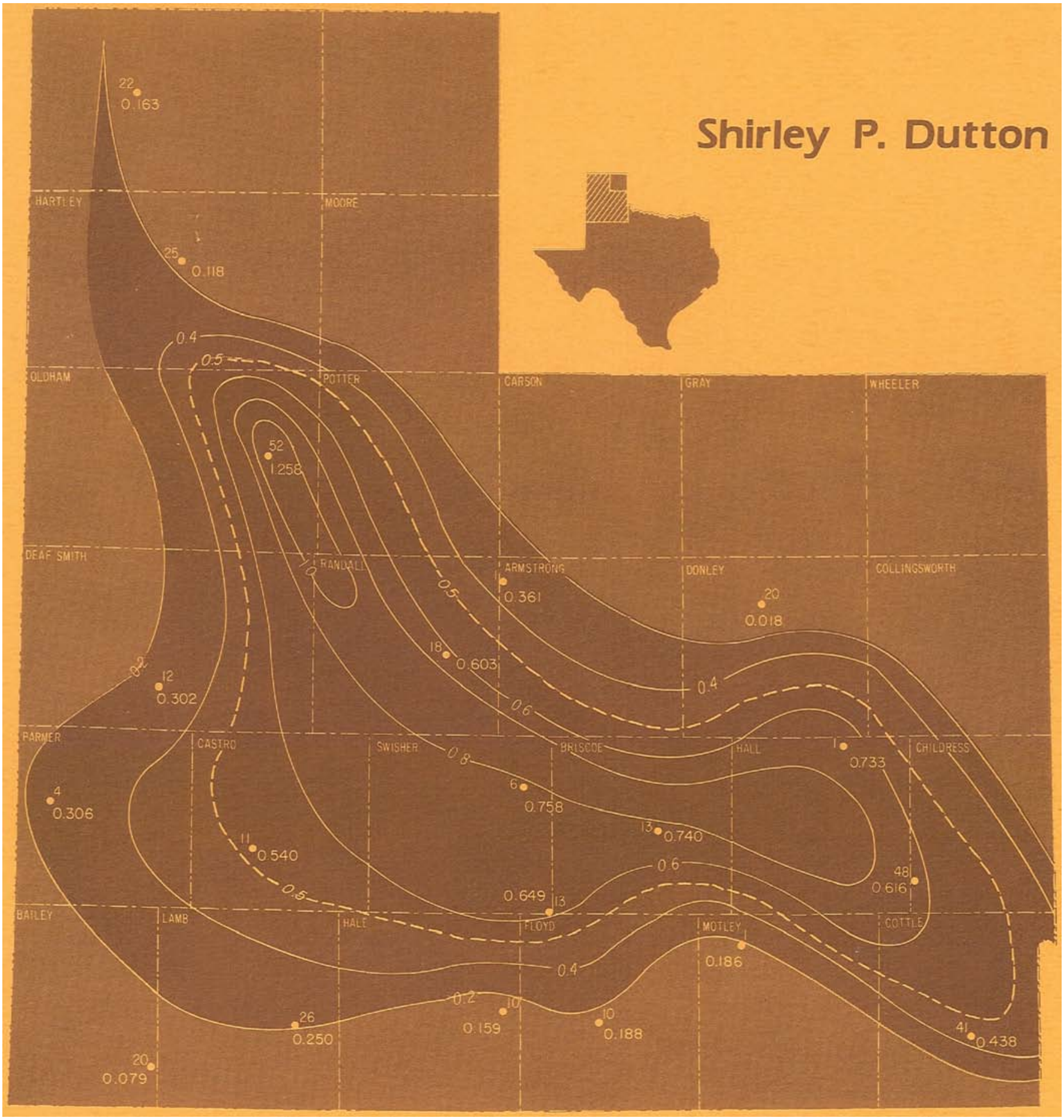
Geological Circular 80-10

Petroleum Source Rock Potential and Thermal Maturity, Palo Duro Basin, Texas

Shirley P. Dutton



Bureau of Economic Geology • W. L. Fisher, Director • The University of Texas at Austin • Austin, Texas 78712

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PETROLEUM SOURCE ROCK POTENTIAL AND THERMAL MATURITY, PALO DURO BASIN, TEXAS

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ABSTRACT

Samples collected from 20 geographically widespread wells in the sparsely drilled Palo Duro Basin were analyzed for total organic carbon content (TOC). Highest values of TOC, up to 6.9 percent, occur in Upper Permian San Andres dolomite in the southern part of the basin. Pennsylvanian and Lower Permian (Wolfcampian) basinal shales contain up to 2.4 percent TOC and are fair to very good source rocks.

Kerogen color and vitrinite reflectance, which indicate maximum paleotemperatures, were analyzed in all samples containing greater than 0.5 percent TOC. Pennsylvanian and Wolfcampian kerogen is yellow orange to orange, an indication that temperatures were sufficiently high to begin to generate hydrocarbons from lipid-rich organic material. Palo Duro Basin samples have a broad range of vitrinite reflectance values, but populations with the lowest reflectance probably indicate the true temperatures that were reached in the basin. Average reflectance in representative Pennsylvanian vitrinite is 0.52 percent; in Wolfcampian samples the average reflectance is 0.48 percent. These values are consistent with kerogen color and suggest that basinal source rocks may have begun to generate hydrocarbons.

INTRODUCTION

The Palo Duro Basin in the Texas Panhandle remains a frontier area for hydrocarbon exploration. Very little oil or gas has been discovered in the basin, but production is considerable on the adjacent Matador Arch and Amarillo Uplift (fig. 1). There is also production around the periphery of the basin in Oldham, Cottle, and Childress Counties. Moreover, the Palo Duro Basin lies between the Anadarko and Midland Basins, which are both important hydrocarbon provinces. The lack of significant discoveries in the Palo Duro Basin could be due to either the low level of drilling or an actual lack of economic hydrocarbon potential. Studies of the source rock quality and the thermal history of the Palo Duro Basin and comparison of these parameters with the Midland Basin provide important evidence on whether hydrocarbons could have formed in the Palo Duro Basin. This information helps determine the resource potential of the basin.

Source rock quality is a function of the amount and type of organic matter in a rock. The boundary between a fair and a poor clastic source rock is commonly defined at approximately 0.5 percent total organic carbon content (Tissot and Welte, 1978). Carbonates with as little as 0.3 percent TOC can be fair source rocks. Good clastic source rocks generally contain greater than 1.0 percent TOC and good carbonate source rocks, greater than 0.5 percent TOC. Unless adequate amounts of organic matter were present in the Palo Duro Basin source rocks, commercial quantities of hydrocarbons would not have been generated. Furthermore, sufficient temperatures must be reached to generate hydrocarbons from disseminated organic material. In general, significant oil generation begins at temperatures around $65^{\circ}C$ ($150^{\circ}F$) (Pusey, 1973). Time is also an element in hydrocarbon formation; oil may form at lower temperatures, given long exposure times (Dow, 1978). Optical properties of the organic material remaining in source rocks, especially kerogen color and vitrinite reflectance, are influenced by both time and temperature; therefore, they can be used as indicators of thermal maturity (Tissot and Welte, 1978). Source rock quality and thermal maturity data can be combined to evaluate hydrocarbon potential of the Palo Duro Basin.

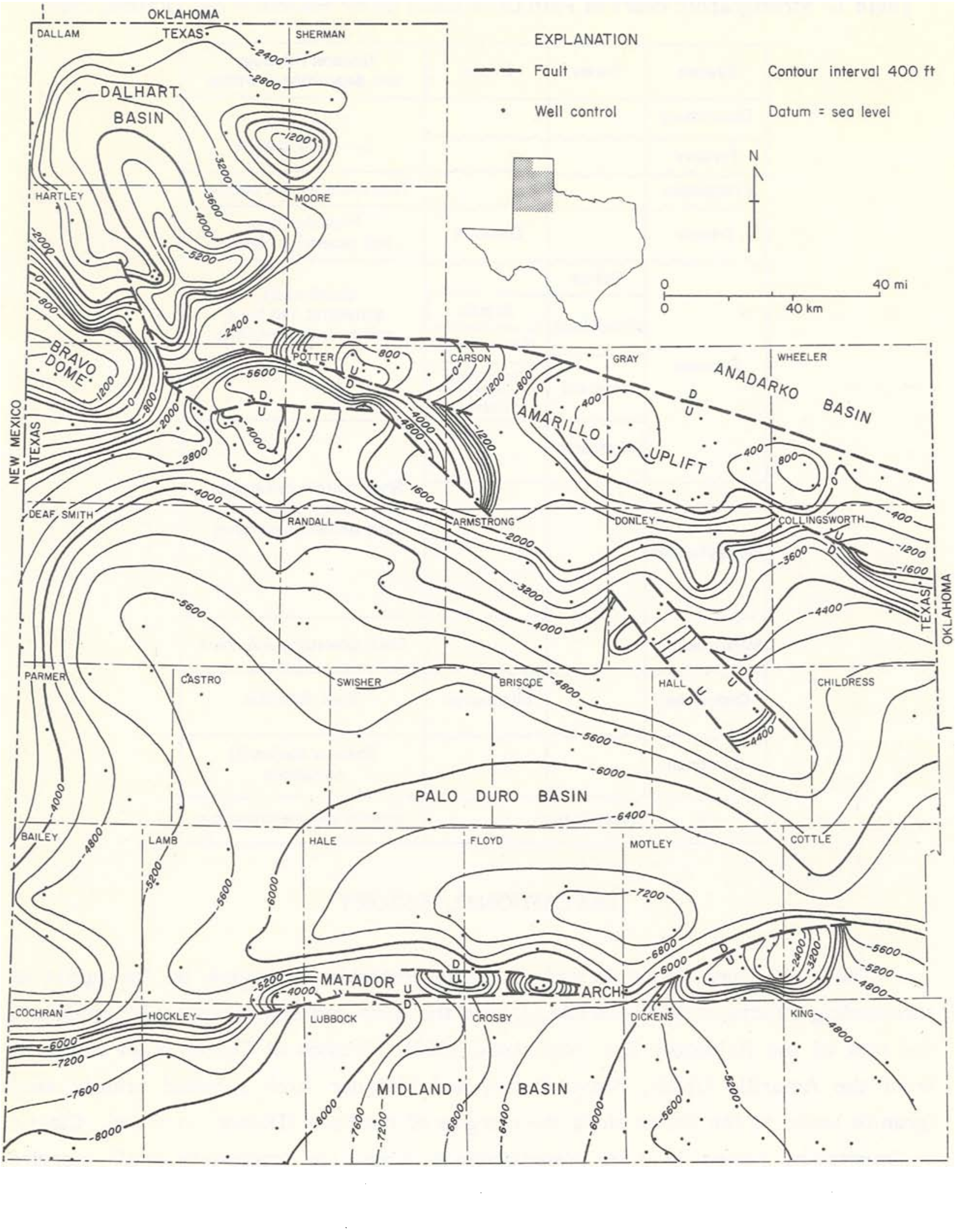


Figure 1. Structure contour map of the top of Precambrian basement illustrating structural elements of the Texas Panhandle (from Dutton and others, 1979).

Table 1. Stratigraphic chart of Palo Duro Basin (after Handford and Dutton, 1980).

System	Series	Group	General lithology and depositional setting
Quaternary			Fluvial and lacustrine clastics
Tertiary			
Cretaceous			Nearshore marine clastics
Triassic		Dockum	Fluvial-deltaic and lacustrine clastics
Permian	Ochoa		Sabkha salt, anhydrite, red beds, and peritidal dolomite
	Guadalupe	Artesia	
		Pease River	
	Leonard	Clear Fork	
		Wichita	
	Wolfcamp		Shelf margin carbonates, basin shale, and deltaic sandstones
Pennsylvanian			
Mississippian			Shelf limestone and chert
Ordovician		Ellenburger	Shelf dolomite
Cambrian			Shallow marine(?) sandstone
Precambrian			Igneous and metamorphic

DEPOSITIONAL HISTORY

The Palo Duro Basin formed in Early Pennsylvanian time by the uplift of surrounding structural highlands (fig. 1), and the basin continued to subside throughout the rest of the Paleozoic Era (Nicholson, 1960). Erosion of Precambrian basement from the Amarillo Uplift, Bravo Dome, and Matador Arch supplied arkosic sand (granite wash) to fan deltas along the margins of the basin (Dutton, in press). Clastic sedimentation waned in Late Pennsylvanian time, and carbonate shelf margins developed around a deep, mud-filled central basin (table 1). High-constructive elongate deltas prograded into the Palo Duro Basin from the east during Late Pennsylvanian and Early Permian time.

During Early Permian (Wolfcampian) time, marine transgression ended, and the basin was gradually filled with shelf margin carbonates and basinal sand and mud

(Handford, 1980). Evaporite deposition was initiated in Leonardian time, continued into Guadalupian time, and resulted in thick sequences of dolomite, anhydrite, and salt.

Several potential hydrocarbon reservoir facies included in the basin (table 1) are Pennsylvanian and Lower Permian fan-delta sandstone, shelf margin dolomite, and high-constructive delta sandstone (Handford and Dutton, 1980). Porous dolomites in Upper Permian evaporite cycles (Presley, 1979) could also be hydrocarbon reservoirs. Dolomite in the Guadalupian San Andres Formation, for example, produces oil from several fields on the Matador Arch.

SOURCE ROCK QUALITY

To determine whether sediments in the Palo Duro Basin contained sufficient organic matter to generate hydrocarbons, 341 samples collected from cuttings from 20 geographically scattered wells were analyzed for TOC (table 2). Samples were taken from a range of depths and stratigraphic intervals from the Guadalupian San Andres Formation to the Lower Ordovician Ellenburger Group (table 1). Sampling was concentrated in Pennsylvanian and Lower Permian shales from basin and prodelta facies.

Total organic carbon content ranges between 0.008 and 6.866 percent (see appendix). One hundred thirty-four samples contain greater than 0.5 percent TOC and are considered fair to very good source rocks (fig. 2). The highest values of TOC in these samples occur in San Andres dolomite in the southern part of the basin.

Pennsylvanian and Wolfcampian basinal shales contain up to 2.4 percent TOC and are poor to very good source rocks (fig. 2). Highest values of Pennsylvanian and Lower Permian TOC occur in basinal shales stratigraphically near the Pennsylvanian-Permian boundary. Geographic distribution of average organic carbon content was mapped for Pennsylvanian, Wolfcampian, and Leonardian strata. Distribution of organic carbon in the Pennsylvanian section reflects the shelf margin position that existed near the end

Table 2. Wells sampled for geochemical source rock analyses.

