thin, lenticular beds of coal. Cross bedding and ripple marks are common locally (Mudge, 1956; Mudge and Yochelson, 1962; Johnson and Wagner, 1967).

A minor proportion of the sandstones and mudstones filling channels in uppermost Wabaunsee rocks may be marine (Mudge, 1956, p. 674-675). Conglomerates are common in channel fillings, and pebbles of limestone and clayey mudstone are their main constituents. Both marine and nonmarine fossils including fish and amphibians have been recovered from the conglomerate which probably was deposited in a fluvial-estuarine environment (Rasmussen and others, 1971).

Limestone members of the Wabaunsee Group are generally thin, but they extend throughout large areas. Their average thickness probably is less than three feet. The limestone is mainly gray and finely crystalline to aphanitic; however, some beds are argillaceous, coquinoidal, or locally, conglomeratic, brecciated, or cross bedded (Johnson and Wagner, 1967; Mudge and Yochelson, 1962; O'Connor, 1953). Most limestones are thin bedded to medium bedded. Small bioherms composed mainly of pelecypods and gastropods constitute a limestone facies of one thick clayey mudstone unit. One bioherm is 10 feet thick and extends throughout approximately 15 square miles (Owen, 1959; Johnson and Wagner, 1967, p. 147-148).

Limestones of the Wabaunsee Group contain abundant marine fossils, especially encrusting algae, fusulinids, brachiopods, crinoid stems, corals, gastropods, pelecypods, bryozoans, echnoid spines and ostracodes (Johnson and Wagner, 1967; Mudge and Yochelson, 1962; O'Connor, 1953). Local occurrences of amphibian tracks and raindrop impressions in one limestone member of the Wabaunsee (Schoewe, 1956; Johnson and Wagner, 1967, p. 138) suggest that some of the limestone beds may have been deposited in the intertidal zone.

The general depositional environments of a typical cyclothem of the Wabaunsee Group were described by Moore (1936, p. 25) as follows:

> The sandstone (.0) may rest disconformably on underlying beds and appears definitely to represent the initial deposits of the cyclothem. Locally a thin conglomerate may occur at the base of the sandstone. The succeeding shale and coal (.1) are clearly continental in origin and indicate deposits made on an extremely low, flat coastal plain. The mollusk-bearing shale and limestone (.2 and .3) indicate the submergence of the coal swamps or coastal plain by a very shallow sea, and the overlying shale (.4) marks continued marine transgression that culminates in making the offshore fusulinid-bearing limestone (.5). The succeeding parts of the cyclothem appear to signify marine regression which leads to shoaling waters inhabited by mollusks and favoring growth of algae (.6, .7 and .8). The terminal unit of the cyclothem (.9) is generally an unfossiliferous shale, but it may contain remains of land plants...The entire cyclothem thus records a single marine pulsation, and it may be divided into an initial emergent phase (.0-.1) a transgressive marine phase (.2-.4), a culminating marine phase, (.5), a regressive marine phase (.6-.8) and a terminal emergent phase (.9).

Specific details of depositional environments represented by most members of the Wabaunsee Group are not known. Several members have been studied closely (e.g., Mudge and Yochelson, 1962; Mudge, 1956; Owen, 1959), however, and a few exceptions to the typical cyclothem have been described (Mudge and Yochelson, 1962, p. 102). The general interpretation of Moore (1936) for depositional environments of Wabaunsee cyclothems seems to be correct.

Transgressions during deposition of the Wabaunsee Group in eastern Kansas probably were across an extensive platform covered by a quiescent, clear, warm sea. Maximum depths are believed to have been only several tens of feet. During episodes of regression eastern Kansas was slightly emergent. Coastal regions probably were swampy and formed a thickly vegetated terrain.

Paleotectonic implications

The major basins of Kansas continued to subside during time of interval E. The region of the former Forest City basin subsided as a northern extension of the Cherokee basin. Together they formed a shallow synclinal basin along the eastern flank of the Nemaha anticline. Subsidence along the axis of the basin was more than 1,000 feet; total subsidence in the deepest part of the basin was more than 1,400 feet in northern Cowley County.

