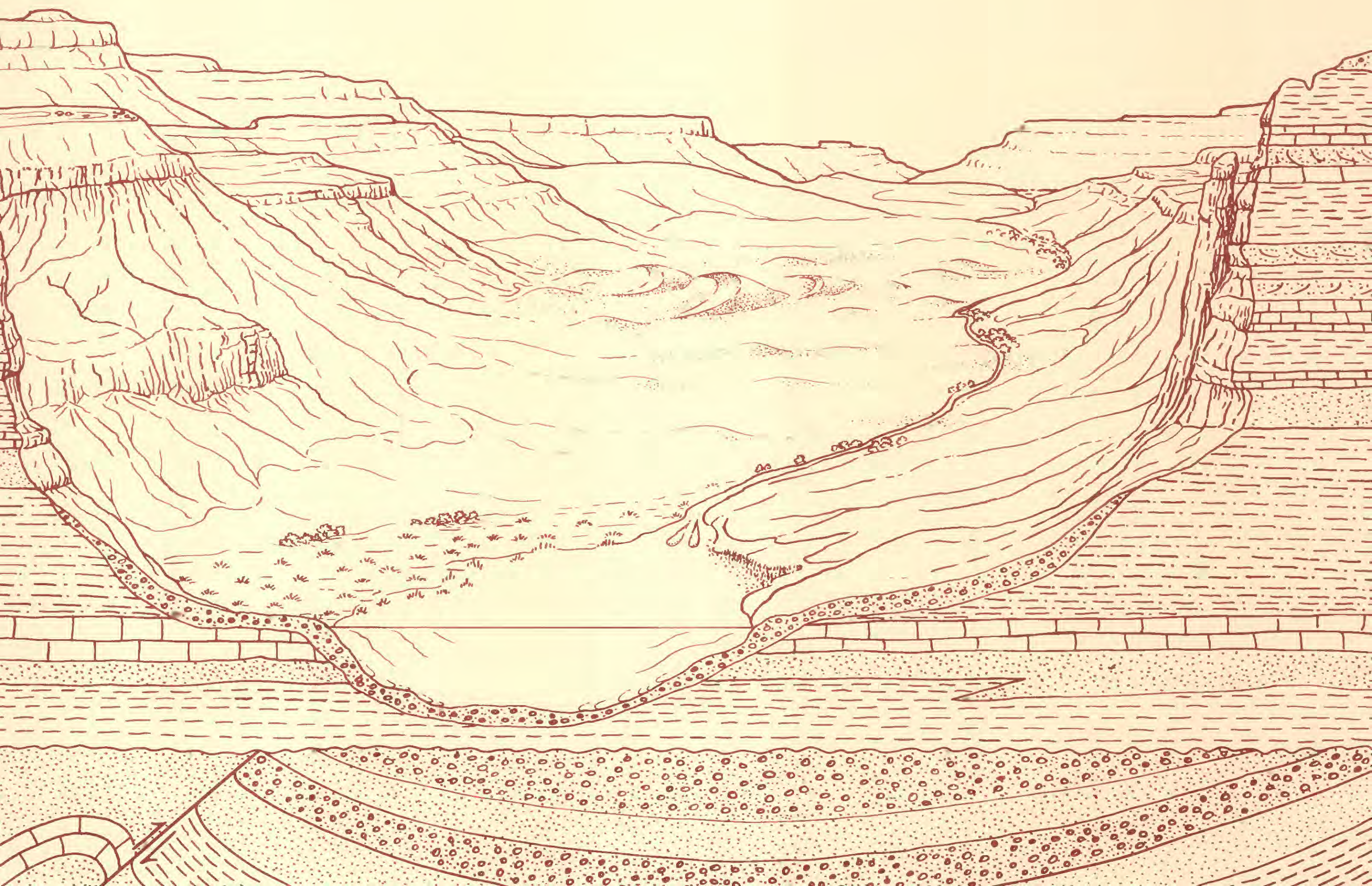
Log-Derived Regional Source-Rock Characteristics of the Woodford Shale, Anadarko Basin, Oklahoma

U.S. GEOLOGICAL SURVEY BULLETIN 1866–D



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Chapter D

Log-Derived Regional Source-Rock Characteristics of the Woodford Shale, Anadarko Basin, Oklahoma

By TIMOTHY C. HESTER, JAMES W. SCHMOKER,
and HOWARD L. SAHL

A multidisciplinary approach to research studies of sedimentary rocks and their constituents and the evolution of sedimentary basins, both ancient and modern

U.S. GEOLOGICAL SURVEY BULLETIN 1866

EVOLUTION OF SEDIMENTARY BASINS—ANADARKO BASIN

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CONVERSION FACTORS FOR SOME SI METRIC AND U.S. UNITS OF MEASURE

To convert from	To	Multiply by
Feet (ft)	Meters (m)	0.3048
Miles (mi)	Kilometers (km)	1.609
Pounds (lb)	Kilograms (kg)	0.4536
Degrees Fahrenheit (°F)	Degrees Celsius (°C)	Temp °C = (temp °F–32)/1.8

Log-Derived Regional Source-Rock Characteristics of the Woodford Shale, Anadarko Basin, Oklahoma

By Timothy C. Hester, James W. Schmoker, *and* Howard L. Sahl

Abstract

The Woodford Shale is an organic-rich, highly compacted, "black" shale of Late Devonian and Early Mississippian age that is widely regarded as a major hydrocarbon source rock in the Anadarko basin of Oklahoma. The Woodford is divided here, on the basis of log character, into three informal stratigraphic units: the lower, middle, and upper members of the Woodford Shale. Higher kerogen content of the middle member is the physical basis for this subdivision. Because source-rock properties of each member differ, geochemical and other data are best considered in view of internal Woodford stratigraphy.

Isopachs of the Woodford and its three members reveal a positive structural feature, parallel with and about 75 miles (120 kilometers) north of the Wichita Mountains front, that divided the Woodford into northeast and southwest depocenters and was a hinge line separating areas of regional basement flexure during Woodford time. Lower and middle members of the Woodford thicken to the southwest into the now-eroded central trough of the southern Oklahoma aulacogen. The upper member thickens to the northeast toward Kansas, reflecting initial development of the Sedgwick basin of south-central Kansas.

Total organic carbon (TOC, in weight percent) is calculated here from log-derived formation density (ρ_b, g/cm^3) using the equation: TOC $=(156.956/\rho_b)-58.272$. TOC of the lower, middle, and upper members of the Woodford Shale averages 3.2, 5.5, and 2.7 weight percent, respectively. TOC does not correlate with formation thickness, but does decrease with increasing thermal maturity in response to the progressive generation and expulsion of hydrocarbons.

The total amount of organic carbon in the Woodford Shale of the study area is evenly divided between the lower, middle, and upper members. Of the 73 trillion kilograms of organic carbon mapped here, some 54 trillion kilograms are in thermally mature areas characterized by vitrinite reflectance (R_o) greater than 0.6 percent. Most of the hydrocarbons sourced by the Woodford Shale of the study area were generated from the lower and middle members, in that these two members contain 74 percent of the thermally mature organic carbon.

Manuscript approved for publication, June 14, 1989.

INTRODUCTION

The Woodford Shale is one of several organic-rich "black" shales of Late Devonian and Early Mississippian age present in basins of the North American craton. Other examples of similar age include the Antrim Shale of the Michigan basin, the New Albany Shale of the Illinois basin, the lower and upper members of the Bakken Formation of the Williston basin, the Exshaw Formation of the Alberta basin, and the "Devonian" shales of the Appalachian basin. Where thermally mature, these black shales are economically important as hydrocarbon source rocks.

The Woodford Shale is widely regarded as a major source rock in the Anadarko basin (Cardott and Lambert, 1985). This report describes regional depositional trends and organic-carbon content of the Woodford Shale as evidenced by wire-line logs in the Oklahoma portion of the Anadarko basin (fig. 1). The relation between depositional patterns and organic-carbon content is discussed, and the mass and distribution of organic carbon in thermally immature and mature areas of the Woodford Shale is estimated. To better document variations and regional trends within the Woodford Shale, the formation is considered here in terms of three

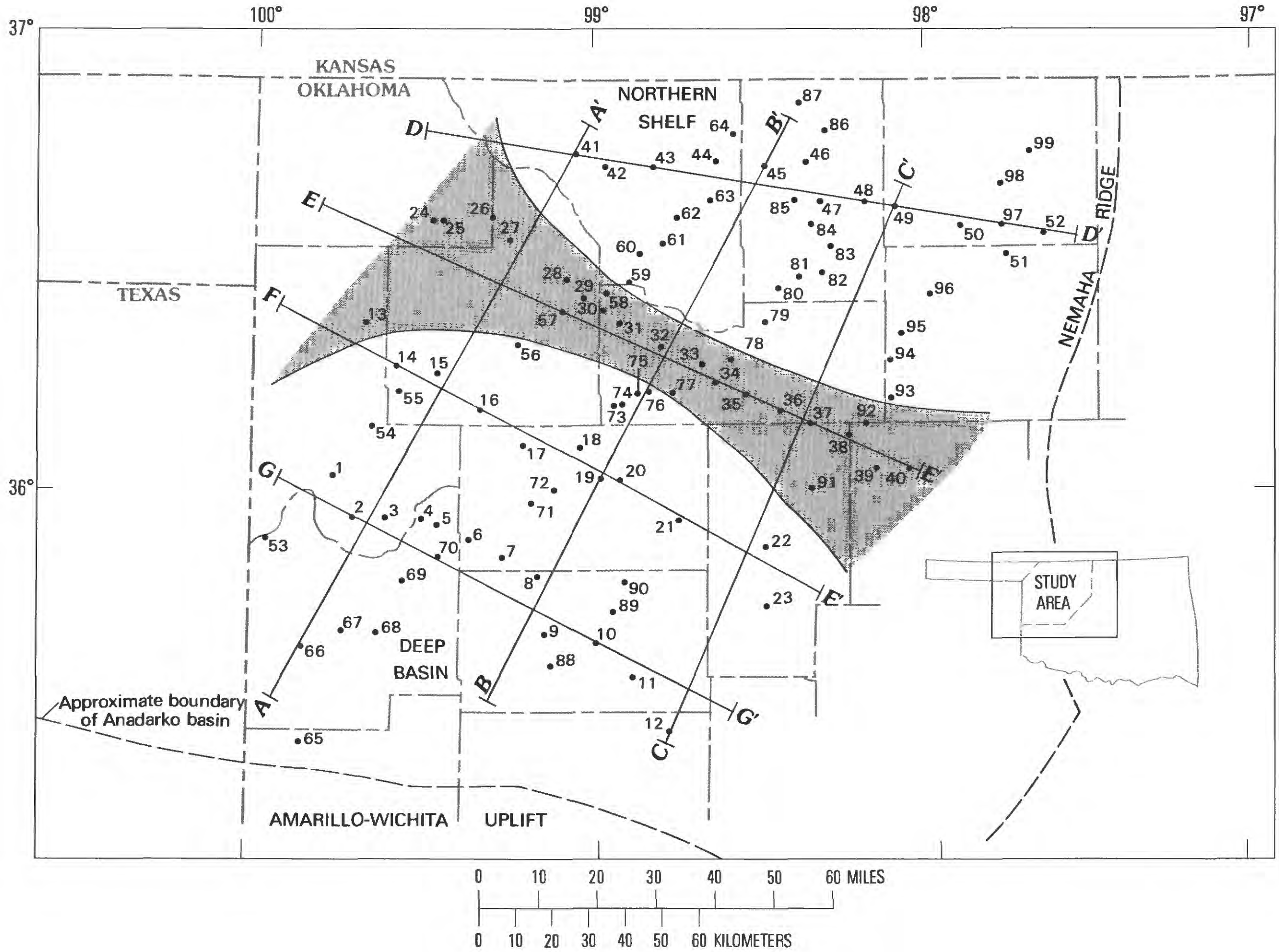

Figure 1. Location of study area, lines of cross sections, locations of wells used in study, and major structural features, Anadarko basin, Oklahoma. Shaded zone separates southwest and northeast regions of figures 11, 20, and 27. Wells are identified by number in appendix 1.

informal members (Hester and others, 1988) analogous to those described by Ellison (1950) for the Woodford Shale in the Permian basin of west Texas and southeast New Mexico.

GEOLOGIC SETTING

The Late Devonian and Early Mississippian age Woodford Shale is present throughout most of the Oklahoma portion of the Anadarko basin. The Woodford is deposited on a major regional unconformity developed in the Late Devonian (Amsden, 1975) and is conformably overlain by shales and limestones of Early Mississippian (Kinderhookian) age. Total thickness ranges from near zero to about 125 ft (40 m) on the extensive northern shelf areas and increases to more than 900 ft (270 m) in limited parts of the deep Anadarko basin (Amsden, 1975). Maximum thickness in the area of this study (fig. 1) is about 300 ft (90 m).

The Woodford is a highly radioactive, carbonaceous and siliceous, dark-gray to black shale. In most areas of the basin, total organic carbon (TOC) of the Woodford Shale exceeds a commonly accepted shale source-rock minimum of 0.5 weight percent (Tissot and Welte, 1984). Organic matter in the Woodford is thought to be a mixture of type II and type III kerogens preserved as a result of deposition in anoxic (but not necessarily extremely deep) waters (Heckel, 1972; Cluff, 1981). Large areas of the Woodford Shale have attained the maturation levels required for hydrocarbon generation (Schmoker, 1986).

In terms of wire-line character, the Woodford Shale can be generally described as two similar shales separated by a less dense, more radioactive, and often more resistive middle member (Hester and others, 1988). For this reason, the Woodford is considered here to consist of three informal stratigraphic units: the lower, middle, and upper members of the Woodford Shale. The typical log character of these three members is illustrated in figure 2. The Woodford and its members were identified in the 99 wells of this study (fig. 1) by Hester and others (1988).

The Anadarko basin is a Paleozoic basin that formed in two stages. The Woodford Shale was deposited upon the predominantly carbonate sediments of the first-stage southern Oklahoma aulacogen (Feinstein, 1981). The present-day configuration of the basin, reflected by structure on top of the Woodford (fig. 3), developed primarily in a post-Woodford (Pennsylvanian and Permian), second-stage foreland-style basin.

The Woodford Shale dips into the Anadarko basin from subsea depths of roughly 4,000 ft (1,200 m) near the Kansas-Oklahoma border to more than 25,000 ft (7,600 m) near the Amarillo-Wichita uplift (fig. 3) and thus encompasses an unusually broad range of thermal maturities. Vitrinite reflectance (R_o) ranges from slighty less than 0.5 percent on the northern shelf to well over 2.0 percent in the deep basin (fig. 4). Thermal maturity trends are generally similar to structural trends, although vitrinite-reflectance contours cut those of present-day structure in parts of the central and northeastern study area.

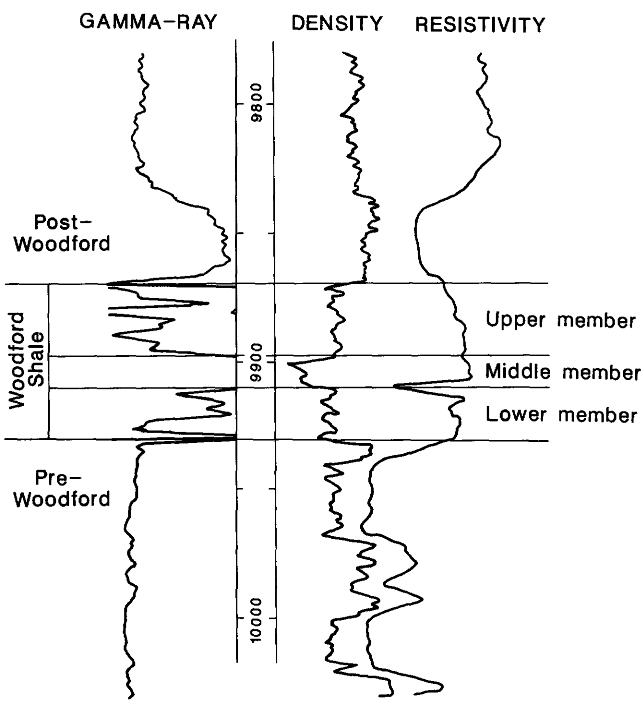

Figure 2. Characteristic log signatures of lower, middle, and upper members of Woodford Shale (well 75, appendix 1). Modified from Hester and others (1988).

DATA SET

Data of this report, collected from 99 wells distributed throughout the study area (fig. 1, appendix 1), are tabulated in appendix 2. In each well, depth, thickness, and average formation density are taken directly from wire-line logs. Total organic carbon is calculated from average formation density (equation 1), and the mass of organic carbon per unit surface area is calculated using equation 2. Vitrinite reflectance at each well location is picked from contoured data of Cardott and Lambert (1985) and B.J. Cardott (Oklahoma Geological Survey, written commun., 1987).

Because the specific gravity of kerogen is low relative to that of shale matrix minerals (Smith and Young, 1964; Kinghorn and Rahman, 1983), variations in the formation density of organic-rich, low-porosity shales such as the Woodford can be equated to changes in organic-matter content (Schmoker, 1979; 1980; Hashmy and others, 1982). Total organic carbon (weight percent) is calculated here according to the equation (Schmoker and Hester, 1983, equation 7):

$$\mathrm{TOC} = (A/\rho_b) - B, \qquad (1)$$

where ρ_b is average formation density (g/cm^3), A = 156.956 and B = 58.272.

A and B are empirically derived constants incorporating shale and organic-matter properties and interactions. These constants are determined from the least-squares fit to the crossplot of 148 pairs of laboratory TOC analyses and log-derived formation densities (fig. 5). The calibration data represent four organic-rich black shales of Late Devonian and Early Mississippian age of which the Woodford is a typical example. The least-squares fit to the data of figure 5 has a correlation coefficient of –0.97.

TOC is independent of thickness and thus does not reflect the total amount of kerogen in a formation. To better characterize source-rock properties of the Woodford Shale, the mass of organic carbon per unit surface area (OC/cm2) is introduced:

$$\mathrm{OC/cm^2} = (\mathrm{TOC}/100)(\rho_b)(\mathrm{DZ}), \qquad (2)$$

where DZ is formation or member thickness (cm) and OC is in grams.

