POTENTIAL SOURCE ROCKS IN THE WESTERN KANSAS PETROLEUM PROVINCE

by

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Abstract

The source of the hydrocarbons in western Kansas has been an ongoing debate for many years. The highly organic-rich Anadarko basin, directly south of western Kansas, has been a very prolific producer for many years. This basin is the most widely accepted source of the oil in Kansas, as it is very deep and thermally mature. The main source rock in this area is the Woodford Shale, a very thick, very organic-rich unit which has been proven to produce many hydrocarbons. Several studies have been done on the oils that are presently in Kansas, suggesting that they can be traced back to the source of the Woodford Shale. The hydrocarbons in the Anadarko basin would have traveled several hundred miles, which would require that the migration mechanism be unusually efficient. An alternate explanation could be that one of the many organic black shales in western Kansas may have sourced this oil.

This study examines formations of Cambrian to Permian ages which include organic shales interbedded with several known producing formations. Shales of these ages in other areas have produced thermally mature hydrocarbons, which indicate relatively high temperatures and pressures. Several models suggest that thermal maturity may be reached even with lower temperatures if burial times are longer. The shales in western Kansas were deposited in marine seas, and upon TOC testing, proved to be very organic-rich. Two sets of data were analyzed in this study, with the first from northwestern Kansas, and the second from southwestern Kansas. These two sets were analyzed for TOC, whole-rock analysis, and vitrinite reflectance. The shales analyzed from the first set proved to be thermally immature. Had they been subjected to higher temperatures, then they would have made excellent source rocks. The second set of shales analyzed also proved to be thermally immature with the exception of a few deeper shales,

which are closer to being mature source rocks. These shales may have contributed to some of the hydrocarbons currently within Kansas.

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CHAPTER 1 - INTRODUCTION

The western Kansas petroleum province has been a prolific producer for almost a century. Overall Kansas ranks eighth in the nation for oil producing states. Records have been kept since 1930, and in that time Kansas has produced 4.3 trillion barrels of oil. This is a significant amount of oil. There are multiple producing formations, from Cambro-Ordovician rocks through the Permian. The Hugoton field of southwest Kansas is one of the largest gas-producing regions from relatively shallow Permian-aged Chase Group rocks. Kansas has also produced a large amount of gas, since 1930 it has produced 31,468,596,708 mcf. A map of all of the oil and gas fields in Kansas can be seen in Figure 1. The red areas indicate gas fields, green areas indicate oil fields, and orange indicates oil and gas fields.
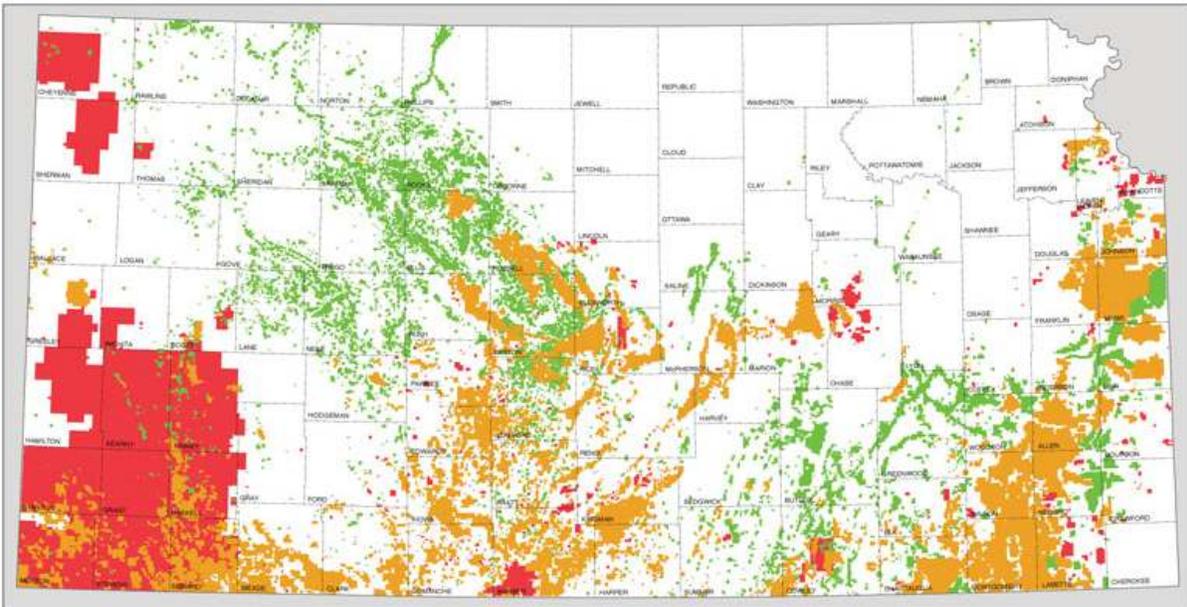
Figure. 1 Map showing Kansas oil and gas fields.
(Modified from KGS, 2009)

There are two hypotheses regarding the generation of the petroleum deposits in western Kansas. The first hypothesis suggests that the petroleum was generated in the deeper portions of

the Anadarko basin in Oklahoma, and migrated northward into Kansas reservoirs. The second hypothesis suggests that the petroleum was generated from nearby source rocks with limited migration into local reservoirs. Both of these hypotheses have distinct advantages and disadvantages in explaining the distribution of Kansas petroleum deposits.

In the first hypothesis the deeper Anadarko basin has abundant organic-rich source rocks that have undergone considerable thermal maturation, in some cases through the gas window. These source rocks are proven petroleum generators, as evidenced by the considerable reserves within the Oklahoma portions of the Anadarko basin. Migration over considerable distance (greater than 300 miles) is required for these sources to charge Kansas reservoirs. Potential oil migration pathways can be seen in Figure 2. In addition, multiple sources are required to explain the vastly different character of petroleum reserves from different aged reservoirs. It is not easy to explain why this long-distance migration results in the observed distribution of oils in specific aged reservoirs, regardless of reservoir depth.
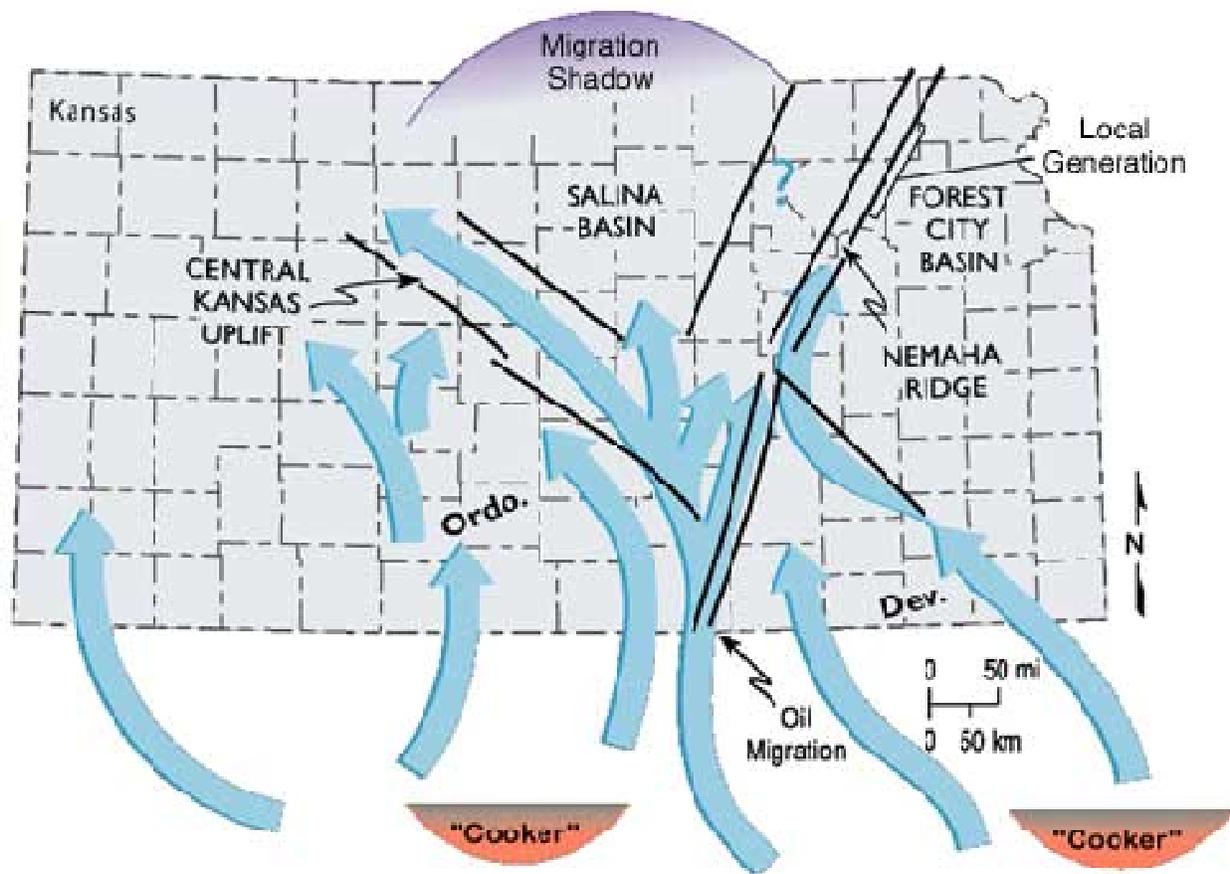
**Figure 2. Map showing potential oil migration from the Anadarko basin.
(Modified from Gerhard, 2004.)**

In the second hypothesis there are potential source rocks within the Kansas region which might have generated the petroleum, but they are not adequately studied. Long-distance migration is not necessary in this model, and variation between the different-aged deposits may be explained by different source rocks. The shallower depths in Kansas, however, limit the thermal maturation potential. Additional catalysts to petroleum generation are probably required in this model.

1.1 Significance

The significance of this study has a considerable impact on western Kansas. Kansas is a major petroleum producer with oil being produced from several different rock formations. The oil is currently thought to have been generated in the Anadarko basin, with long distance migration into the current reservoirs; or was generated from nearby source rocks with limited migration into nearby reservoirs. Knowing which hypothesis better explains where the oil was sourced will contribute to a better understanding of where to look for additional deposits. This study may be applicable to other areas where the geology is similar to western Kansas.

1.2 Literature Review

The formation of petroleum has several aspects that have to occur in specific order for oil or gas deposits to form. This includes time, temperature, carbohydrates from once living things, and the correct geologic setting. Petroleum generation is based on the accumulation of organic matter from living material, and on the generation of hydrocarbons by the action of heat on accumulated organic matter (Hunt, 1979).

Oil has formed in many different types of sedimentary rocks all over the world. This has resulted from thermal generation of hydrocarbons from the organic matter within the sedimentary rocks. Migration processes have not significantly altered this distribution since more than 80 percent of the hydrocarbons in most fine-grained sediments are autochthonous (Hunt, 1979).

Temperature is the most studied aspect in the formation of petroleum. It plays the key role in the transformation of organic matter to hydrocarbon. Generally in sedimentary basins, oil formation is at relatively low temperatures of between 150 degrees F and to 300 degrees F (Hunt,

1979). These temperatures are not thought to have been reached for the oil province in western Kansas, due to the shallower burial depths.

Time is also a major factor in the generation of oil. The range of in this study is the Paleozoic Era, which is the age of the oil-bearing rocks in western Kansas. This range is 570 up to 240 million years ago. Western Kansas is an old basin compared to many oil producing basins, such as the Gulf of Mexico. Most formations are thought to have been at current burial depths since early in the Mesozoic, which is several hundred million years ago (Merriam, 1963).

A key paradigm to my research is that the correct time and temperature combination can prove to be very effective in the formation of oil. High temperatures over a short time have been proven to produce oil, however an equivalent degree of oil generation should be realized at lower temperatures over a longer period of time. The latter conditions could have been realized western Kansas. According to Sweeney and Burnham (1990) 100 degrees C for 100 million years can reach a vitrinite reflectance of 0.7, which is adequate to begin oil generation. Vitrinite reflectance has been successfully demonstrated as a reliable indicator of organic maturation in sedimentary rocks and is widely used in the oil industry for the evaluation of kerogens according to Senftle and Landis (1991).

1.3 Geologic Setting

The study area is located in midwest, and southwest Kansas. Part of the samples analyzed are on the Central Kansas Uplift, with the rest of the samples situated in the Hugoton embayment (Figure 3).