County	BEG number	Operator	Well name	County	BEG number	Operator	Well name
Armstrong	1	Standard of Texas	#1A Palm	Hale	10	Amerada	#1 Kurfees
Bailey	20	Shell	#1 Nichols	Hall	1	Amarillo	#1 Cochran
Briscoe	13	Weaver	#1 Adair	Hartley	25	Phillips	#1A Cattle
Castro	11	Sun	#1 Herring	Lamb	26	Stanolind	#1 Hopping
Childress	48	Griggs	#1 Smith	Motley	1	Central	#1 Ross
Cottle	41	Baria & Werner	#1 Mayes	Oldham	52	Stanolind	#1 Herring
Dallam	22	Harrington	#1 Brown & Tovrea	Parmer	4	Stanolind	#1 Jarrell
Deaf Smith	12	Honolulu	#1 Ponder	Randall	18	Slessman	#1 Nance
Donley	20	Doswell	#1 McMurty	Swisher	6	Standard	#1 Johnson
Floyd	10	Sinclair	#1 Massie	Swisher	13	Sinclair	#1 Savage

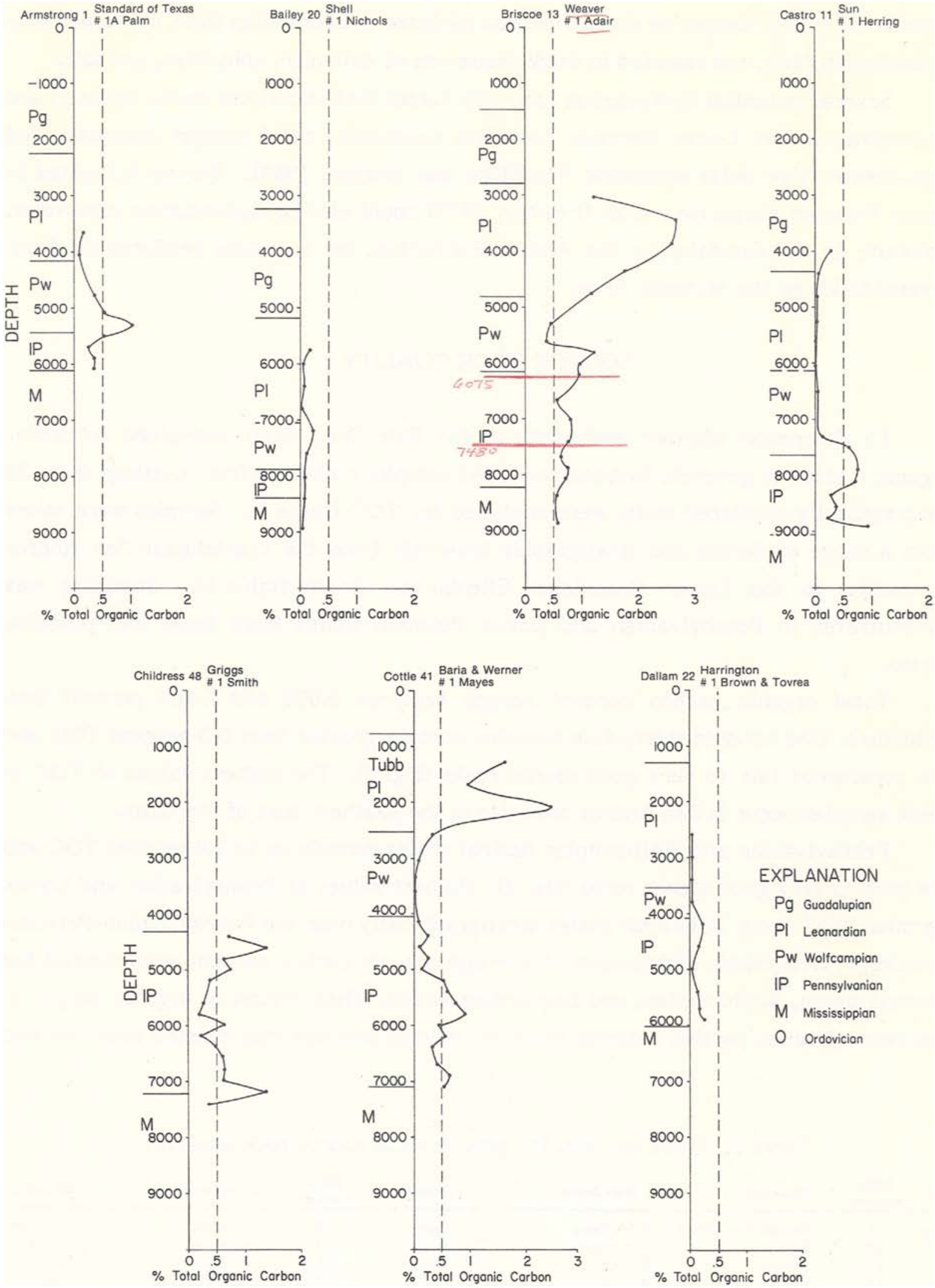
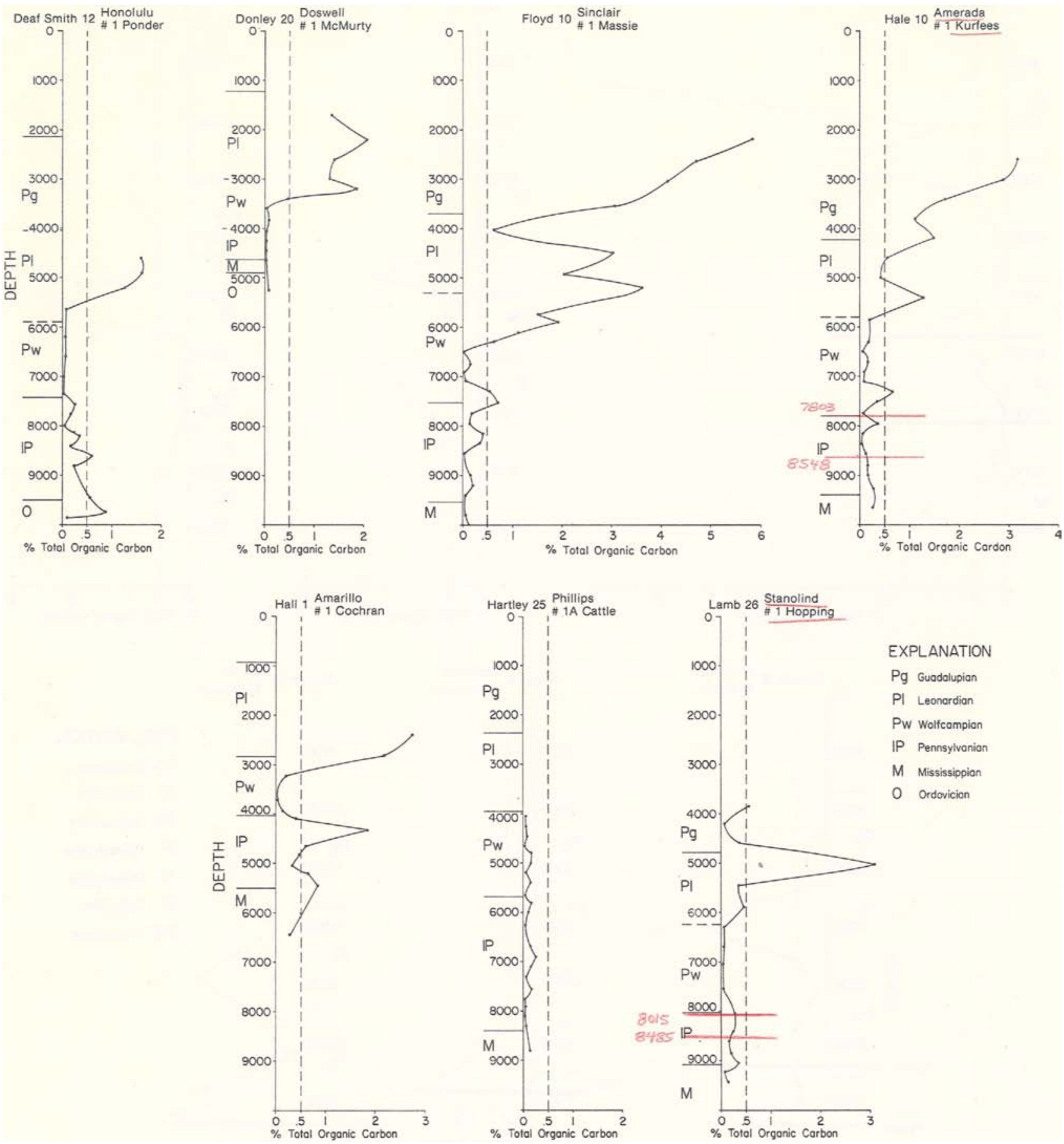


Figure 2. Plot of total organic carbon (TOC) with depth for 20 wells in the Palo Duro and Dalhart Basins.



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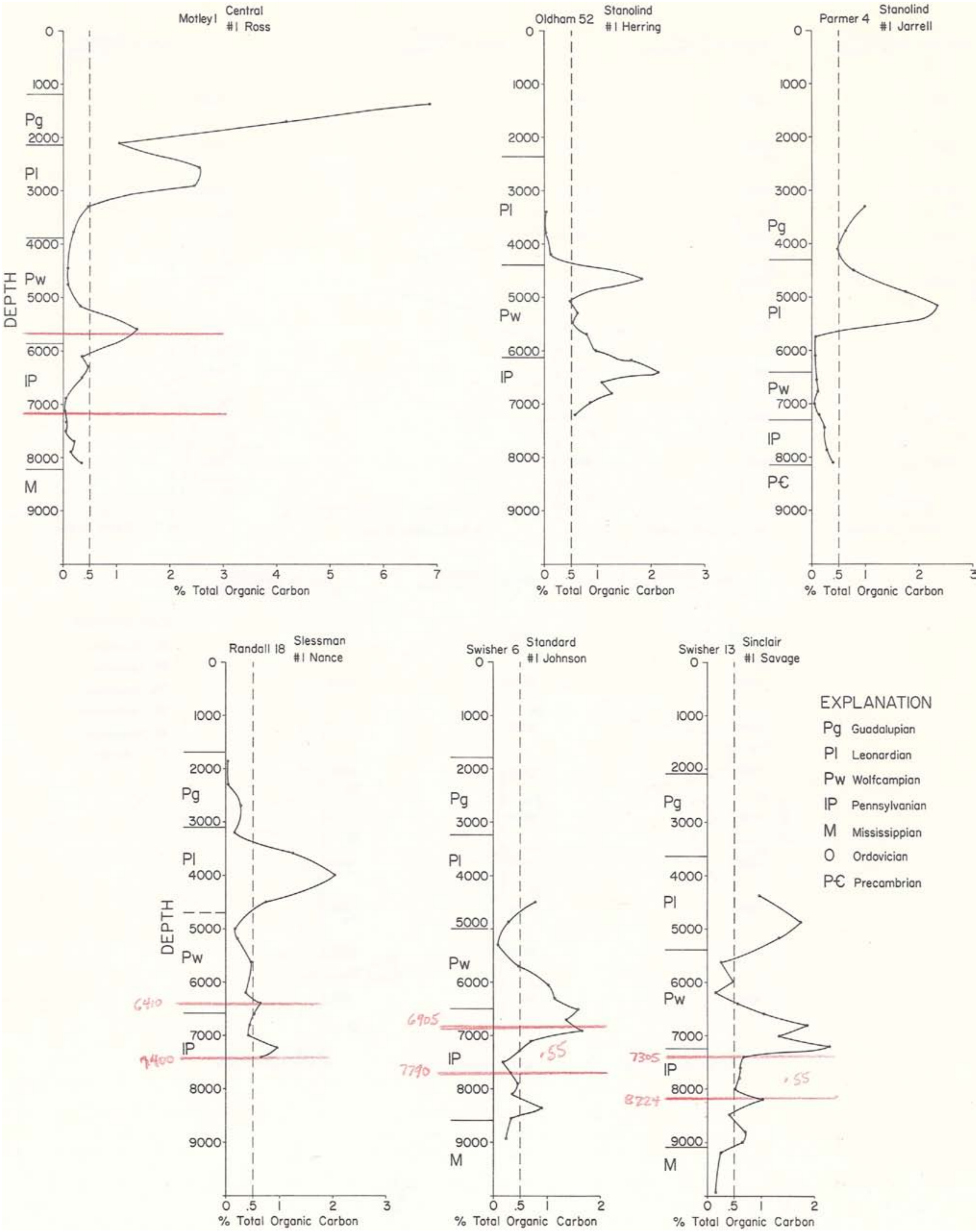

Figure 2 continued.

of Pennsylvanian and the beginning of Wolfcampian time; high values of TOC occur in the basin center facies (figs. 3 and 4). The 0.5-percent-TOC contour line (fig. 3) delineates the area containing fair to good potential source rocks. In the Wolfcampian section, the highest values of TOC are to the east of the Pennsylvanian values (fig. 5) and do not reflect the shelf margin outline as closely as do TOC values of the Pennsylvanian section. Organic carbon distribution in the Leonardian section has a different configuration; the highest values of TOC occur in the northeastern part of the basin and extend southwestward (fig. 6).

Additional core samples of Leonardian and Guadalupian strata were obtained from the DOE/Gruy Federal, Inc., Rex White, Jr., No. 1 Well in northeastern Randall County. Samples were selected from the Guadalupian San Andres Formation and the Leonardian Lower Clear Fork, Red Cave, and Wichita Formations. Lithologies that were sampled include dolomite, anhydrite, banded salt, and red and black shales. High values of TOC, up to 5.38 percent, are present in some of these evaporite units (table 3). Lower Clear Fork samples average 1.508 percent TOC and are considered good to very good potential source rocks because of their organic carbon content. Red Cave anhydrite, dolomite, and red beds contain less organic carbon, averaging 0.196 percent. Much of the Red Cave Formation consists of red beds, an indication that it was deposited under oxidizing conditions that destroyed organic matter.

In San Andres strata, the highest values of TOC are found in the oldest dolomite unit. The Lower San Andres contains five cycles of subtidal dolomite, nodular and bedded anhydrite, and salt (Presley, 1979); the three oldest dolomites were sampled for TOC. The oldest (Cycle 1) averaged 1.152 percent TOC; the next (Cycle 2) averaged 0.264 percent TOC; and the youngest cycle sampled (Cycle 3) averaged 0.411 percent TOC. These values of TOC suggest that only Cycle 1 dolomite in the San Andres in this area contains sufficient organic matter to be a possible source rock. Several fields in the San Andres Formation along the Matador Arch are productive, but the oil may have migrated from the Midland Basin.

