KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 91-65

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE CHEROKEE GROUP (MIDDLE PENNSYLVANIAN) BOURBON ARCH REGION, EAST-CENTRAL KANSAS

by

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B. S., Eastern Illinois University, 1986

Submitted to the Department of Geology and the Faculty of the Graduate school of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Science.

Professor in Charge

Committee Members

For the Department

Date Thesis Accepted

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ABSTRACT

The Atokan (?) and Desmoinesian Cherokee Group of the Bourbon arch region of eastern Kansas consists of interbedded sandstone, siltstone, and shale, with thin beds of coal and limestone. Stratigraphic and environmental interpretations of this Group were based on geophysical well logs, cores, and outcrops. Ten marker complexes, consisting of a basal underclay and coal overlain by a shelly lag or black shale extend throughout the Bourbon arch region and into the Cherokee, Forest City, and Sedgwick basins.

Upper Cherokee Group sediments overstepped the limits of the lower Cherokee Group sediments and lapped out against the eastern margin of the post-Mississippian Nemaha uplift. The Bourbon arch is a low relief post-Mississippian structure that separates the Cherokee basin in the south from the Forest City basin in the north. The arch lies between three Precambrian tectonic zones, the Fall River and Chesapeake to the south and the Bolivar-Mansfield to the north, which may have been reactivated during the Ouachita orogeny. Thickness changes of about 70 ft (21 m) follow a subtle west-northwest to east-southeast trend of thinning which delineates the boundaries of the arch. Extensive uplift of the northern boundary of the arch or rapid subsidence in the Forest City basin may have resulted in Atokan (?) age sediments onlapping the arch from north and not the south. Desmoinesian age sediments thin over the arch from the north and south before inundating it. Broad regional uplift of the Bourbon arch coupled with cyclic rises and falls of sea level may have created conditions necessary for thick coal accumulations that occur over this region.

Three geophysical well log responses characterize the Cherokee

Group; coarsening-upward, occurring in the Cabaniss Formation; shale-dominated, occurring in the Krebs Formation; and fining-upward, occurring primarily in the Krebs Formation. Each of the seven coarsening-upward sequences were deposited during a regression and deltaic progradation. Each sequence is overlain by an underclay and a transgressive coal, shelly lag, and black shale. Shale-dominated sequences, bounded above and below by a marker complex, show a slight coarsening-upward well log profile and represent deposition in subaqueous prodeltas, lower delta plains, and possibly restricted, shallow bays of a mud-dominated low energy deltaic system. Fining-upward sequences occurring below the Bluejacket B marker are upper delta plain channel deposits, which backfilled a major incised valley during a relative rise in sea level. Fining-upward sequences occurring in the Mulky through Scammon intervals cut down into distributary-mouth-bar and prodelta deposits and represent distributary channel deposits.

INTRODUCTION

Objectives of investigation

In the Forest City and Cherokee basins of eastern Kansas, the Cherokee Group (Atokan (?) and Desmoinesian Stages, Middle Pennsylvanian Series) consists of interbedded sandstones, siltstones, shales, thin coals, and thin limestones. It lies disconformably on karsted Mississippian limestone, and extends to the base of the Fort Scott Limestone of the Marmaton Group. The Cherokee Group comprises the Krebs Formation (lower) and the Cabaniss Formation (upper; Jewett et al., 1968; Fig. 1).

The objectives of this study were threefold:

1) To provide detailed rock-stratigraphic correlations among the sandstone, siltstone, shale, coal and limestone beds of the Cherokee Group in the northern Cherokee basin and southern Forest City basin;

2) To interpret depositional environments from examination of sedimentary structures, and vertical and lateral lithofacies relationships;

3) To establish the significance of the Bourbon arch as a depositional or tectonic feature during deposition of the Cherokee Group.

Significance of study

The Cherokee basin and Forest City basin are economically important because of the quantity of oil, gas, and coal produced from the Cherokee Group. Ebanks and James (1974) reported that over half a billion barrels of petroleum have been produced from Cherokee strata. In addition, a demonstrated reserve base of 2 billion tons of deep coal and 150 million tons of strippable coal has been identified in this study area (Brady, pers. com., 1990). Recent technological developments and federal tax incentives

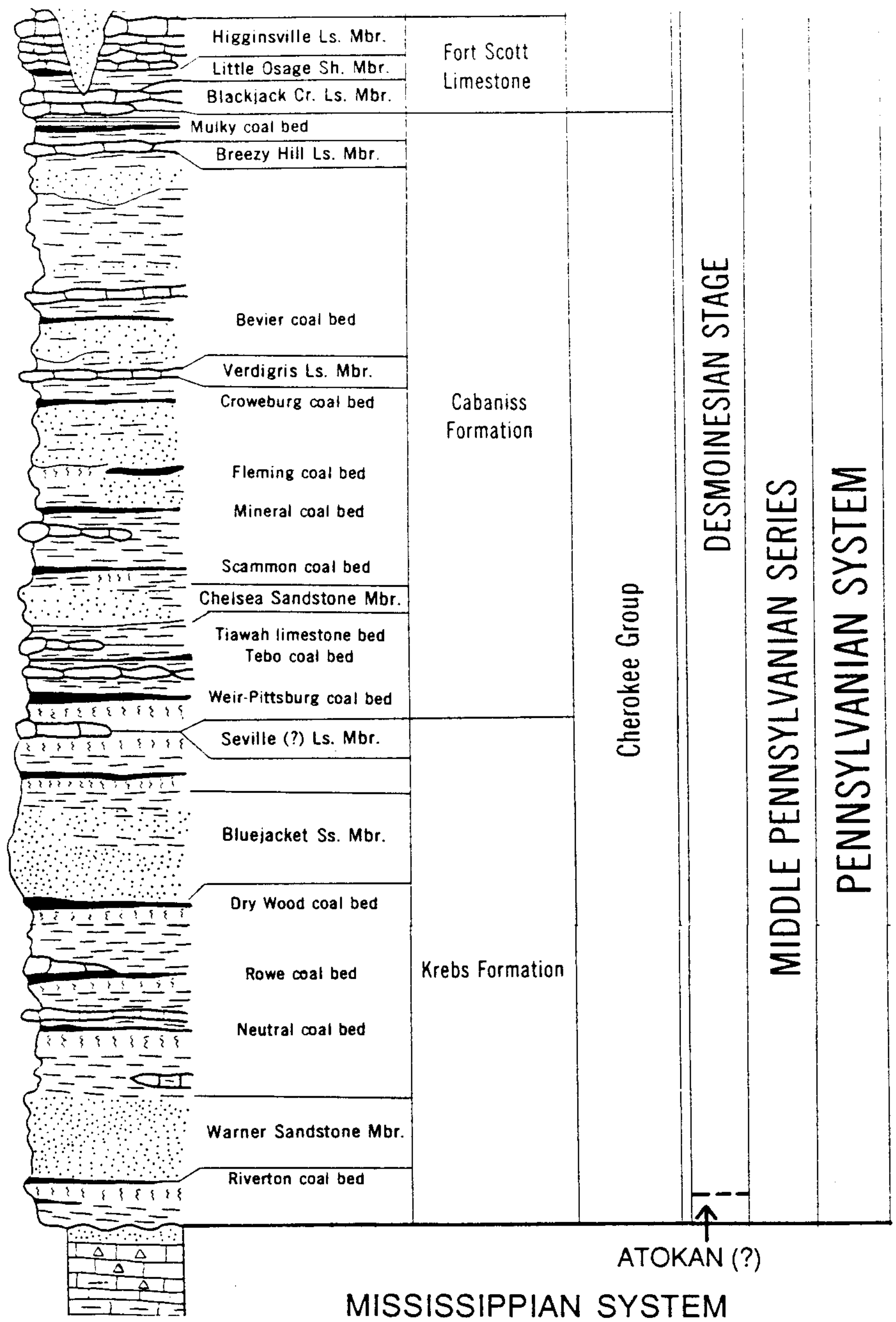


Figure 1. Formal stratigraphic classification system of the Cherokee Group currently used by the Kansas Geological Survey (modified from Zeller, 1968) The X-marker and McLouth Sandstone are not included in this section. For location of all markers used in this study see figure 13.

have made this area potentially attractive to development of coal bed methane. This unconvential gas method relies on thick coal deposits as source and reservoir for methane gas. Exploration for coal bed methane is new in this area and no production amounts are available. However, producers are optimistic about finding economically producible amounts of methane gas. Stoeckinger (1991) estimated that there is about 1 trillion cubic feet of gas in-place in eastern Kansas in Cherokee Group coal beds.

Studying the stratigraphy and depositional environments of the Cherokee Group will improve correlation of strata within the Cherokee and Forest City basins and will help define the depositional and tectonic history of the Cherokee and Forest City basins during Middle Pennsylvanian time. This information should lead to a better understanding of how to locate potential oil, gas, and coal reserves in eastern Kansas. By linking this study to previous work by Murphy (1978), Harris (1984), Killen (1986), Staton (1987), and Strickland (1987) a better regional understanding of Cherokee Group stratigraphy and depositional environments in east-central Kansas will emerge.

<u>Location of study area</u>

This study covers the Bourbon arch region in Kansas, which includes the northern Cherokee and southern Forest City basins. The eastern limits of the Sedgwick and Salina basins are also included in this area. The Cherokee basin is a northern shelf-like extension of the McAlester basin in northeastern Oklahoma and is bounded on the east by the Ozark uplift and on the west by the Nemaha Uplift (Jewett,1951). The Bourbon arch separates the Cherokee basin from the Forest City basin, which is a structural and depositional basin in northeastern Kansas and adjacent

Nebraska, Missouri, and Iowa (Jewett, 1951; Fig. 2). The study area covers approximately 18,000 km^2 within a ten-county area in southeastern Kansas (Fig. 3).

Previous investigations

The need to classify and describe Cherokee stratigraphy became important with the discovery of coal and petroleum in the Cherokee basin. Haworth and Kirk (1894) were the first to describe Cherokee rocks cropping out along the Neosho River in Cherokee County. Haworth and Crane (1898) were the first to use coal marker beds to describe Cherokee stratigraphy. Other workers using coal and sandstone beds for stratigraphic classification were Gould (1927), Pierce and Courtier (1937), Abernathy (1936), Abernathy et al. (1947), Moore (1949), and Oakes (1953). Weller (1930), Reger (1931), Moore (1936), and Howe (1956) used the concept of cyclic sedimentation to divide Cherokee strata.

Because of the diversity of classification schemes, geologists from Kansas, Iowa, Missouri, Nebraska, and Oklahoma met in 1953 to try to alleviate correlation problems. Searight et al. (1953) and Howe (1956) reported that all states (except Iowa) reached an agreement on division, classification, and nomenclature of pre-Marmaton Desmoinesian strata. However, today only Missouri follows the guidelines set up at this meeting. Previous investigations of Cherokee strata are outlined in Table 1 and Table 2. Figure 4 outlines the various stratigraphic classifications of the Cherokee Group in eastern Kansas.

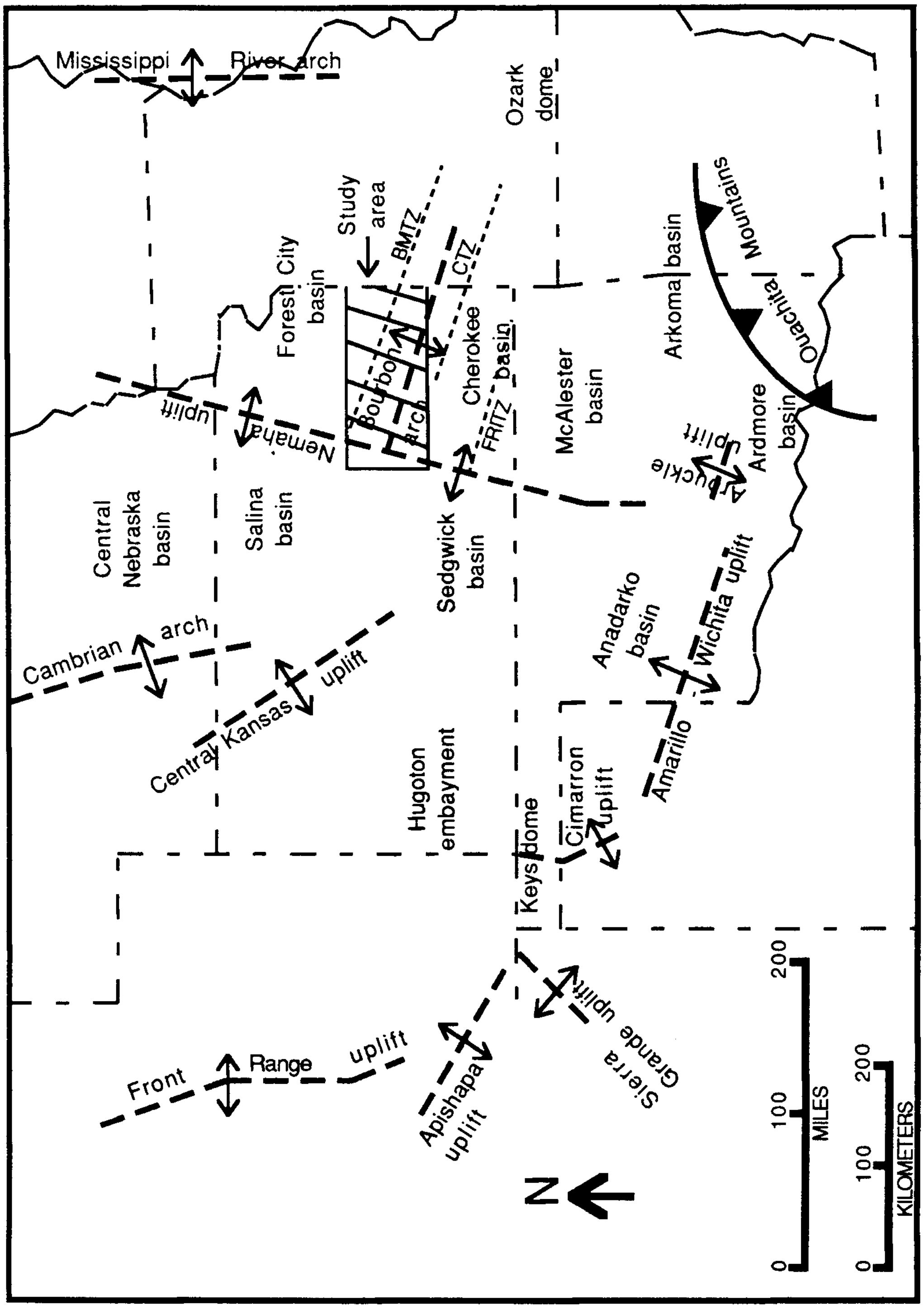
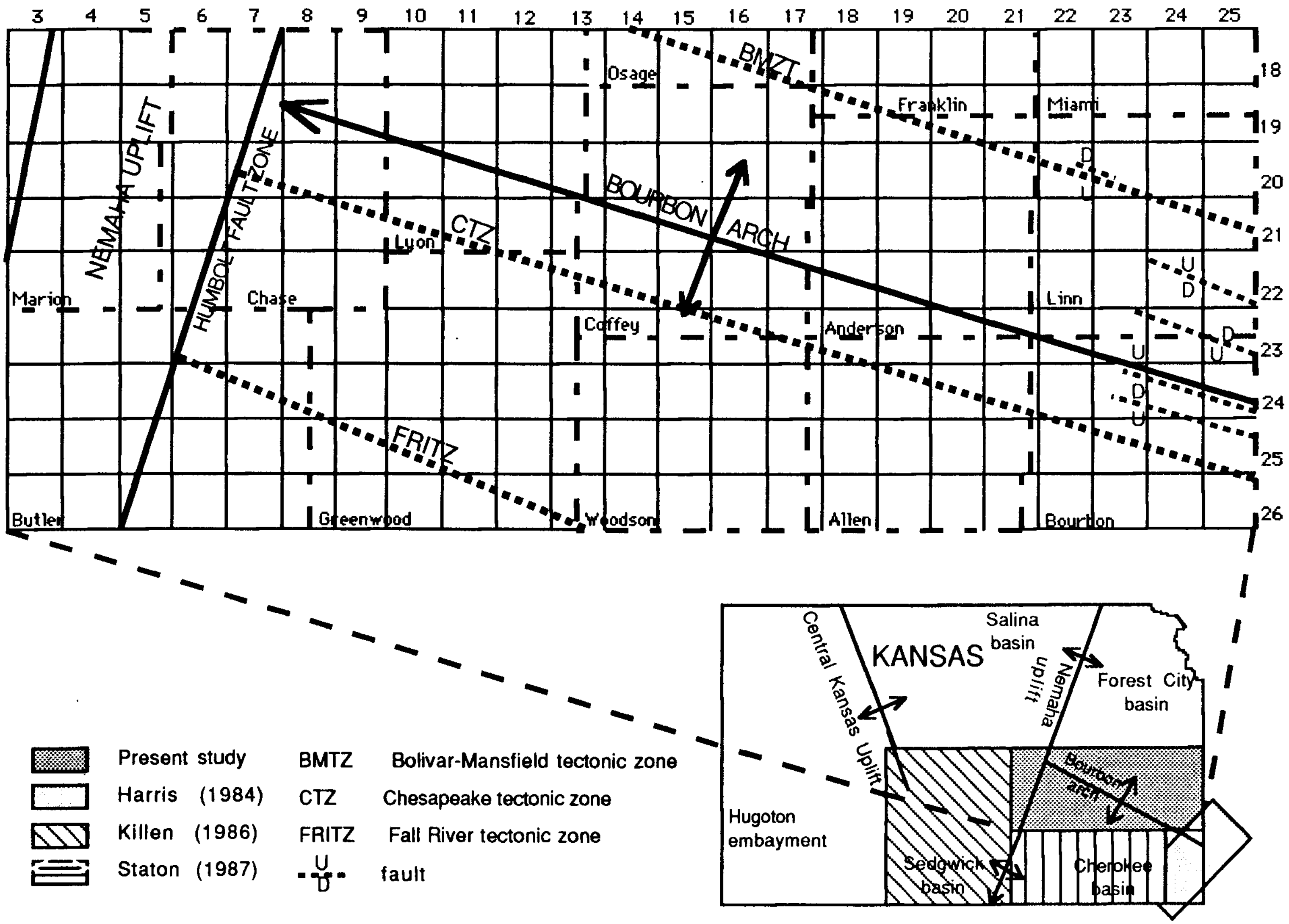


Figure 2. Location of study area and regional structural features (modified from Wanless, 1969; Moore, 1979; Berendsen and Blair, 1991).

Figure 3. Map of major structural features in Kansas in relation to this study area and to study areas of Harris (1984), Killen (1986), and Staton (1987) (modified from Wanless, 1969; Moore, 1979).


3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
18 19 20 21 22 23 24 25 26
Osage
Franklin
Miami
Lyon
Marion
Chase
Coffey
Anderson
Linn
Butler
Greenwood
Woodson
Allen
Bourbon
NEMAHA UPLIFT
HUMBOLDT FAULT ZONE
BOURBON ARCH
BMZT
CTZ
FRITZ
U
D
KANSAS
Salina basin
Forest City basin
Central Kansas Uplift
Nemaha uplift
Hugoton embayment
Bourbon arch
Sedgwick basin
Cherokee basin
Present study
Harris (1984)
Killen (1986)
Staton (1987)
BMTZ Bolivar-Mansfield tectonic zone
CTZ Chesapeake tectonic zone
FRITZ Fall River tectonic zone
fault

AUTHOR	INVESTIGATION
Haworth and Kirk (1884)	First to describe Cherokee rocks along Neosho River
Haworth and Crane (1898)	First to use coal marker beds to describe Cherokee stratigraphy
Gould (1927), Abernathy (1936) Abernathy et al. (1947), Pierce and Courtier (1937), Moore (1949), Oakes (1953)	Used coal and sandstone beds for stratigraphic classification
Weller(1930), Reger(1931), Moore (1936)	Attempted to use cyclothem sedimentation to divide Cherokee strata
Searight et al. (1953), Howe (1956)	Geologists from Kansas, Iowa, Missouri, Nebraska, and Oklahoma meet in 1953 to try to alleviate correlation problems. All states reached an agreement (except for Iowa) on division, classification and nomenclature of pre-Marmaton Desmoinesian strata.
Branson (1957), Searight and Howe (1961)	Cherokee Group stratigraphy of Kansas, Oklahoma, and Missouri
Jewett (1959), Jewett et al. (1968)	Current classification of Cherokee stratigraphy in Kansas

Table 1. Early investigations of Cherokee Group strata.

Seevers (1975), Murphy (1978), Harris (1984), Denesen (1985), Strickland (1987),Staton (1987), Sutherland(1988),Brenner(1989)	Described Cherokee stratigraphy and depositional environments in Kansas, Oklahoma, and Missouri
Rich (1923), Bass (1936), Hayes (1963)	Described shoestring sands in southeastern Kansas as being beach barrier or beach bar deposits
Cole (1969),Visher et al.(1971), Wanless et al. (1969), Ebanks et al.(1977),Hulse(1979)	Described shoestring sands in southeastern Kansas as being fluvial deltaic deposits
Brady et al. (1976), Brady and Dutcher (1974)	Estimated strippable demonstrated coal reserves in Kansas
Wanless et al. (1969)	Discussed depositional conditions of Pennsylvanian coal beds
Ebanks and James (1974), Ebanks et al. (1977),Wells(1979)	Reported on heavy crude oil-bearing sandstones in Kansas and Missouri
Schlinsog and Angino (1983)	Examined potential oil recorvery from Kansas oil shales
Walton et al. (1986), Bouquet (1984)	Characterized sandstone reservoirs in the Cherokee Group
Rascoe and Adler (1983)	Examined Permo-Carboniferous hydrocarbon accumulations of the midcontinent
Rofheart (1980), Lardner (1984), Hayes (1963), Aden (1982), Nodine-Zeller (1981), Reinholtz (1982), Woody (1983), Worthington(1982),Nelson(1985)	Petrology, diagenesis and clay mineralogy studies of Cherokee rocks
Nodine-Zeller and Thompson (1977), Wilson (1980)	Used paleontological and palynological evidence for age determination of Cherokee strata

Table 2. Recent investigations of the Cherokee Group.

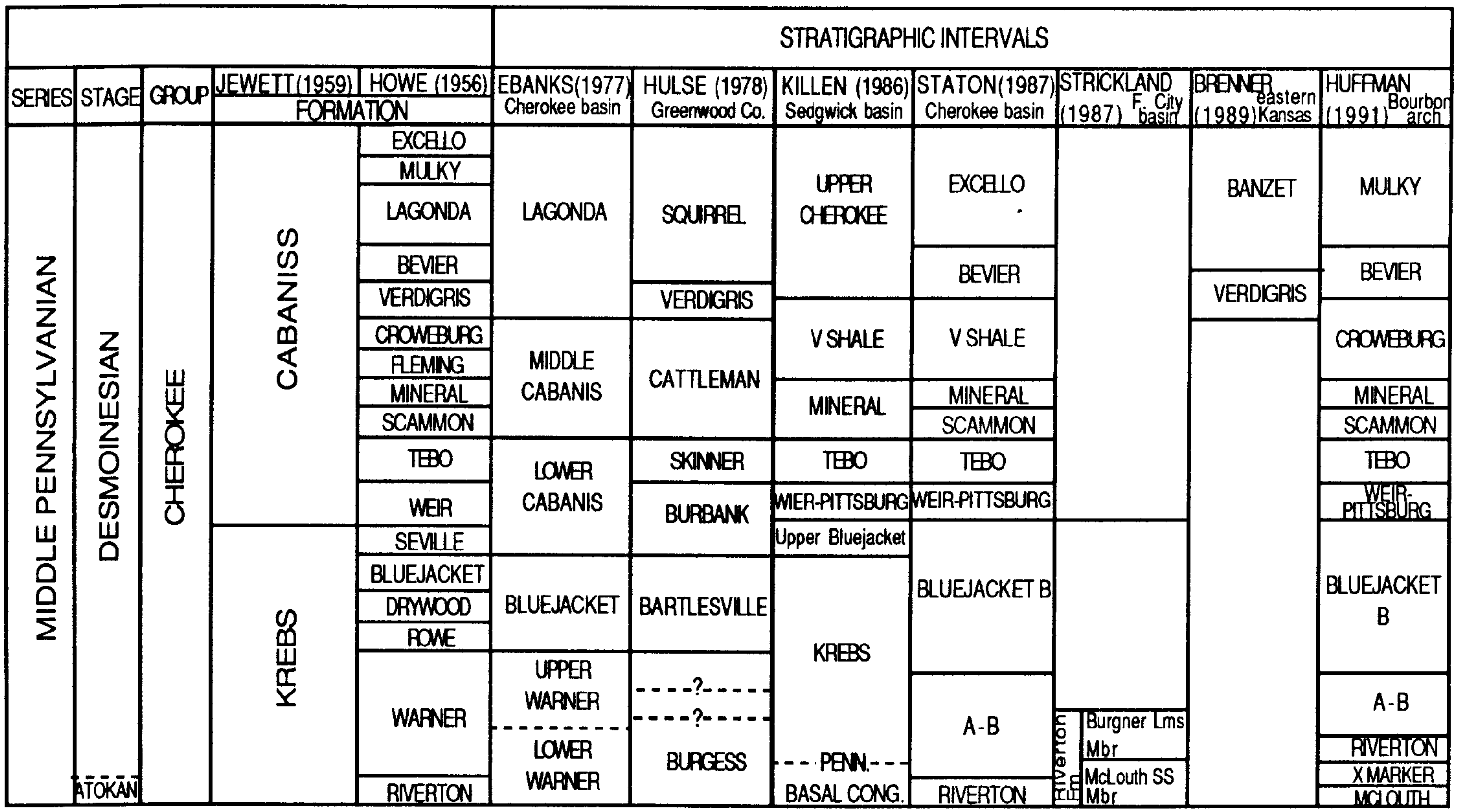


Figure 4. Stratigraphic classification of the Cherokee Group in eastern Kansas (modified from Staton,1987 after Woody,1983)

Methods of investigation

Cross sections

A closed loop network of cross sections (Fig. 5) was constructed based on analyses of geophysical well logs, core samples, and outcrops to insure that correlations were accurate and consistent on all well logs. North-south cross section E - E' was tied into P&M #20 core in Cherokee County and was correlated northward over the Bourbon arch to Strickland's (1987) cross-section through the Cherokee and Forest City basins. The importance of this cross section is that it : (1) showed that black shale markers continue from the Cherokee basin into the Forest City basin; (2) showed that the Bourbon arch was a positive structural feature in post-Mississippian time; (3) demonstrated that the X- marker and McLouth sandstone of Strickland (1987) onlap the Bourbon arch from the north and were not deposited in the Cherokee basin in Kansas; (4) showed several northwest-southeast trending faults that parallel the Bourbon arch.

Well log analysis

Analysis of geophysical well logs (scale 1in = 40 ft) was the primary method of obtaining data. Well logs that penetrated the entire Cherokee Group were given preference over those that did not. This study examined 300 well logs of which 232 measured the entire Cherokee Group (Fig. 6). A spacing of approximately 2 well logs per township was used for control. Unscaled gamma-ray-neutron logs were the primary log types used because of their availability and usefulness in identifying lithologies. Gamma-ray-neutron logs highlight radioactive black shale and coal units, which are regional stratigraphic markers. Geophysical well logs used in this study are on file at the Kansas Geological Survey. Difficulties in analyzing

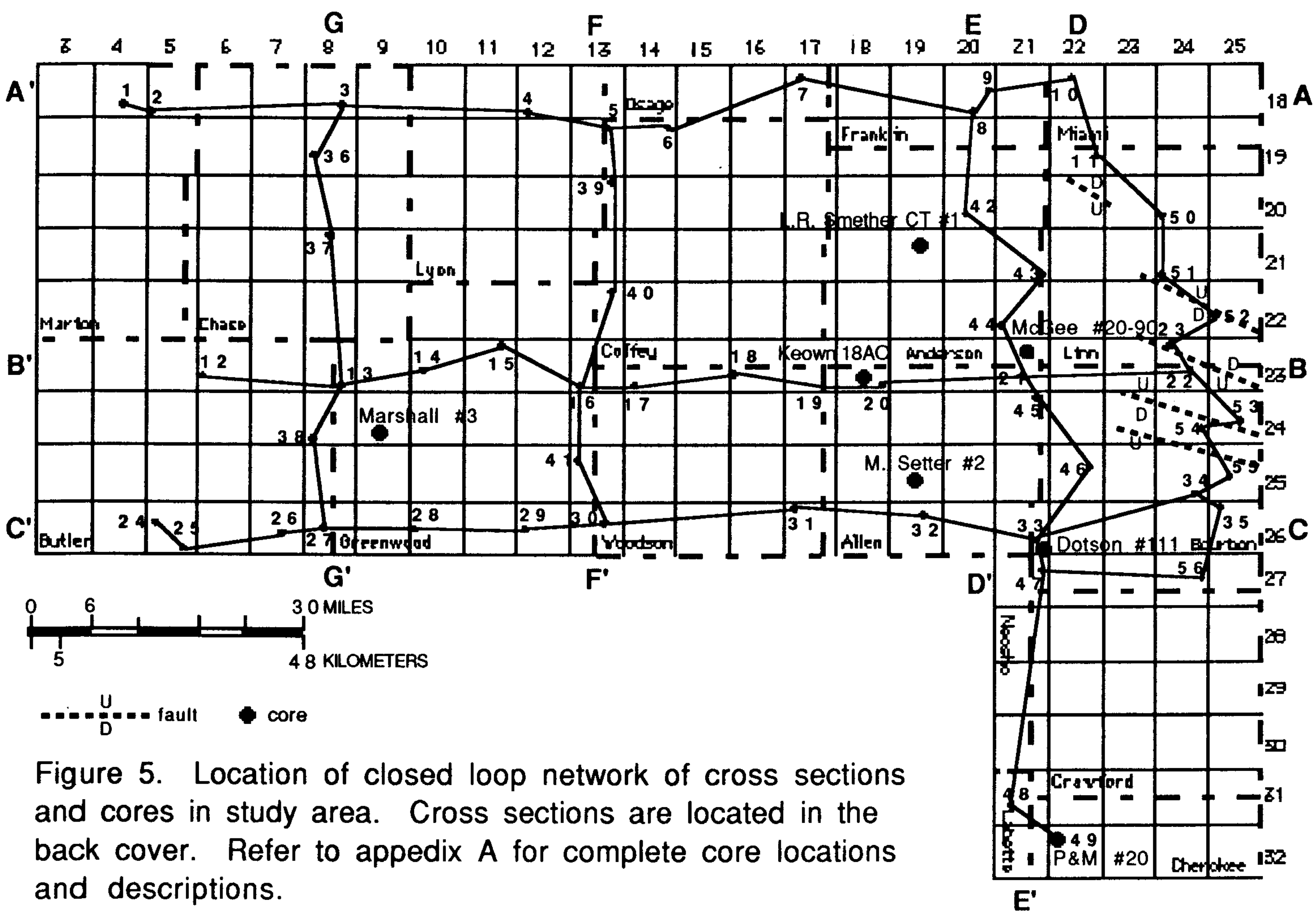


Figure 5. Location of closed loop network of cross sections and cores in study area. Cross sections are located in the back cover. Refer to appedix A for complete core locations and descriptions.

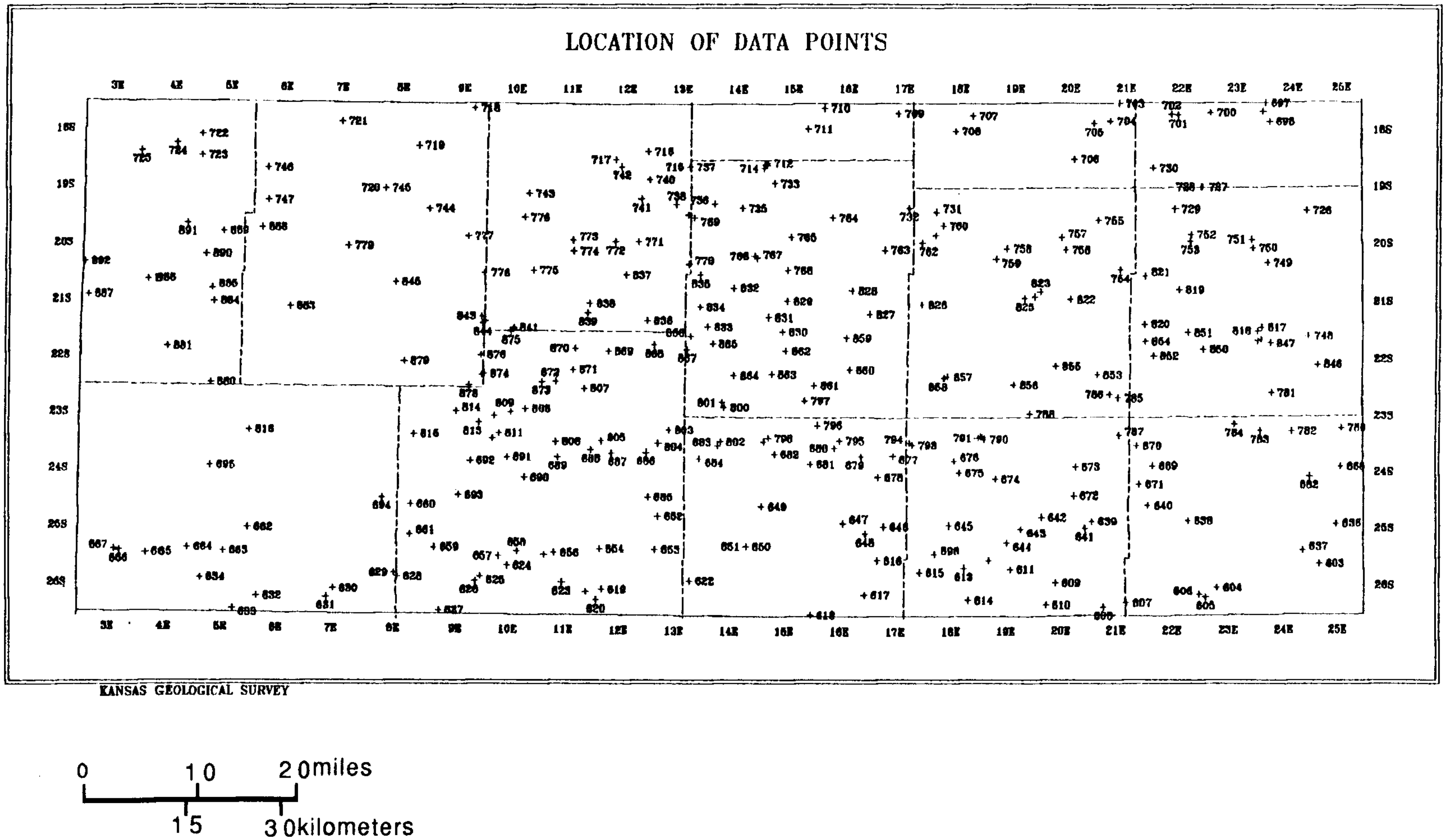


Figure 6. Location of geophysical well logs used in this study.

geophysical well logs from the Bourbon arch region include noncalibrated well logs, incorrect spot locations, and incorrect ground elevations.

When analyzing uncalibrated well logs a consistent method was needed to ensure that correct measurements of net sand and shale were being recorded. This technique involved drawing baselines for a normal shale (i.e. not highly radioactive) and a clean carbonate on a gamma-ray log (Fig. 7). Mississippian limestone was used to draw a left baseline because it gave a consistent gamma-ray response. A clean sandstone baseline was not used in this study because most sands in the intervals studied did not give a consistent gamma-ray response due to varying amounts of clay content. Once shale and carbonate baselines were established, a 50 percent line was drawn between the two. Any area to the left of the 50 percent line is netted as sand and to the right of the line as shale. Use of the neutron curve in conjunction with the gamma-ray curve is vital when employing this technique. The neutron curve allows the user to make distinctions among various lithologies. This method of netting sand was checked by comparing well log results with cored sands of the same intervals. Six cores were used for comparison to the well logs and the results are shown in Table 3. Net sand differences varied from 2 to 5 ft (0.6 to 1.5 m) or -8.6 to +25 percent.

Incorrect well locations and ground elevations were problems commonly encountered with geophysical well logs in the study area. Well locations frequently were reported only to the section, with no quarter section or smaller division being reported. Ground elevations in many cases were not recorded. To ensure accuracy when recording well locations, driller's logs were checked for complete location information. All

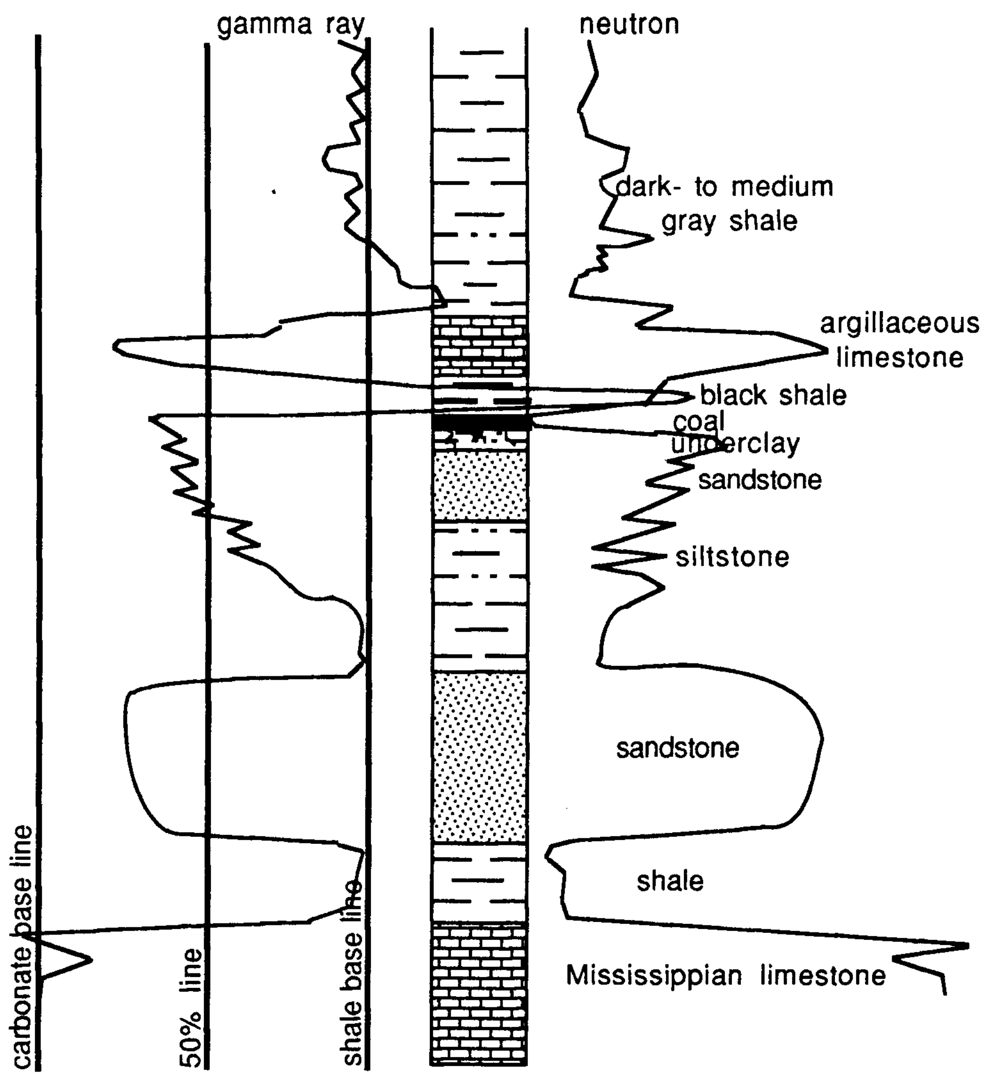


Figure 7. Illustration of method used to determine thicknesses of sandstone and other lithologies from gamma-ray-neutron log signitures.

Well Name	net sand (feet)		% error
	well log	core	$\frac{\text{core - well log}}{\text{core}} \times 100$
*L. R. Smethers CT #1	38	35	-8.6
Dotson #111	6	8	+25
M. Setter #2	34	38	+11
Marshall #3	32	35	+8.6
AO Keown #18	94	99	+5.1
McGee #1-85	6	8	+25

* Well log is appoximately 1 mile from the core location.

Table 3. Comparison of net sand measurements from well logs and cores. Well locations are listed in appendix A.

geophysical wells were then spotted on 7.5 minute topographical maps to obtain estimated ground elevations. Elevations obtained by this method could be incorrect by as much as ± 40 ft (12.2 m) and could affect the accuracy of structure contour maps.

Lithologic analysis

While geophysical well log analysis was the primary method of obtaining lithologic information, cores obtained from the Kansas Geological Survey and Oil Field Research were examined for lithology, color, texture, sedimentary structures, fossil content and diagenesis (Fig. 5). Most cores in this study area sample only productive sandstone intervals and omit the non-reservoir facies. However, P&M #20 and Keown 18AO penetrated the entire Cherokee Group and were used along with five incomplete cores to construct a composite section of the Cherokee Group. A complete listing of cores and core descriptions and geophysical well logs used in this study are included in Appendix A and B.

Computer applications

Well-log data were entered into two data bases on the Data General MV 20000 mainframe computer system at the Kansas Geological Survey. Results of this study can be integrated with results of Killen (1986) and Staton (1987), who also studied the Cherokee Group. Killen outlined how this computerized system works. The first data base contains basic information listed on the cover page of a geophysical well log: the well identification number, well name, company, field, geophysical log type, county, quadrangle map identification number, location, longitude, latitude, elevation and x and y coordinates (Fig. 8). The second data base consists of the marker bed identification number, marker bed depth, thickness to the

CHEROKEE BASIN

PLEASE ENTER THE DECIMAL POINT, IF ANY, AT THE POSITION POINTED BY ^.

WELL ID	WELL NAME
(813)	(LUTHI #1)

COMPANY	FIELD
(PETROLEUM ENERGY, INC.)	(W/C)

LOG	CNTY	QUAD MAP	SEC	TWN	RNG	LOCATION
(GR-N) (SE)	(GW)	(1047)	(32)	(S32)	(E 9)	(NE) (SW)

LONGITUDE	LATITUDE	ELEV. (GL)	X	Y
(38.03102)	(1348.0)	(1289)	(6.63058)	(3.62133)

GEOLOGIST	COMMENT
(DPH)	( )

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Figure 8. Terminal display of database #1.

next deeper identified marker bed, and lithologic division of the interval into thickness of shale, sandstone, limestone, and coal (Fig. 9). Interval thickness is calculated by subtracting the depth of the upper marker from the depth of the lower marker. This is the interval thickness of the higher marker. Total thickness of the Cherokee Group and total thickness of each lithology are then calculated.

The Surface III computer graphics system (Sampson, 1988) was used to construct structure, isopach, and net isolith maps, and to plot well locations. Files from the first and second data bases were merged into a separate file and the neccesary information was then obtained by Surface III commands. For instances where the well log did not record the entire Cherokee interval, Surface III was instructed not to use the totals (total thickness of interval, shale, sandstone, limestone, and coal) calculated for this well since they reflected an incomplete Cherokee interval. When this situation occurred, a square symbol was posted to mark the well location. In cases where a marker bed was unobservable on the geophysical well log (i.e. marker bed onlaps the Nemaha uplift or was not deposited), the number 8888.8 was recorded as the depth of that marker and a triangle was posted on all maps for that interval. When a marker bed and its entire interval had been cut into and removed by a channel, the number 9999.9 was recorded as the depth of that marker. The thicknesses of the intervals above and below the removed marker were not calculated and an (X) was posted on all maps for that interval. In certain cases channels cut into and removed only an underlying marker bed but not the entire interval. When this was observed, depth of the bottom of the channel fill was recorded as the top of the mapped interval.

CHEROKEE BASIN

PLEASE ENTER THE DECIMAL POINT, IF ANY, AT THE POSTION POINTED BY ^.

WELL ID#	GEOLOGIST	COMMENT
(813)	(DPH)	( )

	MARKER		LITHOLOGIC THICKNESS			
ID	DEPTH	THK	SHALE	S.S	L.S.	COAL
(1000)	(2076.0)	(.0)	(.0)	(.0)	(.0)	(.0)
(960)	(8888.8)	(.0)	(.0)	(.0)	(.0)	(.0)
(900)	(2152.0)	(76.0)	(72.0)	(0.0)	(3.0)	(1.0)
(780)	(2168.0)	(16.0)	(13.0)	(2.0)	(1.0)	(.0)
(720)	(2196.0)	(28.0)	(27.0)	(1.0)	(.0)	(.0)
(680)	(2214.0)	(18.0)	(17.0)	(.0)	(.0)	(1.0)
(640)	(2233.0)	(19.0)	(19.0)	(.0)	(.0)	(.0)
	^	^	^	^	^	^
		TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
		(340.0)	(321.0)	(7.0)	(6.0)	(6.0)

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NEW CARD (A)

NEW RESPECTIVE TOTALS WILL BE CALCULATED AFTER YOU SEND THIS CARD

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CHEROKEE BASIN

PLEASE ENTER THE DECIMAL POINT, IF ANY, AT THE POSTION POINTED BY ^.

WELL ID#	GEOLOGIST	COMMENT
(813)	(DPH)	( )

	MARKER		LITHOLOGIC THICKNESS			
ID	DEPTH	THK	SHALE	S.S	L.S.	COAL
(590)	(2250.0)	(17.0)	(17.0)	(.0)	(.0)	(.0)
(510)	(2270.8)	(20.0)	(20.0)	(.0)	(.0)	(.0)
(200)	(2365.0)	(95.0)	(88.0)	(4.0)	(.0)	(3.0)
(120)	(2396.0)	(31.0)	(30.0)	(.0)	(.0)	(1.0)
(100)	(8888.8)	(.0)	(.0)	(.0)	(.0)	(.0)
(50)	(8888.8)	(.0)	(.0)	(.0)	(.0)	(.0)
(0)	(2416.0)	(20.0)	(18.0)	(.0)	(2.0)	(.0)
	^	^	^	^	^	^
		TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
		(340.0)	(321.0)	(7.0)	(6.0)	(6.0)

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NEW CARD ( )

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Figure 9. Terminal display of data base #2.

The advantages of using Surface III for a large mapping project outweigh the limitations. The contour maps for this study could have been hand contoured. However, the large number of data points and contour maps constructed mandated that Surface III be employed because it has the advantages of speed, consistency, and efficiency. Surface III is ideal for constructing isopach maps where the intent is to delineate lithologic trends over large areas. Structure contour maps can be used in the same capacity by revealing regional structural trends.

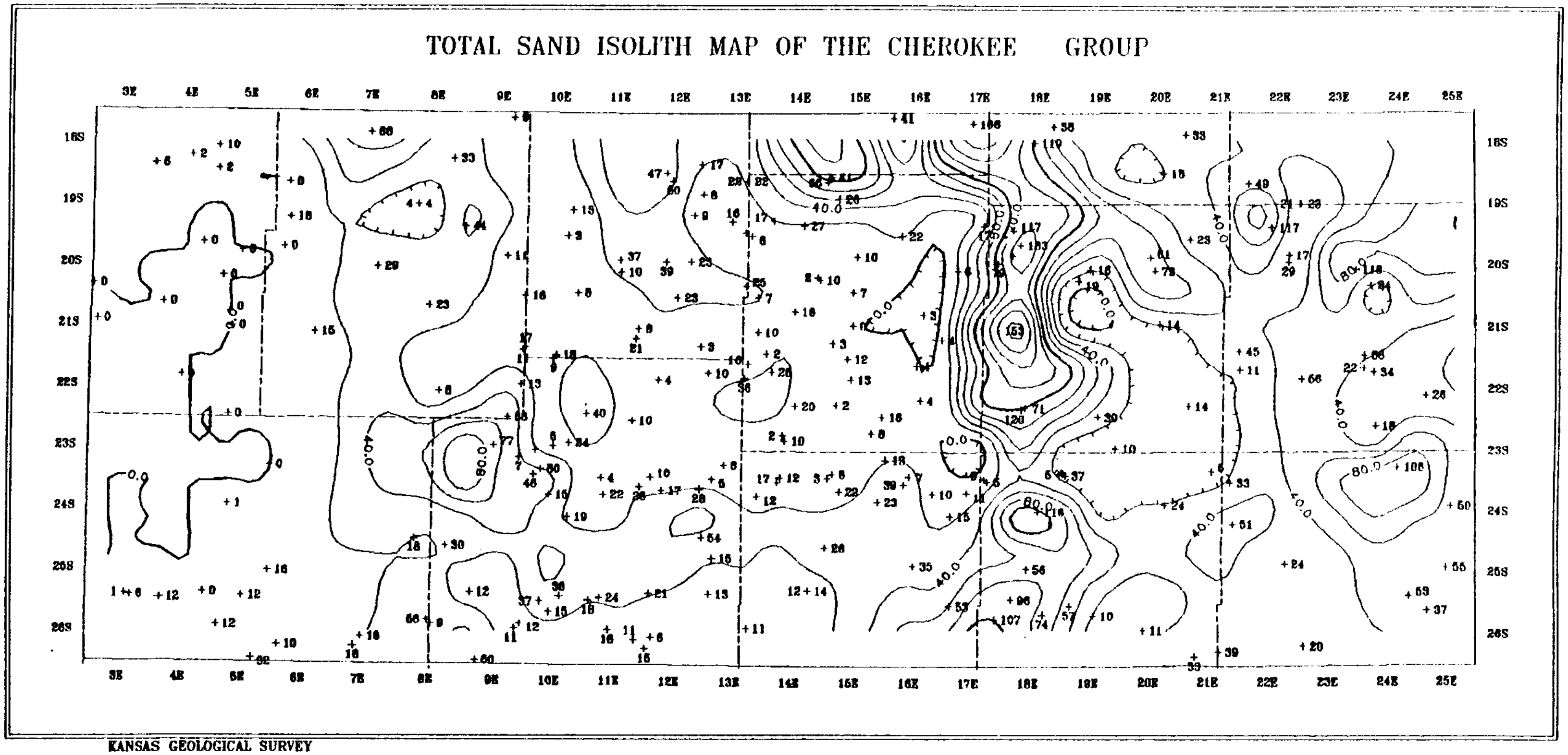
However, there are drawbacks to using a computer to construct contour maps. This paragraph discusses the contouring procedures Surfaces III uses to generate a contour map and the limitations of it and was summarized from Sampson (1988). Surface III produces a contour map by using a contouring algorithm to interpolate values from known control points to a closely spaced grid or network of values. A grid is a mathematical model of the surface represented by equally spaced lines representing the coordinate system of the map. The points where grid lines intersect are called grid nodes and values of the surface must be known or estimated at each of these. Thus, a contouring algorithm is a complicated spatial averaging process used to interpolate data points at nodes and draw contour lines. The interpolation process is essentially a weighted averaging of the values at the closest few control points. Surface III will not correctly contour closely spaced data points that differ by a factor greater than the contour interval and will instead take a weighted average of the values. The interpolation method will cause some data points that are the same as the contour interval to lie outside or inside of the contour line, instead of going through the data point.

Computer mapping does not allow the experience and general geologic understanding of the geologist to influence the contour map. The total sand isolith map of the Cherokee Group (Fig. 10) does not show the "shoestring" sands in Greenwood County, for example. Limited data points forced the computer to construct circular contours, inferring a large area of thick sand accumulation. An experienced geologist familiar with this region would have contoured the limited data points as a series of narrow, elongate channel fills.

The contouring program does not automatically identify faults and instead requires that the faults be included in the base map of the area. Surface III then draws contours near the faults as if they were separate maps and ignores the fact that contours will truncate against the fault. Because Surface III does not contour faults correctly, the faults recognized along the Nemaha uplift and the Bourbon arch were dashed in by hand and no contours were drawn around them.

Units of Measurement

English units where used in this study to measure core and well log thicknesses, to construct contour maps, to report areal distances, and to report oil and coal production figures. The petroleum industry standard is to record core and well log measurements in English units. This study did not convert core or well log measurements into metric units because doing so would introduce some error. English units were converted into metric units when the thicknesses of isopach, isolith, and structure contour maps were reported and when the areal extent of a marker bed and the study area was reported. A conversion factor of 0.3048 was used when converting feet into meters and a conversion factor of 1.61 was used to change miles into



0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 20 feet

Figure 10. Total sand isolith map of the Cherokee Group.

kilometers. The metric system was used primarily to describe sedimentary structures, bedding, and clast size in cores.

REGIONAL STRUCTURAL SETTING

Cherokee Group strata accumulated within the slowly subsiding and tectonically stable Forest City and Cherokee basins. However, many post-Mississippian and Early Pennsylvanian structural features may have influenced Cherokee Group deposition (Fig. 2). The collision of the North American and South American plates near the end of Early Pennsylvanian time produced the Ouachita-Marathon orogeny. The collision resulted in a southwestward suturing of the continents that created many uplifts and basins in the west-central United States (Kluth and Coney, 1981; Rascoe and Adler, 1983), among these were the Ozark uplift in southern Missouri, and in Kansas the Nemaha uplift, and possibly the Bourbon arch. The Ouachita orogeny, the phase of the collision that occurred during middle Atokan through late early Desmoinesian time in southeastern Oklahoma, may have formed the present Ozark uplift in Missouri (Frezon and Dixon, 1975; Elmore et al., 1990).

The Bourbon arch, a low relief post-Mississippian structure trending northwest-southeast, separates the Forest City basin from the Cherokee basin (Jewett 1951) and is expressed as a subtle northwest to southeast trend of thinning. The significance of the Bourbon arch will be explored in detail in the section dealing with post-Mississippian structures.

The Nemaha uplift is a major post-Mississippian structure of north-northeast to south-southwest trending faulted anticlines which extends from Nebraska, through Kansas, and into central Oklahoma. (Jewett, 1951; McElroy, 1961; Frezon and Dixon, 1975). Suturing of the North American and South American plates continued southwestward and created the Amarillo-Wichita uplift of southern Oklahoma and the Nemaha uplift, which were reported by Frezon and Dixon (1975) and Rascoe and Adler (1983) to have occurred near the end of Early Pennsylvanian time. Berryhill (1960) reported that no major tectonic movement along the Nemaha uplift has occurred since earliest Atokan time. However, post-Permian movement along the Humbolt fault zone on the eastern flank of the Nemaha uplift in northern Kansas, has displaced strata up to 660 ft (200 m) in places (Steeples, 1988). The Cedar Creek syncline is a major downdropped block occurring in southwestern Chase and northeastern Butler counties along the intersection of the Humbolt and Fall River tectonic zones (Berendsen and Blair, 1986). It displaces Cherokee Group rocks about 500 to 1000 ft (150 to 310 m). Lower and middle upper Cherokee Group rocks within this study area onlapped the Nemaha uplift before it was buried by upper Cherokee Group deposition. Killen (1986), Staton (1987) and I were able to correlate upper Cherokee markers from the Cherokee basin across the Nemaha uplift into the Sedgwick basin.

STRATIGRAPHY

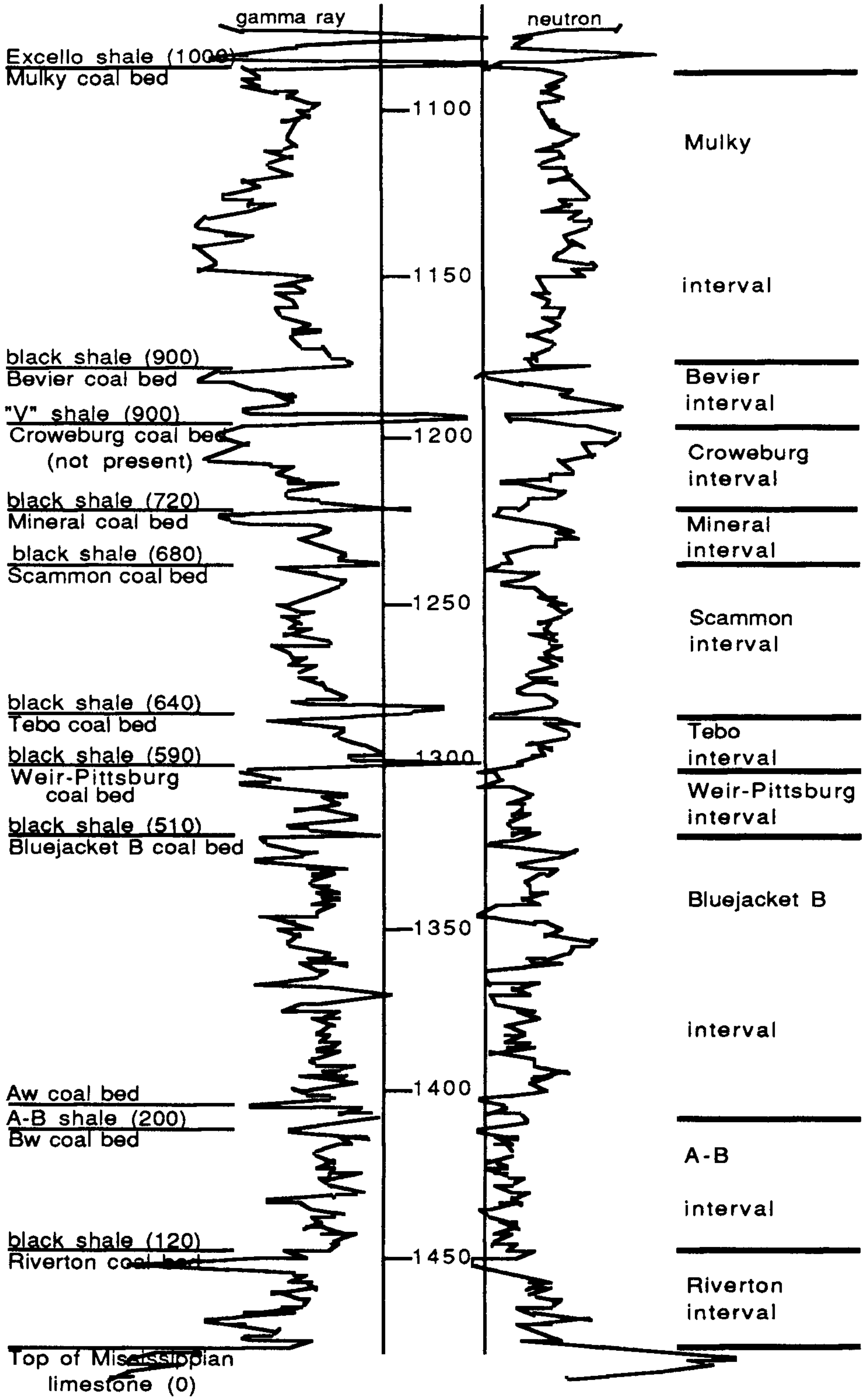
Stratigraphic markers

Figures 11A and 11B, the type gamma-ray-neutron logs of the Cherokee Group in the Bourbon arch region, show the markers and marker intervals used in this study. This study used informal stratigraphic markers established by Harris (1984), Killen (1986), and Staton (1987). The markers are radioactive, black shales that separate stratigraphic intervals. One minor difference between this study and Staton's study concerned the recording of marker bed depth. Staton picked the top of the thin (average of 3 ft (0.9 m) thick) black shales, while this study used a complex of markers consisting of a basal underclay overlain by a coal, shelly lag (transgressive limestone), and black shale. The marker complex was used for three reasons: (1) Black shale and coal give distinctly different gamma-ray and neutron log responses (Fig. 7); (2) The sharp contact between the coal and the overlying shelly lag or black shale represents a shift from terrestrial to marine facies; (3) When the shelly lag and black shale had been removed by channeling or were unrecognizable, the top of the underlying coal bed or even the underclay could be used, if present.