The Central Kansas Uplift is a large structural feature (5,700 square miles) that runs through the center of the state. The uplift is northwest-trending, and separates the Hugoton embayment to the west, and the Salina basin to the east. The sedimentary rocks that lie on top of

the structure are less than 5,000 feet thick in places (Merriam, 1963). The outline of the uplift is surrounded by the Mississippian beds which have been eroded away on the uplift.

The surface of the Central Kansas Uplift is covered by Cretaceous, Tertiary, and Quaternary age formations. The uplift occurred during the end of the Mesozoic. Within the uplift, there is a large unconformity, and the Precambrian rocks are overlain by Pennsylvanian sediments.

The Hugoton embayment is a major structural unit, occupying one-third of Kansas. It covers almost 28,600 square miles, and is situated in far western Kansas. The eastern boundary of the embayment is stopped by the Cambridge arch, the Central Kansas Uplift, and the Pratt Anticline. The western edge extends into eastern Colorado, and stops at the Las Animas Arch. The southern extent thickens to the south and feeds into the Anadarko basin.

The Hugoton embayment is a large shelflike extension into western Kansas from Oklahoma's Anadarko basin (Merriam, 1963). The south plunging structure, which is full of sediments, thickens toward the south and the center of the embayment stretching into the much larger Anadarko basin. This is the deepest structural basin in Kansas, exceeding 9,500 feet thick. This thick sediment overlies Precambrian rocks.

The embayment was formed before the Mesozoic Era. The Paleozoic beds are covered by Cretaceous, Tertiary, and Pleistocene age rocks (Merriam, 1963). The large thick structure includes rocks from the Cambrian-Ordovician, Mississippian, Pennsylvanian-Permian, Triassic, Jurassic, Cretaceous, Tertiary, and Pleistocene age.

1.4 Study Area

This study area looks at several organic-rich black shales in four different counties (Ness, Ellis, Comanche, and Meade) in western Kansas which might have served as source rocks for petroleum generation (Figure 3). There are many wells that have been drilled in this area beginning in the 1930's to the present day. The basis for choosing the wells to analyze relied on several different parameters. Each well had a suite of well logs (resistivity, neutron density, and geologists reports), and each well had to have rock cuttings that were available.
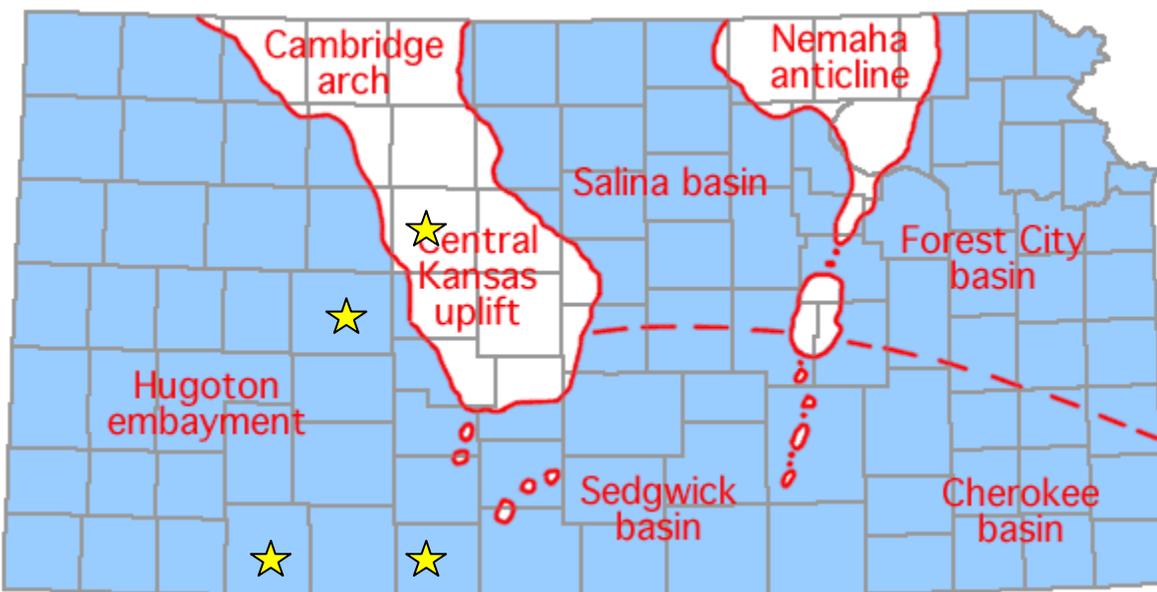
Figure 3. Study area in western Kansas, denoted by yellow stars.
(Modified from Gerhard, 2004)

Many cores have been taken and studied in western Kansas. Unfortunately the cores that were taken have not been through the rock formations that were potential source beds. As a result geophysical logs and well cuttings were employed for this study, both of which are open to the public and easily accessible. A total of nine wells were sampled for geochemical analyses (Table 1).

1.5 Stratigraphy of Study Area

Stratigraphy can be described as the study of rock layers with emphasis on their origin, formation, and depositional environments. Throughout this study many different shales from many different ages, within western Kansas, have been analyzed. The ages range from late Pennsylvanian to early Ordovician. Shales from within the formations that have been sampled include the Lansing-Kansas City (LKC), Stark, Swope, Labette, Ft. Scott, Cherokee, Morrow, and Arbuckle.

The Lansing-Kansas City group is part of the Missourian Stage of the upper Pennsylvanian series. The Lansing-Kansas City Groups in Kansas are composed of interbedded carbonates and shales with occasional minor coals and sandstones (Watney, 1980). Within this group there is a variety of depositional environments. They range from phylloid algal-bearing, lime-mud banks to oolite shoals (Watney, 1980). The total thickness of the LKC can range from 370 to 600 feet thick (Merriam, 1963). The LKC has a wide range in western Kansas, extending from southwest Nebraska down to the Anadarko basin in Oklahoma. In general the LKC thickens towards the south. The shales that are interbedded within the limestones range in color from gray, to black with the black shales being the most organic-rich.

The LKC is a large producing formation in Kansas, producing from as many as seven or eight different limestone members. The Stark and Swope black organic shales are also part of the LKC Group. The Stark shale member is part of the Dennis Limestone Formation (Figure 4). It is described as relatively thin (five to fifteen feet thick), fissile, black, and organic-rich. The Swope shale is part of the Swope Limestone Formation (Figure 5). It is also described as relatively thin (five to fifteen feet thick), fissile, black, and organic-rich. While both of these shales can be described the same, they vary in organic richness from area to area.
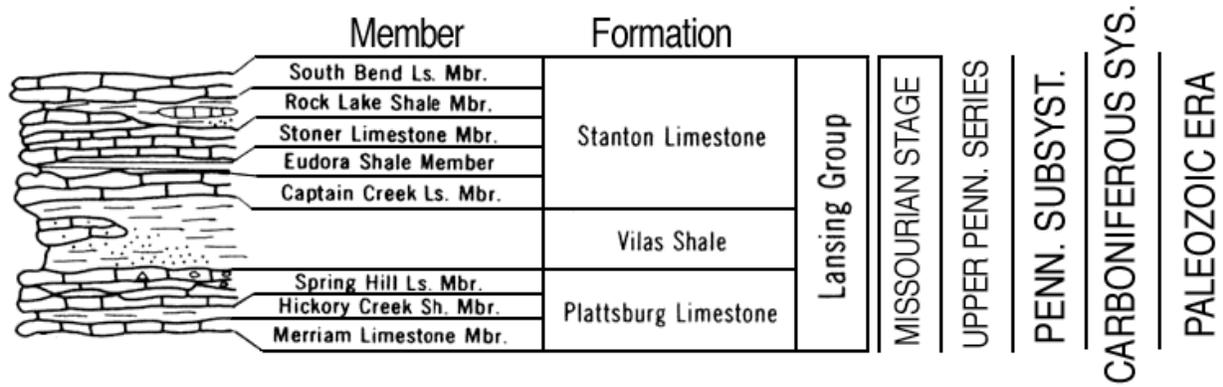
**Figure 4. Stratigraphic column of the Lansing Group.
(Zeller, 1968)**
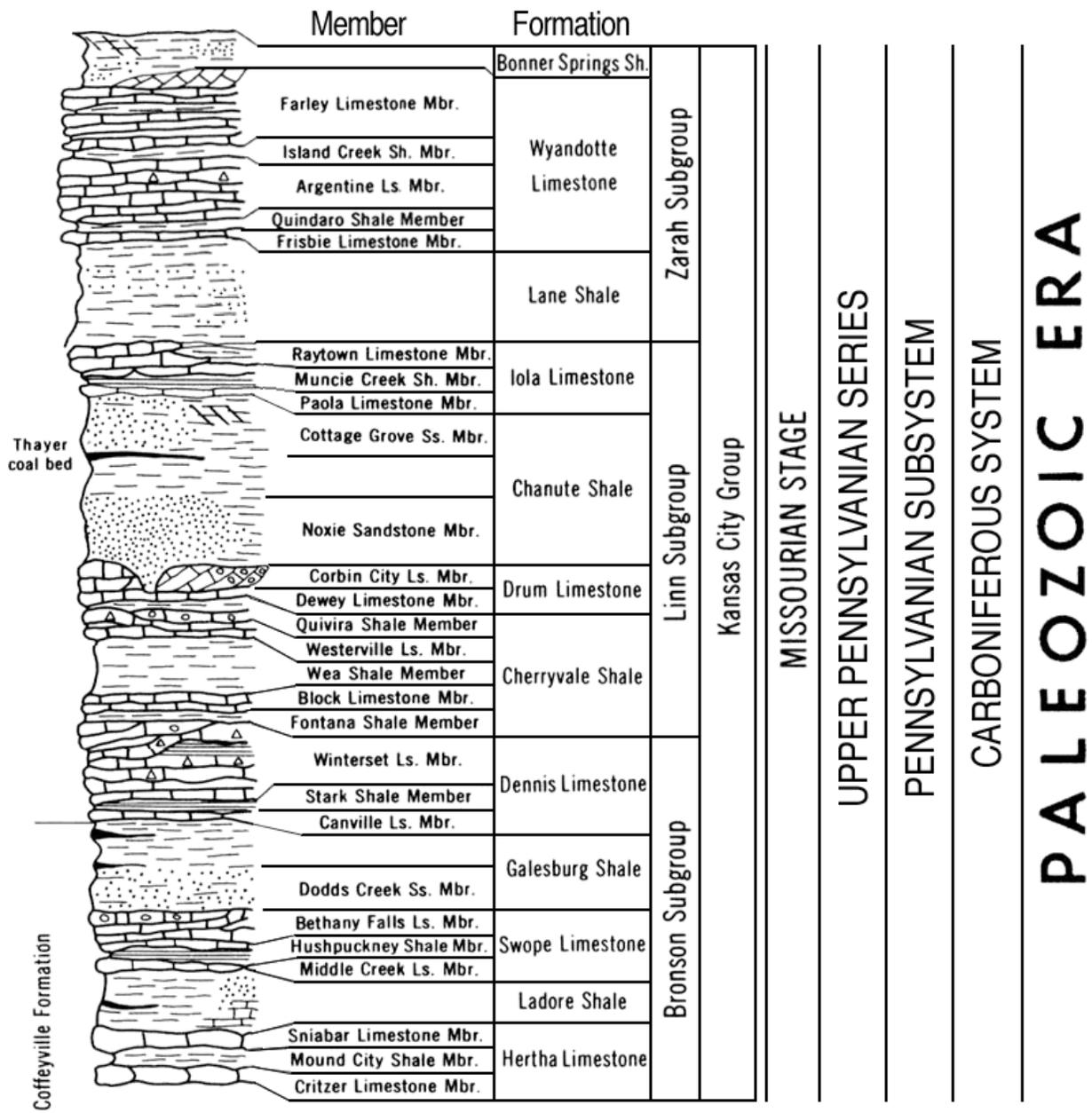
Figure 5. Stratigraphic column of the Kansas City Group.
(Zeller, 1968)

The Labette Shale Formation is part of the Marmaton Group (Figure 6). It is Middle

Pennsylvanian in age. The Marmaton Group underlies the Pleasonton Group unconformably.