DEPOSITIONAL PATTERNS

The total thickness of the Woodford Shale is less than 125 ft (40 m) over most of the study area (fig. 6) but increases rapidly to the south near the Amarillo-Wichita uplift. The Woodford isopach map of figure 6 depicts the northern shelf area of the southern Oklahoma aulacogen

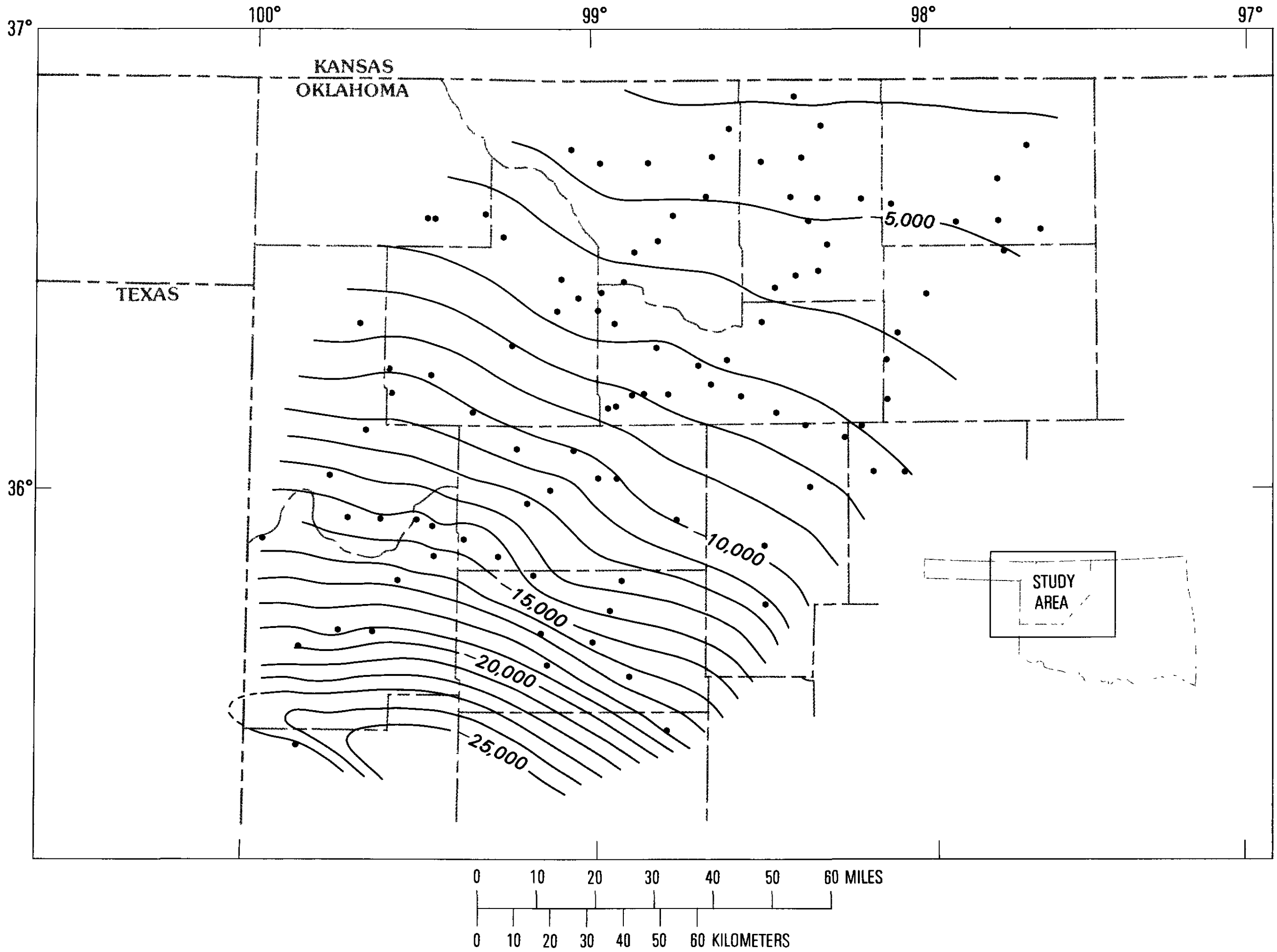

Figure 3. Depth below sea level of top of Woodford Shale. Contour interval 1,000 ft (305 m); dots show well locations (fig. 1, appendix 1).

prior to the rapid subsidence of Pennsylvanian and Permian time.

The heavy arrow of figure 6 marks the axis of a structural element that divides the study area into southwest and northeast regions. As seen in subsequent figures, this positive feature influenced deposition throughout Woodford time and was a hinge line separating areas of regional basement flexure and downwarping.

Local thickness variations of the lower member of the Woodford Shale (fig. 7) reflect the eroded and karsted surface on which it was unconformably deposited. The structural element marked in figure 6 separates the lower member of the Woodford into two distinct depocenters (fig. 7). Maximum thickness in the northeast depocenter is only about 25 ft (8 m). Isopachs of the southwest depocenter do not close in the study area but show thickening into the (now eroded) deep axis of the southern Oklahoma aulacogen. Figure 7 indicates that during deposition of the lower member of the Woodford the northeast region of the study area was quite stable, but the central trough of the southern Oklahoma aulacogen was actively subsiding.

Because the lower member tended to smooth and bury pre-Woodford topography, the thickness of the middle member of the Woodford Shale (fig. 8) varies more uniformly than that of the lower member. Like the lower member, maximum thickness in the northeast depocenter is about 25 ft (8 m). In the southwest depocenter, the middle member gradually thickens into the deep axis of the southern Oklahoma aulacogen (fig. 8). Figure 8 indicates continued stability of the northeast depocenter and moderate subsidence of the central trough of the southern Oklahoma aulacogen during middle Woodford time.

In contrast to the lower and middle members, isopachs of the upper member of the Woodford Shale do not close in the northeast depocenter, but show thickening to the northeast into Kansas (fig. 9). Also in contrast to the lower and middle members, the upper

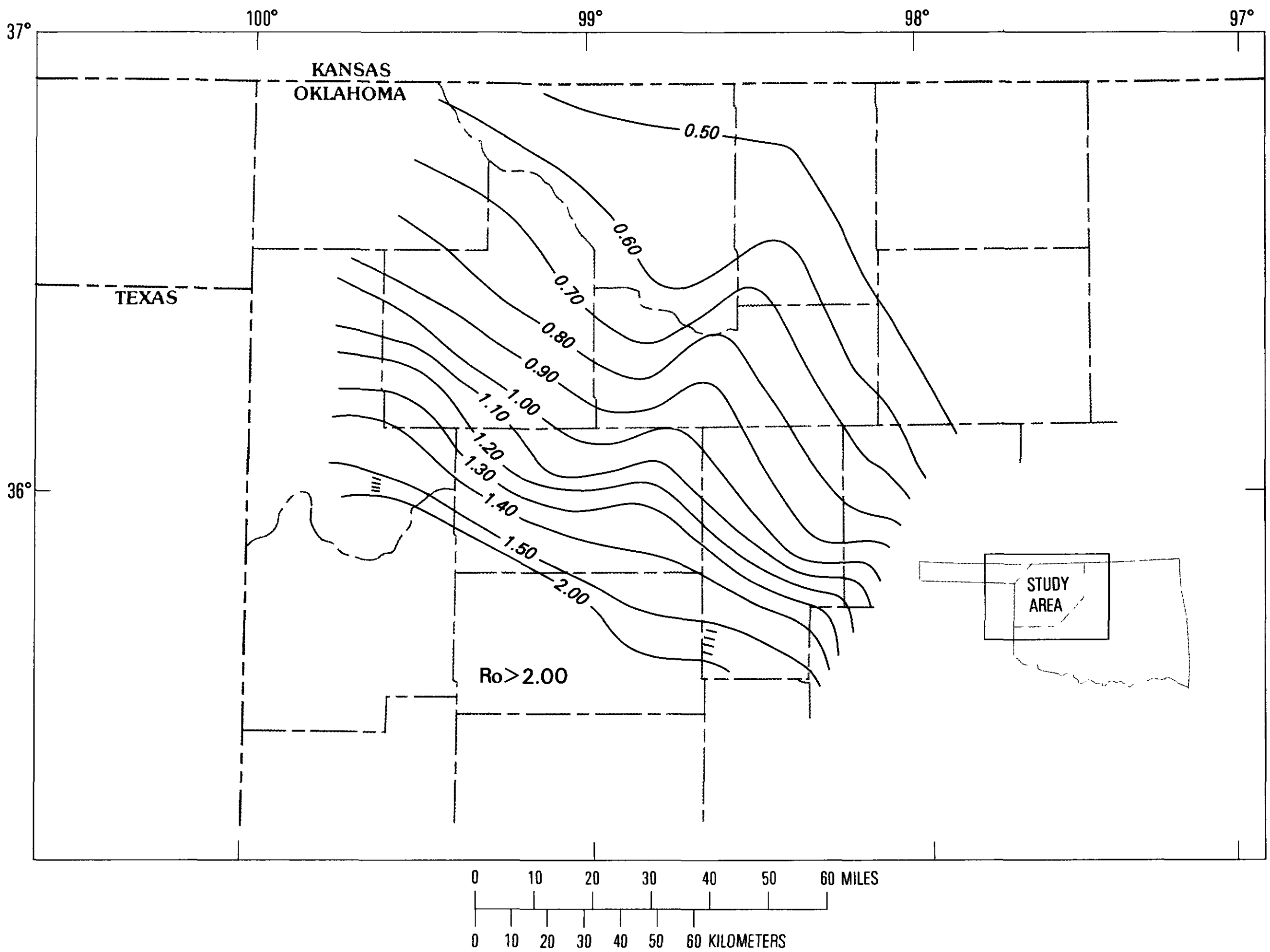

Figure 4. Vitrinite reflectance of Woodford Shale. Contour interval 0.1 percent R_o. Contoured from data of Cardott and Lambert (1985) and B.J. Cardott (Oklahoma Geological Survey, written commun., 1987).

member does not thicken appreciably to the southwest near the Amarillo-Wichita uplift. Figure 9 indicates a shift in depositional pattern during upper Woodford time due to both initial development of the Sedgwick basin of south-central Kansas (Kelly and Merriam, 1964) and marked slowing of subsidence along the axis of the southern Oklahoma aulacogen.

Average thickness of both the lower and upper members of the Woodford Shale is about 30 ft (9 m), but thickness distributions of these two members appear quite different (fig. 10). The thickness distribution of the lower member (fig. 10) reflects deposition on an irregular, eroded and karsted surface that had greater topographic relief in the southwest region than in the northeast region (fig. 11). The bimodal thickness distribution of the upper member (fig. 10) reflects a significantly greater accumulation of sediment in the northeast region than in the southwest region (fig. 11).

The middle member has an average thickness of only 20 ft (6 m) (fig. 10). In the southwest region, the thickness distribution of the middle member resembles that of the lower member, but with no outliers. In the northeast region, the middle member is thin and approximates a uniform blanket of sediment (fig. 11).

Depositional relationships between the three members of the Woodford Shale suggested by figures 7–11 are more easily visualized in the smoothed regional cross sections of figures 12 and 13. The middle member generally onlaps the lower member. The upper member tends to offlap the middle member in the southwest region and to onlap the middle member in the northeast region, reflecting the shift of deposition to the northeast during late Woodford time. The series of basement movements indicated by figures 12 and 13 hinged along the northwest-trending axis identified in figure 6. Woodford depositional patterns (figs. 12, 13) depict the transition between the first-stage southern Oklahoma aulacogen and the second-stage Pennsylvanian and Permian foreland downwarping that together shaped the present-day Anadarko basin.

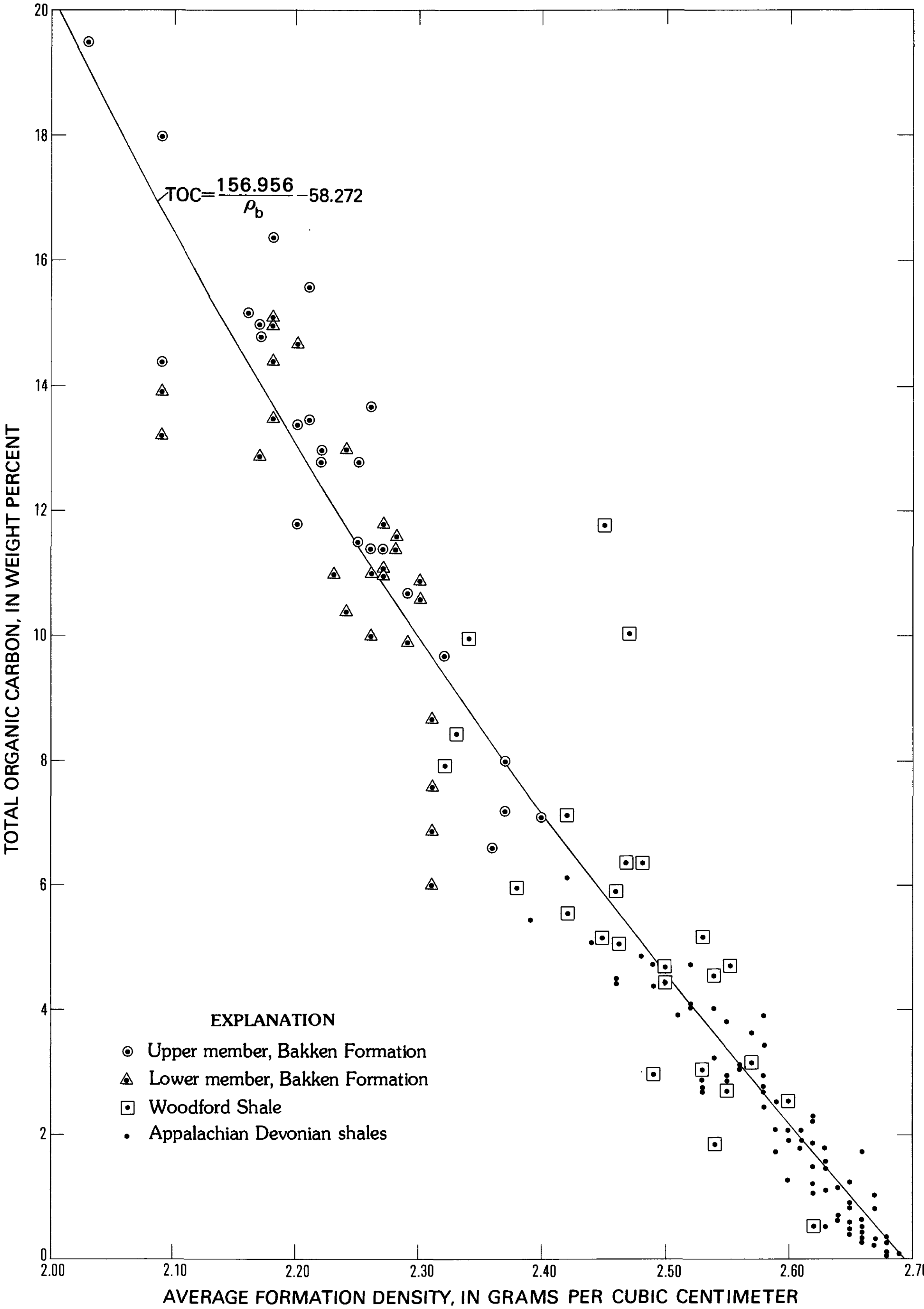

Figure 5. Laboratory analyses of total organic carbon (TOC) versus log-derived average formation density (ρ_b) of equivalent interval for lower and upper shale members of the Bakken Formation of the Williston basin (Schmoker and Hester, 1983), Appalachian Devonian shales (Schmoker, 1979), and the Woodford Shale (Hester and Schmoker, 1987).

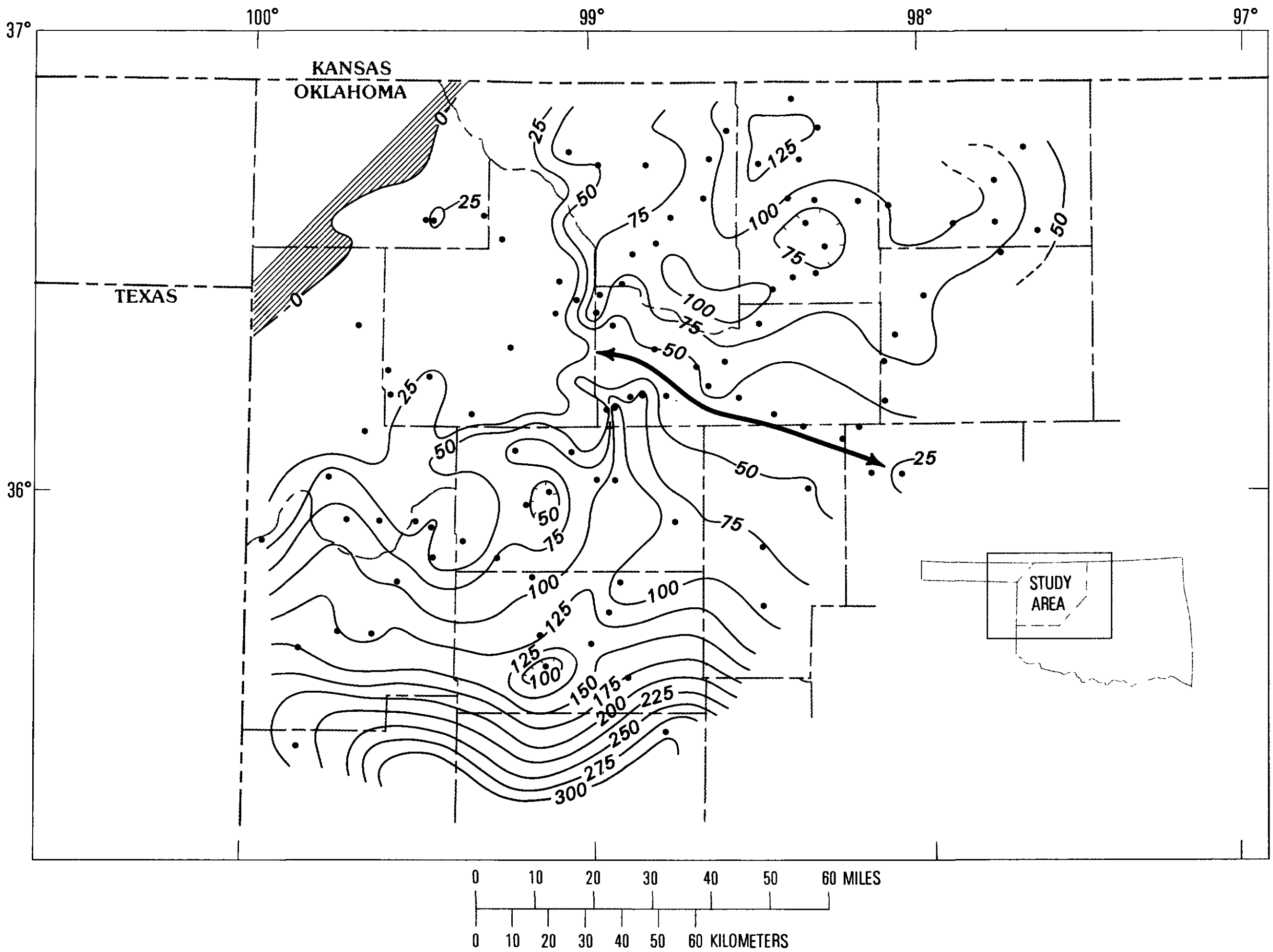

Figure 6. Thickness of Woodford Shale; contour interval 25 ft. Arrow marks axis of structural feature that separates Woodford into northeast and southwest regions. Area where Woodford Shale is absent is hachured; dots show well locations (fig. 1, appendix 1).

TOTAL ORGANIC CARBON

Total organic carbon (TOC) of the lower, middle, and upper members of the Woodford Shale averages 3.2, 5.5, and 2.7 weight percent, respectively (fig. 14), and is rarely less than a commonly accepted shale source-rock minimum of 0.5 weight percent (Tissot and Welte, 1984). As calculated from density logs, the middle member is significantly richer in organic carbon than the lower and upper members (fig. 14). Higher kerogen content accounts for the lower density, higher gamma-ray intensity, and moderately higher resistivity typical of the middle member (fig. 2) and is the physical basis for the subdivision of the Woodford Shale into three members according to log character.