Two informal stratigraphic intervals established by Strickland (1987), the X-marker and McLouth, were incorporated into this study. These two intervals were not recorded using the coal/black shale combination because of the nature of the intervals; the X-marker interval consisted of an argillaceous limestone and the McLouth interval consisted of sandstone. The top of the argillaceous limestone and of the sandstone was recorded as the depth of the top of those intervals respectively.

Marker beds were assigned identification numbers by using the same

Figure 11 A. Type gamma-ray-neutron log of the Cherokee Group in the Bourbon arch region with designated stratigraphic intervals. X-marker and McLouth marker are not present at this location. Mahony-Cannan-Lindsay, Mitchell #1, sec 19 T23S R16E, Woodson County, Kansas, elev. 1090'.


gamma ray
neutron
Excello shale (1000)
Mulky coal bed
1100
Mulky
1150
interval
black shale (900)
Bevier coal bed
Bevier
interval
"V" shale (900)
Croweburg coal bed
(not present)
1200
Croweburg
interval
black shale (720)
Mineral coal bed
Mineral
interval
black shale (680)
Scammon coal bed
1250
Scammon
interval
black shale (640)
Tebo coal bed
Tebo
interval
black shale (590)
1300
Weir-Pittsburg
coal bed
Weir-Pittsburg
interval
black shale (510)
Bluejacket B coal bed
Bluejacket B
1350
interval
Aw coal bed
1400
A-B shale (200)
Bw coal bed
A-B
interval
black shale (120)
Riverton coal bed
1450
Riverton
interval
Top of Mississippian
limestone (0)

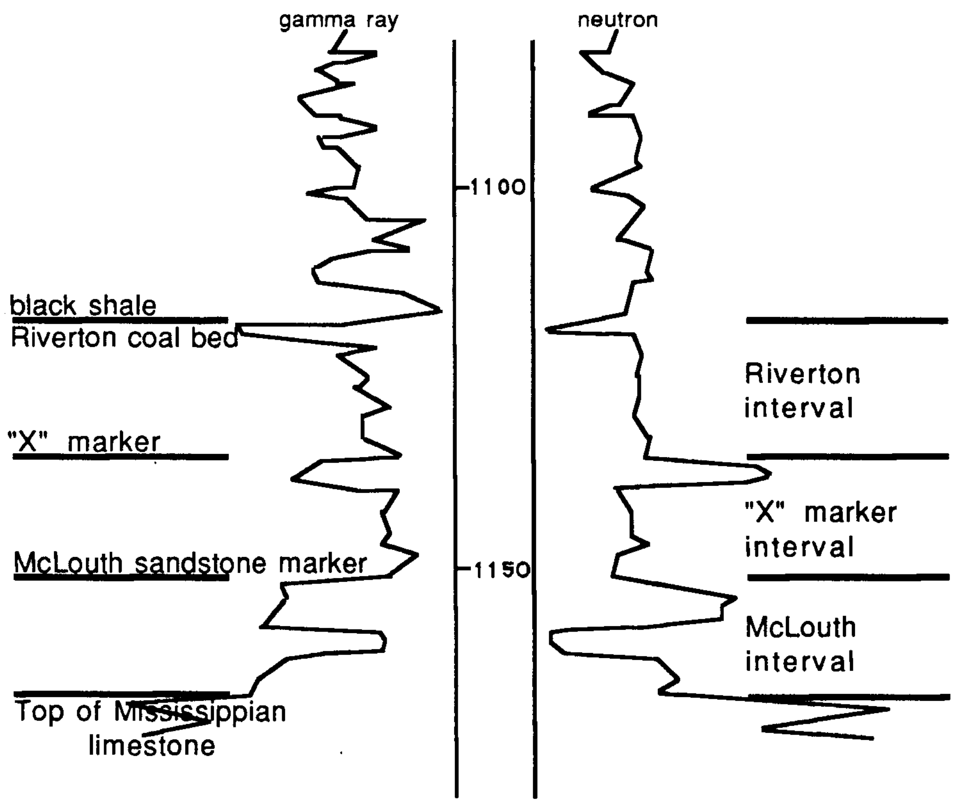


Figure 11B. Composite well log response of the Riverton, "X", and McLouth intervals. "X" and McLouth markers are present only in the northern most part of the study area. Refer to figure 14 for their lateral extent.

sequence as Killen (1986) and Staton (1987) with the exception of Strickland's X-marker and McLouth, which were assigned identification numbers 100 and 50. The Iron Post coal (Staton's number 960) and overlying black shale marker were not observed in this study area. The markers were observed only in the south-central and northwestern portions of Staton's study area in southeastern Kansas. This marker was listed in this study because the existing computer data base of Staton was set up for recording it. Many computer programming changes would have been necessary to rid the data base of the marker bed listing, and the resulting files would have been less compatible with those of Staton and Killen.

Markers and Intervals

Figures 11A, 11B, and 12 illustrate the markers and marker intervals used in this study and are representative of the Cherokee Group in the Bourbon arch region of Kansas.

McLouth interval - (0 - 50)

The McLouth interval unconformably overlies the Mississippian limestone and extends to the bottom of an overlying dark-gray to black marine shale. Strickland (1987) defined it as the first sand body occurring below the X-marker. The interval is composed of clay, shale, and siltstone and may grade into clean, porous to argillaceous sandstone. This interval ranges in thickness from 7 to 30 ft (2.1 to 9.1 m) (Fig. 13) and onlaps the Bourbon arch from the north and northeast at about township 18 south to 21 south and from range 14 east to 21 east (Fig. 14). The McLouth sandstone was first described by Lee (1941) from cores taken in the Forest City basin in Kansas. This interval is equivalent to Strickland's (1987) zone 4 or 5 and is possible Atokan in age, based on palynological evidence (Strickland,1987).

COMPOSITE SECTION OF THE CHEROKEE GROUP BOURBON ARCH REGION, KANSAS

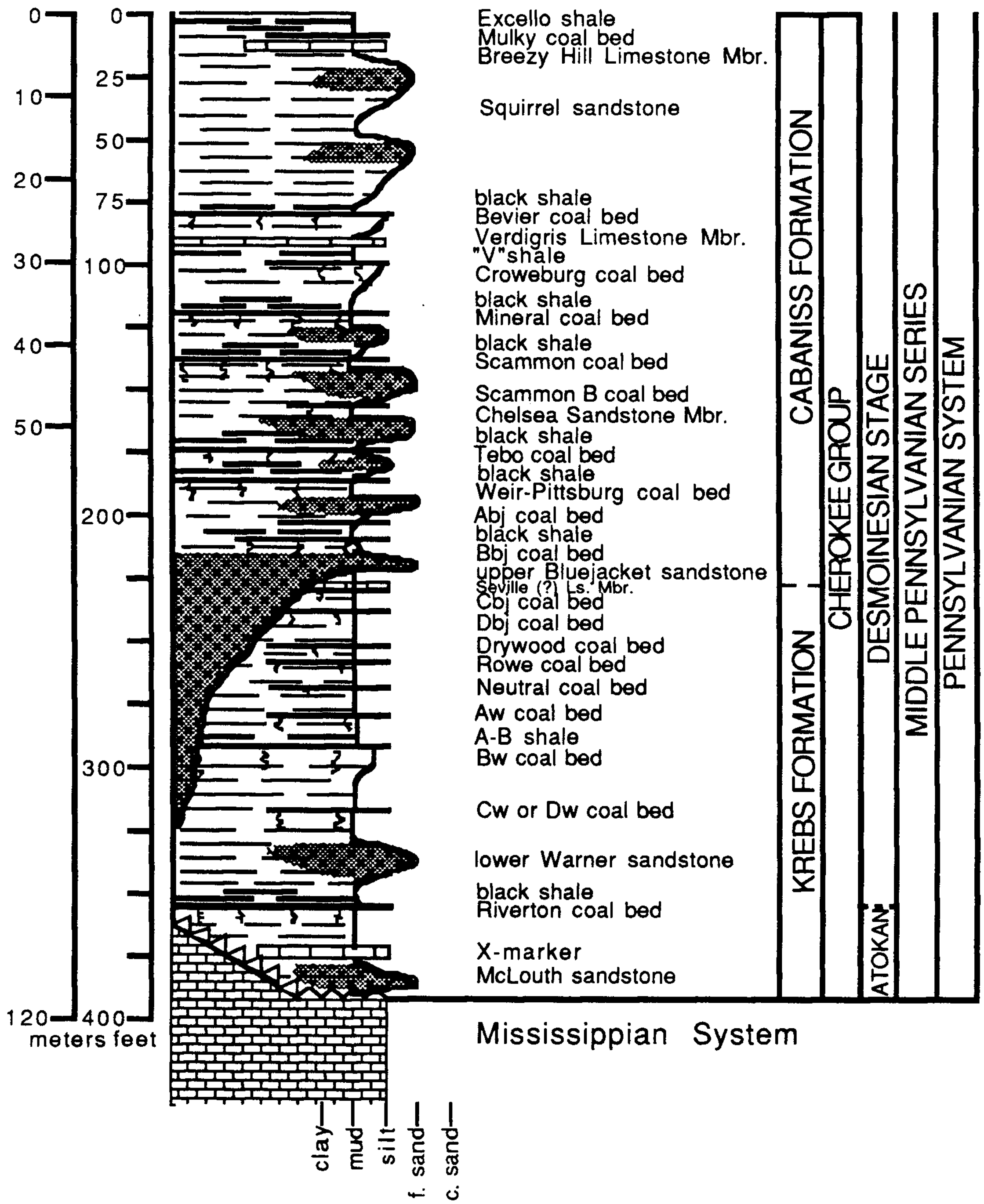


Figure 12. Composite section of the Cherokee Group in the Bourbon arch region.

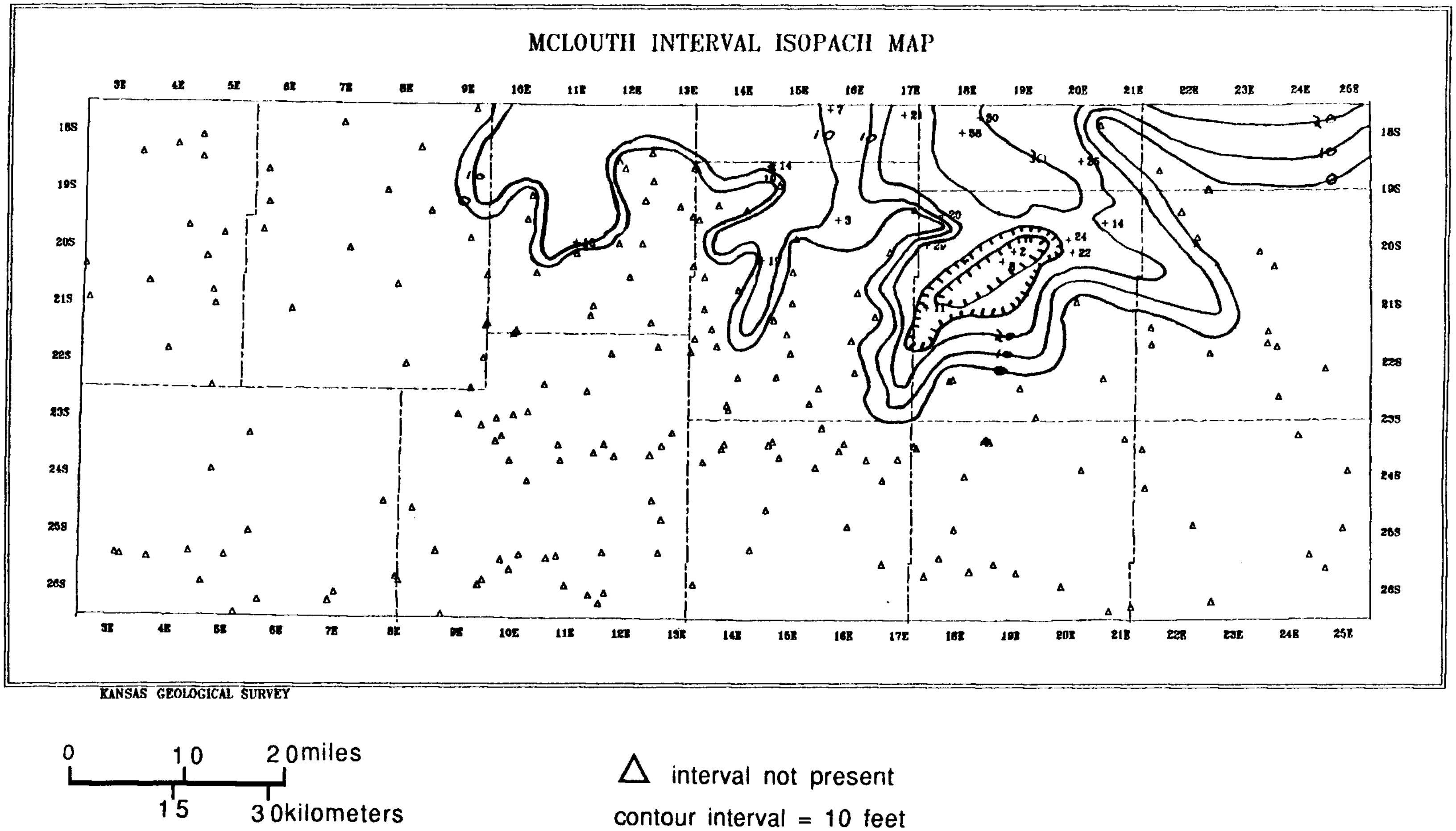


Figure 13. McLouth interval isopach map.

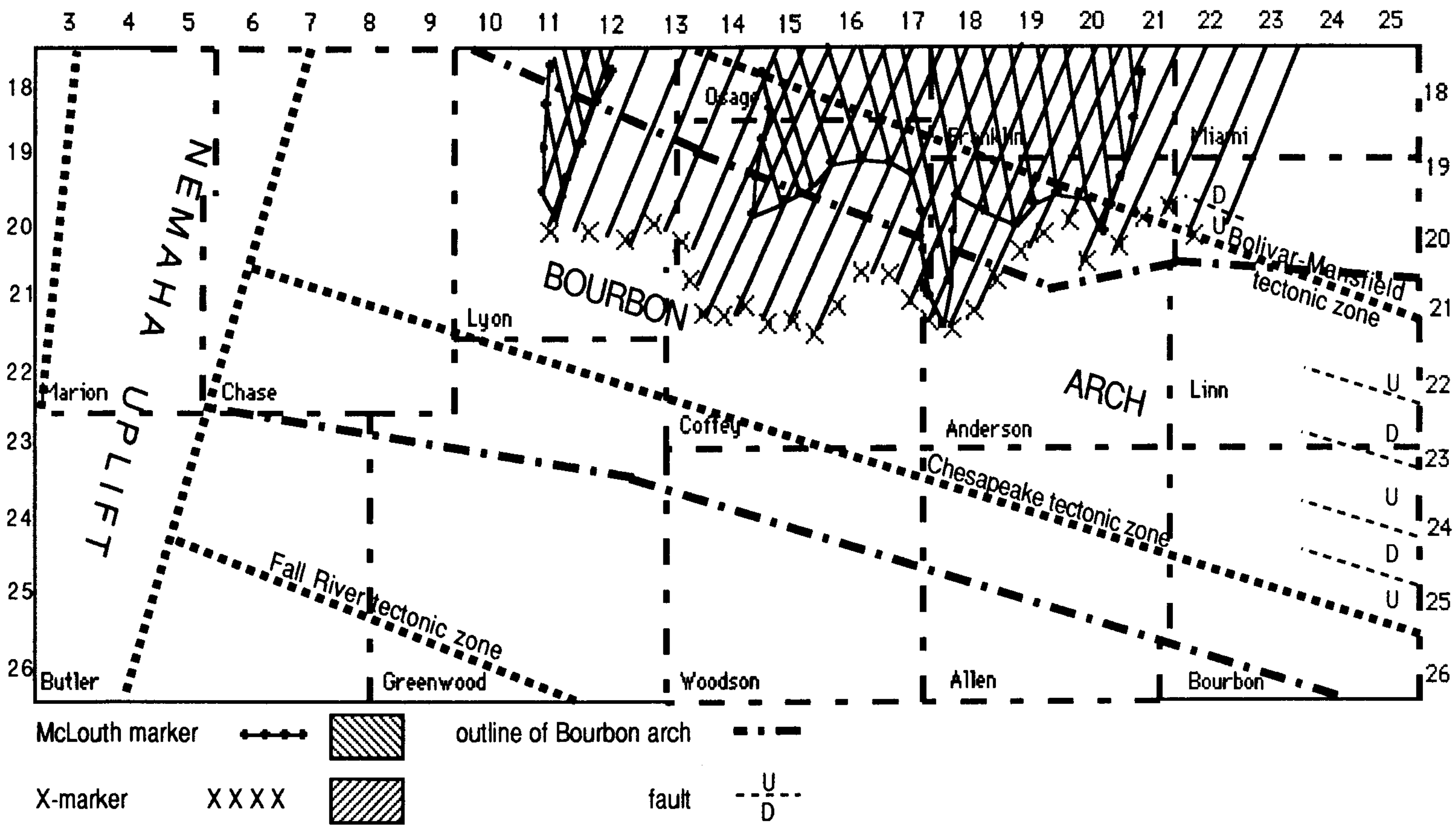
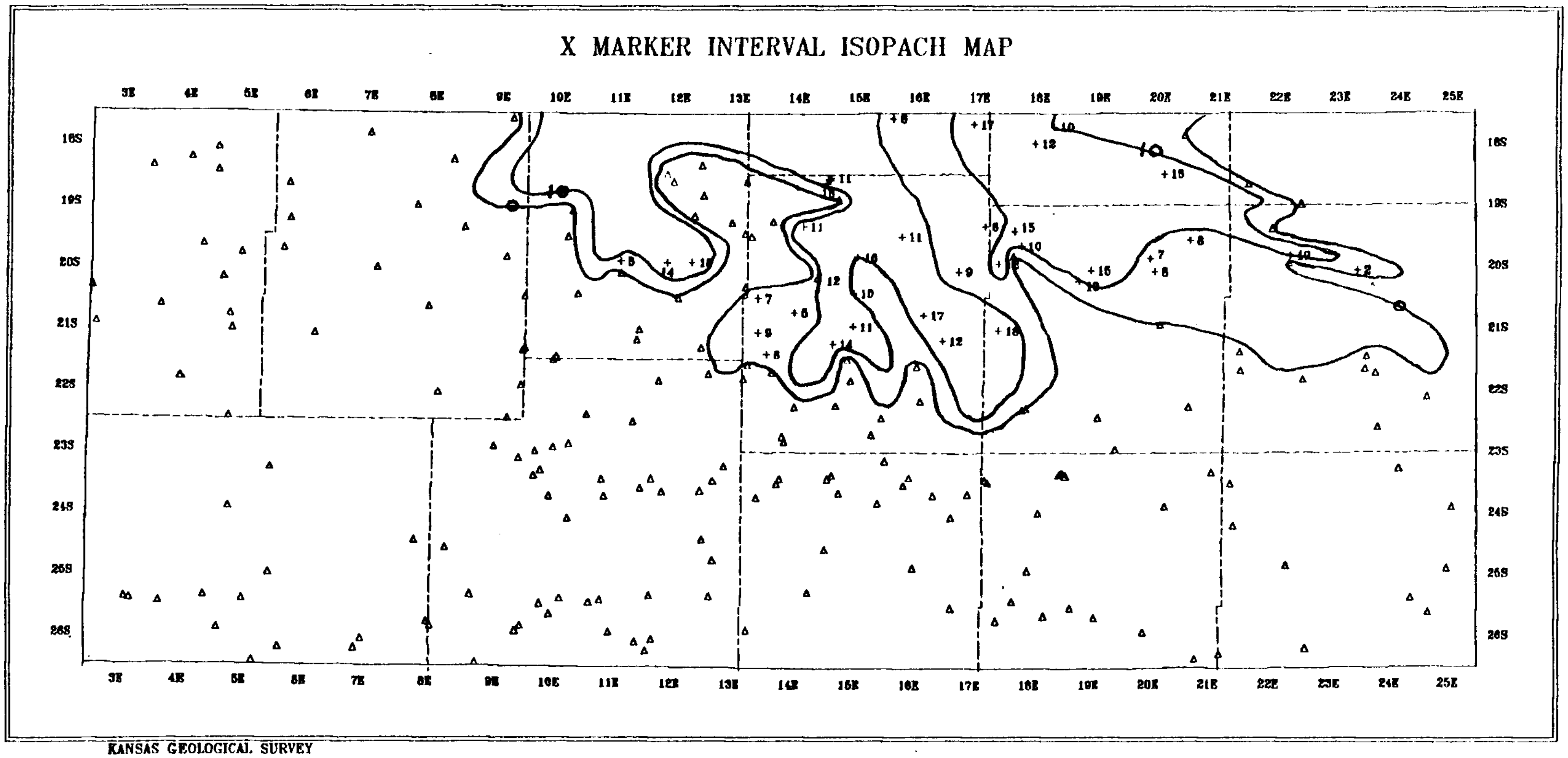


Figure 14. Lateral extent of the McLouth and X-markers in relation to the Bourbon arch and the Nemaha uplift (Berendsen and Blair, 1986).

X-marker interval - (50 - 100)

The X-marker interval extends from the top of the X-marker limestone to the top of the McLouth sandstone marker and ranges in thickness from 2 to 18 ft (0.6 to 5.5 m) (Fig. 15) before onlapping the Bourbon arch from the north in central Coffey County (Fig. 14). This interval unconformably overlies Mississippian limestone where the McLouth sandstone marker is not present and extends from townships 18 south to 21 south and from ranges 11 east to 23 east.

This interval changes facies from silts and fine sands in the north into muddy carbonates in the south before onlapping the northern limb of the boundary of the Bourbon arch. The dominant lithology is shale. Sandstone, limestone and coal isolith maps of this interval reveal only minor amounts of each lithology. Strickland (1987) defined the X-marker as a thin limestone occurring below Riverton coal and tentatively correlated it with a limestone of the Burgner Formation (Searight and Palmer, 1957). Strickland reported the X-marker to be Atokan in age, based on the presumed correlation with a limestone of the Burgner Formation of Missouri. This correlation has not been demonstrated to be correct. Searight and Palmer (1957) were the first to describe and name the Burgner Formation from cores taken in isolated sinkholes in karsted Mississippian strata near Webb City, Missouri, which is located south of the Bourbon arch. Mid-Atokan age fossils found in a limestone of the Burgner Formation include primitive Fusulinella (Thompson, 1953), mega-invertibrates (Searight and Palmer, 1957), monodies (Unklesbay and Palmer, 1958), and conodonts (Nuelle; pers. com. from Thompson, 1990).



0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 10 feet

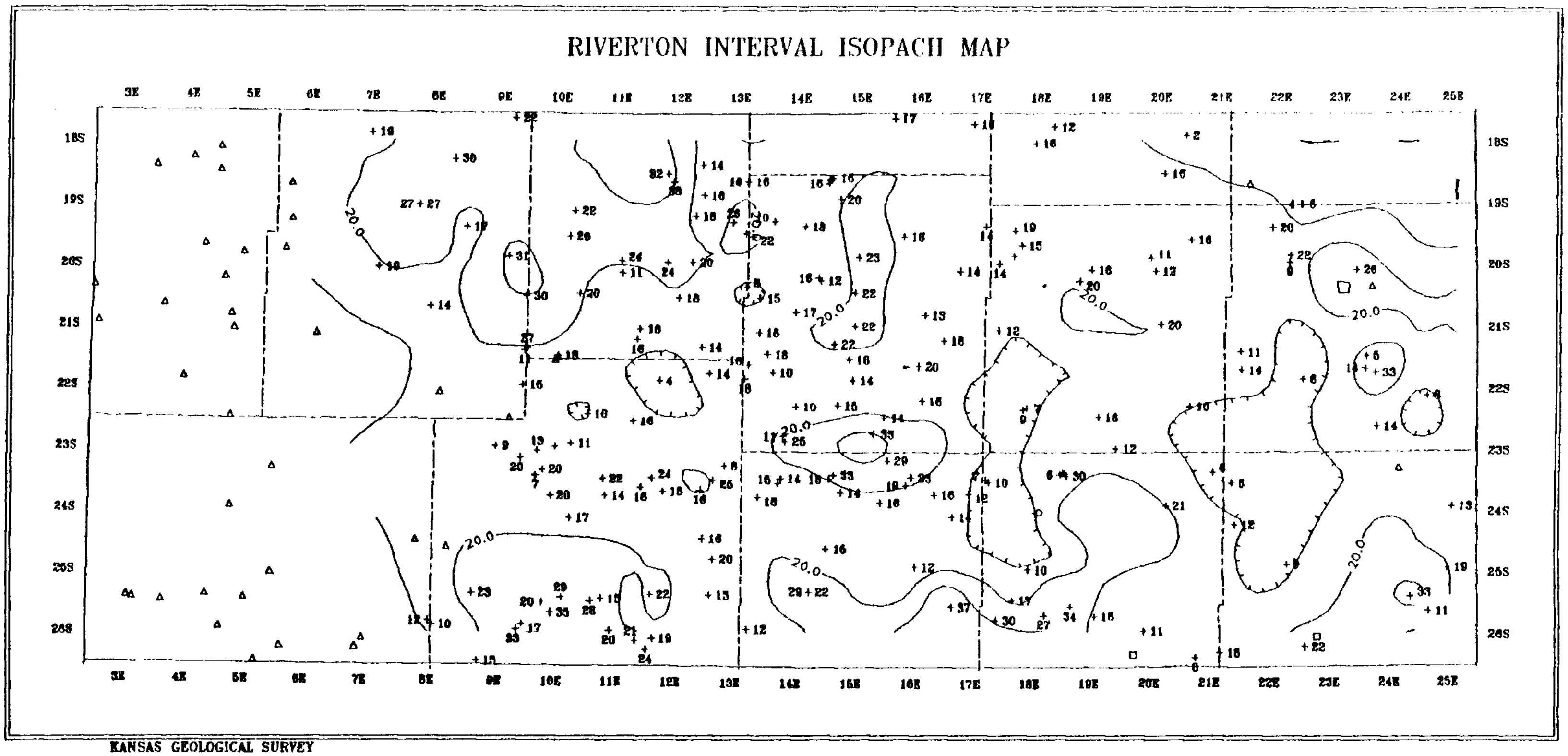
Figure 15. X-marker interval isopach map.

Riverton interval - (100 - 120)

The Riverton interval extends from the top of the Riverton coal bed or the base of the overlying shale to the top of the X-marker or the top of the Mississippian limestone, where the McLouth sandstone and the X-marker are absent. The Riverton interval ranges in thickness from 2 ft (0.6 m) in southern Franklin and southeastern Butler counties to 38 ft (11.6 m) in northern Lyon County (Fig. 16). This interval lies disconformably on top of the Mississippian limestone or older carbonates and consists of a basal Pennsylvanian conglomerate, light- to dark-gray laminated siltstone and mudstone, and a continuous 1 to 3 ft (0.3 to 0.9 m) coal unit (Fig. 17). The Riverton interval locally includes the basal Pennsylvanian conglomerate facies. This material is similar to that described by Nodine-Zeller (1981) in Ness County, Kansas and is referred to as the Chat by local petroleum operators. The basal Pennsylvanian conglomerate consists of angular to rounded carbonate lithoclasts, 1 to 2 cm in diameter, in a mottled, medium-gray mudstone matrix (Fig. 18). Carbonate clasts were probable derived from the underlying Mississippian limestone. Upper and lower contacts are often scoured and erosional. This facies may grade vertically into a laminated medium-gray shale.

Sandstone in the Riverton interval is generally missing, although, 25 ft (7.6 m) of sand occurs in one point in north central Linn County and 10 ft (3 m) of sand was recorded in one point in northwestern Allen County. The Riverton shale interval is found consistently throughout the study area except in western Chase and eastern Butler counties, where it onlaps the Nemaha uplift (Fig. 19).

Conodonts from the Riverton Formation in Missouri, which includes all

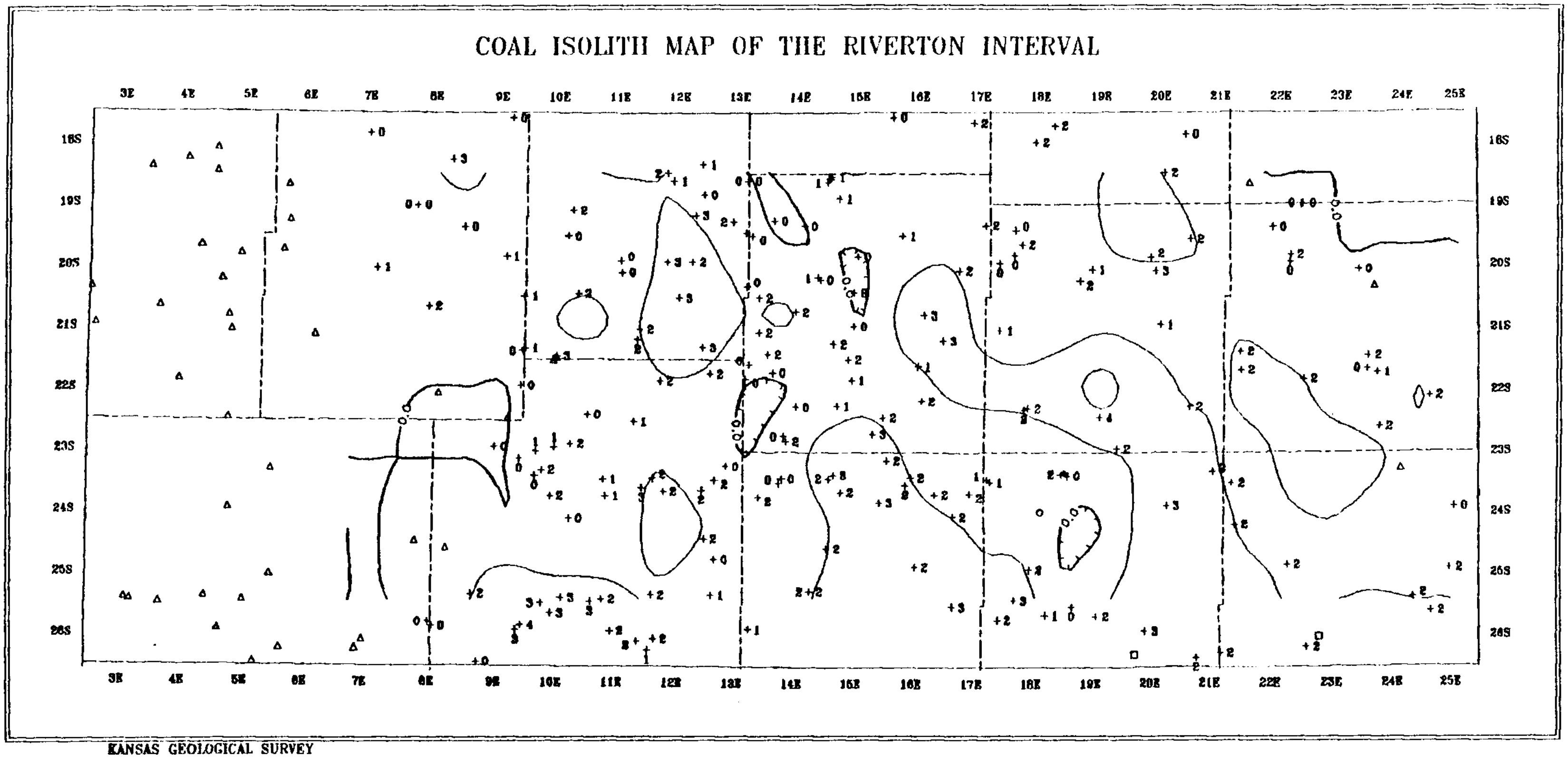


0 10 20 miles
15 30 kilometers

△ interval not present

contour interval = 10 feet

Figure 16. Riverton interval isopach map.



0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 2 feet

Figure 17. Coal isolith map of the Riverton interval.

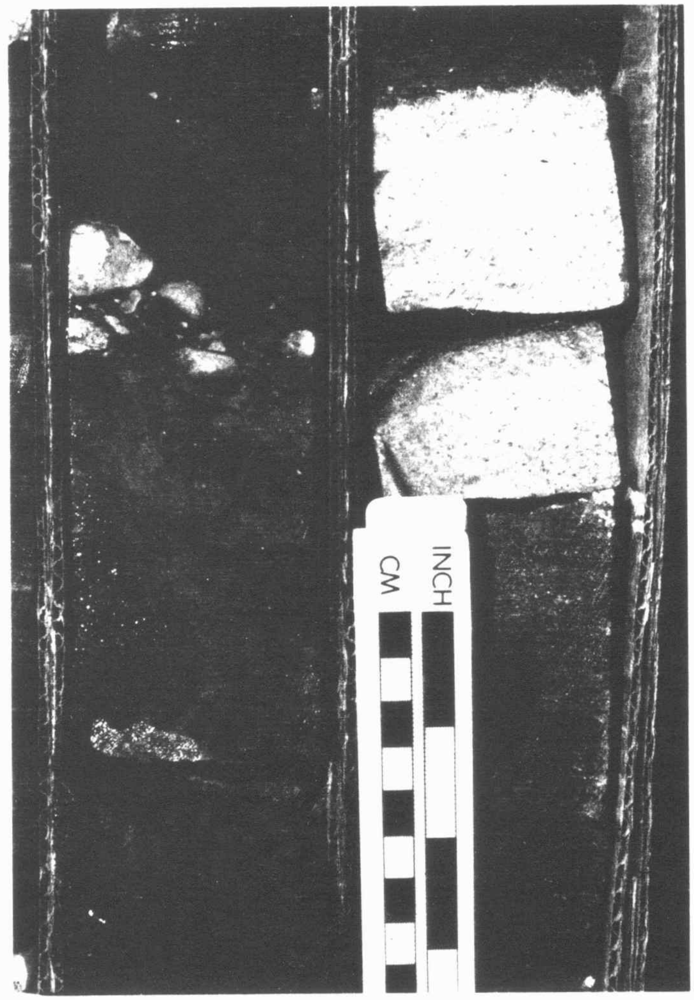


Figure 18. Photograph of a slabbed core showing the basal Pennsylvanian conglomerate facies lying disconformably on the Mississippian limestone. The top of the core is located at the top left of the photograph. (Sample from McGee Lease #20-90, Sec. 3-T23S-R21E, Anderson County, Kansas, 913'-914')

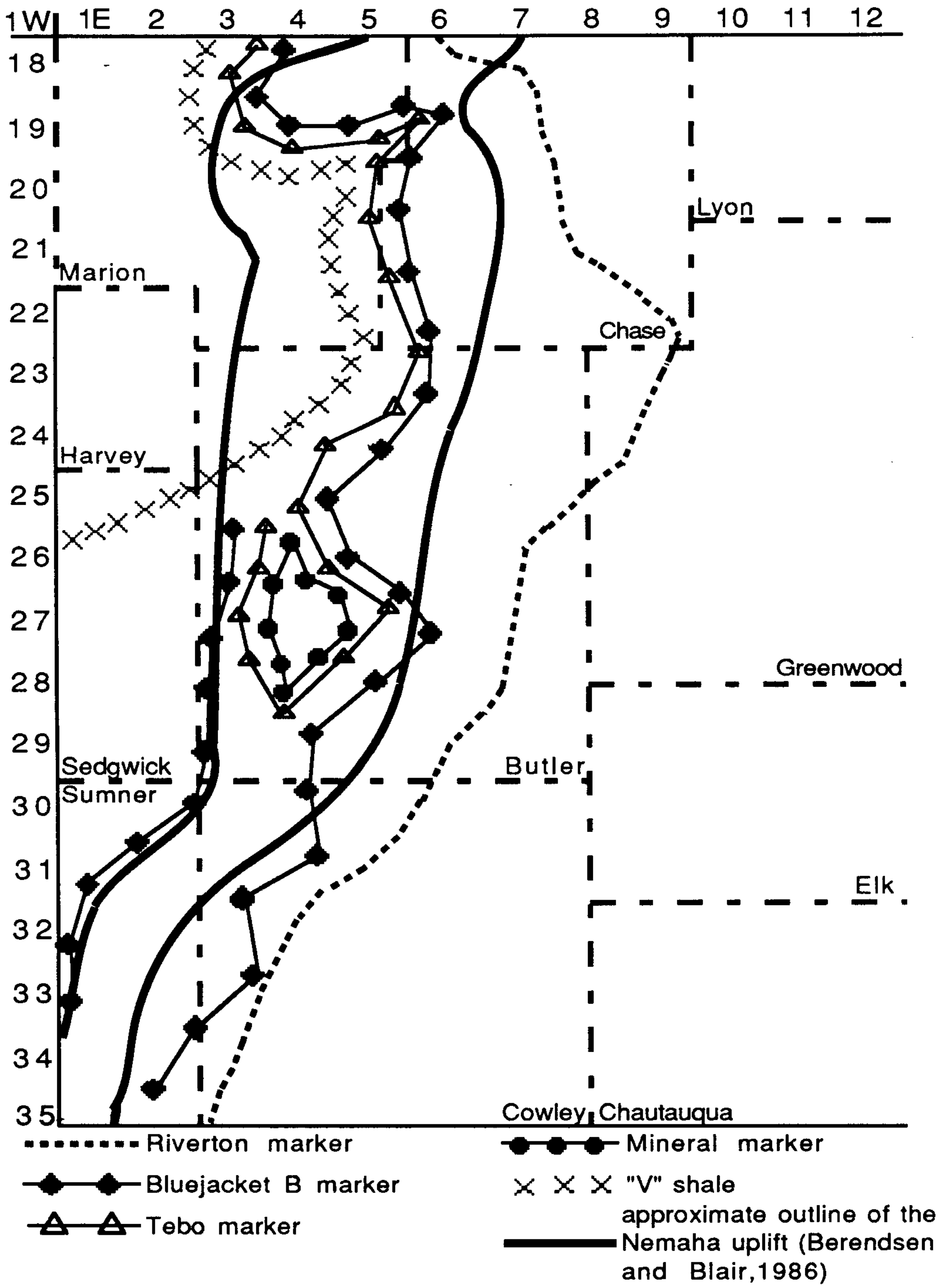


Figure 19. Lateral extent of specific marker beds showing an onlapping relationship with the Nemaha uplift (modified from Staton, 1987).

strata from the top of the Aw coal bed in Kansas to the top of the Mississippian Limestone (i.e. the Riverton, A-B, and lowermost Bluejacket B intervals of this study), were dated by Thompson (1979) as Atokan in age. Thompson recovered conodonts from the "basal part of the Riverton at two localities, one an open sink structure near Joplin, the other an outcrop in west-central Missouri" (Thompson, 1979, p. 16). It is probable that the Riverton Formation sampled in the sinkhole was not stratigraphically equivalent to the Riverton coal interval in Kansas. Correlation of strata found only in such isolated sinkholes is difficult and should be documented carefully. Nodine-Zeller and Thompson (1977) examined the #1 Velie Swalley core in southeastern Cherokee County and recovered foraminifera from the black shale above the Mississippian limestone. The precise age of the black shale could not be determined from foraminifera dating and was reported as Atokan or Desmoinesian. In contrast to Nodine-Zeller and Thompson's (1977) and Thompson's (1979) findings, Rosowitz's (1980) palynological study of the Riverton coal bed in southeastern Kansas arrived at a Desmoinesian age. Peppers (1989, personal communication) confirmed that the spore assemblage found in the Riverton coal indicates an early Desmoinesian age.

A-B interval - (120 - 200)

The A-B interval extends from the top of the Bw coal bed or the base of the A-B shale marker (Staton, 1987) to the Riverton marker and consists of laminated mudstone, interbedded siltstone and mudstone, fine to coarse sandstone, and coal. This interval ranges in thickness from 2 ft (0.6 m) in southeastern Butler County to 88 ft (26.8 m) in southwestern Woodson County (Fig. 20). The overlying upper Bluejacket sandstone scours into the

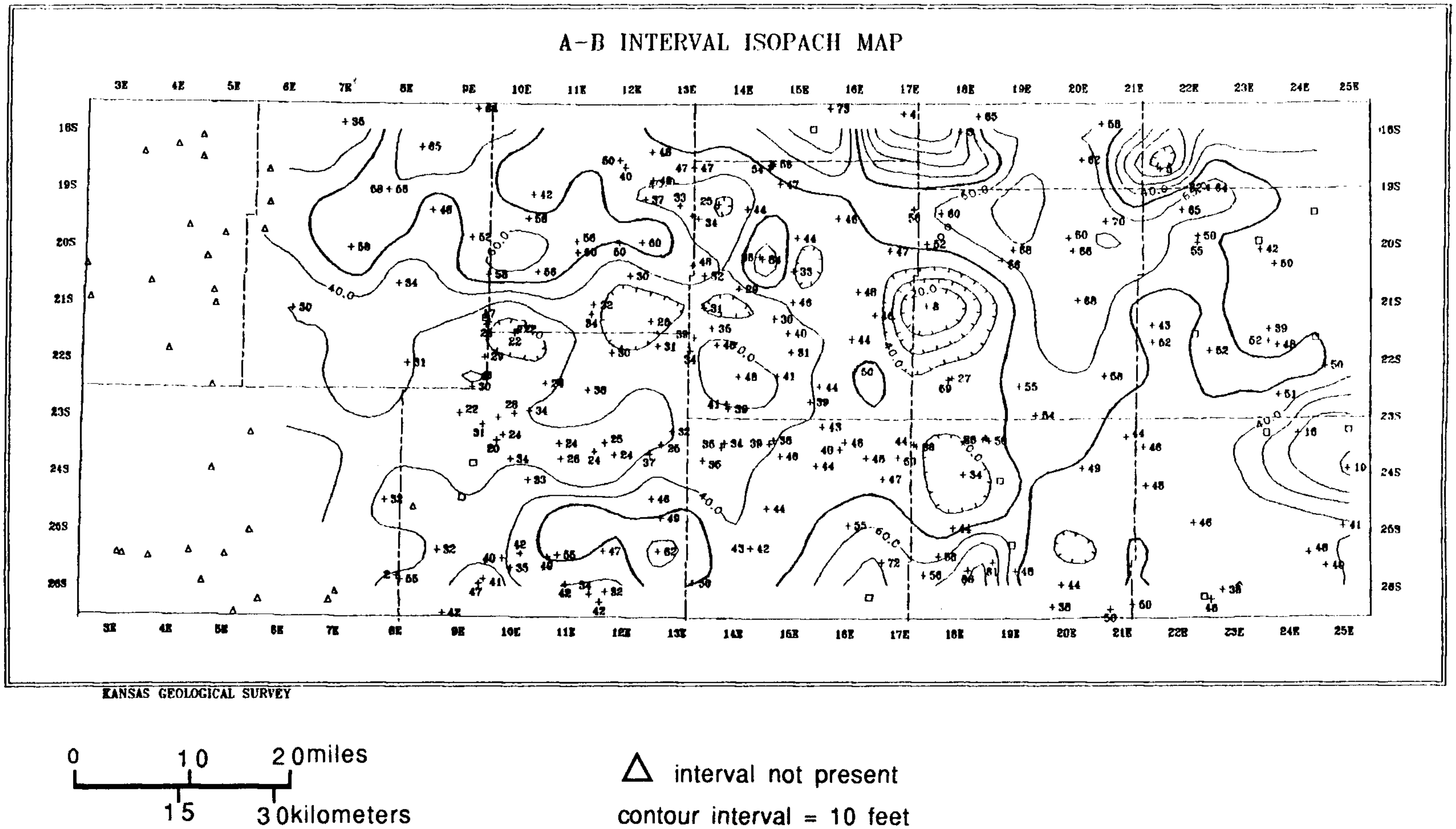


Figure 20. A-B interval isopach map.

underlying A-B and Riverton intervals in places causing anomalously thin intervals. The sandstone isolith map (Fig. 21) shows a long, north-south trend of thick sand extending from townships 18 south to 26 south and between ranges 17 east and 19 east. Other areas of isolated thick sands occur in northwestern Linn and southeastern Bourbon counties. These sands are equivalent to the lower Warner sandstone of Ebanks (1979). The north-south linear trend suggests that they are channel deposits. The coal isolith map reveals thicknesses up to 8 ft (2.4 m) occurring in eastern Chase County, which can be mostly attributed to the Bw coal bed (Fig. 22; Harris, 1984). However, a coal bed occurring in the middle of the interval, possibly the Cw or Dw (Harris, 1984), is laterally persistent over the entire area and gives a moderate to good well log response.

Bluejacket B interval - (200 - 510)

The Bluejacket B interval extends from the top of the Bbj coal bed (Harris, 1984) or base of the overlying black to dark-gray shale to the A-B shale marker. The Bluejacket B interval consists of laminated mudstone, rippled siltstone, rippled fine sandstone, cross-stratified fine to coarse sandstone, and numerous discontinuous coal units. Upper Bluejacket sandstone (Ebanks, 1979) occurring in this interval may range in thickness from 1 to 183 ft (0.3 to 55.8 m; Fig. 23). These thick sands commonly scour into and remove the underlying A-B and Riverton intervals, making correlations difficult in these areas. The sand isolith map of this interval delineates a north-south trend of thick sand in the same location as the sand found in the A-B marker interval. The isopach map of this interval (Fig. 24) shows thickening occurring in the same location as the thick north-south-trending sands. Thicknesses range from 20 ft (6.1 m) in south-central Butler

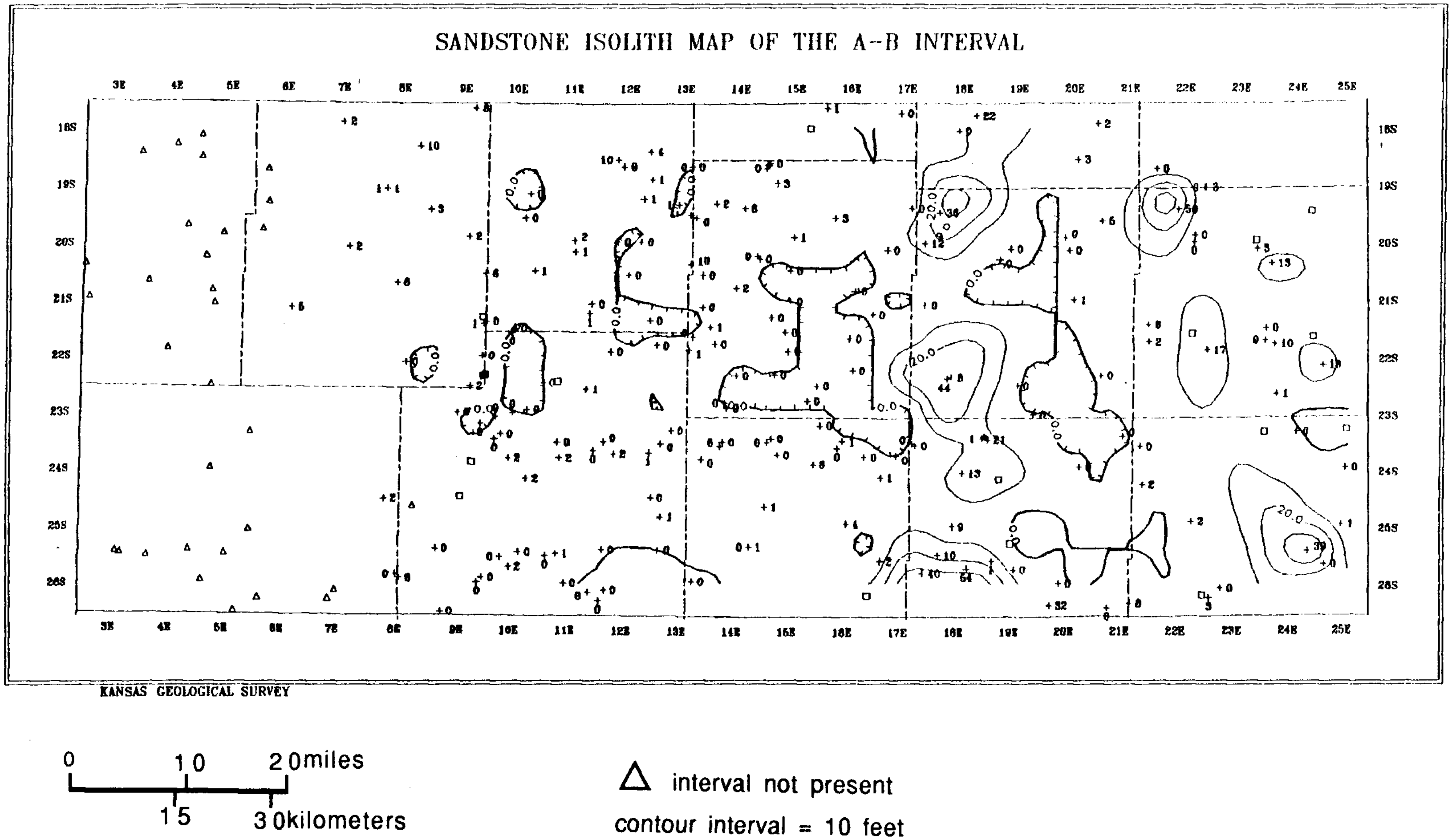


Figure 21. Sandstone isolith map of the A-B interval.

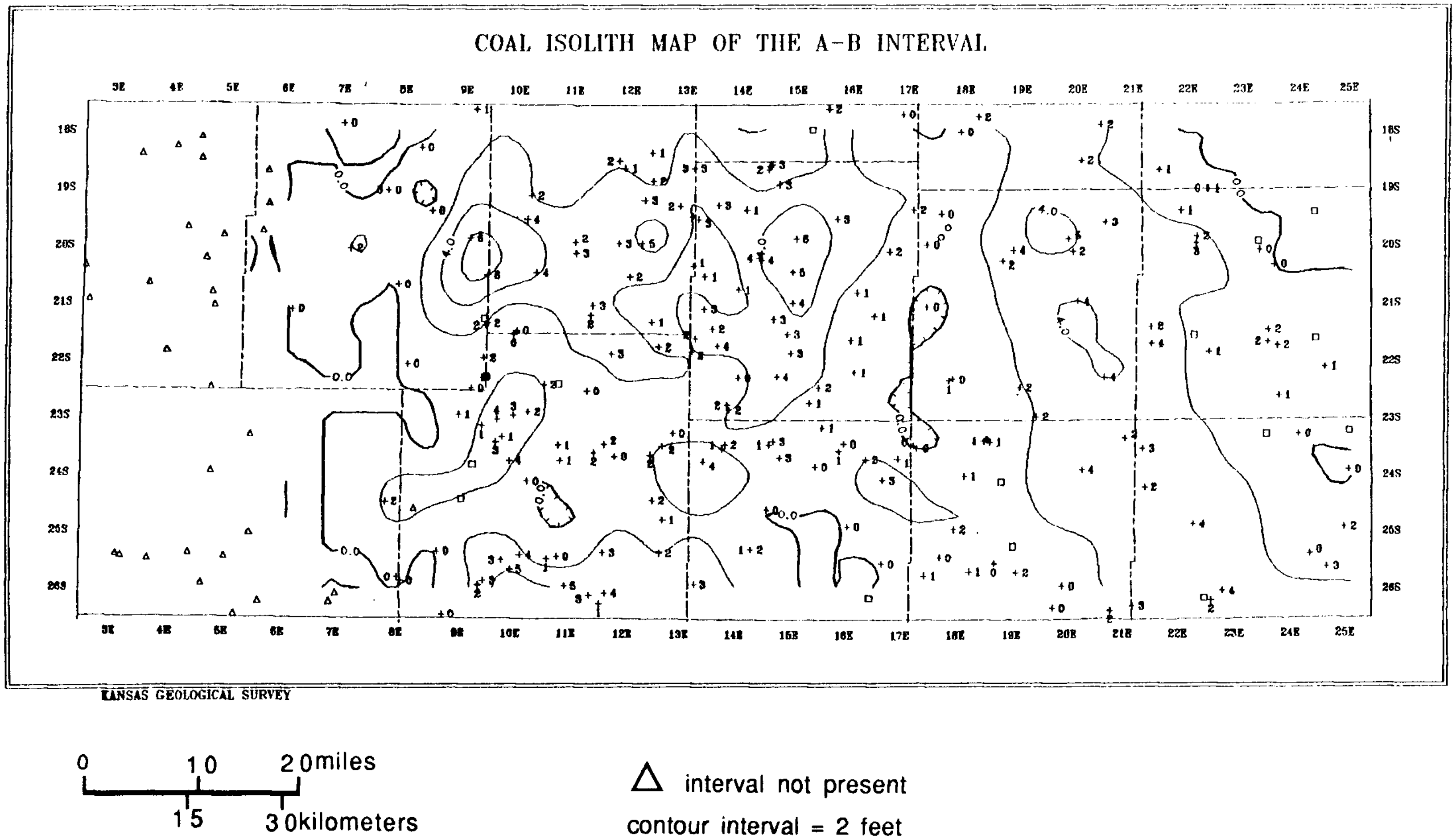


Figure 22. Coal isolith map of the A-B interval.

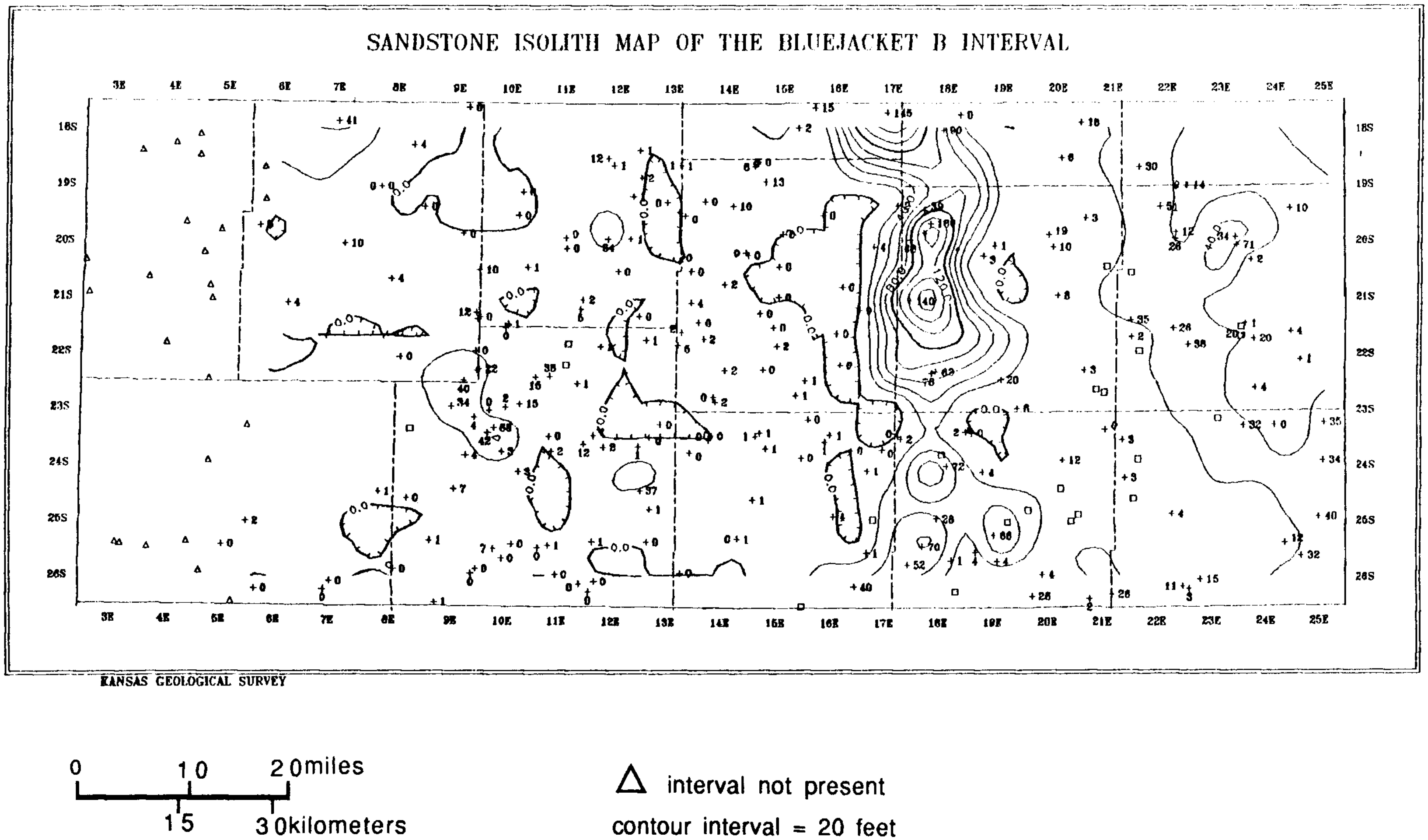


Figure 23. Sandstone isolith map of the Bluejacket B interval.