The Marmaton Group is interbedded with carbonates and shales. It has four limestone

formations that are separated by four shale formations. The whole group is approximately 250

feet thick (Merriam, 1963). On radioactive logs the Labette shale has a high gamma ray value making it a good marker for wellsite geologists. It is approximately ten to twenty five feet thick, and is described as gray to black, fissile, and carbonate in part.
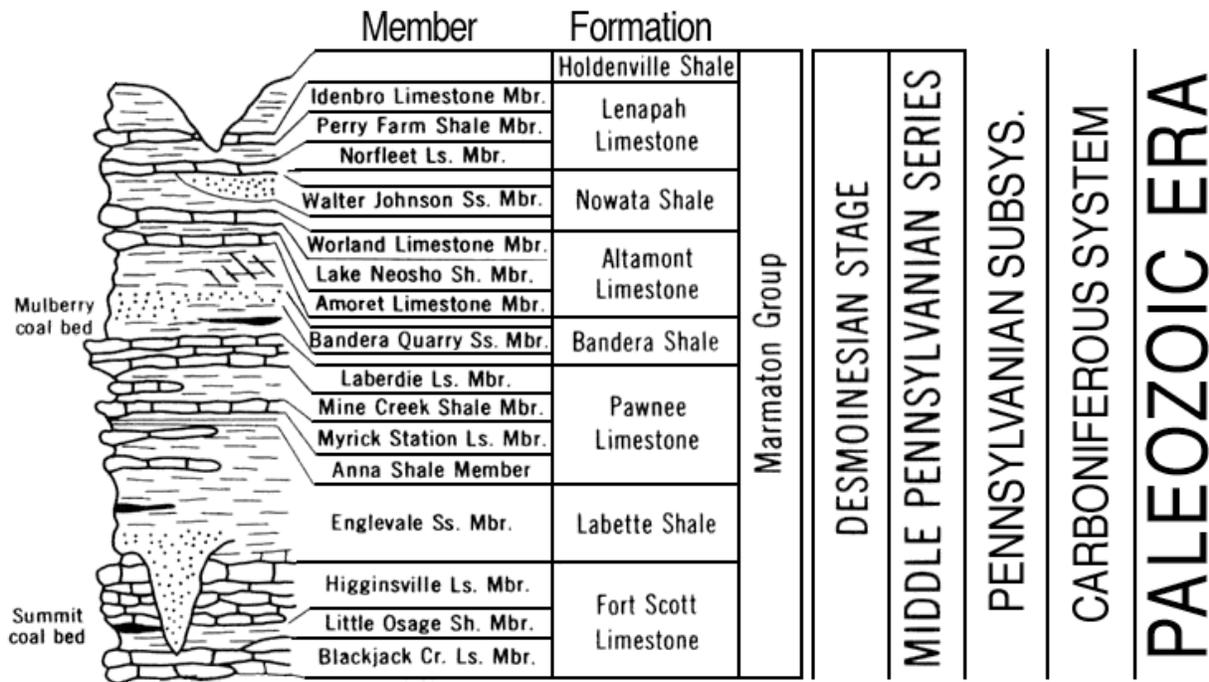
Figure 6. Stratigraphic column of the Marmaton Group.
(Zeller, 1968)

The Fort Scott Limestone Formation lies directly below the Labette Shale, as part of the Marmaton Group (Figure 6). It has two limestone members that are separated by a shale member. The Fort Scott Formation ranges in thickness from 13 feet to 145 feet (Merriam, 1963). The Little Osage Shale Member ranges in thickness from 4 feet to 12 feet, with the uppermost part being gray, and turning to a black fissile shale towards the bottom.

The Cherokee Group is Middle Pennsylvanian in age. It conformably lies below the Marmaton Group, and lies unconformably on the Mississippian Lime. There is very little limestone present, being made primarily of sand, shale and a few coal beds. It ranges in

thickness from 450 to 500 feet thick (Merriam, 1963). There are a total of seventeen formations present within the Cherokee Group (Figure 7).

The sand and shale of the Cherokee Group were deposited as the Pennsylvanian sea advanced from the south. They were laid onto the eroded surface of the Mississippian rocks, making the unconformity between the two members. This area was at or near sea level as evidenced by the coal and other swamp deposits that are present in the coal, shale and sandstone formations (Merriam, 1963).
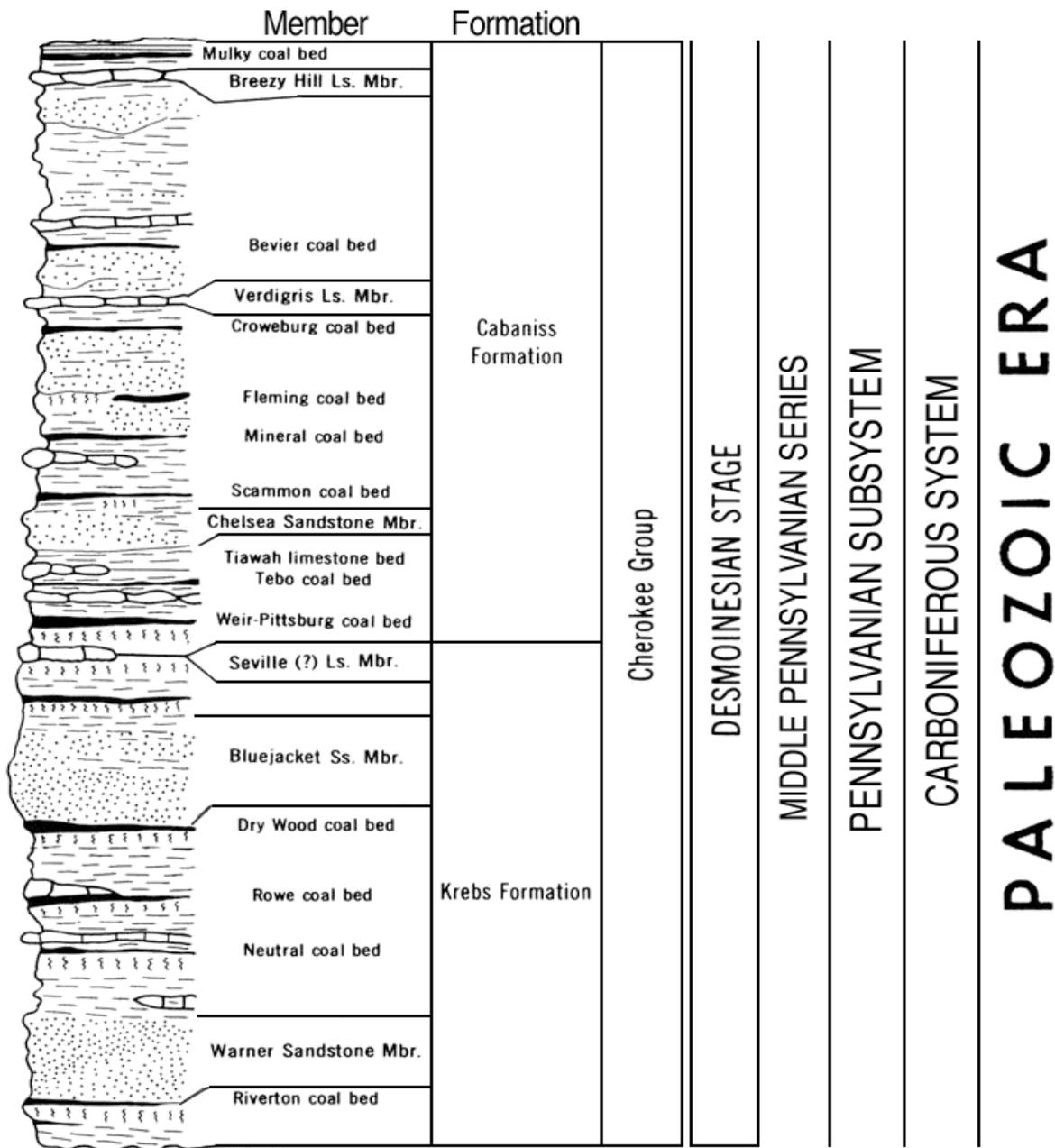
Figure 7. Stratigraphic column of the Cherokee Group.
(Zeller, 1968)

The Morrowan Stage is lower Pennsylvanian in age. The Kearney Formation is the only formation present. Most of the available data from this formation is from wells that have been drilled through the formation. This formation is confined mainly to basinal areas like the Hugoton Embayment. The thickness ranges from 0 to about 600 feet thick (Franz, 1985). There

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is an unconformity at the top and base of the Morrowan Stage, which are the Atokan Stage, and Meramecian Stage (Robinson, 1985). This formation is also a large producer from the Morrow sand.

The Kearny can be subdivided into two distinct sections, the upper and lower (Figure 8). The lower section is made up of marine deposits, whereas the upper younger section is made up of nonmarine deposits. The lower Kearney is made up of black shales, glauconitic limestones, sandstones, and fossiliferous sandstones (Franz, 1985). The upper Kearney is made up of black shales, carbonaceous shales, and coarse grained arkosic sandstones (Franz, 1985). Deposition of these sediments took place during a transgression from the Anadarko basin into the Hugoton Embayment (Franz, 1985).
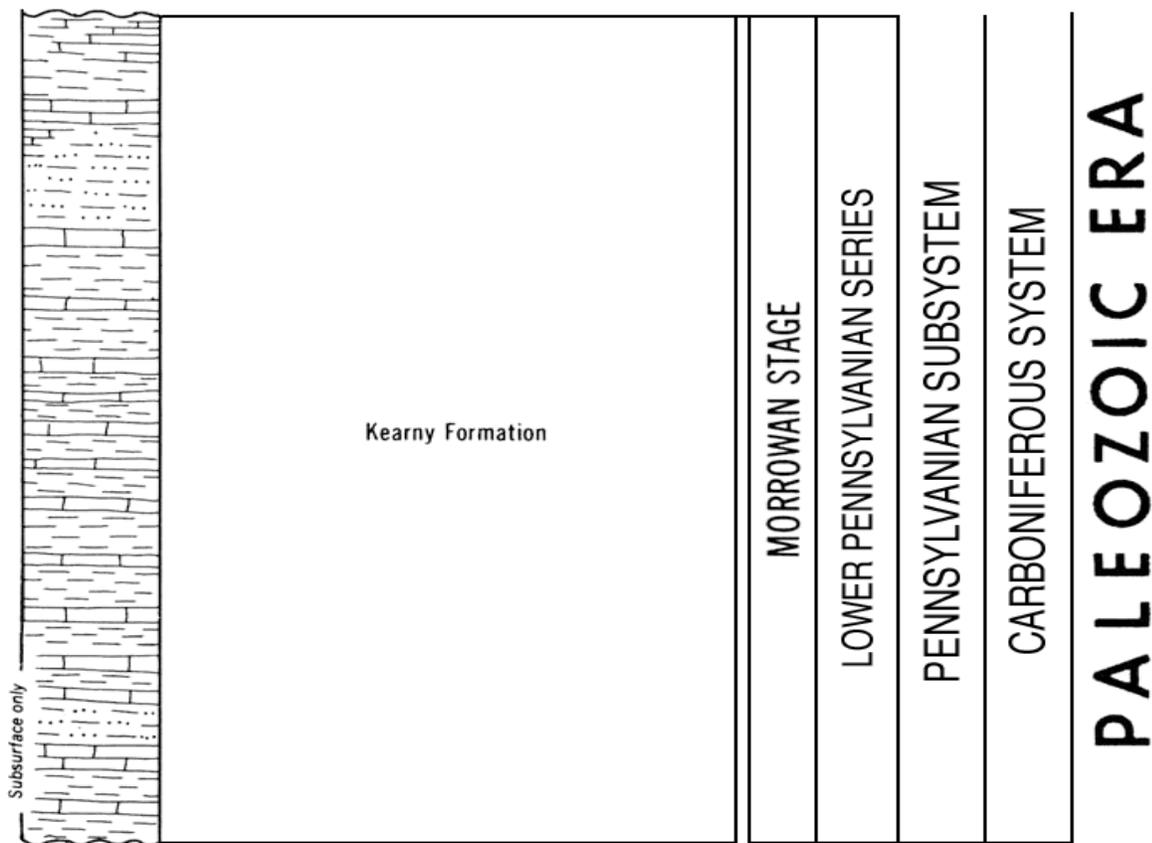
Figure 8. Stratigraphic column of the Morrowan Stage.
(Zeller, 1968)

The Arbuckle Group is lower Ordovician, and upper Cambrian in age. The Arbuckle is a big producer in western Kansas. There are five members in this group which consist mainly of dolomite (Figure 9). The Arbuckle Group is bounded on the top and bottom by major interregional unconformities, depending on whether or not the Reagan sandstone has been eroded away.