All of these TOC analyses of cuttings and cores from the Palo Duro Basin indicate that potential hydrocarbon source rocks are present in Pennsylvanian, Wolfcampian, Leonardian, and Guadalupian strata. However, the type of organic matter in the rocks influences the kinds of hydrocarbons that will form and at what temperatures they will be generated. Kerogen is insoluble organic matter with high molecular weight and is found in shales and other sediments (Barker, 1979). It consists mainly of plant material, including amorphous sapropel, algal debris, spores, pollen, plant cuticle, woody tissue (vitrinite), and inert coaly material. Amorphous sapropel and algal debris are generally of marine origin (Tissot and Welte, 1978). This type of

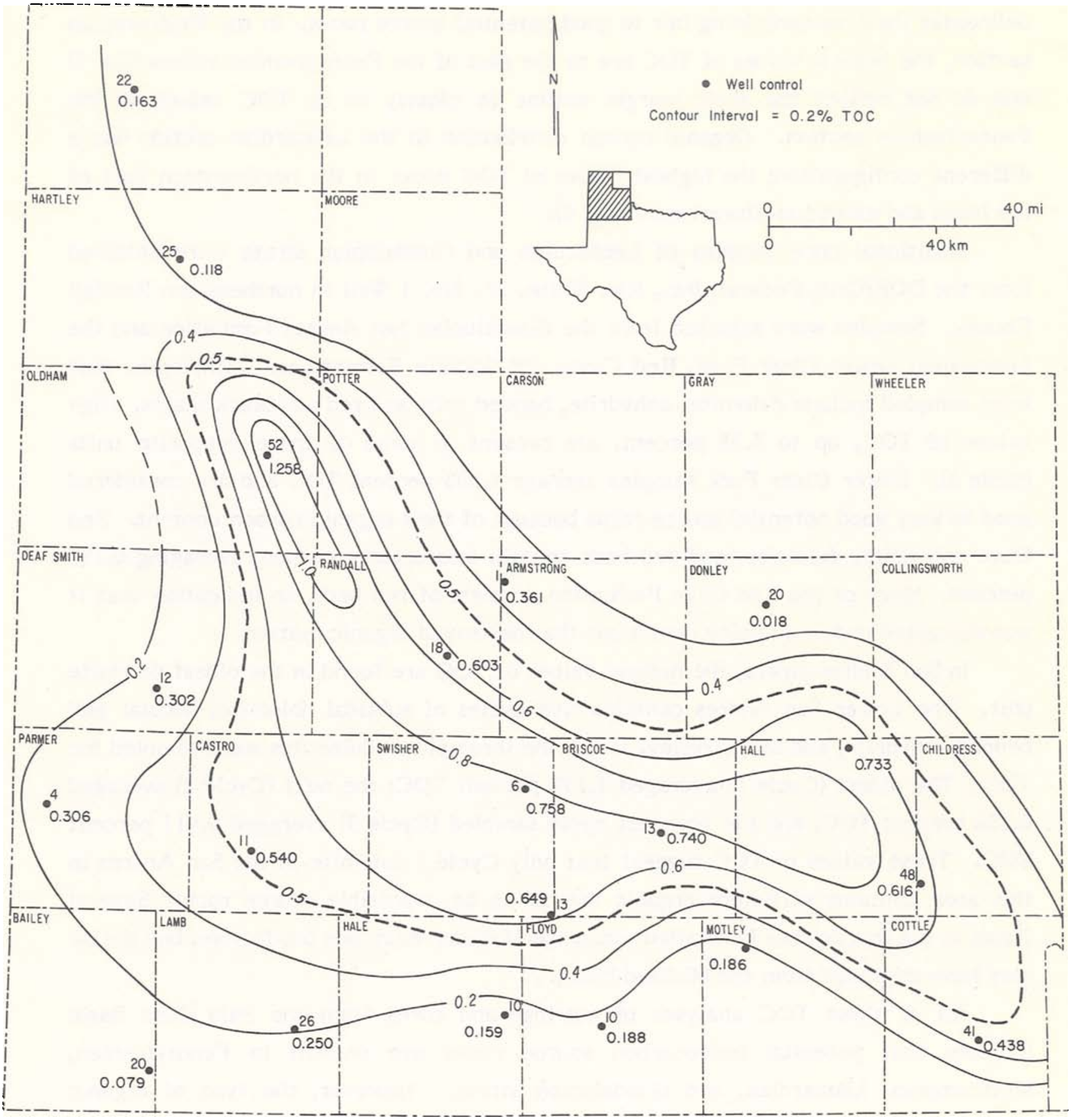

Figure 3. Distribution of organic carbon in Pennsylvanian rocks of the Palo Duro Basin.

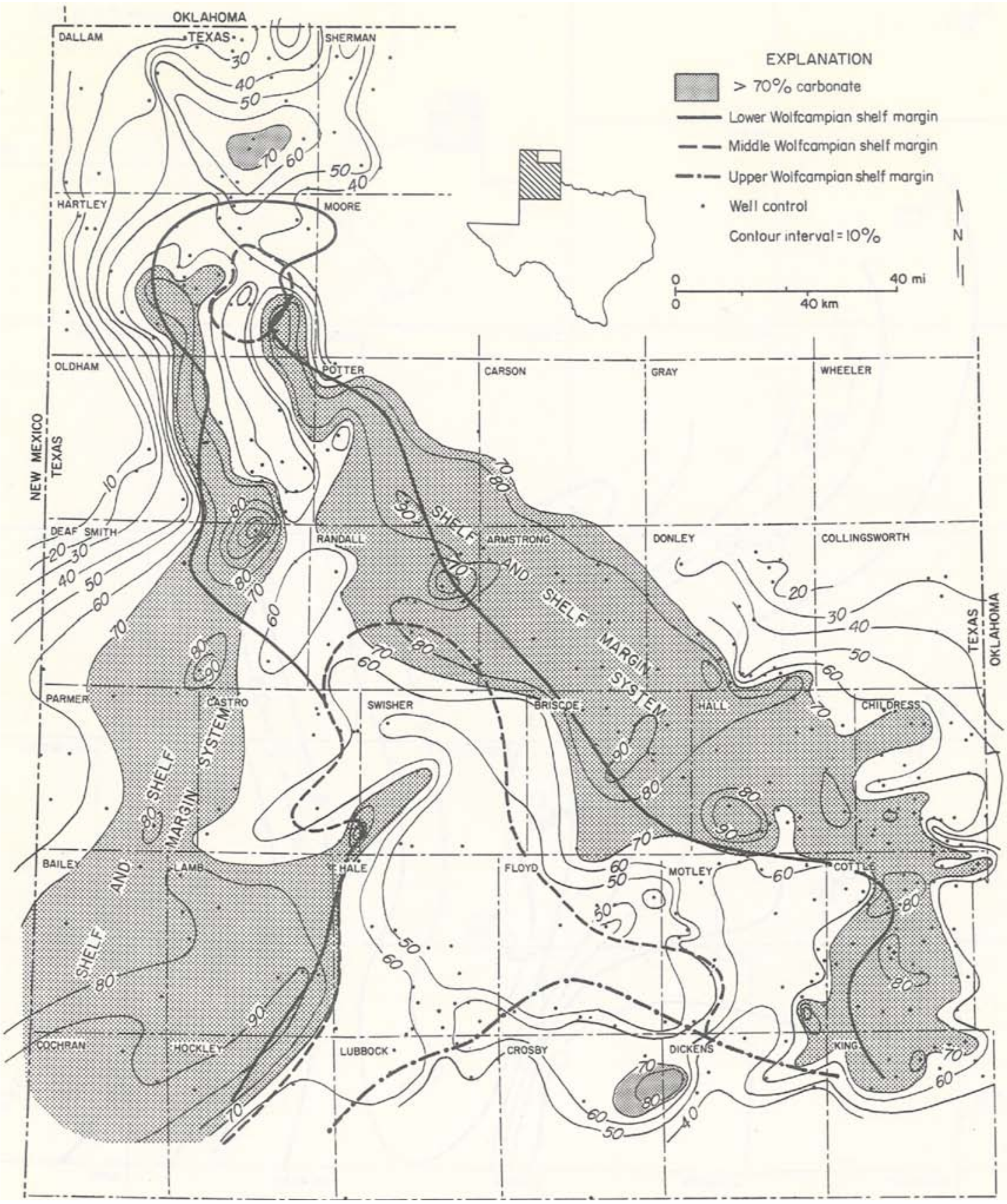

Figure 4. Carbonate percent map of Wolfcampian Series showing positions of Wolfcampian shelf margins (from Handford, 1980).

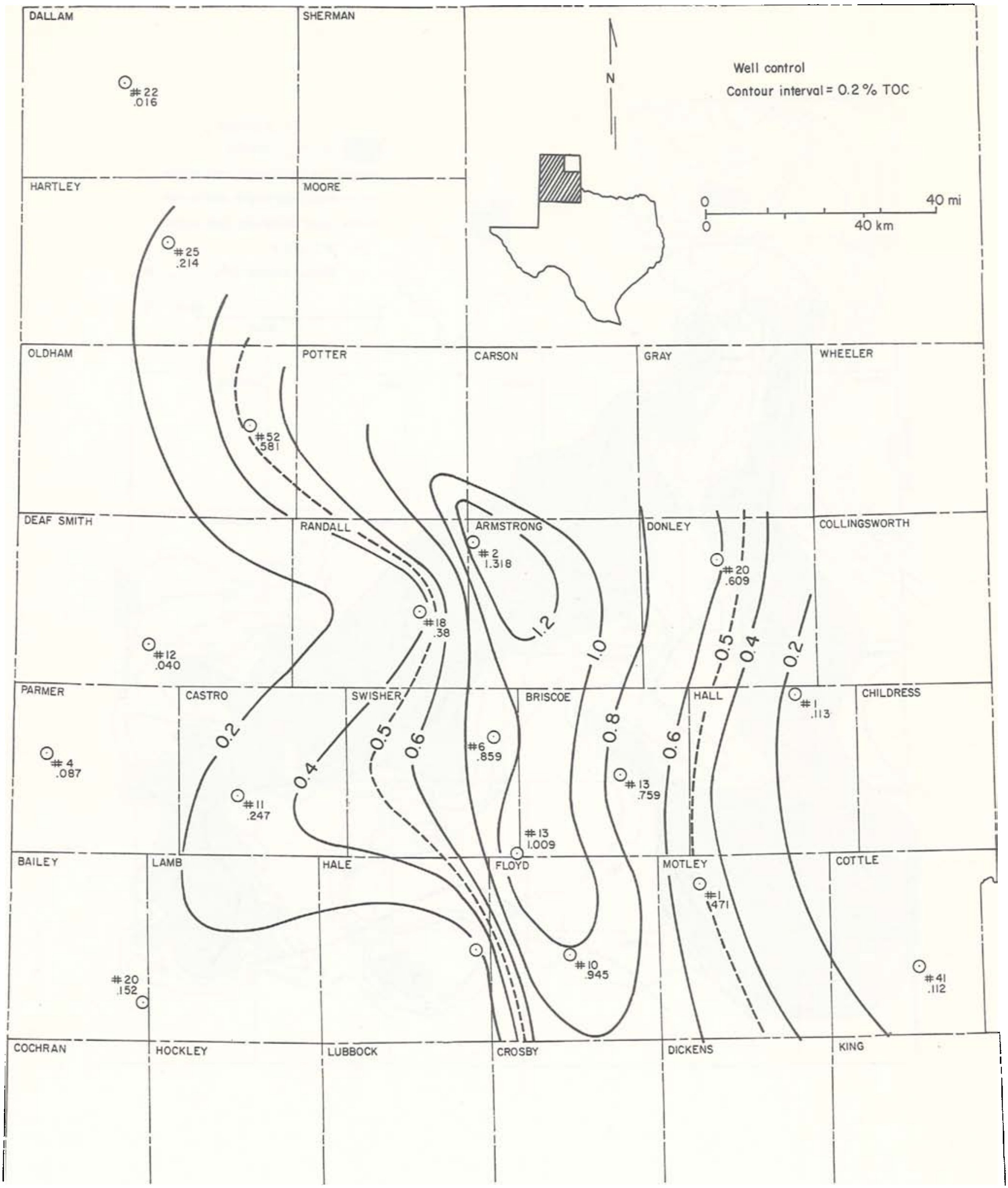

Figure 5. Distribution of organic carbon in Wolfcampian rocks of the Palo Duro Basin.

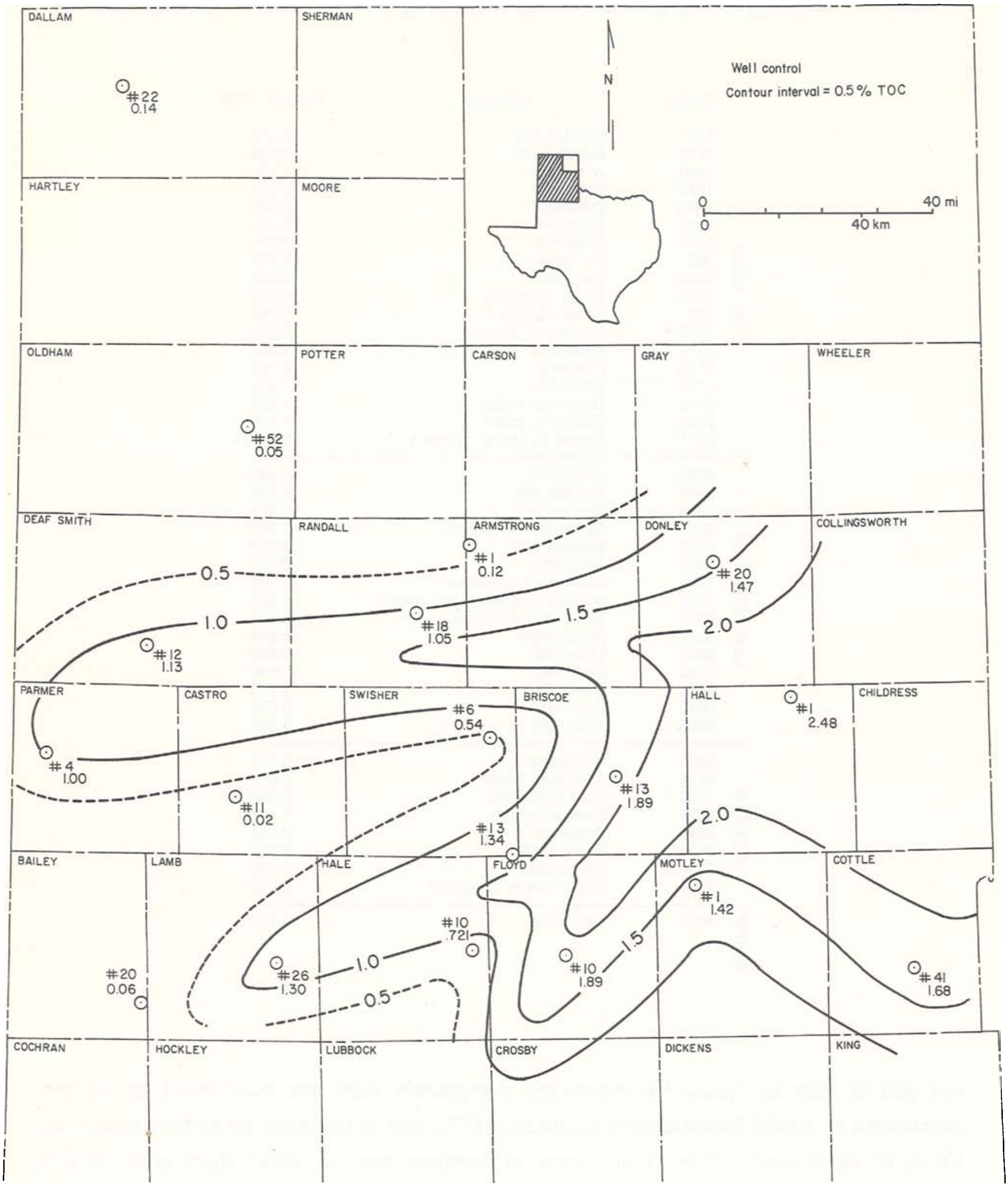

Figure 6. Distribution of organic carbon in Leonardian rocks of the Palo Duro Basin.