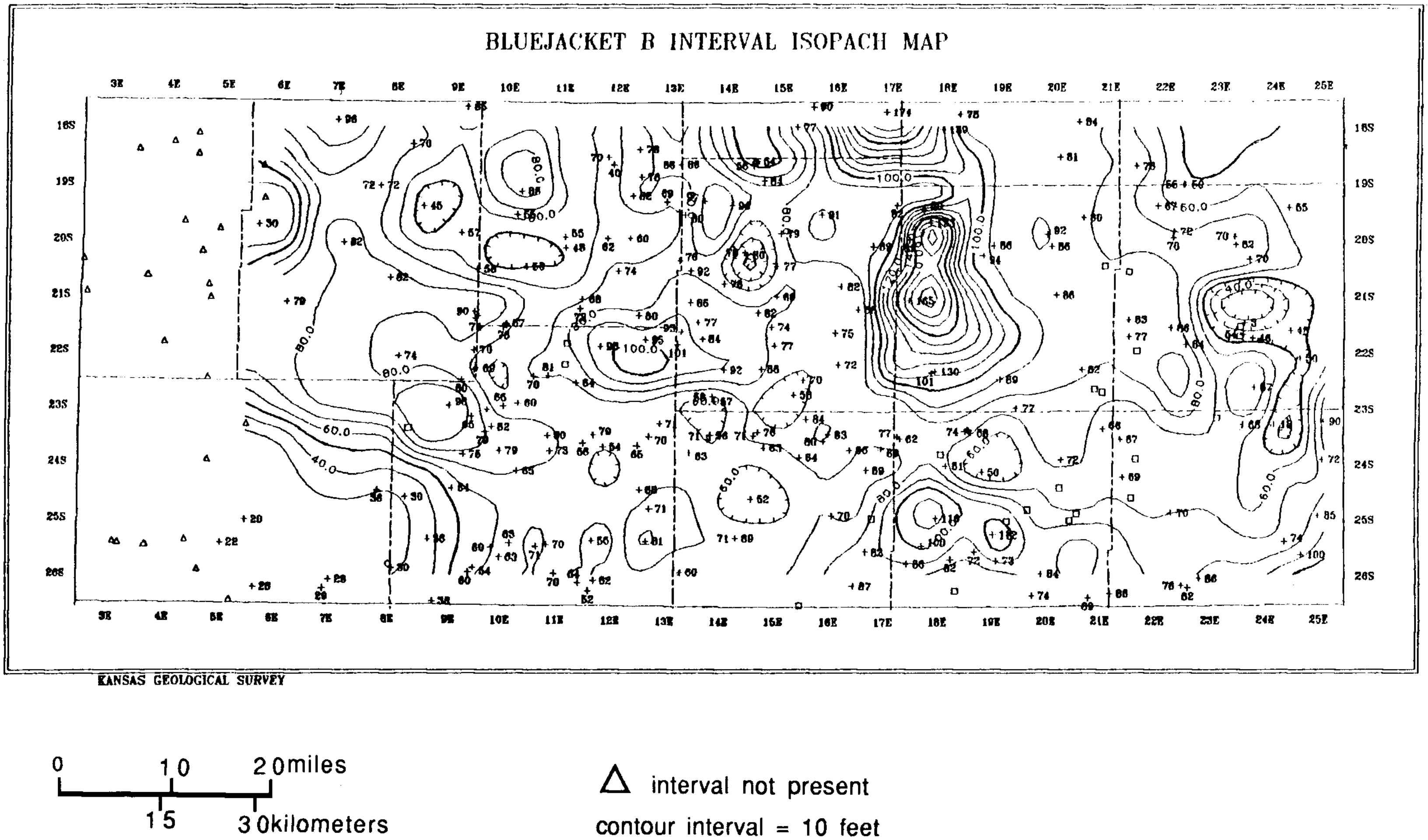


Figure 24. Bluejacket B interval isopach map.

County, where the interval thins onto the Nemaha uplift (Fig. 19), to 183 ft (55.8 m) in northeastern Anderson County where a Bluejacket sand has filled a valley. This abrupt increase in interval thickness is due to the upper Bluejacket sands filling valleys scoured into and removing the underlying A-B and Riverton intervals. The significance of the deep sand-filled valleys will be addressed in a latter section on incised valleys.

Because of the discontinuous nature of the many coal units in this interval and the downcutting of overlying sands, it was impossible to correlate previously recognized coal beds (Abj, Cbj, and Dbj coal beds; Harris, 1984, and the Dry Wood, Rowe, and Neutral coal beds; Jewett et al., 1968) from outcrops in the southeastern part of the study area to the subsurface farther west (Fig. 25). Ebanks (1979) defined the upper and lower Bluejacket sandstones and the upper Warner sandstone based on relative position of coal units. Because it was difficult to correlate many of these coal units accurately from the outcrop to the subsurface, the terms lower Bluejacket and upper Warner will not be used in this study. Instead, this paper will refer to all the sands within the Bluejacket B interval as upper Bluejacket sandstone.

Another marker bed not recognized in this interval is a thin, argillaceous, limestone that marks the top of the Krebs Formation, called the Seville (?) Limestone Member by Jewett et al. (1968). This marker is laterally continuous in outcrop (Harris, 1984) but is not easily recognized on well logs. Reasons for this will be discussed in the section on the Krebs and Cabaniss formation boundary.

Weir-Pittsburg interval - (510 - 590)

The Weir-Pittsburg interval extends from the top of the Weir-Pittsburg

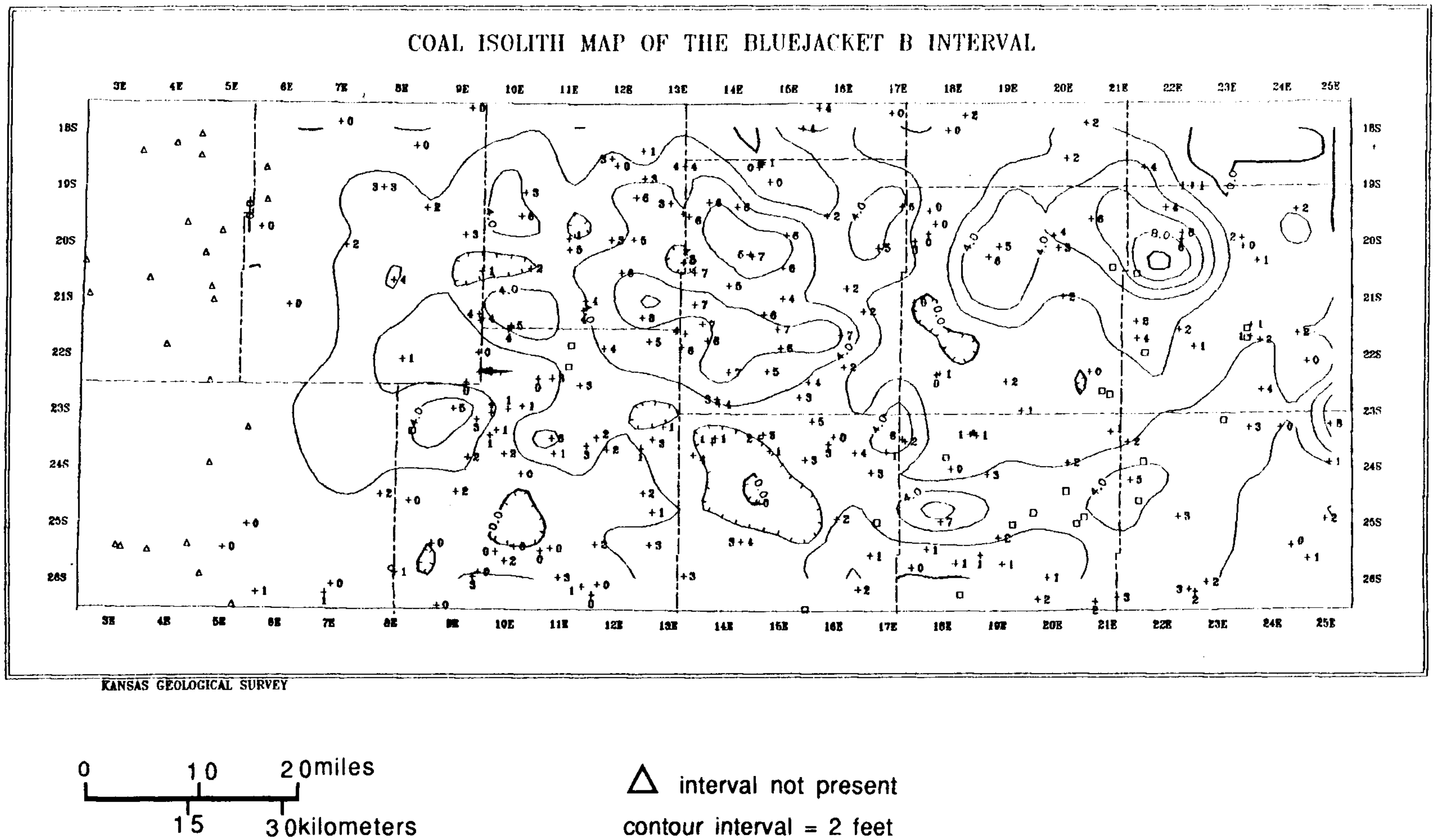


Figure 25. Coal isolith map of the Bluejacket B interval.

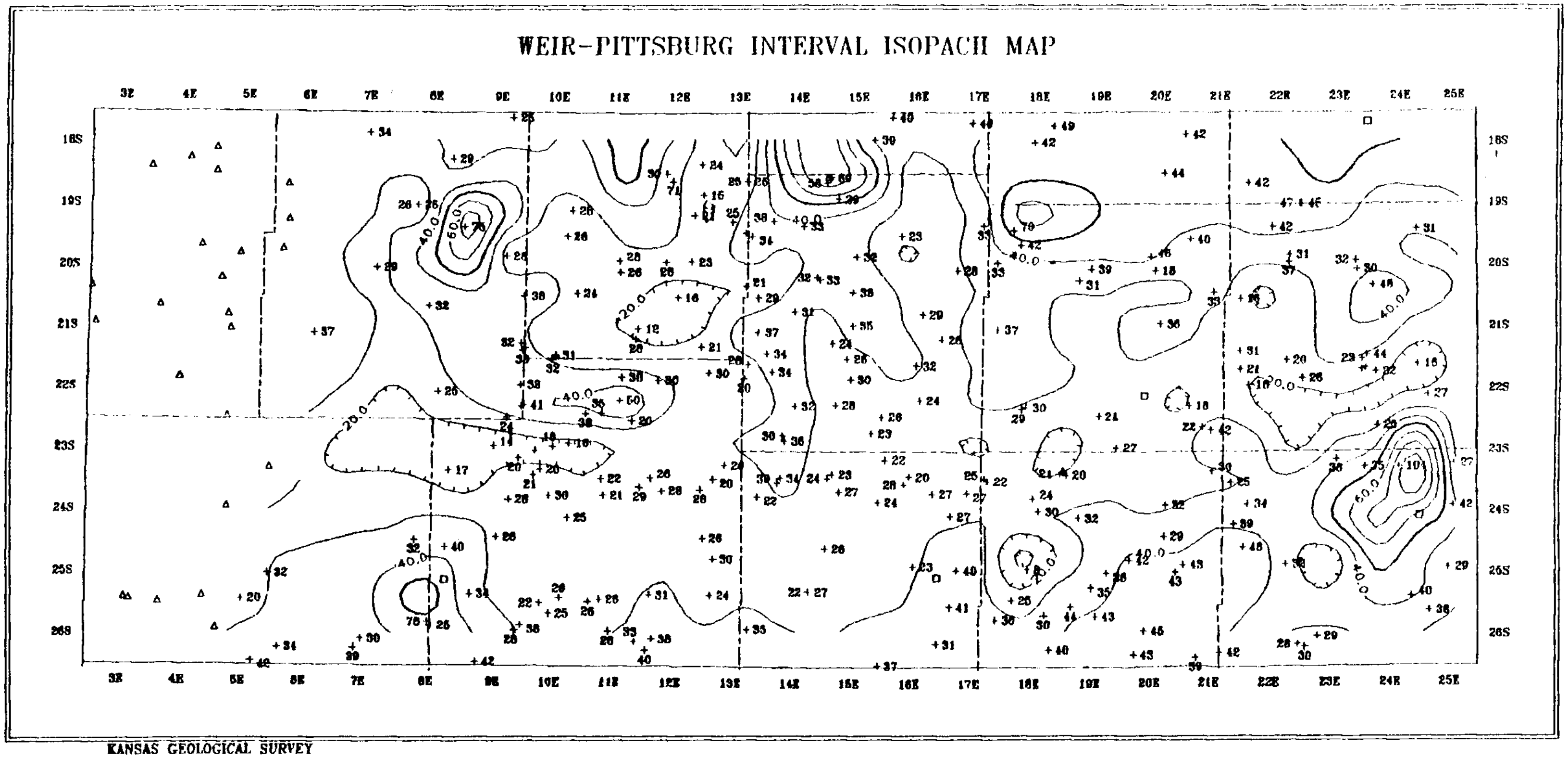
coal bed or the base of the overlying black shale to the Bluejacket B marker and consists of laminated mudstone, rippled fine sand and siltstone, cross-stratified fine to coarse sand, and coal units. This interval ranges in thickness from 8 ft (2.4 m) in west central Allen County to 104 ft (31.7 m) in northeastern Bourbon County (Fig. 26). The extremely thin intervals represent situations where the Weir-Pittsburg interval has been partially or totally removed by channeling from an overlying interval. Sandstones filling channels, which have cut down into and partially removed the underlying Bluejacket B interval, account for the thick, linear trends occurring in the Weir-Pittsburg interval (Fig. 27). The thickest coal deposits, up to 9 ft (2.7 m), occur in central Coffey and Franklin counties (Fig. 28).

Tebo interval - (590 - 640)

The Tebo interval extends from the top of the Tebo coal or the base of the overlying black shale to the Weir-Pittsburg marker. This interval ranges in thickness from 2 ft to 33 ft (0.6 to 10 m) in Greenwood County (Fig. 29). The Tebo coal and Tebo B coal, lying approximately 4 ft below, are discontinuous in the study area. An isolith map of the Tebo coals shows that the thickest coal deposits, up to 3 ft (0.9 m), occur in central Franklin County (Fig. 30). A thin, discontinuous fine sandstone to siltstone also occurs within this interval (Fig. 31).

Scammon interval - (640 - 680)

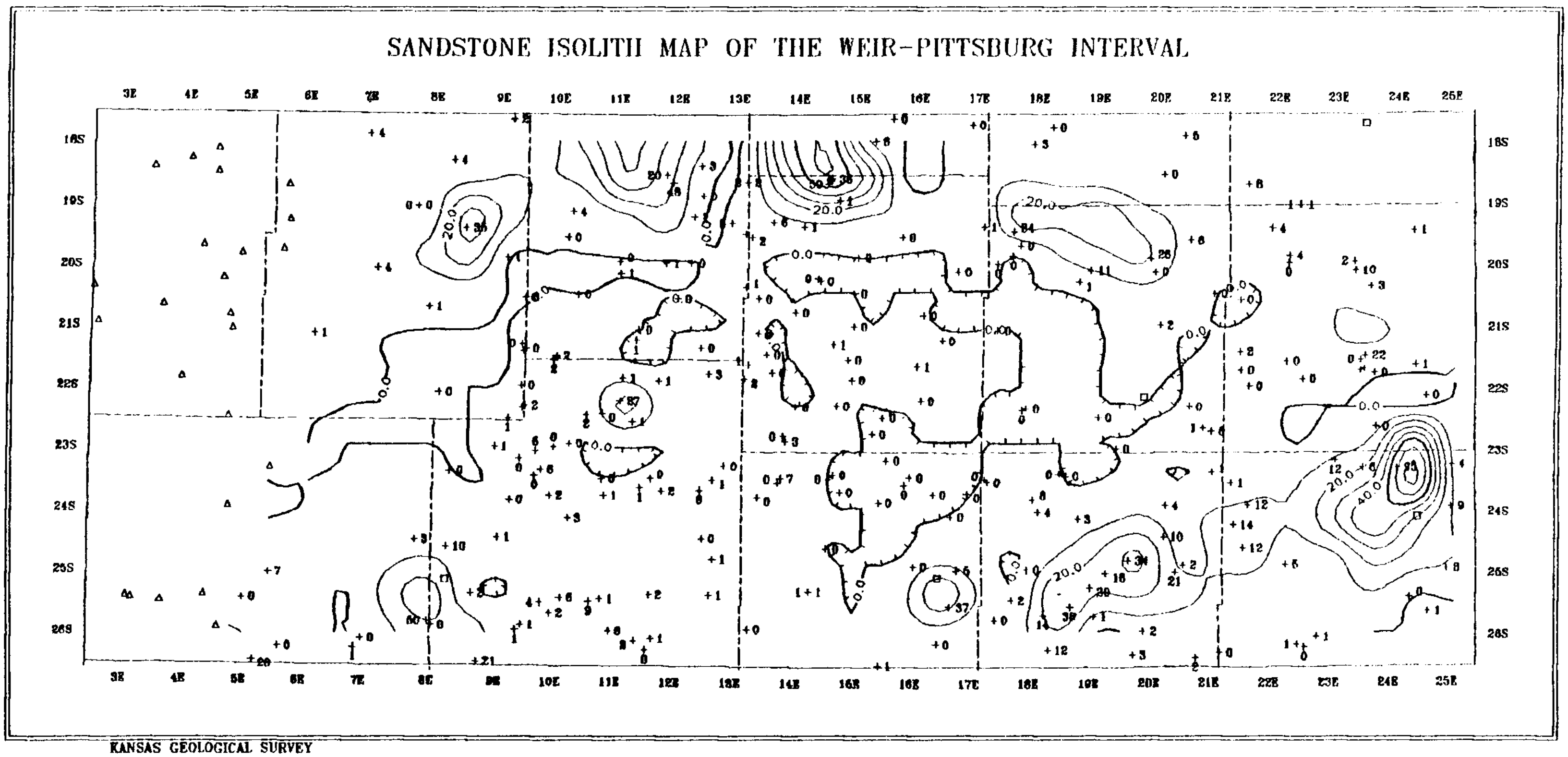
The Scammon interval extends from the top of the Scammon coal bed or the base of the overlying black shale to the Tebo marker and consists of laminated mudstone, rippled siltstone, small-scale cross-stratified fine sandstone, and coal. This interval ranges in thickness from 13 ft (4.0 m) in southeastern Chase County to 72 ft (21.9 m) in eastern Anderson County



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 10 feet

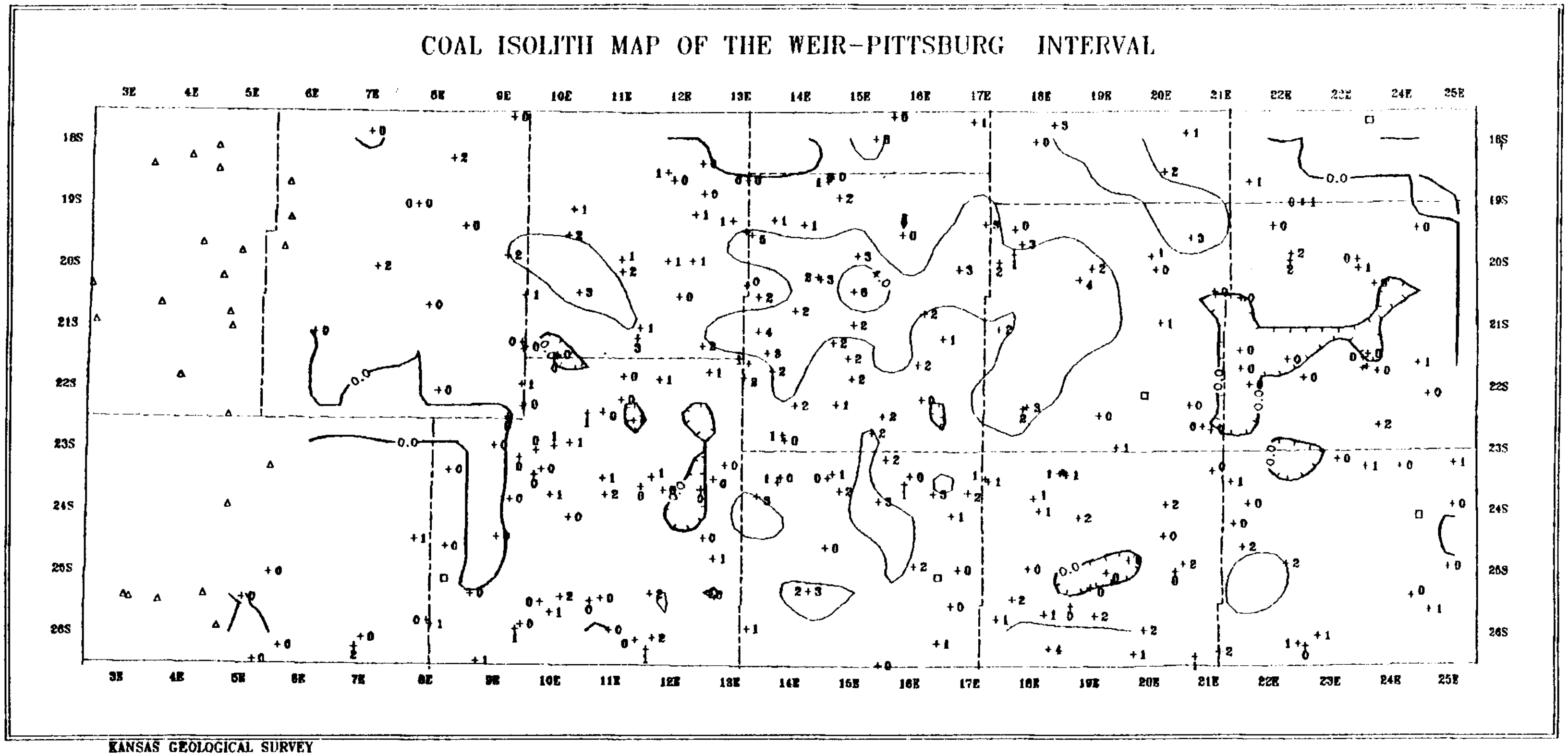
Figure 26. Weir-Pittsburg interval isopach map.



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 10 feet

Figure 27. Sandstone isolith map of the Weir-Pittsburg interval.



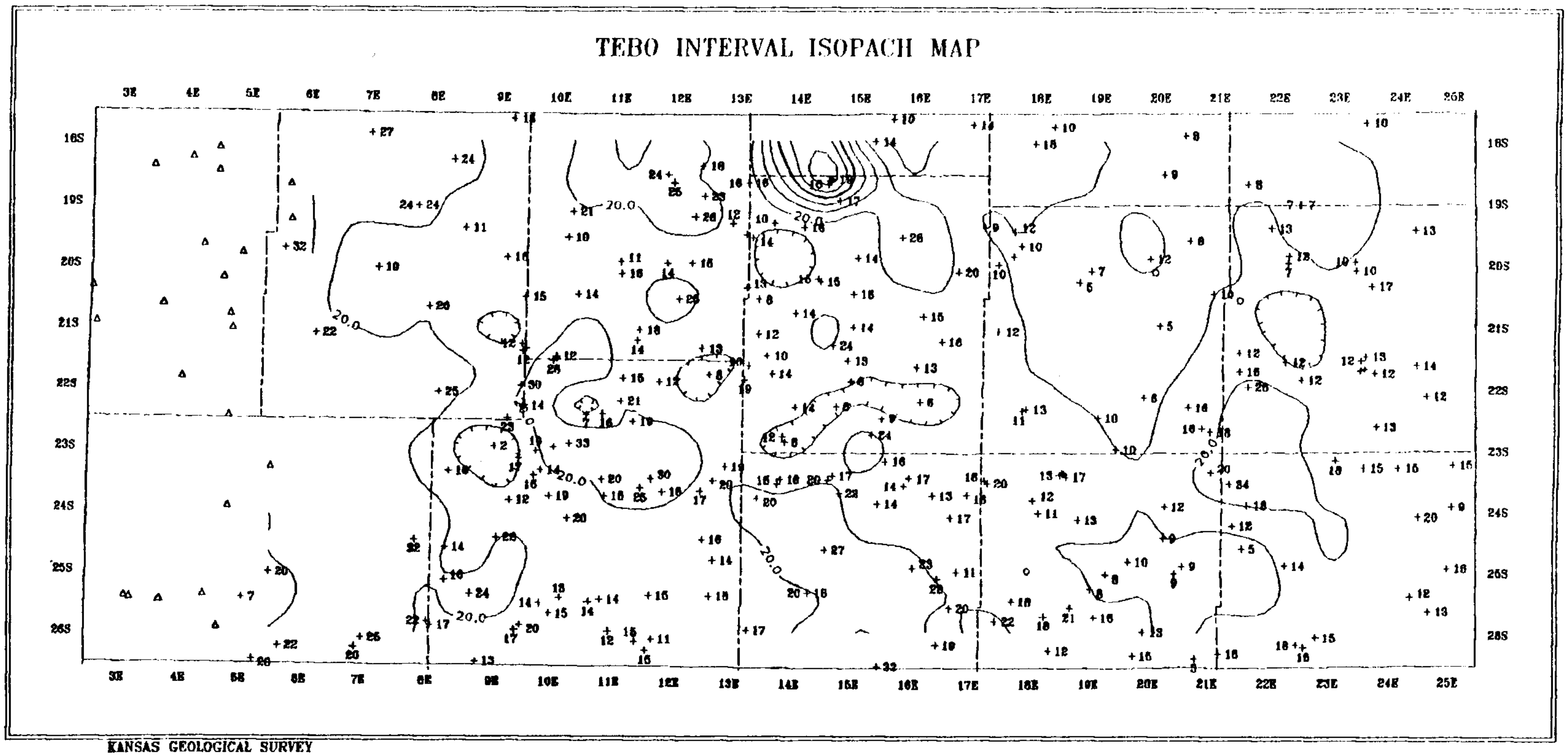
0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 2 feet

Figure 28. Coal isolith map of the Weir-Pittsburg interval.



0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 10 feet

Figure 29. Tebo interval isopach map.

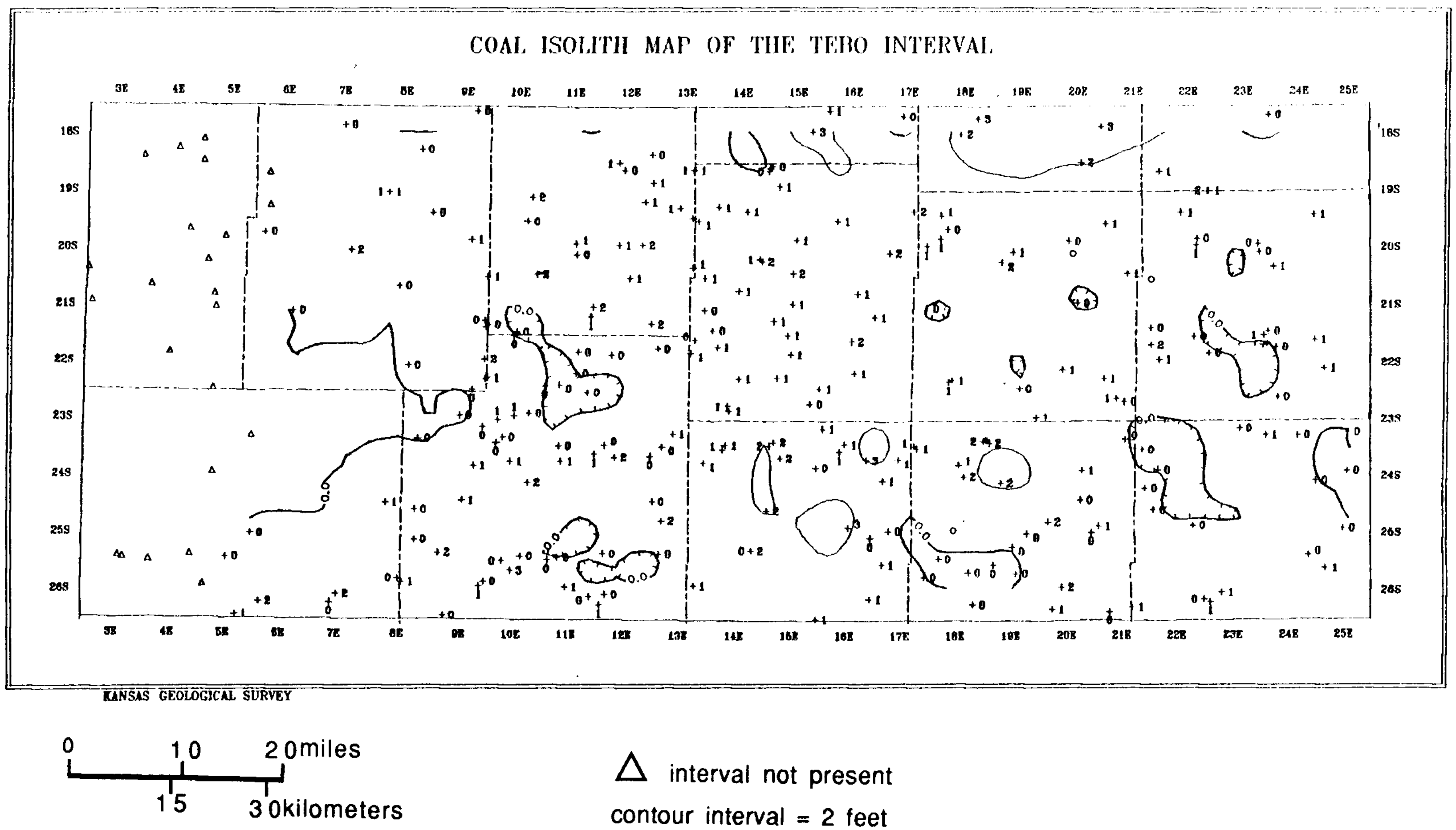
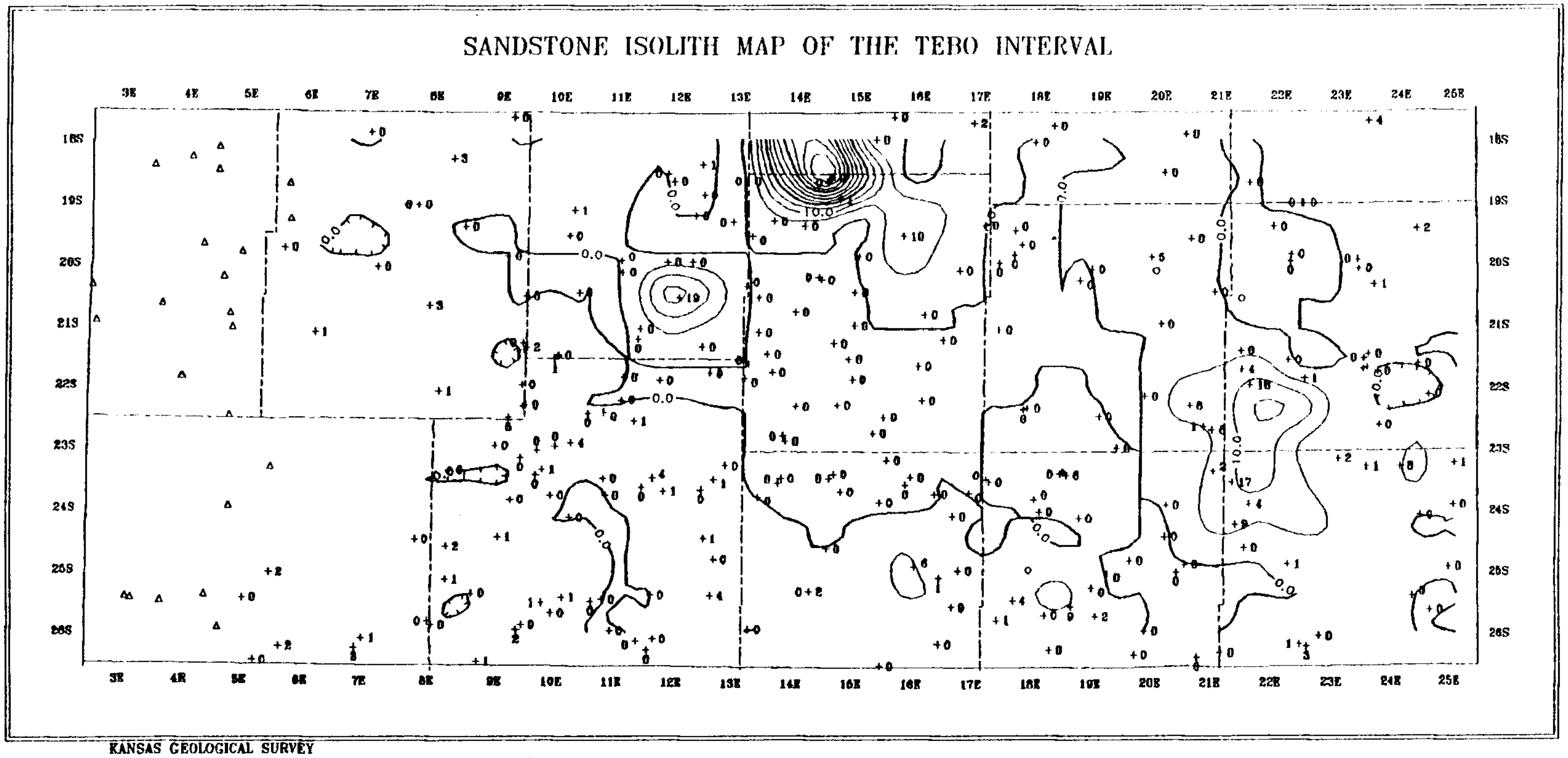


Figure 30. Coal isolith map of the Tebo interval.



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 5 feet

Figure 31. Sandstone isolith map of the Tebo interval.

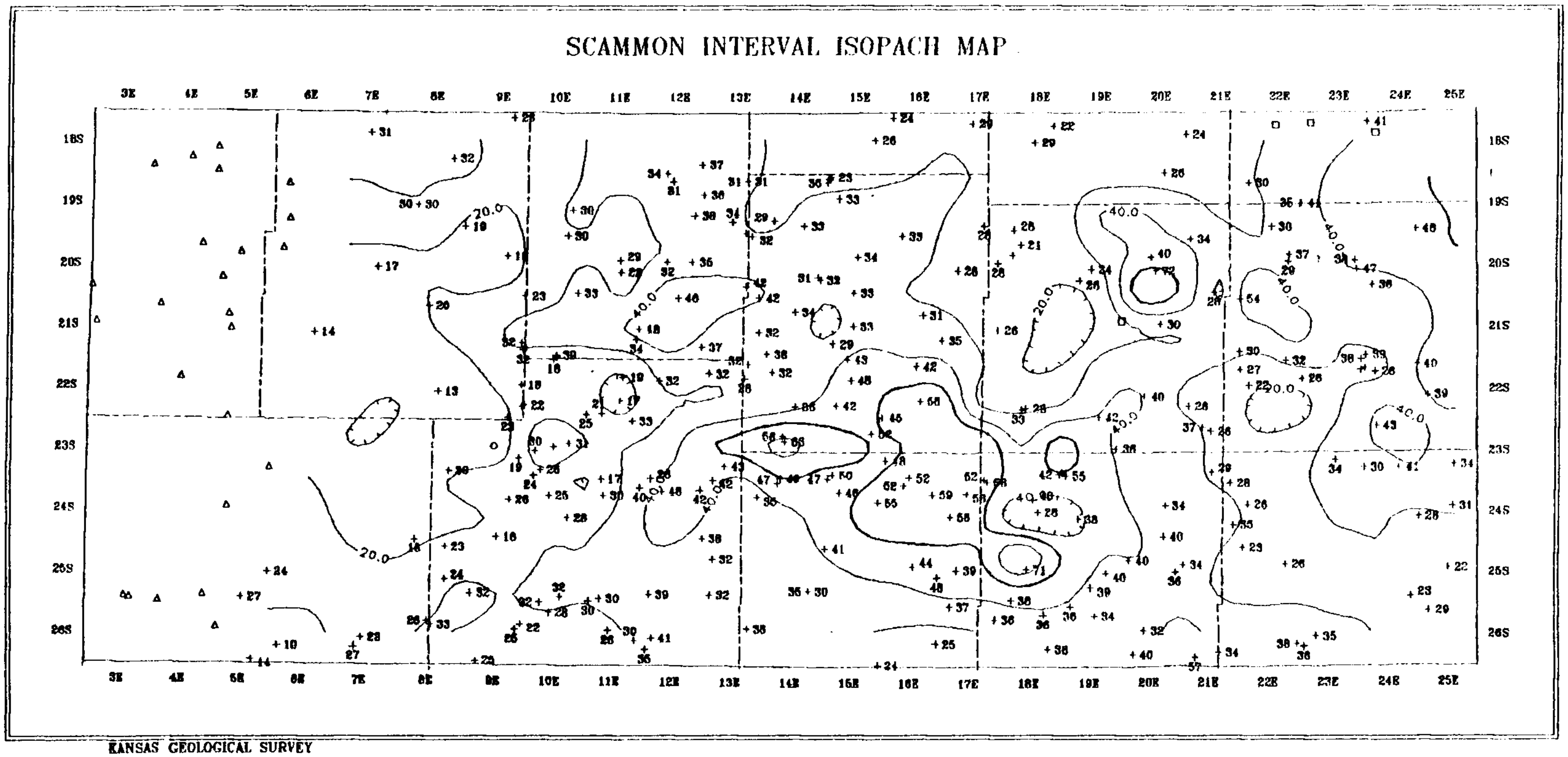
(Fig. 32). The Chelsea Sandstone Member occurs within this interval and ranges in thickness from 1 to 37 ft (0.3 to 11.3 m) (Fig. 33). Where this member is thickest, it will commonly be separated into an upper and lower unit by a silty, dark- to medium-gray shale overlying a coal. Staton (1987) informally referred to the coal in this shale-coal break as the Scammon B coal. The Scammon B marker is not continuous throughout the study area, however it does contribute to the 4 ft (1.2 m) of coal accumulations in northern Franklin and western Coffey counties (Fig. 34).

The basal black shale of this interval directly overlies the Tebo coal, is fissile, contains phosphate nodules, and gives a high gamma-ray response. The black shale can be traced continuously throughout the study area, except where it onlaps the Nemaha uplift (Fig. 19) or has been removed by channel sands from the overlying Scammon interval. This study and Staton's (1987) study suggested using the Tebo marker as the break between the Krebs and Cabinass formations because it is correlatable throughout a wide area and is easily identified in outcrop and on gamma-ray-neutron-density logs.

The Tiawah limestone bed, which directly overlies the Tebo marker, is observed in outcrop in Kansas only in eastern Cherokee and Crawford counties (Howe, 1956) and is not present in cores in western Cherokee County, nor is it observed in the subsurface in southeastern Kansas (Staton, 1987). However, it is present in core and well-logs around the Kansas City area in the Forest City basin. The Tiawah limestone bed was not observed in cores or geophysical well logs in this study.

Mineral interval - (680 - 720)

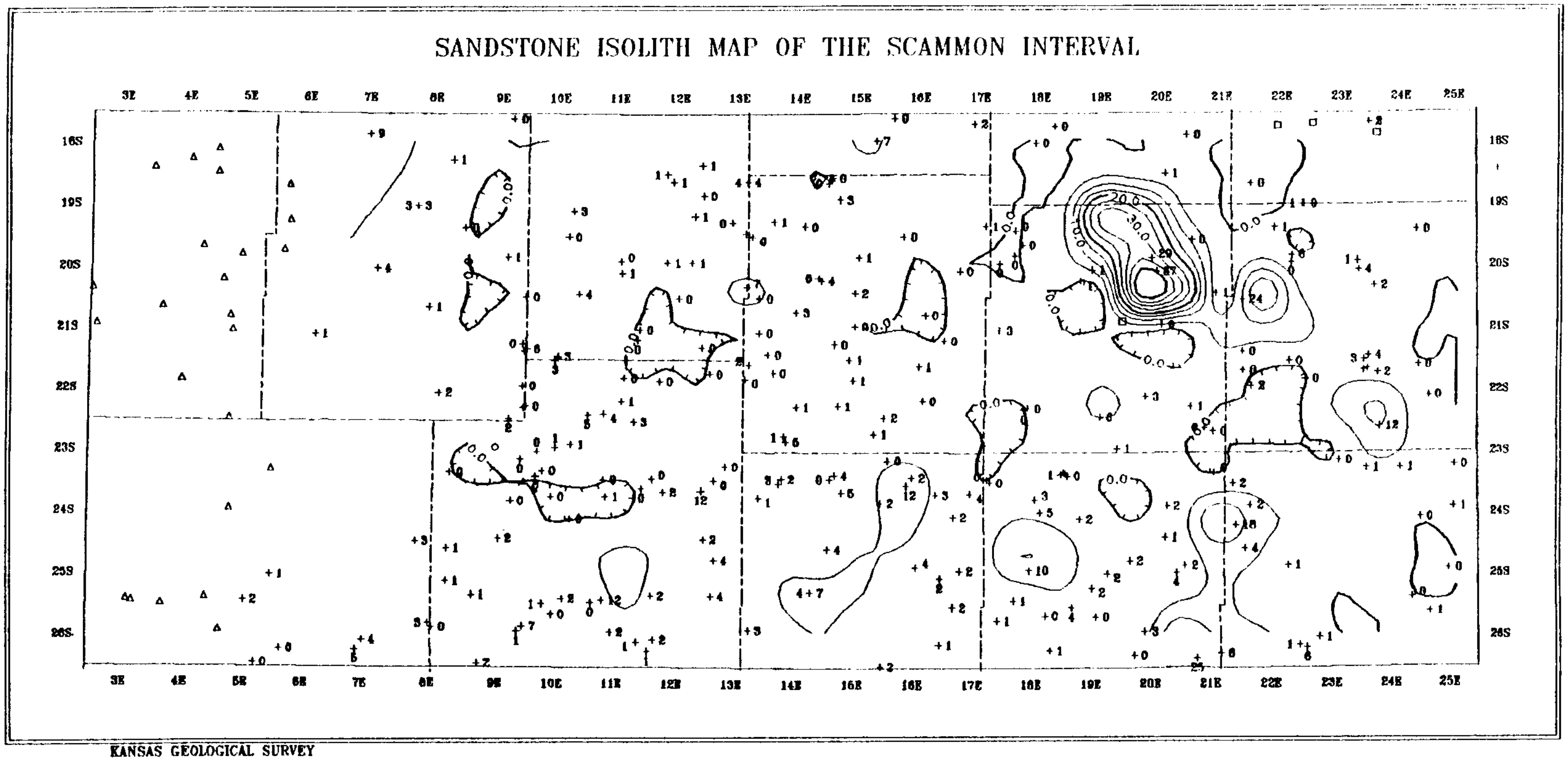
The Mineral interval extends from the top of the Mineral coal bed or



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 10 feet

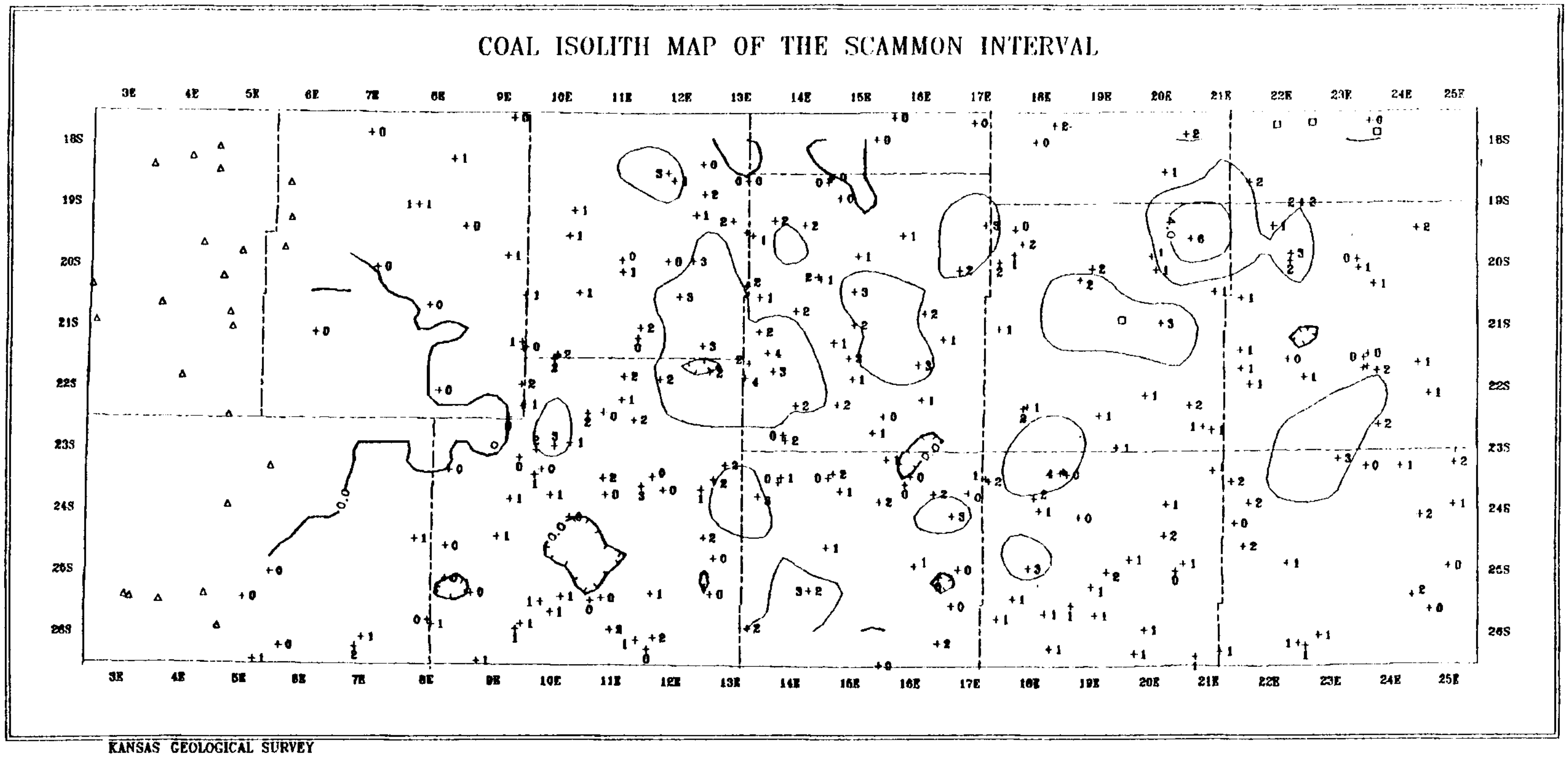
Figure 32. Scammon interval isopach map.



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 5 feet

Figure 33. Sandstone isolith map of the Scammon interval.



0 10 20 miles
15 30 kilometers

△ interval not present

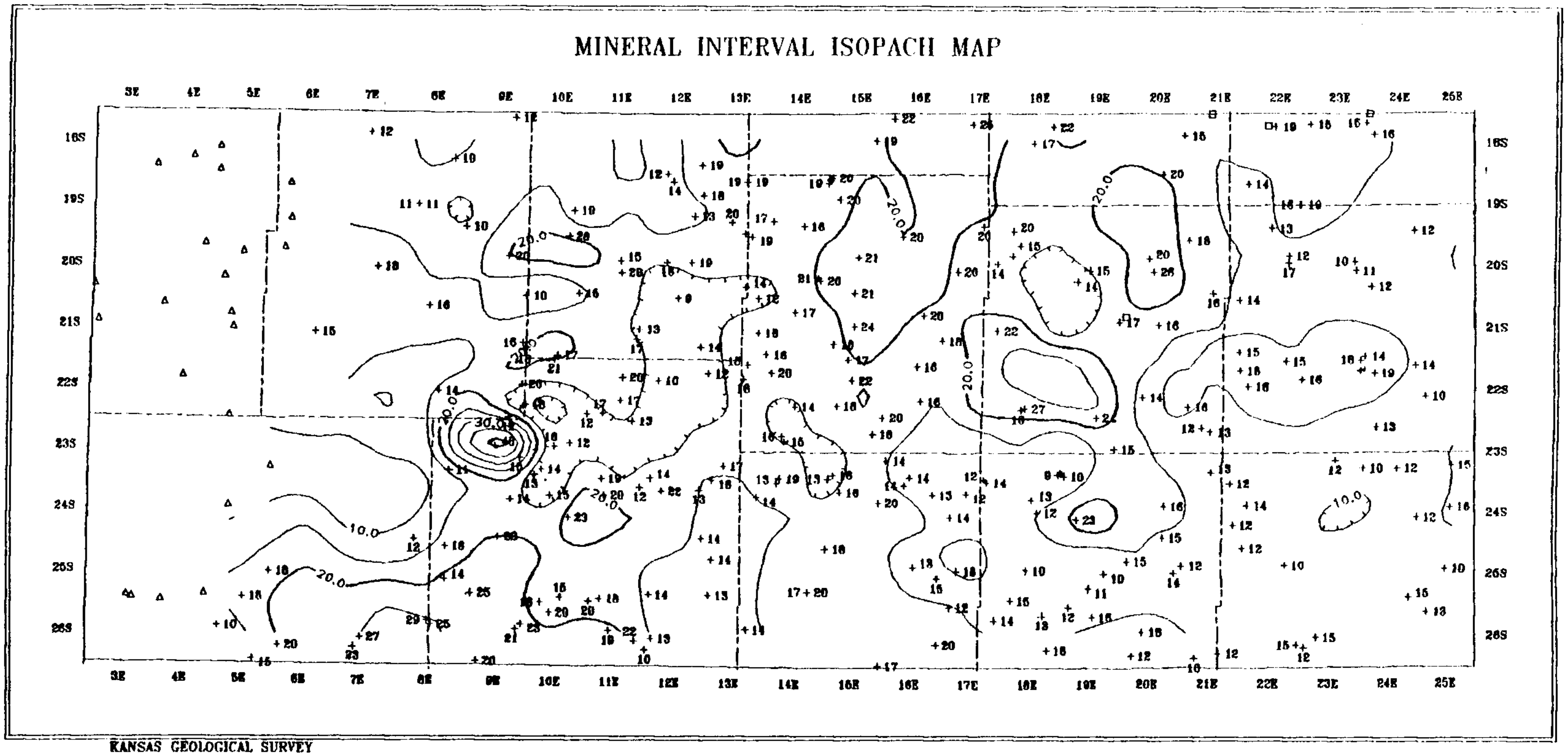
contour interval = 2 feet

Figure 34. Coal isolith map of the Scammon interval.

the base of the overlying black shale to the Scammon marker and consists of laminated mudstone, rippled siltstone, small-scale cross-stratified fine-grained sandstone, and coal. The Mineral interval is laterally persistent and continuous except in western Chase and eastern Butler counties where it thins and onlaps the Nemaha uplift (Fig. 19). This interval ranges in thickness from 9 to 27 ft (2.7 to 8.2 m) with an isolated 45 ft (13.7 m) thick interval occurring in northwestern Greenwood County (Fig. 35). The sandstone isolith map shows a 40 ft (12.2 m) thick sand deposit that cuts into the underlying Scammon interval (Fig. 36) at this location. The Mineral coal at the top of the interval is up to 3 ft (0.9 m) thick in Woodson County (Fig. 37). This coal is widespread and easily identifiable on gamma-ray-neutron logs because of its association with an overlying black, radioactive shale and its association with a coarsening-upward sequence in the Mineral interval.

Croweburg interval - (720 - 780)

The Croweburg interval extends from the top of the Croweburg coal bed or the base of the overlying "V" shale (Angino et al., 1981) to the Mineral marker and ranges in thickness from 1 ft (0.3 m) in western Butler County to 37 ft (11.3 m) in western Greenwood County (Fig. 38). The thinning in Butler County is caused by the interval onlapping the Nemaha uplift. Lithotypes found within this interval are laminated mudstone, rippled siltstone and fine sandstone, and coal. The Croweburg coal bed (Fig. 39) is 1 to 2 ft (0.3 to 0.6 m) thick, is laterally continuous throughout the study area, and directly underlies the "V" shale. Pierce and Courtier (1937) also reported that a phosphatic, black shale directly overlies the Croweburg coal in a few places in Cherokee and Labette counties. However, in outcrops present in western



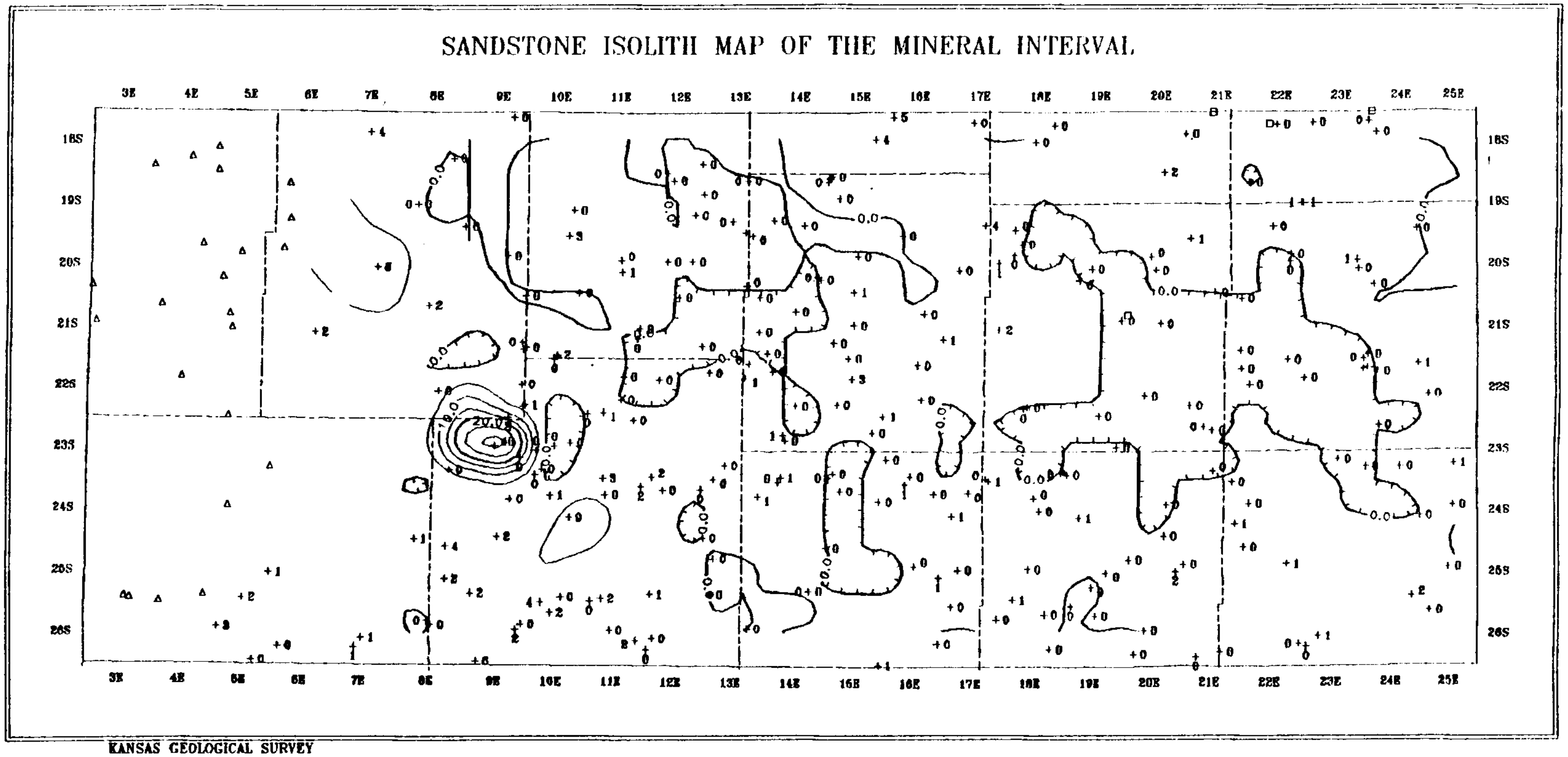
0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 5 feet

Figure 35. Mineral interval isopach map.



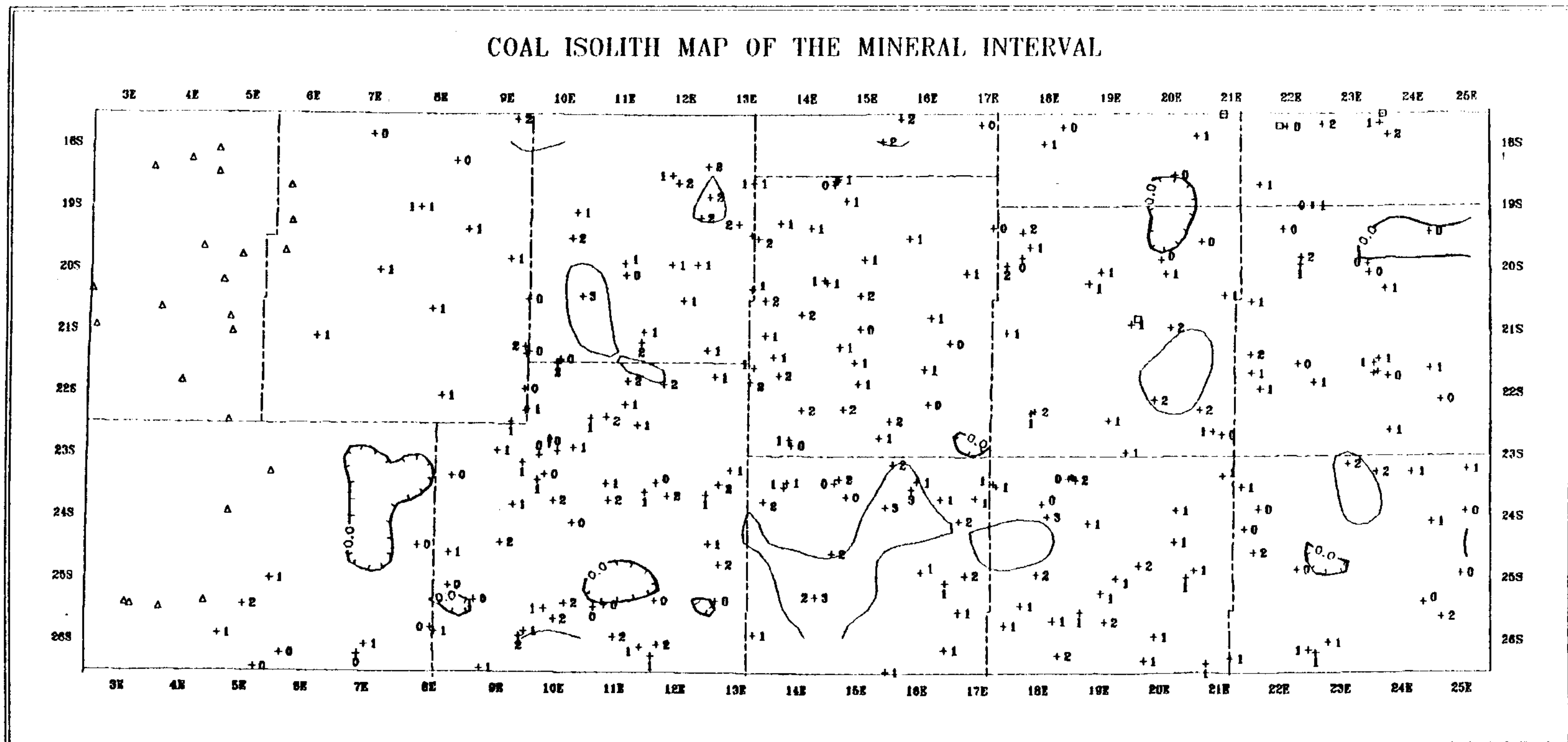
0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 5 feet

Figure 36. Sandstone isolith map of the Mineral interval.