The group as a whole consists of mainly dolomite with some interbedded sands and shales. The dolomite is white, buff, light gray, cream and brown (Merriam, 1963). There are large amounts of various types of chert present within the dolomite. The sands and shales where present are sparse, and not continuous. The shales appear as gray to black.

**Figure 9. Stratigraphic column of the Arbuckle Group.
(Zeller, 1968)**

1.6 Geochemistry

Peters et al (2006) describes petroleum source rocks as fine-grained organic-rich rocks that could generate (potential source rock) or have already generated (effective or active source rock) significant amounts of petroleum. In western Kansas there are a plethora of fine-grained organic-rich rocks that could possibly generate oil, and be a potential source rock.

According to Oko (2006) hydrocarbon potential is dependent on four factors: 1) the quantity and quality of insitu organic matter in the rock, 2) the origins of the various types of constituent organic matter and their capacity for hydrocarbon generation, 3) the degree of conversion of the organic matter to hydrocarbons, and 4) the adsorption capacity of the rock. Factors 1 and 2 are mostly dependent on the prevailing conditions at the place of deposition. Factor 3 is related to maximum burial depth and maturation. The fourth factor is vital for any shale to be producible. Each of these factors will be discussed in this chapter.

1.6.1 Discussion of TOC

Total organic carbon (TOC) is the measure of the quantity, or organic richness of organic carbon within a rock sample. Peters et al (2006) pointed out that it is a measure of the quantity and not the quality. This measurement is the first step toward assessing the potential of a sediment to generate hydrocarbons.

The organic matter is derived from a variety of biological origins which has been deposited and buried through geologic time (Tissot and Welte, 1984). The bulk of petroleum is formed from the thermal decomposition of organic matter through time (Jarvie 1991). TOC measures how much organic matter is present within the rocks that were deposited originally. The organic carbon is different from the inorganic carbon, and can be distinguished by its

derivation. Organic carbon comes from biogenic matter, and the inorganic matter comes from mineral matter, such as carbonates.

The overall amount of TOC is actually a very small percent of the entire rock (Figure 10). Peters et al (2006) says that for a potential source rock to be excellent, it must have greater than 4% by weight. For a poor source rock the TOC is less than 0.5% by weight.

TOC will only answer whether or not the rocks selected are rich enough to produce hydrocarbon. According to Jarvie (1991) even the leanest TOC values (poor to fair) can produce hydrocarbons, under the correct thermal maturity. These lean TOC values, however, rarely produce commercial quantities of hydrocarbons.

Potential (quantity)	TOC (wt.%)	Rock-Eval (mg/g rock)		Bitumen (ppm)	Hydrocarbons (ppm)
		S1	S2		
Poor	<0.5	<0.5	<2.5	<500	<300
Fair	0.5–1	0.5–1	2.5–5	500–1000	300–600
Good	1–2	1–2	5–10	1000–2000	600–1200
Very good	2–4	2–4	10–20	2000–4000	1200–2400
Excellent	>4	>4	>20	>4000	>2400

Figure 10. TOC evaluation.
(Modified from Peters, 2006)

1.6.2 Discussion of Pyrolysis

Pyrolysis is a very useful analytical technique that analyzes kerogens and whole rock. Kerogen is organic matter that is insoluble in organic solvents. It covers a number of different parameters which include the measure of quality, quantity, thermal maturity, and petroleum generative potential of prospective source rocks (Peters 1986). Peters (1986) goes on to define pyrolysis as the heating of organic matter in the absence of oxygen, to yield organic compounds. In Rock-Eval pyrolysis (method used in this study) pulverized well cutting samples are gradually

heated under an inert atmosphere. The heating distills the free organic compounds (bitumen),

then cracks pyrolytic products from the insoluble organic matter (kerogen).

There are several different parameters that are measured in this analysis. During

pyrolysis there is a flame ionization detector (FID) that senses any organic compounds that were

generated throughout the process (see appendix). There are also several different peaks that are

measured: S1, S2, and S3. S1 according to Peters (1986) represents milligrams of hydrocarbons

that can be thermally distilled from one gram of rock. This is basically the amount of

hydrocarbons that have already been generated from the source rock before it was analyzed.

This is a very useful measurement, because it gives a good indication on whether or not the

potential source rock has already produced hydrocarbons. S2 according to Peters (1986)

represents milligrams of hydrocarbons generated by pyrolytic degradation of the kerogen in one

gram of rock. This measures the amount of hydrocarbons that are left within the source rock that

have not yet been generated. This is also a very useful measurement when comparing S1 to S2,

because it gives the ratio of hydrocarbons that have already been generated, to hydrocarbons that

have yet to be generated. S3 according to Peters (1986) represents milligrams of carbon dioxide

generated from a gram of rock during temperature programming. There is also one more

measurement that is taken during pyrolysis, in which the temperature is measured. The

temperature at which the maximum amount of S2 hydrocarbons is generated is called Tmax

(Peters 1986).

This information is then plotted into pyrograms or modified van Krevelen diagrams

(Figure 11). The Hydrogen Index is plotted on the vertical axis, and the Oxygen Index is plotted

on the horizontal axis. The hydrogen index (HI) corresponds to the quantity of pyrolyzable

organic compounds or hydrocarbons (HC) from S2 relative to the total organic compound

(TOC). The oxygen index (OI) corresponds to the quantity of carbon dioxide from S3 relative to the TOC (Peters 1986).

Kerogen (quality)	Hydrogen index (mg hydrocarbon/g TOC)	S2/S3	Atomic H/C	Main product at peak maturity
I	>600	>15 ~	>1.5	Oil
II	300–600	10–15	1.2–1.5	Oil
II/III	200–300	5–10	1.0–1.2	Oil/gas
III	50–200	1–5	0.7–1.0	Gas
IV	<50	<1	<0.7	None

Figure 11. Kerogen quality.
(Modified from Peters, 2006).

The van Krevelen diagrams can be used to classify different types of organic matter. The different types of kerogens are plotted into four different types. Type I is very oil prone, type II is oil prone, type III is gas prone, and type IV is inert. Type IV kerogens contain very little hydrogen and plot near the bottom of the graph. These different types are classified by using the hydrogen index versus the oxygen index.

One of the many benefits of pyrolysis is the ability to characterize what type of depositional environment the shales were deposited in. Tissot and Welte (1984) describe how the chemical structure of a shallow immature kerogen varies with the original mixture of organisms and with the physical, chemical, and biochemical conditions of deposition. These kerogens are broken into four different types that explain the different depositional environments.

Type I organic matter contains material with an identifiable algal and bacterial structure. It is highly anoxic lacustrine and marine, with minor terrestrial component.

Type II organic matter, as described by Tissot and Welte (1984), appears visually in several different forms. This material appears as allochthonous material, principally as exinites

consisting of spores, pollen grains, and phytoplankton cysts, and as cuticles from plant leaves and stems. Alternatively, this material may be autochthonous and derived principally from bacterially reworked phyto- and zooplankton. This bacterially reworked material will also appear largely as finely disseminated amorphous organic matter. It is anoxic-oxic marine or lacustrine. It is also mixed marine terrestrial.

Type III organic matter, as described by Tissot and Welte (1984), often appears as vitrinite. It may also appear as finely disseminated amorphous material. This material forms through the degradation and or oxidation of the other maceral types. It is anoxic-oxic marine or lacustrine. It can also range to mildly oxic, and coal swamp deposition. Its organic matter is terrestrial, mostly vitrinite, and partially degraded algal.

Type IV organic matter is highly oxidized. Its depositional environment is highly oxic, and its organic matter is highly oxidized marine and terrestrial. This type of organic matter generally forms coal.

The classification of the different kerogens can be plotted in a different type of graph where S2 is plotted against TOC. This works better in evaluating the kerogens because it indicates the petroleum potential and the type of kerogen present (Langford and Blanc-Valleron 1990). This plot forms a linear regression with a high degree of correlation which indicates a very coherent group, whereas in the standard van Krevelen diagram the plot forms a broad group in the center, with some points scattered more widely (Langford and Blanc-Valleron 1990).

1.6.3 Discussion of Vitrinite Reflectance

Bostick (1979) showed that the optical properties of vitrinite from finely dispersed organic matter in sedimentary rocks could be used to assess thermal maturity. According to Peters et al (2006) vitrinites are a maceral group derived from terrigenous higher plants.

Vitrinite Reflectance (Ro) is a key measure of the thermal maturity. Vitrinites were well developed by Devonian time, so anything of Devonian age or younger can usually be tested for its thermal maturity. Vitrinite reflectance offers a means to evaluate organic maturity over temperatures ranging from early diagenesis through catagenesis to metamorphism (Senftle and Landis, 1991). The oil maturation window (Figure 13) ranges from 0.7% to 1.2% according to Senftle and Landis (1991). This makes it a useful tool, being able to differentiate between mature and immature source rocks.

Maturity	Maturation			Generation		
	R_o (%)	T_{max} (°C)	TAI	Bitumen/TOC*	Bitumen (mg/g rock)	Production index (S1/(S1+S2))
Immature	0.20–0.60	<435	1.5–2.6	<0.05	<50	<0.10
Mature						
Early	0.60–0.65	435–445	2.6–2.7	0.05–0.10	50–100	0.10–0.15
Peak	0.65–0.90	445–450	2.6–2.7	0.15–0.25	150–250	0.25–0.40
Late	0.90–1.35	450–470	2.9–3.3	–	–	>0.40
Postmature	>1.35	>470	>3.3		–	–

Figure 12. Vitrinite reflectance qualities.
(Modified from Peters, 2006).

ORGANIC STAGE	COAL RANK	VITRINITE REFLECTANCE (% Ro)	TAI (STAPLIN)	TAO (EXLOG)	DEGREE OF THERMAL ALTERATION (BATTEN)	FLUORESCENCE COLOR-SPORES	SPORE-COLOR INDEX (SCI) (ROBERTSON RES.)	ROCK-EVAL TMAX (°C)	CONODONT-COLOR INDEX	KEROGEN COLOR	LOM HOOD
DIAGENESIS	PEAT	0.2	1.0	1.0	1.0		-1.0-			LIGHT YELLOW	1
	LIGNITE		1.0				-2.0-				2
		0.3	1.5	1.5	1/2	YELLOW		400		YELLOW	3
			2.0		2.0		-3.0-				4
	SUB-BITUMINOUS	0.4			2/3 3.0	YELLOW-ORANGE	-4.0-				5
		0.5	2.5	2.0	3.4 4.0	ORANGE	-5.0-	425	1.0	ORANGE	6
	HIGH VOLATILE BITUMINOUS	0.6			4/5		-6.0-				7
CATAGENESIS		0.7	2.5		5.0	ORANGE-RED	-7.0-		1.5		8
		0.8			5/6						9
		0.9			6.0		-8.0-				
		1.0	3.0	3.0				450	2.0	BROWN	10
	MEDIUM/LOW V.S.	1.3	3.0				-8.5-				11
					6/7						12
			3.5				-9.0-	500	3.0		13
METAGENESIS	SEMI-ANTHRACITE	2.0	3.5	3.5						DARK BROWN-BLACK	14
							-9.5-				15
	ANTHRACITE		4.0	4.0							16
		3.0	5.0		7.0		-10.0-		4.0		17
										BLACK	

Figure 13. Correlation table of common organic maturation parameters with coal rank and hydrocarbon generation.
(Modified from Senftle and Landis, 1991).