Table 3. Total organic carbon content of DOE/Gruy Federal core in Randall County.

	Depth	Lithology	Percent TOC
San Andres	1427	Banded salt	0.074
	1948	Banded salt	0.040
	1960	Anhydrite	1.208
	1970	Dolomite	0.012
	1988	Dolomite	0.018
	2000	Dolomite	1.864
	2014	Dolomite	0.238
	2021	Dolomite, salt	0.014
	2023	Dolomite	0.088
	2028	Shale, dolomite	0.100
	2031	Shale - Cycle 3	0.164
	2095	Dolomite - Cycle 2	0.264
	2172	Dolomite	1.280
	2180	Dolomite	1.146
	2184	Dolomite	1.412
	2190	Dolomite, shale	1.202
	2200	Dolomite, shale	1.010
	2201	Dolomite, shale - Cycle 1	0.864
Lower Clear Fork	3235	Anhydrite	0.240
	3244	Banded salt	0.798
	3288	Banded salt	0.574
	3339	Dolomite, shale, salt	2.140
	3376	Banded salt	0.024
	3384	Anhydrite	0.010
	3401	Laminated dolomite	0.100
	3432	Nodular anhydrite and matrix	5.380
	3451	Laminated dolomite	0.374
	3456	Black shale	1.216
	3527	Dolomite	0.456
	3560	Dolomite	1.640
	3582	Black shale	4.226
	3612	Dolomite	0.576
	3655	Anhydrite	4.864
Red Cave	3675	Red shale	0.012
	3715	Dolomite, shale	0.014
	3793	Dark anhydrite	0.040
	3815	Dark anhydrite	1.020
	3840	Dolomite	0.444
	3879	Black shale	0.012
	3887	Red shale	0.010
	3932	Green shale, anhydrite	0.018
Wichita	3946	Dolomite	0.180

kerogen is rich in lipids, hydrogen-rich compounds that are considered to be the precursors of liquid hydrocarbons (Schwab, 1977), and is the most important source of liquid hydrocarbons. The other forms of kerogen have a lower lipid content and originate mainly from terrestrial plants. Humic material forms dry gas at higher temperatures than are needed to form oil from lipid-rich kerogen (Dow, 1978). For potential source beds to generate hydrocarbons, sufficient temperatures must be reached for the type of kerogen present.

THERMAL HISTORY

As organic matter in source beds is heated during burial, hydrocarbons are generated from kerogen disseminated in the sediment (Dow, 1978). Temperatures of at least 65°C (150°F) are commonly necessary to begin significant oil generation (Pusey, 1973). The current geothermal gradient in the Palo Duro Basin is 2.0°C per 100 m (1.1°F per 100 ft) (Dutton, in press), so temperatures of 65°C (150°F) are reached at about 2,200 m (7,200 ft). Present burial depths of Pennsylvanian stata are 1,500 to 2,800 m (5,000 to 9,000 ft); these rocks were probably buried even deeper in the past, before erosion of Triassic and Upper Permian strata. Pennsylvanian sediments, therefore, should have reached temperatures near the threshold of the oil-generating zone. Lower Wolfcampian deposits also probably reached the temperatures necessary to generate oil. Younger sediments may never have been buried deep enough to reach temperatures near 65°C (150°F), unless the geothermal gradient was higher in the past than it is now.

Kerogen color and vitrinite reflectance are used as paleothermometers to determine paleotemperatures reached by source rocks. These optical properties of organic matter are affected by both time and temperature, and they reflect the stage of thermal maturity reached by the sediments (Tissot and Welte, 1978).

Kerogen Color

Kerogen darkens progressively from colorless to dark brown and black with increasing temperature. The color indicates the degree of thermal alteration and can be quantified as a thermal alteration index, or TAI (Staplin, 1969). By this system, kerogen color is measured on a scale of light yellow to black, corresponding to thermal alteration from 1 (no alteration) to 5 (severe alteration). A modification of this system by Schwab (1977) uses a TAI scale from 1.0 to 8.0. Most of the kerogen in Palo Duro Basin cuttings is yellow orange to orange, which corresponds to a TAI of 3 in the Schwab (1977) system (TAI of 2 in Staplin's system) and indicates slight alteration. Kerogen color varies little with depth. Pennsylvanian kerogen averages 3.01 TAI; Wolfcampian kerogen is 2.95; and Leonardian is 2.91 (Schwab system) (see appendix). The younger sediments were not buried as deeply as were the older ones, and the TAI values reflect the lower burial temperatures. Leonardian and Guadalupian kerogen color is considerably lighter in samples from the DOE/Gruy Federal core in Randall County than in the cuttings; it is generally pale yellow to yellow (TAI of 2.49 in the Schwab system).

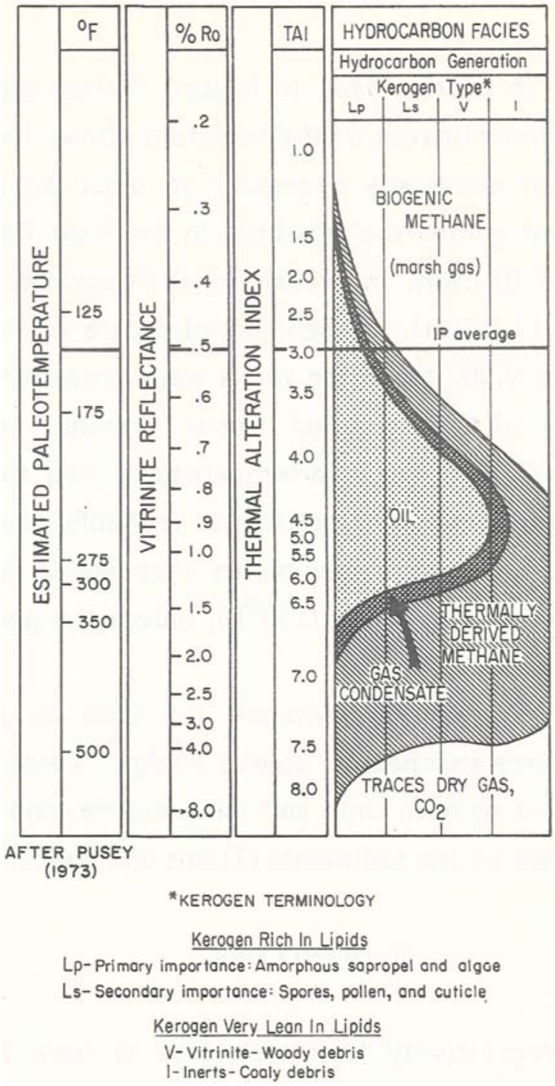

Figure 7. Paleotemperature, vitrinite reflectance, and kerogen color (thermal alteration index) related to hydrocarbon facies (from Schwab, 1977).

Kerogen color (TAI) can be related to paleotemperature and zones of hydrocarbon generation (fig. 7). A TAI value of 3.0 corresponds to a temperature of about 62°C (145°F), which is slightly lower than the temperature of 65°C (150°F) given by Pusey (1973) as the temperature at which oil generation begins. However, only organic matter rich in lipids will begin to generate oil at 62°C (fig. 7); other types of kerogen require higher temperatures to form oil. Kerogen type can be quantified by an organic matter index (OMI) by assigning numerical values from 1 to 8 (table 4) to different forms of kerogen (Schwab, 1977). Lipid-rich organic matter has low OMI values, and values increase in more humic-rich kerogen.

Table 4. Organic matter index values of different kerogen types.

	OMI Number	Kerogen Type
Lipid-rich	1	Algae: Lp
	2	Amorphous debris: Lp
	4	Spores - pollen: Ls
	4	Cuticle - membranous debris: Ls
	6	Vitrinite: V
Lipid-poor	8	Coal debris: I

If the relationship between kerogen type and source rock maturity is plotted using values of kerogen color (TAI) and kerogen type (OMI), Pennsylvanian source rocks fall in the transition or immature zones (fig. 8). Similarly, Wolfcampian source rocks are also generally in the transition zone between maturity and immaturity (fig. 9). This indicates that source rocks in the Palo Duro Basin probably did not reach the principal zone of oil generation. However, in those areas where lipid-rich kerogen was most abundant, there is a greater chance that oil may have been generated. Figure 10 shows that the distribution of kerogen type in Pennsylvanian source rocks generally follows the outline of the Pennsylvanian basin, lipid-rich kerogen being more common in the deep-basin shale facies. Organic matter index values for Wolfcampian rocks are somewhat lower and thus indicate the abundance of lipid-rich kerogen in Wolfcampian basinal shales (fig. 11). Areas where lipid-rich kerogen is most abundant and where TOC values are sufficiently high are the most likely places for hydrocarbon generation, despite the relatively low temperatures.

Vitrinite Reflectance

The amount of light reflected by vitrinite particles (Ro) is affected by time and temperature of burial and is, therefore, another paleotemperature indicator for source rocks (Tissot and Welte, 1978). Vitrinite reflectance can also be related to hydrocarbon generation (fig. 7). Vitrinite reflectance values for Pennsylvanian source rocks (see appendix) average 0.52 percent Ro (fig. 12), which is near the thermal alteration index value of 3.01 (fig. 7). Reflectance values for Wolfcampian (average Ro = 0.48 percent) and Middle and Upper Permian (Leonardian and Guadalupian) vitrinite (average Ro = 0.49 percent) are somewhat lower and reflect the lower burial depths

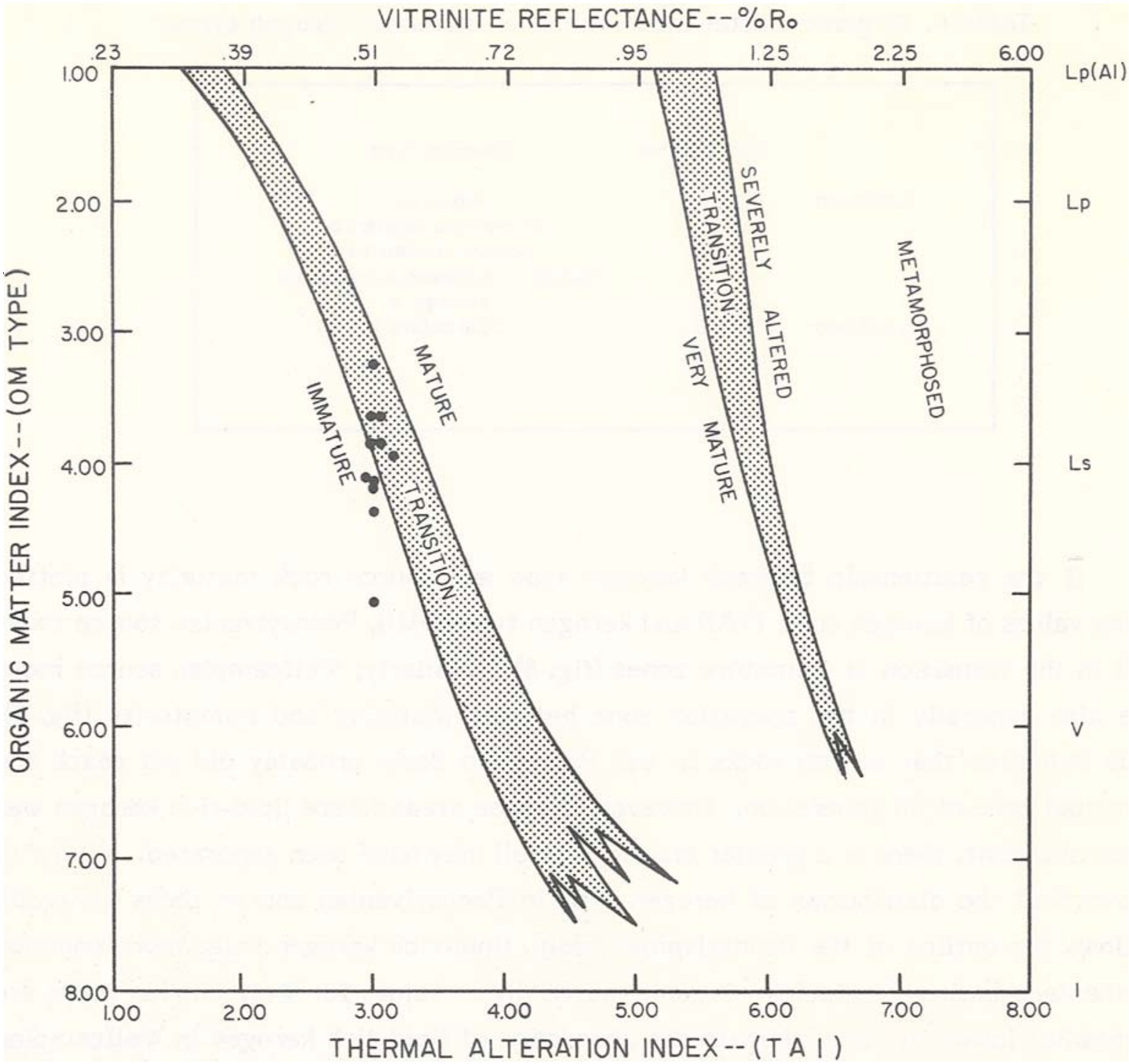

Figure 8. Pennsylvanian source rock maturity based on kerogen type (organic matter index) and kerogen color (thermal alteration index) (from Schwab, 1977).

and temperatures (figs. 13 and 14). According to Tissot and Welte (1978), vitrinite reflectance less than 0.5 to 0.7 percent indicates that source rocks are immature, whereas reflectance between 0.5 to 0.7 and 1.3 percent indicates that source rocks have reached the principal zone of oil generation. No sharp boundary exists between maturity and immaturity because organic matter with different compositions responds at different rates to temperature increases.