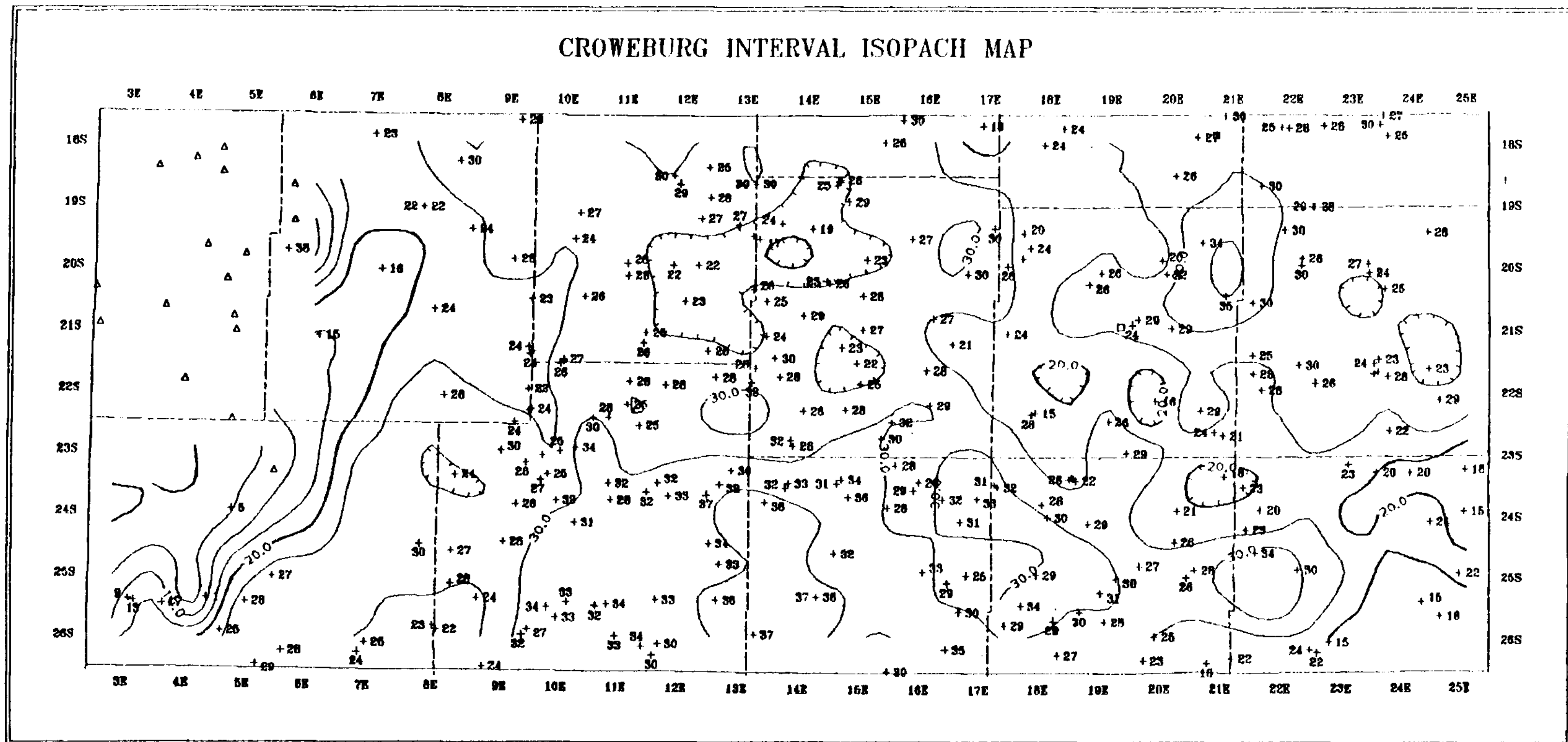


KANSAS GEOLOGICAL SURVEY

0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 2 feet

Figure 37. Coal isolith map of the Mineral interval.



KANSAS GEOLOGICAL SURVEY

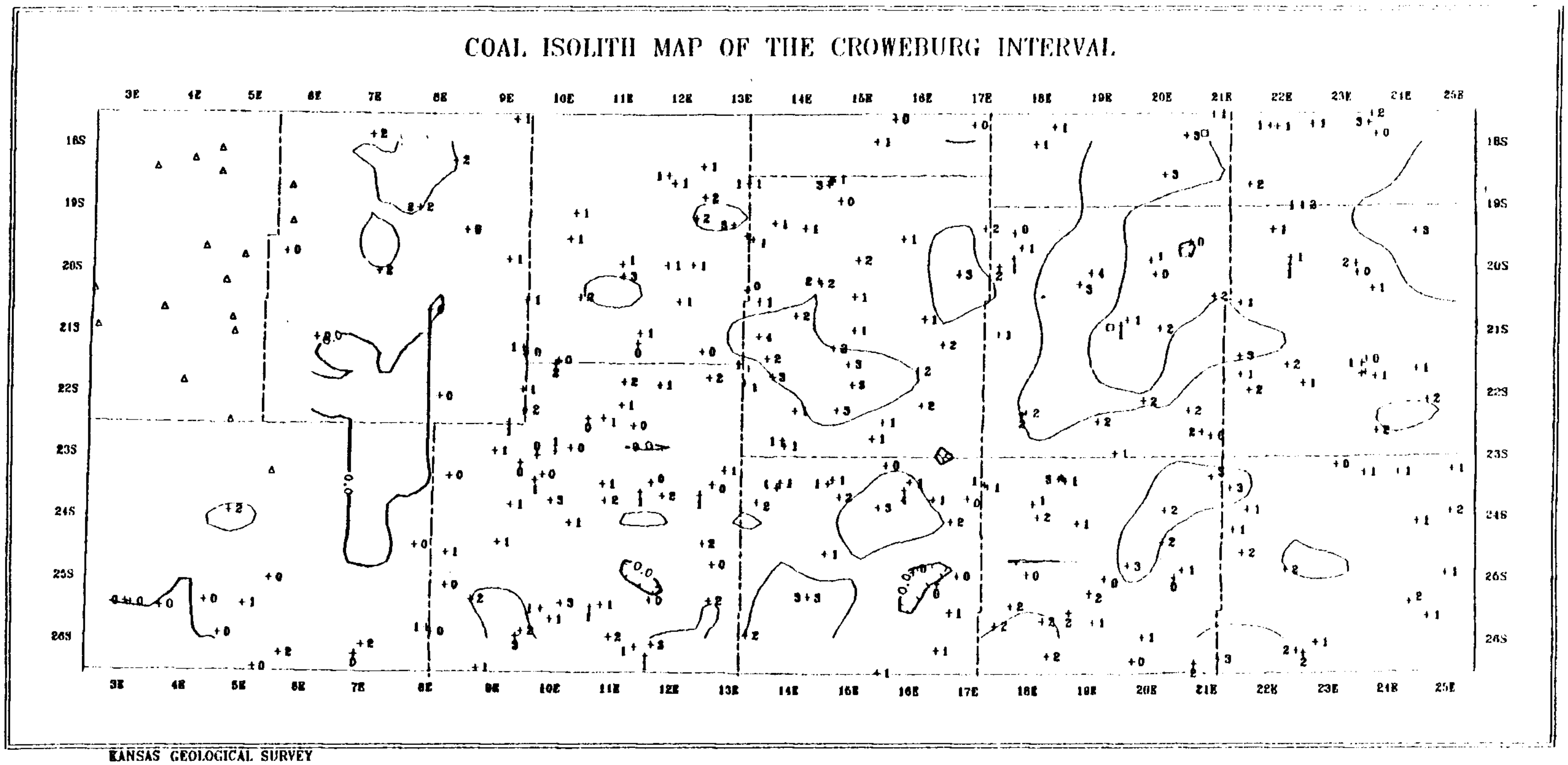
0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 10 feet

Figure 38. Croweburg interval isopach map.



0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 2 feet

Figure 39. Coal isolith map of the Croweburg interval.

and northern Missouri, northern Oklahoma, and southeastern Kansas there is normally a light-gray shale directly overlying the Croweburg coal and separating it from the phosphatic, black shale above (Howe, 1956). Howe reported that the light-gray shale occurring in southeastern Kansas ranges from 2 to 18 ft (0.6 to 5.5 m) and has an average thickness of about 8 ft (2.4 m). Fleming and Robinson Branch coals are not as consistent as the Croweburg coal and are found intermittently throughout the study area. The sandstone isopach map reveals no significant sand deposits, with one exception being an isolated 10 ft (3.0 m) thick sand occurring in southern Osage County (Fig. 40).

Bevier interval - (780 - 900)

The Bevier interval extends from the top of the Bevier coal bed or the base of the overlying black shale to the base of the "V" shale and consists of limestone, laminated mudstone, rippled siltstone, fine sandstone, and coal. This interval is approximately 25 to 30 ft (7.6 to 9.1 m) thick in the east and thins to 5 ft (1.5 m) in western Butler County (Fig. 41).

The "V" shale is black, phosphatic, fissile, and is stratigraphically equivalent to the Mecca Quarry Shale in Indiana (Coveney et al., 1991) and to the Oakley Shale in Iowa (Deneson, 1985). The "V" shale has been correlated throughout the Cherokee, Forest City and into the Sedgwick basins. The "V" shale is the lowest unit of the Cherokee Group that is continuous across the Nemaha uplift in Kansas and into the Sedgwick basin (Killen, 1986; Fig. 19), although isolated high areas on the Nemaha uplift were not completely overstepped by the "V" shale. Triplehorn and Brady (1991) reported a 0.5 to 1.1 cm thick tonstein (altered volcanic ash)

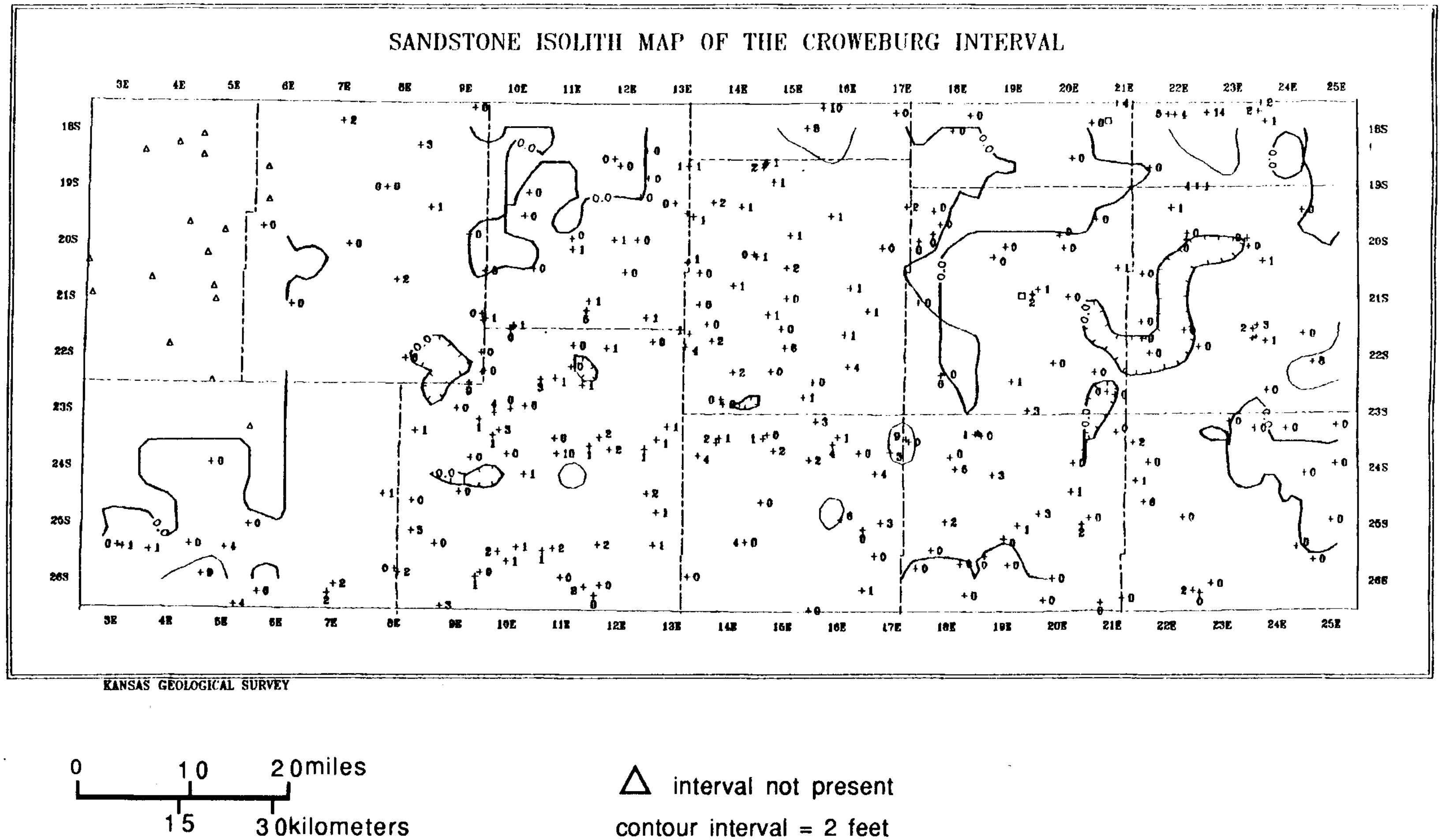
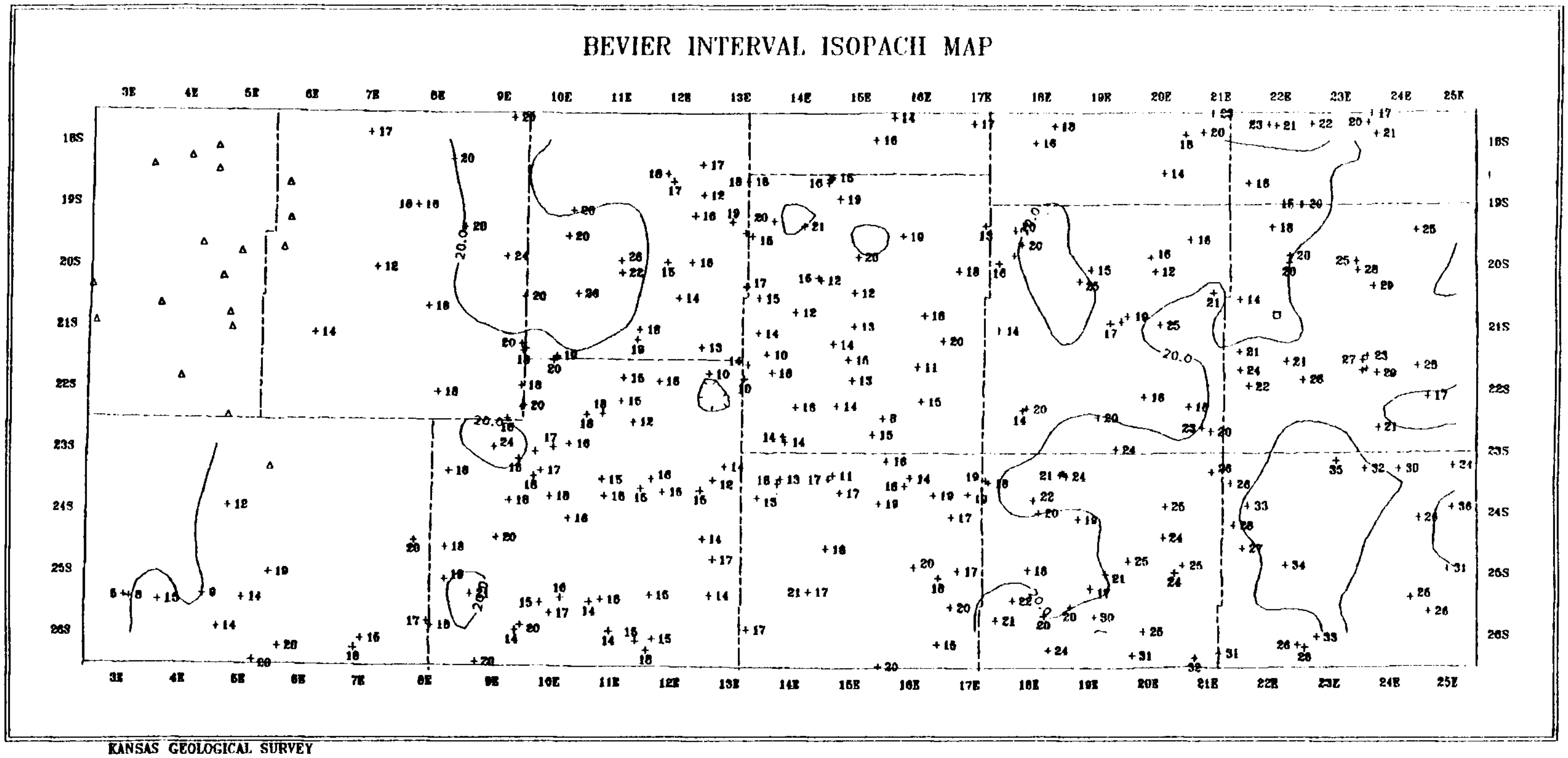


Figure 40. Sandstone isolith map of the Croweburg interval.



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 10 feet

Figure 41. Bevier interval isopach map.

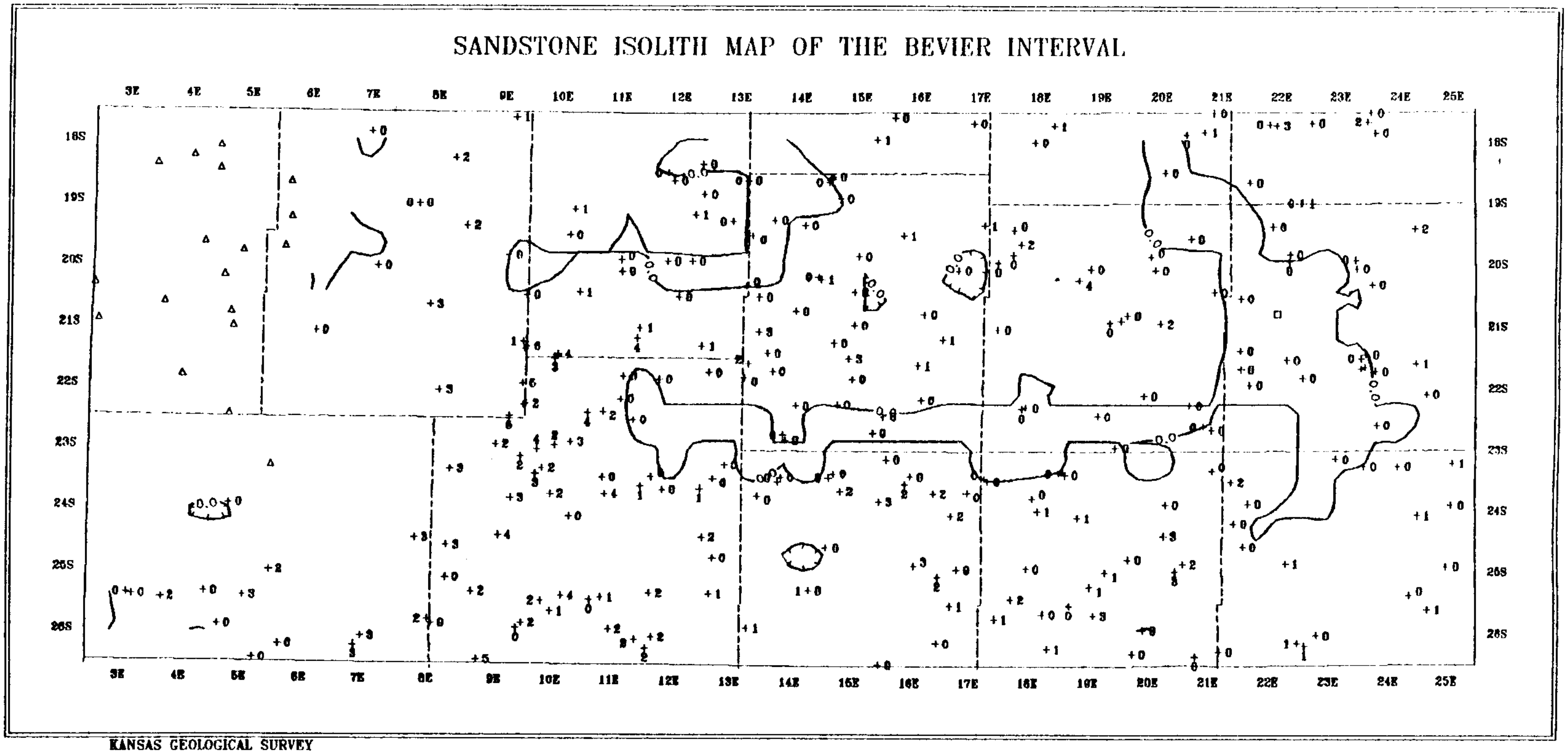
occurring about 0.3 m above the base of the "V" shale in Crawford County, Kansas.

The Verdigris Limestone Member is laterally continuous, ranges from 1 to 2 ft (0.3 to 0.6 m) thick, and lies directly above the "V" shale. The Verdigris Limestone Member is also referred to as the Ardmore Limestone in Oklahoma. A laterally discontinuous, thin sandstone situated stratigraphically above the Verdigris Limestone Member occurs most commonly in Allen, Woodson, and Greenwood counties (Brenner, 1989; Fig. 42). Where no fine sandstone is present, the middle of this interval commonly consists of rippled siltstone and laminated mudstone.

The Bevier coal is laterally continuous and easily recognizable on geophysical well logs because of the black shale directly above it. The coal isolith map shows the Bevier coal to be continuous, averaging 1.5 ft (0.46 m) throughout the study area (Fig. 43).

Mulky interval - (900 - 1000)

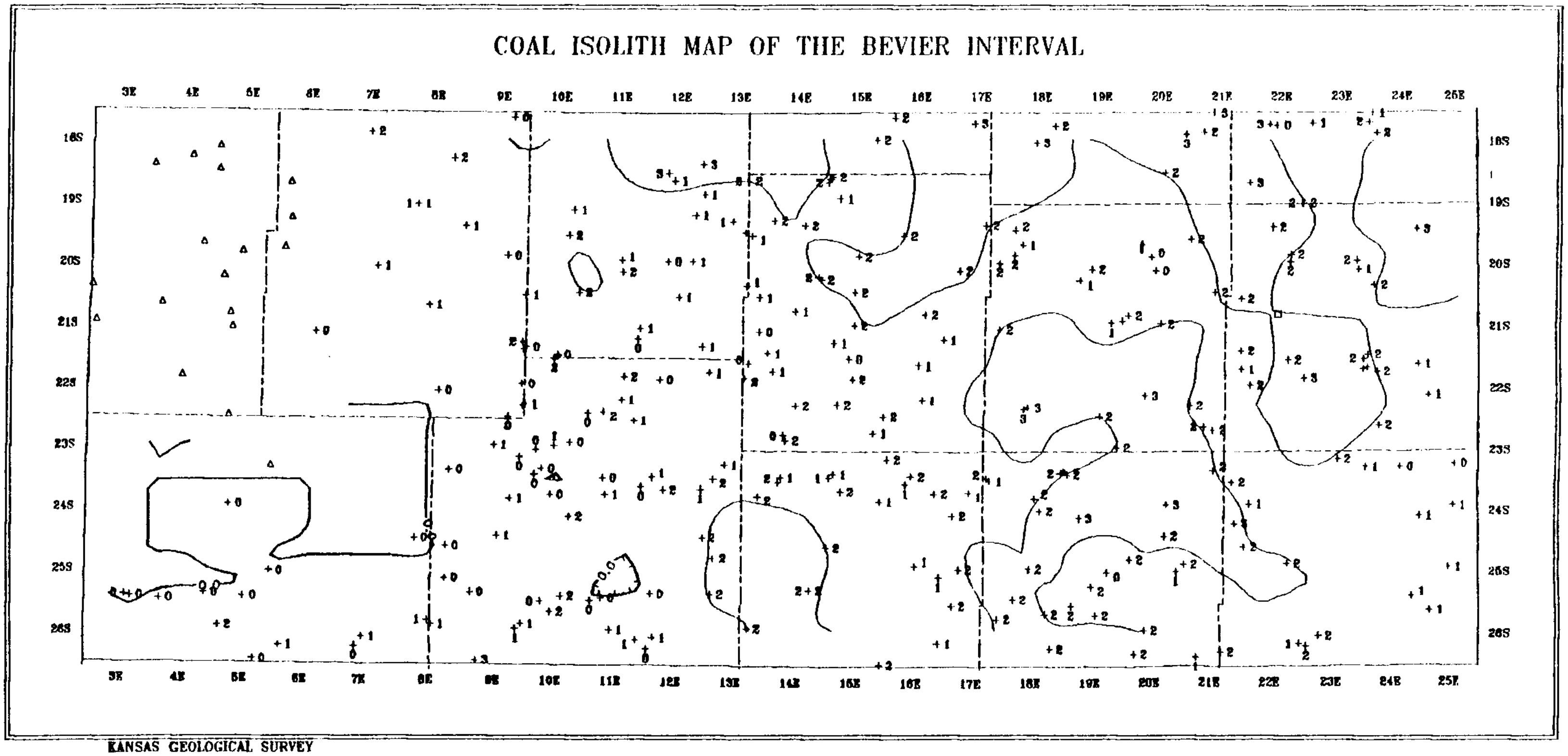
The Mulky interval extends from the top of Mulky coal bed or the base of the overlying Excello shale to the Bevier marker and consists of interlaminated mudstone and siltstone, rippled siltstone and fine sandstone, small-scale cross-stratified fine sandstone, and coal. This interval is 100 ft (30.5 m) thick in the central and eastern parts of the study area (Fig. 44) and thins markedly in eastern Marion and western Butler counties were it onlaps high areas of the Nemaha uplift. The sandstone isolith map shows 1 to 10 ft (0.3 to 3.0 m) of net sand in this interval in continuous bodies, with isolated thick (up to 42 ft (12.8 m)) intervals occurring in central Allen, Woodson, and Greenwood counties, and southwestern Coffey County (Fig. 45). The coal isolith map reveals 4 to 5 ft (1.2 to 1.5 m) of net coal in the four corners area



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 5 feet

Figure 42. Sandstone isolith map of the Bevier interval.



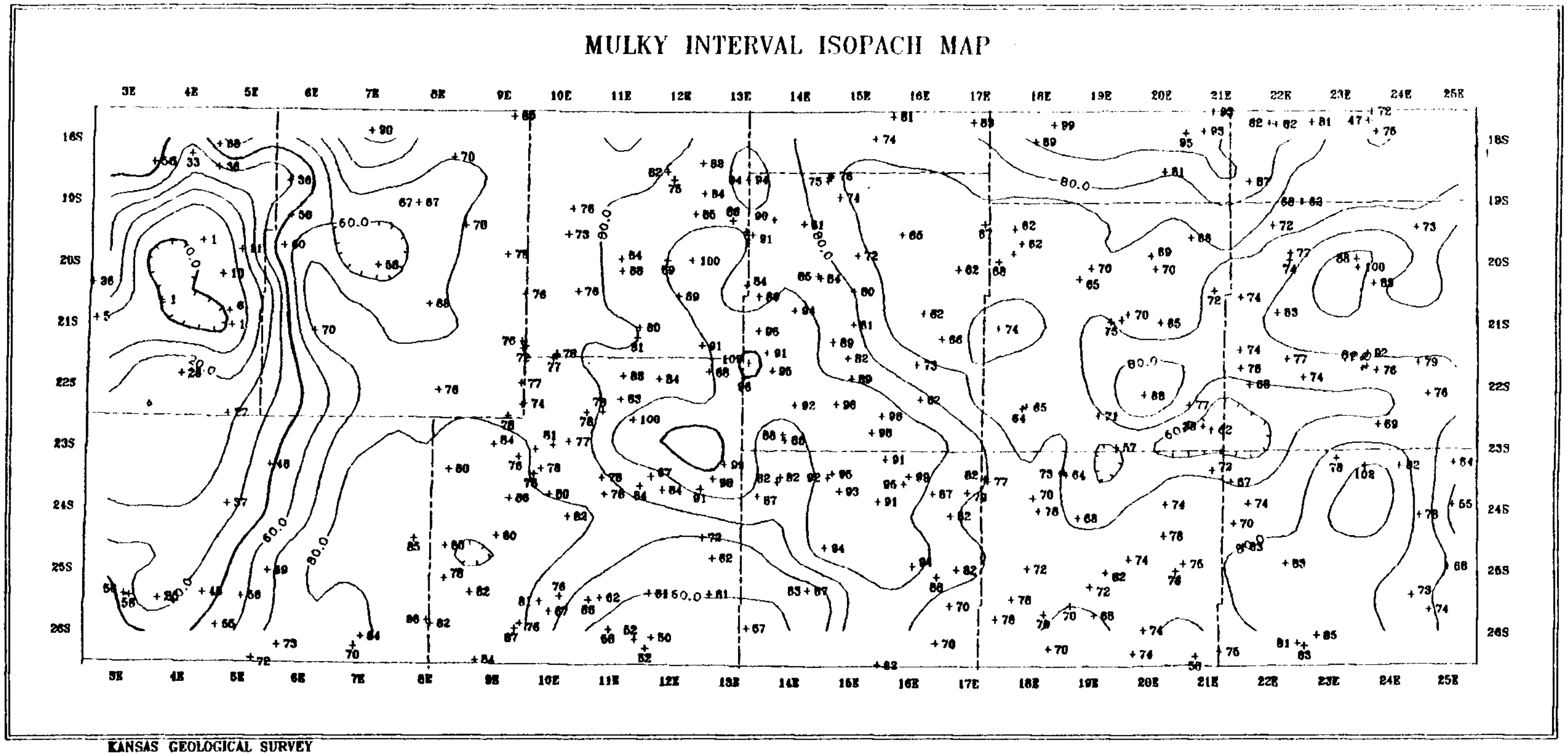
0 10 20 miles

15 30 kilometers

△ interval not present

contour interval = 2 feet

Figure 43. Coal isolith map of the Bevier interval.



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 10 feet

Figure 44. Mulky interval isopach map.

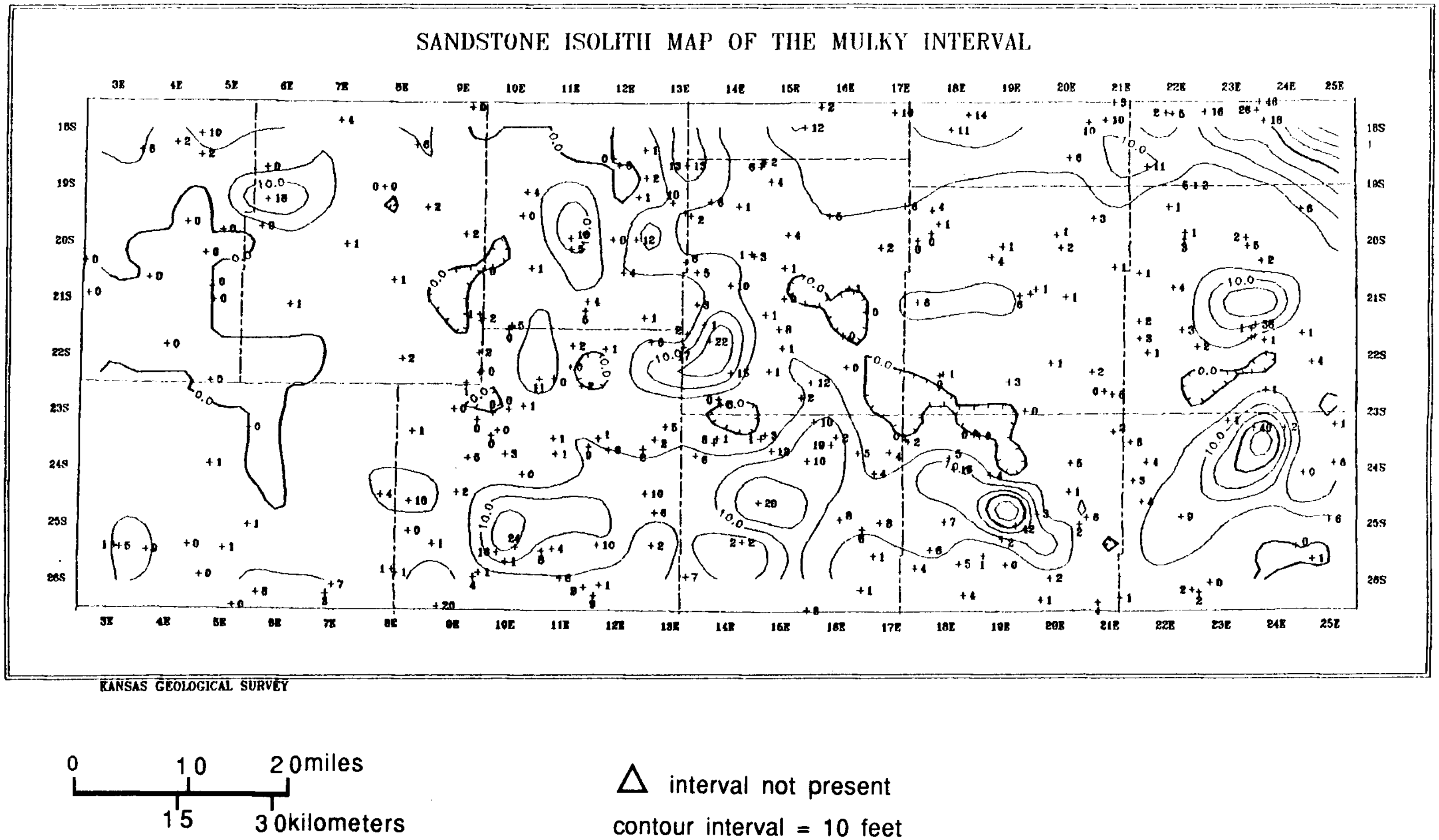
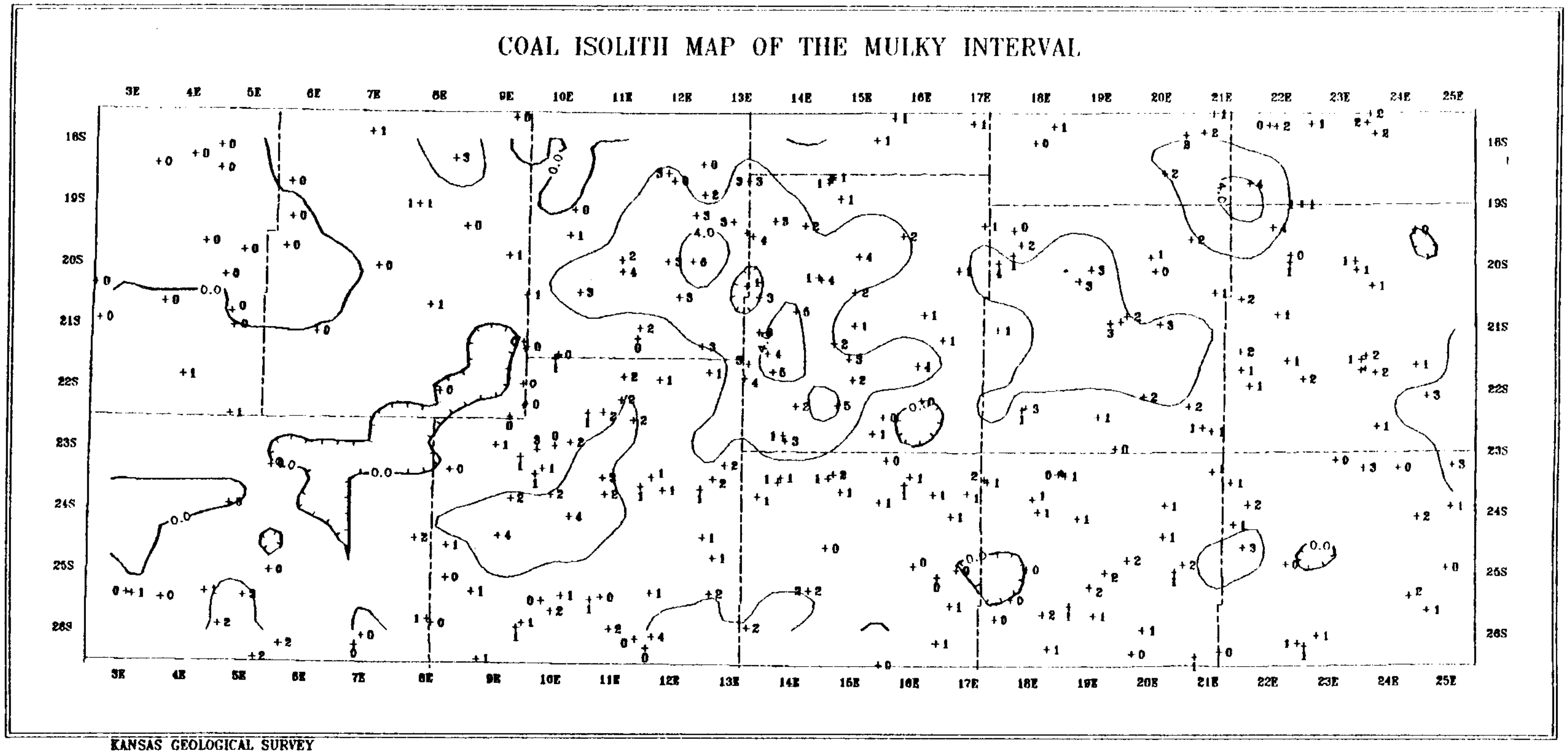


Figure 45. Sandstone isolith map of the Mulky interval.

of Miami, Franklin, Linn, and Anderson counties as well as in western Coffey and eastern Lyon counties (Fig. 46). The remainder of the study area contains 1 to 2 ft (0.3 to 0.6 m) of net coal. The Mulky coal, situated directly underneath the Excello shale, is the most laterally extensive coal recognized within the Mulky interval. The Breezy Hill Limestone Member lies stratigraphically underneath the Mulky coal and is discontinuous in this study area.

Sedimentologic and stratigraphic studies on the Bevier and Mulky intervals have been conducted by Brenner (1989), Aden (1982), Reinholtz (1982), Lardner (1984), and Nelson (1985). Brenner incorporated the previous work into his 1989 study and made several recommendations regarding stratigraphic nomenclature on the upper Cherokee. He defined a Verdigris Formation, which included the "V" shale (Oakley Shale of Iowa) and the overlying Verdigris Limestone Member (Ardmore Limestone). Brenner also defined the Banzet Formation, which included all strata from the top of the Verdigris Limestone Member to the base of the Excello shale, and was divided into the Bevier, Lagonda, and Mulky Members.

A comparison of isopach maps of the Verdigris-Banzet interval of Brenner's study to the Mulky and Bevier (Figs. 44 and 41) intervals of this study shows similarities. These intervals thicken to over 100 ft (30.5 m) in Bourbon and Linn counties as well as in the four county region of Greenwood, Woodson, Coffey, and Lyon. These intervals thin to over 80 ft (24.4 m) in Franklin, Anderson, Allen, and eastern Coffey counties. The sandstone isolith maps also show similar patterns with sand thicknesses of over 40 ft (12.2 m) occurring in eastern Bourbon and Linn counties (Figs. 42 and 45).



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 2 feet

Figure 46. Coal isolith map of the Mulky interval.

Krebs and Cabaniss Formation boundary, discussion

Current stratigraphic classification of the Cherokee Group by Jewett et al. (1968; Fig. 1) was based on outcrops in southeastern Kansas with the type section in Cherokee County, Kansas (Howe, 1956). Current stratigraphic nomenclature can be applied to areas within the outcrop belt but many members or beds are unrecognizable in the subsurface. The boundary between the Krebs and Cabaniss formations, which is marked by the top of the Seville (?) Limestone Member (Jewett, 1959), is an example of this type of correlation problem. The Seville (?) Limestone Member is a thin (about 6 inches thick), fossiliferous, argillaceous limestone that lies directly above the Bluejacket C coal bed (Howe, 1956; Harris, 1984). This limestone reportedly correlates with the Seville Limestone Member in Missouri, Iowa, and Illinois, although this correlation is subject to debate. Harris mapped the distribution of the Seville (?) Limestone Member along the Krebs Formation outcrop belt and showed it to be relatively continuous in cores and outcrops, but only present in about half of the well logs examined. This study, as well as those of Staton (1987) and Strickland (1987), did not recognize the Seville (?) Limestone Member on geophysical well logs because: (1) If present, the limestone marker may be too thin to be resolved on geophysical well logs; (2) The Seville (?) Limestone Member possibly underwent a facies change from the outcrop region westward into the study area; (3) The marker bed is not present in the subsurface due to non-deposition or erosion in areas of thick upper Bluejacket sandstone.

Staton (1987) suggested that the Tebo coal and the overlying black shale, which in outcrop lies about 75 ft (23 m) above the Seville (?) Limestone Member, be considered as a possible boundary between the

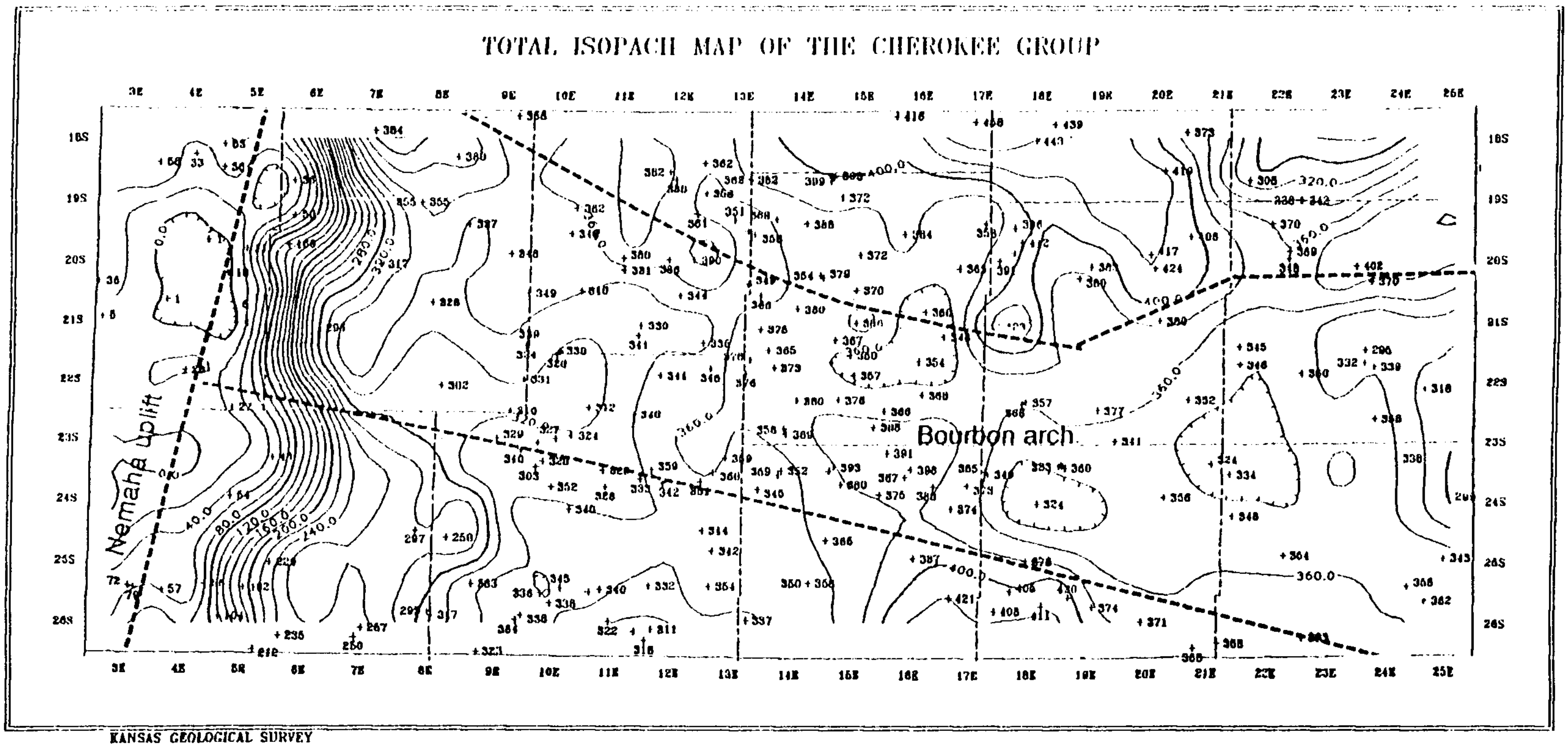
Krebs and Cabaniss formations. The black shale is highly radioactive, easily distinguishable on gamma-ray-neutron logs, and widely traceable in outcrops. It has been correlated throughout three separate basins in Kansas; the Sedgwick basin by Killen (1986), the Forest City basin by Strickland (1986) and this study, and the Cherokee basin by Harris (1984), Staton (1987) and in this study. In outcrop, the black shale caps the Tebo coal and is overlain by the Tiawah limestone bed (Harris, 1984). This study found the black shale overlying the Tebo coal to be widespread and easily identifiable on geophysical well logs and agrees with Staton's suggestion that the base of the black shale be adopted as the boundary between the Krebs and Cabaniss formations in Kansas.

POST-MISSISSIPPIAN STRUCTURES

A total isopach map of the Cherokee Group was constructed for the interval from the top of the Mississippian limestone to the base of the Excello shale (Fig. 47). Current stratigraphic classification includes the Excello shale in the Cherokee Group. However, this study excluded the Excello shale when constructing isopach and isolith maps of the Cherokee Group because of the method used to pick stratigraphic markers. The Cherokee Group in the Cherokee basin is approximately 420 ft (128 m) thick in southeastern Woodson County and thickens to 565 ft (172 m) in southern Cherokee County (Staton, 1987). Cherokee Group strata in the Forest City basin are about 460 ft (140 m) thick in southeastern Osage County and reaches a maximum thickness of over 850 ft (260 m) in north-central Brown County (Strickland, 1987). Thinning of the Cherokee Group occurs noticeably in two locations: the Nemaha uplift region and the Bourbon arch region.

Nemaha uplift

Post-Mississippian structures, such as the Nemaha uplift, Bourbon arch, and Ozark dome confined deposition in the Cherokee and Forest City basins (Fig. 2). The Nemaha uplift, present in the western part of the study area, is a north-northeast to south-southwest trending tectonic zone, associated with the Ouachita orogeny in post-Mississippian and pre-Desmonesian Pennsylvanian time (Rascoe and Adler, 1983; Berendsen and Blair, 1986). The total isopach map (Fig. 47) shows pronounced thinning in the Nemaha uplift area between ranges 7 east and about 4 east. Thicknesses change from 317 ft to 1 ft (96.6 to 0.3 m) over a distance of approximately 14 mi (23 ft/mi; 4.3 m/km). Thinning was due to onlapping of



0 10 20 miles
15 30 kilometers

△ interval not present
contour interval = 20 feet

- - - - - - approximate boundries of the Bourbon arch and Nemaha uplift.

Figure 47. Total isopach map of the Cherokee Group.

progressively younger sediments onto the Nemaha uplift, until Excello shale deposition completely covered it. As the Atokan-Desmoinesian sea inundated the Nemaha uplift, upper Cherokee Group sediments overstepped the limits of the lower Cherokee Group sediments, and lapped out against the pre-Pennsylvanian rocks (Rascoe and Alder, 1983). Figure 19 demonstrates this overstepping of younger sediments onto the Nemaha uplift by marking the lateral extent of the Riverton, Bluejacket B, and Tebo markers, and the "V" shale. Cole (1969) and Staton (1987) observed this same onlapping relationship along the Nemaha uplift in north-central Oklahoma and southeastern Kansas. Subsea structure maps constructed on the top of the Mississippian limestone (Fig. 48), base of the "V" shale (Fig. 49), and base of the Excello shale (Fig. 50) delineate the trend of the Nemaha uplift and are consistent with observations by Merriam (1960), Jewett (1951), and Berendson and Blair (1986).

Bourbon arch

The Bourbon arch has traditional been described as a low relief post-Mississppian structure trending northwest across parts of Bourbon, Linn, Allen, Woodson, Anderson, Coffey, Greenwood, Lyon, and Chase counties. This structure is noted by a subtle thinning of Cherokee Group sediments over a broad region that has been reported by Lee (1939) and Jewett (1951) to trend west-northwest to east-southeast and more recently by Strickland (1987) to trend east-northeast to west-southwest. Thinning is apparent in an east-southeast to west-northwest linear trend from ranges 8 east to 25 east and from townships 21 south to 26 south (Fig. 47). This region shows thickness changes of about 50 to 70 ft (15.2 to 21.3 m) over a distance of 6 to 17 mi (8-4 ft/mi; 1.6-0.77 m/km). Indications from structure and isopach

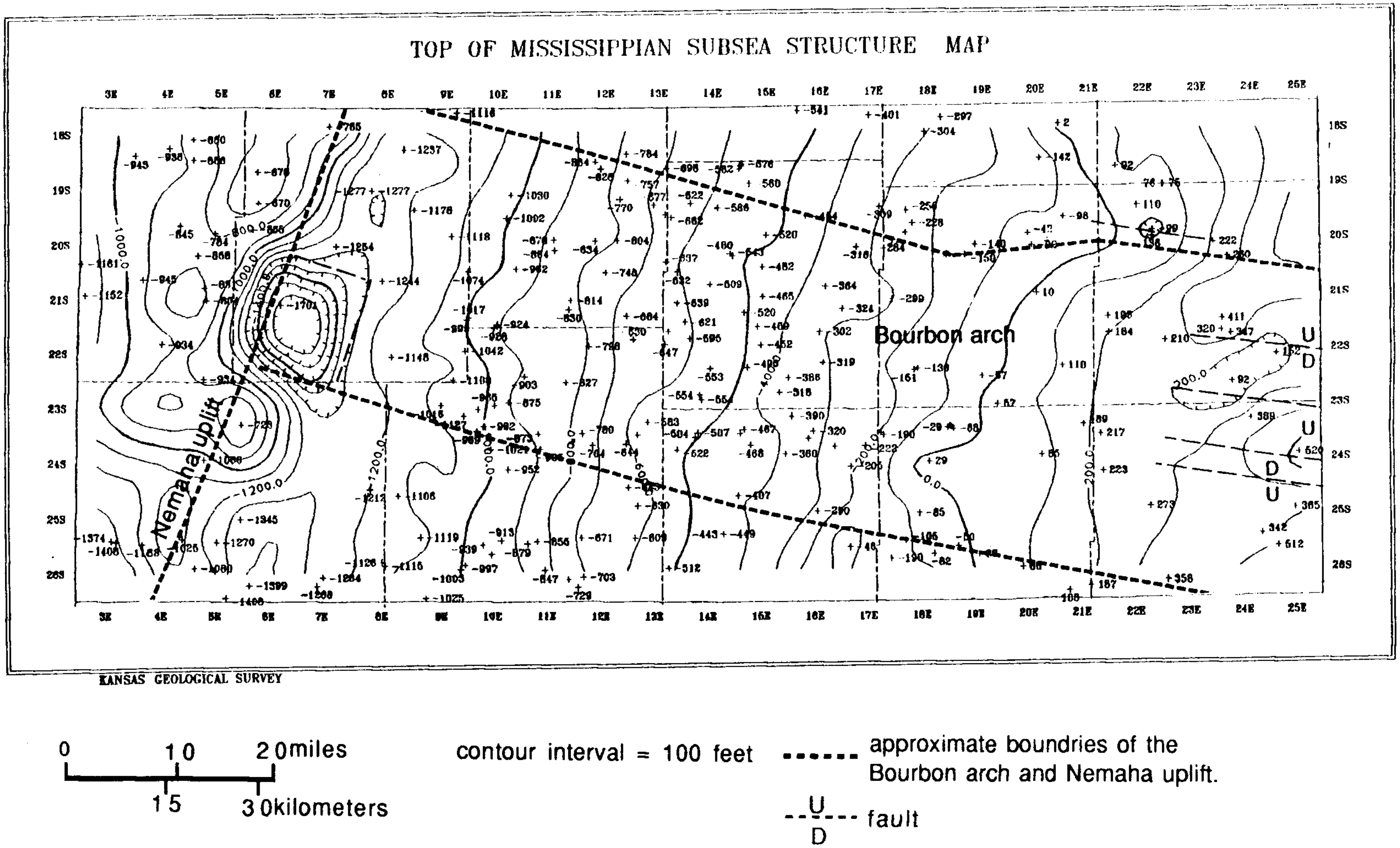
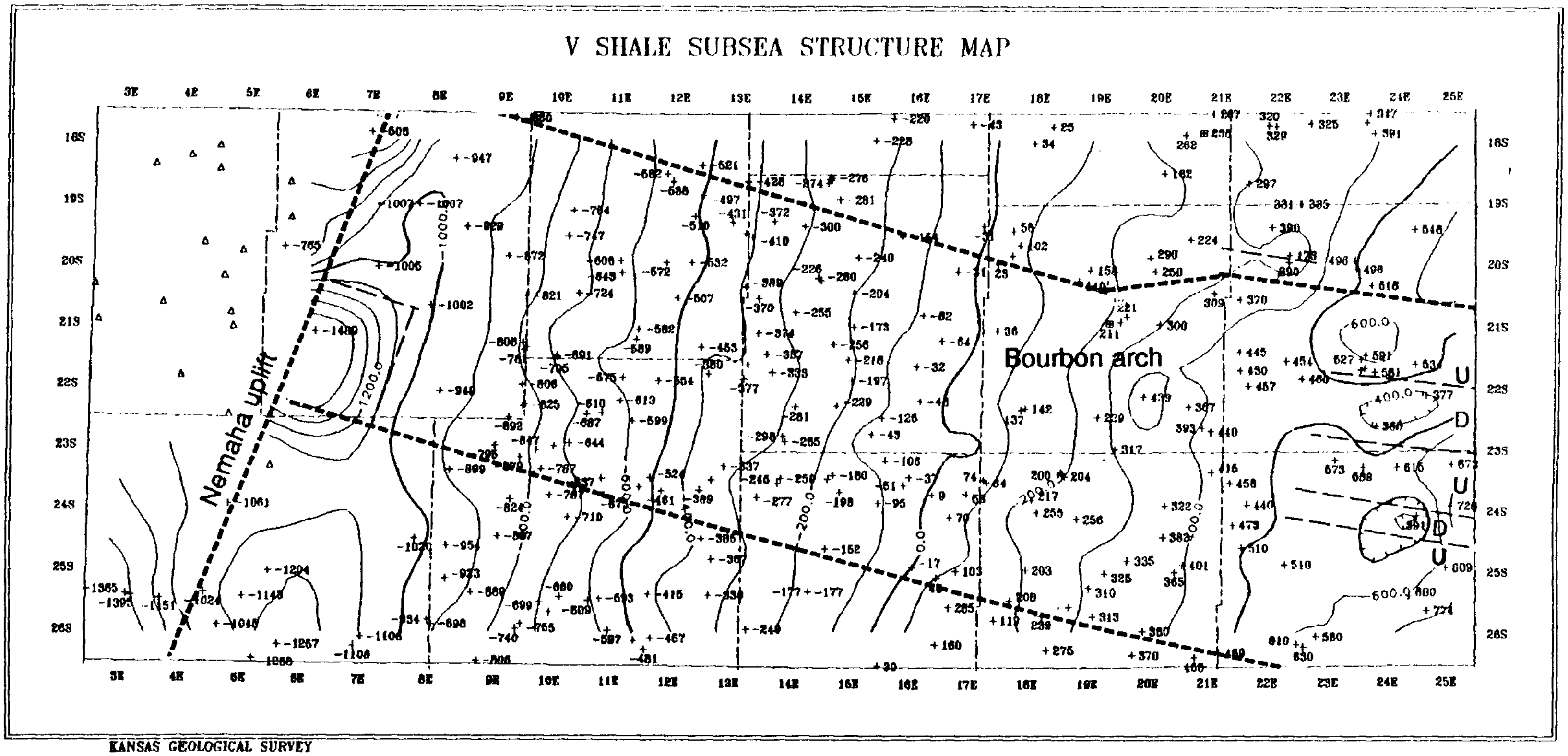


Figure 48. Top of Mississippian subsea structure map.