Right side zones: DIAGENETIC ZONE OF GAS FORMATION; OIL; OIL WINDOW; PRINCIPAL ZONE OF OIL FORMATION; WET GAS; PRINCIPAL ZONE OF GAS - CONDENSATE FORMATION; METHANE; PRINCIPAL ZONE OF GAS FORMATION; MODIFIED AFTER VASSORVICH ET. AL. (1974)

1.8 Thermal Maturation and Burial History

In most cases the maturity of any source rock is directly related to thermal heating due to burial. There can be some localized heat sources such as thrust faults and deep-seated basement features. Within the study area the question arose on whether or not the thermal heating due to burial had reached temperatures high enough to begin hydrocarbon generation. This is mainly

due to the shallow depths at which the potential source rocks are buried. In Figure (14) Bostick (1979) and several other authors proposed that low to medium temperatures at long periods of time were enough to reach the onset of oil generation. Vitrinite reflectance at 0.7% should be enough to produce hydrocarbon generation within source rocks. According to the figure, 5 ma at 120 degrees C should be enough to reach 0.7% reflectance. However, a lower temperature for a longer period of time (70 ma at 80 degrees C) 0.7% reflectance should be achieved, and also be enough to reach the oil maturation window.
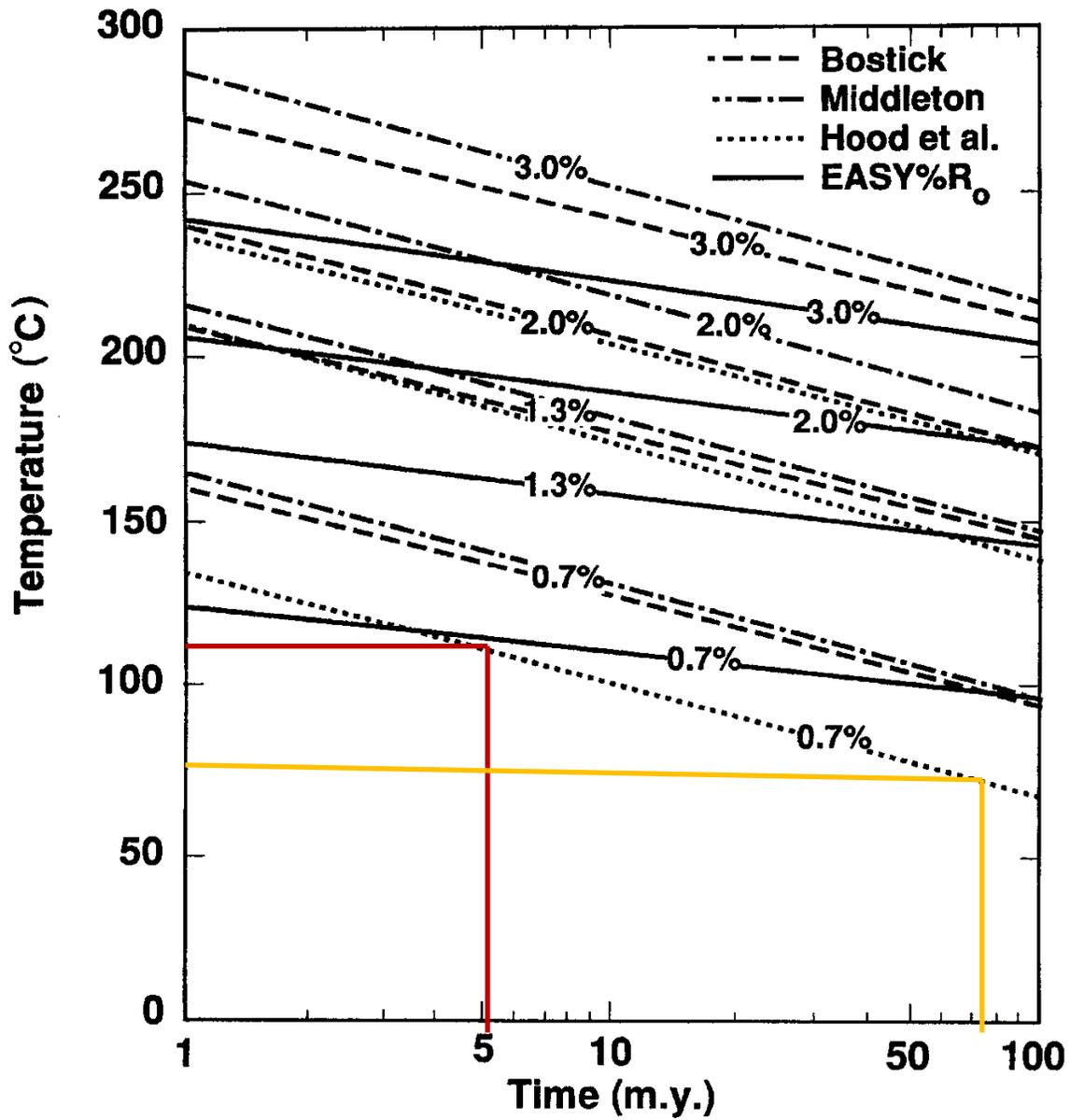
Figure 14. Approximate vitrinite reflectance based on time and temperature relationship. (Modified from Bostick, 1979).

CHAPTER 2 - MATERIALS AND METHODS

Analysis of source rocks are most easily studied through several different

interdisciplinary techniques. In this study integration of stratigraphy, and geochemical data was

employed. Drill cuttings, well-logs, and geochemical data sets were utilized to characterize and

assess the source potential of several different black shales in the western Kansas Petroleum

province. The shales analyzed in this study were easiest to work with based on previously

drilled wells within the study area of western Kansas. Surface exposures are limited within the

study area. Thus, subsurface data based on well-logs became the easiest method to characterize

the different potential source rocks. Cores would have been the best method to study and

sample. However, they are very rarely taken in the black shales, with the bulk of them being in

zones of oil and gas production. The next best thing to studying cores, were well-cuttings which

are collected for almost every well drilled in Kansas. For detailed geochemical work, twenty-

four bulk shale samples were collected in five to ten foot intervals from nine different wells

spread throughout western Kansas (Table 1).

2.1 Sedimentology

The sedimentology of the organic black shales analyzed in this thesis discuss the

relationships with other similar age rocks, and the depositional environments. Stratigraphic and

sedimentologic characterization of these shales were achieved through subsurface techniques.

These techniques include geophysical well logs which include: gamma ray, neutron porosity,

bulk density, and density porosity.

Geologist's reports were also used to pick pertinent black shales (Figure 15). On the

figure the organic black shales are marked by a red arrow. These reports made choosing the

shales to analyze much easier. They would point out the obvious organic black shales, which could then be double checked on the gamma ray (geophysical well logs) to see if there was an increase. On the gamma ray logs, there is an increase, or spike where they are highly radioactive due to the high organic material. Organic material is concentrated in uranium, so when the gamma ray logging tool is run over an area that is high in organic matter, then there is an increase in the gamma ray log response.

The organic shales within the study area are usually not more than twenty feet thick (averaging four to ten feet). These shales were then picked out of the well cuttings that were available from the Well Sample Library in Wichita, Kansas.

2.2 Geochemical Analytical Tests

Twenty-four samples from nine different wells (Table 1) were collected from rock cuttings and sent to Weatherford Laboratories in Houston, Texas. The average sample weighed about one gram (the size of a pencil eraser). The shale samples were picked based off of the available well logs. The shale samples were collected out of the well cuttings, by looking through a microscope. All twenty-four samples were analyzed to assess organic richness, kerogen type, and thermal maturity. The samples were then analyzed for total organic content (TOC) and kerogen type using Rock-Eval pyrolysis. Whole rock analysis, for vitrinite reflectance, was also performed on eight of these samples by the same laboratory.

Sample	County	API	Location	Well	Formation	Depths
1	Comanche	15-033-21470	T32S, R20W, Sec. 18	Gal 1-18	LKC	4595-4599
2	Comanche	15-033-21470	T32S, R20W, Sec. 18	Gal 1-18	Stark	4745-4755
3	Comanche	15-033-21470	T32S, R20W, Sec. 18	Gal 1-18	Stark	4786-4792
4	Comanche	15-033-21470	T32S, R20W, Sec. 18	Gal 1-18	Cherokee	5012-5016
5	Comanche	15-033-21470	T32S, R20W, Sec. 18	Gal 1-18	Cherokee	5046-5050
6	Ellis	15-051-25825	T11S, R18W, Sec. 36	Marshall A 29	LKC	3546-3549
7	Ellis	15-051-25825	T11S, R18W, Sec. 36	Marshall A 29	LKC	3576-3580
8	Ellis	15-051-25316	T12S, R17W, Sec. 6	Shutts 2-6	LKC	3440-3450
9	Ellis	15-051-25316	T12S, R17W, Sec. 6	Shutts 2-6	Arbuckle	3660-3672
10	Ellis	15-051-25316	T12S, R17W, Sec. 6	Shutts 2-6	Arbuckle	3725
11	Ellis	15-051-25233	T11S, R18W, Sec. 15	Mcgehee Davis 1-15	LKC	3216-3220
12	Meade	15-119-21194	T33S, R30W, Sec. 3	Stevens Unit 'SMU' 316	Swope	5080-5084
13	Meade	15-119-21194	T33S, R30W, Sec. 3	Stevens Unit 'SMU' 316	Fort Scott	5309-5313
14	Meade	15-119-21194	T33S, R30W, Sec. 3	Stevens Unit 'SMU' 316	Cherokee	5346-5350
15	Meade	15-119-21194	T33S, R30W, Sec. 3	Stevens Unit 'SMU' 316	Cherokee	5414-5418
16	Meade	15-119-21194	T33S, R30W, Sec. 3	Stevens Unit 'SMU' 316	Morrow	5668-5671
17	Ness	15-135-23895	T18S, R24W, Sec. 23	Ummel 4	Cherokee	4235-4240
18	Ness	15-135-24186	T18S, R24W, Sec. 9	Wells 1-9	Labette	4212-4218
19	Ness	15-135-24253	T18S, R24W, Sec. 11	Hopper 1	LKC	4020-4024
20	Ness	15-135-24253	T18S, R24W, Sec. 11	Hopper 1	Labette	4275-4280
21	Ness	15-135-24254	T18S, R24W, Sec. 10	Lawrence Shuler 2	LKC	3925-3930
22	Ness	15-135-24254	T18S, R24W, Sec. 10	Lawrence Shuler 2	Labette	4226-4232
23	Ness	15-135-24314	T19S, R24W, Sec. 7	Stum 1	LKC	3855-3860
24	Ness	15-135-24314	T19S, R24W, Sec. 7	Stum 1	Cherokee	4232-4237