Total organic carbon of the Woodford Shale and its three members is mapped in figures 15–18. Local variations in TOC probably relate to the accumulation and preservation of kerogen early in the depositional history of the formation. The general grain of the contours, however, tends to parallel present-day structure (fig. 3) and thermal maturity (fig. 4) and probably reflects regional processes of kerogen maturation during burial. The lowest values of TOC occur along the western edge of the lower and upper members and are perhaps indicative of poor organic-matter preservation at the time of deposition. Other occurrences of thinning or pinchout are not characterized by unusually low TOC values (figs. 16–18). TOC does not decrease as thickness decreases to near zero (fig. 19), showing that organic matter was in general not anomalously degraded near depositional edges. At the other extreme, TOC does not decrease as thickness increases (fig. 19), showing that a fixed supply of organic matter was not diluted by varying rates of clastic sedimentation.

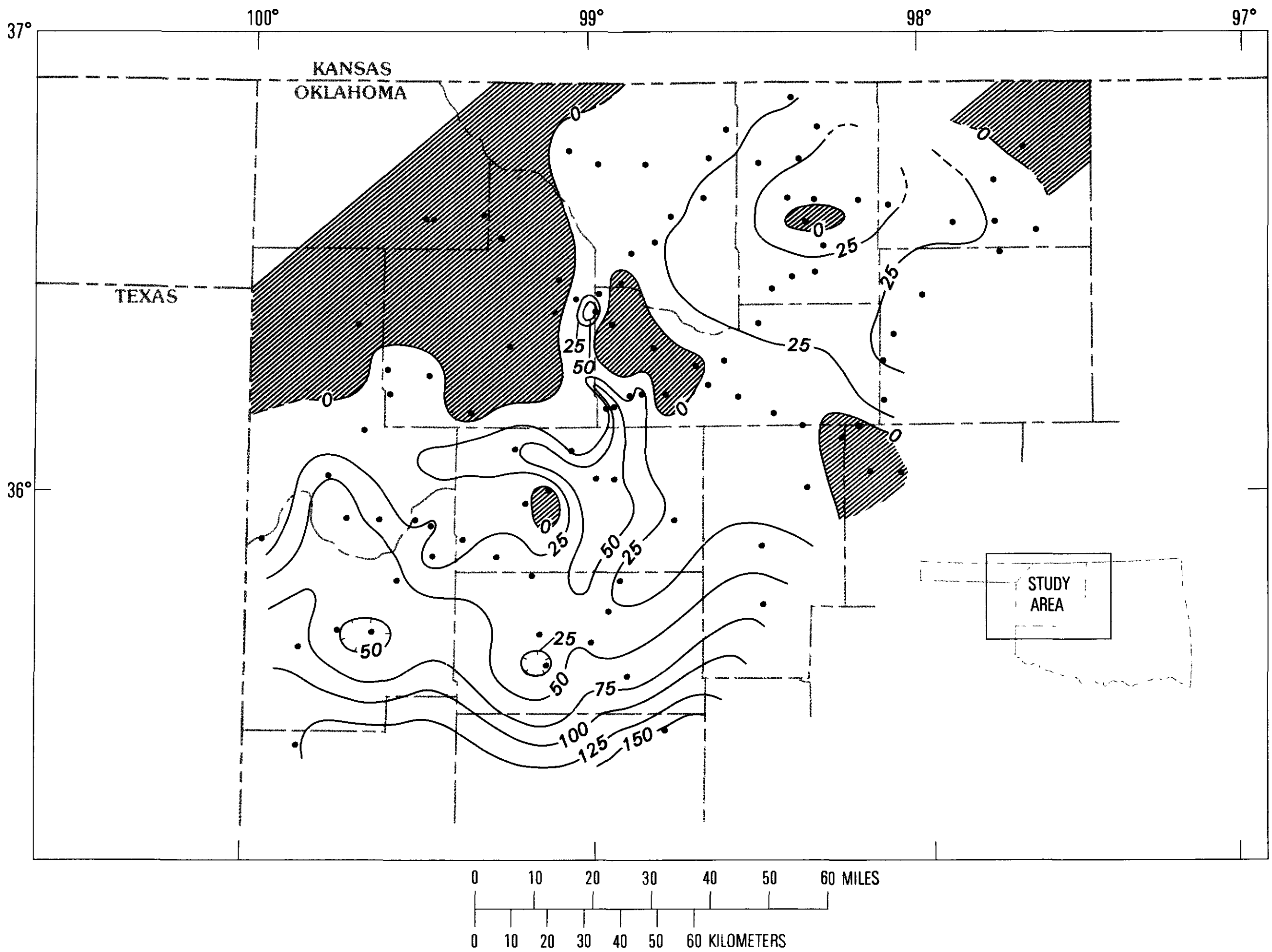

Figure 7. Thickness of lower member of Woodford Shale; contour interval 25 ft. Areas where lower member is absent are hachured; dots show well locations (fig. 1, appendix 1).

Thermal maturity of the northeast region of the study area is significantly lower than that of the southwest region. TOC of each member of the Woodford Shale tends to be higher in the northeast region than in the southwest region (fig. 20). Lower TOC associated with higher thermal maturity is interpreted here to result from the progressive depletion of organic carbon by the conversion of kerogen to oil and gas and the subsequent expulsion of these hydrocarbons from the formation. The middle member, which is a better source rock in terms of TOC than the lower and upper members (fig. 14), also appears to be a better source rock in terms of generation potential and expulsion efficiency (fig. 20). An alternative but less likely explanation for the differences between northeast and southwest regions apparent in figure 20 is that the original, preserved quantity of organic matter decreased regionally from northeast to southwest.

Crossplots of TOC versus burial depth (fig. 21) show that maximum values of TOC decrease by 3–4 weight percent in each member of the Woodford Shale as depth increases to about 18,000 ft (5,500 m), or as vitrinite reflectance increases to about 2.0 percent. This decrease of maximum TOC with depth, like the decrease of average TOC from northeast to southwest regions (fig. 20), is attributed here to the progressive loss of organic carbon from the formation as hydrocarbons are generated and expelled. At depths greater than 18,000 ft (5,500 m), maximum values of TOC no longer decline (fig. 21), suggesting that the potential for generation of additional hydrocarbons has been largely exhausted. About 40–50 percent of the organic carbon originally preserved in the Woodford Shale remains in the formation at high thermal maturities in the form of inert kerogen or unexpelled hydrocarbons (fig. 21).

MASS OF ORGANIC CARBON

The mass of organic carbon per unit surface area (OC/cm^2), calculated using equation 2, combines

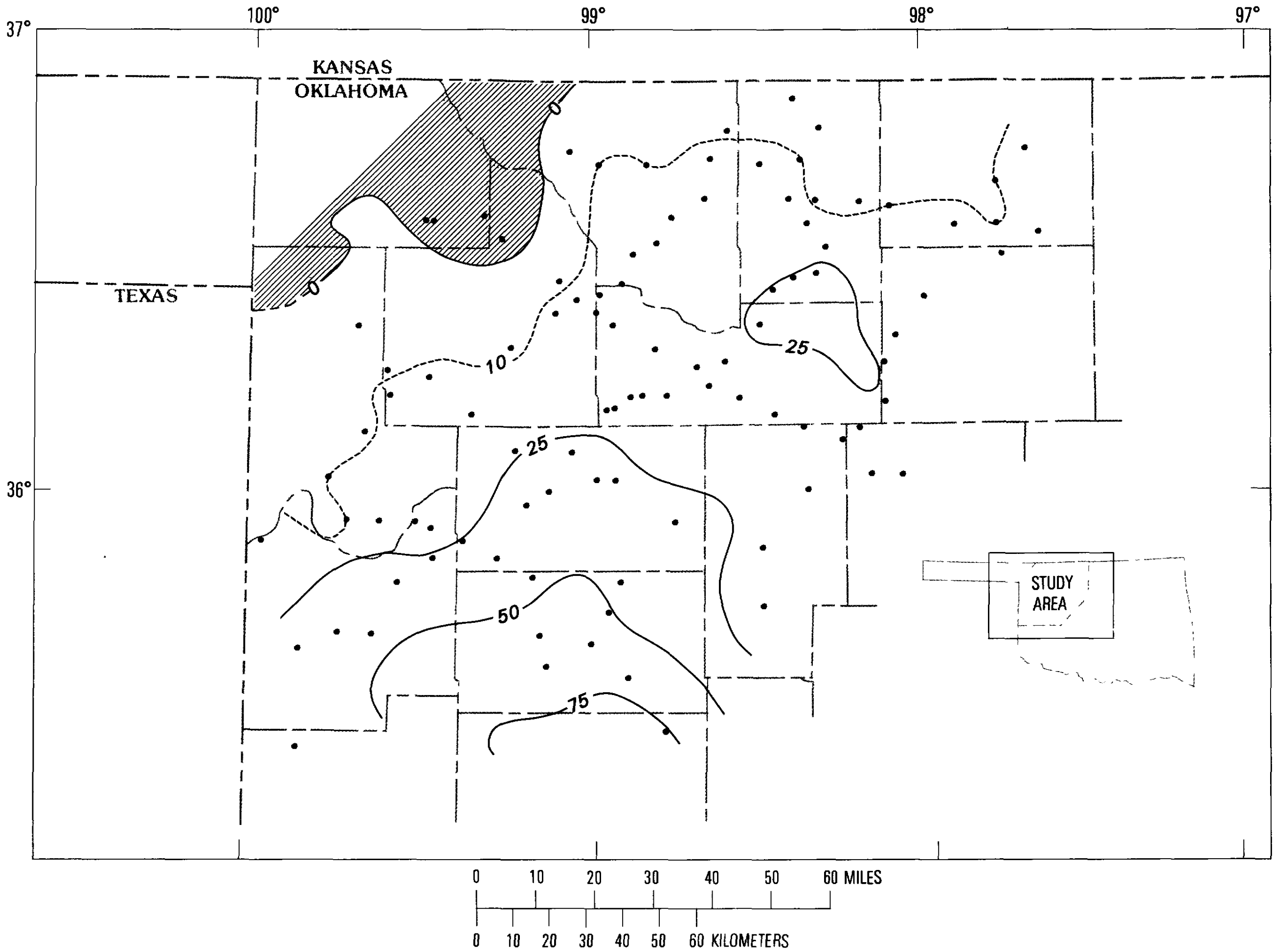

Figure 8. Thickness of middle member of Woodford Shale; contour interval 25 ft. Area where middle member is absent is hachured; dots show well locations (fig. 1, appendix 1).

thickness and TOC and can be thought of as the grams of organic carbon that would be recovered in a 1-cm^2 core through the formation. Maps of OC/cm^2 for the Woodford Shale and its three members (figs. 22–25) are characterized by relatively smooth regional trends. These trends correlate with those of corresponding isopach maps (figs. 6–9), reflecting the fact that percent changes in thickness tend to exceed those of TOC or formation density.

For the Woodford as a whole, OC/cm_2 in the northeast region ranges as high as 400 g/cm^2; OC/cm^2 in the southwest region is as high as 600 g/cm^2 at the extreme southern edge of the mapped area (fig. 22). These values are of the same magnitude as those determined in similar fashion for the Bakken Formation of the Williston basin, in which OC/cm^2 is as high as 350 g/cm^2 in the lower shale member and 150 g/cm^2 in the upper shale member (Schmoker and Hester, 1983).

The distributions of OC/cm^2 for the lower, middle, and upper members of the Woodford Shale have nearly identical means of 77, 76, and 70 g/cm^2, respectively, and are similar in general appearance for values of OC/cm^2 greater than the means (fig. 26). However, the mode of the lower- and upper-member distributions is 0–25 g/cm^2, whereas only 5 percent of middle-member values fall in this range. The mode of the middle-member distribution is 50–75 g/cm^2 (fig. 26).

The thermal maturity of the Woodford Shale in the southwest region is generally greater than that of peak oil generation, whereas the Woodford in the northeast region is generally immature to marginally mature. Distributions of OC/cm^2 for the northeast depocenter reflect kerogen that has retained its potential to generate hydrocarbons, and distributions of OC/cm^2 for the southwest depocenter reflect kerogen whose generative potential has been significantly depleted (fig. 27).

The total mass of organic carbon in each member of the Woodford Shale in the mapped area, estimated by planimetering the isopleths of figures 23–25, is measured in the tens of trillions of kilograms (table 1). Somewhat

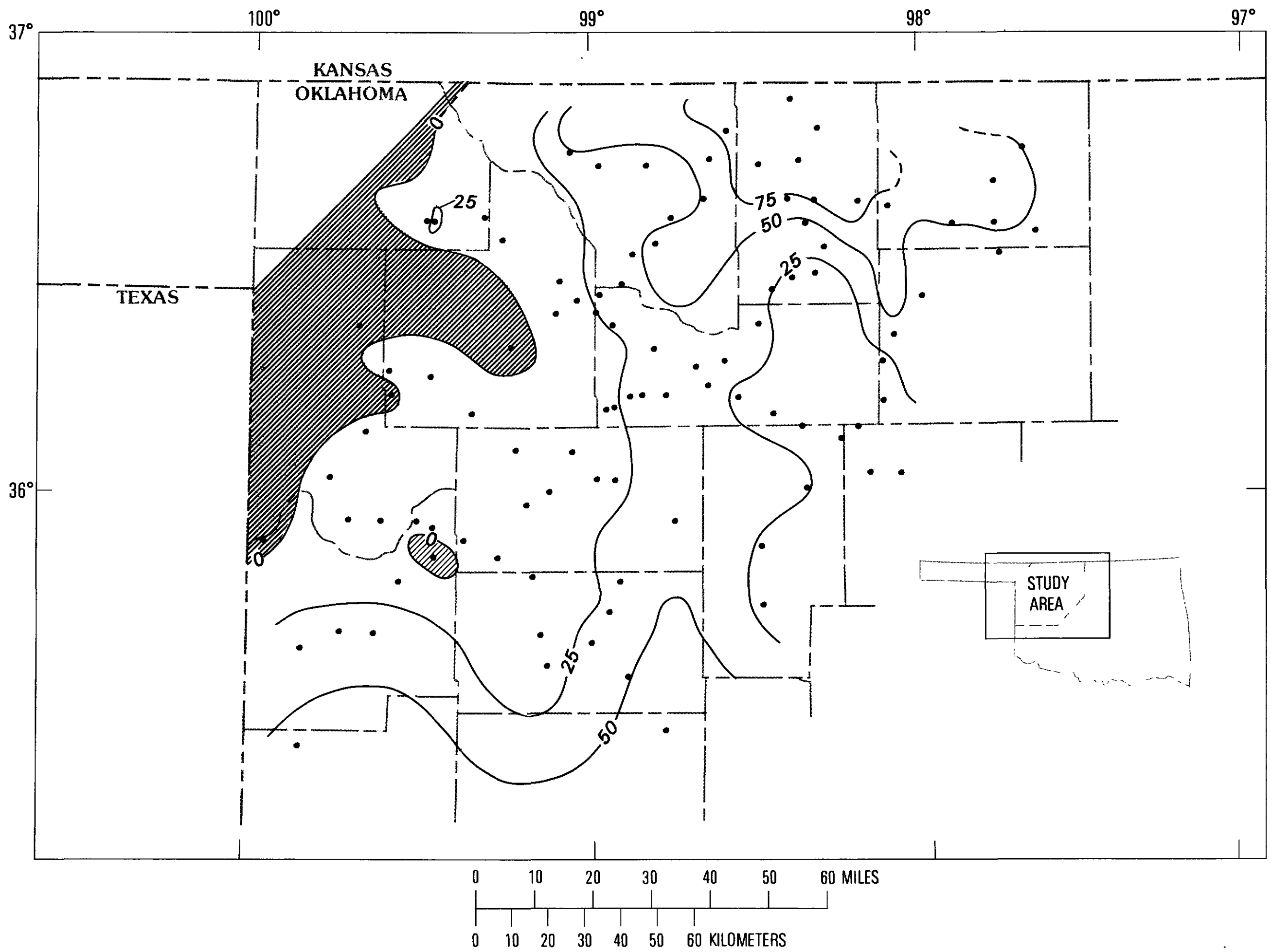

Figure 9. Thickness of upper member of Woodford Shale; contour interval 25 ft. Areas where upper member is absent are hachured; dots show well locations (fig. 1, appendix 1).

surprisingly, the total amount of organic carbon in the Woodford Shale is evenly divided between its three members (table 1).

Of the 73 trillion kilograms of organic carbon in the Woodford Shale of the study area (table 1), some 54 trillion kilograms are in thermally mature areas characterized by $R_o \geq 0.6$ percent, and 38 trillion kilograms are in areas where R_o is ≥ 1.3 percent. As a point of comparison, the two shale members of the Bakken Formation in North Dakota and Montana contain 126 trillion kilograms of organic carbon, of which 102 trillion kilograms are in thermally mature areas (Schmoker and Hester, 1983).

Because the upper member is generally thicker in the low-maturity northeast region than the lower and middle members combined (fig. 12), geochemical analyses to establish baseline values for immature Woodford source rocks are likely to be analyses of the upper member. Table 1 shows, however, that most hydrocarbons sourced by the Woodford Shale of the study area were generated from the lower and middle members, in that these two members contain 74 percent of the thermally mature organic carbon. As illustrated by this example, geochemical data should be considered in view of the three members of the Woodford Shale.

SUMMARY

The Woodford Shale is present throughout most of the Anadarko basin of Oklahoma, and is thought to be a major source of the basin's hydrocarbons. The Woodford Shale is usually treated as a single depositional package, in the sense that its physical and chemical properties are not considered with respect to vertical stratigraphy. As a result, changes in depositional and environmental factors during Woodford time that affected the source-rock

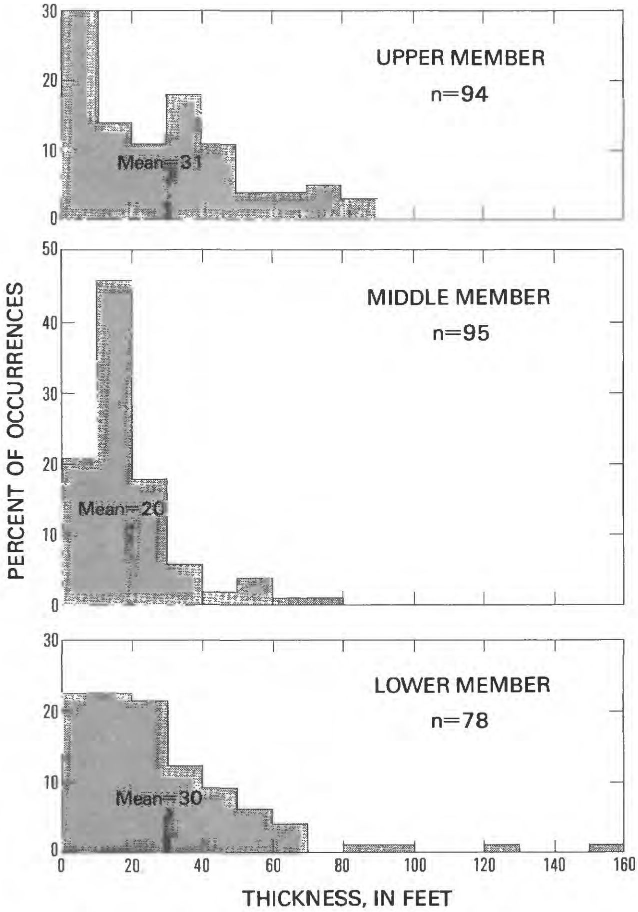

Figure 10. Distributions of thickness of lower, middle, and upper members of Woodford Shale. Data are from well locations of figure 1 (tabulated in appendix 2).