The Palo Duro Basin source rock samples exhibit a broad range of vitrinite reflectance values. Vitrinite populations with the lowest reflectance probably indicate the temperatures that were reached in the basin. Vitrinite with higher reflectance may have been reworked from older sediments (Tissot and Welte, 1978). Alternatively,

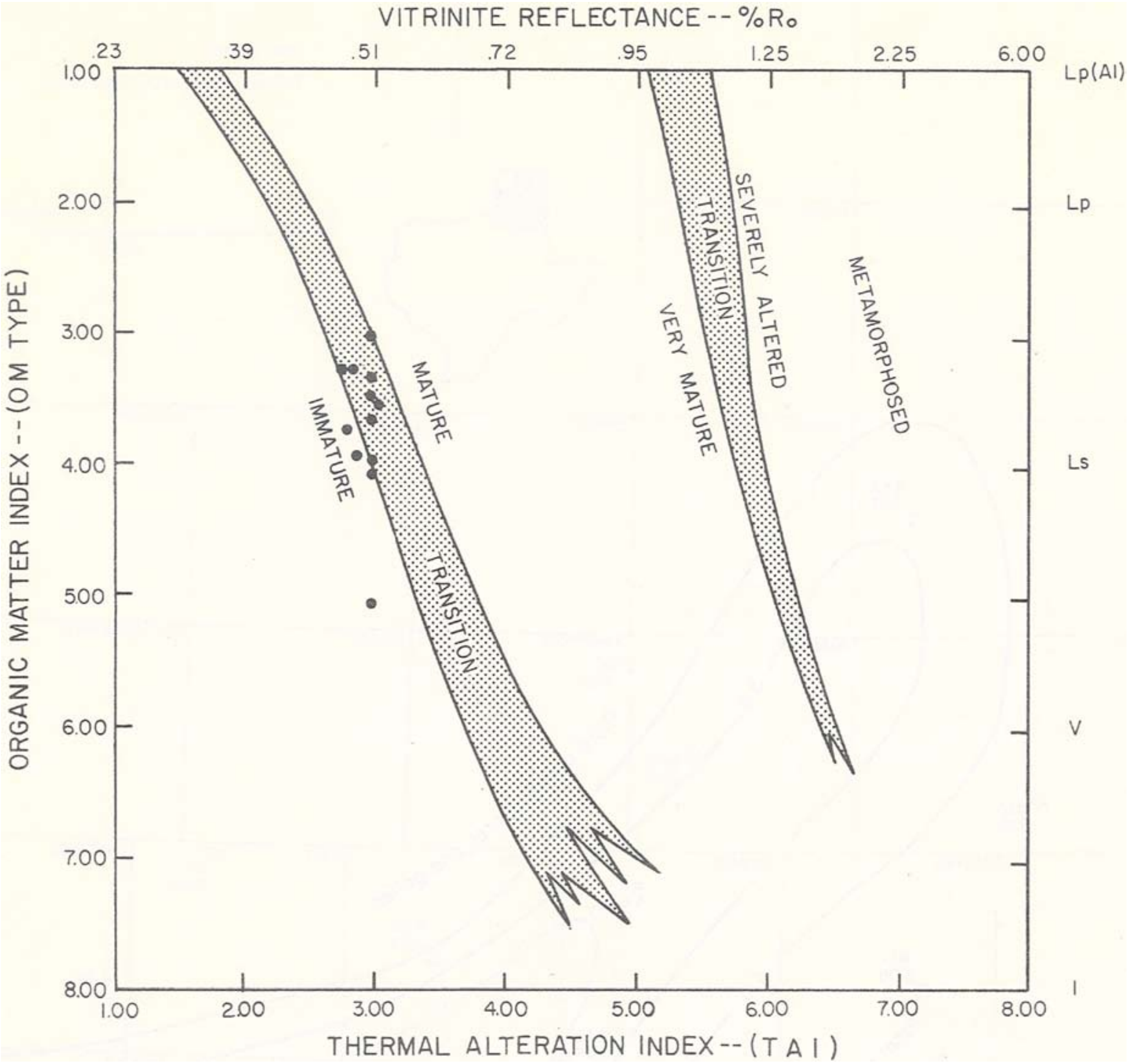

Figure 9. Wolfcampian source rock maturity based on kerogen type (OMI) and kerogen color (TAI) (from Schwab, 1977).

the organic material may have been oxidized at some time, perhaps since the well was drilled and the cuttings were recovered. This might affect vitrinite reflectance and give values of Ro that are too high (Schwab, 1979, personal communication). Ro values of vitrinite reflectance vary less in core samples than they do in cutting samples. This suggests that some of the variation may be the result of the grinding process to produce the cuttings (Ramondetta, 1980, personal communication).

Vitrinite reflectance values are plotted against organic matter type in the same way as is kerogen color (figs. 15 and 16). These plots show somewhat greater scatter than those made using TAI values, but most samples still fall within the transition zone.

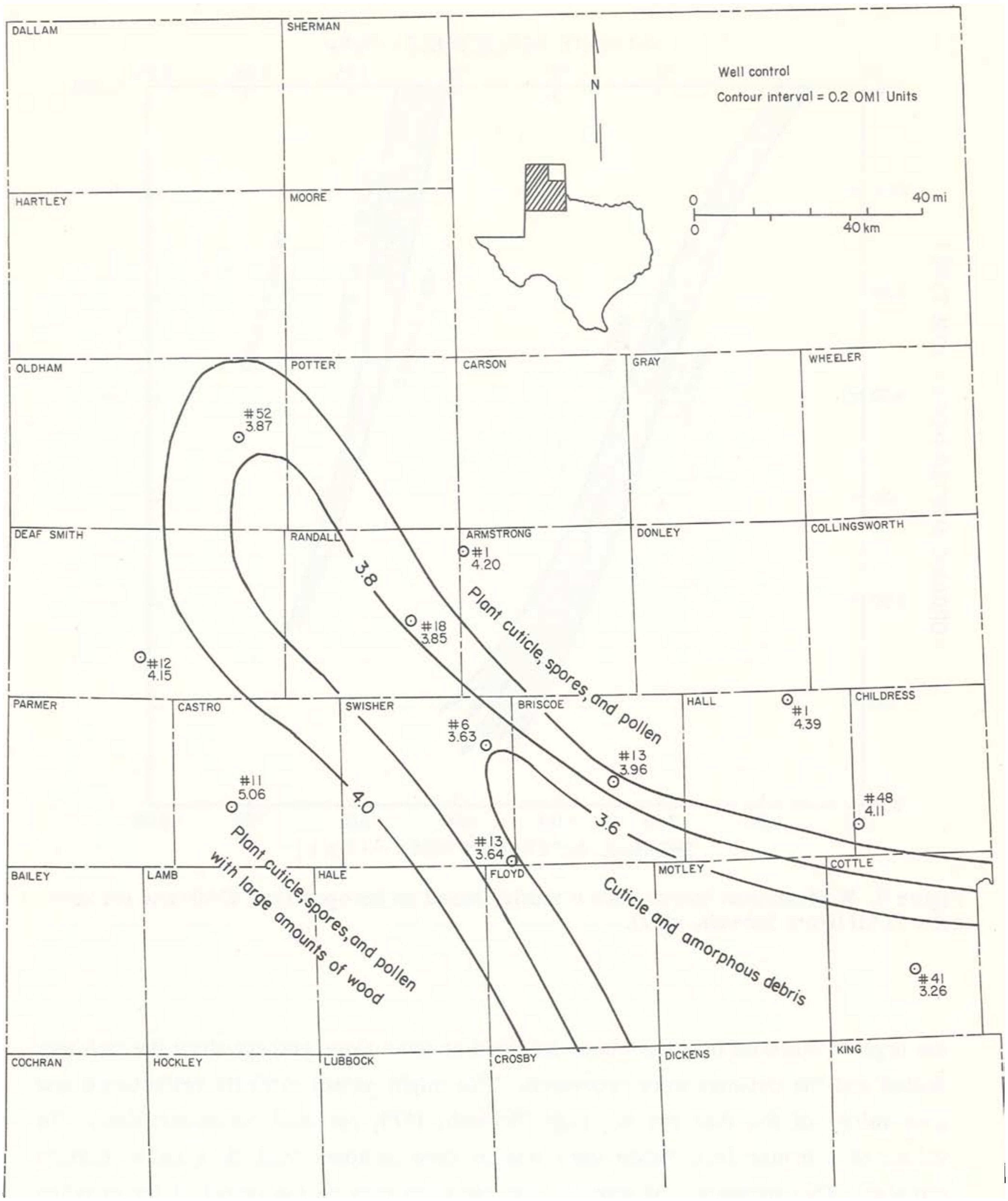

Figure 10. Geographic distribution of kerogen type (OMI) in Pennsylvanian strata.

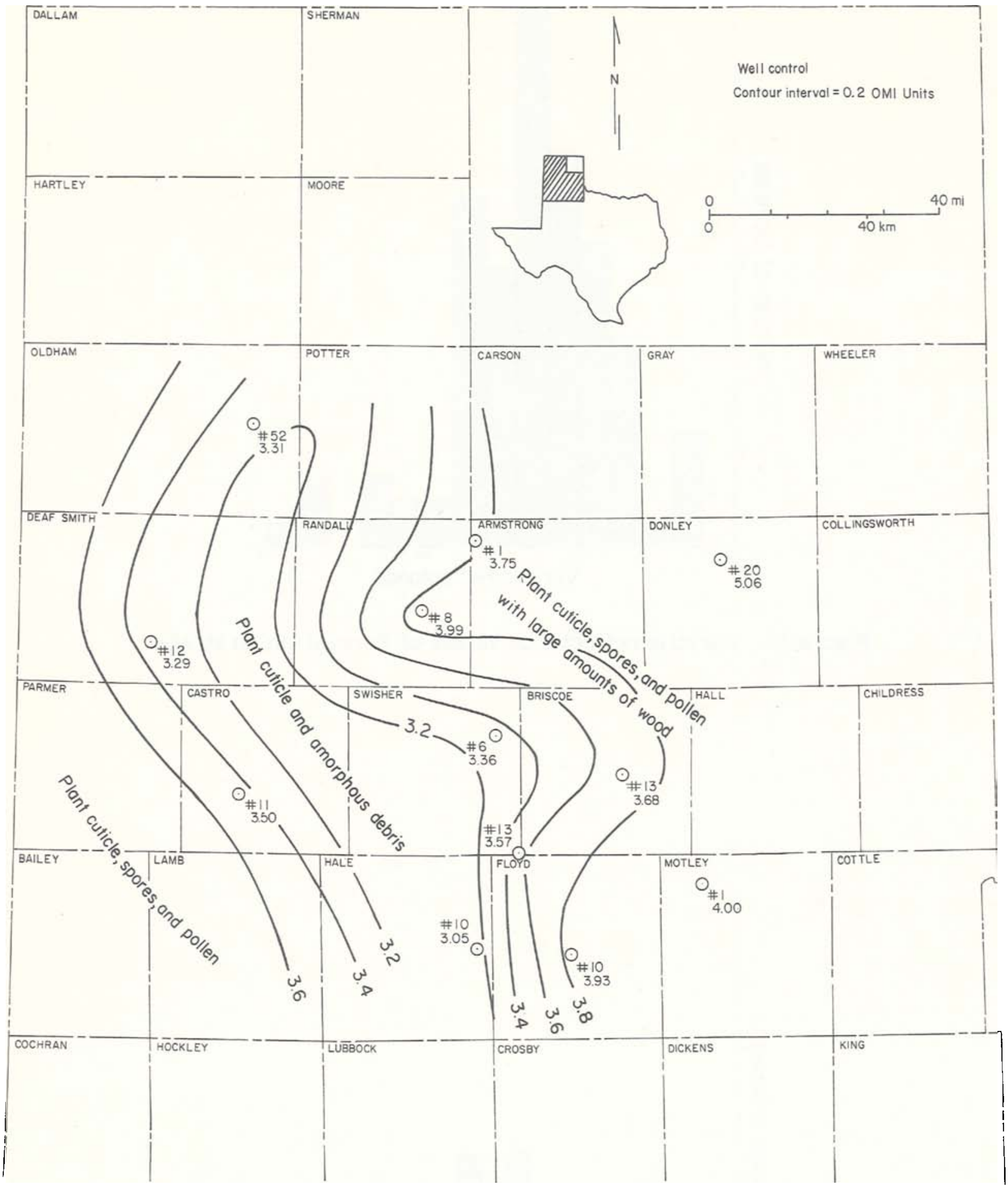

Figure 11. Geographic distribution of kerogen type (OMI) in Wolfcampian strata.

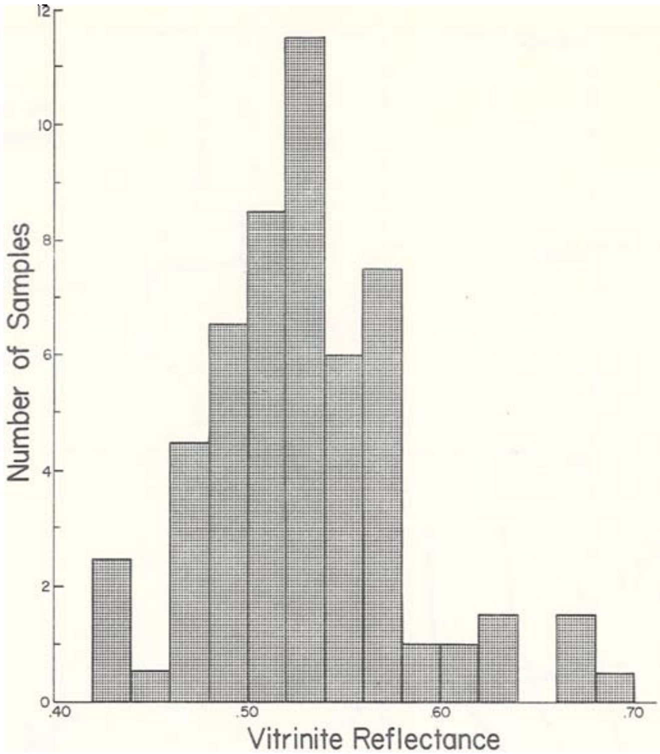

Figure 12. Vitrinite reflectance values of Pennsylvanian strata.

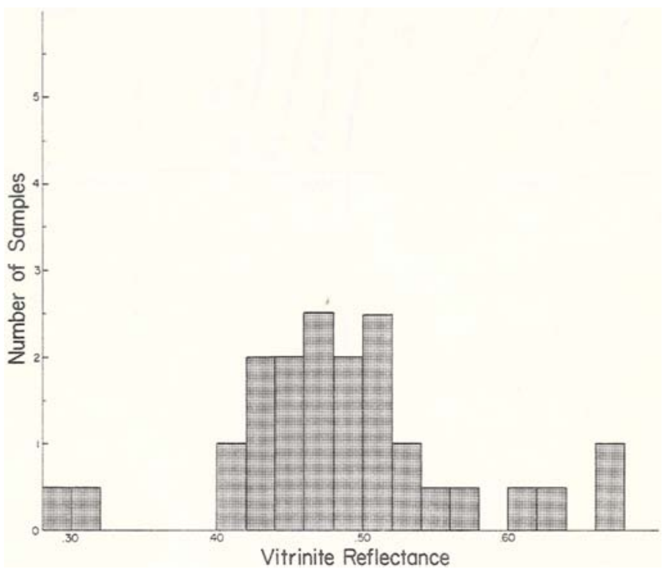

Figure 13. Vitrinite reflectance values of Wolfcampian strata.