The region of the former Salina basin was a vast northern shelf of the Sedgwick basin. Total subsidence in the Sedgwick basin was about 600 feet at the Kansas-Nebraska boundary in Jewell County and about 1,500 feet near the Kansas-Oklahoma boundary in southwestern Sumner and southeastern Harper Counties. Maximal subsidence in the Hugoton embayment was more than 1,100 feet, near the Kansas-Oklahoma boundary in southeastern Clark County. The northern flank of the embayment was exceedingly broad and low dipping; only minor amounts of differential subsidence occurred throughout southwestern Kansas. During maximal stages of submergence in Kansas, marine waters probably were only several tens of feet deep.

The Nemaha anticline was uplifted slightly during time of interval E. It probably had little effect on sedimentation (see Ball, 1964, p. 222-227, for example). The Cambridge arch and Central Kansas uplift continued to be uplifted slightly; they formed a broad anticlinorium that extended from northwestern Kansas to south-central Kansas. The crest of the anticlinorium in Kansas was located in the northwesternmost counties; it extended into southwestern Nebraska. The Keyes dome was folded slightly, but apparently was not an important source of detrital sediments.

Seas transgressed and regressed periodically during time of interval E. Fluctuations of sea level probably were mostly eustatic. Some of the changes in depositional environments may have been due to subsidence or uplift within the northern Midcontinent region, or to changes in amounts of sediment transported from source areas to the south, southeast, and north. Whatever the cause, the various depositional environments were recurrent and widespread. Thin but relatively uniform beds of sediment were deposited. At the end of interval E time all of Kansas probably was submergent.

TOTAL THICKNESS OF PENNSYLVANIAN ROCKS

Thickness trends

Pennsylvanian rocks in Kansas range from an erosional edge in southeastern Kansas to more than 3,000 feet in the axis of the Hugoton embayment in southeastern Morton and southwestern Stevens Counties (pl. 10). In the area of outcrop in eastern Kansas, variations in thickness are caused partly by post-Pennsylanian erosion. In the rest of Kansas, Pennsylvanian rocks were not beveled by erosion before deposition of Permian rocks. Therefore variations in thickness are interpreted as being caused by depositional thickening in synclines and thinning above anticlines.

Plate 10 here refers to isopach of total Penn. G78

Paleotectonic implications

Major negative structural features that influenced sedimentation during the Pennsylvanian Period are the Cherokee and Sedgwick basins, the Forest City and Salina basins, and the Hugoton embayment of the Anadarko basin (fig. GFS-3). Total subsidence in the deepest parts of the Cherokee and Sedgwick basins during Pennsylvanian time was more than 2,500 feet. Total subsidence in the deepest part of the Hugoton embayment was more than 3,000 feet.

Major anticlinal features that influenced sedimentation during the Pennsylvanian are the Nemaha anticline and the anticlinorium of the Central Kansas uplift and Cambridge arch (fig. GFS-3). Pennsylvanian rocks are thinner than 700 feet on the crests of these anticlinoria.