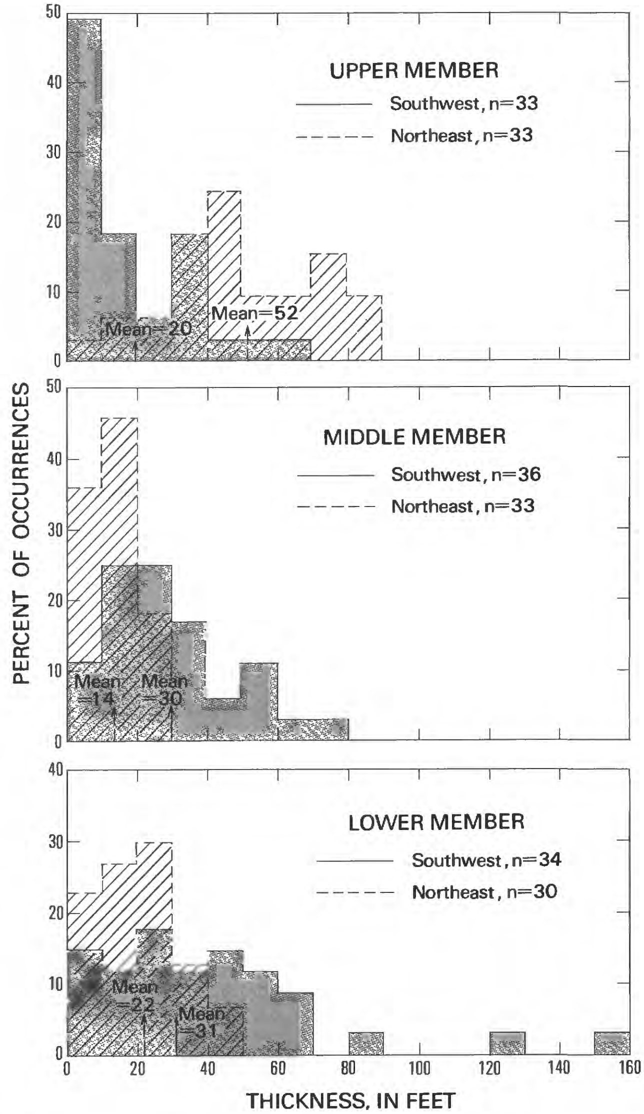

Figure 11. Distributions of thickness of southwest and northeast regions of lower, middle, and upper members of Woodford Shale. Data are from well locations of figure 1 (tabulated in appendix 2); southwest and northeast regions shown in figure 1.

characteristics of the formation have been largely unexplored.

In this study, the Woodford Shale is subdivided into lower, middle, and upper members on the basis of log character. Differing kerogen concentrations account for the distinctive character of the three members and are the physical basis for this subdivision. Isopachs of the three members of the Woodford reveal a positive structural feature, parallel with and about 75 mi (120 km) north of the Amarillo-Wichita uplift, that divided the Woodford into northeast and southwest depocenters and was a hinge line separating areas of regional basement flexure during Woodford time.

Lower and middle members of the Woodford Shale thicken to the southwest into the now-eroded central trough of the southern Oklahoma aulacogen. The upper member thickens to the northeast towards the Sedgwick basin of south-central Kansas. In the southwest region, present-day thermal maturity of the Woodford is generally greater than that of peak oil generation, whereas in the northeast region, the Woodford is generally immature to marginally mature. As a result of these regional depositional and thermal-maturity trends, most hydrocarbons sourced by the Woodford Shale of the study area were generated from the lower and middle members.

The regional tripartite zonation of the Woodford Shale reveals depositional patterns and variations in organic-matter content that are obscured if the formation is treated as a single unit. Subdivision of the Woodford into three informal members, as suggested here, provides a framework for the planning and integration of detailed source-rock studies of the formation.

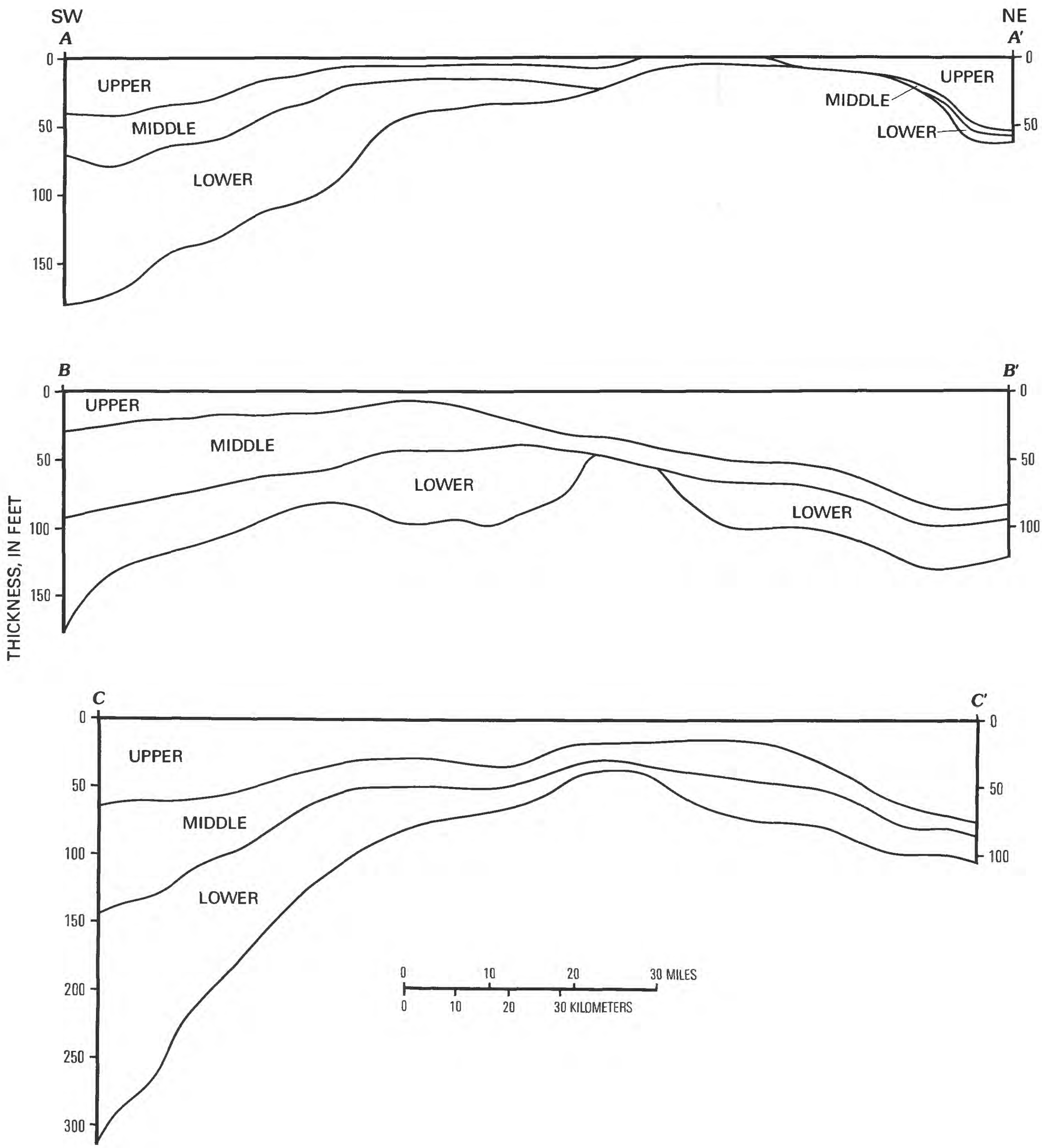

Figure 12. Southwest-northeast cross sections *A–A'*, *B–B'*, and *C–C'* showing Woodford Shale in Anadarko basin. Datum is top of upper member. Lines of sections shown on figure 1.

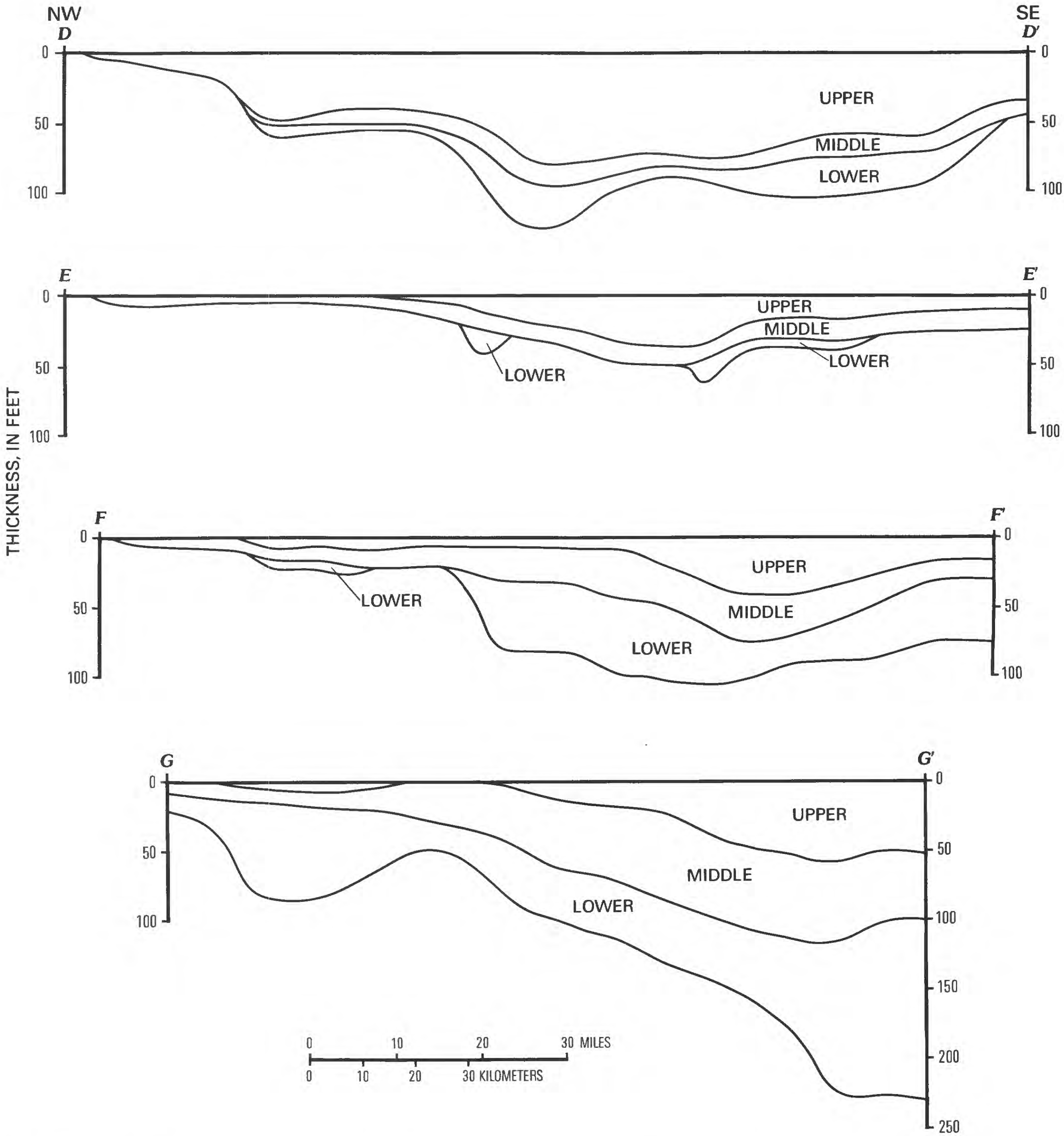

Figure 13. Northwest-southeast cross sections *D–D′*, *E–E′*, *F–F′*, and *G–G′* showing Woodford Shale. Datum is top of upper member. Lines of section shown on figure 1.

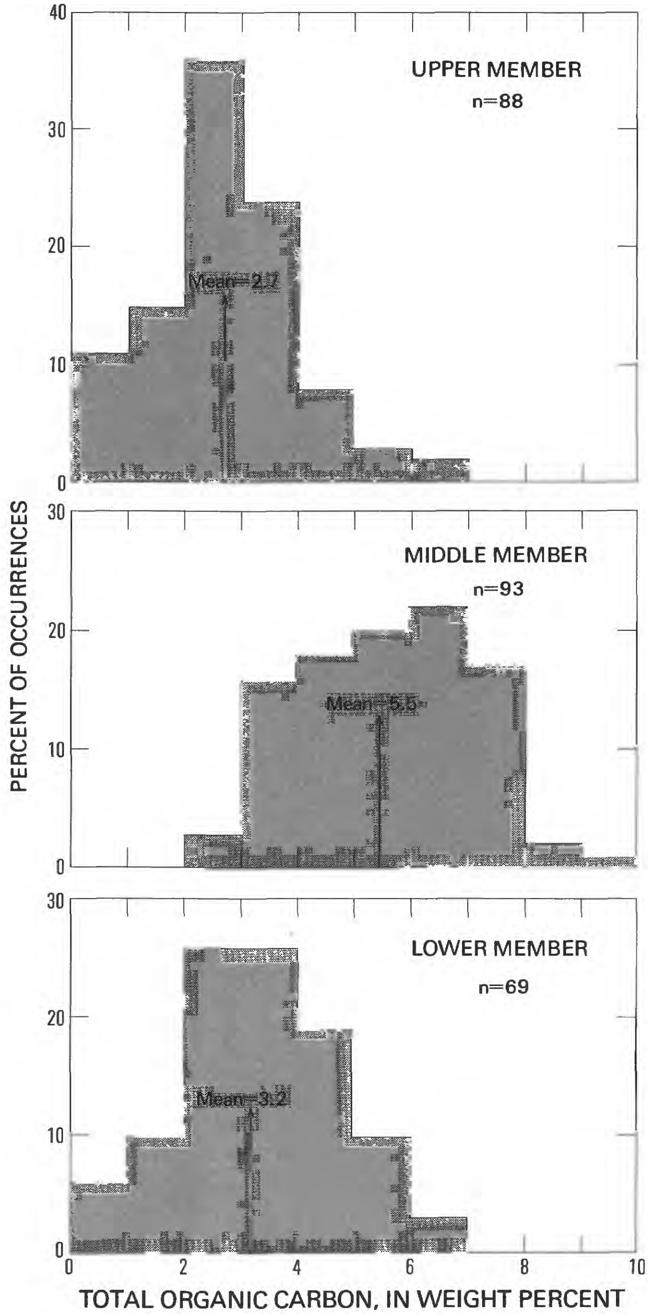

Figure 14. Distributions of total organic carbon (TOC) of lower, middle, and upper members of Woodford Shale. TOC is calculated from average formation density (see text, equation 1). Data are from well locations of figure 1 (tabulated in appendix 2).

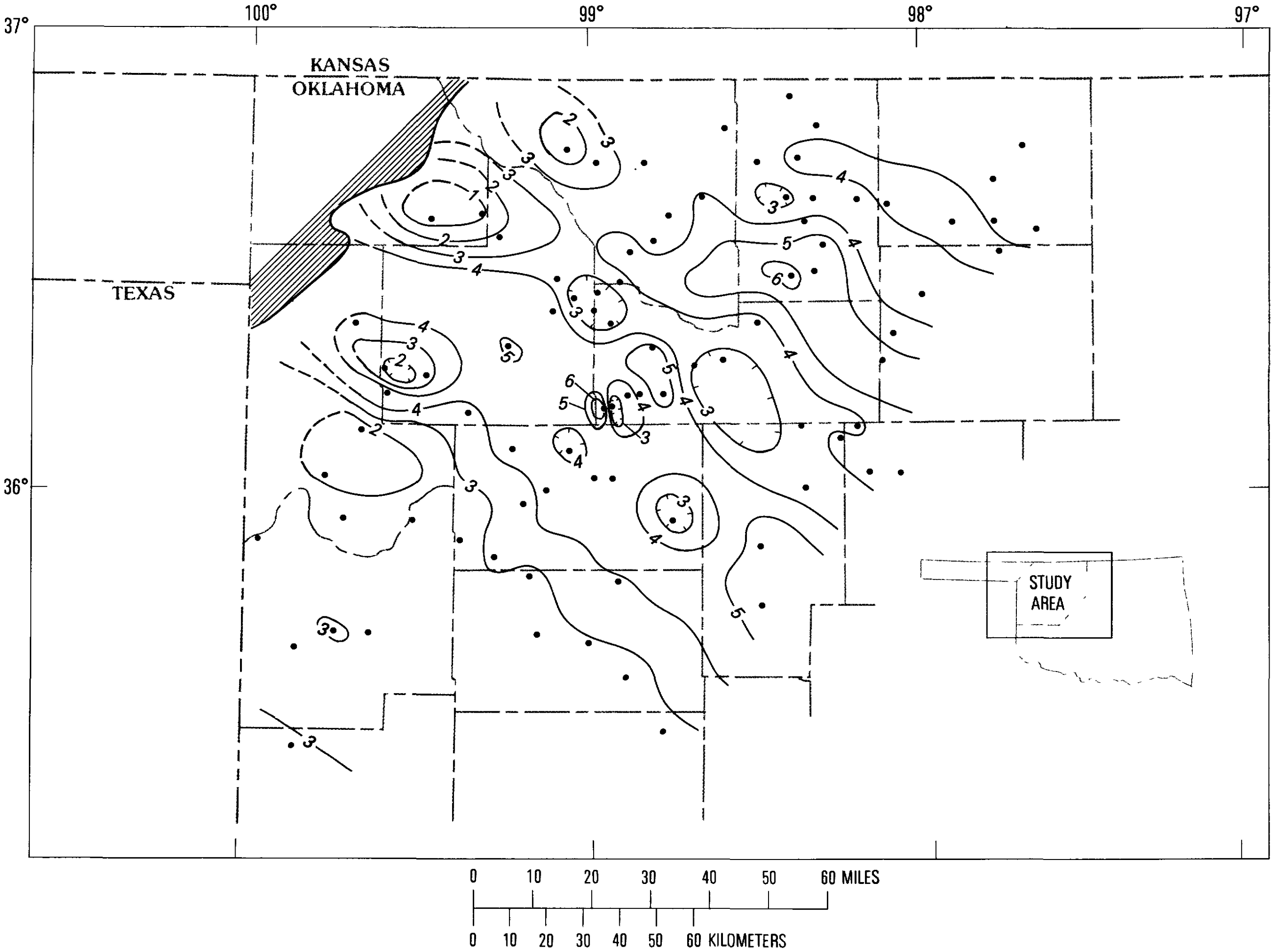

Figure 15. Total organic carbon (TOC) of Woodford Shale; contour interval 1.0 weight percent. TOC is calculated from average formation density (see text, equation 1). Area where Woodford Shale is absent is hachured; dots show well locations (fig. 1, appendix 1).