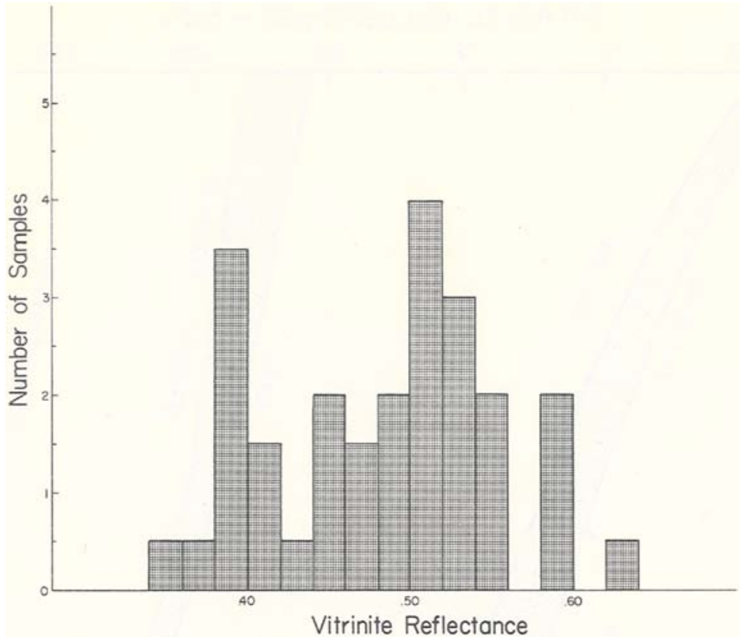

Figure 14. Vitrinite reflectance values of Middle and Upper Permian (Leonardian and Guadalupian) strata.

MIDLAND BASIN

General Statement

Geochemical analyses have been performed on samples from seven wells in northern and central Midland Basin (fig. 17) to compare source rock quality with that of the Palo Duro Basin. Samples from the four northern Midland Basin wells (fig. 17) were taken from cuttings of Permian, Pennsylvanian, Mississippian, and Ordovician strata. The three central Midland Basin wells were sampled from core within the oil-producing Spraberry Formation of Leonardian age. TOC content in the Midland Basin, a hydrocarbon-producing area, is generally greater than that in the Palo Duro Basin (figs. 17 and 18). TOC values as high as 4.4 percent are found in Midland Basin Pennsylvanian and Wolfcampian basinal shales, compared with 2.4 percent in the Palo Duro Basin. TOC values in Middle Permian strata are also generally higher in the Midland Basin. TOC content of shales interbedded with Spraberry sandstones suggests that they are good to excellent source rocks. Spraberry cores from three wells in the central Midland Basin have TOC values as high as 5.0 percent (see appendix). Average organic content in Spraberry shales ranges between 1.1 and 2.8 percent (fig. 17).

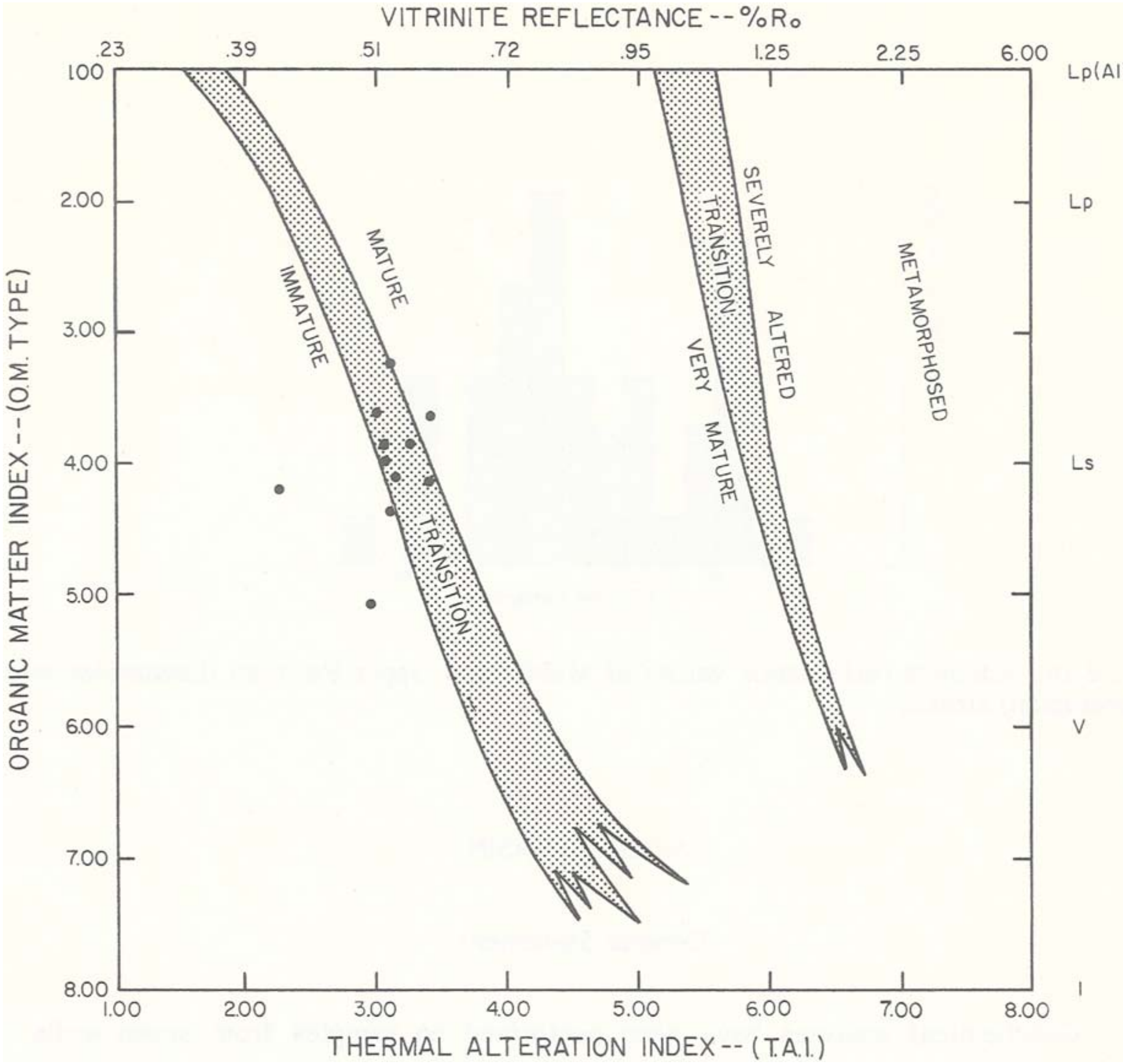

Figure 15. Pennsylvanian source rock maturity based on kerogen type (OMI) and vitrinite reflectance (% Ro) (from Schwab, 1977).

Thermal Maturity

Kerogen color and vitrinite reflectance were measured in cuttings and core samples containing approximately 0.5 percent or greater TOC. Vitrinite reflectance averages 0.63 percent in Pennsylvanian samples and 0.46 percent in Permian samples (see appendix). Pennsylvanian samples exhibit a broad range of vitrinite reflectance values, and an average value may not accurately reflect temperatures reached during burial. The highest Ro values may be from reworked sediments or oxidized cuttings. True temperatures reached in the basin are probably indicated by the vitrinite populations with lower Ro values.

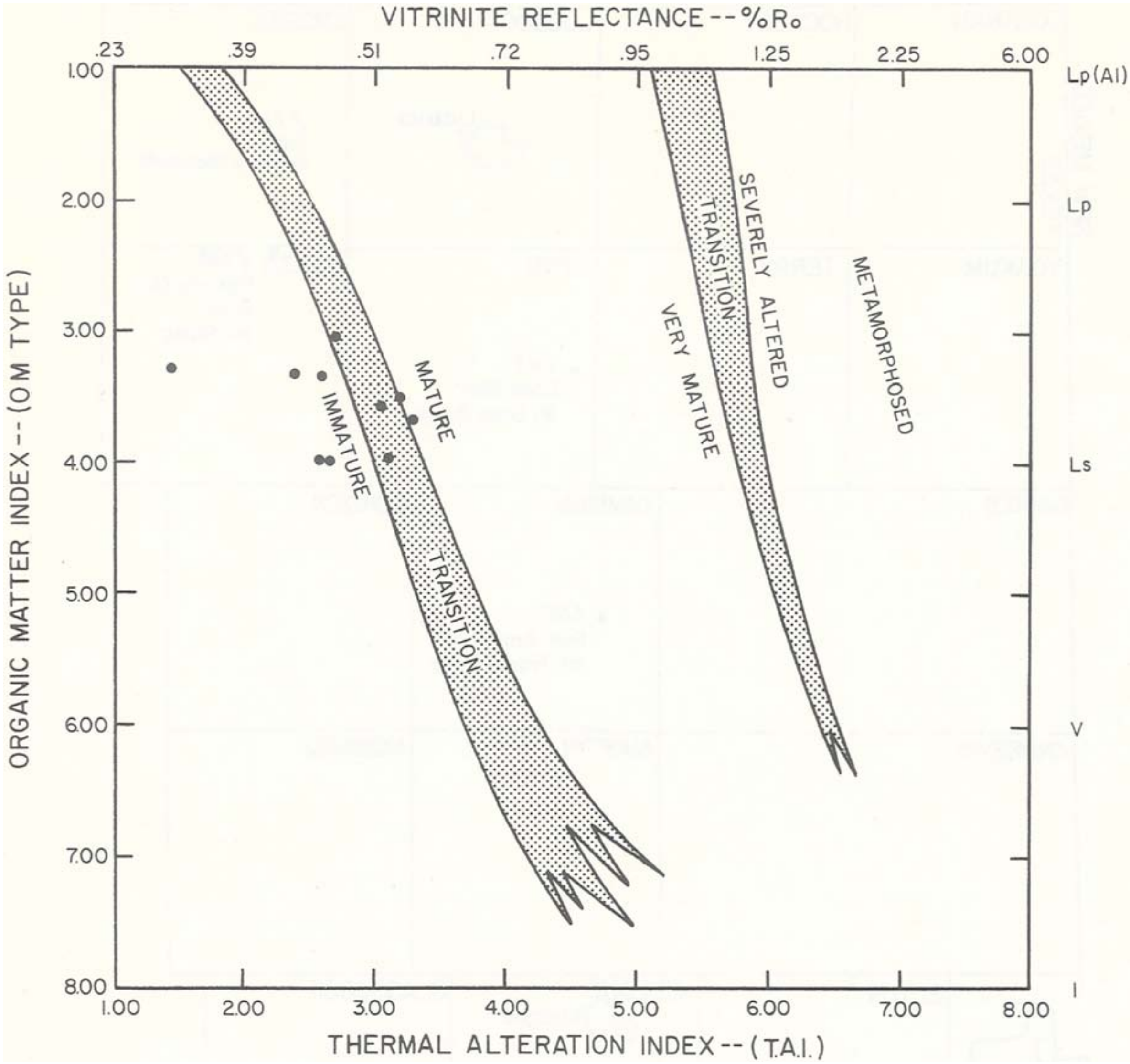

Figure 16. Wolfcampian source rock maturity based on kerogen type (OMI) and vitrinite reflectance (% Ro) (from Schwab, 1977).

Kerogen from the northern part of the Midland Basin is generally yellow. Pennsylvanian samples have an average thermal alteration index of 2.69, and Permian samples average 2.29 (see appendix). These TAI values are actually lower than values in the Palo Duro Basin, an indication that these potential source beds in the Midland Basin did not reach as high a temperature. The type of organic matter in the northern Midland Basin shale is similar in lipid content to that in the Palo Duro Basin. The average Pennsylvanian organic matter index is 3.64, and the Permian OMI average is 3.52. If the kerogen color (TAI) is plotted against kerogen type (OMI) (as in figs. 8 and 9), both Pennsylvanian and Permian samples fall in the immature zone.

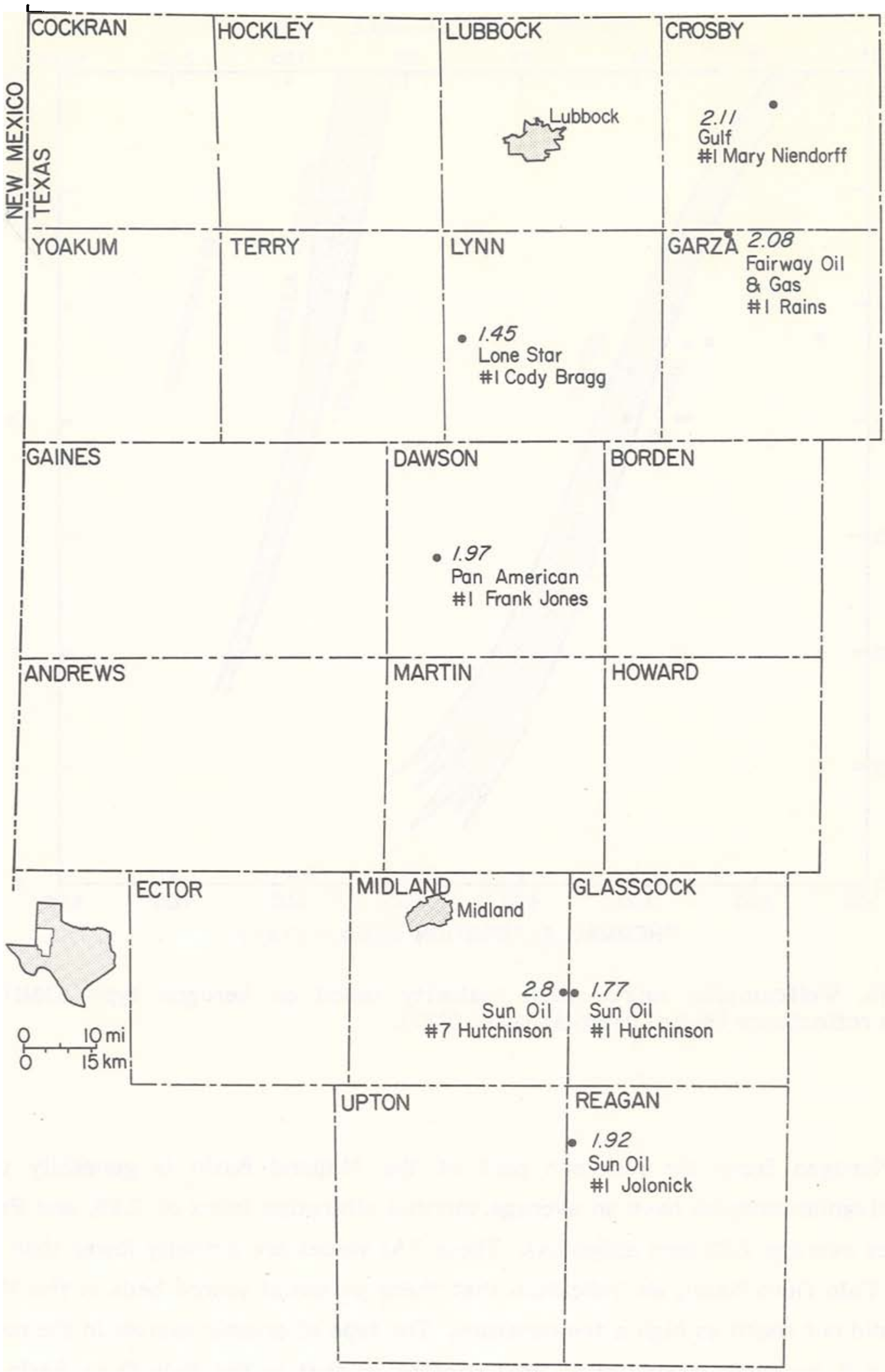

Figure 17. Average Permian total organic carbon (TOC) in Midland Basin wells. Spraberry samples only from Midland, Glasscock, and Reagan County wells.