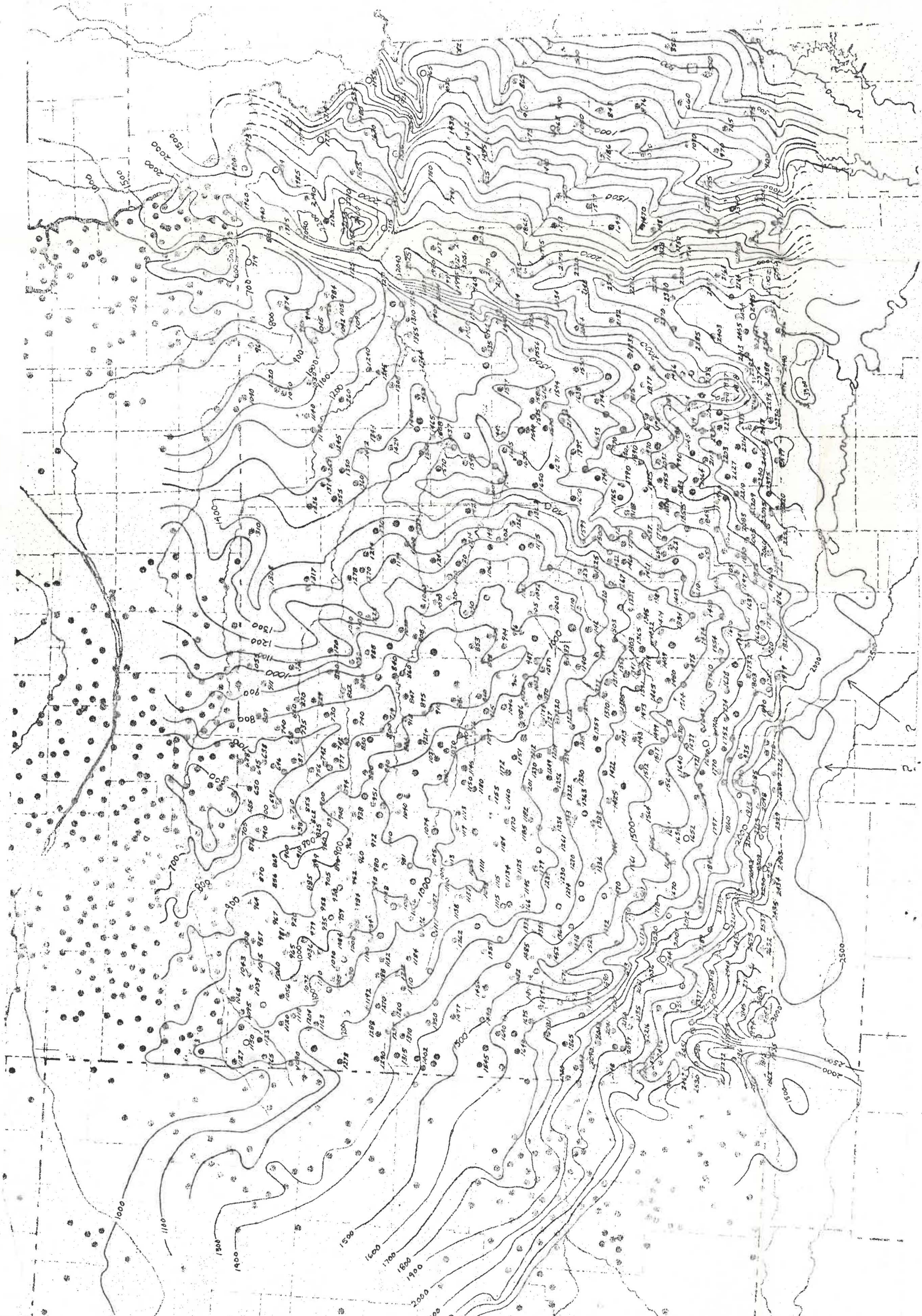

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Plate GS-10 Isopachous map of total Pennsylvanian rocks in Kans. Cont. Int. = 100 ft.

GEOLOGIC UNITS DIRECTLY ABOVE PENNSYLVANIAN SYSTEM

Units overlying Pennsylvanian

In the area of Pennsylvanian outcrop thin Tertiary deposits (not shown on pl. 2) of chert gravel in brownish red clay overlie Pennsylvanian rocks locally as high terrace deposits. Pleistocene and Recent terrace deposits and alluvium lie upon the Pennsylvanian in valleys of the larger streams. Pleistocene Nebraskan and Kansan till and outwash overlie Pennsylvanian rocks in several of the northeasternmost counties.

Westward from the area of outcrop, Pennsylvanian rocks are overlain conformably by the Admire Group (Wolfcamp age) of the Permian System. The Admire Group is mostly clayey mudstone and sandstone but contains thin limestones and thin coal beds.