0 10 20 miles
15 30 kilometers

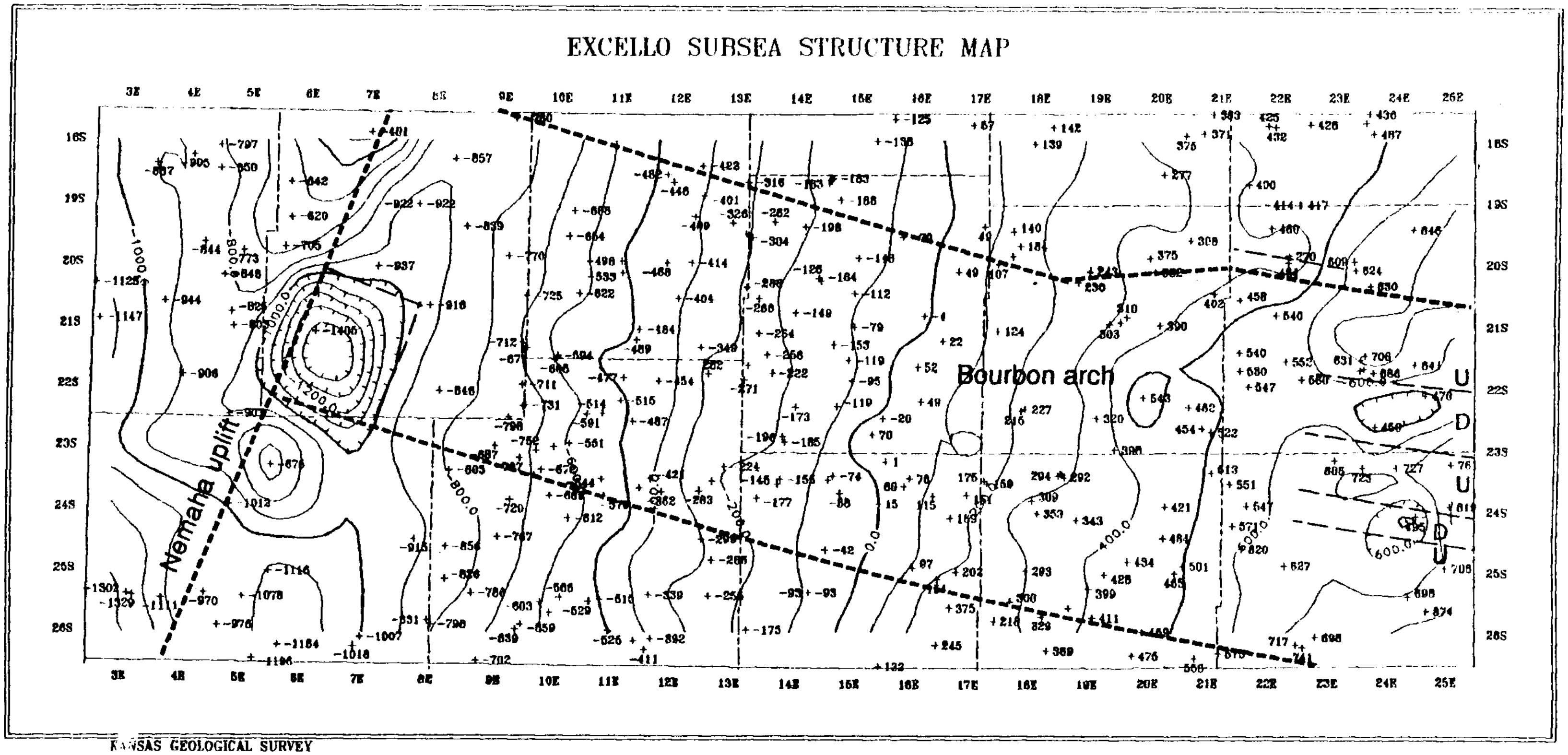
contour interval = 100 feet

△ marker not present

approximate boundries of the Bourbon arch and Nemaha uplift.

U/D fault

Figure 49. "V" shale subsea structure map.



0 10 20 miles
15 30 kilometers

contour interval = 100 feet

△ marker not present

approximate boundries of the Bourbon arch and Nemaha uplift.

U/D fault

Figure 50. Excello shale subsea structure map.

maps along with cross-sections from this study agree with Lee and Jewett's reported west-northwest to east-southeast trend for the Bourbon arch. Three possible explanations for thinning in this region will be addressed: 1) The Bourbon arch is a post-Mississippian and pre-Cherokee Group structural feature; 2) The region represents differential compaction of relatively thick coal deposits; 3) The Bourbon arch structure was caused by a combination of structural uplift that created conditions favorable for coal accumulation and subsequent differential sediment compaction.

Structural features

Lee (1939) reported that Mississippian carbonates are about 100 ft (30.5 m) thinner on the Bourbon arch than areas to the north and south. Jewett (1951) indicated that possible uplift of the area caused subaerial exposure and removal of the Mississippian carbonates.

Subsea structure maps constructed on the top of the Mississippian limestone (Fig. 48), base of the "V" shale (Fig. 49), and base of the Excello shale (Fig. 50) were used along with the total isopach map of the Cherokee Group (Fig. 47) to delineate the boundaries of the Bourbon arch. Five west-northwest to east-southeast trending faults observed in northern and southern Linn and northern Bourbon counties were noticed on all three structure maps and were interpreted as a series of horsts and grabens. All five faults occur along the reported trend of the Bourbon arch. The northernmost fault, occurring at about township 20 south and range 22 east, marks the northern boundary of the Bourbon arch. The next fault to the south is located on the southern end of the Mound City Dome, a pronounced structural high in southern Linn County (Jewett, 1951). Harris (1984) observed northwest-southeast trending faults in Bourbon County, Kansas and Vernon County, Missouri, that project into the faults observed in this study. It appears that the faults are post-Cherokee Group because they were observed on all three structure maps. The trend of the faults suggests that they may have been reactivated Precambrian structures, possible related to the Bolivar-Mansfield, Chesapeake, and Fall River tectonic zones. Precambrian metasedimentary rocks found in the graben between the Bolivar-Mansfield and the Chesapeake tectonic zones were interpreted by Berendsen and Blair (1991) to be indicators of localized Precambrian basins. A magnetic high in southern Linn County was recorded on the magnetic map of Kansas (Yarger, 1989) and also supports the idea of Precambrian structures. The anomalously high reading may be caused by differences in the subsurface magnetic distribution between Precambrian igneous rocks and surrounding, younger sedimentary rocks. The Bouguer gravity map of Kansas (Lam and Yarger, 1989), however, does not reflect a major change in subsurface mass distribution in the Bourbon arch region. This may be due to a lack of density contrast in the Precambrian basement rocks.

The Boliver-Mansfield fault zone trends northwest from Douglas County, Missouri across southeastern Linn County, Kansas at about township 21 south, and terminates at the Humbolt fault zone in Morris County, Kansas at about township 16 south and range 8 east (McCracken,1971; Berendsen and Blair, 1991). The northern-most fault observed in this study parallels the Boliver-Mansfield fault zone in northwestern Linn County and marks the northern boundry of the Bourbon arch. Faulted anticlines and synclines, with throws up to 300 ft (91 m), comprise the Boliver-Mansfield structural zone in Missouri (McCracken, 1971). The Chesapeake tectonic zone consists of faulted anticlines and synclines extending from the Arkansas-Missouri border in Taney County, Missouri northwestward across southeastern Missouri entering Kansas in central Bourbon County between townships 25 south and 26 south and ending obliquely against the Humbolt fault zone in central Chase County at about township 21 south and range 7 east. The northwest trending faults observed in northern and southern Linn and northern Bourbon counties indicate that the Bolivar-Mansfield and Chesapeake tectonic zones were active after Cherokee Group deposition.

These tectonic zones may have been active during the interval between Mississippian and Pennsylvanian deposition as well. The Ouachita orogeny, which occurred in southeastern Oklahoma and central Arkansas during middle Atokan through late early Desmoinesian, formed the present Ozark uplift and Arkoma basin (Elmore et al., 1990). The same compressive forces that formed these structures may have reactivated the Bolivar-Mansfield, Chesapeake, and Fall River tectonic zones causing the Bourbon arch region to be a broad, positive structural feature.

Structure maps, however, did not show any relief or closure along the reported west-northwest to east-southeast trend of the Bourbon arch. Data points, averaging about two per township, and a contour interval of 100 ft, may not have been adequate to reveal broad structural closure. A subsea structure map constructed on the top of the Mississippian (Fig. 48) reveals a general west to northwest dip of about 18 ft/mi (3.4 m/km) from eastern Kansas to the Nemaha uplift region. Contours generally trend north-northeast to south-southwest across the map without any deflection to the west-northwest that would indicate a structural high.

North-south cross section E-E' and east-west cross section A-A' through the region indicate that deposition took place earlier in the Forest City basin than in the Cherokee basin. Figure 14 shows the lateral extent of the McLouth and X-markers in relation to the Bourbon arch. The younger X-marker oversteps the older McLouth marker as both onlap the Bourbon arch from the north. The "X" interval and McLouth interval combine for approximately 60 ft (18.3 m) of sediment in areas just north of the Bourbon arch before thinning to a feather edge on the Bourbon arch. This onlapping relationship can account for much of the thickness change observed over the Bourbon arch region from the north. The total isopach map of the Cherokee Group (Fig. 47) confirms that sediment thicknesses decrease by as much as 70 ft (21.3 m) in the Bourbon arch region as compared to areas north and south of this region. The Bourbon arch was a depositional barrier during McLouth and X-marker interval deposition.

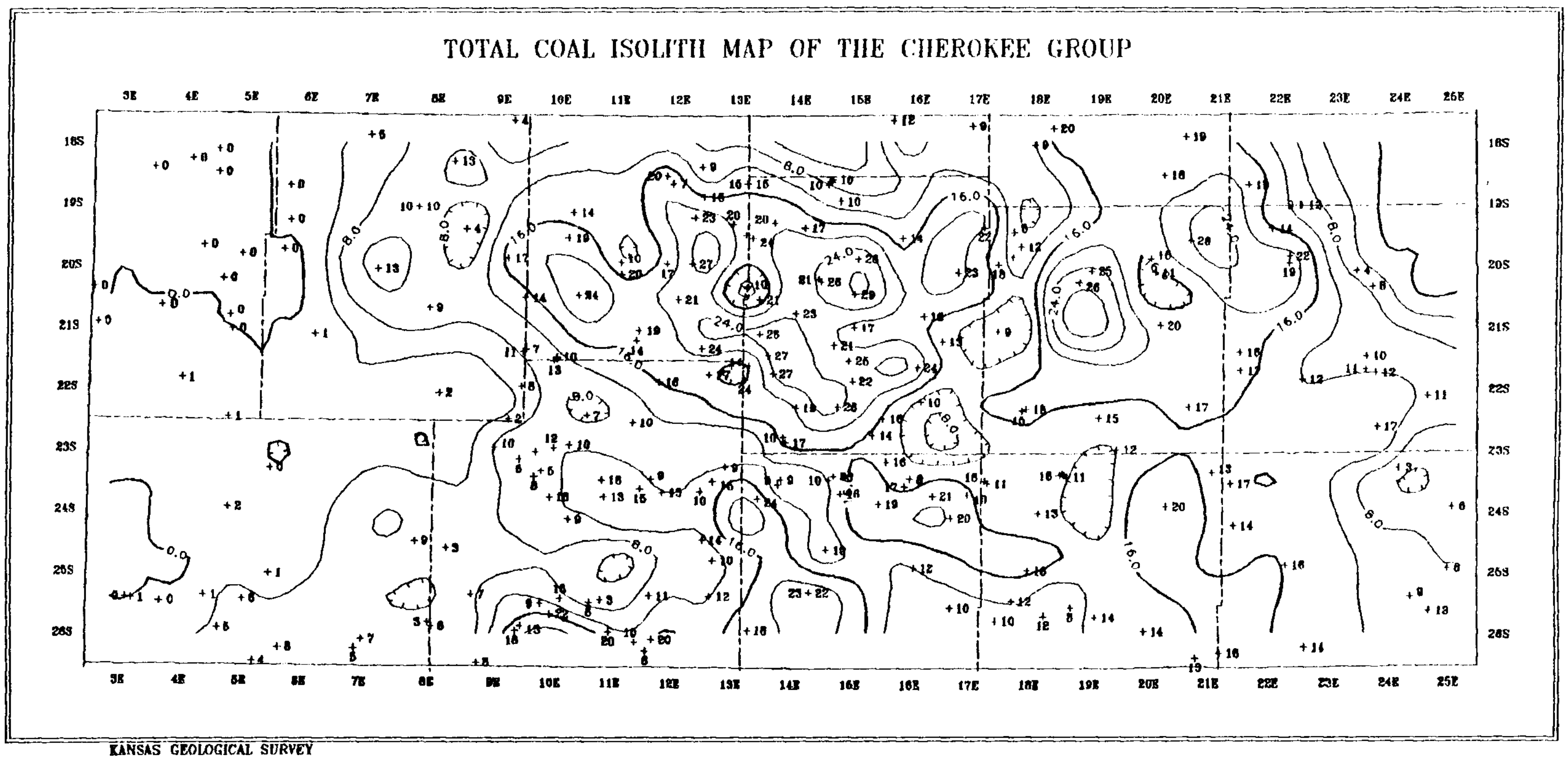
This same onlapping pattern was not observed with Riverton interval sediments on the south side of the Bourbon arch. This one-sided onlapping pattern may have resulted from rapid subsidence in the Forest City basin or it may reflect the nature of post-Mississippian faulting along the Bourbon arch. During broad regional uplift, the northern side of the Bourbon arch may have undergone more intense uplift than the southern side, resulting in a structure with a gentle southward dip and a relatively higher northern margin. The region immediately to the north of the upthrown structure would be graben-like and act as basin. In the early stages of Cherokee Group deposition (McLouth and "X" intervals), the gently dipping, southern and central upthrown block would be a depositional barrier receiving very little sediment. The northern downthrown side, however, would be filled in first as

McLouth and "X" interval sediments accumulated in the down thrown block. Infilling in the northern region would continue until the upthrown part of the Bourbon arch was inundated and covered by Riverton interval sediments. More information needs to be assimilated to adequately address this hypothesis. Deep seismic studies of the Bourbon arch region along with selected cored intervals would be a major step towards revealing the structural nature of the region.

Compactional features

The total isopach map of the Cherokee Group (Fig. 47) reveals thinning of up to 70 ft (21 m) over the Bourbon arch along a subtle, west-northwest to east-southeast thinning trend from ranges 8 east to 25 east and from townships 21 south to 26 south. Cherokee Group strata in this region are approximately 360 ft (110 m) thick. This broad region shows thickness changes of about 50 to 70 ft (15 to 21 m) over distances of 6 to 17 miles (8-4 ft/mi; 1.6-0.77 m/km). To the south of this area of thinning, the Cherokee Group thickens to about 420 ft (128 m) in southeastern Woodson County and thickens to 565 ft (172 m) in southern Cherokee County (Staton, 1987). To the north of the area of thinning, Cherokee Group strata thicken to about 460 ft (140 m) in southeastern Osage County and reach a maxium thickness of over 850 ft (260 m) in north-central Brown County (Strickland, 1987).

The total coal isolith map of the Cherokee Group (Fig. 51), when overlain by the total isopach map (Fig 47), reveals that the thickest coal deposits are found within the west-northwest to east-southeast trending belt of thin Cherokee Group strata that define the Bourbon arch. The map shows a tendency for coal accumulation to be thickest in Anderson, Coffey, and Lyon counties, areas that also show thin Cherokee Group deposition. The



0 10 20 miles
15 30 kilometers

contour interval = 4 feet

Figure 51. Total coal isolith map of the Cherokee Group.

thick coal accumulations, projected up to 30 ft (9.1 m) thick, are the result of numerous 1 to 3 ft (0.3 to 0.9 m) thick coal beds found throughout the Cherokee Group. Coals account for approximately 3 percent of the total volume of the Cherokee Group in the study area.

The thick north-south trending sands that occur in the A-B, Bluejacket B, and Weir-Pittsburg intervals combine to produce the thickest area of sands in the study. The upper Bluejacket sandstone and the lower Warner sandstone make up this trend and range in thickness from 41 to 185 ft (12.5 to 56.4 m) (Fig. 10). Staton's (1987) total sandstone isolith map of the Cherokee Group revealed a similar linear sand trend in Wilson and Neosho counties to the south that aligns with the trend observed in this study. This major transport axis most likely fed sediment to the Bluejacket-Bartlesville deltaic deposits in northeast Oklahoma. Visher et al. (1971) mapped delta patterns of the Bartlesville Sandstone in northeastern Oklahoma and suggested that a single major drainage system in eastern Kansas was responsible for the deltaic deposits. Busch (1959) and Cole (1969) suggested that the sand trends followed lows on the eroded pre-Pennsylvanian surface. However, a structure contour map on the top of the Mississippian limestone (Fig. 48) showed no structural lows or pre-Cherokee channel patterns. Other thick sand accumulations occur in northwestern Greenwood, northeastern Bourbon, and central Linn counties. Sand content goes to zero over the Nemaha uplift. Sandstones account for approximately 11 percent of the total volume of the Cherokee Group in the study area. Overlaying the total Cherokee Group isopach map (Fig. 47) with the total sandstone isolith map (Fig. 10), reveals that the areas of thickest sand accumulation occur generally in the areas where the Cherokee Group is thickest, southern Franklin, northern and western Anderson, southern Coffey, and southwestern Allen counties. There is also a tendency for the thickest sand deposits to occur in areas of thin coal and shale deposits. Thick sands, deposited in fluvial and distributary channels, cut into and removed much of the underlying coal and shale deposits. Brown (1975) reported that thick isopach trends coincided with the distribution of elongate fluvial and deltaic sandstones of the Cisco Group in north-central Texas. This relationship suggests that sandstones were compacted significantly less than the other sediments.

The total shale isolith map of the Cherokee Group (Fig. 52) shows trends that complement the total sand isolith map just discussed. Shale totals are thinnest along the north-south trend followed by the thick sands. The thick sands within this elongate trend may have removed and replaced most of the prevously deposited shales. The thickest shale intervals and the thinnest Cherokee Group intervals are found in areas adjacent to the thick, linear sand trend. Shales account for approximately 85 percent of the total volume of the Cherokee Group in the study area.

The Breezy Hill Limestone Member and Verdigris Limestone Member account for most of the carbonate accumulation in the study area, while the Seville, Tiawah, and X-marker limestones account for only a small fraction (Fig. 53). Limestones account for approximately 1 percent of the total volume of the Cherokee Group in the study area. The areas of thickest limestone accumulation are found in central Coffey and southwestern Chase counties. In these areas total net limestone thickness averages 5 to 10 ft (1.5 to 3.0 m). The thick limestones that accumulated in southwestern Chase County may have been deposited on topographically high areas of

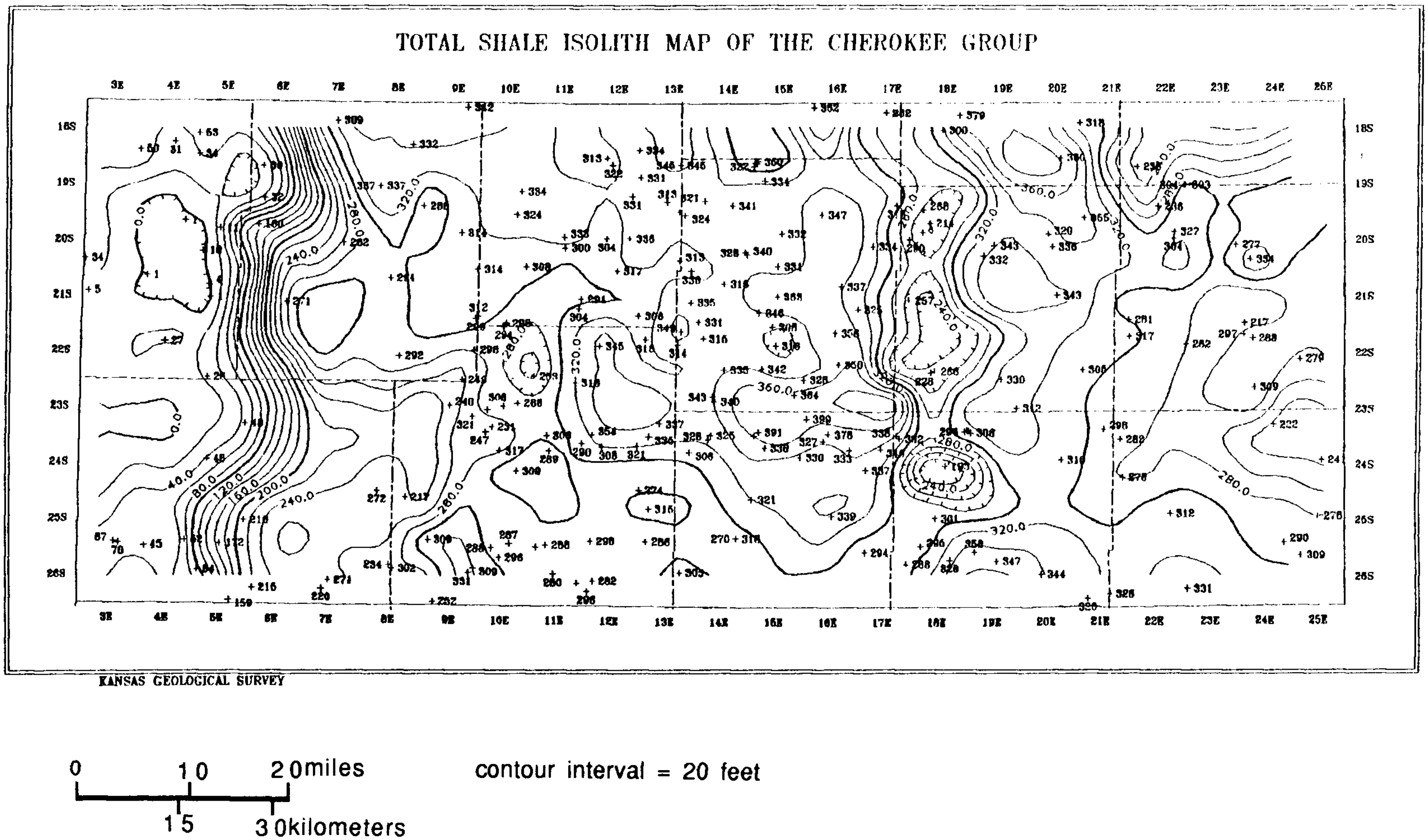
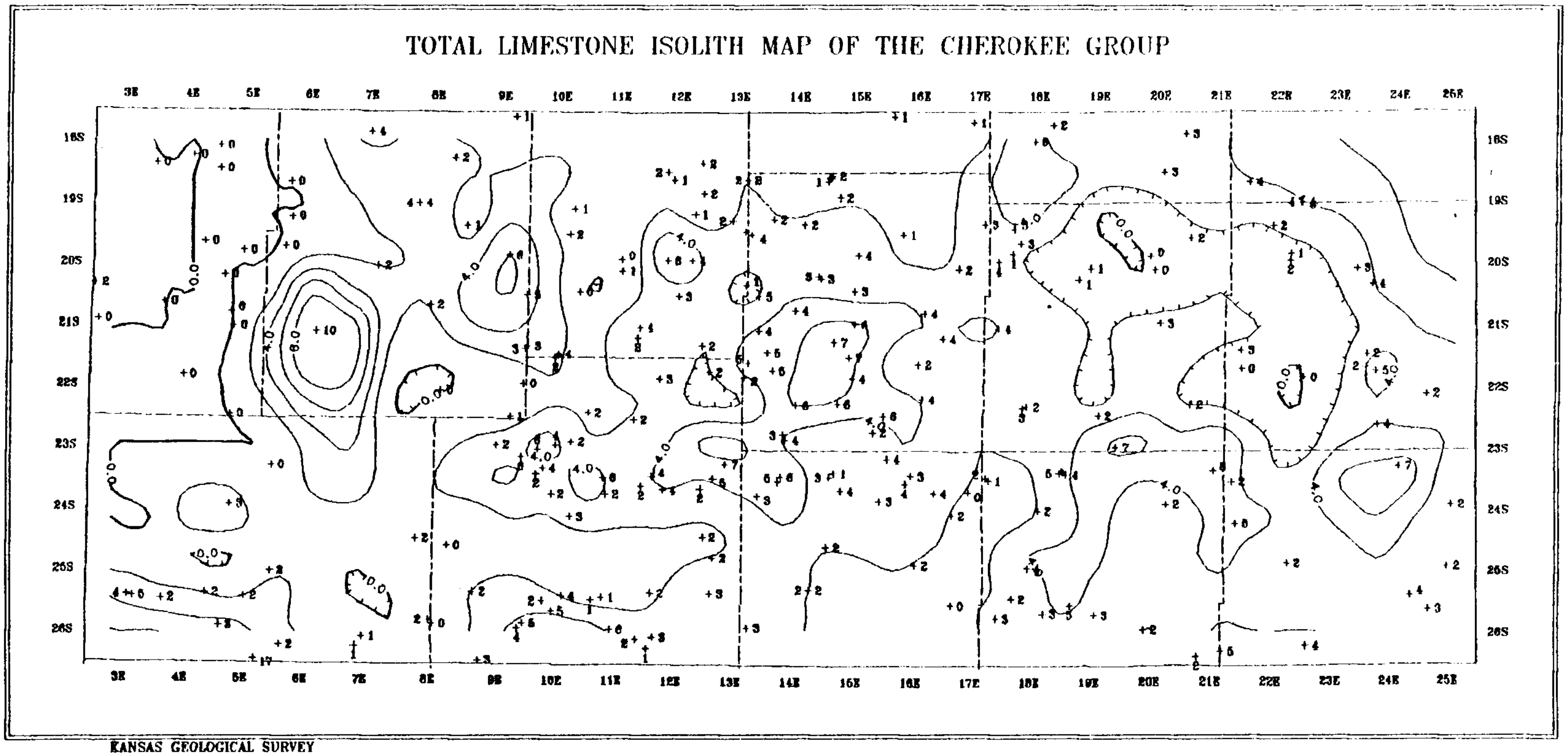


Figure 52. Total shale isolith map of the Cherokee Group.



0 10 20 miles

15 30 kilometers

contour interval = 2 feet

Figure 53. Total limestone isolith map of the Cherokee Group.

the Nemaha uplift that were isolated from terrigenous sediment influx. Killen (1986) reported that during upper Cherokee interval (Croweburg through Mulky intervals of this study) deposition of a carbonate shelf extended into southern Marion and western Butler counties. Staton (1987) reported thin limestones occurring in the Mulky and Bevier intervals in Butler County. Brenner (1989) also made allowances for the possibility of carbonate environments that existed to the west in the Sedgwick basin to have extended into the Cherokee basin.

Areas of thick coal and shale, and thin sand and limestone were compacted more than areas of thick sand and thin coal, shale, and limestone, resulting in a band of thinning along the axis of the thickest coal deposits. These relationships point to the possibility that the Bourbon arch has a compactional component. Two questions are raised by this: 1) Can differential compaction of coal, shale, sand, and limestone account for the approximately 70 ft (21.3 m) of thinning observed over the Bourbon arch? 2) What were the depositional conditions that favored the accumulation of thick coal deposits?

The first question can be addressed by examining compaction figures for coal, sandstone, shale, and limestone. Coal deposits in the Cherokee and Forest City basin are high volatile bituminous deposits. McCabe (1984) and Ryer and Langer (1980) reported peat to coal thickness ratios ranging from 2.2:1 to 40:1, but agreed on an average ratio of about 10:1. Compaction ratios for shales were derived from a figure by Perrier and Quiblier (1974) relating initial thickness to burial depth of compacted shales. Using that figure, and a burial depth of approximately 1.5 km for the Bourbon arch region, average compaction ratios (uncompacted to compacted) are

1.7:1. Laboratory results show that sandstone will compact 10 to 15 percent of its total thickness, while limestone compaction is on the order of 5 percent of the total thickness (Blatt et al., 1980). Intuitively, areas of thick coal deposits will compact more than areas of thick sand deposits. However, compaction ratios only tell how much total sediment was compacted after final deposition and do not reflect the timing of sediment deposition or compaction. Timing of peat/coal compaction is not well understood. Cecile (1991, pers. com.) noted that peats undergo a 40% reduction of volume at burial depths of about 3,000 ft. These conditions suggest that peat compaction is the result of extensive sediment loading, which occurs late in the burial history of a basin. However, other studies suggest that peats are compacted at shallow depths in a matter of decades to a few centuries. Kvale and Archer (1990) suggested that rapid burial and compaction of about 11 m of peat provided the accomodation space necessary for deposition of approximately 8 m of tidalite deposits occurring in the Lower Pennsylvanian of Indiana. Tidalites can be related to neap-spring tidal-current cyclicity and have sedimentation rates that vary from 1 cm/yr to 1 m/yr (Kvale and Archer, 1990). Because of wide ranging coal/peat compaction ratios and differences of opinion on the timing of coal compaction, comparison of uncompacted thin versus thick Cherokee Group deposits occurring in the Bourbon arch region is inconclusive.

The answer to the second question is problematic. Coal deposits in the Cherokee Group are thin, continuous, widespread, and usually cap a coarsening-upward sequence, which is overlain by a marine shale, indicating deposition in a fluvial-deltaic environment (Courel, 1989). Conditions affecting coal (peat) deposition in fluvial-deltaic environments include; level of the water-table, climate as it effects plant production and organic decay, and latitude (McCabe, 1984). Clastic input can retard coal deposition. McCabe listed three possibilities for the formation of economic coal deposits in areas of high clastic input:

1) the chemistry of some swamp waters may shield them from clastic deposition,

2) the peat formed in raised or floating swamps which, by their physical nature, are protected from clastic deposition,

3) the peat deposition was not contemporaneous with local clastic deposition; i.e. the regional clastic supply was cut off during swamp development.

Heckel (1991) and Courel (1989) hypothesized that peat (coal) formation occurred during an early transgressive phase, which impeded fresh-water runoff and clastic influx into the basin. Low-lying peat forming swamps then migrated landward ahead of the transgression (Heckel, 1991). Frazier and Osanik (1969) reported that the thickest peat deposits along the Louisiana coastal plain formed in more stable fresh water inland swamps and that vegetation close to clastic sources can be periodically “choked-out”. The third possibility may apply to Cherokee Group sediments, given the apparent cyclic nature of these deposits. However, if any or all of the above conditions were met during coal deposition in the Bourbon arch region, thick coal deposits could have resulted.

Structural and compactional features

The third explanation of the Bourbon arch region is most plausible and is a combination of the two previous ones. Regional uplifting of the Bourbon arch created conditions favorable to coal accumulation and subsequent differential compaction of sediments. The Bourbon arch region is situated between three Precambrian tectonic zones, the Fall River and Chesapeake to the south and the Bolivar-Mansfield to the north. These fault zones have been periodically active throughout the Paleozoic. Broad uplift coupled with cyclic relative rises and falls in sea level may have created coal-forming conditions similar to those suggested by Heckel (1991) and Courel (1989). The Bourbon arch region influenced Cherokee Group deposition up to the time of A-B marker deposition and possibly as late as Bluejacket B marker deposition. Intervals deposited after the A-B marker show no signs of thinning over the Bourbon arch area. This is especially true of the Mulky interval (Fig. 44). This interval shows a thickening trend over the Bourbon arch region. Thinning in the Bourbon arch region is confined to the intervals below the A-B marker.

In summary, the third hypothesis most accurately reflects conditions that led to the formation and subsequent deposition of sediments over the Bourbon arch. The Bourbon arch is a post-Mississippian structural high that may have created conditions favorable for thick coal accumulation. The timing and degree of differential sediment compaction is ambiguous. However, compaction did contribute to thinning and thickening in areas over and adjacent to the Bourbon arch.

LITHOFACIES DESCRIPTIONS

The following lithofacies descriptions are based on detailed core examination, geophysical well log responses, and observations from outcrops. Outcrop descriptions are based on work by Murphy (1978) and Harris (1984), who studied the Cabaniss Formation and the Krebs Formation in southeastern Kansas and southwestern Missouri. Brenner (1989) and his students did detailed petrographic studies on the upper Cabiness Formation (Excello shale through "V" shale) based on observations of outcrops, cores, well cuttings, and geophysical well log responses. Petrographic studies were also conducted by Woody (1983), who examined cored intervals of the upper Bluejacket sandstone in southeastern Kansas, and Rofheart (1980), who studied cored intervals of the upper Bluejacket sandstone from Allen County, Kansas. Strickland (1987) and Killen (1986) described well log responses and core and well cuttings to delineate lithofacies in the Forest City and Sedgwick basins respectively. Other authors discribing the lithofacies of Cherokee rocks were Howe (1956), Hulse (1978), Ebanks (1979), Bouquet (1984), and Jordan and Tillman (1987).

Most cores available in the study area sample sand-bearing intervals and very seldom recover the entire Cherokee Group. However, the Colt Keown 18AO core in Allen County penetrates the entire Cherokee Group as does the P&M #20 core in Cherokee County. Limited availability of complete Cherokee core requires that well log analysis be used as a supplemental investigative tool when describing lithofacies. This study also drew from previous investigations and developed a composite lithofacies analysis of the study area. Well log responses were used in conjunction with lithofacies descriptions to obtain a complete understanding of the

Cherokee Group in the study area. Lithofacies are described in terms of lithology, color, bedding type, sedimentary structures, fossils, thickness, and relationship with the underlying facies. Color of the lithofacies were described using the Rock-color chart from the Geological Society of America (Goddard et al., 1980).

Lithofacies are grouped in terms of the vertical association of facies observed from cores and then related to geophysical well log responses representative of Cherokee Group sedimentation and depositional styles. This section will first describe the underclay, coal, shelly lag, and black shale facies, which define the stratigraphic marker complex used in this study. Next, this section will describe fine-grained facies consisting of mudstones, siltstones, and fine sandstones and show how they relate to coarsening-upward and shale-dominated sequences observed from well log responses. The third section will discuss fine sandstone, medium to coarse sandstone, and mud clast conglomerate facies and will show how they relate to fining-upward sequences observed from well log responses.

Marker complex

This study used a complex of markers consisting of a basal underclay overlain by a coal, shelly lag (equivalent to transgressive limestone of the Missourian cyclothems), and black shale to define stratigraphic intervals in the Cherokee Group (Fig. 54).

Underclay

Underclay, also known as seatearth, seatrock, and fireclay, is a mottled light- gray (N7) clay or siltstone containing carbonized plant fragments up to 2 cm long (Fig. 55 A). Underclay ranges from 2 to 50 cm in thickness and is structureless and blocky and may contain slickensides. It

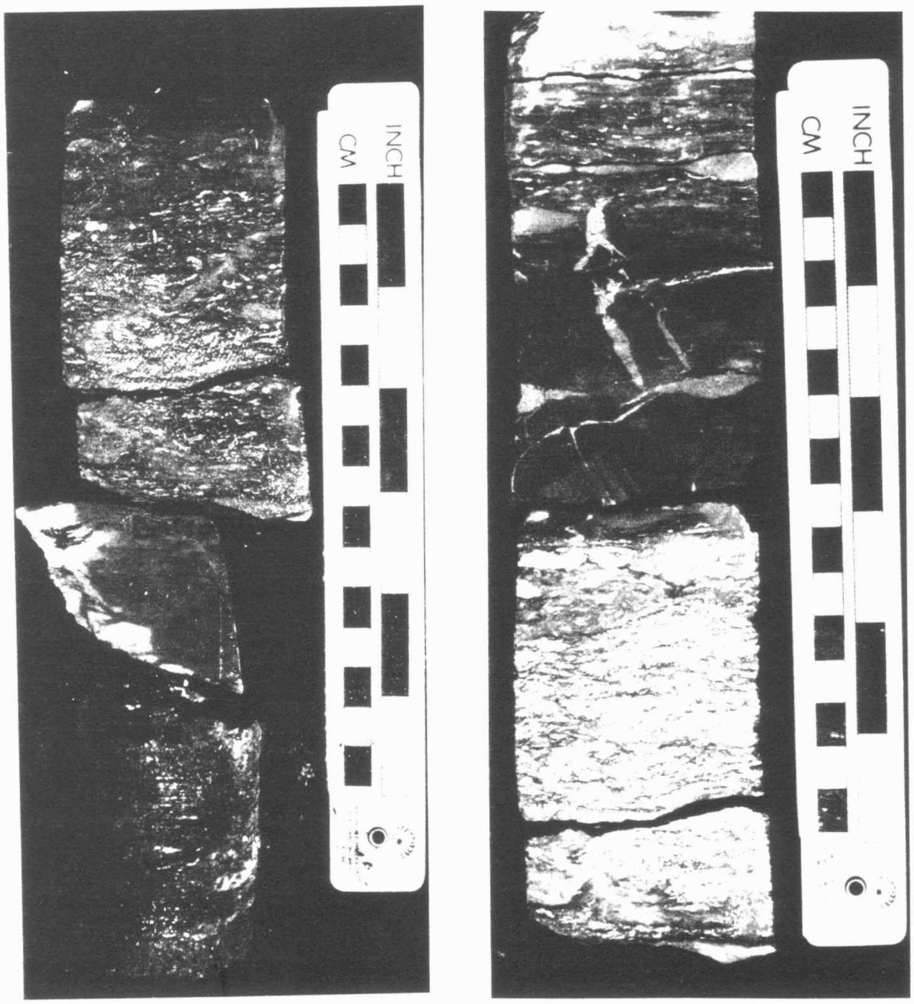
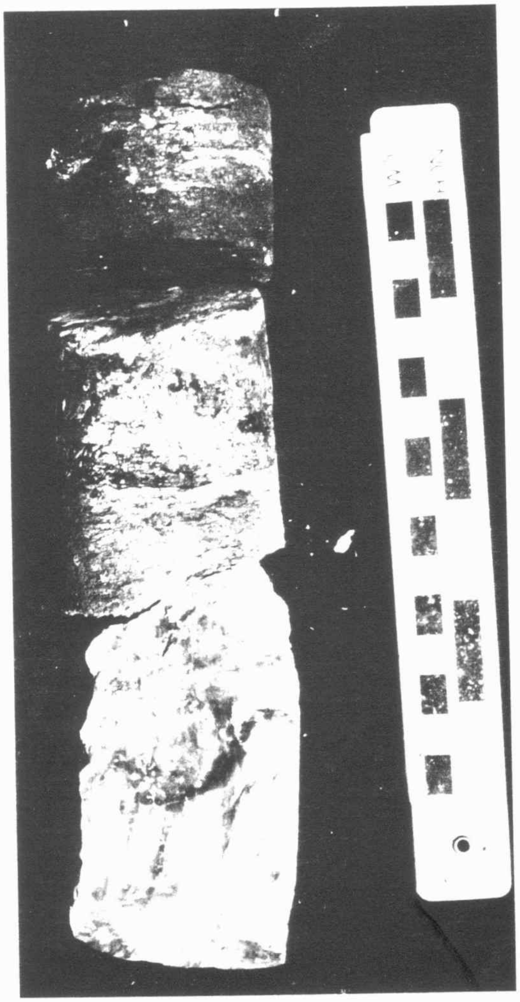
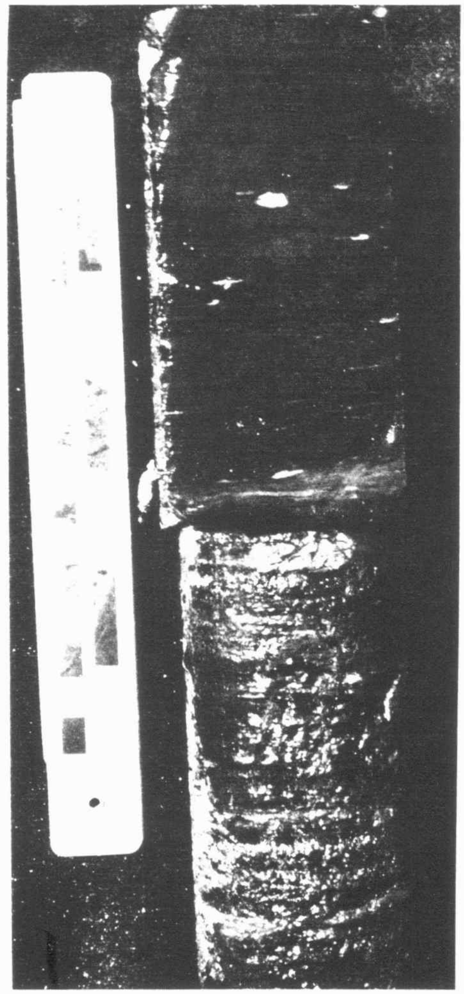


Figure 54. Photographs of a slabbed core showing a marker complex consisting of a basal coal sharply overlain by a shelly lag and grading upward into a Type 2 black shale. (Sample from Dotson #111, NW-NW-SE Sec. 26-T26S-R-21E, Bourbon County, Kansas, 610'-611.5')



55A



55B

Figure 55 A. Photograph of a core showing the Scammon coal bed overlying a light-gray underclay with slickensides. (Sample from Dotson #111, NW-NW-SE Sec. 26-T-26S-R21E, Bourbon County, Kansas, 611'-612')

Figure 55 B. Photograph of a slabbed core showing the Riverton coal bed. (Sample from McGee Lease #20-90, Sec. 3-T23S-R21E, Anderson County, Kansas, 910') contains abundant root casts and less commonly has horizontal and vertical burrows. Pyrite and siderite nodules are common as well. This facies is commonly capped by a coal but may be present where no coal has formed or has been removed. The bottom contact is gradational with the silty, dark- to medium-gray shale facies or laminated medium-gray shale facies. Underclays are not well lithified and wash out during drilling of oil wells. On caliper logs they appear as large diameter parts of the hole.

Coal

Coals are black (N1), banded and contain pyrite and sulfate minerals in cleats (Fig. 55 B). Coals are sharply overlain by a shelly lag or by a black or dark- to medium-gray shale and abruptly overlie a light-gray underclay. Vitrinite reflectance is an indicator of the carbon or volatile-matter yield of a coal. Vitrinite reflectance values from Barker et al. (in press) indicate that coals in the Cherokee Group are high volatile bituminous with a rank ranging between A and C. Brady (1990) reported average proximate, energy and sulfur values for Cherokee coals along the outcrop belt in southeastern Kansas and southwestern Missouri: moisture, 3.5 percent; volatile matter, 34.7 percent; fixed carbon, 46.6 percent; ash, 15.2 percent; BTU, 12,000; sulfur, 5.1 percent. Table 4 lists the values for moisture, volatile matter, fixed carbon, ash, sulfur, and Btu/lb for the Mulky, Bevier, Croweburg, Mineral, Drywood, Rowe, and Aw coal beds occurring in coal mines in southeastern Kansas and southwestern Missouri (Brady and Hatch, in review; Wedge and Hatch, 1980). Coals observed in cores ranged from 0.5 to 2 ft (0.15 to 0.6 m) in thickness, whereas coals observed from well log responses ranged from 1 to 4 ft (0.3 to 1.2 m) in thickness with an average thickness of about 2 ft (0.6 m). Coals are recognized on neutron logs by a

Coal bed	# samples		Moisture	Vol. matter	Fixed C	Ash	Sulfur	Btu/lb
Mulky	5	high	3.4	39.9	52.6	12.1	5.0	12,780
		low	2.7	33.5	45.5	10.3	4.3	12,530
		mean	3.0	38.3	47.4	11.4	4.6	12,696
Bevier	2		4.0	36.8	48.7	12.3	3.0	12,440
			3.8	35.3	48.4	10.7	2.4	12,060
			3.9	36.1	48.6	11.5	2.7	12,250
Croweburg	7		4.5	37.9	47.1	23.6	6.1	12,550
			1.9	31.5	41.0	12.8	3.0	10,780
			3.2	35.4	44.2	17.2	4.5	11,706
Mineral	8		6.2	37.2	49.9	17.2	5.4	12,690
			2.3	32.7	41.8	11.9	4.4	11,230
			4.3	35.6	45.6	14.5	4.7	12,084
Drywood	3		3.7	35.5	48.3	31.1	12.8	12,560
			1.9	28.2	37.0	14.3	4.5	9,290
			2.7	31.9	43.6	21.8	8.4	11,060
Rowe	5		4.4	35.3	49.4	21.0	12.3	12,260
			1.7	33.2	43.3	13.0	6.3	10,970
			3.0	34.1	46.1	16.9	8.8	11,724
Aw	1		3.3	31.2	50.4	15.1	4.1	12,060

Table 4. Analyses of moisture, volatile matter, fixed carbon, ash, sulfur, and Btu/lb of Cherokee Group coals sampled from coal mines in southeastern Kansas and southwestern Missouri (Brady and Hatch, in review; Wedge and Hatch, 1980).

sharp deflection to the left, indicating high porosity. Coal responses on a gamma-ray log will deflect to the left, indicating very low gamma-ray activity.

Shelly lag - The shelly lag facies is a grayish-black (N2) to dark-gray (N3), structureless, and calcareous mudstone that is equivalent to Howe's (1956) dark, irregular limestone and to Harris's (1984) argillaceous limestone facies. Brachiopods, bivalves, gastropods, bryozoans, crinoid columnals, simple corals and other fossil fragments are normally the most abundant fossils in this facies (Howe, 1956; Harris, 1984; Fig. 54). Macerated plant debris may also be present along with vague, low angle cross-stratification (Harris,1984). Recorded thicknesses from cores were up to 15 cm with an average thickness of 6 cm, but Harris reported thicknesses of up to 3 ft (0.9 m) in outcrops in southeastern Kansas. Harris also reported that about about 46 percent of Cherokee Group coal beds were overlian by shelly lags. Howe (1956) observed shelly lags occurring above the Neutral, Rowe, Bluejacket B, Scammon, Mineral, Robinson Branch, Fleming, and Bevier coal beds in outcrops in southeastern Kansas. This facies was commonly observed in cores, but not in well logs because of limited vertical resolution. The shelly lag facies commonly has a sharp and sometimes scoured lower contact with a coal or an underclay if no coal is present. The upper contact with the overlying black shale facies is gradational.

Black shale - Black shale contains millimeter scale laminations of silt and mud and may be fissile. The color of this facies is actually grayish-black (N2) to dark-gray (N3), but is referred to as black to be consistant with previous and current publications of this facies. This lithofacies typically contains brachiopods, echinoderms, bivalves, gastropods, ostracodes, fish scales, and abundant terrestrial plant fragments (Howe, 1956; Harris, 1984).

Phosphate nodules, pyrite and calcareous concretions are common diagenetic features. Phosphate nodules are commonly found in the black shale of the Cabaniss Formation, but not in the Krebs Formation (Howe, 1956). Howe (1956) reported thicknesses of this facies in outcrops in southeastern Kansas ranging from 1 to 10 ft (0.3 to 3.0 m), with an average of about 6 ft (1.8 m). Thicknesses observed from well logs in this study ranged from 1 to 6 ft (0.3 to 1.8 m), with an average of about 3 ft (0.9 m). This facies is characterized by a high gamma-ray log response and a gradational lower contact with a shelly lag deposit, or a sharp lower contact with a coal or underclay and has an upper contact that grades into a laminated, dark- to medium-gray shale.

Heckel (1977) suggested that more than one type of black shale exists in the Cherokee Group. He noted that the Excello shale and the "V" shale (Coveney et al., 1991) had proportionally greater abundances of marine-derived organic material than did other black shales in the Cherokee Group, which were higher in land-derived humic components. The two types of black shale marker beds found in the Cherokee Group are referred to here as Type 1 (Fig. 56) and Type 2 (Fig. 54). Type 1 black shales are characterized by a high gamma-ray response, moderate amounts of phosphate nodules, and possibly higher marine sapropelic organic matter (Runnells et al., 1952; Coveny et al., 1991). Type 2 black shales have a lower gamma-ray response, no phosphate nodules, minor amounts of silt, and possible a higher content of land-derived (humic) organic material. Type 1 black shales include the Excello, and "V", and those above the Tebo, Weir-Pittsburg, and in places the Bluejacket B coal beds. Type 2 black shales include those above the Bevier, Mineral, and Scammon coals, and in

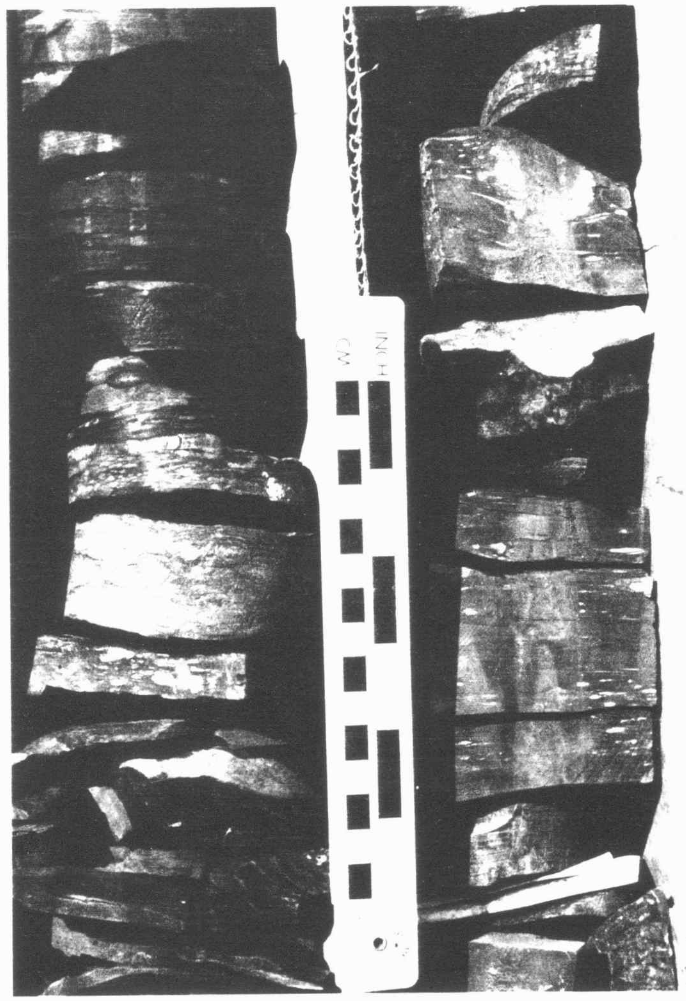


Figure 56. Photograph of a slabbed core showing a Type 1 black shale, which overlies the Bluejacket B coal bed. (Sample from Keown 18AO, NE-NW-SW Sec. 22-T23S-R18E, Allen County, Kansas, 1086')

places those above the Bluejacket B and Riverton coal beds and the A-B shale. Unfortunately, the gamma-ray logs used in this study were uncalibrated, so that quantitative differentiation of Type 1 and Type 2 black shales is not possible. Type 1 shales give an extremely high gamma-ray reading, while Type 2 shales give a lower response, but still higher than average shale. The possibility that differences in gamma-ray responses may be a direct result of Type 1 shales being thicker than Type 2 shales was considered. Both shale types ranged from 1 to 6 ft (0.3 to 1.8 m) thick and had an average thickness of about 3 ft (0.9 m). In a majority of wells it was observed that Type 1 and Type 2 shales of equal thickness, would give different gamma-ray responses. Relative gamma-ray responses of Type 1 and Type 2 shales appears to be independent of the thickness.

Gamma-ray responses reflect the amount of radioactive isotopes of Th, U, and K present in the shale. Most black shales are radioactive because of anomalously high U values. High content of organic material and reducing environments favor fixing of uranium (Doveton, 1988). Type 1 black shales may have been deposited farther offshore in deeper, more reducing environments than Type 2 black shales. Therefore, Type 1 black shales should have a higher uranium content than Type 2 black shales. Middelburg et al. (1991) conducted high-resolution profiles of organic carbon, Mo, V, and U, in cores from Kau Bay (Indonesia) and the Black Sea, which are both silled basins. The transgressive sequence preserved in these silled basins reflects a change from a fresh-water-brackish water lake to an anoxic marine basin. They found that fresh- to brackish-water sediments were characterized by high contents of terrestrial organic matter, average Mo and U concentrations, while fresh to marine-water transitional facies had a predominance of marine organic matter and were enriched in Mo, V, and U. The marine facies was moderately rich in organic carbon and slightly enriched in Mo and U. Type 1 black shales have charcteristics similar to the fresh to marine-water transitional facies and Type 2 black shales resemble the fresh-to brackish-water facies.

However, data from Coveney et al. (1991) tends to contradict aspects of the proposed Type 1 and Type 2 black shale hypothesis. Coveney et al. used Mo abundances to classify black shales into two end member types: Heebner-type (offshore) and Mecca-type (nearshore): Heebner-type (Mo-poor) black shales formed offshore and contain relatively low amounts of terrestrial organic matter, Mo, V, U, and Se, but abundant phosphate and marine organic matter. Heebner-type shales include the "V" shale and possibly the Excello (Runnells et al., 1952) of the Middle Pennsylvanian and numerous others of the Upper Pennsylvanian. The "V" and Mecca Quarry Shales are stratigraphically equivalent, but contain different ratios of organic and chemical components because they may have different depositional environments. Mecca-type (Mo-rich) black shales formed near the ancient (deltaic) shoreline and are enriched in terrestrial organic matter, Mo, V, U, and Se, but only slightly phosphatic. Mecca-type shales are only known in the Middle Pennsylvanian.

Middelburg et al. (1991) and Coveney et al. (1991) disagreed on the abundances of Mo, V, and U occurring in nearshore and offshore sediments, but agreed on amounts of terrestrial and marine organic matter. Heckel (in press) noted that nearshore, Mecca-type shales described by Coveney et al. (1991) probably represent the more shoreward extent of the offshore black shale facies deposited during maxium transgression and were not deposited in a shoreline environment. The high terrestrial organic content of Type 2 and Mecca-type shales has been attributed to their proximity to freshwater runoff from densely vegetated shore enviroments. Another possible influx of humic organic material could have occurred during the initial phases of the marine transgression (Walton, pers. com., 1991). During the initial phases of transgression, the underlying peat deposits may have been eroded and reworked into the overlying black shale. A ravinement surface, represented by a shelly lag deposit, directly overlies a coal bed or in many instances has removed the coal and overlies an underclay. Evidence of scouring into the underlying units is needed to identify a ravinement surface.

High concentrations of organic matter that accumulated under a range of reducing conditions may be responsible for higher gamma-ray readings in Type 1 black shales versus Type 2 black shales. To test this suggestion, Type 1 and Type 2 black shales should be analyzed for specific organic content. The quantity of sapropelic versus humic organic content should then be compared with gamma-ray log responses from calibrated well logs.

Gamma-ray response, phosphate abundance, and possibly organic components were the principal differences observed between Type 1 and Type 2 black shales. Type 1 and Type 2 shales are similar in that they occur within the same interval in a vertical stratigraphic sequence. Both shale types overlie a shelly lag, an underclay, or a coal deposit, grade upward into a dark- to medium-gray shale, and form the basal part of a coarsening-upward sequence.

Depositional environment

Several models have been proposed for the depositional environment of black shales. This study favors the model proposed by Heckel (1977), which attributed upwelling of cold, deep, anoxic, phosphate-rich water as being responsible for formation of the black shale. Heckel (1991) suggested that fluctuations in the pycnocline (long-term density stratification) may cause bottom waters to be dysoxic (forming the dark-gray facies) to anoxic (forming the black facies). Heckel's modified thermocline model, which includes the pycnocline, may account for the observed differences between Type 1 black and Type 2 black shales. Under this scenerio, Type 1 black shales would have been deposited farther basinward under anoxic, phosphatic, and possibly under conditions favoring intense uranium fixing and away from terrestrial organic input, whereas Type 2 black shales would have been deposited in a nearer shore position closer to terrestrial organic input and on the dysoxic fringes of the pycnocline removed from phosphatic production.

Other models suggest that the black shales of the Cherokee Group were deposited in a shallow water, restricted, marine bay environment (Howe, 1956; Wanless et al., 1969; Harris, 1984). Black shales, characterized by quiet-water deposition, reducing conditions, and carbonaceous sediments are currently being deposited in interditributary bays and lakes of the modern Mississippi delta (Frazier, 1967; Coleman and Prior, 1982). Frazier (1967) reported that marine inundation of the Maringouin delta lobe of the Mississippi delta complex resulted in bay deposits containing shell debris overlying the delta plain facies, similar to the shelly lags of the Cherokee.

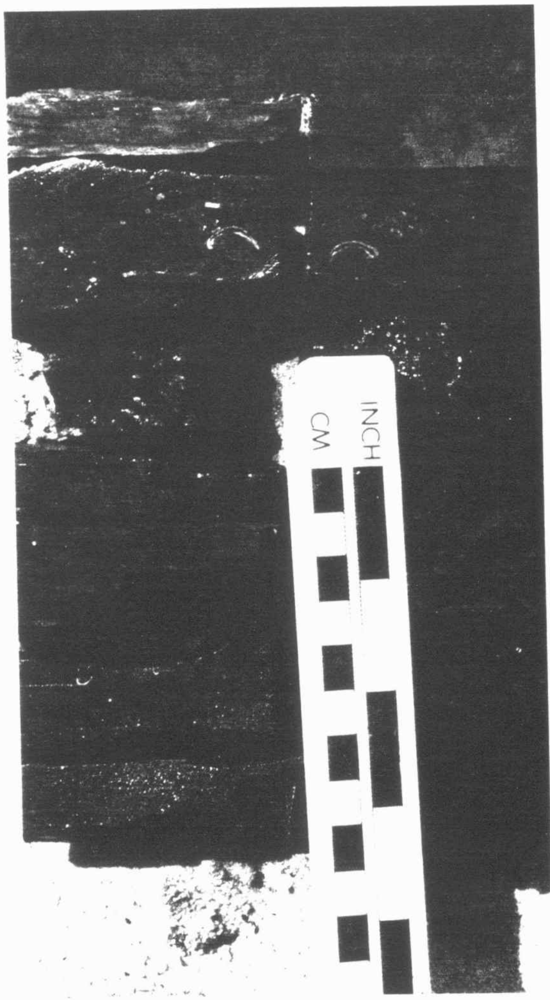
Coarsening-upward sequence

Well log responses and core descriptions show that two common types of successions in the Cherokee, coarsening-upward and shale-dominated sequences, consist predominately of mudstones, siltstones, and fine sandstones.

Mudstones

Dark- to medium-gray shale - Dark- to medium-gray shale is grayish-black (N2) to medium-gray (N5) and consists of millimeter-scale laminations of quartz silt and clay (Fig. 57). This facies lacks phosphatic nodules and is non-fissile, although it does contain brachiopods, criniods, and other marine fauna along with vertical and horizontal burrows. Observations from cores and well logs indicate thicknesses ranging from 5 to 50 ft (1.5 to 15.2 m). Dark- to medium-gray shale becomes increasingly silty and micaceous as it grades vertically into a laminated medium-gray shale or a siltstone. This facies may overlie coal, or underclay if coal is not present. Dark- to medium-gray shale is distinguished from black shale on a well log by a lower gamma-ray response.