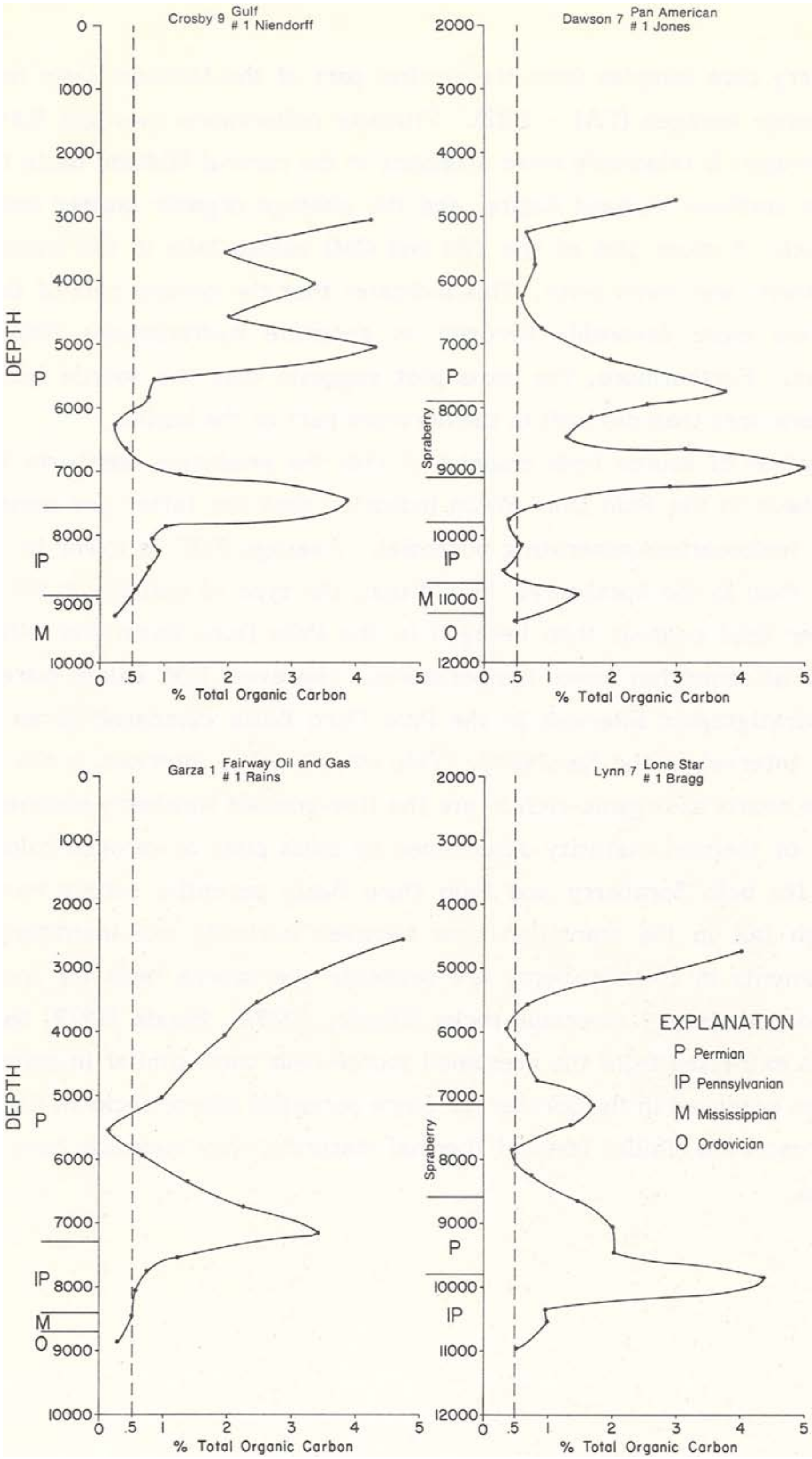

Figure 18. Plot of total organic carbon (TOC) with depth for wells in the northern Midland Basin.

Spraberry core samples from the central part of the Midland Basin have yellow to yellow-orange kerogen (TAI = 2.82). Vitrinite reflectance averages 0.44 percent. Lipid-rich kerogen is relatively more abundant in the central Midland Basin than in the Palo Duro or northern Midland Basins, and the average organic matter index is 3.28 (see appendix). A cross plot of the TAI and OMI values falls in the transition zone between maturity and immaturity. This indicates that the central part of the Midland Basin contains more favorable kerogen to generate hydrocarbons than does the northern part. Furthermore, the cross plot suggests that the source beds reached higher temperatures than did beds in the northern part of the basin.

Comparison of source beds associated with the producing Spraberry Formation and source beds in the Palo Duro Basin indicates that the latter are somewhat less favorable in hydrocarbon-generating potential. Average TOC is lower in Palo Duro Basin strata than in the Spraberry. In addition, the type of kerogen in the Spraberry has a greater lipid content than kerogen in the Palo Duro Basin and will generate hydrocarbons at somewhat lower temperatures. However, TOC values were averaged over large stratigraphic intervals in the Palo Duro Basin compared to an individual organic-rich interval in the Spraberry. Thin stratigraphic intervals in the Palo Duro Basin may be nearly as organic-rich as are the fine-grained Spraberry sediments.

Levels of thermal maturity determined by cross plots of kerogen color and type are similar for both Spraberry and Palo Duro Basin potential source rocks (figs. 8 and 9). Both fall in the transition zone between maturity and immaturity. Fine-grained sediments in the Spraberry are probably the source beds for hydrocarbons produced from Spraberry reservoir rocks (Houde, 1979). Houde (1979) showed that hydrocarbons extracted from the presumed source beds were similar in composition to the oil that is produced in the Spraberry. Since potential source rocks in the Palo Duro Basin have reached a similar level of thermal maturity, they may also have generated hydrocarbons.

CONCLUSIONS

Organic geochemistry of Palo Duro Basin source rocks indicates that the basin probably was not an area of major hydrocarbon generation. In some intervals, however, possible source rocks do exist. Source rock quality, assessed on total organic carbon content, is fair to good in some stratigraphic intervals. Lipid-rich kerogen occurs in deep-basin shale facies.

Paleotemperature data -- kerogen color and vitrinite reflectance -- indicate that temperatures in the basin have always been relatively cool. Temperatures up to 62°C (145°F) were reached in the source beds, an indication that only lipid-rich kerogen would have reached the early stages of hydrocarbon generation. However, in source beds where relatively high values of TOC coincide with abundant lipid-rich kerogen, hydrocarbons may have been generated. Basinal shales in the Pennsylvanian and Wolfcampian section are the most probable source rocks in the Palo Duro Basin.

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APPENDIX

GEOCHEMICAL DATA

Values given are for weight percent organic carbon (TOC), thermal alteration index (TAI), organic matter index (OMI), and average percent vitrinite reflectance (Ro). Wells are grouped from the Palo Duro Basin, northern Midland Basin, and central Midland Basin.

PALO DURO BASIN

Armstrong 1
Standard of Texas #1A Palm

Depth	TOC	TAI	OMI	Ro
3610-3610	0.154	-	-	-
4010-4090	0.084	-	-	-
4750-4820	0.462	-	-	-
5050-5120	0.518	-	-	-
5250-5340	1.014	2.80	3.75	-
5460-5540	0.512	3.00	4.20	-
5660-5740	0.246	-	-	-
5860-5940	0.336	-	-	-
6060-6120	0.350	-	-	-

Bailey 20
Shell #1 Nichols

Depth	TOC	TAI	OMI	Ro
5670-5790	0.116	-	-	-
5960-6040	0.064	-	-	-
6360-6440	0.062	-	-	-
6760-6840	0.010	-	-	-
7160-7240	0.208	-	-	-
7560-7640	0.104	-	-	-
8000-8030	0.076	-	-	-
8350-8430	0.082	-	-	-
8940-9020	0.022	-	-	-

Briscoe 13

Weaver #1 Adair

Depth	TOC	TAI	OMI	Ro
2970-3050	1.220	2.67	3.33	-
3380-3460	2.684	2.80	3.33	-
3800-3880	2.598	3.00	4.31	0.53
4300-4380	1.760	3.00	3.94	0.52
4710-4790	1.178	3.00	5.06	0.40
5280-5360	0.450	-	-	-
5560-5640	0.386	-	-	-
5760-5840	1.226	3.00	5.40	0.51
5960-6040	0.972	3.00	3.68	0.62
6160-6240	0.946	3.00	3.90	0.67
6630-6710	0.576	3.14	3.90	0.49
6950-7030	0.790	3.14	3.67	0.51
7360-7440	0.740	3.00	3.89	0.44
7610-7690	0.634	3.00	3.41	0.52
7810-7890	0.756	3.33	5.30	0.53
8010-8090	0.716	3.20	3.67	0.48
8310-8390	0.546	3.00	5.30	0.55
8810-8890	0.570	3.00	4.95	0.52

Castro 11

Sun #1 Herring

Depth	TOC	TAI	OMI	Ro
3960-4040	0.282	-	-	-
4360-4440	0.050	-	-	-
4760-4840	0.018	-	-	-
5210-5290	0.012	-	-	-
5560-5640	0.008	-	-	-
5990-6070	0.004	-	-	-
6460-6540	0.040	-	-	-
7260-7340	0.108	-	-	-
7460-7540	0.592	3.00	3.50	0.53
7860-7940	0.736	3.00	5.00	0.53
8060-8140	0.708	3.00	4.60	0.49

8310-8390	0.288	-	-	-
8510-8590	0.360	-	-	-
8710-8790	0.214	-	-	-
8860-8940	0.932	3.00	5.58	0.48

Childress 48

Griggs #1 Smith

Depth	TOC	TAI	OMI	Ro
4360-4440	0.726	3.00	3.47	0.48
4560-4640	1.396	3.00	4.00	0.54
4760-4840	0.636	2.80	3.50	0.56
4940-5020	0.734	3.00	4.63	0.60
5140-5220	0.384	-	-	-
5560-5640	0.276	-	-	-
5760-5840	0.190	-	-	-
5920-6000	0.626	2.80	4.22	0.51
6130-6220	0.206	-	-	-
6320-6410	0.492	-	-	-
6510-6600	0.604	3.00	4.70	0.54
6740-6830	0.630	3.00	3.76	0.57
6930-7020	0.622	3.00	5.00	0.55
7140-7230	1.374	3.00	3.73	0.52
7360-7450	0.350	-	-	-

Cottle 41

Baria & Werner #1 Mayes

Depth	TOC	TAI	OMI	Ro
1260-1340	1.616	2.80	3.94	0.55
1640-1720	0.994	4.50	3.23	0.59
2040-2120	2.422	4.50	3.76	0.45
2560-2640	0.312	-	-	-
3000-3090	0.094	-	-	-
3300-3390	0.018	-	-	-
3560-3640	0.024	-	-	-
4100-4190	0.080	-	-	-
4360-4440	0.242	-	-	-
4560-4640	0.106	-	-	-

4760-4840	0.254	-	-	-
4960-5040	0.148	-	-	-
5160-5240	0.528	3.00	3.70	0.51
5360-5440	0.598	3.00	3.67	0.47
5560-5640	0.744	3.14	3.50	0.54
5760-5840	0.906	3.20	3.00	0.51
5960-6040	0.452	-	-	-
6160-6240	0.546	3.00	3.00	0.57
6360-6440	0.324	-	-	-
6660-6740	0.442	-	-	-
6860-6940	0.634	3.00	3.00	0.53
7060-7140	0.568	4.50	3.00	0.54

Dallam 22

Harrington #1 Brown & Tovra

Depth	TOC	TAI	OMI	Ro
2560-2640	0.018	-	-	-
3360-3440	0.012	-	-	-
3710-3790	0.022	-	-	-
4120-4240	0.218	-	-	-
4610-4690	0.148	-	-	-
4960-5040	0.026	-	-	-
5360-5440	0.138	-	-	-
5660-5740	0.192	-	-	-
5860-5940	0.256	-	-	-

Deaf Smith 12

Honolulu #1 Ponder

Depth	TOC	TAI	OMI	Ro
4560-4640	1.596	2.80	3.47	0.64
4860-4940	1.606	2.80	4.33	0.55
5260-5340	1.270	2.80	3.29	0.30
5640-5720	0.018	-	-	-
6180-6260	0.054	-	-	-
6560-6640	0.062	-	-	-
6960-7040	0.026	-	-	-
7330-7410	0.018	-	-	-

7510-7590	0.262	-	-	-
7710-7790	0.186	-	-	-
7960-8040	0.042	-	-	-
8160-8240	0.342	-	-	-
8360-8440	0.182	-	-	-
8560-8640	0.600	3.00	3.80	0.56
8760-8840	0.236	-	-	-
9400-9480	0.562	3.00	4.50	0.58
9710-9790	0.864	3.00	3.47	-
9820-9900	0.090	-	-	-

Donley 20

Doswell #1 McMurty

Depth	TOC	TAI	OMI	Ro
1660-1750	1.136	2.80	4.53	-
2160-2240	2.048	3.00	4.38	0.59
2560-2640	1.402	3.00	4.12	0.46
2970-3050	1.326	3.00	5.06	-
3160-3240	1.876	3.00	5.06	-
3360-3440	0.448	-	-	-
3560-3640	0.018	-	-	-
3770-3850	0.092	-	-	-
4010-4090	0.022	-	-	-
4180-4260	0.024	-	-	-
4400-4480	0.018	-	-	-
4590-4670	0.008	-	-	-
5220-5300	0.092	-	-	-

Floyd 10

Sinclair #1 Massie

Depth	TOC	TAI	OMI	Ro
2160-2250	5.838	3.00	3.60	0.44
2610-2700	4.714	3.00	3.68	0.48
3080-3170	4.160	3.00	3.44	0.48
3530-3620	3.082	3.00	4.15	-
4070-4160	0.620	3.00	3.83	-

4460-4550	3.028	3.00	3.70	-
4870-4960	2.022	3.00	4.29	-
5260-5350	3.618	3.00	4.00	0.67
5680-5770	1.526	2.80	4.00	-
5860-5940	1.924	3.00	4.90	-
6060-6140	1.128	2.80	3.44	0.44
6260-6340	0.622	3.00	3.44	0.51
6460-6540	0.010	-	-	-
6690-6770	0.162	-	-	-
6860-6940	0.038	-	-	-
7060-7140	0.086	-	-	-
7260-7340	0.566	2.80	3.80	0.56
7480-7560	0.718	2.80	4.60	0.49
7710-7790	0.184	-	-	-
7910-7990	0.150	-	-	-
8110-8190	0.408	-	-	-
8310-8390	0.340	-	-	-
8510-8590	0.018	-	-	-
8960-9040	0.148	-	-	-
9160-9240	0.200	-	-	-
9360-9440	0.052	-	-	-
9760-9840	0.060	-	-	-
10,140-10,220	0.242	-	-	-