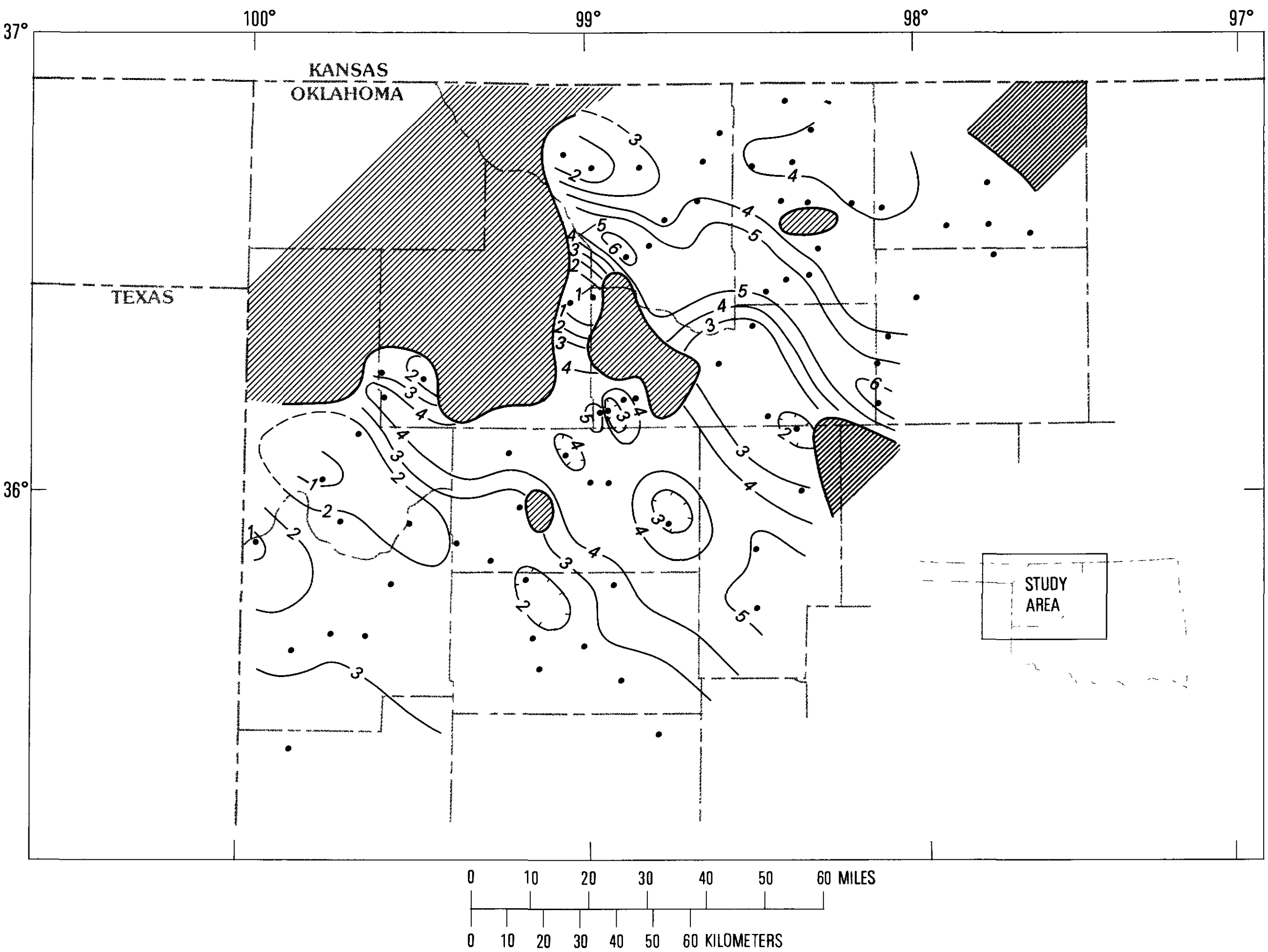

Figure 16. Total organic carbon (TOC) of lower member of Woodford Shale; contour interval 1.0 weight percent. TOC is calculated from average formation density (see text, equation 1). Areas where lower member is absent are hachured; dots show well locations (fig. 1, appendix 1).

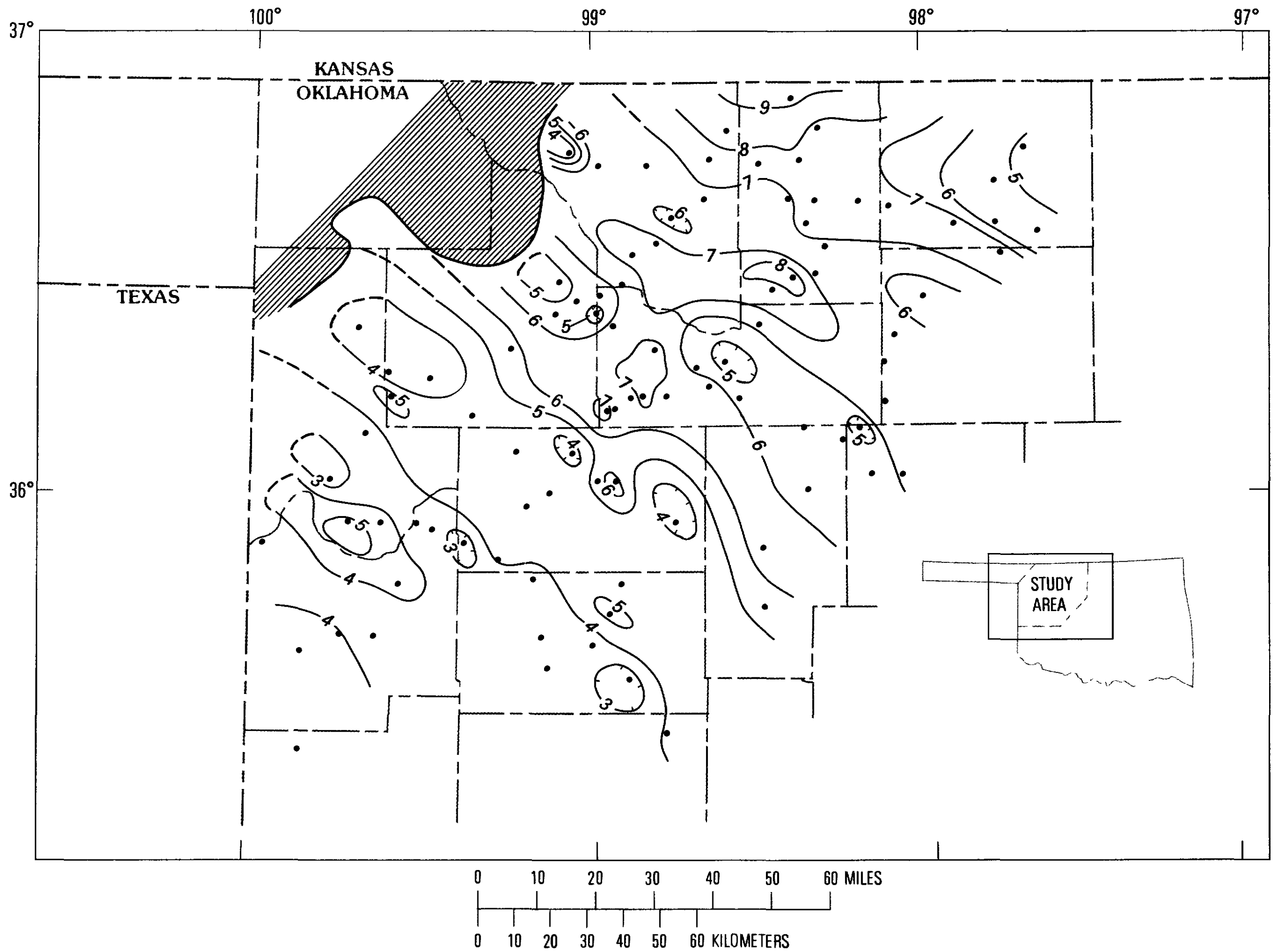

Figure 17. Total organic carbon (TOC) of middle member of Woodford Shale; contour interval 1.0 weight percent. TOC is calculated from average formation density (see text, equation 1). Area where middle member is absent is hachured; dots show well locations (fig 1, appendix 1).

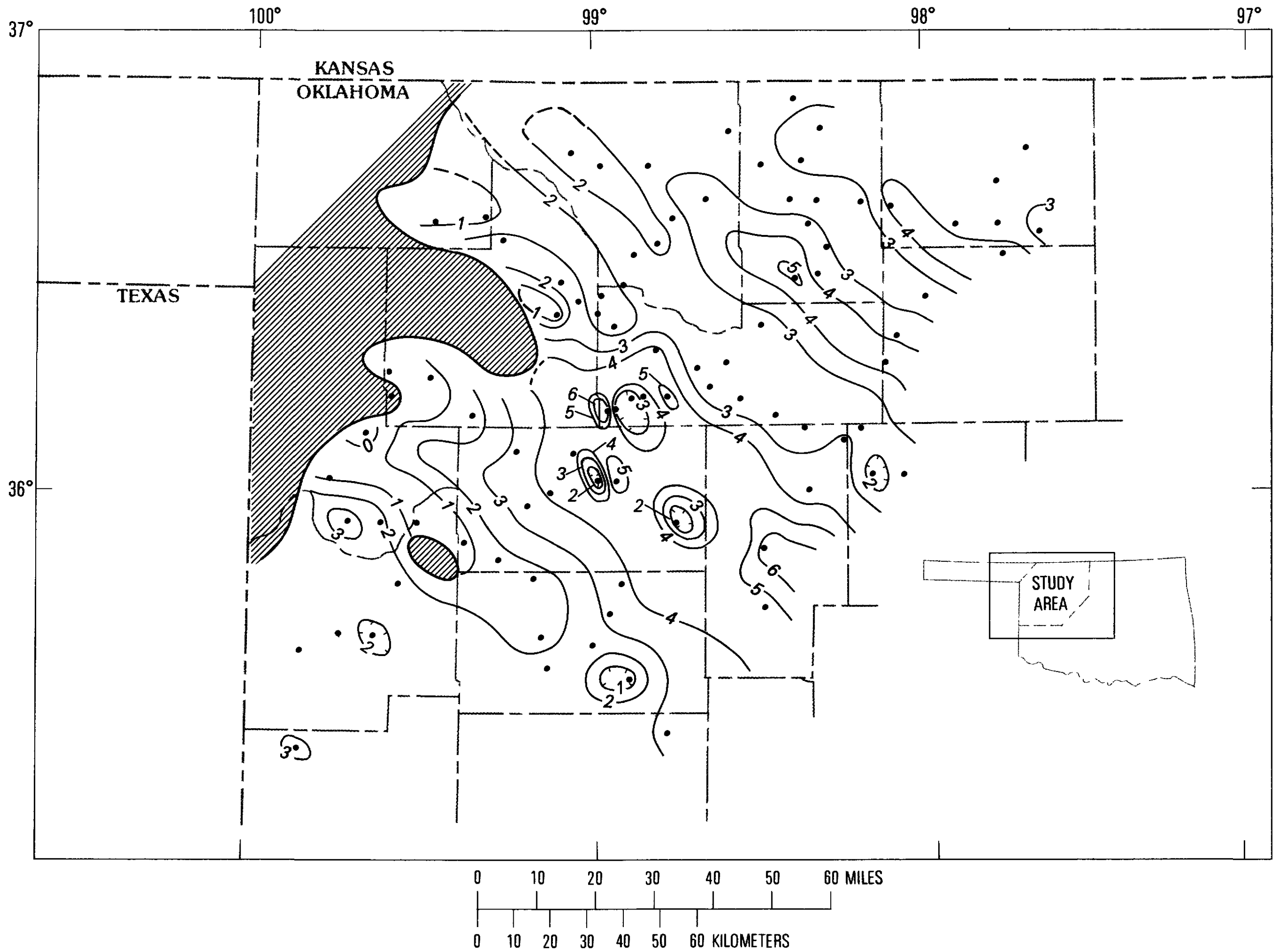

Figure 18. Total organic carbon (TOC) of upper member of Woodford Shale; contour interval 1.0 weight percent. TOC is calculated from average formation density (see text, equation 1). Areas where upper member is absent are hachured; dots show well locations (fig. 1, appendix 1).

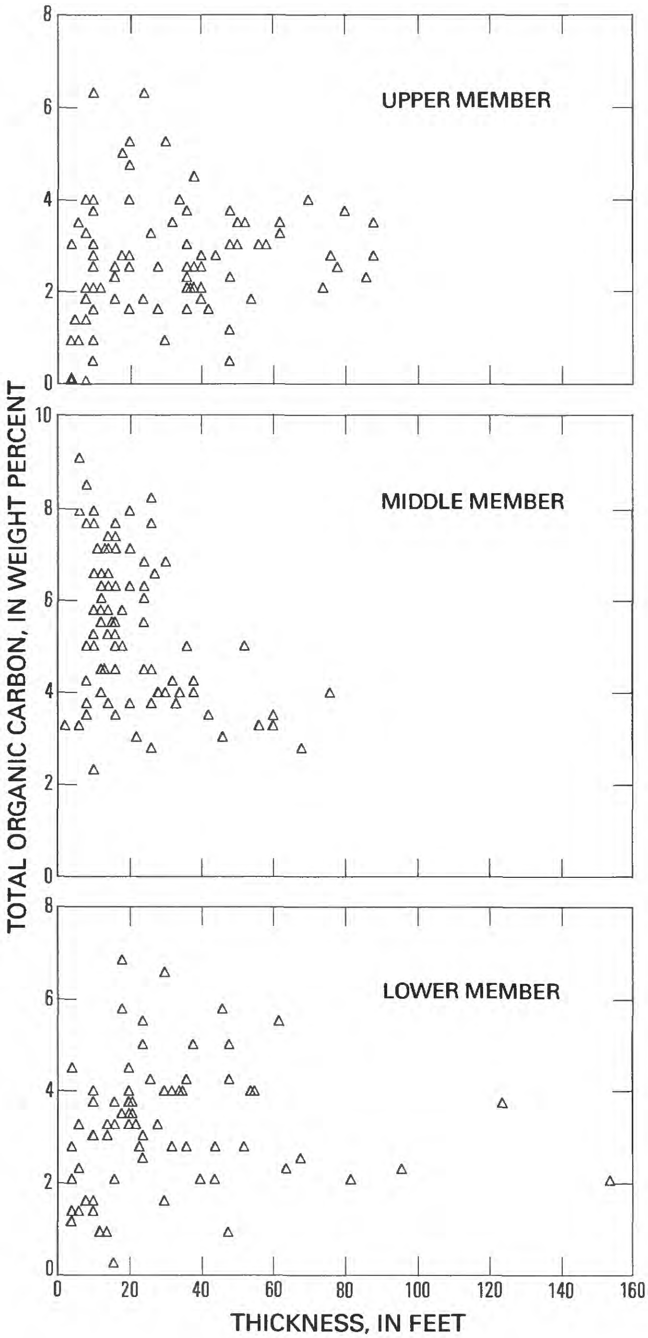

Figure 19. Total organic carbon (TOC), calculated from average formation density (see text, equation 1), versus thickness for lower, middle, and upper members of Woodford Shale. Data are from well locations of figure 1 (tabulated in appendix 2).

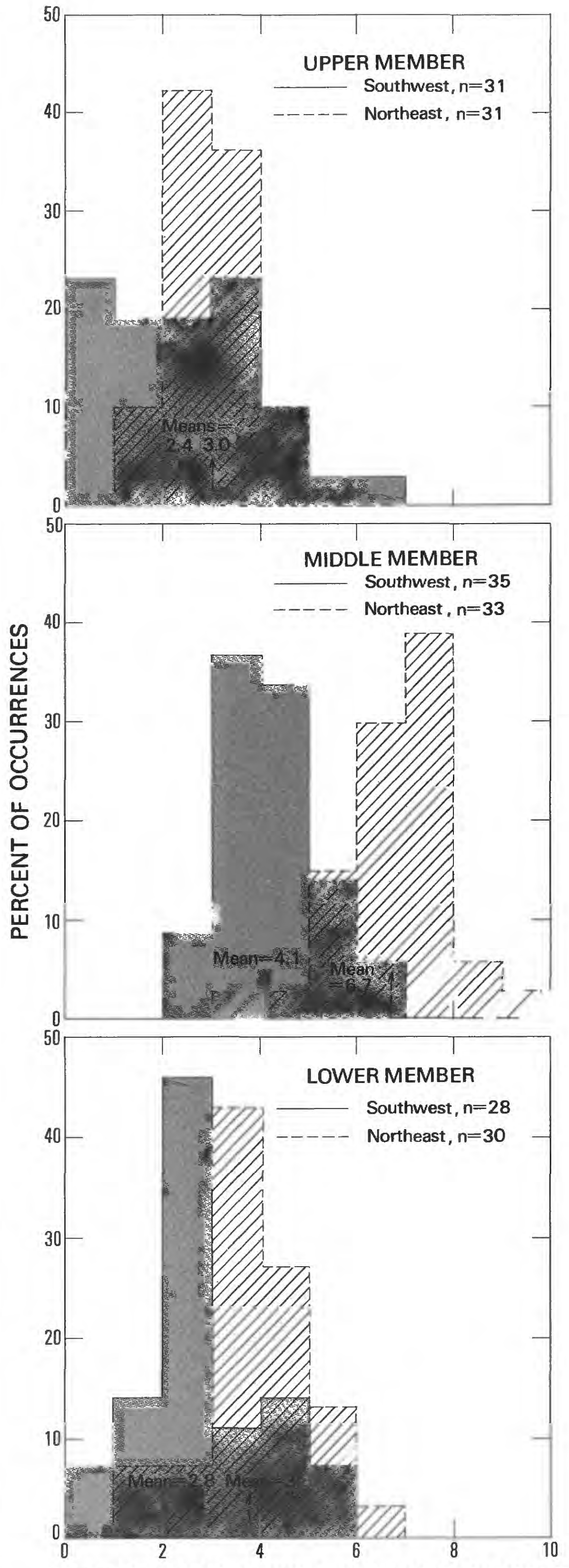

Figure 20 (facing column). Distributions of total organic carbon (TOC) of southwest and northeast regions of lower, middle, and upper members of Woodford Shale. TOC is calculated from average formation density (see text, equation 1). Data are from well locations of figure 1 (tabulated in appendix 2).