Laminated medium-gray shale - Laminated medium-gray shale is medium dark-gray (N4) to medium light-gray (N6) and is characterized by 1 to 2 mm thick coarse-fine laminations of silt and mud and has a "poker chip" appearance in core samples (Fig. 58). Carbonized plant material such as fossil leaves is the most common fossil type. Marine body fossils are absent, although there is burrowing in places. Common diagenetic features include pryite and clay ironstone concretions. Laminated medium-gray shale ranges in thickness from 5 to 30 ft (1.5 to 9.1 m). This lithofacies becomes increasingly silty as it grades vertically into a siltstone or an underclay or coal. The laminated medium-gray shale facies has a gradational lower contact with a black shale facies or a dark- to



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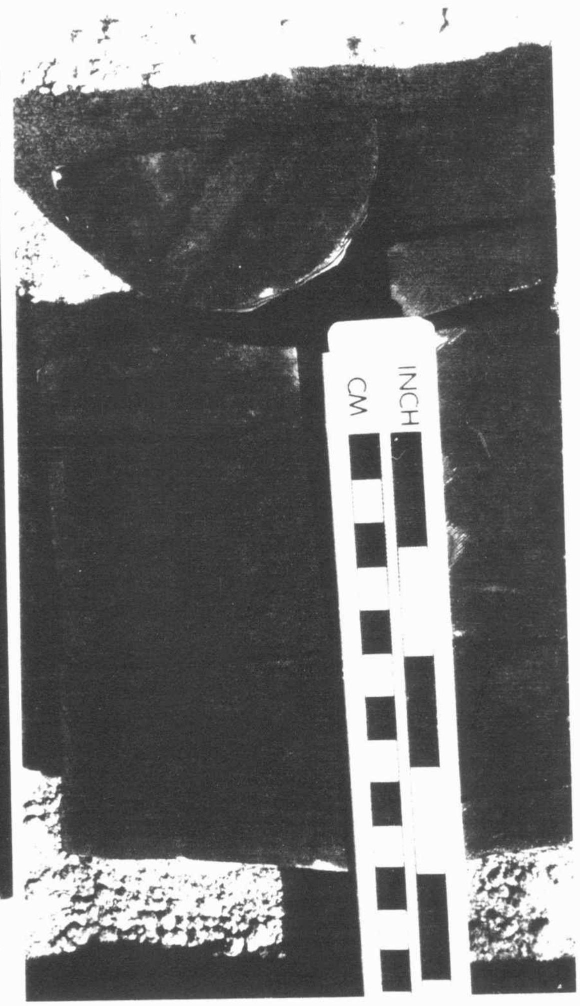


58

Figure 57. Photograph of a slabbed core showing a dark- to medium-gray shale. (Sample from Keown 18AO, NE-NW-SW Sec. 22-T23S-R18E, Allen County, Kansas, 891')

Figure 58. Photograph of a slabbed core showing a laminated medium-gray shale. Note the plant fragment in the upper left corner. (Sample from Keown 18AO, NE-NW-SW Sec. 22-T23S-R18E, Allen County, Kansas, 858')

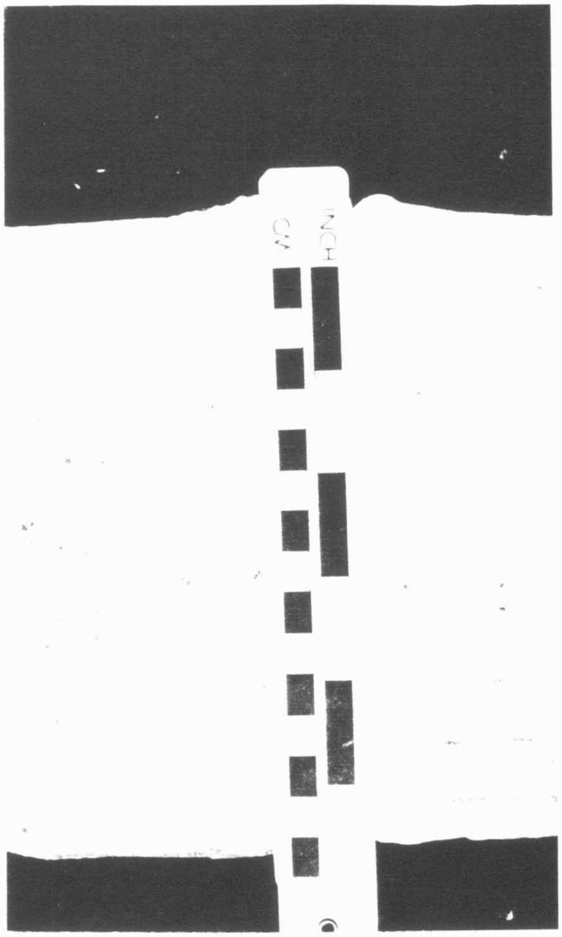
medium-gray shale facies.

Siltstone

Structureless siltstone - Structureless siltstone is light-gray (N7), micaceous, and contains minor amounts of quartz and carbonized plant fragments. Vertical and horizontal burrows and pyrite are common. This lithofacies may grade upward into an underclay or coal and averages less than a meter thick. The lower contact with the laminated medium-gray shale facies is also gradational.

Laminated siltstone - Laminated siltstone is light-gray (N7) and is characterized by alternating coarse-fine silt and mudstone laminations that average 3 mm in thickness and in places may show graded bedding. Vertical and horizontal burrows may occur in the mudstone portion this lithofacies (Fig. 59 and 60). Laminated siltstone may be micaceous, contain pyrite, and have load structures and convolute laminations. Measurements from well logs and cores indicate that this facies has an average thickness of about 10 ft (3.0 m) and has extremes ranging from 2 to 30 ft (0.6 to 9.1 m) thick. Laminated siltstone is found in the middle of coarsening-upward sequences and grades upward into rippled and cross-laminated fine sand. Laminated siltstone has a gradational lower contact with a structureless siltstone or a laminated medium-gray shale.

Ripple-laminated siltstone - Ripple-laminated siltstone is light-gray (N7) and has lenses of fine sand, one to two mm thick and cross-laminated, occurring within the troughs of the ripples. Small ripple laminations are unidirectional and may display climbing sequences (Fig. 61). Convolute structures are common, but burrowing is not. Ripple-laminated siltstone ranges in thickness from 1 to 15 ft (0.3 to 4.6 m). This



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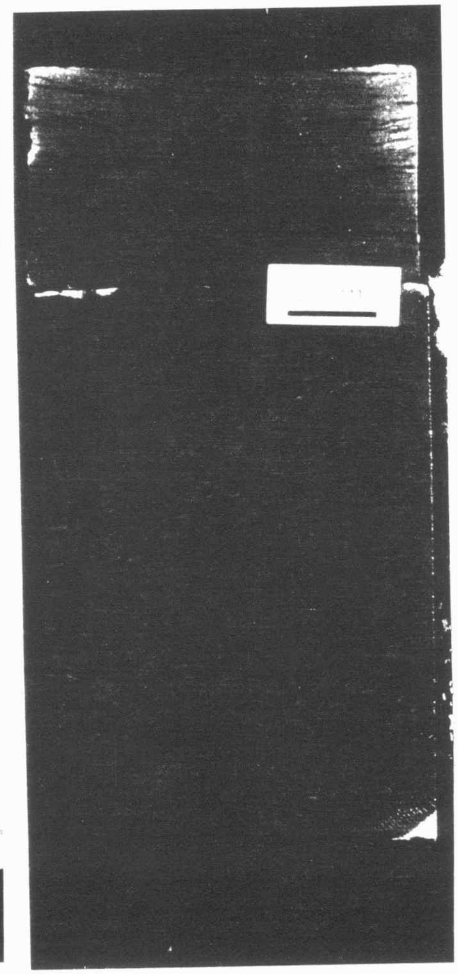

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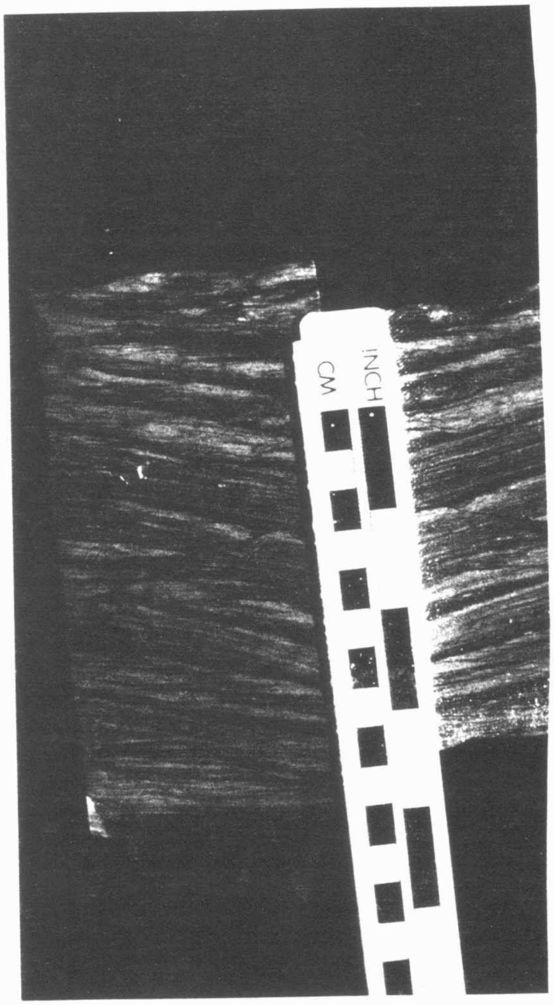
Figure 59. Photograph of a slabbed core showing a laminated siltstone. (Sample from Keown 18AO, NE-NW-SW Sec. 22-T23S-R18E, Allen County, Kansas, 850')

Figure 60. Photograph of a slabbed core showing a convolute bedded siltstone at the base and grading upward into a laminated siltstone. (Sample from L. R. Smethers CT#1, N-NE-NE Sec. 9-T21S-R19E, Anderson County, Kansas, 880'-881')



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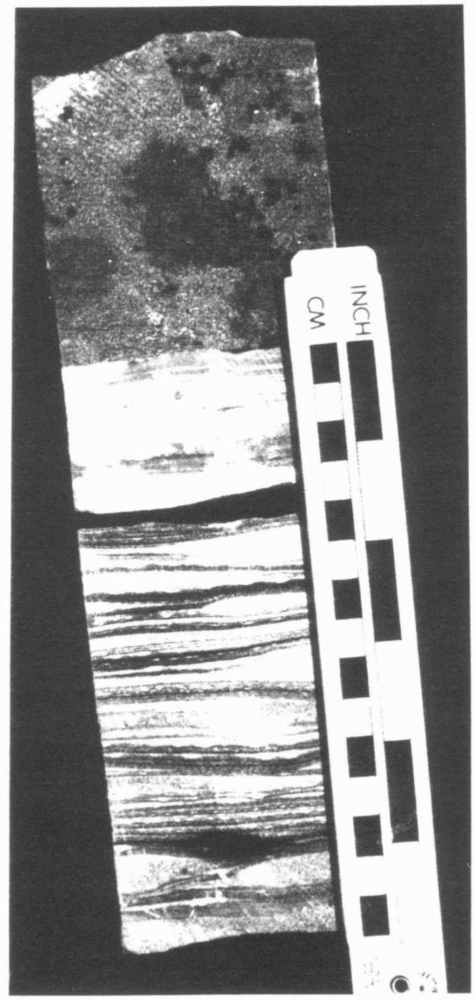

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Figure 61. Photograph of a slabbed core showing a ripple-laminated siltstone. (Sample from Keown 18AO, NE-NW-SW Sec. 22-T23S-R18E, Allen County, Kansas, 1144')

Figure 62. Photograph of a slabbed core showing a lenticular- to wavey-bedded siltstone abruptly overlain by a structureless fine-grained sandstone. (Sample from Keown 18AO, NE-NW-SW Sec. 22-T23S-R18E, Allen County, Kansas, 970')

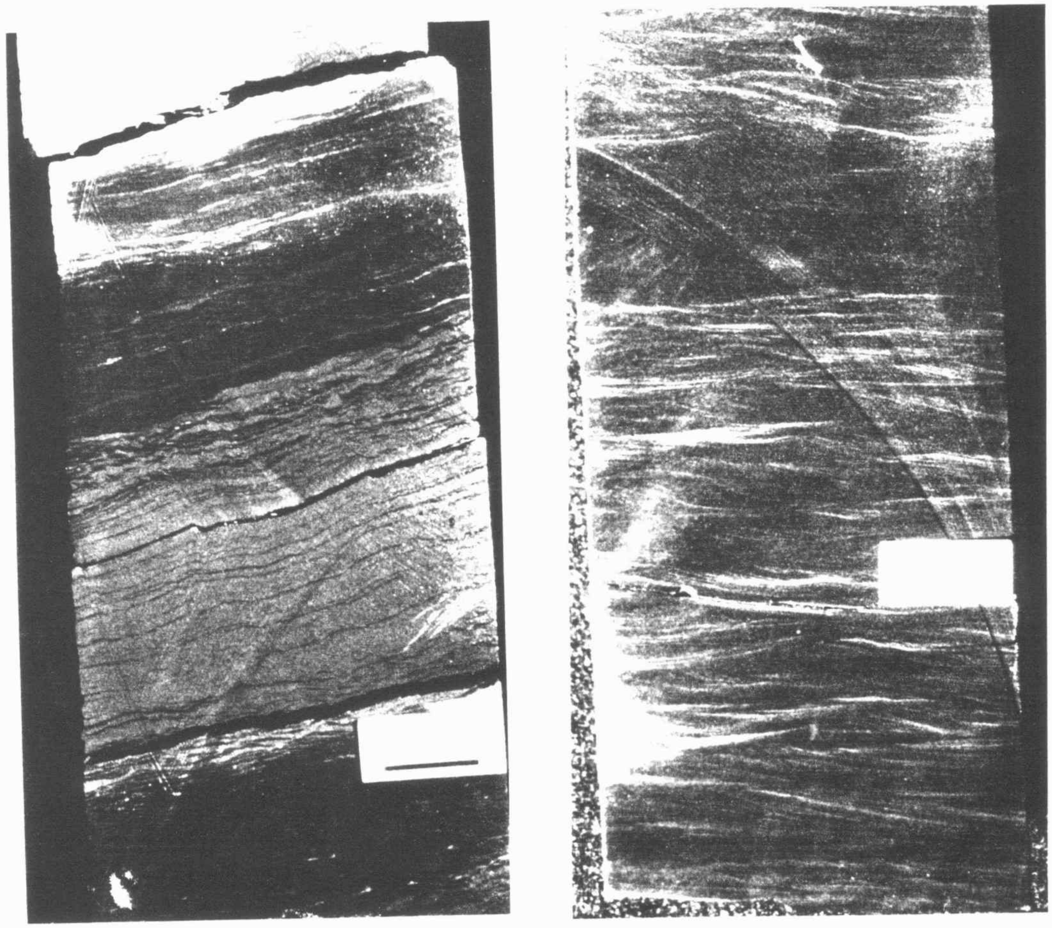
facies may coarsen upward into a fine sand or cap a fine sand. Ripple-laminated siltstone may also be intergradational with lenticular- to wavy-bedded siltstone.

Lenticular- to wavy bedded siltstone - Lenticular- to wavy bedded siltstone consists of light-gray (N7) mud interlaminated with thin (5 mm to 1cm) light-gray (N7) silt lenses (Fig. 62). This facies ranges from 1 to 10 ft (0.3 to 3.0 m) in thickness. This facies is intergradational with the ripple-laminated siltstone facies and is usually found at the siltstone and shale breaks near the top of fining-upward sequences and less commonly occurs towards the top of a coarsening-upward sequence.

Fine sandstone

Ripple-laminated fine sandstone - Ripple-laminated fine sandstone contains unidirectional current ripples and may be interbedded with a small-scale cross-stratified fine sandstone (Figs. 63 A). It commonly has a gradational lower contact with the ripple-laminated siltstone facies and may be found towards the top of a coarsening-upward sequence. Carbonaceous material and convolute beds are common. Vertical and horizontal burrows are rare.

Cross-bedded fine sandstone - This lithofacies is composed of moderately sorted quartz, mica, and rock fragments and carbonaceous material and has a very light-gray (N8) color. Trough or planar cross-beds are common, with bedsets 1 to 5 cm apart (Fig. 63 B and 64). Low angle bedsets may be draped by mud and carbonaceous debris. Mud rip-up clasts, up to 3 cm long, are found at the base of the sandstone where it has scoured into an underlying shale. Cross-bedded fine sandstone ranges in thickness from 1 to 20 ft (0.3 to 6.1 m). This facies is commonly interbedded



63A

63B

Figure 63 A. Photograph of a slabbed core showing a ripple-laminated fine sandstone. (Sample from L. R. Smethers CT#1, N-NE-NE Sec. 9-T21S-R19E, Anderson County, Kansas, 879'-880')

Figure 63 B. Photograph of a slabbed core showing a small-scale cross-stratified fine sandstone. (Sample from M. Setter #2, SW-NE-SE Sec. 22-T25S-R19E, Allen County, Kansas, 858'-859')

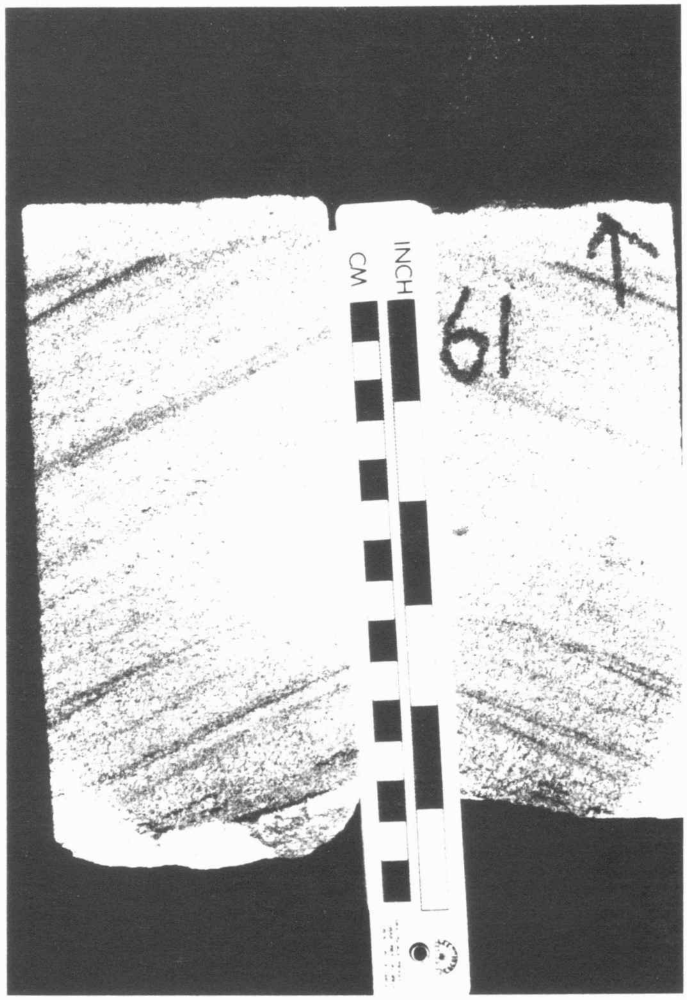


Figure 64. Photograph of a slabbed core showing a cross-bedded fine sandstone. (Sample from Keown 18AO, NE-NW-SW Sec. 22-T23S-R18E, Allen County, Kansas, 1165')

with ripple-laminated fine sandstone, may have convolute beds, and may be oil stained. This facies also may cap a coarsening upward sequence, having graded up from a ripple-laminated siltstone below. Several authors, including Walton et al. (1986) and Jordan and Tillman (1987), have recognized this facies as a good hydrocarbon reservoir.

Vertical sequence

The typical coarsening-upward sequence gives a distinctive inverted bell-shaped gamma-ray-neutron well-log response. At the base of a coarsening-upward sequence there is a shelly lag overlain by a black shale, which gives a high to moderate gamma-ray response and is part of the marker sequence. This facies grades upward into a dark- to medium-gray shale which in turn grades upward into a laminated medium-gray shale. The laminated medium-gray shale facies coarsens upward into a laminated and ripple-laminated siltstone and cross-bedded, fine-grained sandstone. Hydocarbons occur occasionally in the fine-grained sandstone facies, but less frequently in the rippled siltstone. Cross-bedded, fine-grained sandstone grades back into a ripple-laminated or laminated siltstone which passes upward into an underclay and coal. Capping the coal and starting the next coarsening-upward sequence may be a shelly lag or black shale which has a sharp and often scoured lower contact with the coal or underclay below. The typical sequence ranges from 20 to 50 ft (6.1 to 15.2 m) from the bottom of the shelly lag facies to the top of the coal.

This study recognized seven coarsening-upward sequences (CUS) in the interval from the Weir-Pittsburg marker to the base of the Excello shale (Fig. 65A and B). However, this study focused on the four most persistent coarsening-upward sequences that occurred within the Tebo, Scammon,

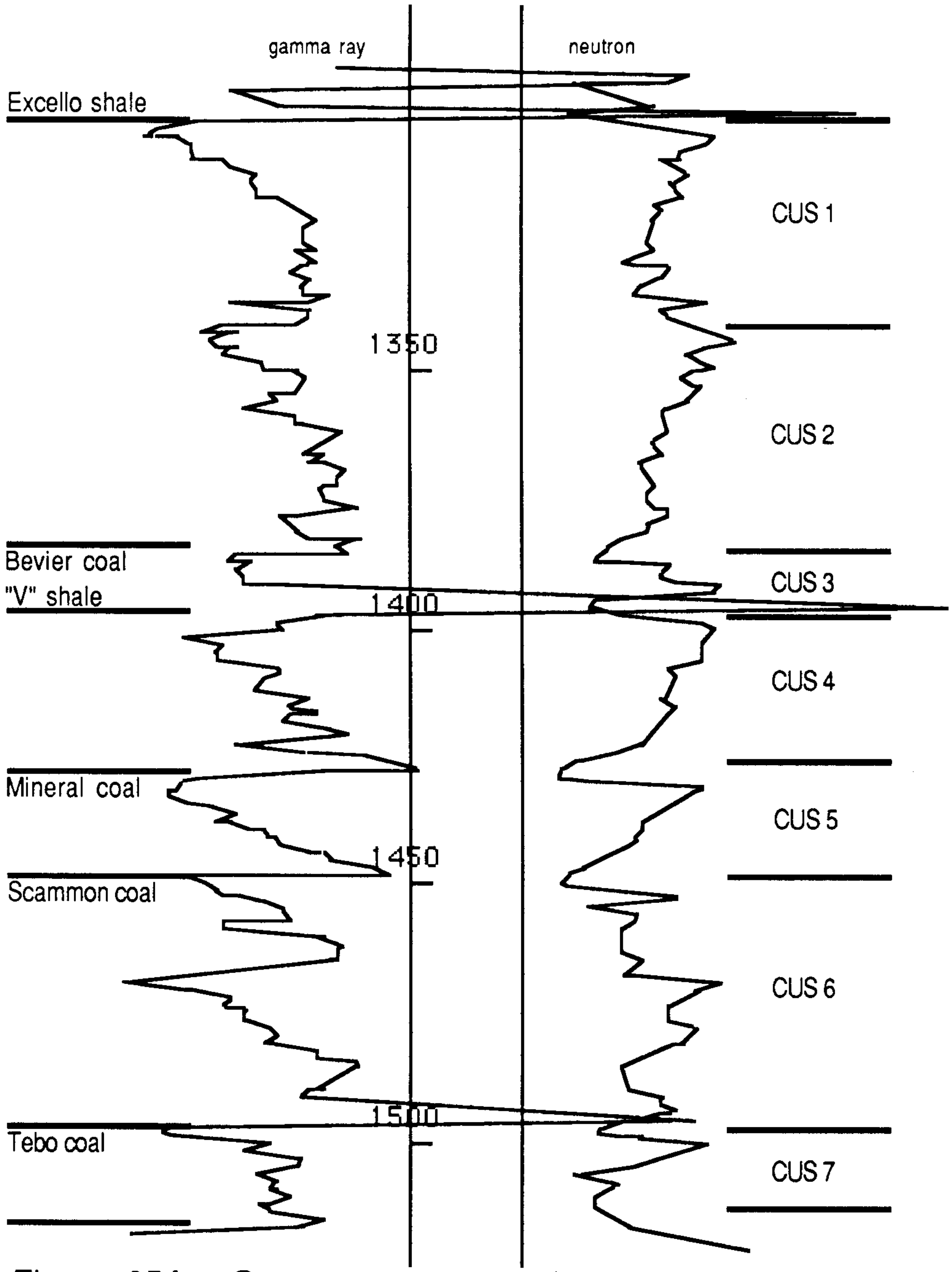


Figure 65A. Gamma-ray-neutron log response for coarsening-upward squences (CUS). Sinclair Oil & Gas Co., J. W. Maclaskey #24, 32-23S-14E, Woodson County, Kansas.

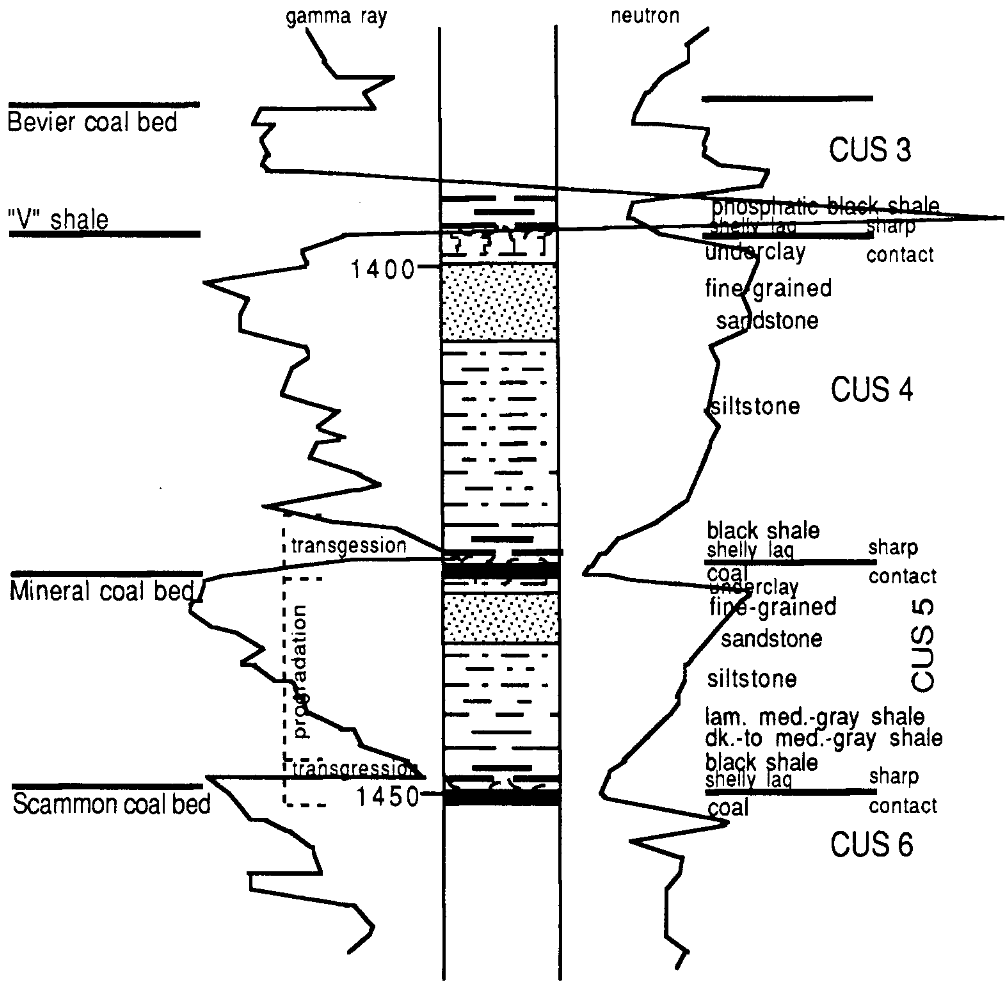
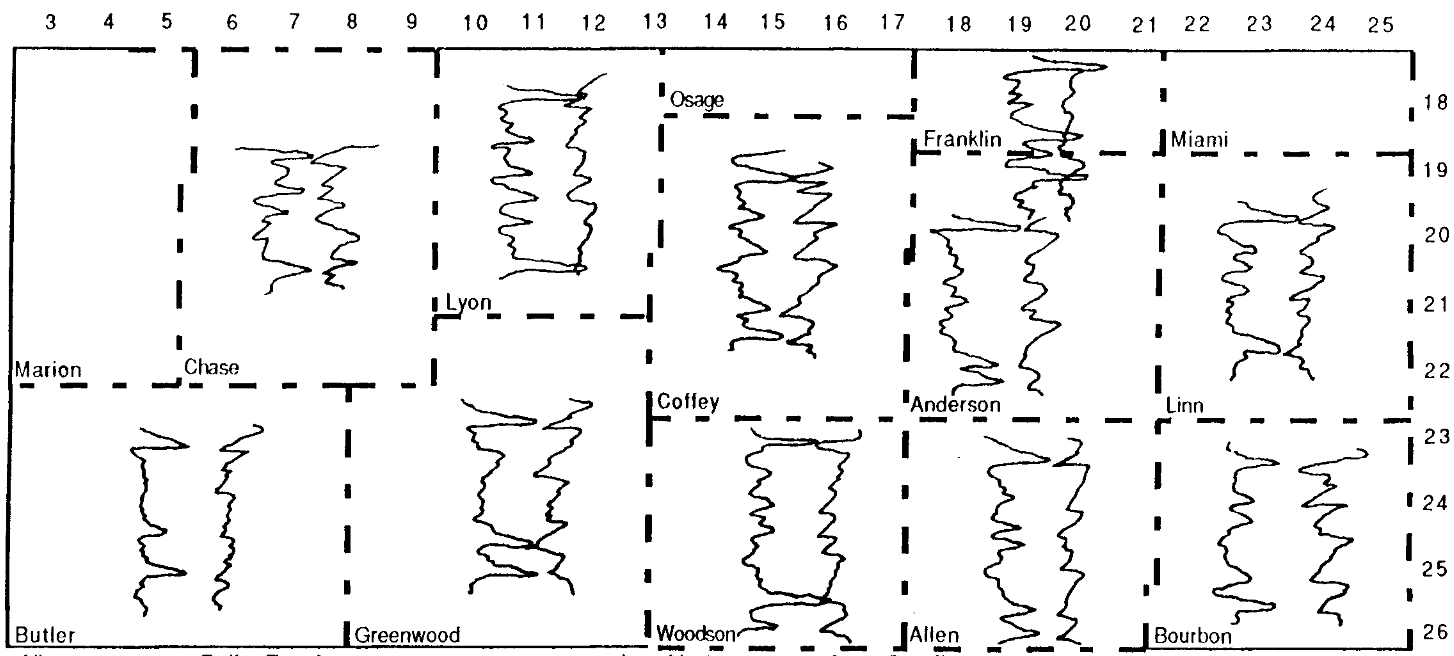


Figure 65B. Gamma-ray-neutron log response for coarsening-upward seqeunces (CUS). Coal, shelly lag and black shale were deposited during a transgression and are overlain by a coarsening-upward sequence deposited during deltaic progradation and regression. Sinclair Oil & Gas Co., J. W. Maclaskey #24, 32-23S-14E, Woodson County, Kansas.

Mineral, and Croweburg intervals. Each of the four sequences were present throughout this study area and Staton's (1987) study area in southeastern Kansas, for a total area of nearly 13,500 mi^2 (35,000 km^2). They reportedly extend into the Kansas City area of the Forest City basin, increasing the total area to about 17,400 mi^2 (45,000 km^2) . Figure 66 shows the regional distribution of the coarsening-upward sequences occurring in the study area.

Coarsening-upward sequences have been documented elswhere in the Cherokee Group. Visher et al. (1971) recognized coarsening-upward sequences in the Bluejacket-Bartlesville sandstone of the lower Cherokee Group in eastern Oklahoma. Murphy (1978) studied the Cherokee Group along the outcrop belt in southeastern Kansas and recognized five cycles of progradation between the Scammon marker and the "V" shale. Strickland (1987) applied transgressive and regressive sequences to the proposed Riverton formation in the Forest City basin. Heckel (1986) observed four transgressive and regressive sequences from the Verdigris limestone through the Excello shale. Brenner (1989), using well log responses and core descriptions, identified the same four cycles as Heckel, including an additional sedimentary sequence within the same interval. Staton (1987), using well log signatures and core data, recognized five sedimentary cycles from the Bluejacket B marker through the "V" shale in southeastern Kansas.

Numerous examples of coarsening-upward sequences occurring in modern deltaic environments have been documented, but studies by Frazier (1967), who reported common occurrences of coarsening-upward sequences in the Mississippi River delta complex, and Courel (1989) who



Allen	Bulfer Exp. Inc.	Lenski #1	20-24S-19E
Anderson	James E. Russell Petroleum, Inc.	J.Q. Adams #1	13-23S-19E
Bourbon	Franklin Oil Enterprises	Dotson #105	26-26S-21E
Butler	Little Nell Oil Corporation, Inc.	Simon #2	22-26S-7E
Chase	Brandt Oil Co.	Rettiger #1	20-19S-8E
Coffey	Teichgraeber-Westran	Warren #3	25-20S-14E
Franklin	Alco Drilling Inc.	Rubick #1	16-18S-18E
Greenwood	Icer Addis	Elmer Hollis #1	20-23S-10E
Linn	Scimitar Resources	Clark #2	15-20S-22E
Lyon	Jackson Brothers	Pixley #20	34-21S-10E
Woodson	Mecca Petroleum Corp.	Mecca-Sheedy #3	26-25S-14E

Figure 66. Weir-Pittsburg through "V" shale interval coarsening-upward gamma-ray - neutron well log responses. Type log locations are listed below.

observed similar coarsening-upward sequences occurring in deltaic deposits of the Jerada basin of Morocco, and Allen et al. (1979), who studied the Mahakam delta off the eastern coast of Kalimantan in Indonesia, may be the best modern anologs to the coarsening-upward sequences obeserved in the Cherokee Group.

Depositional environments

The radioactive, black shale lying above the shelly lag at the base of a coarsening-upward sequence possibly marks the position of maximum depth of marine waters or the maximum rate of transgression (Heckel, 1977). Black shale and shelly lag deposits, characterized by quiet-water deposition, abundant burrowing, and organic sediments, were reported by Frazier (1967) and Coleman and Prior (1982) to have occurred in interdistributary lakes or bay bottoms of the modern Mississippi delta. However, lateral consistency, presence of marine organisms, and lack of burrowing suggest that black shale and shelly lag deposits are open marine sediments that were deposited during a transgression. The black shale grades upward into dark- to medium gray shale, which contains millimeter-scale laminations of silt and mud, abundant marine fauna, and vertical and horizontal burrows, indicating deposition in a calm normal marine shelf environment. Coleman and Prior (1982) and Elliott (1986) stated that diverse marine fauna and burrows are indicative of an open, inner to outer shelf depositional environment and that silt and mud laminations resulted from sediment settling out of suspension.

Dark- to medium-gray shale grades upward into a laminated medium-gray shale, which is characterized by millimeter-scale coarse-fine silt and mud laminations, carbonized plant material, an absence of marine organisms, and sparse burrowing. The sequence becomes increasingly siltier as it grades upward into a laminated siltstone, which is characterized by coarse-fine silt and mudstone laminations that average 3 mm in thickness and in places may be graded. The silt and mud laminations of these facies accumulated in an environment with alternating energy and an abundant supply of sediment, possibly in a prodelta, distal bar, or distributary bay of a deltaic system, or a low-energy shoreline. Silt and mud laminations may have been deposited in an offshore or in a distributary bay environment by suspension or as a result of mass movement processes, possibly sediment gravity flows (Frazier, 1967), or crevasses. The absence of marine organisms and burrows was probably due to rapid deposition of sediments or because of fluctuating water salinity.

The possibility that tidal processes similar to those described by Kvale and Archer (1990) were responsible for the laminated mudstones and siltstones of this study was considered. Kvale and Archer interpreted rhythmically interlaminated mudstones and siltstones, occurring above low-sulfur coals in Lower Pennsylvanian sediments in Indiana, as having formed in brackish water tidal deposits in an estuarine environment (tidalites). The laminated mudstone and siltstone facies of this study were not rhythmically interlayered and usually occurred in the middle of a coarsening-upward sequence, not above a coal. However, lack of rhythmicity and location in the stratigraphic sequence does not exclude the possibility of tidal processes acting on these facies.

Laminated medium-gray shale and siltstone coarsen upward into ripple-laminated siltstone and cross-bedded, fine-grained sandstone, indicating that deposition was closer to the source of sediment input or occurred under conditions of increasing energy. Ripple-laminated siltstone consists of unidirectional, small ripple laminations that display climbing sequences and convolute bedding. Cross-bedded, fine-grained sandstone is characterized by trough to planar cross-beds, mud rip-ups, convolute bedding, and carbonaceous debris. Unidirectional, small ripple laminations overlain by trough- to planar cross-beds indicate an upward-increasing current energy (Jordan and Tillman, 1987) and proximity to the splay or distributary mouth. High depositional rates are suggested by the presence of climbing ripples (Harms et al.,1982) and convolute bedding. This vertical succession suggests that the facies were deposited as a result of a prograding distal to distributary-mouth bar or as a crevasse splay into a distributary bay.

The cross-bedded, fine-grained sandstone grades into a ripple-laminated or laminated siltstone, which passes upward into an underclay or coal. The laminated siltstone is characterized by coarse-fine laminations of silt and burrowed mud, load structures and convolute bedding indicating rapid deposition in an fluctuating energy setting. Coleman and Prior (1982) reported that ripple-laminated and laminated sitstones commonly occur near the top part of distributary-mouth bar deposits as a result of overbank splays. Burrowing occurred in the mud portion of this facies between splay deposits.

The underclay most likely formed during prolonged periods of subaerial exposure and a low water table in an upper to lower delta plain environment, most likely an overbank swamp or marsh. Evidence of subaerial exposure includes the presence of carbonized plant fragments, burrows, root casts, and the leached appearance of the light-gray underclay. This lithofacies is a paleosol and the contact between the coal and underclay may be considered as a sequence boundary when applying sequence stratigraphy to the rock units (Van Wagoner, 1990).

Coals represent rapid burial of terrestrial organic matter (peat) that accumulated in paralic swamps and marshes. Autochthonous peat deposits form in a continuum of swamp environments from floating to raised and to low-lying (McCabe, 1984). Peat accumulation in floating swamps, such as the Everglades complex of southern Florida (Spackman et al., 1969), is affected by the interaction of rate of subsidence, rate of influx of fresh water, and tidal range. Raised swamps, such as those found in tropical Malaysia, have flat central areas and steep convex sides and do not reflect preexisting topography (McCabe, 1984). Low-lying swamps currently forming in the Gulf Coast region of the U.S.A. are deposited over an underlying topography and tend to build-up to a near horizontal surface (McCabe, 1984; Frazier and Osanik, 1969; Courel, 1989). Frazier and Osanik investigated recent peat deposits in the Mississippi River delta plain and concluded that peat accumulation occurred in the aggradational delta-plain facies and overlie progradational delta-front and prodelta facies. It is unclear as to the exact environment of deposition for coals in the Cherokee Group, but they were probably deposited in low-lying peat-forming swamps similar to the current Mississippi River delta (Wanless, 1975).

Many studies have been conducted relating well log responses to depositional environments in deltaic sequences and Coleman and Prior (1982) give an excellent synthesis of this. Upper delta plain lacustrine deltas, lower delta plain bays, and subaqueous delta plain distributary mouth bars are depositional environments that exhibit coarsening-upward well log responses and reflect the facies observed in a coarsening-upward sequence described in this study. Well log shapes associated with a lacustrine delta will vary, depending on the proximity to the channel, but generally retain a coarsening-upward profile (Coleman and Prior, 1982).

Coarsening-upward sequence, discussion

One major difference between lacustrine deltas and the coarsening-upward log response observed in this study is the lateral extent of the facies distribution. The coarsening-upward sequences in southeast Kansas cover at least 50,000 km^2. Lacustrine delta fills on the other hand may cover from 80 to 100 km^2. Bay fill deposits form in response to a break in the major distributary channel during flood stage, which allows crevasse deposits to build into shallow interdistributary bays (Coleman and Prior, 1982). Bay fill deposits range in thickness from 3 to 15 m, and may have an areal extent of 15 to 20 km^2 (Coleman and Prior, 1982). Distributary mouth bar deposits are progradational and result in a coarsening-upward sequence that may include lower prodelta clays, overlain by alternating silt and sand units of the distal bar, and distributary mouth bar sands (Coleman and Prior, 1982). Numerous delta lobes consisting of mouth bar deposits will enclose the entire deltaic complex as a result of distributary abandonment and lobe shifting, an area covering about 300 mi (480 km) around the periphery of the Mississippi delta complex (Frazier, 1967). The sands occurring at the top of a coarsening-upward sequence in this study were lobate and not continuous, covering 13,500 mi^2 (35,000 km^2) or an area 116 mi by 116 mi, which compares to the scale of the subaerial Mississippi delta complex.

In summary, the vertical association of facies and inverted bell shaped well-log signature suggest that a coarsening-upward sequence observed in this study represents progradation of upper and lower delta plain sediments over subaqueous delta plain deposits. The dark- to medium-gray shale facies contains abundant marine fauna and burrows, indicating an open marine environment, and are overlain by laminated medium-gray shale, laminated silt, and rippled sand indicating a progradational lower to subaqueous deltaic depositional environment. The basinward shift of coarser non-marine sediments overlying fine-grained marine sediments marks the beginning of the progradational sequence. Extensive underclays formed in the lower delta plain as coarser sediments built out basinward and over finer grained sediments.

Coal deposits formed in marshes and swamps of the lower and upper delta plain in response to a rising water table, possibly marking the initial marine transgression (Scholl, 1967). The incursion of marine water is marked by a thin, shelly lag consisting of marine fossils capping the coal. The sharp, scoured contact between the coal and the shelly lag deposit or black shale may be ravinement surface that has removed part of the underlying peat deposit. The black, radioactive shale lying directly above the shelly lag marks the beginning of the next coarsening-upward sequence.

A second possibility is that the coarsening-upward sequences represent transgressions and regressions of a tidal flat environment. In this model, peats and underclays form in supratidal flat marshes and swamps during the initial rise in sea level. As the shoreline transgresses, shell debris and upper-tidal flat mud and lagoonal muds will accumulate above the peat deposit. Shell debris accumulating in modern tidal flats may be disarticulate, indicating rapid deposition from a high-energy event, but are usually articulate, indicating very short transport distances or low energy conditions (Weimer et al., 1982). The shelly lag facies observed in this study consisted of disarticulated shells, indicating reworking and moderate transport distances that could have occurred during a transgression or during a high energy storm event. The sequence may coarsen upward as intertidal flat deposits consisting of flaser-bedded silt and mud, and ripple-bedded sand are deposited farther landward. Cross-bedded fine-grained sands, occurring next in the vertical sequence, may represent reworked offshore bars or lower tidal flat sands. Offshore marine mud may lie above the fine-grained sand deposits, marking the maximum landward extent of the transgression. A relative fall in sea level could cause a regression of the shoreline and shift the facies basinward, thus allowing an underclay to develop on the offshore shale and bar sands. However, during the relative fall in sea level, scouring and downcutting may remove much of the underlying sequence. Because of this erosion, it is not likely that a complete coarsening-upward sequence would be preserved. The position of the coal and underclay with respect to the type of facies and surface it develops on would be different in the proposed tidal flat model than from that observed in the data. The underclay and coal deposits in the tidal flat model would develop on an erosional surface possibly consisting of offshore deposits. In contrast to this, the data show that underclay forms on a conformable surface consisting of upper delta plain mud and silt deposits.

Depositional controls on coarsening-upward sequences

Mechanisms that can generate a coarsening-upward sequence in a deltaic setting are delta lobe switching and eustasy. Delta switching results from alluvial- or distributary-channel abandonment, compaction of subaqueous and lower deltaic sediments, and subsequent flooding of the abandoned delta lobe (Frazier, 1967). Frazier and Osanik (1969) illustrated that the three youngest lobes in the Holocene Saint Bernard delta in southeastern Louisiana have areal extents ranging from 300 to 3,000 mi^2 (800 to 8000 km^2). The Louisiana coastal plain, which includes the Mississippi River deltaic plain, has a areal extent of about 15,000 mi^2 (39,000 km^2) and covers approximately 300 mi (570 km) of coast line (Frazier and Osanik, 1969). The areal extent of a coarsening-upward sequence observed in this study and Staton's (1987) are at least 17,400 mi^2 (45,000 km^2), about the same observed for the entire Mississippi deltaic plain and about 5 times the area of the largest delta lobe.

The markers bounding a coarsening-upward sequence, a basal underclay and coal overlain by a shelly lag and black shale, are correlatable over much of eastern Kansas, whereas the sand occurring at the top of a sequence is not continous throughout the study area. The sand concentrations are more lobate than sheet like, reflecting the abandoning and switching nature of distributaries that supply the sand to the mouth bar deposits. The discontinuous nature of the sand bodies may also be an indication that more than one river or delta complex was supplying sediment into the basin. Delta lobe switching may occur between the markers bounding coarsening-upward sequences. Occasional interruptions from progradational events occur in the Scammon interval and were caused by river or distributary avulsion and lobe abandonment. Cross-sections E-E' and B-B' demonstrate a discontinuous coarsening-upward event present within the Scammon interval believed to represent lobe abandoment. More detailed study of the Tebo, Scammon, Mineral, and Croweburg intervals may reveal a series of delta lobes within each coarsening-upward sequence.

The extensive regional distribution of a coarsening-upward sequence and its cyclic nature suggest allocyclic controls on deposition. It is unlikely that switching of delta lobes could account for the large areal extent and cyclic nature of the coarsening-upward sequences observed in this study. Eustacy is a more likely explanation for the sequences. A eustatic model developed by Heckel (1986) attributes eustatically driven marine transgressive/regressive depositional cycles in the Middle Pennsylvanian to Gondwanan glaciation induced by Milankovitch insolation cycles. Regression of the strand line takes place during a slow build-up of polar ice caps and a gradual lowering of sea-level (Heckel, 1986). While Heckel did not address siliciclastic deposits, like the Cherokee Group, the fall in sea level would result in a coarsening-upward sequence consisting of thick prodelta clay and silt grading upward into delta front sand and lower delta plain underclay. Rapid marine transgression may take place during fast melting of the ice caps. However, the marine transgression may only appear to be rapid, when it is actually much slower. Erosion during the rise in sea-level may place relatively offshore marine facies immediately above non-marine facies, thus removing any transitional facies in the process. The transgression is marked by a relatively thin shelly lag deposit, that may represent a ravinement surface, and a black, radioactive shale above it. The black shale and shelly lag represent an abrupt increase in water depth and are considered to be a marine-flooding surface by Van Wagoner et al. (1990). A coarsening-upward sequence bounded on the top and bottom by a black shale and shelly lag represents "a relatively conformable succession of genetically related beds or bed sets bounded by marine-flooding surfaces or their correlative surfaces" or a parasequence (Van Wagoner et al., 1990, p. 8).

Heckel (1986) divided cycles into three types; minor cycles with periods from 44,000 to 118,000 years; intermediate with periods from 131,000 to 176,000 years; major with periods from 235,000 to 393,000 years. Heckel's criteria for dividing cycles into three types is based on lateral extent of marine inundation; the most extensive transgressions are marked by conodont rich, black, phosphatic shales. Using this criterion, coarsening-upward sequences observed in this study would be intermediate to minor. Heckel's model emphasized carbonate cycles, thus making it difficult to apply periodicity calculations of transgressive and regressive cycles to this study. Staton (1987) suggested that the cycles in his study area represented glacially induced eustatic sea-level changes and calculated a periodicity of about 390,000 years per cycle, making it a major cycle. Staton's calculation was based on a method devised by Heckel (1980) and later revised by Heckel (1986) because the method probably overestimated cycle length by ignoring the shorter cycles or assigning them to major cycles. Glacio-eustatic changes are probably responsible for the progradational or regressive sequences recognized in the Tebo, Scammon, Mineral, and Croweburg intervals. Visher et al. (1971) stated that Cherokee Group deposition took place in fluvial-deltaic and shallow marine complexes during a major Middle Pennsylvanian transgression that was punctuated by extensive regressions and deltaic progradations.

Shale-dominated sequence

Vertical sequence

The Riverton and A-B intervals each consist predomantly of a shale-dominated sequence, which is charcterized by black or dark- to medium-gray shale, laminated medium-gray shale, laminated siltstone, and structureless siltstone (Fig. 67). The Bluejacket B interval may consist of up to three such shale-dominated sequences. Coals, up to 1 ft (0.3 m) thick, may cap a shale-dominated sequence, which usually shows a slight coarsening-upward well log profile. At the base of a sequence there is either a dark- to medium-gray shale or a slightly radioactive, non-phosphatic, black shale, which grades upward into a laminated medium-gray shale. The laminated medium-gray shale passes into a siltstone or grades into an underclay and then a coal. A shelly lag deposit may directly overlie the coal. The shale-dominated sequence was different from the coarsening-upward sequence found in the Weir-Pittsburg through the Croweburg intervals in that it was not observed to coarsen upward into a fine sand.

Depositional environments

The lack of coarse clastics suggests that deposition occurred in a mud-dominated low-energy deltaic system, most likely in the distal to prodelta areas or possibly within the distributary bays. Harris (1984) interpreted the slightly coarsening-upward, mud-dominated sequences of the Krebs Formation as being the result of repeated infilling of interdistributary areas and cited as evidence a shallow water, restricted environment for the formation of the black shales and the vertical association of facies. Black shales forming in a restricted, shallow bay should grade

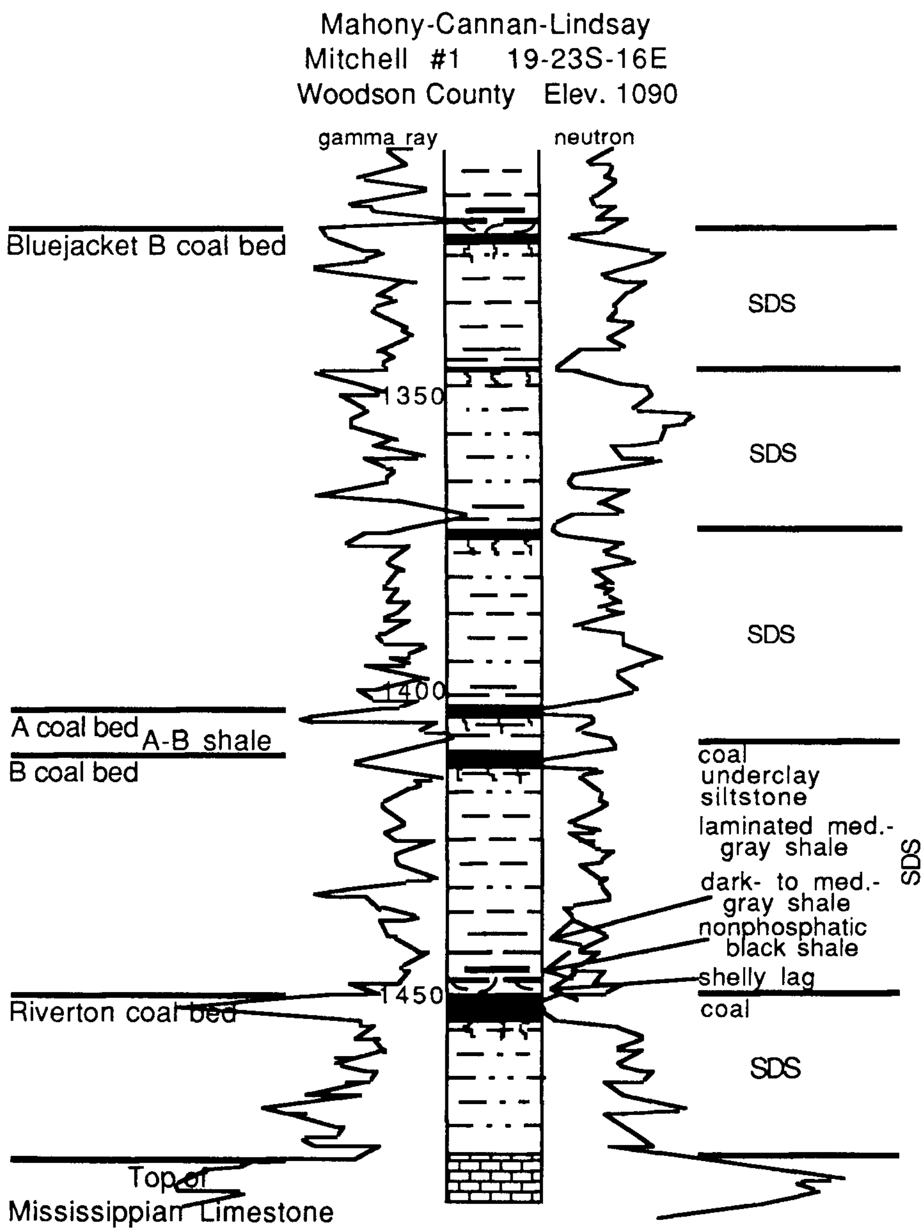


Figure 67. Gamma-ray-neutron log response for shale-dominated sequences (SDS) occurring in the Krebs Formation.

laterally into different coastal environments. Bay deposits are laterally discontinuous and have areal extents of 15 to 20 km^2 (Coleman and Prior, 1982). However, black shales and underlying coal deposits found in the Lower Cherokee Group were laterally continuous and could be correlated over at least 50,000 km^2. Black and dark- to medium-gray shales, such as those occurring above the Riverton, A-B, and Bluejacket B coals, contained marine indicators, such as brachiopods, echinoderms, bivalves, and vertical and horizontal burrows. Laterally continuous black shales represent offshore marine deposits that were probably shifted landward in response to basin-wide rises in sea level.

As the black and dark- to medium-gray shales grade upward into a laminated medium-gray shale, marine fossils become less abundant and terrestrial plant detritus and silt content increase. This facies is also characterized by 1 to 2 mm thick mud and silt laminations indicating deposition in a low energy environment that was perodically subjected to pulses of silt input. Possible depositional environments that receive pulses of silt are the distal end of a splay deposit occurring in a distributary bay and distal distributary mouth bars (Jordan and Tillman, 1987). Silt and mud are carried by wave and current action and settle out of suspension basinward of the mouth bar (Coleman and Prior, 1982).

The laminated medium-gray shale coarsens upward into a laminated siltstone consisting of burrowed mud laminations and soft sediment deformation structures. Burrowing occurred during deposition of the mud layers and ceased when silt was rapidly dumped into the system, causing load structures and convolute bedding (Coleman and Prior, 1982).

Crevasse splays occurring in distributary bays and mouth bars can cause rapid deposition of silts and fine sand followed by periods of mud deposition.

The top of a mud-dominated sequence was capped by an underclay, which commonly was overlain by a coal. The coal and underclay are interpreted to have formed on the subaerial areas of the delta plain. Directly overlying the underclay or coal and starting the next sequence is a shelly lag or a black or dark- to medium gray shale. The absence of coarse clastics and abundance of fine grained sediments making up this sequence, suggests that deposition occurred in an environment remote from clastic input, probably a distal distributary mouth bar of a mud-dominated deltaic system or possible a distributary bay.

Depositional environments that give a slight coarsening-upward shale-dominated well-log response include lower delta plain bays and subaqueous prodelta and distal bars (Coleman and Prior, 1982). Bay fill deposits show an inverted bell shaped well log response which is caused by bay fill crevasse deposits but, in areas where crevassing did not occur, the entire sequence may consist of interdistributary bay silts and clays, grading upward to marsh deposits (Coleman and Prior, 1982). Coleman and Prior (1982) reported that prodelta deposits are characterized by high rates of deposition, thin silts, silty clay laminations, and slump structures and give a slightly coarsening-upward well-log response.

Fining-upward sequence

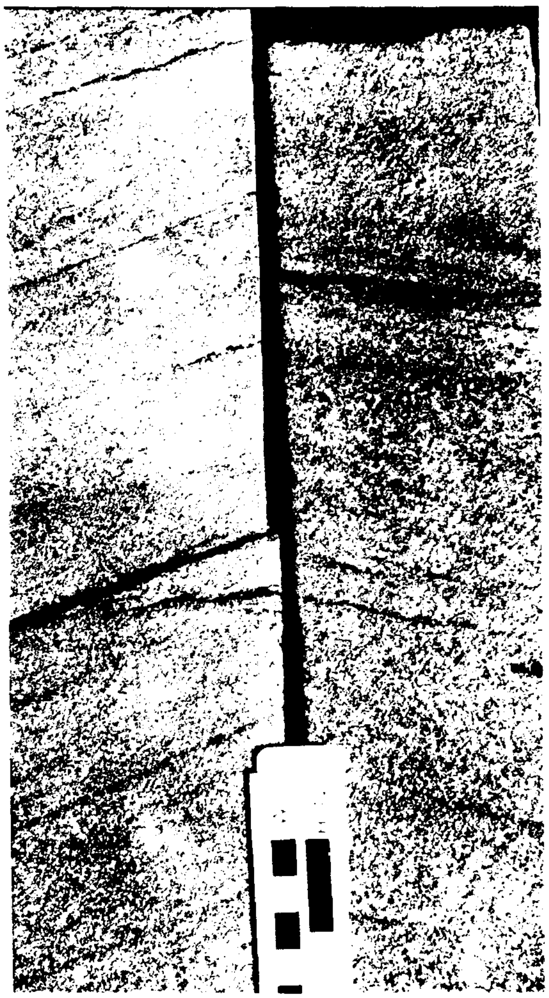
Well log responses and core descriptions show that a fining-upward sequence found in the Cherokee Group consists predominately of fine- to coarse-grained sandstone and mud clast conglomerate.

Medium to coarse sandstone

Medium to coarse sandstone is pale brown (5YR 5/2) to very light-gray (N8), poorly to moderately sorted, and consists of rounded to subrounded quartz and rock fragments. This facies commonly exhibits low to high angle cross-beds, which may be trough or planar (Fig. 68A and B). Crossbed sets, up to 7 cm apart, are revealed by plant debris and mud drapes. The lower contact may be scoured, having cut into an underlying coal and underclay or shale. Plant debris and coal clasts, up to 5 cm long, and mud chips, up to 3 cm in length, may be found at base of the often scoured lower contact. The facies may range in thickness from 1 to 20 ft (0.3 to 6.1 m). Medium to coarse sandstone is found at the bottom of a fining-upward sequence and eventually grades upward into a cross-bedded or ripple-laminated fine sandstone. This facies has good hydrocarbon reservoir characteristics, however it is most commonly water saturated. Numerous petrographic studies have been conducted on Cherokee Group sandstones and the reader is referred to Woody (1984), Reinholtz (1982), Lardner (1984), and Rofheart (1985).