Table 1. General well data.
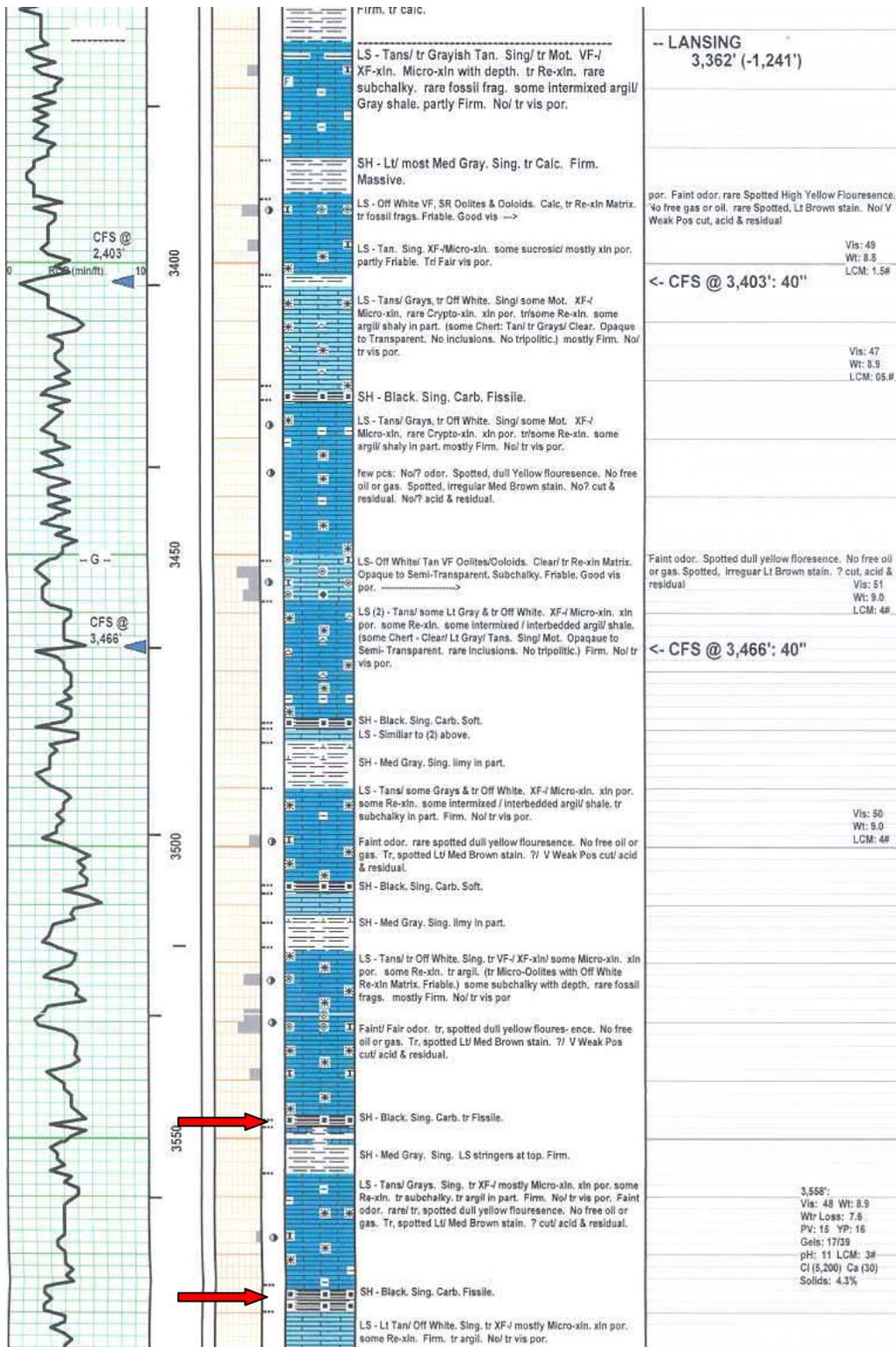
Figure 15. Geologist's Report for well 15-051-25825 within the LKC formation. Red arrows denote shales sampled.
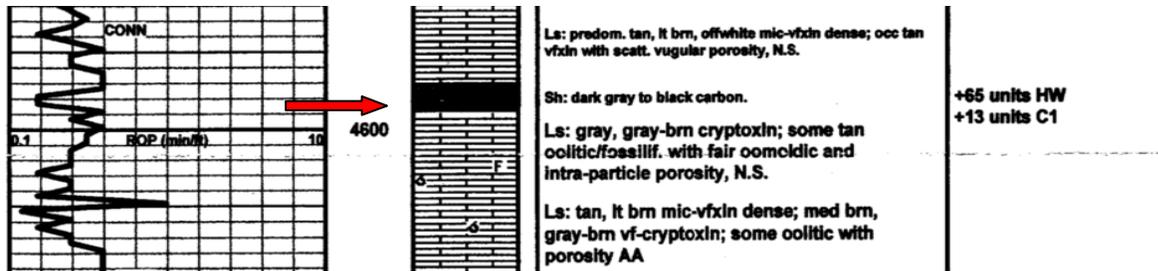
Figure 16. Geologist's Report for well 15-033-21470 within the LKC formation. Red arrows denote shales sampled.
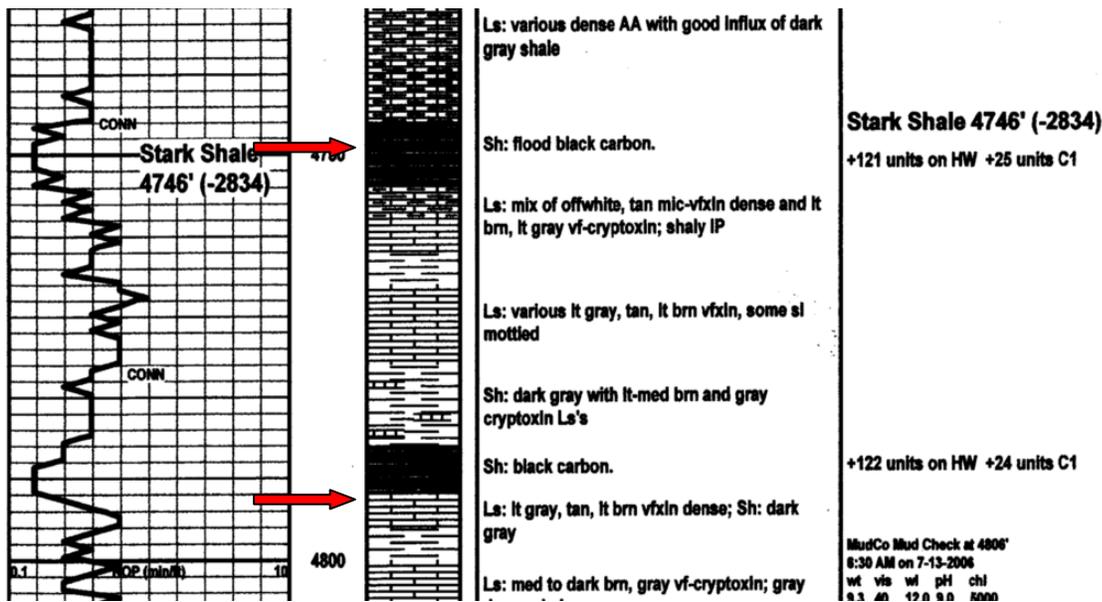
Figure 17. Geologist's Report for well 15-033-21470 within the Stark shale formation. Red arrows denote shales sampled.
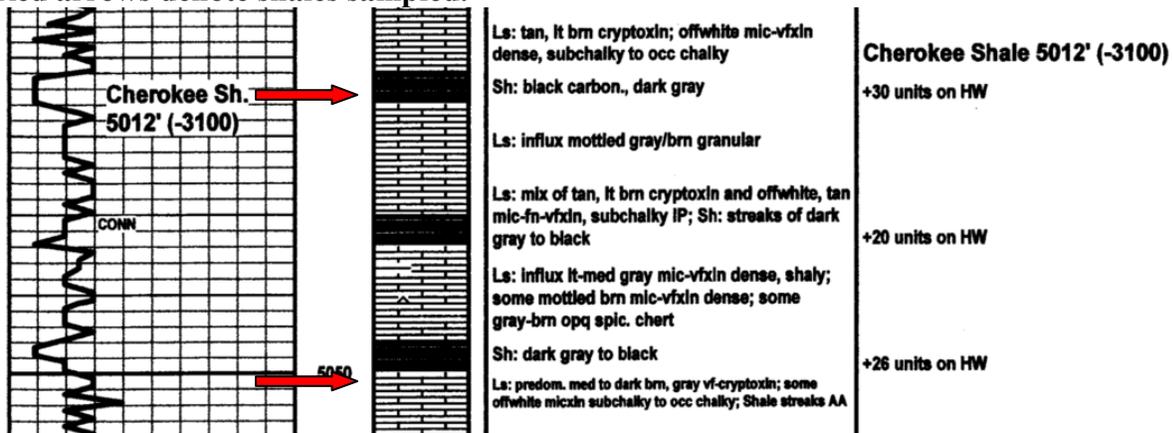
Figure 18. Geologist's Report for well 15-033-21470 within the Cherokee shale formation. Red arrows denote shales sampled.
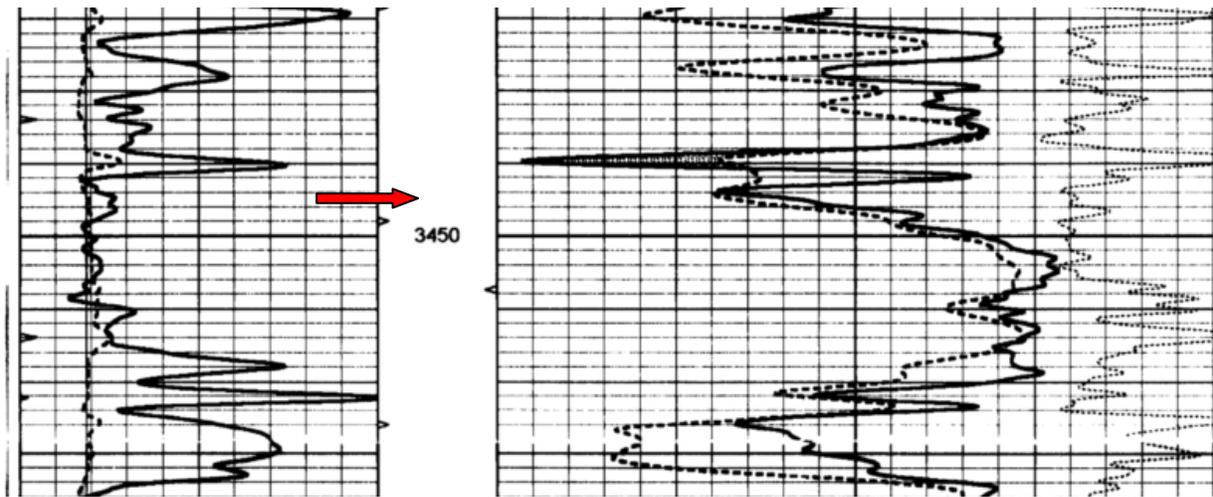
Figure 19. Porosity log for well 15-051-25316 within the LKC shale formation. Red arrows denote shales sampled.
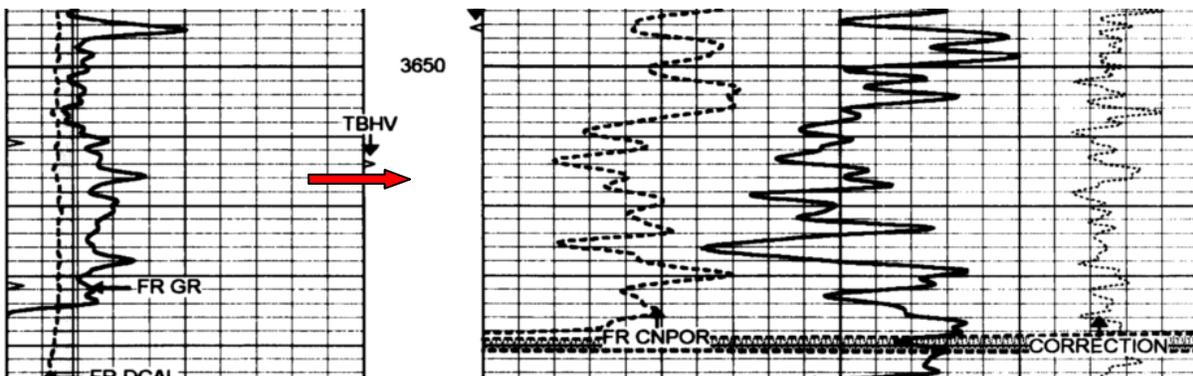
Figure 20. Porosity log for well 15-051-25316 within the Arbuckle shale formation. Red arrows denote shales sampled.
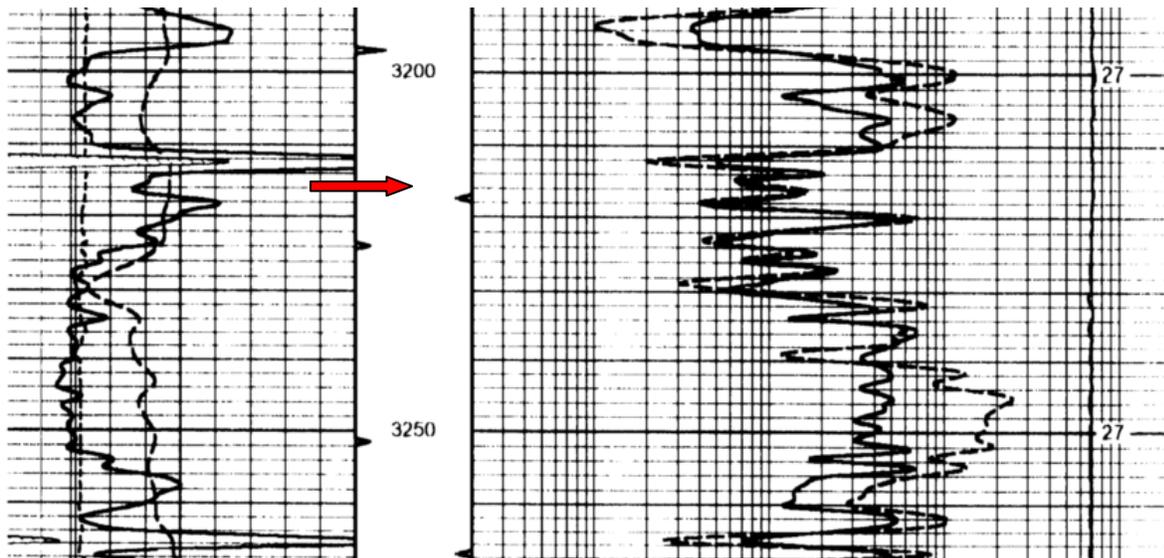