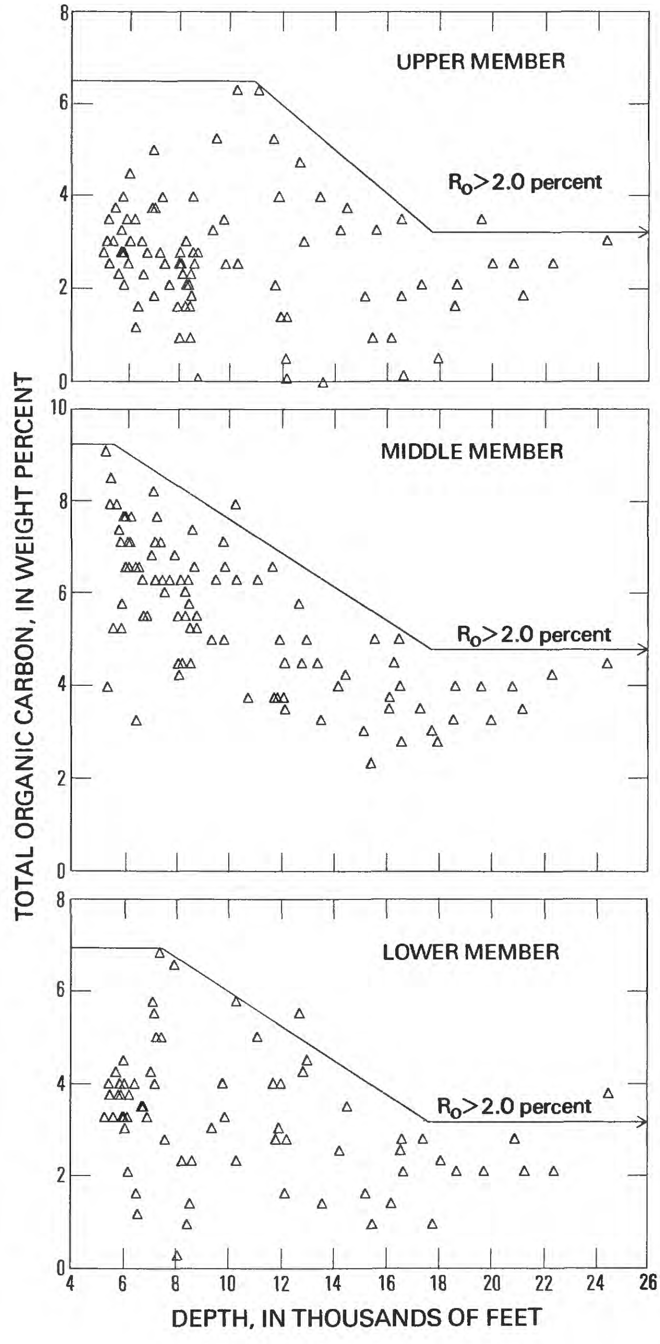

Figure 21. Total organic carbon (TOC), calculated from average formation density (see text, equation 1), versus burial depth for lower, middle, and upper members of Woodford Shale. Lines approximate maximum TOC values as a function of depth for each member. Data are from well locations of figure 1 (tabulated in appendix 2).

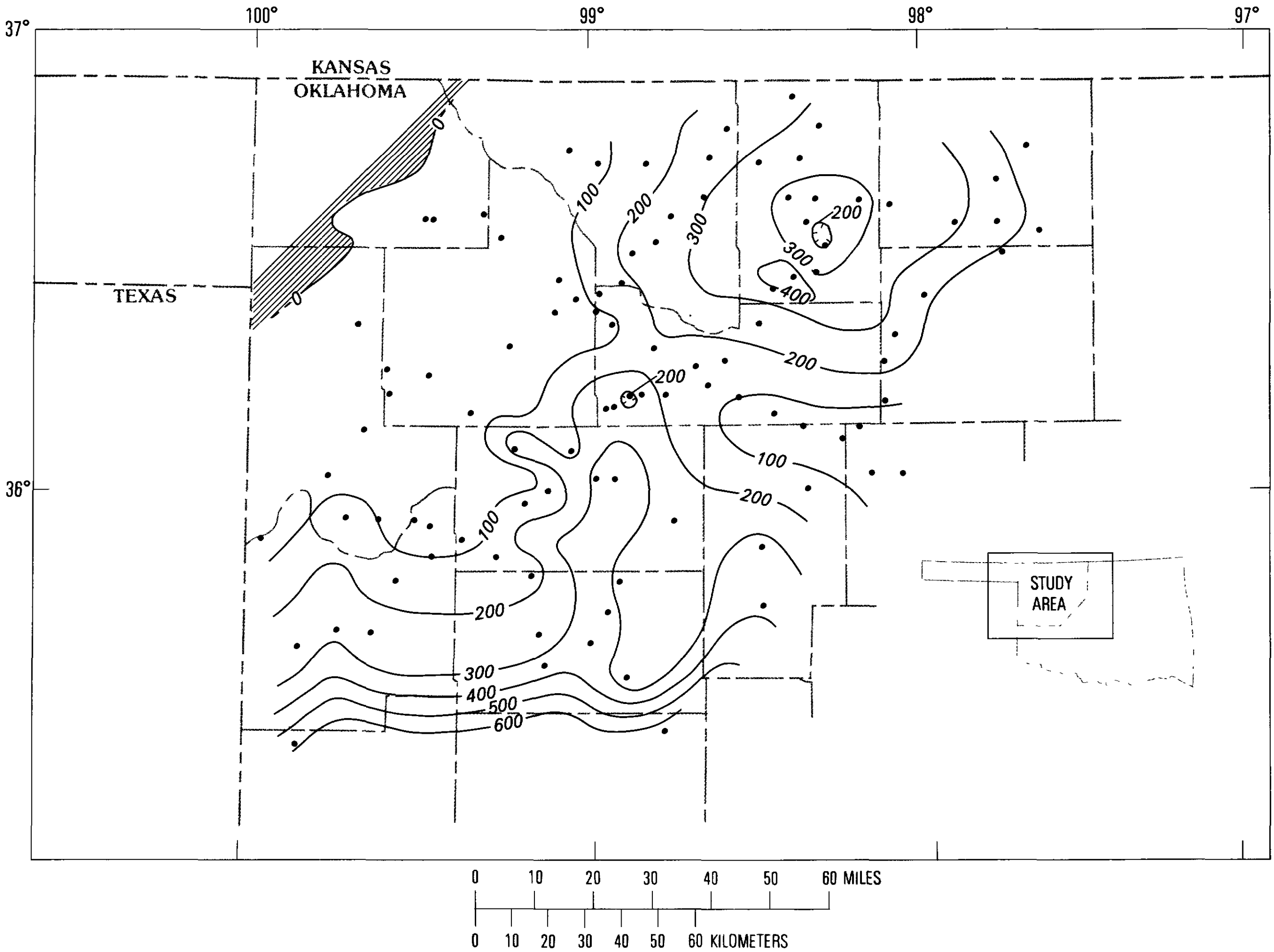

Figure 22. Mass of organic carbon of Woodford Shale per unit surface area (OC/cm^2), calculated using equation 2 (see text); contour interval 100 g/cm^2. Area where Woodford Shale is absent is hachured; dots show well locations (fig. 1, appendix 1).

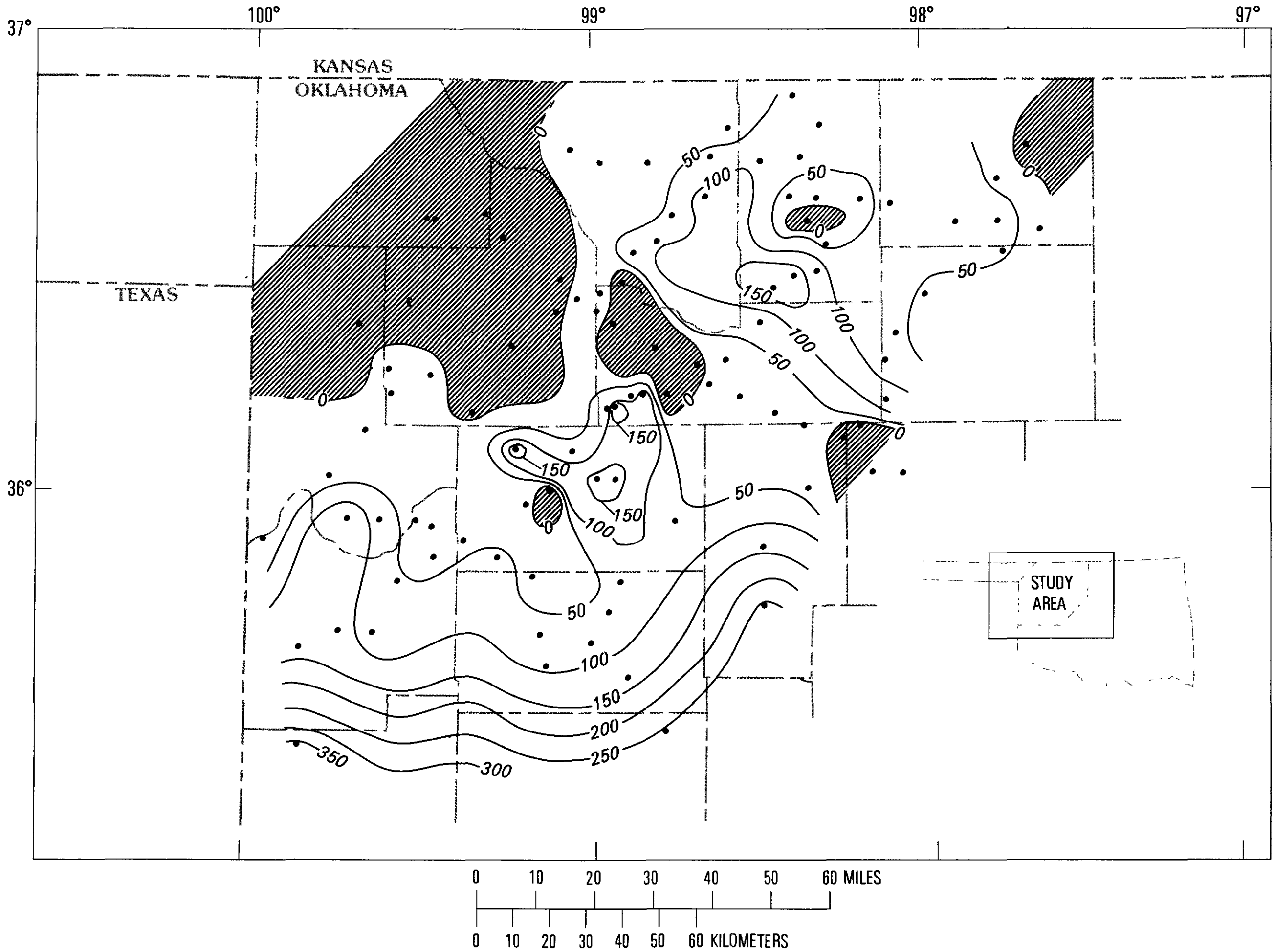

Figure 23. Mass of organic carbon of lower member of Woodford Shale per unit surface area (OC/cm^2), calculated using equation 2 (see text); contour interval 50 g/cm^2. Areas where lower member is absent are hachured; dots show well locations (fig. 1, appendix 1).

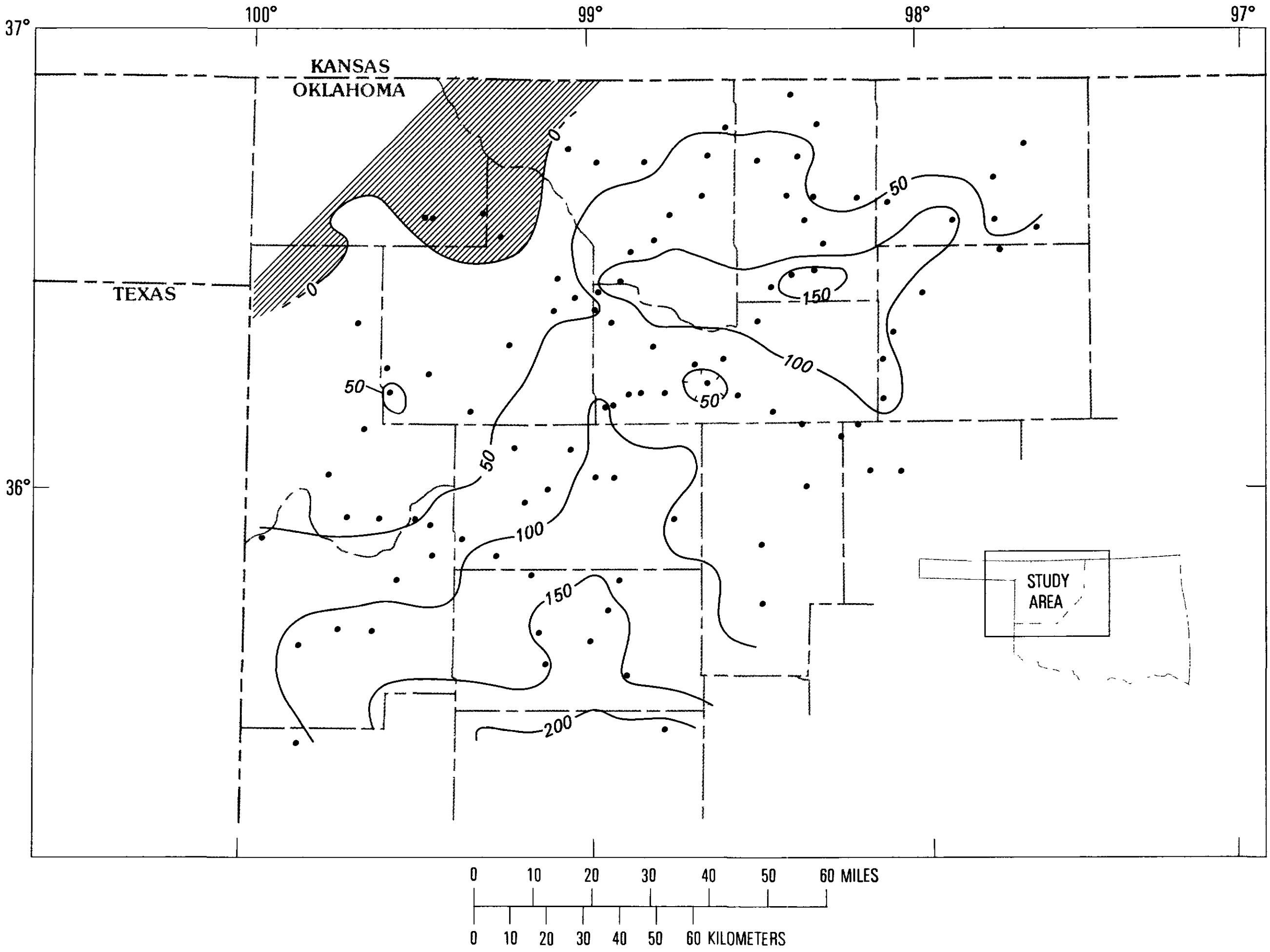

Figure 24. Mass of organic carbon of middle member of Woodford Shale per unit surface area (OC/cm^2), calculated using equation 2 (see text); contour interval 50 g/cm^2. Areas where middle member is absent is hachured; dots show well locations (fig. 1, appendix 1).

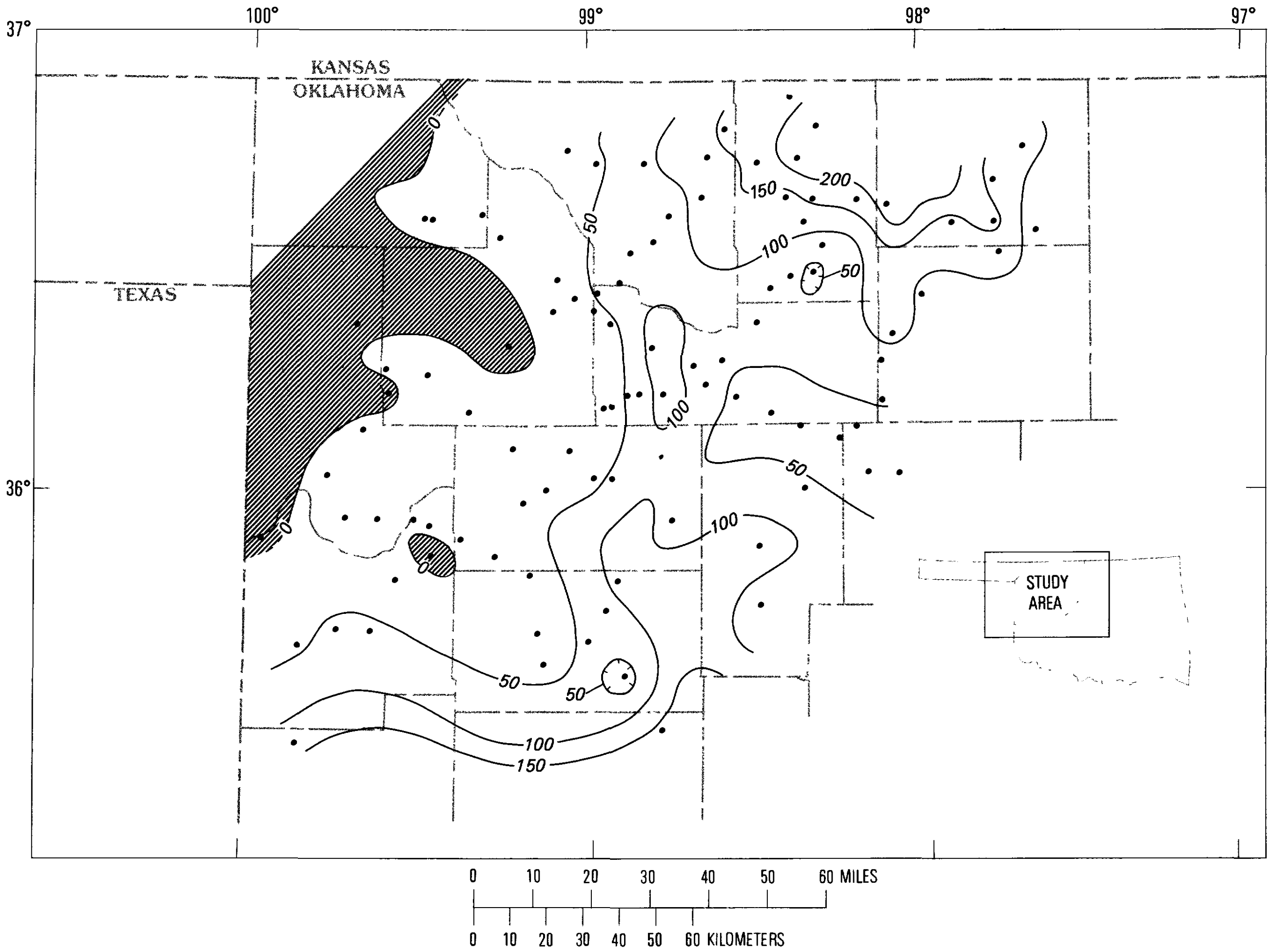

Figure 25. Mass of organic carbon of upper member of Woodford Shale per unit surface area (OC/cm²), calculated using equation 2 (see text); contour interval 50 g/cm². Areas where upper member is absent are hachured; dots show well locations (fig. 1, appendix 1).