Mud clast conglomerate

Clasts commonly found in the mud clast conglomerate include coal fragments up to 6 cm long, plant fragments 2 to 5 cm long, and mud chips up to 5 cm long (Fig. 69 A and B). Carbonized logs, up to 1 m long, were observed in a mud clast conglomerate occurring at the base of the lower Bluejacket sandstone in the abandoned Clemens Coal Company mine located in southeastern Crawford County. The matrix is poorly sorted, quartz-rich coarse sand. The lower contact may be scoured, having cut into an underlying coal and underclay or shale. This facies is usually thin,



68A

68B

Figure 68 A. Photograph of a slabbed core showing a cross-bedded medium sandstone. (Sample from Keown 18AO, NE-NW-SW Sec. 22-T23S-R18E, Allen County, Kansas, 1075')

Figure 68 B. Photograph of a slabbed core showing a cross-bedded coarse sandstone. (Sample from Keown 18AO, NE-NW-SW Sec. 22-T23S-R18E, Allen County, Kansas, 1055')

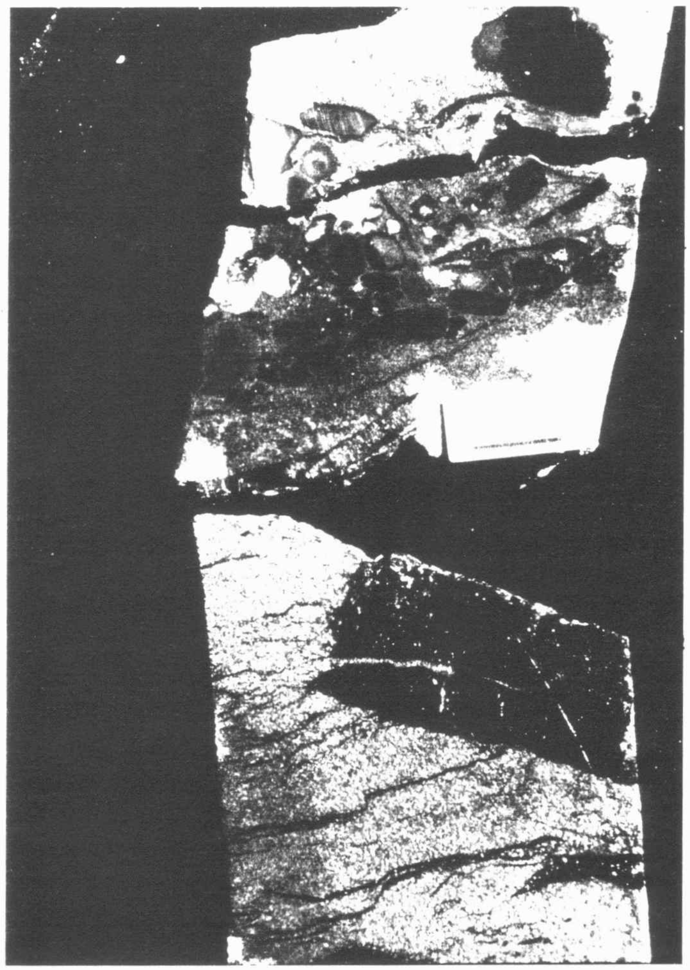


Figure 69. Photograph of a slabbed core showing a mudclast conglomerate. Note the 6 cm long coal clast at the base of the conglomerate. (Sample from L. R. Smethers CT#1, N-NE-NE Sec. 9-T21S-R19E, Anderson County, Kansas, 960')

having thicknesses of about 1 to 6 cm. The mud clast conglomerate facies commonly grades upward into a coarse- to fine-grained sandstone facies. This facies is commonly found at the bottom of a fining-upward sequence.

Vertical sequence

Figure 70 demonstrates a fining-upward sequence commonly found within the interval from the A-B marker to the Tebo marker and occasionally within the Croweburg, Mineral, and Scammon intervals. Cole (1969), Hulse (1979), Harris (1984), Woody (1984), Rofheart (1985), Walton et al. (1986), Staton (1987), and Jordan and Tillman (1987) have all reported fining-upward sequences in the lower Cherokee Group.

Fining-upward sequences range in thickness from 5 to 180 ft (1.5 to 54.9 m). The base of the sequence typically has scoured into the underlying stratigraphic unit, which may be a coal, underclay, or shale. This basal section consists of a mud clast conglomerate or a coarse-grained sandstone that grades into a high angle cross-bedded medium- to fine-grained sandstone. This facies grades upward into a ripple-laminated fine-grained sandstone and laminated siltstone. The fine-grained sandstone and siltstone found in the middle of the sequence were commonly separated by laminated medium-gray shale breaks (2 to 3 cm). Also interrupting the middle of the sequence were sand-filled scours consisting of mud rip-ups, plant fragments, macerated plants debris, and coal clasts. The sequence continues to fine upward, grading into a rippled or lenticular to wavey or structureless siltstone and laminated medium-gray shale, that often have soft sediment deformation structures and vertical and horizontal burrows. A coal or an underclay may cap the fining-upward sequence.

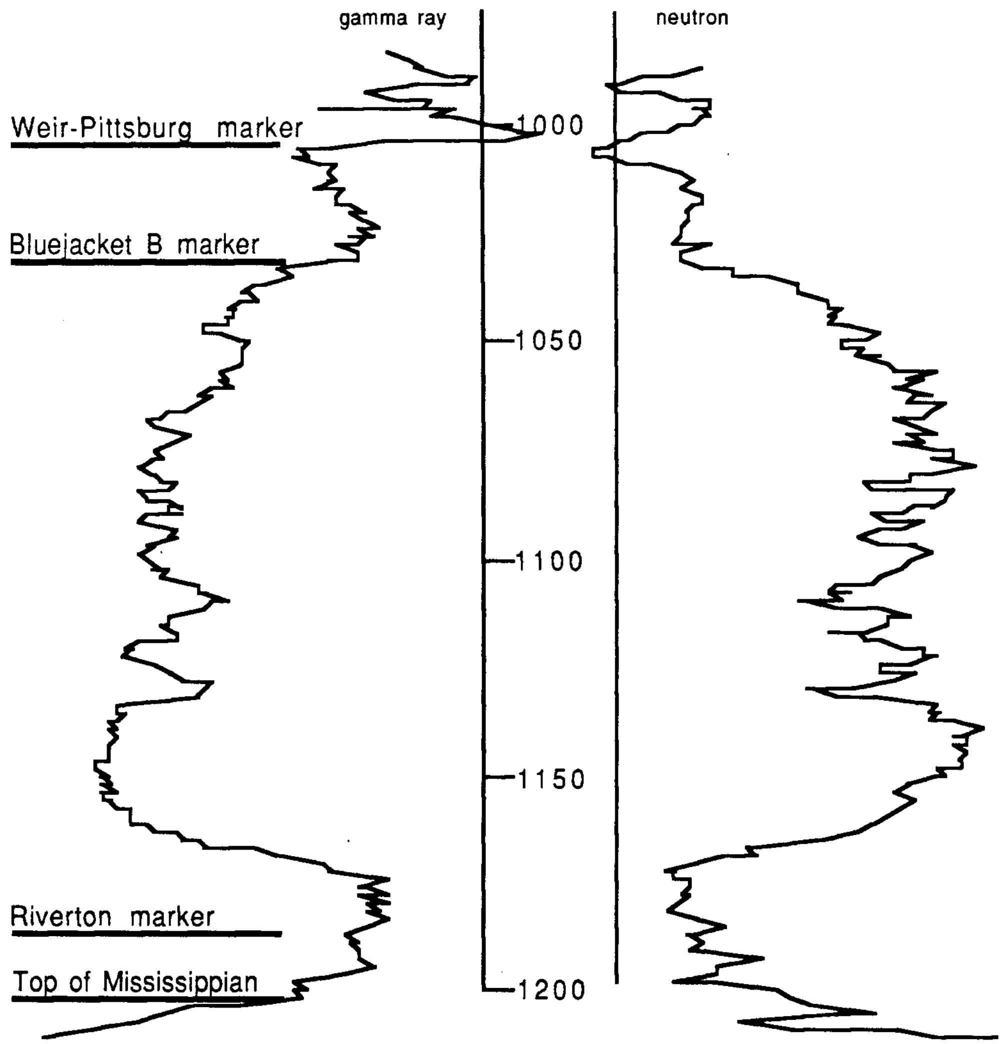


Figure 70. Gamma-ray-neutron log response for a fining-upward sequence. Glacier Petroleum Co., Lay #2, 28-22S-18E, Anderson County.

Depositional environments

The basal section, consisting of a mud clast conglomerate or cross-bedded coarse- to fine-grained sandstone and a scoured lower contact, indicates that deposition took place under high energy flow conditions, possible in the thalweg of a channel. Coal and plant fragments and mud chips, up to 5 cm long, found in the mud clast conglomerate were most likely derived from lateral channel migration and down cutting into flood plain deposits. Coarse- to fine-grained sand facies commonly had plant debris draping the low- to high-angle trough crossbed sets, suggesting that these facies may represent point bar deposits in a meandering river (Jackson, 1976) or lateral accretion deposits in a meandering to straight channel (Miall, 1985).

The ripple-laminated fine-grained sandstone and laminated siltstone found in the middle of the sequence are often interbedded with a laminated medium-gray shale. These facies represent a change from the upper flow regime of the coarse- to fine-grained sand to a lower flow regime possibly as a result of channel abandonment or overbank splay deposits resulting from periodic flooding events (Elliott, 1986).

The top of the fining-upward sequence consists of structureless to rippled siltstone and a laminated medium-gray shale, which has convoluted bedding and minor burrowing. These facies may represent deposition from overbank splays or distributary channel abandoment. Jordan and Tillman (1987) studied the lower Bluejacket sandstone in Greenwood County and noted that rippled- to laminated silt and mud facies occurred in delta plain distributaries as overbank and crevasse splay deposits. As water current slows and subsidence increases, an abandoned distributary channel may be filled with rippled- to laminated silt and muds deposited from waning flow of unidirectional currents and from suspension of overbank fines (Elliott, 1986). Abandoned distributaries consisting of interbedded silt, mud, and organic debris deposited from suspension may also be inundated by saline or brackish water allowing burrowing organisms to proliferate (Galloway and Hobday, 1983).

Depositional environments that may display a fining-upward or bell-shaped well log response are upper delta plain braided channel, meander point bar, and valley-fill deposits, and lower delta plain distributary channel deposits. Braided channels form laterally extensive deposits (20-50 km) characterized by multiple fining-upward sequences, representing deposition by laterally migrating channels (Coleman and Prior, 1982). The resulting fining-upward, bell-shaped well log response may show a box-shaped base associated with channel scouring and coarse sand deposits and may be punctuated by local coarse-sand-filled scours fining-up into silts and clays (Elliott, 1986). Most meander point-bar deposits will show a bell-shaped fining-upward well log response but locally thick sands may give a blocky response (Coleman and Prior, 1982). Well log responses show an overall tendency for distributary deposits to fine upward, however they may be blocky or erratic in appearance with no overall change in grain size (Coleman and Prior, 1982).

Fining-upward sequences occurring in the A-B through Tebo intervals represent upper delta plain channel deposits that most likely backfilled a major incised valley during a relative rise in sea level. This idea is developed more fully in the next section. Fining-upward sequences occurring in the Mulky, Croweburg, Mineral, and Scammon intervals are characteristic of distributary channels. The sandstone isolith maps of these intervals (Figs. 45, 40, 36, and 33) reveal several narrow, elongate sand trends ranging from 3 to 60 ft (0.9 to 18 m) thick. The Mulky, Croweburg, Mineral, and Scammon intervals typically consist of progradational lower and subaqueous delta plain sediments. As deltaic progradation moved sediments basinward, lower delta plain distributary channels to cut into the mouth-bar and prodelta clay and silt. Distributary channel deposits cannot be accurately correlated using well logs because of downcutting into distributary-mouth-bar and prodelta deposits and the limited lateral extent of channel deposits, which very in width from 1 m up to 1 km and vary in depth from 1 to 30 m (Coleman and Prior, 1982). Small distributary channels are commonly filled with mud, thus making recognition from well logs difficult.

Incised valleys

Deep cutting incised channels, which can be observed in cross sections A-A', B-B', and C-C' and the total sand isolith map of the Cherokee Group (Fig. 10), may have formed during a relative fall in sea level and were later back filled with fluvial or marine sediments during a relative rise in sea level. The following comments are offered to better understand incised valleys. First, the lateral and vertical dimensions of the channel must be defined by using closely spaced well logs and a network of closed loop cross sections. Secondly, closely spaced cores are essential in order to describe the various lithofacies in and around the incised channel. Finally, a model is needed to predict what lithofacies were deposited during the relative rise and fall of sea level. The following paragraph summarizes a model of incised valleys (Van Wagoner et al., 1990).

During the initial sea-level fall, upper delta plain fluvial channels will shift basinward and cut down into lower delta plain and subaqueous delta sediments. It is important to distinguish between distributary channels and incised valleys. Distributary channels are encased in delta-plain or stream-mouth bar deposits. Incised valleys are encased in outer- to mid-shelf mudstones and thin, distal marine sandstones. Down cutting can be recognized on cross sections by the lateral termination of marker beds against channel boundaries. Lithofacies that can be expected within the upper reaches of the incised valley are braided fluvial and estuarine deposits. Lower reaches of the incised valley may include lowstand-delta and tidal-flat sandstones and mudstones and beach and estuarine sandstones. During the initial down-cutting phase, underclay and rooted horizons can be expected to form on areas adjacent to the incised channel. As relative sea level rises, distal marine sandstones and shelf mudstones inundate the incised valley and adjacent areas. Coal deposits may form over underclay and rooted horizons in adjacent areas during the rise in sea level. Incised valleys range in width from less than several kilometers to many tens of kilometers. They range in depth from several meters to around a hundred meters.

Initial observations indicate that some channels recognized in this and other studies fit the model of an incised valley. Visher et al. (1971) reported that the Bluejacket-Bartlesville sandstone of eastern Oklahoma was lenticular in shape and encased by marine shales or limestones. Cole (1969), Hulse (1979), Harris (1984), Walton et al. (1986), and Staton (1987) have all reported fining-upward sequences in the lower Cherokee Group that have characteristics of incised valleys. However, Jordan and Tillman (1987) concluded that the Bartlesville Sandstone (upper Bluejacket sandstone) in Greenwood County was deposited by a low-sinuosity distributary channel in a middle to outer delta-plain environment. An important step towards answering this problem exists in core and well log coverage adequate enough to define the channel geometry and facies.

The external dimensions as well as the internal facies relationships must be defined to determine the history and depositional events related to incising and possible backfilling of the channel. To do this, two cross sections were constructed through a major incised valley in eastern Coffey, southwestern Anderson, and northwestern Allen counties (Figs. 71, 72, and 73). Cross sections H-H' and H-I outline the shape and lateral extent of the incised valley. The deepest point in the valley is approximately 165 ft (50.3 m) at well location #2. The valley has a maxium lateral extent of about 21 miles (34 km), the distance from well #1 to well #6 and about 17 miles (27 km), the distance from well #1 to well #9. These dimensions assume that the cross sections are perpendicular to the valley. Analysis of cores and well log responses from other wells in the area indicate that this valley is encased in marine silts and muds, and occasional prodelta muds and silts. The channel boundaries and facies, both laterally and vertically, fit the characteristics of an incised valley fill outlined above.

Defining the internal structure of the incised valley is difficult because of limited well log and core data. However, examination of cross sections H-H' and H-I should reveal something about the timing of down cutting and infilling of the incised valley. Cross section H-H' shows that there were at least two episodes of fluvial incision. The first downcutting event is represented by channel A and is found only in well #5. The original western extent of this channel is unknown because of later channel incision from

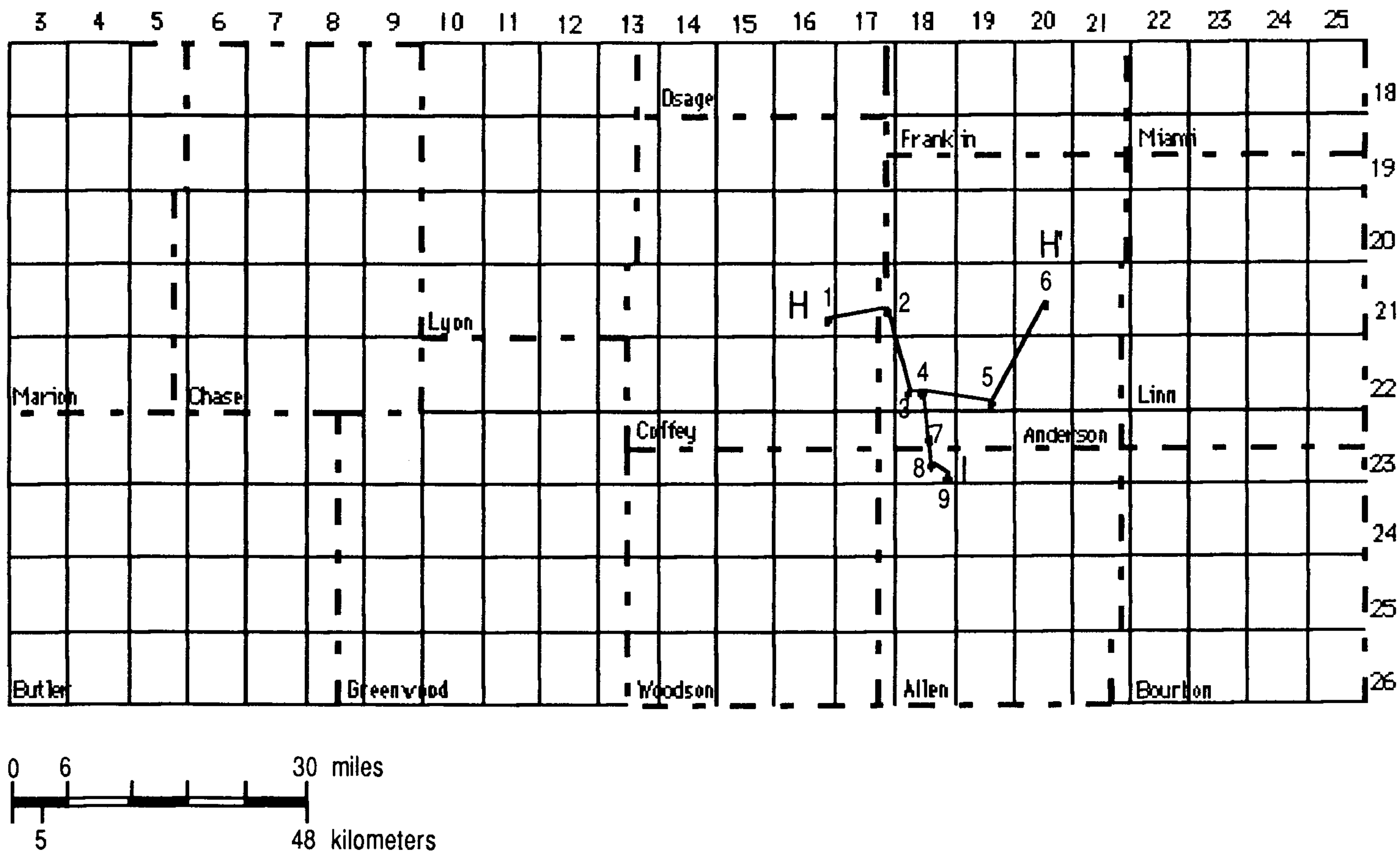
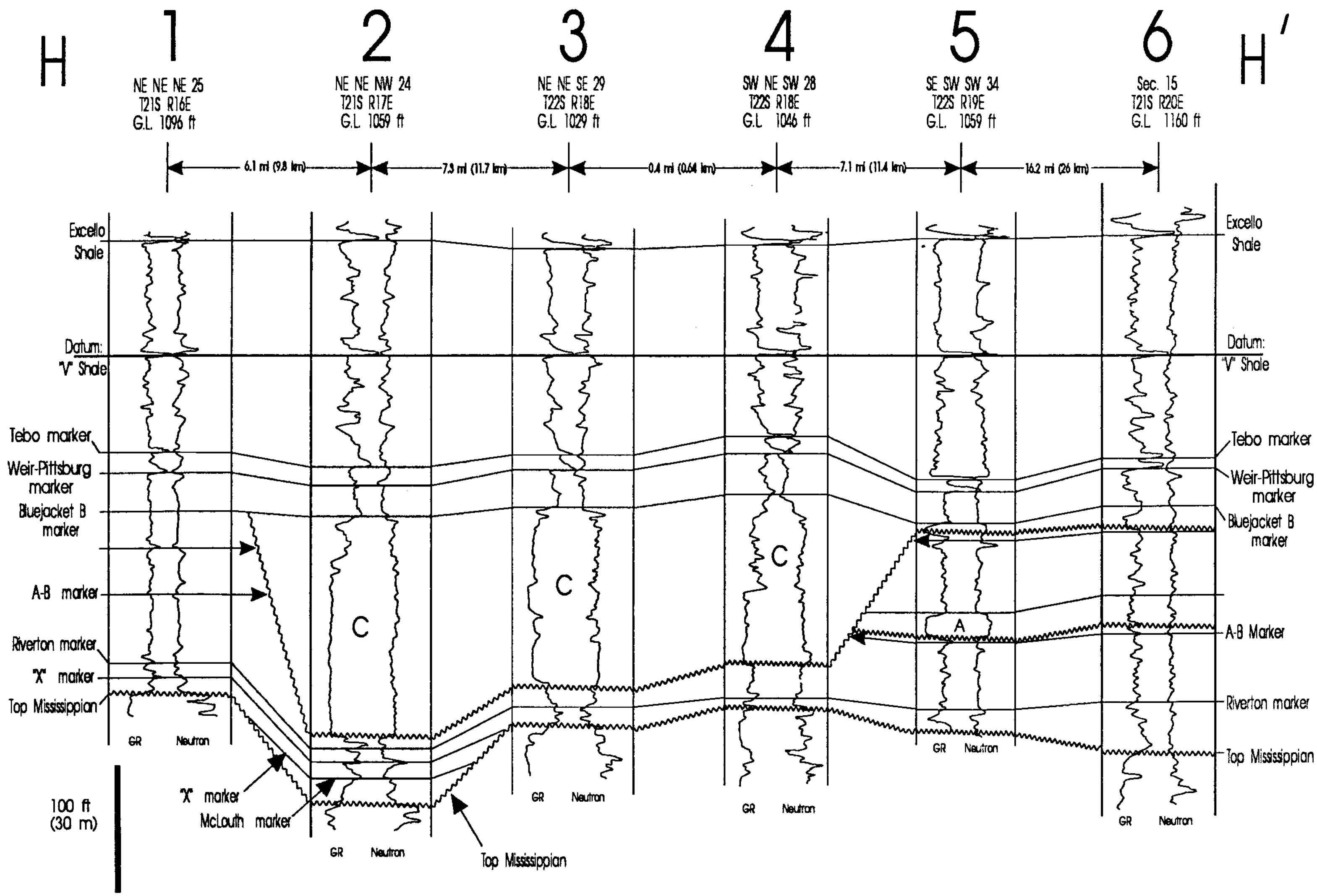


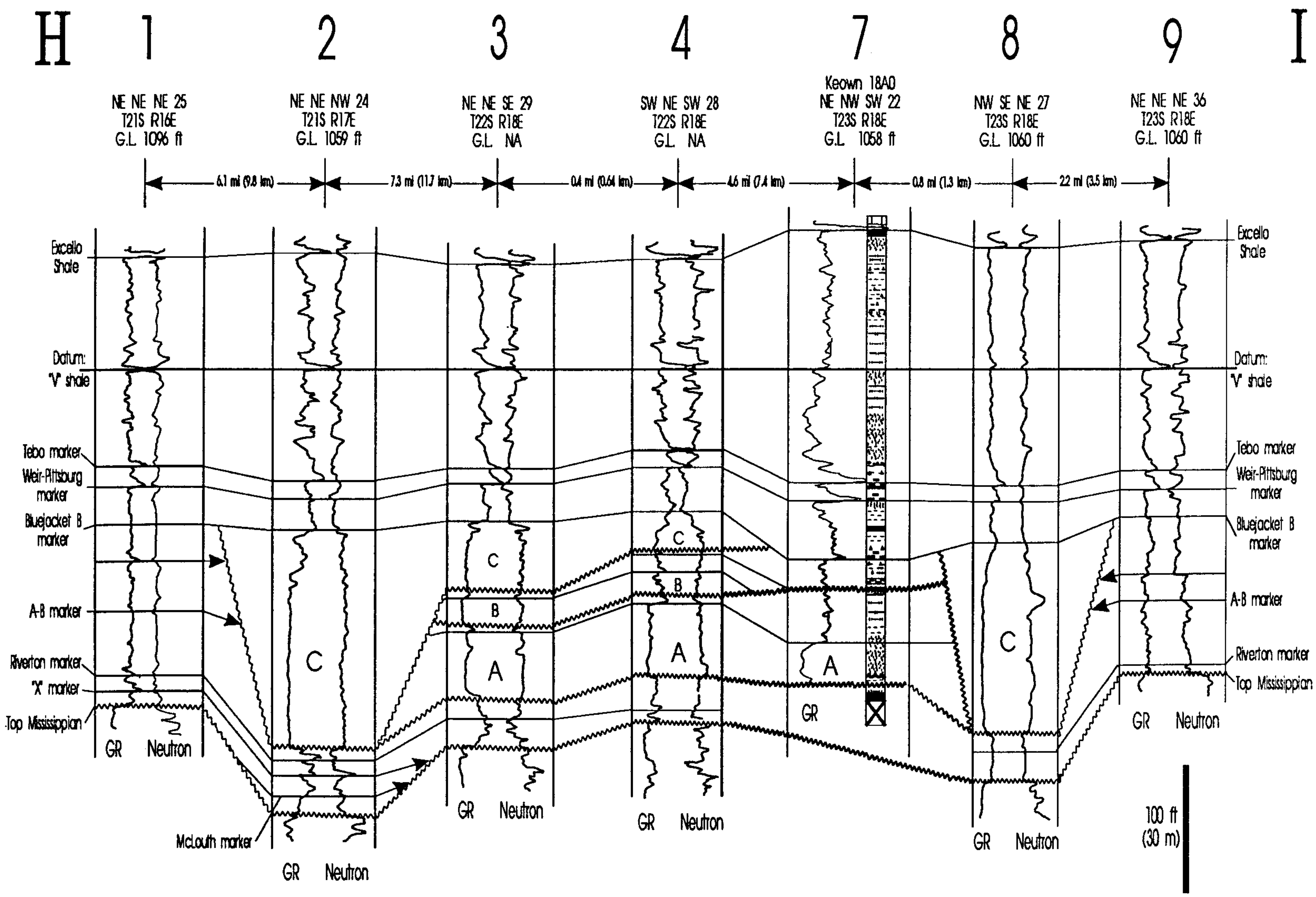
Figure 71. Location of cross sections H-H' and H-I.

Figure 72. Cross section H-H' illustrating and incised valley. Refer to figure 71 for cross section location.



H
H′
1
NE NE NE 25
T21S R16E
G.L. 1096 ft
2
NE NE NW 24
T21S R17E
G.L. 1059 ft
3
NE NE SE 29
T22S R18E
G.L. 1029 ft
4
SW NE SW 28
T22S R18E
G.L. 1046 ft
5
SE SW SW 34
T22S R19E
G.L. 1059 ft
6
Sec. 15
T21S R20E
G.L. 1160 ft
6.1 mi (9.8 km)
7.5 mi (11.7 km)
0.4 mi (0.64 km)
7.1 mi (11.4 km)
16.2 mi (26 km)
Excello Shale
Datum: "V" Shale
Tebo marker
Weir-Pittsburg marker
Bluejacket B marker
A-B marker
Riverton marker
"X" marker
Top Mississippian
C
C
C
A
A-B Marker
McLouth marker
GR
Neutron
100 ft
(30 m)

Figure 73. Cross section H-I' illustrating and incised valley. Refer to figure 71 for cross section location.


H
I
1
NE NE NE 25
T21S R16E
G.L. 1096 ft
2
NE NE NW 24
T21S R17E
G.L. 1059 ft
3
NE NE SE 29
T22S R18E
G.L. NA
4
SW NE SW 28
T22S R18E
G.L. NA
7
Keown 18A0
NE NW SW 22
T23S R18E
G.L. 1058 ft
8
NW SE NE 27
T23S R18E
G.L. 1060 ft
9
NE NE NE 36
T23S R18E
G.L. 1060 ft
6.1 mi (9.8 km)
7.3 mi (11.7 km)
0.4 mi (0.64 km)
4.6 mi (7.4 km)
0.8 mi (1.3 km)
2.2 mi (3.5 km)
Excello Shale
Datum: "V" shale
Tebo marker
Weir-Pittsburg marker
Bluejacket B marker
A-B marker
Riverton marker
"X" marker
Top Mississippian
McLouth marker
A
B
C
GR
Neutron
100 ft (30 m)

event C. The northeastern boundary is most likely in the area of well #6. Channel C represents the last period of down cutting. No core was available for examination of the lithologies within channel C, however, the blocky well log signature suggests that all lithologies between the base of the channel to the base of the Bluejacket B marker are fluvial sandstones, siltstones, and mudstones. Two coarsening-upward events occurring in mid-channel in well #4 are nonmarine and may represent meander point-bar deposits or overbank splay deposits. Cores need to be taken from this interval to confirm the fluvial, non-marine origin of the sediments. Given the fluvial character of the channel and the absence of any marine or estuarine indicators, it is most likely that this channel was deposited within the upper reaches of the incised valley. Cross sections through the lower reaches of the valley, farther to the south and basinward, should reveal a facies change from braided-stream and fluvial sandstones to lowstand deltas, tidal-flat sandstones and mudstones and beach and estuarine sandstones (Van Wagoner, 1990). Visher et al. (1971) mapping of interdistributary, distributary, and prodelta sequences occurring within the lowstand Bluejacket-Bartlesville deltaic complex of eastern Oklahoma show this relationship.

Downcutting in channel C occurred as a result of a relative fall in sea level that shifted deposition basinward and lowered base level. Prior to sea-level fall, sediments accumulated during a sea-level stillstand or slow fall and built to a position immediately below the Bluejacket B marker. During the ensuing relative fall in sea level, sediments previously accumulated in the area of the newly emerging valley were eroded and removed. A slow sea-level rise and a plentiful sediment supply, and the upper valley position, allowed the channel to be backfilled with fluvial sediments only. Harris (1984) and Staton (1987) examined cores and outcrops in southeastern Kansas and noted an underclay and the Bluejacket B coal in the Bluejacket B marker. The initial rise in sea level is marked by the accumulation of the coal. The overlying black, slighty radioactive shale marks the upper boundary of the valley fill and is the first indication of a marine incursion.

Cross section A-B (Fig. 73) is presented as an alternative interpretation of the incised valley. The addition of a continuous core at well location #7 (Keown 18AO in Appendix A) offers information about the internal facies distribution of the incised channel. Well #7 is located on the eastern limit of the incised valley.

The first stage of down cutting occurred with channel A, which is present in well numbers 2, 3, 4, and 7. The top of this channel is capped by a non-marine rippled siltstone, which indicates possible channel migration or stream avulsion but not a major landward shift in facies. Channel B, which is found in wells 3 and 4, indicates that down cutting resumed in this area. At the top of channel B in well #4 there is a mudstone that is correlated tentatively with a black shale occurring below the Bluejacket B marker in well #7. The black shale has a sharp lower contact with an underclay. No coal was observed above the underclay. Facies occurring between the black shale and the Bluejacket B marker in well #7 have marine indicators such as calcareous mudstones, black shales and siltstones with brachiopods, fossil fragments, and burrows.

The marine shale capping channel B is the first indication that a sea-level rise shifted basin sediments landward and backfilled the incised valley. This is also an indication that down cutting in the incised valley was episodic. After channel B was inundated by marine waters, relative sea level fell again as is evidenced by down cutting in Channel C. Channel C was subsequently flooded by the Bluejacket B marker, marking the end of valley incision. It should be pointed out that no coal or underclay was observed in the Bluejacket B marker in well #7. Coal and underclay usually occur at the base of the Bluejacket B marker. A possible explanation for the lack of underclay or coal is that deposition in well #7 took place on a low lying area outside of the incised valley. This area was outside of the major sediment influx and during the rise in sea level was inundated by marine waters. However, well #4, which lies in the incised valley developed an underclay and coal. Another possible explanation for the lack of underclay or coal deposition below the Bluejacket B marker is that it was removed during the final episode of marine transgression that flooded the incised valley.

The key to interpreting this cross section is recognition of the marine flooding unit. The correlation between the shale at the top of channel B and the black shale in well #7 should be verified by coring selected intervals between wells 4 and 7. If this correlation is incorrect, then the interpretation of periodic downcutting events will have to be reconsidered.

SEDIMENT SOURCE

A northerly source for most the Cherokee Group sediments is indicated based on paleocurrent studies and proximity to source areas. Visher et al. (1971) studied Pennsylvanian delta patterns in eastern Oklahoma and concluded that sediment supply was from northern river systems. Jordan and Tillman (1987) used specially oriented cores and isopach maps and delineated a west-southwesterly flow direction for the Bartlesville Sandstone in Greenwood County. Sand isopach maps of fluvial and distributary channels suggest a northerly sediment source, assuming the flow direction of the channels is parallel to the north-south linear trend of sand thicks. Other authors indicating a northeast to southwest current direction are Rich (1923), Bass (1936), Hulse (1979), Ebanks et al. (1977), Harris (1984), and Staton (1987).

Possible sediment source areas were the craton to the north and the Ozark uplift to the southeast (Wanless et al., 1969). The Nemaha uplift did not appear to be a major source of detrital influx in to the Cherokee and Forest City basins. Isopach maps of this area reveal no major accumulations of sand. Detritus being shed off the Ouachita uplift was a major input into the Arkoma basin, but not a probable source of sediment input into the McAlester or Cherokee basins to the north (Sutherland, 1988).

SUMMARY

Ten laterally extensive marker complexes, consisting of a basal underclay and coal and overlain by a shelly lag and black shale, extend throughout the Bourbon arch region and into the Cherokee and Forest City basins. Paleontologic and palyonological evidence suggest that the McLouth and "X" intervals of the lower Cherokee Group may be of Atokan age. However, palynological studies of the Riverton interval give conflicting ages, from late Atokan to early Desmoinsian. Current stratigraphic classification divides the Cherokee Group into an upper Cabinass Formation and a lower Krebs Formation based on the thin, laterally discontinuous Seville (?) Limestone Member. This study suggests that the Seville division be dropped and that the top of the Tebo coal and the bottom of the overlying black shale be adopted as the division between the Cabinass and Krebs Formations.

The Ozark uplift, Nemaha uplift, and Bourbon arch are post-Mississippian structures that affected Cherokee Group deposition in the Cherokee and Forest City basins. Progressively younger rocks overstep each other as they onlap the Nemaha uplift from the east. Onlapping occurred until the Nemaha uplift was completely buried in the study area by the Excello shale. The Bourbon arch was a post-Mississippian structural high that may have created conditions favorable for thick coal accumulation. Isopach maps reveal approximately 70 ft (21 m) of thinning over this region, most of which can be attributed to onlapping and thinning of McLouth and "X" intervals from the north. The thick coal accumulations over the arch region indicate that differential compaction may have played a part in the thinning over the Bourbon arch in subsequent intervals.

Three geophysical well log responses, coarsening-upward, shale-dominated, and fining-upward characterized facies in the Cherokee Group. Seven coarsening-upward sequences were identified between the Weir-Pittsburg and Mulky marker complexes and trend throughout the study area. Each of the four lowermost coarsening-upward sequences between the Weir-Pittsburg and Croweburg markers can be correlated throughout most of eastern Kansas and represents regression and deltaic progradation. Each sequence is overlain by an underclay and a transgressive coal, shelly lag, and black shale.

Shale-dominated sequences, found below the Bluejacket B marker, show a slight coarsening-upward profile. At the base of this sequence there is a shelly lag overlain by a black or laminated, dark- to medium-gray marine shale, which grades upward into prodeltaic medium-gray silts. The sequence is capped by a coal. Shale-dominated sequences represent deposition in subaqueous prodeltas and possibly restricted, shallow bays of a mud-dominated low-energy deltaic system.

Fining-upward sequences commonly occur below the Bluejacket B marker and represent upper delta plain channel deposits. Cross sections through major fluvial channels reveal that two and possible three periods of fluvial incision have occurred as a result of rising and falling of sea level. Observations from cores and well logs indicate that the incised valleys were back-filled with fluvial stream deposits from the upper reaches of the valley during a rise in sea level. Future investigations of incised valleys should concentrate on closely spaced core and well logs in order to determine the sequence and timing of down cutting events.

Paleocurrent studies and isopach maps of the region indicate that the craton to the north and the Ozark uplift to the southeast were possible source areas for Cherokee Group sediments. The Nemaha uplift to west and the Ouachita uplift to the south were not probable sources of sediment into the Bourbon arch region.

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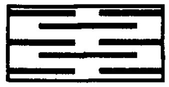
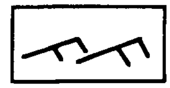
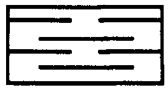
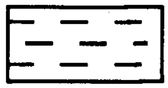
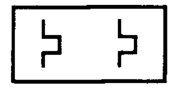
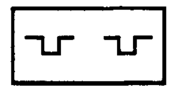
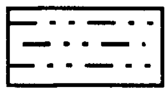
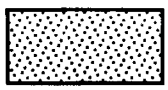
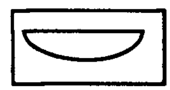
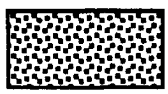
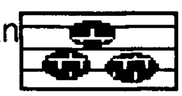
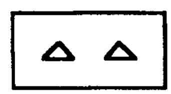
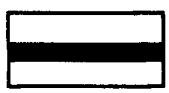
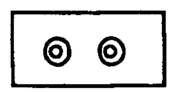
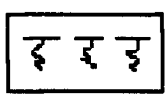
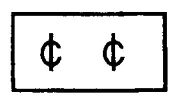
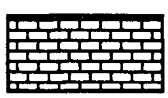
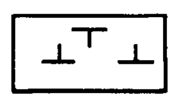
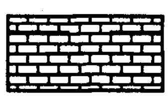
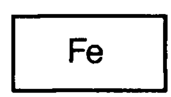
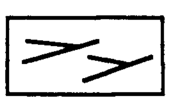
APPENDIX A

List of cores and descriptions

Location	Spot	Well Name	Operator	County	Interval
9-21S-19E	N-NE-NE	L.R.Smethers CT#1	Brazos Oil & Gas	Anderson	Scammon-Bbj
3-23S-21E	N/A	McGee Lse. #20-90	Chaz Oil Co.	Anderson	A-B Riverton
22-23S-18E	NE-NW-SW	Keown 18AO	Mack C. Colt, Inc.	Allen	Cher. Grp.
34-24S-9E	SW-NW-SW	Marshall #3	Jackson Brothers	Greenwood	Tebo Bbj
22-25S-19E	SW-NE-SE	M. Setter #2	Tenneco	Allen	Tebo Bbj
26-26S-21E	NW-NW-SE	Dotson #111	Franklin Oil Ent.	Bourbon	Scammon

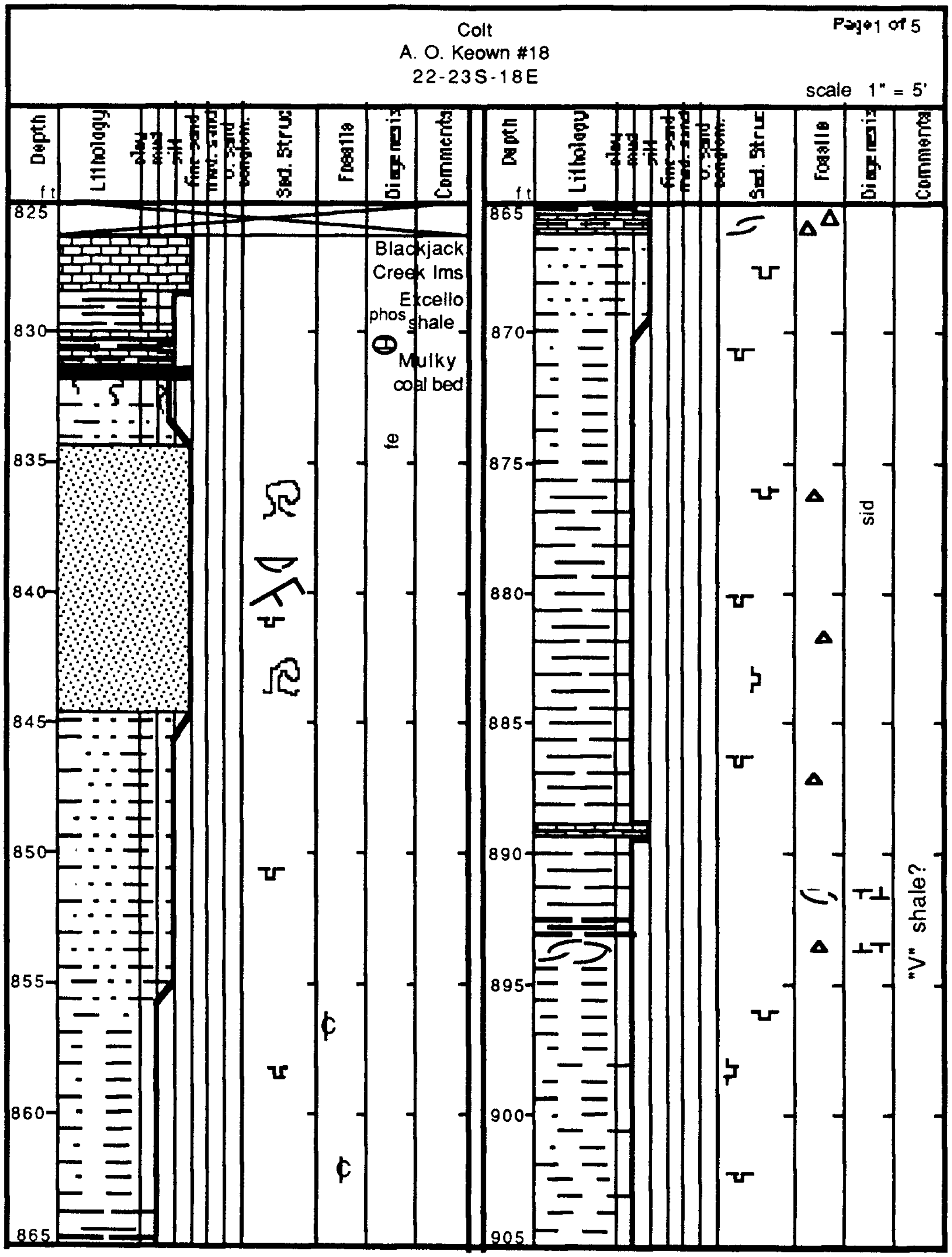
All cores are in the collection of the Kansas Geological Survey, Lawrence, Kansas.

EXPLANATION OF SYMBOLS

black shale		asymmetric ripples	
dark- to medium-gray shale		scour surface	
laminated medium-gray shale		horizontal burrows	
shelly lag		vertical burrows	
siltstone		convolute bedding	
sandstone		wavy bedding	
mud-clast conglomerate		lenticular bedding	
basal Pennsylvanian conglomerate		brachiopods	
coal		crinoids	
underclay		plant fragments	
limestone		calcareous cement	
argillaceous limestone		clay ironstone concretions	
low angle cross beds		trough or tabular cross beds	

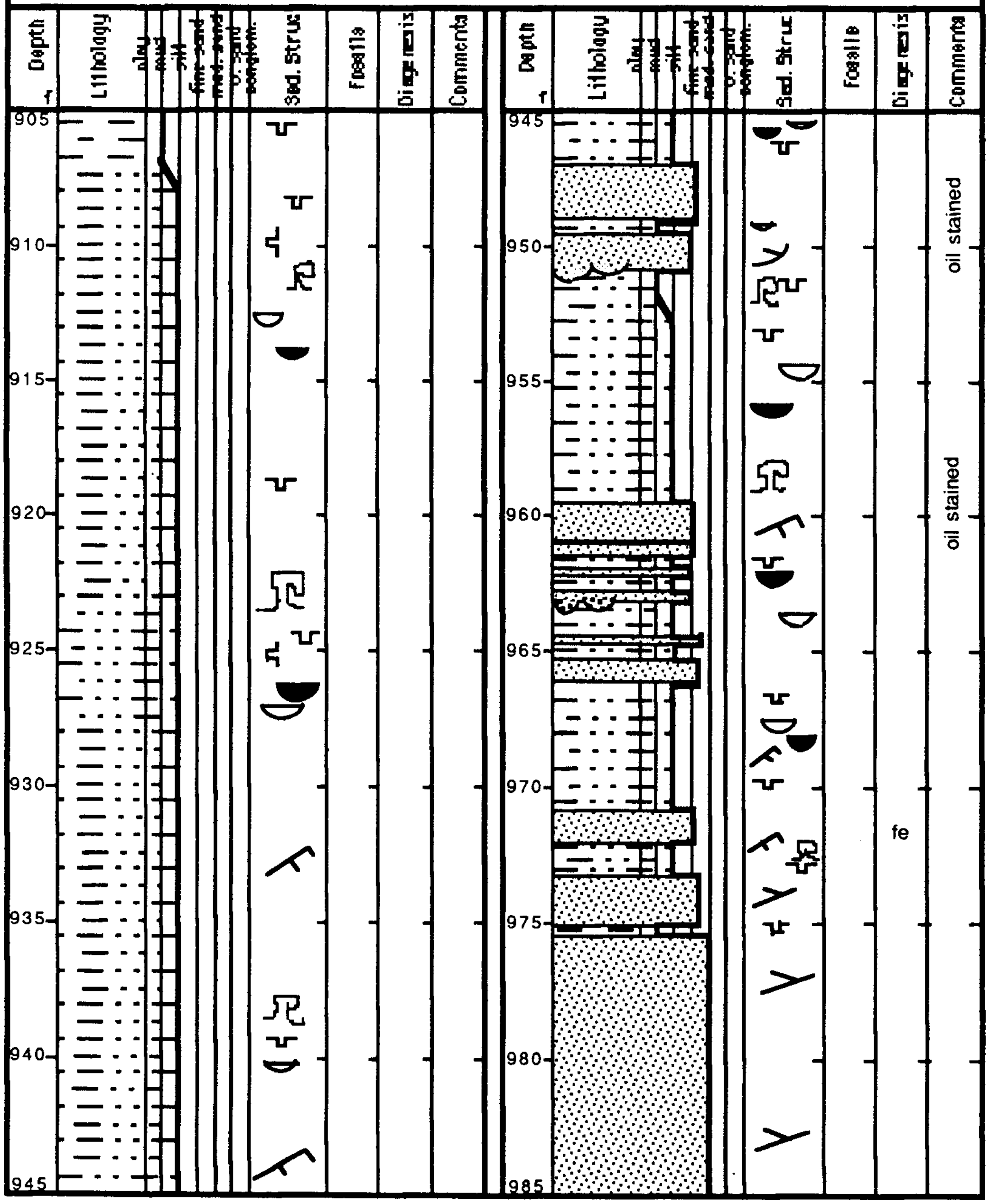
EXPLANATION OF SYMBOLS

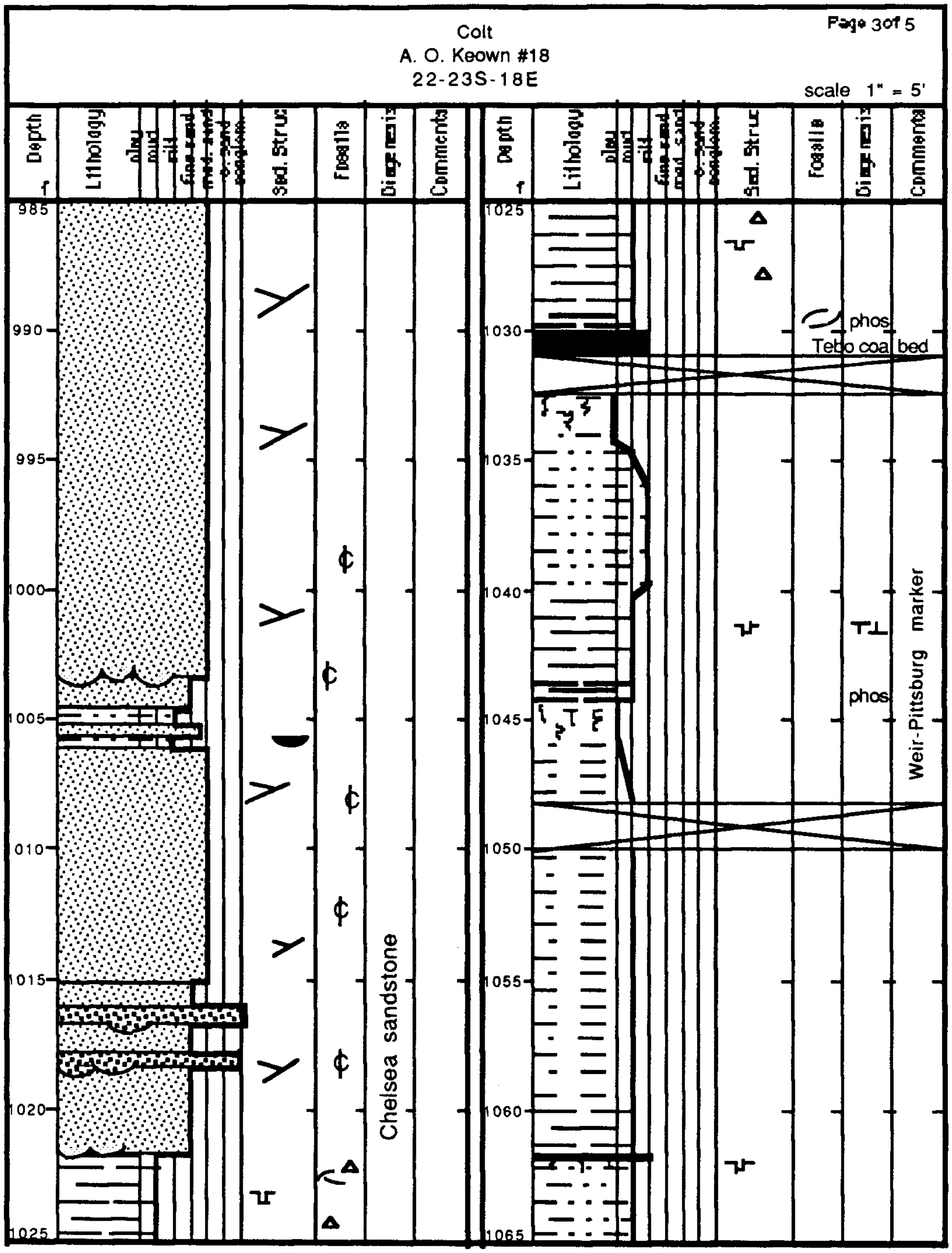
siderite spherulites	sid
pyrite concretions	py
phosphate nodules	phos
unconformity	
no core recovery	

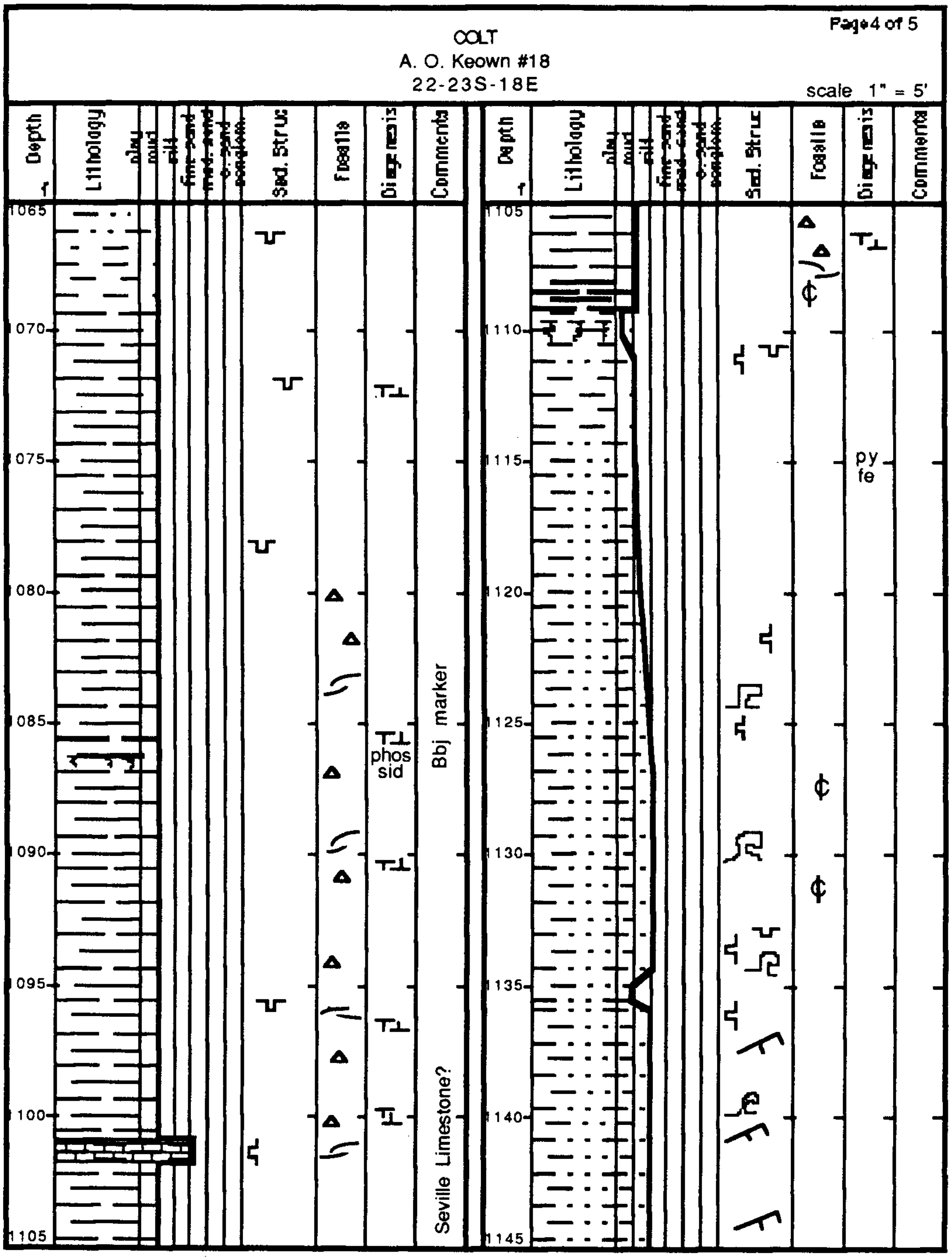

Colt
A. O. Keown #18
22-23S-18E
Page 1 of 5
scale 1" = 5'
Depth ft
Lithology
clay
mud
silt
fine sand
med. sand
c. sand
conglom.
Sed. Struc
Fossils
Diagenesis
Comments
825
830
835
840
845
850
855
860
865
Blackjack Creek lms
Excello shale
phos
Mulky coal bed
fe
870
875
880
885
890
895
900
905
sid
"V" shale?