Hale 10

Amerada #1 Kurfees

Depth	TOC	TAI	OMI	Ro
2560-2640	3.156	2.80	3.47	-
2960-3040	2.876	2.80	3.47	-
3360-3440	1.712	2.80	3.47	-
3760-3840	1.075	2.80	3.47	0.51
4160-4240	1.476	3.00	3.47	0.39
4560-4640	0.508	3.00	3.65	-
4960-5040	0.404	-	-	-
5360-5440	1.252	3.00	3.65	0.39
5810-5890	0.162	-	-	-

6260-6340	0.141	-	-	-
6460-6540	0.044	-	-	-
6660-6740	0.120	-	-	-
6860-6940	0.082	-	-	-
7060-7140	0.064	-	-	-
7260-7340	0.636	3.05	3.00	0.49
7460-7540	0.348	-	-	-
7710-7790	0.044	-	-	-
7910-7990	0.322	-	-	-
8110-8190	0.024	-	-	-
8310-8390	0.010	-	-	-
8510-8590	0.100	-	-	-
8750-8830	0.148	-	-	-
8960-9040	0.158	-	-	-
9240-9320	0.280	-	-	-
9610-9690	0.232	-	-	-

Hall 1

Amarillo #1 Cochran

Depth	TOC	TAI	OMI	Ro
2360-2440	2.758	2.80	4.50	-
2780-2860	2.198	3.00	4.00	0.52
3190-3270	0.200	-	-	-
3660-3740	0.028	-	-	-
3870-3950	0.112	-	-	-
4050-4130	0.398	-	-	-
4270-4350	1.842	3.00	3.90	0.53
4610-4690	0.610	3.00	4.60	0.51
4770-4850	0.460	-	-	-
5010-5090	0.314	-	-	-
5150-5230	0.676	3.00	5.50	0.53
5390-5470	0.832	3.00	3.57	0.53
6430-6510	0.294	-	-	-

Hartley 25

Phillips #1A Cattle

Depth	TOC	TAI	OMI	Ro
4000-4090	0.042	-	-	-
4190-4280	0.050	-	-	-
4330-4420	0.074	-	-	-
4590-4680	0.018	-	-	-
4740-4830	0.134	-	-	-
4960-5050	0.134	-	-	-
5160-5250	0.032	-	-	-
5350-5440	1.240	3.00	3.23	0.53
5600-5690	0.204	-	-	-
5760-5850	0.162	-	-	-
5960-6050	0.098	-	-	-
6200-6290	0.228	-	-	-
6660-6750	0.138	-	-	-
6860-6950	0.264	-	-	-
7050-7140	0.142	-	-	-
7250-7340	0.062	-	-	-
7480-7570	0.188	-	-	-
7680-7770	0.018	-	-	-
7860-7940	0.022	-	-	-
8060-8140	0.034	-	-	-
8270-8350	0.054	-	-	-
8750-8830	0.124	-	-	-

Lamb 26

Stanolind #1 Hopping

Depth	TOC	TAI	OMI	Ro
3800-3880	0.540	2.80	4.08	-
4160-4240	0.084	-	-	-
4550-4630	0.362	-	-	-
4980-5060	3.098	2.80	4.62	-
5410-5490	0.340	-	-	-
5860-5940	0.448	-	-	-
6260-6340	0.042	-	-	-

6660-6740	0.032	-	-	-
7010-7090	0.010	-	-	-
7530-7610	0.018	-	-	-
7980-8060	0.292	-	-	-
8360-8440	0.234	-	-	-
8560-8640	0.176	-	-	-
8800-8880	0.202	-	-	-
9000-9080	0.344	-	-	-
9190-9270	0.080	-	-	-
9430-9510	0.120	-	-	-

Motley 1

Central #1 Ross

Depth	TOC	TAI	OMI	Ro
1340-1420	6.866	2.80	4.00	-
1660-1740	4.184	3.00	3.53	0.44
2070-2150	1.062	3.00	3.87	-
2500-2580	2.550	2.80	4.15	-
2860-2940	2.456	3.00	3.90	0.39
3260-3340	0.492	-	-	-
3780-3860	0.184	-	-	-
4410-4490	0.096	-	-	-
4740-4820	0.092	-	-	-
5110-5190	0.312	-	-	-
5560-5640	1.382	3.00	4.00	0.48
6060-6140	0.340	-	-	-
6260-6340	0.454	-	-	-
6460-6540	0.354	-	-	-
6860-6940	0.020	-	-	-
7070-7150	0.010	-	-	-
7280-7360	0.034	-	-	-
7460-7540	0.024	-	-	-
7660-7740	0.196	-	-	-
7860-7940	0.122	-	-	-
8070-8150	0.308	-	-	-

Oldham 52

Stanolind #1 Herring

Depth	TOC	TAI	OMI	Ro
3360-3450	0.020	-	-	-
3750-3840	0.010	-	-	-
4160-4250	0.112	-	-	-
4600-4690	0.182	-	-	-
5040-5120	0.448	-	-	-
5240-5330	0.614	2.80	3.29	0.42
5430-5520	0.508	2.80	3.29	0.46
5630-5720	0.782	2.80	3.29	0.46
5950-6040	0.952	3.00	3.38	0.42
6140-6230	1.622	3.00	3.50	0.53
6340-6430	2.132	2.80	3.38	0.44
6540-6630	1.092	3.00	3.50	0.47
6740-6830	1.266	3.00	3.53	0.48
6930-7020	0.852	3.00	4.80	0.68
7150-7240	0.586	3.14	4.50	0.50

Parmer 4

Stanolind #1 Jarrell

Depth	TOC	TAI	OMI	Ro
3250-3340	0.986	3.00	4.00	-
3710-3800	0.618	3.00	4.22	-
4050-4140	0.482	-	-	-
4450-4540	0.780	3.20	4.44	-
4850-4940	1.758	3.00	3.87	-
5110-5200	2.326	3.00	3.87	-
5700-5790	0.078	-	-	-
6050-6140	0.040	-	-	-
6490-6580	0.080	-	-	-
6700-6790	0.106	-	-	-
6950-7040	0.038	-	-	-
7150-7240	0.124	-	-	-
7380-7470	0.236	-	-	-
7800-7890	0.286	-	-	-
8050-8140	0.396	-	-	-

Randall 18

Slessman #1 Nance

Depth	TOC	TAI	OMI	Ro
1820-1910	0.034	-	-	-
2260-2350	0.032	-	-	-
2660-2750	0.290	-	-	-
3160-3250	0.148	-	-	-
3570-3660	1.262	2.80	4.67	-
3950-4040	2.020	2.80	4.67	-
4440-4530	0.758	3.00	3.87	-
4960-5050	0.186	-	-	-
5140-5230	0.208	-	-	-
5570-5660	0.488	-	-	-
6160-6250	0.386	-	-	-
6360-6450	0.634	3.00	4.10	0.47
6560-6650	0.510	3.00	3.80	0.56
6760-6850	0.460	-	-	-
6960-7050	0.442	-	-	-
7170-7260	0.974	3.00	4.08	0.56
7360-7450	0.630	3.00	3.67	0.57

Swisher 6

Standard #1 Johnson

Depth	TOC	TAI	OMI	Ro
4460-4540	0.782	3.00	5.00	-
4820-4910	0.292	-	-	-
5260-5340	0.098	-	-	-
5660-5740	0.462	-	-	-
6010-6090	1.028	3.00	3.33	0.44
6260-6340	1.122	3.00	3.38	0.50
6460-6540	1.584	3.00	3.87	0.51
6660-6740	1.364	2.80	3.33	0.52
6860-6940	1.642	3.00	3.87	0.56
7060-7140	0.712	3.00	3.53	0.53
7260-7340	0.492	-	-	-
7460-7540	0.188	-	-	-

7660-7740	0.324	-	-	-
7860-7940	0.456	-	-	-
8060-8140	0.356	-	-	-
8320-8400	0.900	3.00	3.56	0.46
8530-8610	0.320	-	-	-
8880-8960	0.226	-	-	-

Swisher 13

Sinclair #1 Savage

Depth	TOC	TAI	OMI	Ro
4340-4420	0.968	2.67	3.65	0.45
4820-4900	1.736	2.67	3.29	0.49
5150-5230	1.316	2.80	3.38	-
5580-5660	0.240	-	-	-
5960-6060	0.474	-	-	-
6160-6240	0.146	-	-	-
6360-6440	0.558	3.20	4.38	0.50
6560-6640	1.058	3.00	3.41	0.52
6760-6840	1.870	3.00	3.41	0.49
6960-7040	1.340	3.00	3.33	0.50
7160-7240	2.384	3.00	3.33	0.59
7360-7440	0.690	3.20	3.90	0.59
7560-7640	0.602	3.00	3.53	0.62
7760-7840	0.598	3.00	3.79	0.49
7960-8040	0.528	3.00	3.33	-
8160-8240	1.028	3.00	3.56	0.53
8460-8540	0.416	-	-	-
8760-8840	0.696	3.00	3.90	0.63
8960-9040	0.634	3.20	3.50	-
9170-9250	0.232	-	-	-
9900-9980	0.174	-	-	-

NORTHERN MIDLAND BASIN

Samples marked with (?) exhibit a broad range of vitrinite reflectance values. The average value may not accurately reflect temperatures reached during burial.

Crosby 9

Gulf #1 Niendorff

Depth	TOC	TAI	OMI	Ro
3010-3090	4.230	2.00	3.44	0.40
3510-3550	1.976	2.00	3.82	0.37
4010-4090	3.318	2.20	4.00	0.38
4510-4590	2.056	2.33	4.62	0.35
5010-5090	4.304	2.33	4.53	0.44
5510-5590	0.856	2.20	3.29	0.44
5810-5890	0.766	2.20	3.65	0.37
6210-6290	0.224	2.50	3.53	0.36
6610-6690	0.414	2.50	3.80	0.48
7010-7090	1.238	2.57	3.56	0.41
7410-7490	3.864	2.67	4.10	0.53
7810-7890	1.058	2.67	3.65	0.54
8010-8090	0.804	2.67	4.22	0.72(?)
8210-8290	0.930	2.67	3.67	0.73(?)
8460-8540	0.750	2.67	3.65	0.70(?)
8810-8890	0.560	2.67	3.89	0.71(?)
9210-9290	0.240	2.67	3.75	0.61

Dawson 7

Pan American #1 Frank Jones

Depth	TOC	TAI	OMI	Ro
4710-4790	3.046	2.00	3.13	0.43
5210-5290	0.682	2.00	3.23	0.43
5710-5790	0.810	2.20	3.33	0.44
6210-6290	0.608	2.20	3.29	0.46
6710-6790	0.900	2.20	3.23	0.42
7210-7290	1.986	2.20	3.23	0.40
7710-7790	3.760	2.33	3.29	0.44
7910-7990	2.558	2.43	3.33	0.45
8110-8190	1.678	2.50	3.23	0.48

8410-8490	1.288	2.50	3.23	0.43
8610-8690	3.136	2.50	3.23	0.49
8910-8990	4.984	2.50	3.23	0.55
9210-9290	2.928	2.50	3.23	0.71(?)
9510-9590	0.808	2.57	4.00	0.76(?)
9710-9790	0.396	2.57	4.27	0.62
10,110-10,190	0.556	2.57	3.76	0.65
10,510-10,590	0.312	2.80	3.58	0.53
10,910-10,990	1.464	3.00	3.70	0.60
11,310-11,390	0.480	2.80	4.17	0.68

Garza 1

Fairway #1 Rains

Depth	TOC	TAI	OMI	Ro
2510-2590	4.748	2.00	3.44	0.71(?)
3010-3090	3.392	2.20	3.33	0.58(?)
3510-3590	2.470	2.00	3.28	0.72(?)
4010-4090	1.980	2.00	3.41	0.41
4510-4590	1.414	2.00	3.23	0.53(?)
5010-5090	0.992	2.20	3.23	0.37
5510-5590	0.146	2.20	3.29	0.35
5910-5990	0.690	2.20	3.63	0.41
6310-6390	1.338	2.20	3.60	0.38
6710-6790	2.256	2.33	3.23	0.42
7110-7190	3.428	2.67	3.23	0.56
7490-7570	1.210	2.67	3.50	0.63
7810-7890	0.740	2.67	3.29	0.74(?)
8010-8090	0.580	2.67	3.74	0.62
8410-8490	0.518	2.67	4.00	0.53
8810-8890	0.314	2.67	4.85	0.54

Lynn #7

Lone Star #1 Cody Bragg

Depth	TOC	TAI	OMI	Ro
4700-4780	4.084	2.00	4.27	0.36
5110-5190	2.490	2.00	3.38	0.38
5530-5610	0.686	2.00	3.29	0.43
5910-5990	0.336	2.20	3.29	0.44
6310-6390	0.666	2.20	3.29	0.42
6730-6810	0.828	2.33	3.23	0.40
7110-7190	1.696	2.33	3.38	0.41
7410-7490	1.356	2.33	3.68	0.48
7810-7890	0.464	2.33	3.65	0.42
8210-8290	0.754	2.57	3.88	0.42
8610-8690	1.458	2.57	3.23	0.42
9010-9090	2.004	2.57	3.60	0.47
9410-9490	2.080	2.67	3.23	0.66
9810-9890	4.368	2.67	3.23	0.60
10,310-10,390	0.964	2.67	3.65	0.58
10,510-10,590	0.908	2.80	3.81	0.62
10,910-10,990	0.518	2.80	3.47	0.59

CENTRAL MIDLAND BASIN

Glasscock Co.

Sun #1 Hutchinson

Depth	TOC	TAI	OMI	Ro
6883	1.772	2.86	3.23	0.43
6903	2.232	2.86	3.29	0.46
6918	1.840	2.86	3.23	0.48
6924	2.086	2.86	3.23	0.48
6926	1.410	2.86	3.23	0.43
6939	1.060	2.86	3.47	0.46
6984	1.976	2.86	3.23	0.49

Midland Co.

Sun #7 Hutchinson

Depth	TOC	TAI	OMI	Ro
7209	3.312	2.80	3.23	0.41
7213	2.768	2.80	3.23	0.40
7435	2.556	2.80	3.23	0.43
7465	3.296	2.80	3.29	0.44
7487	3.668	2.80	3.29	0.43
7522	2.216	2.80	3.29	0.46
7593	3.208	2.80	3.23	0.46
7758	2.648	2.80	3.23	0.46
7787	2.724	2.80	3.33	0.46
7863	1.616	2.80	3.23	0.48

Reagan Co.

Sun #1 Jolonick

Depth	TOC	TAI	OMI	Ro
6793	1.842	2.80	3.23	0.41
6876	0.888	2.80	3.23	0.42
6884	2.500	2.80	3.29	0.42
6920	2.772	2.80	3.29	0.42
6964	1.176	2.80	3.23	0.42
7720	1.694	2.80	3.33	0.42
7756	2.588	2.80	3.47	0.43