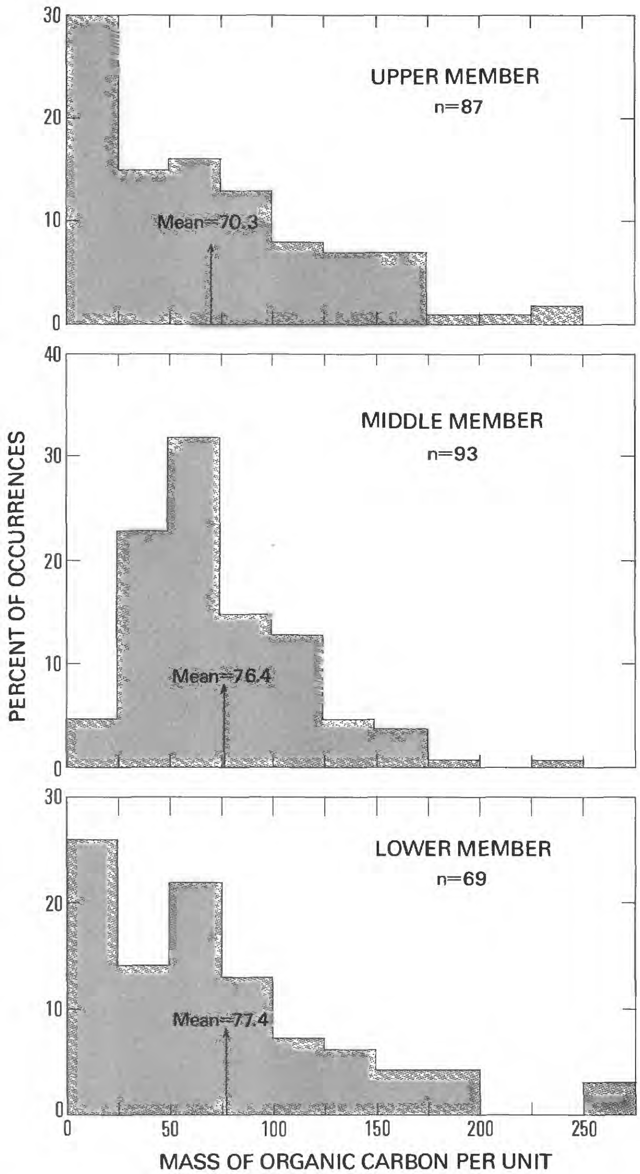

Figure 26. Distributions of mass of organic carbon per unit surface area (OC/cm^2), calculated using equation 2 (see text), of lower, middle, and upper members of Woodford Shale. Data are from well locations of figure 1 (tabulated in appendix 2).

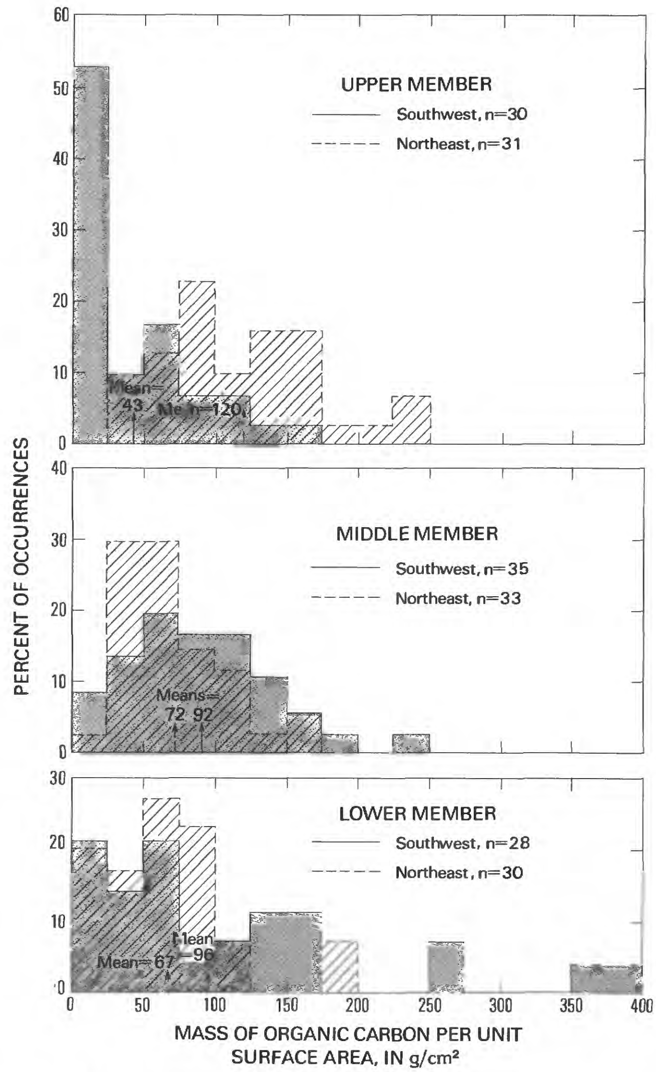

Figure 27. Distributions of mass of organic carbon per unit surface area (OC/cm$_2$), calculated using equation 2 (see text), of southwest and northeast regions of lower, middle, and upper members of Woodford Shale. Data are from well locations of figure 1 (tabulated in appendix 2); southwest and northeast regions are shown in figure 1.

Table 1. Mass of organic carbon in lower, middle, and upper members of Woodford Shale in study area, Anadarko basin, Oklahoma

[In kg×10^{12}. Study area is subdivided into northeast and southwest regions by axis of structural feature (fig. 6), and into zones reflecting stages of hydrocarbon generation according to map of vitrinite reflectance (in percent) (fig. 4)]

	Total study area	Region		Vitrinite reflectance		
		Southwest	Northeast	<0.6	≥0.6<1.3 (oil window)	≥1.3
Upper member	24	11	13	10	5	9
Middle member	25	17	8	5	7	13
Lower member	24	18	6	4	4	16
Total Woodford Shale	73	46	27	19	16	38

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Appendixes 1, 2

Appendix 1. List of wells used in study

[Well numbers shown refer to figure 1 and appendix 2. Location (section, township, and range), operator, and well name are as shown on well-log headers]

Well number	Location	Operator	Well name
1	Sec. 16, T. 18 N., R. 24 W.	Ricks Exploration	16-A Gross
2	Sec. 24, T. 17 N., R. 24 W.	Lone Star Production	1-24 Berryman
3	Sec. 23, T. 17 N., R. 23 W.	Energy Reserves Group	1 Eastham
4	Sec. 23, T. 17 N., R. 22 W.	Shell Oil	2-23 Kennon
5	Sec. 29, T. 17 N., R. 21 W.	Arkla Exploration	1-29 Harrell
6	Sec. 6, T. 16 N., R. 20 W.	Hoover & Bracken	1-6 Anderson
7	Sec. 19, T. 16 N., R. 19 W.	Getty Oil	1-19 Hall
8	Sec. 6, T. 15 N., R. 18 W.	J C Barnes Oil	1 Cecil Rounds
9	Sec. 29, T. 14 N., R. 18 W.	C F Braun	1-29 Walker
10	Sec. 35, T. 14 N., R. 17 W.	J M Huber Corp	1 Arapaho
11	Sec. 35, T. 13 N., R. 16 W.	Roden Oil	35-1 Henry E Nickel
12	Sec. 14, T. 11 N., R. 15 W.	Helmerich & Payne	1 Brown Foundation
13	Sec. 5, T. 22 N., R. 23 W.	Kennedy & Mitchell	38-467 Latta
14	Sec. 18, T. 21 N., R. 22 W.	Miami Oil Producers Inc	1 Driskell
15	Sec. 20, T. 21 N., R. 21 W.	Ramsey Engineering	1 McCaslin
16	Sec. 21, T. 20 N., R. 20 W.	Superior Oil	1 Bruce Unit
17	Sec. 22, T. 19 N., R. 19 W.	Arco Oil & Gas	1 Emmett Buck
18	Sec. 20, T. 19 N., R. 17 W.	OFT Exploration Inc	1-20 Irene Burgess
19	Sec. 13, T. 18 N., R. 17 W.	Helmerich & Payne	1-13 Taloga Townsite
20	Sec. 16, T. 18 N., R. 16 W.	Texas Oil & Gas	1 Dedrick 'B'
21	Sec. 19, T. 17 N., R. 14 W.	Arkla Exploration	1-19 Marshall
22	Sec. 10, T. 16 N., R. 12 W.	Davis Oil	1 Pickett
23	Sec. 34, T. 15 N., R. 12 W.	Coquina Oil	1 Bahan
24	Sec. 8, T. 25 N., R. 21 W.	Cobra Oil & Gas	1 Kinney '8'
25	Sec. 9, T. 25 N., R. 21 W.	A R Dillard Inc	1 W R Kinney
26	Sec. 1, T. 25 N., R. 20 W.	Woods Petroleum	1 Schaefer
27	Sec. 28, T. 25 N., R. 19 W.	Mesa Petroleum	1-28 Janzen
28	Sec. 36, T. 24 N., R. 18 W.	Gulf Oil	2-36 Gulf-State
29	Sec. 16, T. 23 N., R. 17 W.	Hadson Petroleum	1-16 State
30	Sec. 25, T. 23 N., R. 17 W.	Sunmark Exploration	1 G A Whitlaw
31	Sec. 4, T. 22 N., R. 16 W.	Atlantic Richfield	2 Cora G Case Unit S P
32	Sec. 27, T. 22 N., R. 15 W.	Mich Wisc Pipeline	1 Dyche
33	Sec. 11, T. 21 N., R. 14 W.	Tenneco Oil	1-11 Edwards
34	Sec. 30, T. 21 N., R. 13 W.	Hunt Oil	1 Voth
35	Sec. 1, T. 20 N., R. 13 W.	Anchorage Oil & Gas	1-1 Kay
36	Sec. 24, T. 20 N., R. 12 W.	French Petroleum	1-24 Davis
37	Sec. 35, T. 20 N., R. 11 W.	Mineral Resources	3-A Reames
38	Sec. 12, T. 19 N., R. 10 W.	Energy Exchange	1 Leisher
39	Sec. 11, T. 18 N., R. 9 W.	Energy Reserves Group	2 Gerber
40	Sec. 10, T. 18 N., R. 8 W.	An-Son Corp	1-10 Heller
41	Sec. 8, T. 27 N., R. 17 W.	Shenandoah Oil	1 Degeer
42	Sec. 19, T. 27 N., R. 16 W.	Cleary Petroleum Inc	1 Davidson
43	Sec. 21, T. 27 N., R. 15 W.	Calvert Mid-America	2 Bloyd
44	Sec. 17, T. 27 N., R. 13 W.	Texaco Inc	1 Stuckey
45	Sec. 22, T. 27 N., R. 12 W.	Harper Oil	1 Bouziden
46	Sec. 14, T. 27 N., R. 11 W.	Michigan Oil	1 Hodgson
47	Sec. 20, T. 26 N., R. 10 W.	Mack Oil	1 Sayer
48	Sec. 21, T. 26 N., R. 9 W.	Anadarko Production	2-21 Tucker 'E'
49	Sec. 29, T. 26 N., R. 8 W.	Champlin Petroleum	1 Maxine Garrison
50	Sec. 7, T. 25 N., R. 6 W.	TXO Production	1 Hardiman 'A'

Appendix 1. Continued

Well number	Location	Operator	Well name
51	Sec. 4, T. 24 N., R. 5 W.	Bogert Oil	1 Duffy
52	Sec. 21, T. 25 N., R. 4 W.	Worrall Engineering	1 Mary Balzer
53	Sec. 4, T. 16 N., R. 26 W.	Hoover & Bracken Inc	1-4 Cecil
54	Sec. 4, T. 19 N., R. 23 W.	Ricks Exploration	4-A Eddie Max
55	Sec. 6, T. 20 N., R. 22 W.	Anadarko Land & Expl	1-6 Hamilton
56	Sec. 27, T. 22 N., R. 19 W.	Woods Petroleum	1 Peach
57	Sec. 26, T. 23 N., R. 18 W.	Apache Corp	1 Garvie Unit
58	Sec. 7, T. 23 N., R. 16 W.	Don Leeman	1 W B Johnson
59	Sec. 35, T. 24 N., R. 16 W.	Clifford Resources	1-35 Bouma
60	Sec. 1, T. 24 N., R. 16 W.	Natol-Kirkpatrick Oil	1 Tissue
61	Sec. 26, T. 25 N., R. 15 W.	Amerada Petroleum	1 Beard Estate
62	Sec. 6, T. 25 N., R. 14 W.	Calvert Funds Inc	1 Wenzel
63	Sec. 19, T. 26 N., R. 13 W.	Search Drilling	1-19 Kirmse
64	Sec. 23, T. 28 N., R. 13 W.	Damson Oil	1 Lee
65	Sec. 32, T. 11 N., R. 25 W.	Mesa Petroleum	1-32 Crook
66	Sec. 9, T. 13 N., R. 25 W.	El Paso Natural Gas	1 Pierce
67	Sec. 27, T. 14 N., R. 24 W.	Tenneco Oil	1-27 M C Bradshaw
68	Sec. 27, T. 14 N., R. 23 W.	El Paso Natural Gas	1 Maddux
69	Sec. 8, T. 15 N., R. 22 W.	Clark-Canadian et al	1 Vierson
70	Sec. 17, T. 16 N., R. 21 W.	Arkla Exploration et al	1-17 Harrell
71	Sec. 1, T. 17 N., R. 19 W.	Exxon Corp	1 Sabine
72	Sec. 34, T. 18 N., R. 18 W.	Dyco Petroleum	1-34 Gore
73	Sec. 17, T. 20 N., R. 16 W.	Southland Royalty	1-17 England
74	Sec. 16, T. 20 N., R. 16 W.	Reading & Bates et al	1 Louthan
75	Sec. 1, T. 20 N., R. 16 W.	Texas Oil & Gas	1-B Jellison
76	Sec. 5, T. 20 N., R. 15 W.	Pioneer Production	1-5 Rumsey
77	Sec. 1, T. 20 N., R. 15 W.	Southport Exploration	1 Mungold
78	Sec. 3, T. 21 N., R. 13 W.	Viersen & Cochran	1-3 Penner
79	Sec. 3, T. 22 N., R. 12 W.	MWJ	1 Kelln
80	Sec. 1, T. 23 N., R. 12 W.	Vaughn Good	2 Singree
81	Sec. 27, T. 24 N., R. 11 W.	Vaughn Good	1 Dupus A
82	Sec. 19, T. 24 N., R. 10 W.	Rachalk Production	1 Thomas
83	Sec. 33, T. 25 N., R. 10 W.	California Time Petroleum	1 Ray Hartman
84	Sec. 12, T. 25 N., R. 11 W.	Anadarko Productio	2-12 Newlin A
85	Sec. 21, T. 26 N., R. 11 W.	J M Huber Corp	1 Cherokee Methodist Church
86	Sec. 20, T. 28 N., R. 10 W.	Fuel Exploration	1 Clark-Waggoner
87	Sec. 27, T. 29 N., R. 11 W.	Conoco Inc	27-1 Hadwiger
88	Sec. 21, T. 13 N., R. 18 W.	Arkla Exploration et al	1 Beauchamp
89	Sec. 5, T. 14 N., R. 16 W.	Mcculloch Oil	1-5 Schimmer
90	Sec. 10, T. 15 N., R. 16 W.	Southern Union Prod	1 Jones Droke
91	Sec. 25, T. 18 N., R. 11 W.	Seneca Oil	1-25 Meier
92	Sec. 33, T. 20 N., R. 9 W.	Rodman Corp	1-33 Maggie Malone
93	Sec. 7, T. 20 N., R. 8 W.	Thetis Energy	7-3 Montcastle
94	Sec. 6, T. 21 N., R. 8 W.	Harper Oil	3 Munkres
95	Sec. 16, T. 22 N., R. 8 W.	Atlantic Richfield	2 State Of Oklahoma
96	Sec. 8, T. 23 N., R. 7 W.	Davis Oil	1 Riffel
97	Sec. 8, T. 25 N., R. 5 W.	C E Dinsmore	1-8 Fothergill
98	Sec. 5, T. 26 N., R. 5 W.	Conoco Inc	5-2 Conoco
99	Sec. 6, T. 27 N., R. 4 W.	Indian Wells	1-6-1A Hein

Appendix 2. Tabulation of data

[Leaders (--) indicate no data available. Well number refers to figure 1 and appendix 1; member refers to informally named members of the Woodford Shale and to total Woodford Shale; depth is burial depth (in feet) to top of member; DZ is thickness of unit (in feet); ρ_b is average formation density (g/cm^3) from wire-line logs; TOC is total organic carbon (in weight percent) calculated from average formation density (see text, equation 1); OC/cm^2 is mass of organic carbon per unit surface area calculated using equation 2 (see text); R_o is vitrinite reflectance (in percent) of Woodford Shale]

Well number	Member	Depth	DZ	ρ_b	TOC	OC/cm^2	R_o
1	Upper	15,530	4	2.65	0.96	3.09	
	Middle	15,534	10	2.59	2.33	18.38	
	Lower	15,544	48	2.65	0.96	37.09	
	Total		62	2.64	1.18	58.56	1.52
2	Upper	16,596	6	2.54	3.52	16.36	
	Middle	16,602	10	2.48	5.02	37.92	
	Lower	16,612	68	2.58	2.56	137.09	
	Total		84	2.57	2.92	191.37	2.00
3	Upper	16,390	4	--	--	--	
	Middle	16,394	12	2.50	4.51	41.24	
	Lower	16,406	48	--	--	--	
	Total		64	--	--	--	2.00
4	Upper	16,228	10	2.65	0.96	7.73	
	Middle	16,238	16	2.54	3.52	43.62	
	Lower	16,254	6	2.63	1.41	6.77	
	Total		32	2.59	2.32	58.12	2.00
5	Upper	16,238	4	--	--	--	
	Middle	16,242	20	2.53	3.77	58.08	
	Lower	16,262	28	--	--	--	
	Total		52	--	--	--	2.00
6	Upper	16,686	4	2.70	0.14	0.00	
	Middle	16,690	26	2.57	2.80	57.03	
	Lower	16,716	16	2.60	2.10	26.57	
	Total		46	2.59	2.31	83.60	2.00
7	Upper	16,614	8	2.61	1.86	11.87	
	Middle	16,622	38	2.52	4.01	117.10	
	Lower	16,660	32	2.57	2.80	70.20	
	Total		78	2.55	3.29	199.17	2.00
8	Upper	15,222	16	2.61	1.86	23.73	
	Middle	15,238	46	2.56	3.04	109.08	
	Lower	15,284	30	2.62	1.63	39.17	
	Total		92	2.59	2.38	171.98	2.00
9	Upper	18,670	20	2.62	1.63	26.11	
	Middle	18,690	60	2.55	3.28	152.93	
	Lower	18,750	44	2.60	2.10	73.07	
	Total		124	2.58	2.60	252.11	2.00
10	Upper	17,374	36	2.60	2.10	59.79	
	Middle	17,410	60	2.54	3.52	163.59	
	Lower	17,470	44	2.57	2.80	96.52	
	Total		140	2.56	2.93	319.90	2.00
11	Upper	18,024	48	2.67	0.51	20.04	
	Middle	18,072	68	2.57	2.80	149.17	
	Lower	18,140	64	2.59	2.33	117.66	
	Total		180	2.60	2.02	286.87	2.00