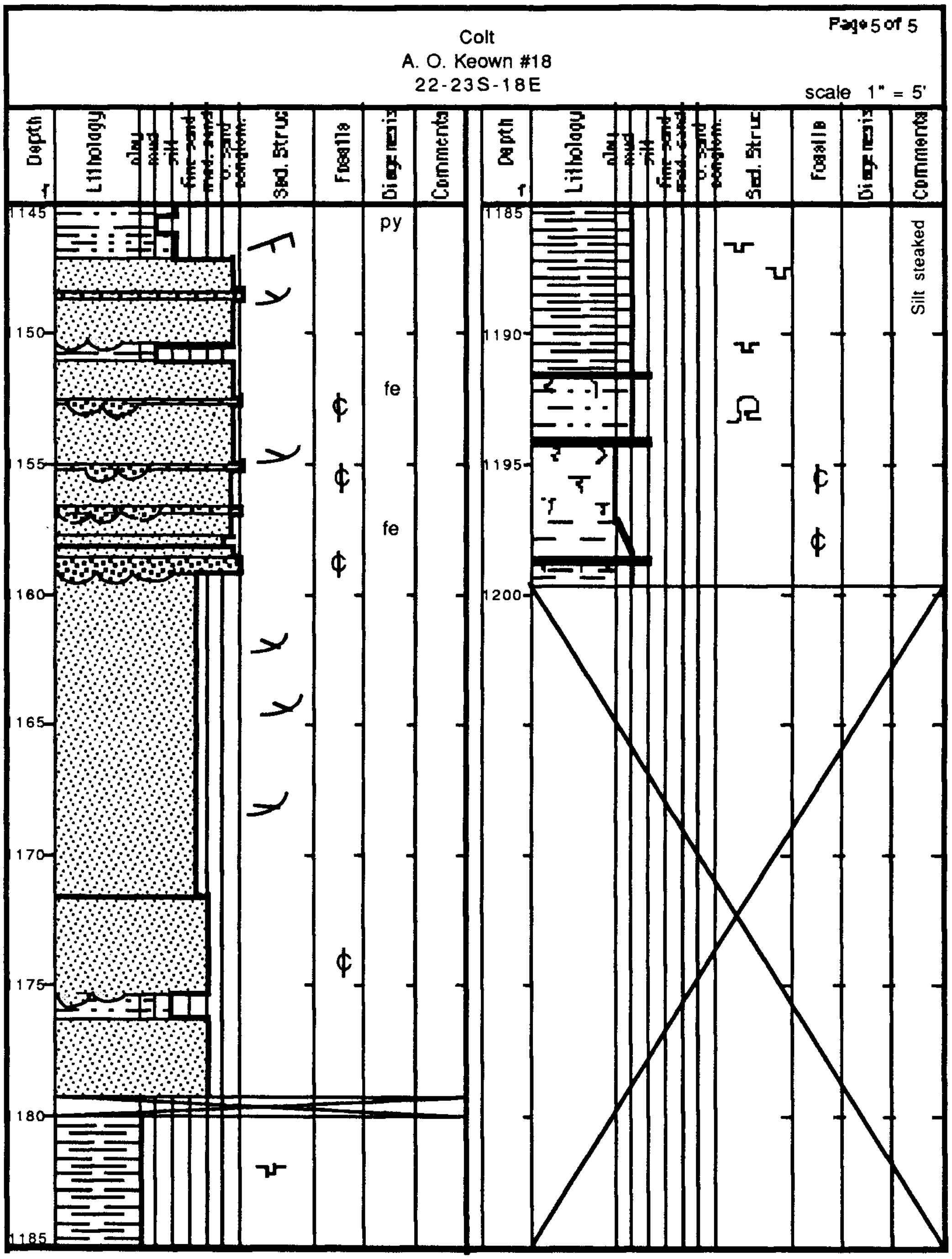
Colt
A. O. Keown #18
22-23S-18E

scale 1" = 5'




Colt
A. O. Keown #18
22-23S-18E
Page 3 of 5
scale 1" = 5'
Depth
ft
Lithology
clay
mud
silt
fine sand
med. sand
c. sand
conglom.
Sed. Struc
Fossils
Diagenesis
Comments
985
990
995
1000
1005
1010
1015
1020
1025
Chelsea sandstone
1030
1035
1040
1045
1050
1055
1060
1065
phos
Tebo coal bed
phos
Weir-Pittsburg marker

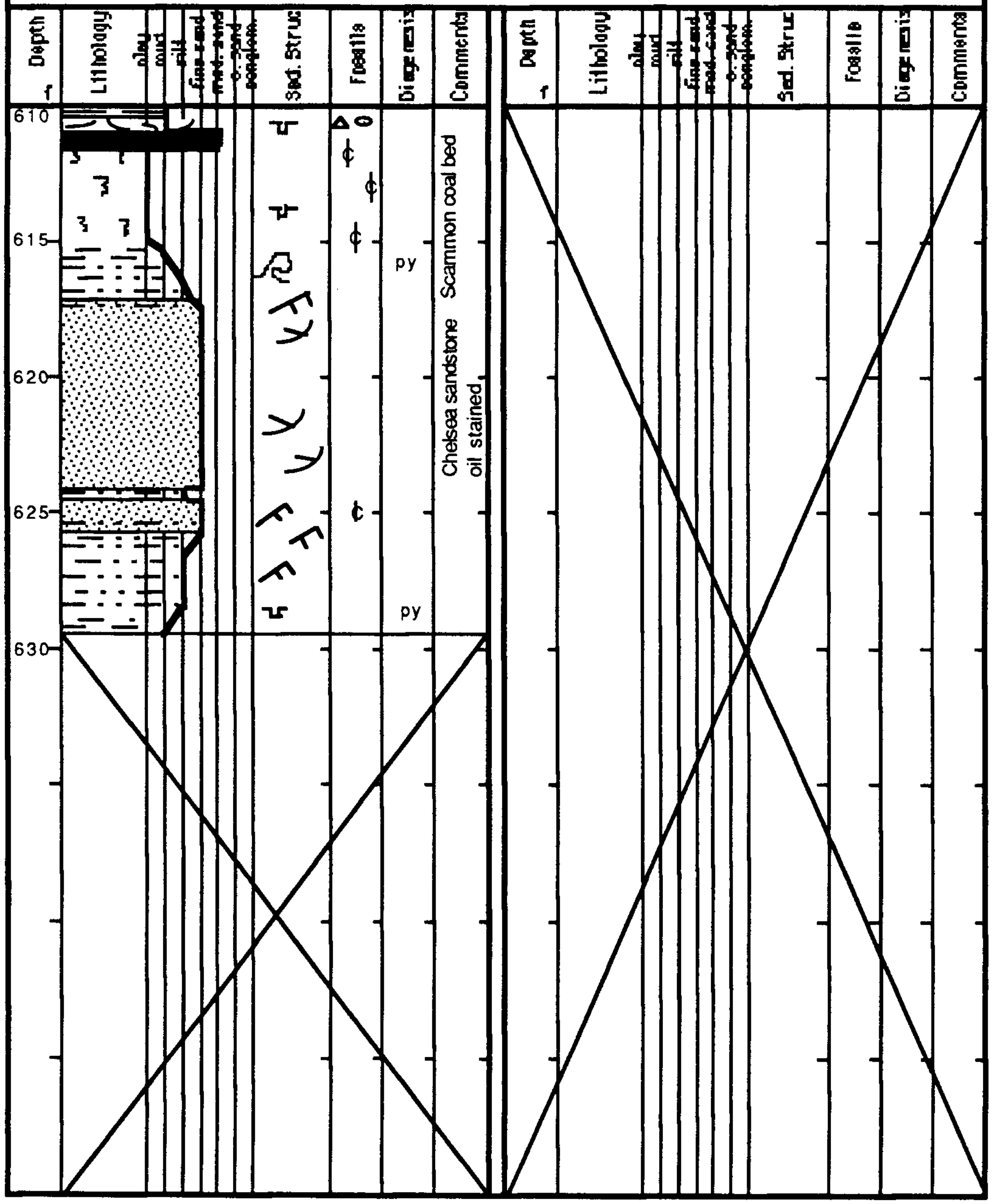

Page 4 of 5
COLT
A. O. Keown #18
22-23S-18E
scale 1" = 5'
Depth ft
Lithology
clay
mud
silt
fine sand
med. sand
c. sand
conglom.
Sed. Struc
Fossils
Diagenesis
Comments
1065
1070
1075
1080
1085
1090
1095
1100
1105
1110
1115
1120
1125
1130
1135
1140
1145
phos
sid
Bbj marker
Seville Limestone?
py
fe

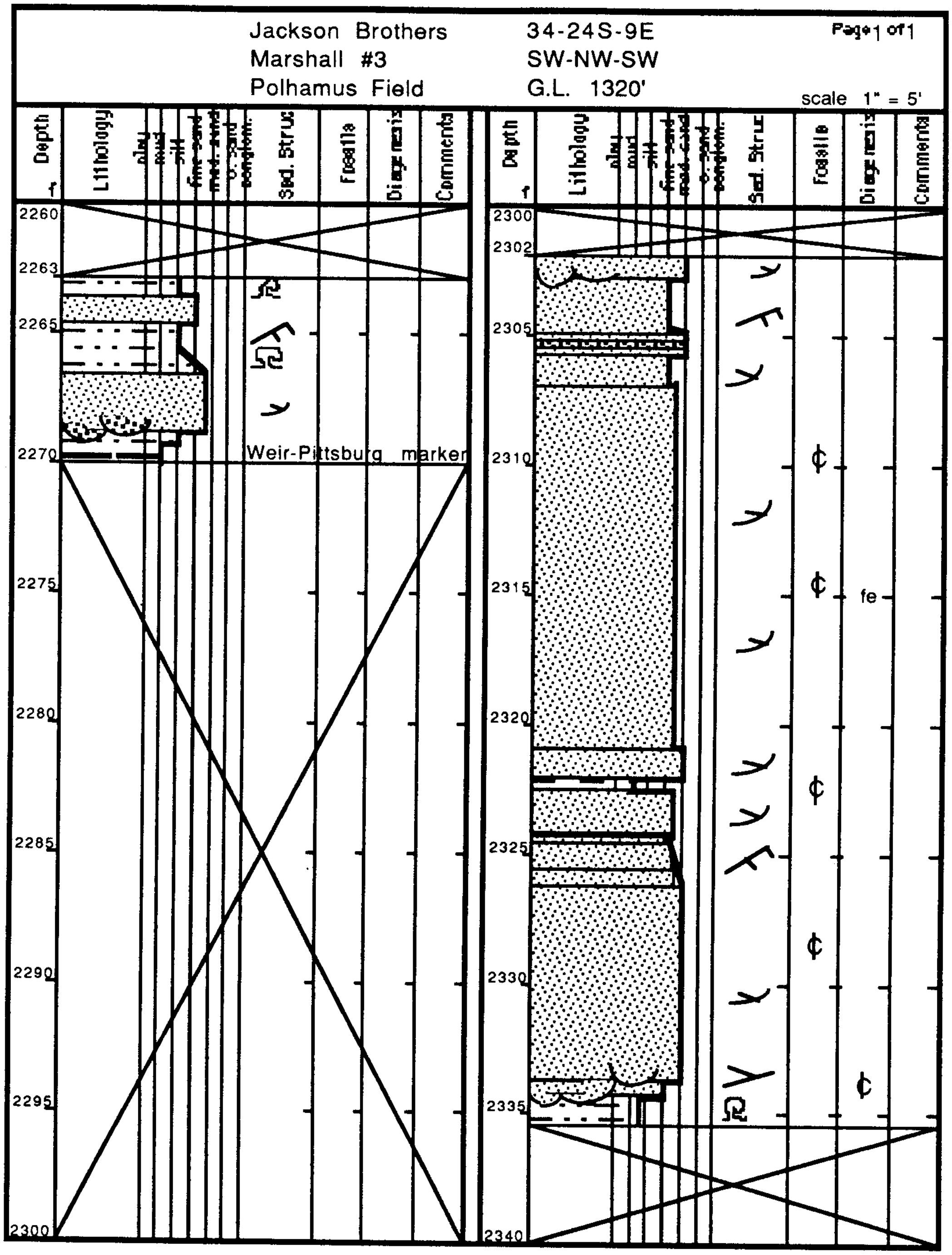


Page 5 of 5
Colt
A. O. Keown #18
22-23S-18E
scale 1" = 5'
Depth
ft
Lithology
clay
mud
silt
fine sand
med. sand
c. sand
conglom.
Sed. Struc
Fossils
Diagenesis
Comments
1145
150
155
160
165
170
175
180
1185
py
fe
fe
1190
1195
1200
Silt steaked

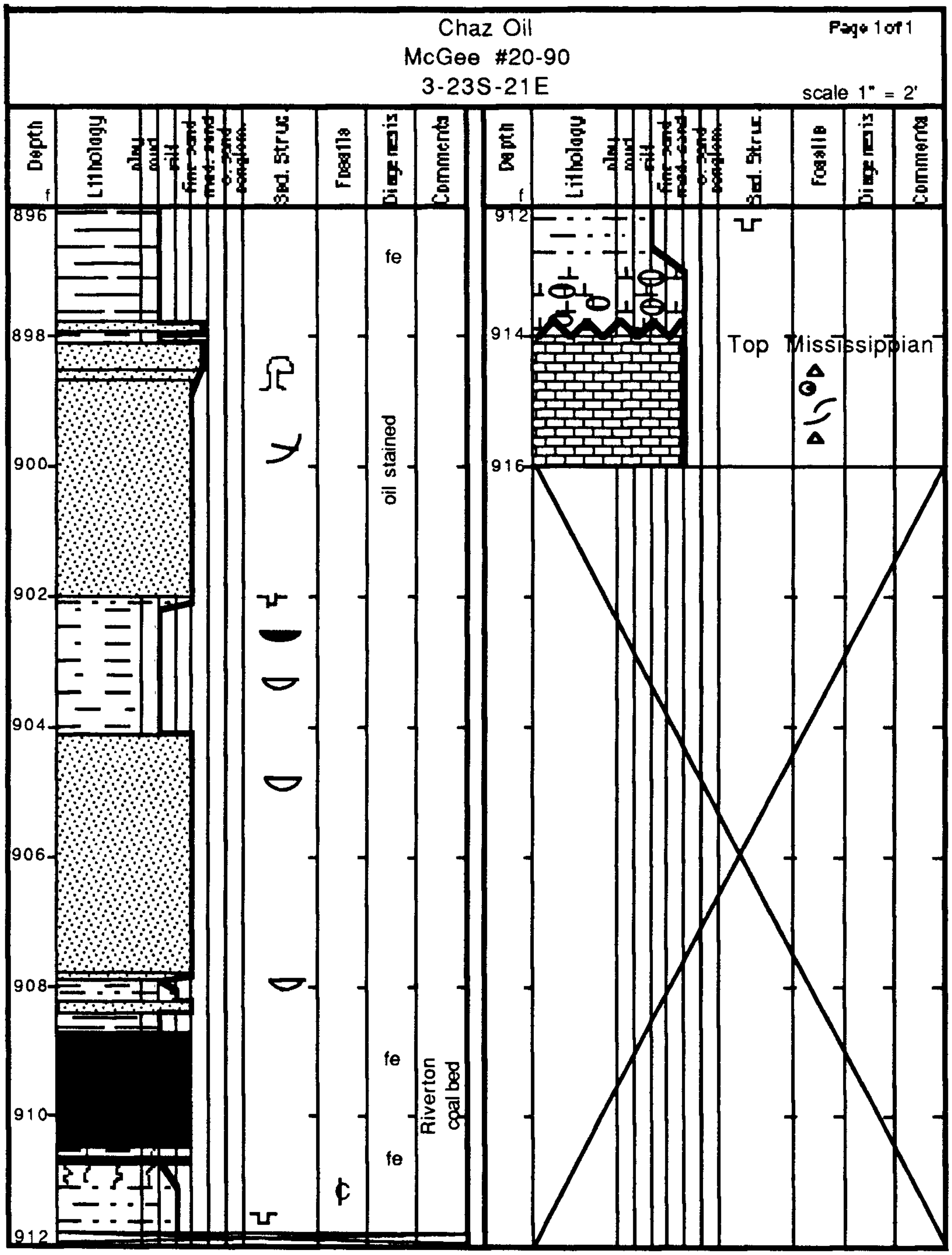
Franklin Oil Enterprises
Dotson #111
26-26S-21E
NW-SW-SE

scale: 1" = 5'





Jackson Brothers
Marshall #3
Polhamus Field
34-24S-9E
SW-NW-SW
G.L. 1320'
Page 1 of 1
scale 1" = 5'
Depth
Lithology
clay
mud
silt
fine sand
med. sand
c. sand
conglom.
Sed. Struc
Fossils
Diagenesis
Comments
2260
2263
2265
2270
2275
2280
2285
2290
2295
2300
Weir-Pittsburg marker
2300
2302
2305
2310
2315
2320
2325
2330
2335
2340
fe

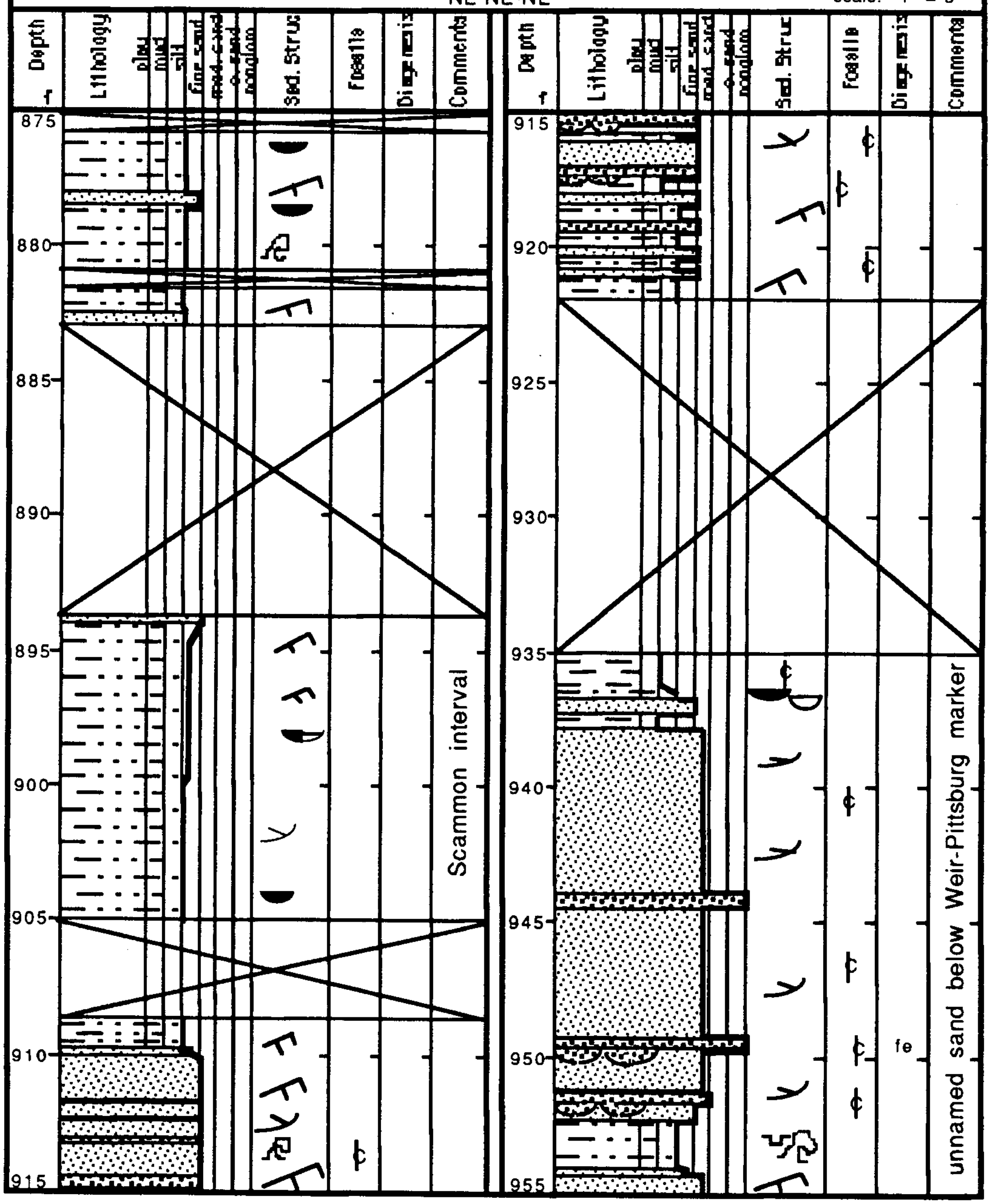


Chaz Oil
Page 1 of 1
McGee #20-90
3-23S-21E
scale 1" = 2'
Depth
Lithology
Sed. Struc.
Fossils
Diagenesis
Comments
896
898
900
902
904
906
908
910
912
fe
oil stained
fe
fe
Riverton coal bed
912
914
916
Top Mississippian

Brazos Oil & Gas Co.
L. R. Smether CT#1
9-21S-19E
NE-NE-NE

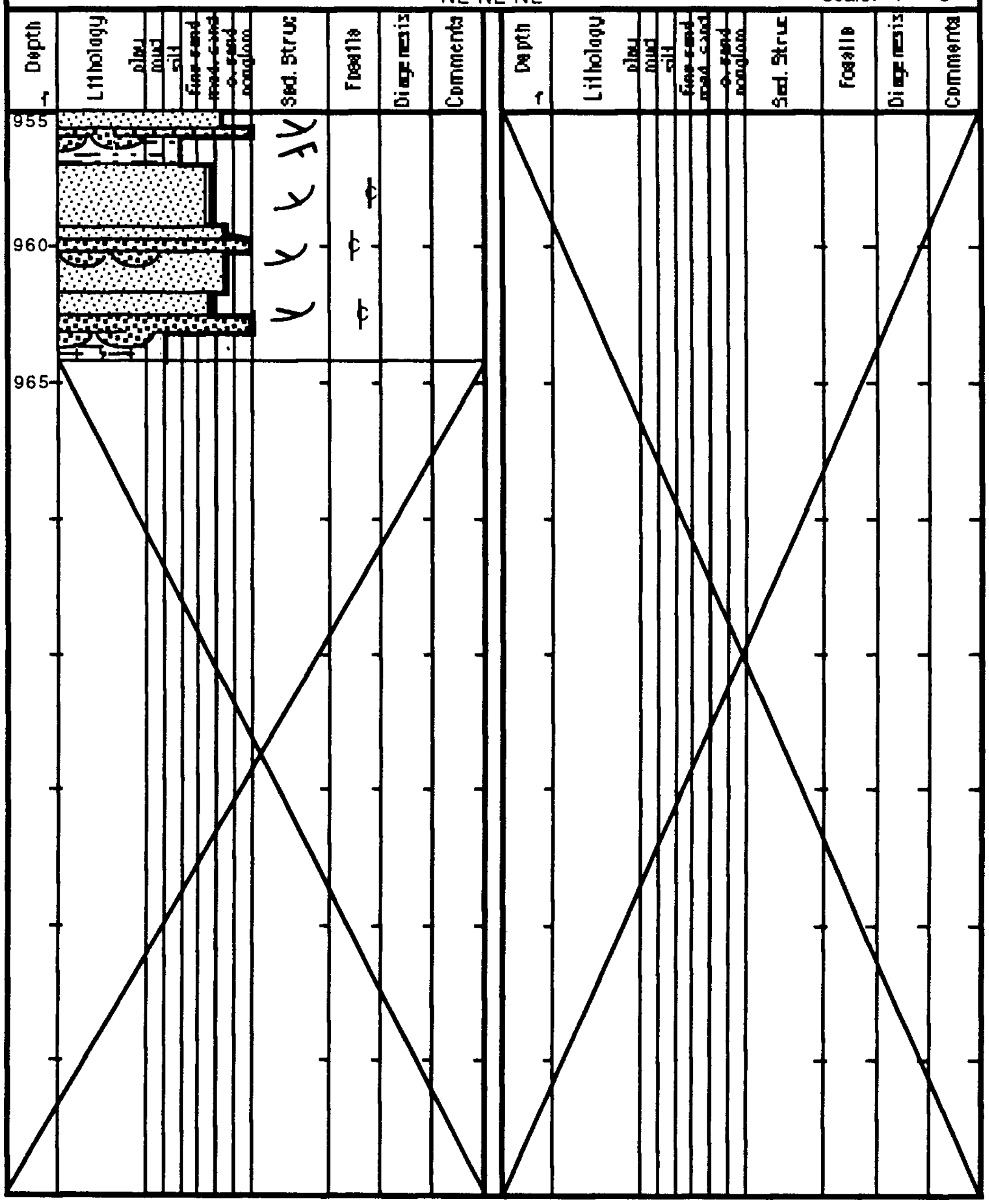
Page 1 of 2

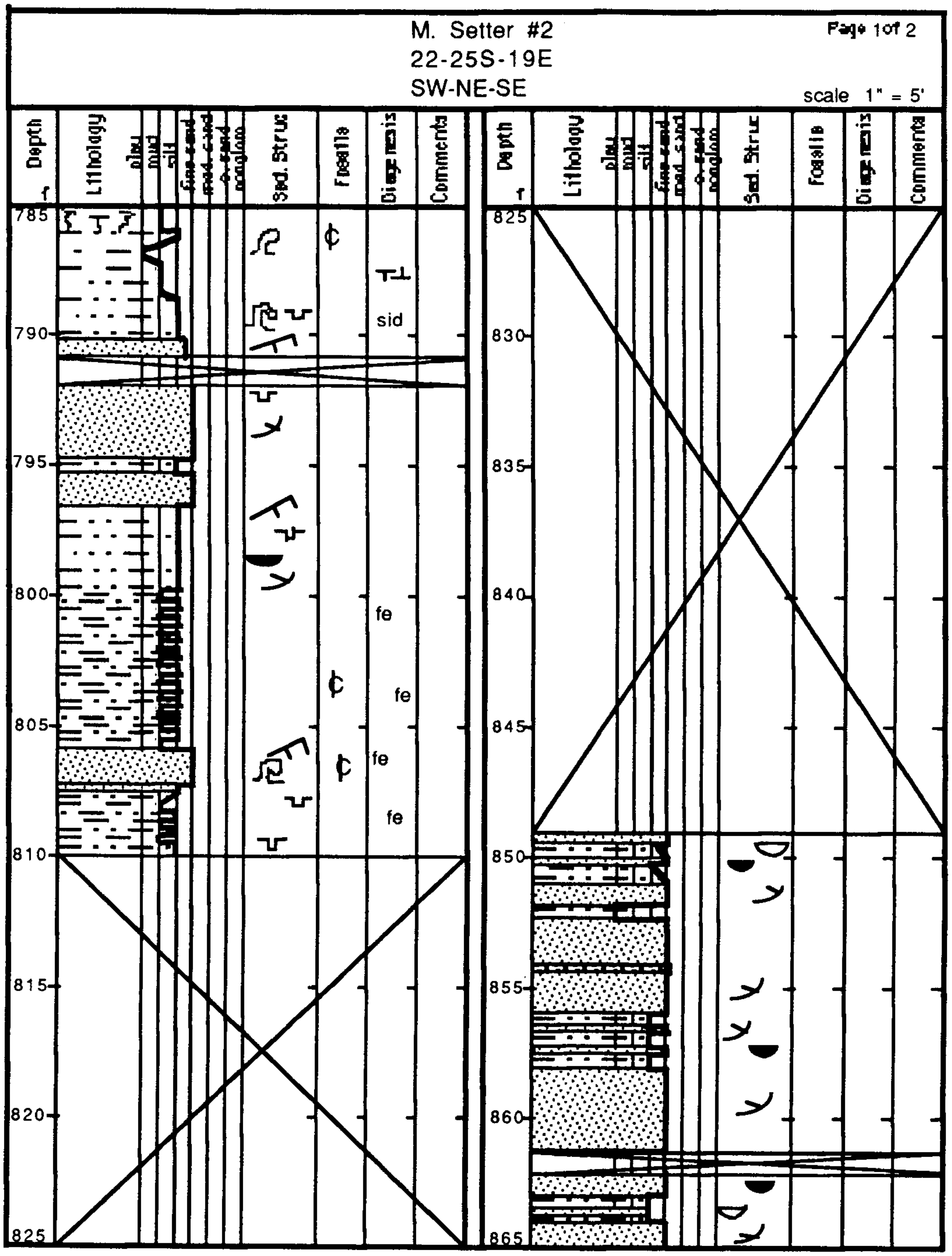
scale: 1" = 5'

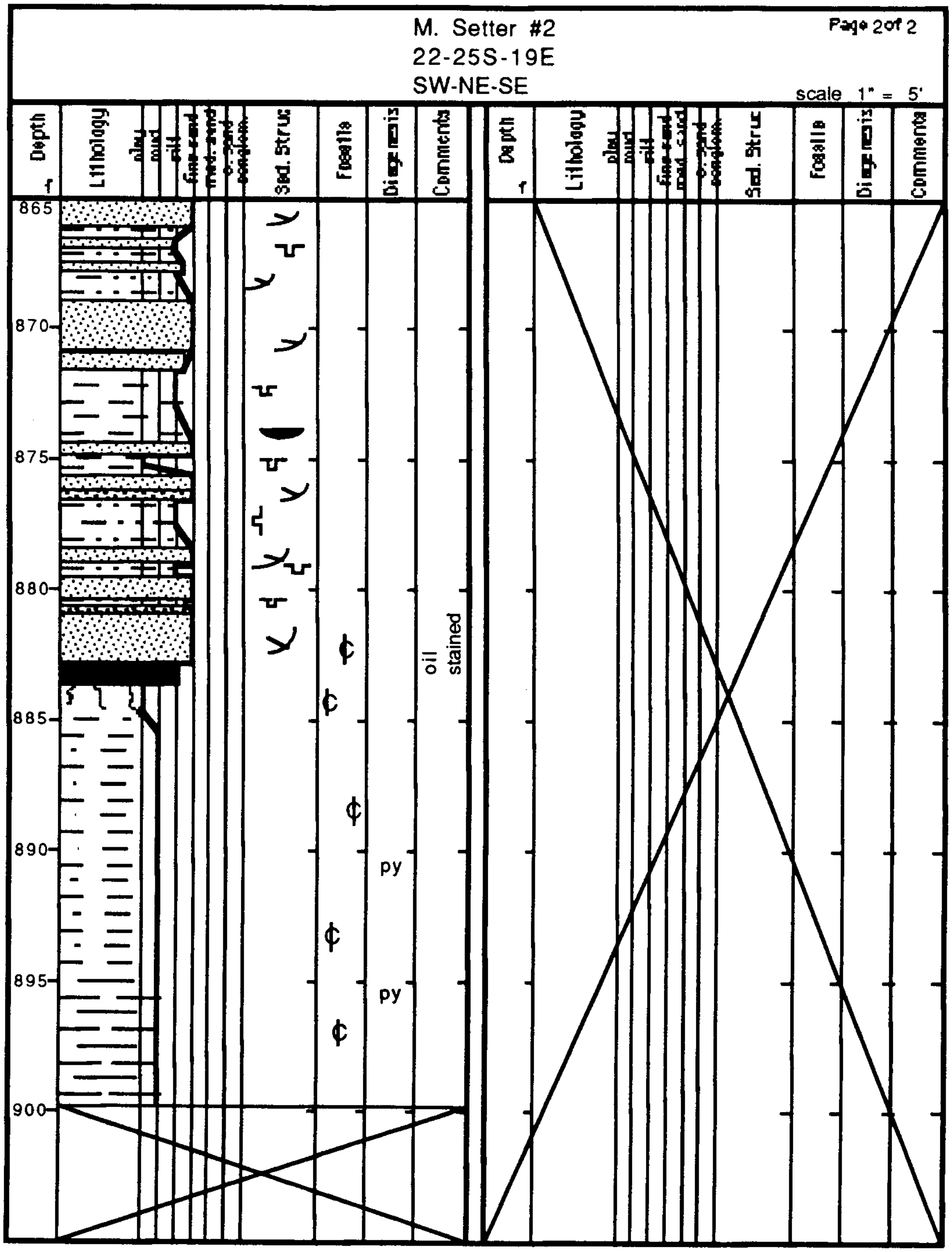


Brazos Oil & Gas Co.
L. R. Smether CT#1
9-21S-19E
NE-NE-NE

scale: 1" = 5'




M. Setter #2
22-25S-19E
SW-NE-SE
Page 1 of 2
scale 1" = 5'
Depth
Lithology
clay
mud
silt
fine sand
med. sand
c. sand
conglom
Sed. Struc
Fossils
Diagenesis
Comments
785
790
795
800
805
810
815
820
825
sid
fe
fe
fe
fe
825
830
835
840
845
850
855
860
865


M. Setter #2
22-25S-19E
SW-NE-SE
Page 2 of 2
scale 1" = 5'
Depth f
Lithology
clay
mud
silt
fine sand
med. sand
c. sand
conglom.
Sed. Struc
Fossils
Diagenesis
Comments
865
870
875
880
885
890
895
900
py
py
oil stained

APPENDIX B

List of geophysical well logs used in this study

Location	Spot	Well Name	Operator	County
27-18S-4E	C-NE-SW	Kremeir #3	Shawmar Oil Co.	Marion
31-18S-4E	NW-SW-NW	N/A	C&S OilCo.	Marion
19-18S-5E	NW-NE-SW	Lindau #1	Messman-Rinehart	Marion
31-18S-5E	NW-SE-SE	Buetha #4	Shawmar Oil Co.	Marion
15-18S-7E	NE-NE-NW	Mulvane #6	Beroing Ent.	Chase
20-18S-8E	NW-NW-NW	Rettieer #1	Brandt Oil Co.	Chase
26-18S-8E	NW-NW-SE	Peak-Hatcher #1	Ablah-Branut	Chase
2-18S-9E	NW-NW-SE	Finley #1	Shawver-Armour	Chase
32-18S-12E	SE-SE-SE	T. Anderson #1	Magnum Land	Lyon
36-18S-12E	NE-NE-NW	Pearson #1	Brunson Spines	Lyon
3-18S-13E	SE-NE-SE	Hodges #1	Brandt Oil Co.	Lyon
1-18S-14E	NE-SE-SE	D.W. Evans #2	Little George Oil Co.	Coffey
6-18S-15E	SW-SW-NW	W. Jones #1	Brunson-Spines	Coffey
6-18S-15E	NW-SE-NW	Jones #1	Little George Oil Co.	Coffey
14-18S-15E	SE-NW-SE	Niles #1	R.I.M. Petro., Corp.	Osage
6-18S-16E	N/A	Everson #1	Reeves	Osage
9-18S-17E	NE-NE-NW	Koehler #1	Alco Drilling, Inc.	Osage
11-18S-18E	NE-SE-NW	Dale Smith #1	Alco Drilling, Inc.	Franklin
16-18S-18E	SW-SW-SE	Rubick #1	Alco Drilling, Inc.	Franklin
13-18S-20E	SW-NW-NE	Trent Burkdoll #1A	G.O.C., Inc.	Franklin
34-18S-20E	SE-SE-SW	Moers #1	Brunson-Spines	Franklin
4-18S-21E	NW-NE-NW	Wakeman #10	Cutler Oil Co.	Franklin
8-18S-21E	SE-SE-SW	Howell #2	Bob Howell	Franklin
8-18S-22E	SE-NE-NE	#28	Town Oil Co.	Miami

Location	Spot	Well Name	Operator	County
9-18S-22E	NE-SW-NE	#3-82	Reese Expl., Inc.	Miami
1-18S-23E	SW-SE-SE	P-1	Energy Energy	Miami
7-18S-23E	NE-NW-NW	#10	Strata Energy	Miami
6-18S-24E	NW-NW-NW	Walter #A-1	Aegean Petroleum	Miami
18-18S-24E	NW-NW-NE	C. Peckman #5-18	Scimitar Resc. Ltd.	Miami
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8-19S-6E	NE-NE-NW	Kowgeboehn #1	Irven Daetwiler	Chase
29-19S-6E	SW-SW-NE	Rennling #1	Branit Oil	Chase
20-19S-8E	NW-NW-NW	Rettiger #1	Brandt Oil Co.	Chase
36-19S-8E	SW-NE-NE	Elmo Starkey #36	Conoco, Inc.	Chase
23-19S-10E	NW-NW-SE	Penny #1	Howard Gough	Lyon
4-19S-12E	SW-NW-SE	Davis #1	Little George Oil	Lyon
13-19S-12E	NW-NW-NE	Wiyard #1	Little George Oil	Lyon
26-19S-12E	NE-NW-NE	Carpenter #1	Magnum Land Corp	Lyon
3-19S-13E	SE-NE-SE	Hodges #1	Brandt Oil Co.	Lyon
28-19S13E	SE-NE-SW	St. Bonnett #1	Little George Oil	Lyon
34-19S-13E	SE-NE-SE	Owens #1	Magnum Land Corp	Lyon
17-19S14E	SW-SW-NW	W. Knight #1	Brunson Spines	Coffey
30-19S-14E	NW-NW-SE	H. Smith #1	Gear Operating Co.	Coffey
34-19S-14E	NW-NW-NE	Jeppers #1	Little George Oil	Coffey
6-19S-15E	NE-NW-SW	Hunter #2	Little George Oil	Coffey
34-19S-17E	NW-NW-NE	James #1	Benson Mineral	Coffey
31-19S-18E	N/A	Lankard 31-D	Rantoul Energy	Anderson
1-19S-21E	SE-SE-SE	Duncon #1	Schwadar	Miami
13-19S-22E	SW-SW-SW	#1	Triple I Energy Corp	Miami
13-19S-22E	SE-SW-SW	#4	Triple I Energy Corp	Miami
33-19S-22E	N-NW	C. Day #1	Oaks Petroleum	Linn
35-19S-24E	N/A	Calvin N-7	Petroleum Prod.	Linn

Location	Spot	Well Name	Operator	County
31-20S-3E	NE-NW-NW	Sunderman A-1	Anadarko Prod. Co.	Marion
2-20S-4E	SE-SE-SE	#1	Time Petroleum Co.	Marion
9-20S-5E	C-SE	Vogel	Patton Oil Co.	Marion
30-20S-5E	SE-NE-NE	S.E. Tibbins #1	Beaumont Petr. Co.	Marion
7-20S-6E	NE-SE-NE	Vogelman #1	George Reed	Chase
23-20S-7E	SW-NE-NW	Monee # 1	Hinkle Oil Co.	Chase
14-20S-9E	NW-NW-NW	Arbuthnot #1	Brandt Oil Co.	Lyon
36-20S-9E	SE-SE-SE	Owens #2	Little George Oil Co	Lyon
2-20S-10E	NW-NW-NW	Miller #1	Little George Oil Co	Lyon
36-20S-10E	C-NW-SW	Conrade #1	Brandt Oil Co.	Lyon
15-20S-11E	SW-SE-NW	M. Jones #1	Brunson-Spines	Lyon
22-20S-11E	NE-NW-SW	Brown #1	Brunson-Spines	Lyon
14-20S-12E	NE-NE-SW	McKinney #1	Icer Addis	Lyon
17-20S-12E	NE-NE-SE	Van Sickle #1	Magnum Land Corp	Lyon
2-20S-13E	NE-NE-NW	Mulson #1	Brunson-Spines	Coffey
27-20S-13E	SW-SE-SE	Gillagan #1	Brandt Oil Co.	Lyon
25-20S-14E	NE-SW-NW	Warner #3	Teichgraeber-West.	Coffey
26-20S-14E	NE-NE-NE	Newkirk #2	Teichgraeber	Coffey
16-20S-15E	NE-NE-NE	Eccles #1	T. G. Wright, et al.	Coffey
35-20S-15E	NW-NW-SE	Prillips #1	Icer Addis	Coffey
5-20S-16E	NE-NE-NW	Greathouse #1	Brandt Oil Co.	Coffey
14-20S17E	SE-NE-SE	Graham #1	Dynamic Expl., Inc.	Anderson
19-20S-17E	SE-SE-NE	Kitchens #1	Benson Mineral	Coffey
5-20S-18E	SE-SW-SW	Pilburn #1	Brunson-Spines	Anderson
7-20S-18E	SE-SE-SW	Miller #1	Brunson-Spines	Anderson
21-20S-19E	NW-SW-NW	Raymond #1	Zorger Oil Co.	Anderson
30-20S-19E	E-NE-SE	Davison #1	Brunson-Spines	Anderson
16-20S-20E	SW-NW-NW	Fruerborn #1	Huff Gas Co.	Anderson

Location	Spot	Well Name	Operator	County
21-20S-20E	N/A	Whitman #1	R. G. Prod. & Roger	Anderson
6-20S-21E	SW-SW-NW	Wittry #1	U.S. American Petr.	Anderson
33-20S-21E	NE-SW	Feter #18	Tripple Oil Co.	Anderson
10-20S-22E	SE-SE-SE	Prather #1	Western Petroleum	Anderson
15-20S-22E	NE-SE	Clark S-2	Scintar Resources	Linn
14-20S-23E	N/A	Tea Garden #1	Petroleum Prod. Inc	Linn
23-20S-23E	C-SW-NE	A-1	Aegean Petr., Inc.	Linn
30-20S-24E	SE-SW-SW	#5	Western Well & P.	Linn
-------	-------	-------	-------	-------
18-21S-3E	NE-NW-SE	Loewen #7	Cities Service Oil	Marion
5-21S-4E	NE-SW-SW	Keirns #1	Raymond Oil Co.	Marion
8-21S-5E	S-N-SE	Strait Ranch #8	Petroleum Land	Marion
21-21S-5E	NW-NW-NW	Strait Ranch #21	Petroleum Land	Marion
23-21S-6E	NW-NE-SW	Odle #23-1	L.G. Williams	Chase
4-21S-8E	SW-SE-SW	Pasal Roniger #4-1	U.N.C. Texas	Chase
25-21S-9E	SE-SW-NW	Eno #1A	LaVerna Ann Oil Co	Chase
36-21S-9E	SW-NE-NE	S.E.J. #2	Gordon Smith	Chase
30-21S-10E	SW-SW-SW	Atyeo #11A	Charles Gould	Lyon
34-21S-10E	SE-NW-SW	Pixley C #31	Jackson Brothers	Lyon
34-21S-10E	NE-SW-SW	Pixley #20	Jackson Brothers	Lyon
24-21S-11E	NE-NE-NW	Mantile #1	Brunson Spines	Lyon
25-21S-11E	NE-NW-NW	Mantile #1	R.A. Comeau	Lyon
3-21S-12E	NE-NE-NW	Grieder #1	Little George Oil	Lyon
25-21S-12E	NW-SE-SE	Jeaneret #1	Brunson Spines	Lyon
1-21S-13E	NW-NW-NE	D. Wilson #1	Brunson Spines	Coffey
24-21S-13E	NW-SW-SE	Wilcox #1	Gear Operating Co.	Coffey
10-21S-14E	NE-SW-NW	Krause #1	Haas Drilling Co.	Coffey
31-21S-14E	SE-SE-NW	Merritt #1	Icer Addis	Coffey

Location	Spot	Well Name	Operator	County
15-21S-15E	SW-NW-SW	Allen #1	Little George Oil	Coffey
29-21S-15E	SW-SW-NW	Ward #1	Louis Mai	Coffey
33-21S-15E	SW-SW-SE	Griffin #1	Little George Oil	Coffey
11-21S-16E	NW-NW-SW	Dalby #1	Benson Minerals	Coffey
25-21S-16E	NE-NE-NE	Colvin #1	Oil Property Mgt.	Coffey
24-21S17E	NE-NE-NW	Drum #1	Ward M. Edinger	Anderson
13-21S-19E	SE-NW-NE	Worthington #2-84	A.C. Oil Co.	Anderson
14-21S-19E	C-SW-NE	Benjamn N-1	Caldwell Ent.	Anderson
7-21S-20E	SW-NE-SW	S.P. Johnson #K19	Ladd Petroleum	Anderson
15-21S-20E	N/A	OKO WSW #1	Deep Rock Oil, Co.	Anderson
1-21S-21E	SW-NW-NE	North Unit #26	Glen Caldwell	Anderson
36-21S-21E	C-NW-NE	Mitchell #3	Kent Drilling Co.	Linn
10-21S-22E	N/A	REF. #35A	Rantoul Energy	Linn
36-21S-23E	SE-SE-SE	Bob Markley #4	Pine Ridge, Inc.	Linn
31-21S-24E	NE-NE-SW	Shinkle # CT131	Layton Oil Co.	Linn

10-22S-4E	SW-SW-SW	Kellen #1	Drillers & Producers	Marion
32-22S-5E	SW-NE-SE	Swanson #2	Tepe Oil & Gas Co.	Marion
22-22S-8E	NE-SE-NW	Crocker #1	Palomino Petr.	Chase
13-22S-9E	NE-NW-SE	Underwood #1	E.W. Sauder	Chase
25-22S-9E	SW-NE-SE	Big Springs #4	E.L. Williams	Chase
35-22S-9E	NE-SE-SW	Big Springs B #3	L&W Exploration	Greenwood
4-22S-10E	NE-NE-NE	Pixlee C #3	Jackson Brothers	Greenwood
30-22S10E	NW-NW-SW	Prather Hutton #1	Lon Farthing	Greenwood
10-22S-11E	NE-SE-SE	Meyers #2	Schankle Well Serv.	Greenwood
27-22S-11E	NE-NW-NE	Huber #5	Schankle Well Serv.	Greenwood
31-22S-11E	SW-SE-NW	Gilbreath #1	Oscar Koepke	Greenwood
32-22S-11E	NE-SE-NE	Schankle #2	Shankle and Sons	Greenwood

Location	Spot	Well Name	Operator	County
17-22S-12E	NW-NW-NE	Luthi #1	Brunson-Spines	Greenwood
2-22S-13E	SW-SW-NE	Hatch A #2	Little George Oil Co	Coffey
7-22S-13E	C-SW-NE	Pete Ott #1	N&B Enterprises	Greenwood
11-22S-13E	NE-SW-SW	Isch #1	Petroleum Energy	Coffey
7-22S-14E	SE-NE-NE	Birk #1	Wells Oil Inc.	Coffey
27-22S-14E	NW-NE-SW	Knapp #1	Barnet Oil Co.	Coffey
9-22S-15E	SE-SE-SE	McMullen #1	French Oil Co.	Coffey
29-22S-15E	SE-SE-NW	Born #1	Petroleum Energy	Coffey
3-22S-16E	NE-NE-SW	Gilmore #1	Twin Western Res.	Coffey
22-22S-16E	SW-SE-SE	Edwards C #3	Lincoln 77, Inc.	Coffey
31-22S-16E	NW-NW-SW	Southerland #3	Cameron K. Reed	Coffey
28-22S-18E	SW-NE-SW	Lay #1	Glacier Petroleum	Anderson
29-22S-18E	NE-SE-SE	Weddin #2	Glacier Petroleum	Anderson
34-22S-19E	NW-NW-SE	Minckley 34 #1	James E. Russel	Anderson
21-22S-20E	NW-NW-SW	Garrison #4	Bellwether Expl.	Anderson
1-22S-21E	SE-SW-SE	#C-9	K.C. Crude, Inc.	Linn
30-22S-21E	Center	Miller #1	Petroleum Res.	Anderson
2-22S-22E	NE-NE-NW	#3	Orion Energy Corp.	Linn
18-22S-22E	C-SW-SE	#15-88	Chaz Oil Corp.	Linn
1-22S-23E	SE-SE-SE	Markley #1	Pine Ridge Devel.	Linn
7-22S-23E	NW-SW-SW	Shaw #1	D.L. Stokes	Linn
1-22S-24E	N/A	Cox #1	Cox Motor Co.	Linn
6-22S-24E	NW-SE-SW	Shinickle #CII-6	Layton Oil Co.	Linn
8-22S-24E	C-NE-NW	Carbon #6-8	Protaal Resources	Linn
19-22S-25E	N/A	Cone S-1E	Schmitar Res., Ltd.	Linn
30-23S-6E	SW-NW-SW	Busening #1	Jun Range Res.	Butler
35-23S-8E	NE-NW-NE	Zebold #1	Lee Phillips	Greenwood

Location	Spot	Well Name	Operator	County
15-23S-9E	NW-SW	Teter B-16	Glacier Petroleum	Greenwood
24-23S-9E	NE-SW-SE	Luthi #1	Petroleum Energy	Greenwood
14-23S-10E	NE-SW-NE	Burkett #C-35	Franklin D. Gaines	Greenwood
15-23S-10E	NW-SW	Bladase #6	Teicherbach Oil Op.	Greenwood
20-23S-10E	NW-NE-NW	Elmer Hollis #1	Icer Addis	Greenwood
29-23S-10E	SE-SE-SE	Thrall #18-B	Glacier Petr. Inc.	Greenwood
32-23S-10E	C-SE-NW	McKee #6	Glacier Petr. Inc.	Greenwood
2-23S-11E	NE-NE-NE	Kipper #1	Lee Phillips Oil Co.	Greenwood
33-23S-11E	NW-SW-SW	Carson #1	Petroleum Energy	Greenwood
31-23S-12E	SE-NE-SE	Harmon #1-A	K.E. Synder Oil Co.	Greenwood
28-23S-13E	SW-SE-NW	Berry #25	Houston-Oklahoma	Greenwood
32-23S-13E	NE-SW-SW	Berry #3	French & Winters.	Greenwood
9-23S-14E	SW-SW-NW	Bahr C #1	Barnett Oil, Inc.	Coffey
9-23S-14E	SW-SE-SW	Bahr #1	Barnett Oil, Inc.	Coffey
32-23S-14E	C-NE-SE	J.W. Maclaskey #24	Sinclair Oil & Gas Co	Woodson
12-23S-15E	SW-NW-NW	Briles #5 WDW	B.T. & B Oil	Coffey
31-23S-15E	C-NW-SE	Weide # W.I.-1	Vanocker Oil Co.	Woodson
32-23S-15E	C-SW-SW	Weide #2	Creek Oil & Gas Co.	Woodson
19-23S-16E	NE-SE-SW	Mithchell #1	Mahony-Cannon-L.	Woodson
33-23S-16E	C-SE-SE	Sturdivan #7	Long Time Oil Co.	Woodson
35-23S-17E	SW-NE-SW	Vanderman #1	Howard Vanderman	Woodson
35-23S-17E	SW-SW-SE	L. Cleaver #5	L. Cleaver Oil Co.	Allen
36-23S-18E	NE-NE-NE	Francis Mae #15	Ric Petroleum	Allen
36-23S-18E	SE-NW-NE	Fances Mae #13	Karankawa Oil Co.	Allen
13-23S-19E	C-NE-SW	J.Q. Adams #1	James E. Russell	Anderson
31-23S-19E	NW-SE-NW	Eastwood WSW #1	James E. Russell	Allen
31-23S-19E	NW-NW	Russell #2	N/A	Anderson
28-23S-21E	SE-SE-SE	Stewart #1.80	Reese Exploration	Allen

Location	Spot	Well Name	Operator	County
4-23S-21E	SW-SE-SE	Gaddis #14	Overland Inv., Ltd.	Anderson
5-23S-21E	NE-NE-SE	N/A	Greenwood Resc.	Anderson
22-23S-23E	NE-SE-SW	#4-81	Reese Expl., In.	Bourbon
5-23S-24E	N/A	#5	Dorwin Jackson	Anderson
27-23S-24E	NE-NW-SE	Dotson #2	Jack Hobson	Bourbon
30-23S-24E	NE-NW-SW	#2	Corneleius Bros.	Bourbon
27-23S-25E	NW-SW-NW	Core Hole #8	CFS Energy, Inc.	Bourbon
17-24S-5E	NE-NE-SE	Joseph 1-17 Disp.	Reach Petr. Corp.	Butler
32-24S-8E	NW-SE-SW	Nutle Estate #1	Rains & Williamson	Butler
11-24S-9E	SE-SE	Anderson/Ols. #29	Bill Soule	Greenwood
34-24S-9E	NE-NW-SE	Nixon #8	Jackson Brothers	Greenwood
9-24S-10E	C-NE-SE	Schwar #2	Berentz Drilling	Greenwood
23-24S-10E	SE-NW-SE	N/A	Berentz Drilling	Greenwood
1-24S-11E	NE-SE	Raymond Harris #2	K.E. Snyder Co.	Greenwood
9-24S-11E	SW-SE-NW	Ellis #1	Little George Oil Co	Greenwood
1-24S-12E	NW-SE-SE	Bobey #2	Lewis Long	Greenwood
4-24S-12E	SW-SW-SW	Gilbert Mitchell #2	K-3 Energy	Greenwood
5-24S-13E	NW-NW-NE	H.D.Stevenson #11	The Pure Oil Co.	Woodson
12-24S-13E	SW-SW-NE	Dalton #1	White Pine Petr. Co	Woodson
31-24S-13E	SW-NW-NW	Dinius #49	Bird & Hanley	Greenwood
5-24S-15E	SW-SE-SE	Weide #3	Mid-American Expl.	Woodson
12-24S-15E	SE-SW-SE	A.M. Weston #20	Arron L. Sauder	Woodson
4-24S-16E	NW	Tannahill SWD #1	Midway Oil Co.	Woodson
12-24S-16E	NW-NW	West Mahre #13	Mid-Continental E.	Woodson
9-24S-17E	NW-NW-NE	T. Fitzpatrick #4	Shade Tree Oil Co.	Woodson
19-24S-17E	NE-SE-NE	Wiljie #2	Dean Morris	Woodson
10-24S-18E	NW-SW	N/A	Layton Oil Co.	Allen

Location	Spot	Well Name	Operator	County
15-24S-18E	SW-SE	Dunlap #4-H-A	Bailey Oil Co.	Allen
20-24S-19E	NW-NW-SE	Lenski #1	Bulfer Expl. Inc.	Allen
14-24S-20E	NW	Brown #1	Nelson Drilling	Allen
35-24S-20E	NW-SW-NW	Weatherbie #1	Inea Oil Co.	Allen
2-24S-21E	NW-NE-NE	WSW #1	Reese Exploration	Bourbon
25-24S-21E	NW-NW	Collins #10	T. B. Bird	Bourbon
18-24S-22E	SW-NW-NE	Ermal B #47	Hillenburg Oil Co.	Bourbon
24-24S-24E	W-NE	Develan #1	G.G.L. & Assoc.	Bourbon
16-24S-25E	SE-SE-NE	Oklac. Dahlgen #1	Baker & Williams	Bourbon

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Location	Spot	Well Name	Operator	County
34-25S-3E	SE-SE-NE	Miller #1	Commerical Oil	Butler
35-25S-3E	NE-NE-SW	Hutchens #1	Sunshine Oil & Su.	Butler
32-25S-4E	NW-SE-SW	Anderson #1	Thorton E. Anders.	Butler
36-25S-4E	C-SW-NE	Girod SWD #1	White & Ellis Drilling	Butler
34-25S-5E	NE-NE-SW	Hill #22	Suerie Oil Co.	Butler
19-25S-6E	NW-NW-NW	Gish #1	Petroleum Mgt. Inc.	Butler
2-25S-8E	NE-NE-SW	Hap Jackson #3	Rucker-Hough	Greenwood
23-25S-8E	SE-NE-SW	Jackson Maira #26	Jackson Brothers	Greenwood
32-25S-9E	NW-NW-NW	Della Ladd #2	Oil Field Supply	Greenwood
32-25S-10E	SE-SE-SE	Bailey #2	Dick Teichgraeber	Greenwood
34-25S-10E	SE-SE-NE	Sears #2	P&M, Inc.	Greenwood
31-25S-11E	NW-SE-SE	Blackstone A #1	Teichgraeber Oil	Greenwood
32-25S-11E	NE-NE-SE	Rhodes #1	Ward Mo. Ginnis	Greenwood
31-25S-12E	NW-NE-NE	Dick Gilbert #1	Rucker-Hough	Greenwood
8-25S-13E	NE-NW-SW	Joe Becker #2	Apollo Oil	Greenwood
31-25S-13E	NW-NE-NE	Keffer #1	John Rick Oil	Greenwood
26-25S-14E	SE-NW-SE	Mecca Sheedy #1	Mecca Petroleum	Woodson
26-25S-14E	SE-NW-SE	Mecca Sheedy #2	Mecca Petroleum	Woodson

Location	Spot	Well Name	Operator	County
6-25S-15E	E-NE-SW	Walton #1	Brunson-Spines	Woodson
15-25S-16E	SE-NW-NW	A & P Ferree #9-A	Eugene S. Cornish	Woodson
24-25S-16E	NW-SW-NE	Drain #1	Carter-Benson	Woodson
17-25S-17E	NW-NW-SE	Led Collins #1	Cater	Woodson
16-25S-18E	N/A	Chet Morre #1	Clyde Thompson	Allen
31-25S-18E	CE-NE-NE	Hinkle #2	Kenneth Kenndy	Allen
14-25S-19E	SE-SW	Scott B-7	Tech-American Res	Allen
28-25S-19E	NW-SE-NE	Hess #8	Thompson Oil&Gas	Allen
7-25S-20E	NW-SE	Stewart #I-39	Sun Oil Co.	Allen
13-25S-20E	SW	Day #3	Petro-American	Allen
18-25S-21E	NW-NW-NW	Booth #25	Inexco Oil Co.	Allen
6-25S-22E	SW-SW-NW	Ramsey #1	Lance Exploration	Bourbon
14-25S-22E	NW-NE-NW	Darrel George #4	Venture Oil Oper.	Bourbon
35-25S-24E	C-NE	Deep Well #2	City of Fort Scott	Bourbon
16-25S-25E	E-SE-SW	E. Wratchford #1	Dr. W.E. Welsh	Bourbon

Location	Spot	Well Name	Operator	County
17-26S-5E	SW-NW	Horner #2	Flowers Prod. Co.	Butler
29-26S-6E	CN-SW	Wagner #2	Mac Oil Co.	Butler
36-26S-6E	NW-SE	Bisagno #4	Bisagno Bros. Inc.	Butler
22-26S-7E	SW-SW-NE	Simon #1-A	Little Nell Oil Corp.	Butler
28-26S-7E	NW-SE-NE	PMA #1	Little Nell Oil Corp.	Butler
9-26S-8E	C-SE	Galyardt #1	Southwind Petr.	Butler
15-26S-8E	NW-NW	Ease #4	Dick Teichgraeber	Greenwood
32-26S-8E	NW-SE	Pagan #1	Dick Teichgraeber	Greenwood
13-26S-9E	NW-NW-SE	Life #2-D	Harold Forbes	Greenwood
4-26S-10E	SE-SE-SE	Sounders #1	Dick Teichgraeber	Greenwood
18-26S-10E	NW-NW-NW	Shinkle #2	K. Lance Snyder	Greenwood
16-26S-11E	NE-SE	Vinson #1	H.A.S. Oil Co.	Greenwood

Location	Spot	Well Name	Operator	County
24-26S-11E	NE-NE-SW	Marlin #1	Brunson Supplies	Greenwood
20-26S-12E	NE-SW-NW	Morris #1	C.F. Urschel Jr.	Greenwood
30-26S-12E	SW-SW-NE	Lora Russell #1	C.F. Urschel Jr.	Greenwood
14-26S-13E	NE-SW-NE	Hibbard #1	Mid-Del Oil & Gas	Woodson
36-26S-15E	SE-SE	O'Bryan #2	Energy Exploration	Woodson
24-26S-16E	SE	Wiltse #C-1	Ponderay Inter.	Woodson
5-26S-17E	NW-NW	Stoll WDW #1	Stoll Prod. Co.	Woodson
12-26S-17E	SW-NE	Ellison #14	Lancer Oil	Allen
2-26S-18E	SE-SE-SW	Perkins #6	Phenix Exploration	Allen
26-26S-18E	NE-SE-NE	Bartlett #7	Ridge Oil & Gas Inc.	Allen
5-26S-19E	NW-NW	WDW #1	Stoll Production Co	Allen
10-26S-19E	NW-NW-NE	Johnson WDW #1	Fairfield Oper. Co.	Allen
16-26S-20E	N/A	Johnson	Rainbow	Allen
29-26S-20E	NE-SE-SW	Manson #I-40	Renflow Oil Co.	Allen
26-26S-21E	NW-SW	Dotson #54 WSW	Yemon Oil Co. & CF	Bourbon
32-26S-21E	SE-NW-NE	Baker WSW #1	N & B Ent.	Allen
24-26S-22E	SE-SE	#1	Petro Valley Serv.	Bourbon
20-26S-23E	C-NE-NE	#2	Petro Valley Serv.	Bourbon
30-26S-23E	C-NW-NE	R. Russell #4	Petro Valley Serv.	Bourbon
5-26S-25E	SW-NW-SW	#1	Peerless Prod. Inc.	Bourbon
12-27S-21E	NW-NW-NE	Johnson #1	Mitidete, Inc.	Bourbon
6-28S-22E	N/A	Ida Henery #1	Fred Moreland	Crawford
30-29S-17E	SW-SW-SW	Monte Erre #D-13	Dico Oil	Wilson
27-30S-21E	SE-NE	Long #14	Hickory Creek Oil	Neosho

Location	Spot	Well Name	Operator	County
34-30S-21	NW-SW-SE	D.D. Gray #11	MO Lead & Zinc	Neosho
21-31S-21E	NW-NW	Larry Cook #2	Hickory Creek Oil	Labette