Figure 21. Resistivity log for well 15-051-25233 within the LKC shale formation. Red arrows denote shales sampled.
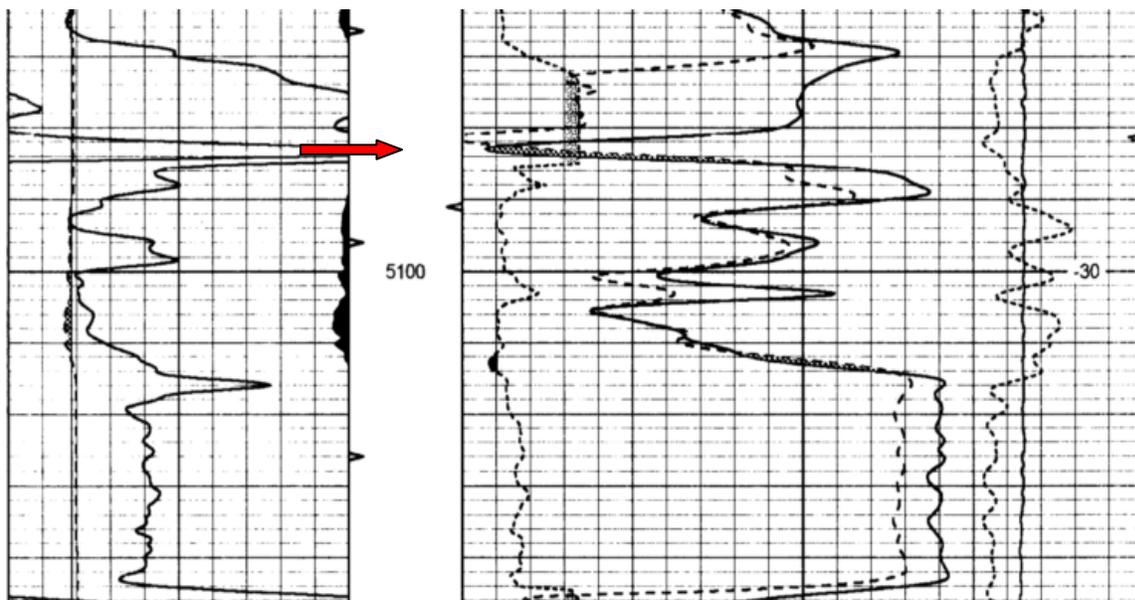
Figure 22. Porosity log for well 15-119-21194 within the Swope shale formation. Red arrows denote shales sampled.
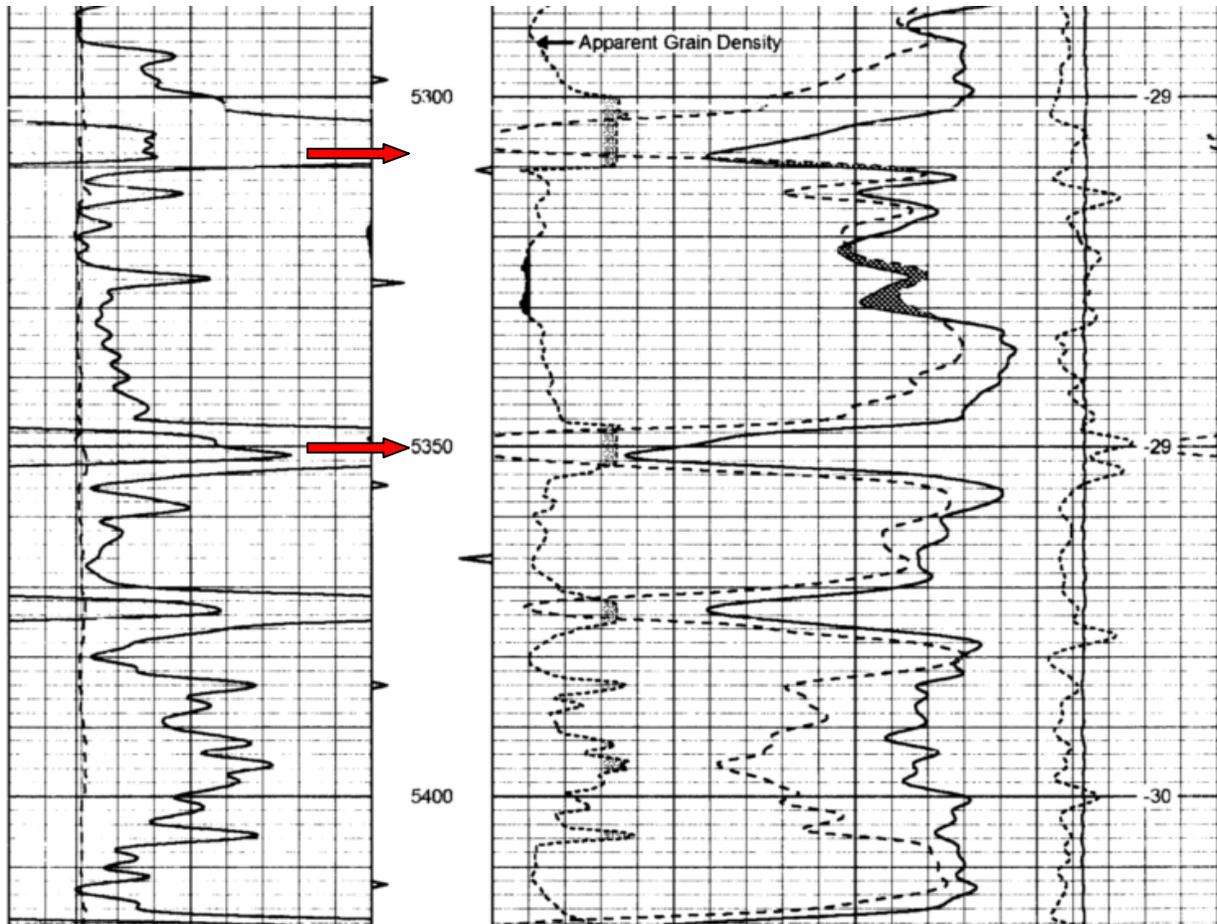
Figure 23. Porosity log for well 15-119-21194 within the Fort Scott and Cherokee shale formations.
Red arrows denote shales sampled.
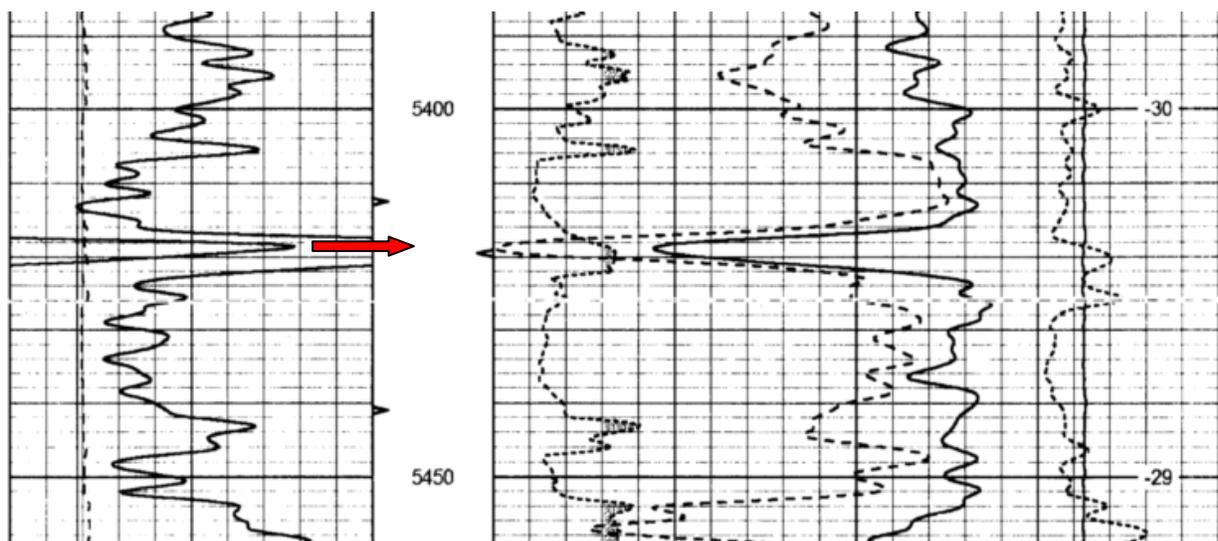
Figure 24. Porosity log for well 15-119-21194 within the Cherokee shale formation. Red arrows denote shales sampled.
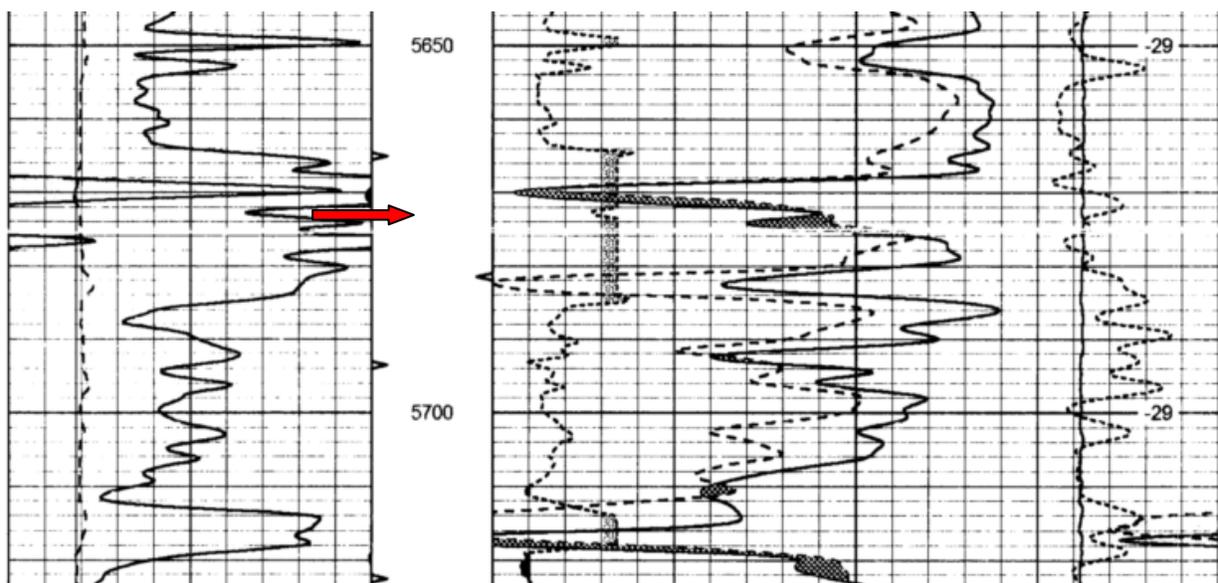
Figure 25. Porosity log for well 15-119-21194 within the Morrow Shale formation. Red arrows denote shales sampled.
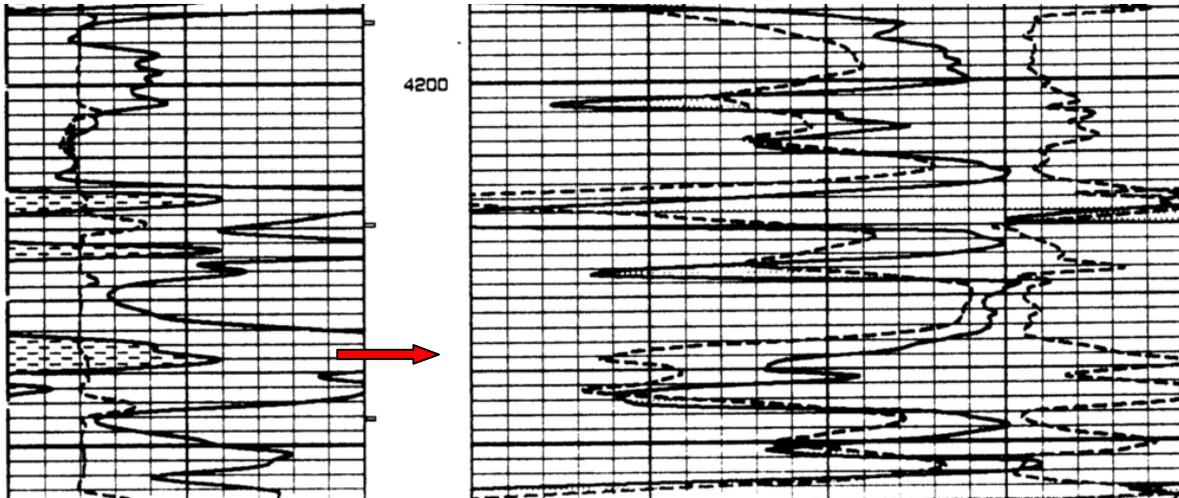
Figure 26. Porosity log for well 15-135-23895 within the Cherokee shale formation. Red arrows denote shales sampled.
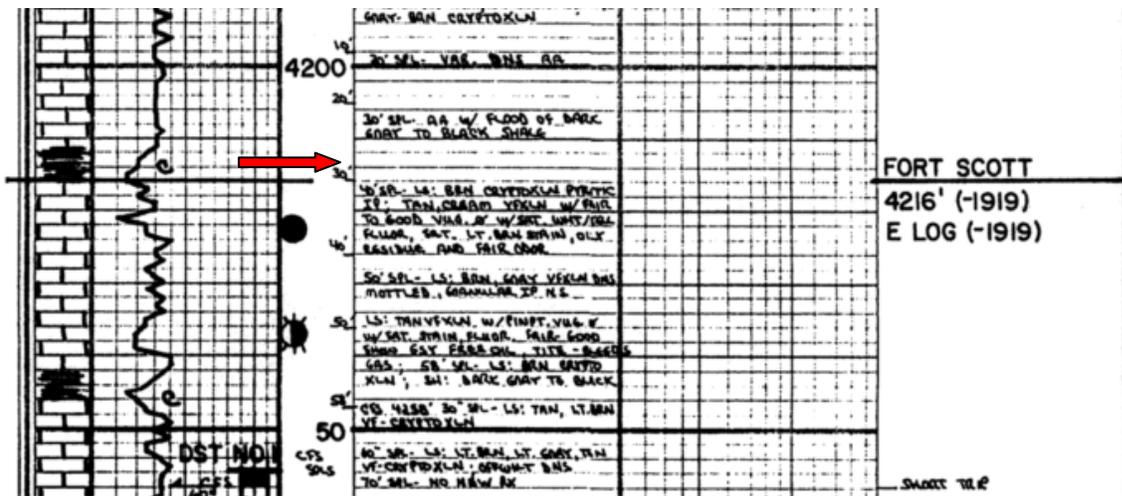
Figure 27. Geologist's Report for well 15-135-24186 within the Labette shale sample. Red arrows denote shales sampled.