Appendix 2. Continued

Well number	Member	Depth	DZ	ρ_b	TOC	OC/cm^2	R_o
12	Upper	19,672	62	2.54	3.52	169.04	
	Middle	19,734	76	2.52	4.01	234.21	
	Lower	19,810	154	2.60	2.10	255.76	
	Total		292	2.57	2.90	659.01	2.00
13	Upper	--	--	--	--	--	
	Middle	10,806	8	2.53	3.77	23.23	
	Lower	--	--	--	--	--	
	Total		8	2.53	3.77	23.23	1.09
14	Upper	12,234	8	2.69	0.08	0.50	
	Middle	12,242	8	2.54	3.52	21.81	
	Lower	12,250	4	2.57	2.80	8.77	
	Total		20	2.61	2.00	31.08	1.23
15	Upper	12,178	10	2.67	0.51	4.18	
	Middle	12,188	14	2.53	3.77	40.66	
	Lower	12,202	8	2.62	1.63	10.44	
	Total		32	2.60	2.22	55.28	1.20
16	Upper	12,226	5	2.63	1.41	5.64	
	Middle	12,231	13	2.50	4.51	44.68	
	Lower	--	--	--	--	--	
	Total		18	2.54	3.65	50.32	1.19
17	Upper	12,868	4	2.56	3.04	9.48	
	Middle	12,872	24	2.50	4.51	82.49	
	Lower	12,896	48	2.51	4.26	156.45	
	Total		76	2.51	4.27	248.42	1.14
18	Upper	11,924	8	2.52	4.01	24.65	
	Middle	11,932	26	2.53	3.77	75.51	
	Lower	11,958	24	2.56	3.04	56.91	
	Total		58	2.54	3.50	157.07	1.02
19	Upper	12,012	8	2.63	1.41	9.02	
	Middle	12,020	36	2.48	5.02	136.52	
	Lower	12,056	54	2.52	4.01	166.41	
	Total		98	2.51	4.17	311.95	1.14
20	Upper	11,708	20	2.47	5.27	79.40	
	Middle	11,728	27	2.42	6.59	131.16	
	Lower	11,755	55	2.52	4.01	169.49	
	Total		102	2.48	4.94	380.05	1.16
21	Upper	11,780	40	2.60	2.10	66.43	
	Middle	11,820	33	2.53	3.77	95.83	
	Lower	11,853	23	2.57	2.80	50.45	
	Total		96	2.57	2.84	212.71	1.29
22	Upper	11,112	24	2.43	6.32	112.33	
	Middle	11,136	14	2.43	6.32	65.52	
	Lower	11,150	38	2.48	5.02	144.10	
	Total		76	2.46	5.67	321.95	1.09
23	Upper	12,718	20	2.49	4.76	72.29	
	Middle	12,738	14	2.45	5.79	60.55	
	Lower	12,752	62	2.46	5.53	257.14	
	Total		96	2.46	5.39	389.98	1.38

Appendix 2. Continued

Well number	Member	Depth	DZ	ρ_b	TOC	OC/cm^2	R_o
24	Upper	8,438	2	--	--	--	
	Middle	--	--	--	--	--	
	Lower	--	--	--	--	--	
	Total		2	--	--	--	0.79
25	Upper	8,510	30	2.65	0.96	23.18	
	Middle	--	--	--	--	--	
	Lower	--	--	--	--	--	
	Total		30	2.65	0.96	23.18	0.78
26	Upper	8,128	6	2.65	0.96	4.64	
	Middle	--	--	--	--	--	
	Lower	--	--	--	--	--	
	Total		6	2.65	0.96	4.64	0.73
27	Upper	8,382	8	2.60	2.10	13.29	
	Middle	--	--	--	--	--	
	Lower	--	--	--	--	--	
	Total		8	2.60	2.10	13.29	0.74
28	Upper	8,124	10	2.57	2.80	21.94	
	Middle	8,134	8	2.51	4.26	26.07	
	Lower	--	--	--	--	--	
	Total		18	2.54	3.45	48.01	0.71
29	Upper	8,454	10	2.60	2.10	16.61	
	Middle	8,464	12	2.48	6.32	45.51	
	Lower	8,476	12	2.65	0.96	9.27	
	Total		34	2.58	2.73	71.39	0.70
30	Upper	8,554	24	2.61	1.86	35.60	
	Middle	8,578	12	2.50	4.51	41.24	
	Lower	8,590	60	--	--	--	
	Total		96	--	--	--	0.70
31	Upper	8,330	28	2.62	1.63	36.56	
	Middle	8,358	12	2.44	6.05	54.03	
	Lower	--	--	--	--	--	
	Total		40	2.57	2.96	90.59	0.70
32	Upper	8,600	34	2.52	4.01	104.78	
	Middle	8,634	16	2.39	7.40	86.25	
	Lower	--	--	--	--	--	
	Total		50	2.48	5.09	191.03	0.71
33	Upper	8,465	37	2.60	2.10	61.45	
	Middle	8,502	12	2.45	5.79	51.90	
	Lower	--	--	--	--	--	
	Total		49	2.56	3.00	113.35	0.84
34	Upper	8,666	38	2.58	2.56	76.61	
	Middle	8,704	10	2.42	6.59	48.58	
	Lower	8,714	4	--	--	--	
	Total		52	--	--	--	0.90
35	Upper	8,792	20	2.57	2.80	43.87	
	Middle	8,812	14	2.47	5.27	55.58	
	Lower	8,826	6	--	--	--	
	Total		40	--	--	--	0.87

Appendix 2. Continued

Well number	Member	Depth	DZ	ρ_b	TOC	OC/cm^2	R_o
36	Upper	8,620	18	2.57	2.80	39.49	
	Middle	8,638	14	--	--	--	
	Lower	8,652	6	2.59	2.33	11.03	
	Total		38	--	--	--	0.83
37	Upper	8,538	16	2.59	2.33	29.41	
	Middle	8,554	16	2.47	5.27	63.52	
	Lower	8,570	4	2.63	1.41	4.51	
	Total		36	2.54	3.53	97.44	0.77
38	Upper	8,344	10	2.56	3.04	23.71	
	Middle	8,354	16	2.46	5.53	66.36	
	Lower	--	--	--	--	--	
	Total		26	2.50	4.57	90.07	0.73
39	Upper	8,504	10	2.62	1.63	13.06	
	Middle	8,514	18	2.45	5.79	77.85	
	Lower	--	--	--	--	--	
	Total		28	2.51	4.30	90.91	0.71
40	Upper	8,172	10	2.58	2.56	20.16	
	Middle	8,182	14	2.43	6.32	65.52	
	Lower	--	--	--	--	--	
	Total		24	2.49	4.75	85.68	0.66
41	Upper	6,470	48	2.64	1.18	45.62	
	Middle	6,518	2	2.55	3.28	5.10	
	Lower	6,520	10	2.62	1.63	13.06	
	Total		60	2.63	1.33	63.78	0.58
42	Upper	6,544	36	2.62	1.63	47.00	
	Middle	6,580	10	2.42	6.59	48.58	
	Lower	6,590	4	2.64	1.18	3.80	
	Total		50	2.58	2.59	99.38	0.57
43	Upper	6,156	40	2.58	2.56	80.64	
	Middle	6,196	10	2.42	6.59	48.58	
	Lower	6,206	4	2.60	2.10	6.64	
	Total		54	2.55	3.27	135.86	0.55
44	Upper	5,750	64	--	--	--	
	Middle	5,814	14	2.39	7.40	75.47	
	Lower	5,828	20	2.53	3.77	58.08	
	Total		98	--	--	--	0.52
45	Upper	5,788	86	2.59	2.33	158.10	
	Middle	5,874	14	2.40	7.13	72.98	
	Lower	5,888	32	2.52	4.01	98.61	
	Total		132	2.55	3.25	329.69	0.53
46	Upper	5,656	80	2.53	3.77	232.33	
	Middle	5,736	10	2.37	7.95	57.46	
	Lower	5,746	26	2.51	4.26	84.74	
	Total		116	2.51	4.24	374.53	0.51
47	Upper	5,940	76	2.57	2.80	166.72	
	Middle	6,016	8	2.38	7.68	44.55	
	Lower	6,024	6	2.55	3.28	15.29	
	Total		90	2.55	3.27	226.56	0.52

Appendix 2. Continued

Well number	Member	Depth	DZ	ρ_b	TOC	OC/cm^2	R_o
48	Upper	5,986	76	2.57	2.80	166.72	
	Middle	6,062	8	2.38	7.68	44.55	
	Lower	6,070	10	2.52	4.01	30.82	
	Total		94	2.55	3.34	242.09	0.46
49	Upper	5,952	70	2.52	4.01	215.72	
	Middle	6,022	10	2.38	7.68	55.68	
	Lower	6,032	20	2.50	4.51	68.74	
	Total		100	2.50	4.48	340.14	0.41
50	Upper	6,100	52	2.54	3.52	141.78	
	Middle	6,152	20	2.40	7.13	104.26	
	Lower	6,172	28	2.55	3.28	71.37	
	Total		100	2.51	4.17	317.41	--
51	Upper	6,204	38	2.50	4.51	130.60	
	Middle	6,242	13	2.40	7.13	67.77	
	Lower	6,255	21	2.53	3.77	60.69	
	Total		72	2.49	4.77	259.06	--
52	Upper	5,886	40	2.57	2.80	87.75	
	Middle	5,926	14	2.47	5.27	55.58	
	Lower	5,940	10	2.58	3.77	20.16	
	Total		64	2.55	3.49	163.49	--
53	Upper	--	--	--	--	--	
	Middle	17,844	22	2.56	3.04	52.17	
	Lower	17,866	14	2.65	0.96	10.82	
	Total		36	2.60	2.23	62.99	1.80
54	Upper	13,610	4	2.71	0.00	00.00	
	Middle	13,614	6	2.55	3.28	15.29	
	Lower	13,620	10	2.63	1.41	11.28	
	Total		20	2.62	1.69	26.57	1.42
55	Upper	--	--	--	--	--	
	Middle	13,054	16	2.48	5.02	60.67	
	Lower	13,070	4	2.50	4.51	13.75	
	Total		20	2.48	4.92	74.42	1.31
56	Upper	--	--	--	--	--	
	Middle	9,876	8	2.48	5.02	30.34	
	Lower	--	--	--	--	--	
	Total		8	2.48	5.02	30.34	0.89
57	Upper	8,804	4	2.69	0.08	0.25	
	Middle	8,808	12	2.46	5.53	49.77	
	Lower	--	--	--	--	--	
	Total		16	2.52	4.17	50.02	0.76
58	Upper	8,040	42	2.62	1.63	54.83	
	Middle	8,082	24	2.46	5.53	99.54	
	Lower	8,106	16	2.68	0.29	3.84	
	Total		82	2.58	2.51	158.21	0.68
59	Upper	7,710	38	2.60	2.10	63.11	
	Middle	7,748	24	2.43	6.32	112.33	
	Lower	--	--	--	--	--	
	Total		62	2.53	3.73	175.44	0.64

Appendix 2. Continued

Well number	Member	Depth	DZ	ρ_b	TOC	OC/cm^2	R_o
60	Upper	7,362	44	2.57	2.80	96.52	
	Middle	7,406	16	2.40	7.13	83.41	
	Lower	7,422	18	2.41	6.85	90.64	
	Total		78	2.50	4.62	270.57	0.61
61	Upper	7,144	54	2.61	1.86	80.09	
	Middle	7,198	16	2.40	7.13	83.41	
	Lower	7,214	24	2.46	5.53	99.54	
	Total		94	2.54	3.69	263.04	0.59
62	Upper	6,724	48	2.59	2.33	88.24	
	Middle	6,772	15	2.46	5.53	62.21	
	Lower	6,787	21	2.54	3.52	57.26	
	Total		84	2.55	3.20	207.71	0.57
63	Upper	6,400	50	2.54	3.52	136.32	
	Middle	6,450	12	2.42	6.59	58.29	
	Lower	6,462	34	2.52	4.01	104.78	
	Total		96	2.52	4.08	299.39	0.54
64	Upper	5,432	78	2.58	2.56	157.25	
	Middle	5,510	8	2.35	8.52	48.81	
	Lower	5,518	16	2.53	3.77	46.47	
	Total		102	2.55	3.22	252.53	0.50
65	Upper	24,490	58	2.56	3.04	137.53	
	Middle	24,548	26	2.50	4.51	89.36	
	Lower	24,574	124	2.53	3.77	360.11	
	Total		208	2.53	3.66	587.00	2.00
66	Upper	22,400	36	2.58	2.56	12.58	
	Middle	22,436	32	2.51	4.26	104.30	
	Lower	22,468	82	2.60	2.10	136.19	
	Total		150	2.58	2.67	253.07	2.00
67	Upper	20,890	40	2.58	2.56	80.64	
	Middle	20,930	34	2.52	4.01	104.78	
	Lower	20,964	52	2.57	2.80	114.07	
	Total		126	2.56	3.05	299.49	2.00
68	Upper	21,274	40	2.61	1.86	59.33	
	Middle	21,314	42	2.54	3.52	114.51	
	Lower	21,356	40	2.60	2.10	66.43	
	Total		122	2.58	2.51	240.27	2.00
69	Upper	18,738	12	2.60	2.10	19.93	
	Middle	18,750	30	2.52	4.01	92.45	
	Lower	18,780	54	--	--	--	
	Total		96	--	--	--	2.00
70	Upper	--	--	--	--	--	
	Middle	17,286	28	--	--	--	
	Lower	17,314	20	--	--	--	
	Total		48	--	--	--	2.00
71	Upper	14,256	8	2.55	3.28	20.39	
	Middle	14,264	28	2.52	4.01	86.29	
	Lower	14,292	24	2.58	2.56	48.38	
	Total		60	2.55	3.33	155.06	1.35

Appendix 2. Continued

Well number	Member	Depth	DZ	ρ_b	TOC	OC/cm^2	R_o
72	Upper	13,468	10	2.52	4.01	30.82	
	Middle	13,478	16	2.50	4.51	54.99	
	Lower	--	--	--	--	--	
	Total		26	2.51	4.32	85.81	1.23
73	Upper	10,300	10	2.43	6.32	46.80	
	Middle	10,310	20	2.37	7.95	114.92	
	Lower	10,330	18	2.45	5.79	77.85	
	Total		48	2.41	6.80	239.57	0.90
74	Upper	10,314	20	2.58	2.56	40.32	
	Middle	10,334	16	2.43	6.32	74.88	
	Lower	10,350	96	2.59	2.33	176.49	
	Total		132	2.57	2.85	291.69	0.89
75	Upper	9,870	28	2.58	2.56	56.45	
	Middle	9,898	12	2.42	6.59	58.29	
	Lower	9,910	20	2.55	3.28	50.98	
	Total		60	2.54	3.61	165.72	0.85
76	Upper	9,792	32	2.54	3.52	87.25	
	Middle	9,824	11	2.40	7.13	57.34	
	Lower	9,835	35	2.52	4.01	107.86	
	Total		78	2.51	4.25	252.45	0.85
77	Upper	9,514	30	2.47	5.27	119.09	
	Middle	9,544	14	2.43	6.32	65.52	
	Lower	--	--	--	--	--	
	Total		44	2.46	5.60	184.61	0.87
78	Upper	8,218	36	2.59	2.33	66.18	
	Middle	8,254	16	2.50	4.51	54.99	
	Lower	8,270	6	2.59	2.33	11.03	
	Total		58	2.57	2.93	132.20	0.84
79	Upper	7,552	28	2.58	2.56	56.45	
	Middle	7,580	24	2.44	6.05	108.06	
	Lower	7,604	36	2.57	2.80	78.97	
	Total		88	2.54	3.61	243.48	0.74
80	Upper	7,248	26	--	--	--	
	Middle	7,274	26	2.38	7.68	144.78	
	Lower	7,300	48	2.48	5.02	182.02	
	Total		100	--	--	--	0.69
81	Upper	7,126	18	2.48	5.02	68.26	
	Middle	7,144	26	2.36	8.23	154.01	
	Lower	7,170	46	2.45	5.79	198.95	
	Total		90	2.43	6.34	421.22	0.63
82	Upper	7,060	10	2.53	3.77	29.04	
	Middle	7,070	30	2.41	6.85	151.06	
	Lower	7,100	36	2.51	4.26	117.34	
	Total		76	2.47	5.22	297.44	0.59
83	Upper	6,680	36	2.56	3.04	85.36	
	Middle	6,716	14	2.43	6.32	65.52	
	Lower	6,730	18	2.54	3.52	49.08	
	Total		68	2.53	3.84	199.96	0.55

Appendix 2. Continued

Well number	Member	Depth	DZ	ρ_b	TOC	OC/cm^2	R_o
84	Upper	6,236	48	2.56	3.04	113.82	
	Middle	6,284	16	2.38	7.68	89.09	
	Lower	--	--	--	--	--	
	Total		64	2.52	4.20	202.91	0.57
85	Upper	5,990	74	2.60	2.10	122.90	
	Middle	6,064	14	2.42	6.59	68.01	
	Lower	6,078	10	2.56	3.04	23.71	
	Total		98	2.57	2.84	214.62	0.56
86	Upper	5,386	88	2.54	3.52	239.93	
	Middle	5,474	6	2.37	7.95	34.48	
	Lower	5,480	30	2.52	4.01	92.45	
	Total		124	2.53	3.85	366.86	0.49
87	Upper	5,214	88	2.57	2.80	193.04	
	Middle	5,302	6	2.33	9.09	38.74	
	Lower	5,308	22	2.55	3.28	56.07	
	Total		116	2.55	3.22	287.85	0.48
88	Upper	20,106	16	2.58	2.56	32.26	
	Middle	20,122	56	2.55	3.28	142.74	
	Lower	20,178	22	--	--	--	
	Total		94	--	--	--	2.00
89	Upper	15,634	26	2.55	3.28	66.27	
	Middle	15,660	52	2.48	5.02	197.19	
	Lower	15,712	32	--	--	--	
	Total		110	--	--	--	1.80
90	Upper	14,506	36	2.53	3.77	104.55	
	Middle	14,542	38	2.51	4.26	123.85	
	Lower	14,580	20	2.54	3.52	54.53	
	Total		94	2.52	3.91	282.93	1.47
91	Upper	9,370	26	2.55	3.28	66.27	
	Middle	9,396	18	2.48	5.02	68.26	
	Lower	9,414	14	2.56	3.04	33.20	
	Total		58	2.53	3.76	167.73	0.84
92	Upper	8,100	10	2.58	2.56	20.16	
	Middle	8,110	16	2.50	4.51	54.99	
	Lower	--	--	--	--	--	
	Total		26	2.53	3.76	75.15	0.67
93	Upper	7,934	12	--	--	--	
	Middle	7,946	24	2.41	6.85	120.85	
	Lower	7,970	30	2.42	6.59	145.73	
	Total		66	--	--	--	0.60
94	Upper	7,448	20	2.52	4.01	61.63	
	Middle	7,468	24	2.43	6.32	112.33	
	Lower	7,492	24	2.48	5.02	91.01	
	Total		68	2.47	5.18	264.97	0.55
95	Upper	7,166	48	2.53	3.77	139.40	
	Middle	7,214	20	2.43	6.32	93.60	
	Lower	7,234	20	2.52	4.01	61.63	
	Total		88	2.51	4.40	294.63	0.51

Appendix 2. Continued

Well number	Member	Depth	DZ	ρ_b	TOC	OC/cm^2	R_o
96	Upper	6,866	44	2.57	2.80	96.52	
	Middle	6,910	16	2.46	5.53	66.36	
	Lower	6,926	16	2.55	3.28	40.78	
	Total		76	2.54	3.48	203.66	0.43
97	Upper	5,892	62	2.55	3.28	158.03	
	Middle	5,954	10	2.45	5.79	43.25	
	Lower	5,964	22	2.55	3.28	56.07	
	Total		94	2.54	3.55	257.35	--
98	Upper	5,564	56	2.56	3.04	132.79	
	Middle	5,620	10	2.47	5.27	39.70	
	Lower	5,630	14	2.55	3.28	35.68	
	Total		80	2.55	3.36	208.17	--
99	Upper	5,352	50	2.56	3.04	118.56	
	Middle	5,402	12	2.52	4.01	36.98	
	Lower	--	--	--	--	--	
	Total		62	2.55	3.23	155.54	--

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SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000 and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

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