Paleotectonic implications

Deposition of the Pennsylvanian continued into the Permian without significant interruption. The original eastern limit of Permian rocks in Kansas is not known, but all Pennsylvanian rocks probably were overlapped (McKee, Oriel and others, 1967, pl. 9A, 9B). Westward tilting of Pennsylvanian rocks occurred during Permian time.

Kansas was emergent during the Triassic, and only westernmost Kansas was covered by Jurassic rocks (Zeller and others, 1968, p. 53-54). Permian rocks probably were eroded from the Pennsylvanian of eastern Kansas mostly during Triassic and Jurassic time. Cretaceous rocks may have overstepped the eroded Pennsylvanian rocks and extended into Missouri (O'Connor, 1971, in press). Pennsylvanian beds were eroded to a peneplain-like "rock plain," probably during Miocene and Pliocene time (Ham, 1939; Melton, 1959, p. 369). The larger streams of eastern Kansas probably were superimposed into Pennsylvanian rocks from the late Tertiary rock plain. The Pennsylvanian beds of northeastern Kansas were glaciated during the Nebraskan and Kansan stages of the Pleistocene.

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United States Department of the Interior
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Denver Federal Center
Denver, Colorado 80225

KGS OF 71-11

IN REPLY REFER TO:

May 20, 1971

Mr. Gary F. Stewart
State Geological Survey
University of Kansas
Lawrence, Kansas 66045

Dear Gary:

We will need a little help on the following references in your manuscript:

1. McQueen and Greene, 1938 has not been located in your text or locality index list and will be deleted from the list of references unless you advise otherwise.

2. Moore, 1922, p. 26-34 (on p. 102, title for fig. GFS-15, in text). This reference is not in your list and we have been unable to identify it. Wrong date? Please check.

3. O'Connor, 1971, in press (on p. 116 in text). Please supply full reference when available.

4. Zeller, etc., 1968, has been changed to Jewett, etc., to conform with Bibliography of North American Geology citation. And Zeller and others, 1967 in text has been changed to Jewett and others, 1968. Please confirm if this is correct.

Other changes include: Ver Wiebe, 1940 (p. 21 in text) to 1941; Crowley, 1966 (p. 77-78 in text) to 1969; Johnson and Wagner, 1957 (p. 9 and 108 in text) to 1967; Melton, 1956 (p. 116 in text) to 1959; Moore, 1949 (p. 60, 76 in text) to 1949b. If we are in error in any case, please let us know.

Someday we'll come to the end of all this!

Sincerely,

Eleanor

Eleanor J. Crosby

KANSAS GEOLOGICAL SURVEY
Environmental Geology Section

The University of Kansas
Lawrence, Kansas 66044
913-864-4014

May 24, 1971

Mrs. Eleanor Crosby
Paleotectonic Map Section
U. S. Geological Survey
Bldg. 25, Federal Center
Denver, Colorado 80225

Dear Eleanor:

In answer to your letter of May 20, 1971:

(1) McQueen and Greene, 1938 - I couldn't find it either. Please delete from list of references.

(2) Moore, 1922, p. 26-34 (on p. 102, caption fig. GFS-15): correct reference Moore, 1936, Kans. Geol. Survey Bull. 22.

(3) O'Connor, 1971: is being edited. Will be O'Connor, H. G., _____, Geology and ground-water resources of Johnson County, northeastern Kansas: (bulletin number to be assigned; will let you know when this information is available.)

(4) Zeller, etc., 1968 - the changes you have made are correct.

(5) Ver Wiebe, 1941 is correct.
Crowley, 1969 is correct.
Johnson and Wagner, 1967 is correct.
Melton, 1959 is correct.
Moore, 1949 (p. 60 and 76 in text) - p. 60 - change to 1949a. p. 76 - 1949b is correct.

Needless to say, I'm embarrassed to be caught in so many errors. I'm grateful for your review.

Cordially,

Gary F. Stewart
Geologist

GFS:cmm