Figure 28. Geologist's Report for well 15-135-24253 within the LKC shale formation. Red arrows denote shales sampled.


Figure 29. Geologist's Report for well 15-135-24253 within the Labette shale formation. Red arrows denote shales sampled.
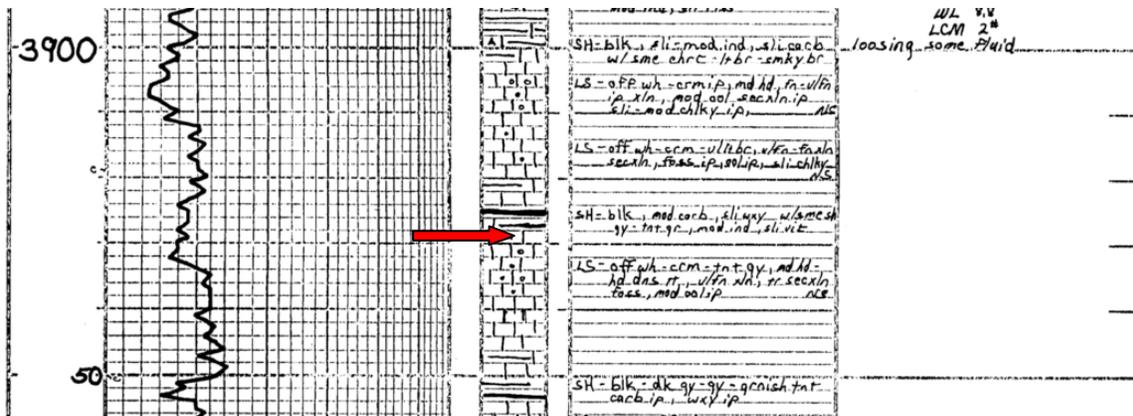
Figure 30. Geologist's Report for well 15-135-24254 within the LKC shale formation. Red arrows denote shales sampled.
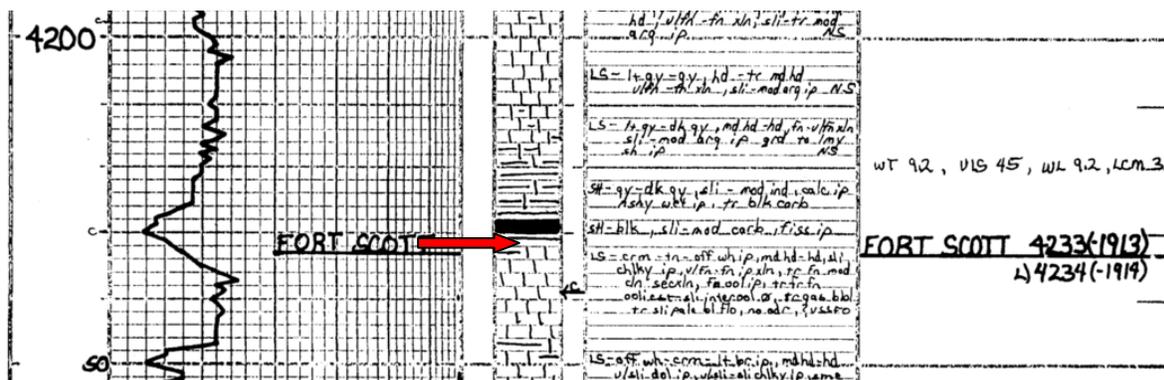
Figure 31. Geologist's Report for well 15-135-24254 within the Labette shale formation. Red arrows denote shales sampled.
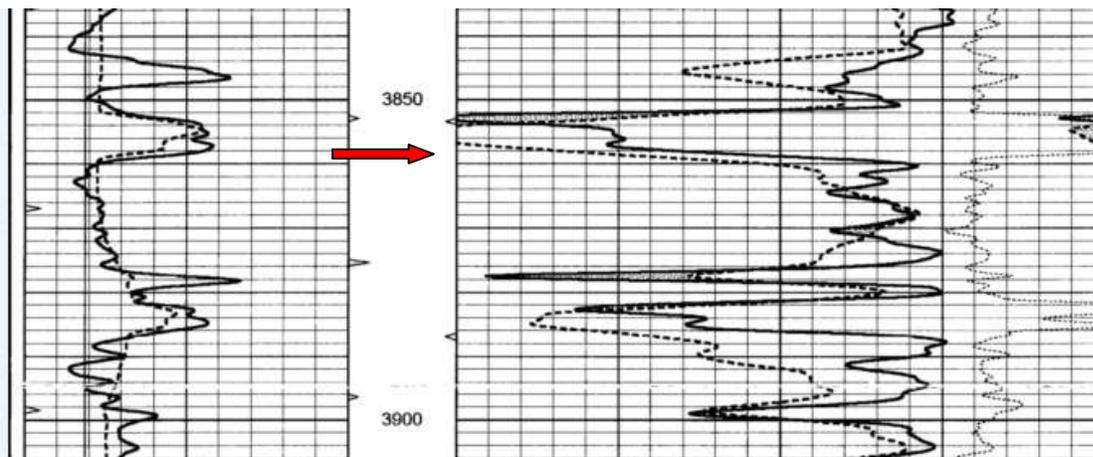

Figure 32. Porosity log for well 15-135-24314 within the LKC shale formation. Red arrows denote shales sampled.
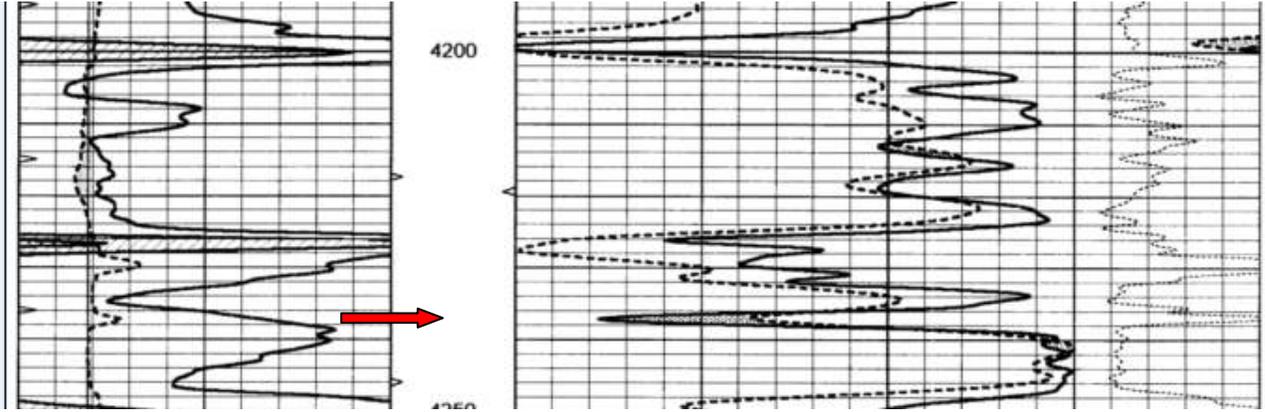
Figure 33. Porosity log for well 15-135-24314 within the Cherokee shale formation. Red arrows denote shales sampled.

CHAPTER 3 - RESULTS

Twenty-four samples, based off of well cuttings were analyzed by Weatherford Laboratories in Houston, Texas. The data is split into two different groups, with the first group of data is located in Northwestern Kansas in Ellis, and Ness counties (Table 2). The second group of data is located in Southwestern Kansas, in Comanche and Meade counties (Table 4).

The data sets were analyzed in this way, so that half the shales were taken further away from the Anadarko basin, and the second half of the shales were collected from deeper wells much closer to the Anadarko basin. This aided in helping us see if burial depths of the shales would make any difference in their potential to produce hydrocarbons.

All twenty-four samples were analyzed to assess organic richness, kerogen type, and thermal maturity. Whole rock analysis was done on eight of these samples in order to confirm maturity measurements by vitrinite reflectance of well cuttings samples. Results of TOC, Rock-Eval, and Vitrinite Reflectance (Table 3 and 5) are split into the first and second sets of data analyses, respectively. The first set of vitrinite reflectance values (Figures 34-36) were performed on three different shale formations, and their TOC and Rock-Eval can be seen in Table 3. The second set of vitrinite reflectance values (Figures 37-41) were performed on five different shale formations, and their TOC and Rock-Eval can be seen in Table 4. Vitrinite reflectance was not tested on every shale chosen. This analysis is much more expensive, and time consuming than regular Rock-Eval. Shales analyzed for vitrinite reflectance were chosen based upon their stratigraphic location. Each reflectance analyses was taken within a different formation. The main purpose for this was to test more formations for their thermal maturity.

Sample	County	API	Formation	Depths	Sample Type	Analysis Run
1	Ellis	15-051-25825	LKC	3546-3549	Cuttings	RE/TOC/Ro
2	Ellis	15-051-25825	LKC	3576-3580	Cuttings	RE/TOC
3	Ellis	15-051-25316	LKC	3440-3450	Cuttings	RE/TOC
4	Ellis	15-051-25316	Arbuckle	3660-3672	Cuttings	RE/TOC/Ro
5	Ellis	15-051-25316	Arbuckle	3725	Cuttings	RE/TOC
6	Ellis	15-051-25233	LKC	3216-3220	Cuttings	RE/TOC
7	Ness	15-135-23895	Cherokee	4235-4240	Cuttings	RE/TOC
8	Ness	15-135-24186	Labette	4212-4218	Cuttings	RE/TOC/Ro
9	Ness	15-135-24253	LKC	4020-4024	Cuttings	RE/TOC
10	Ness	15-135-24253	Labette	4275-4280	Cuttings	RE/TOC
11	Ness	15-135-24254	LKC	3925-3930	Cuttings	RE/TOC
12	Ness	15-135-24254	Labette	4226-4232	Cuttings	RE/TOC
13	Ness	15-135-24314	LKC	3855-3860	Cuttings	RE/TOC
14	Ness	15-135-24314	Cherokee	4232-4237	Cuttings	RE/TOC

Table 2. First set of samples analyzed.

TOTAL ORGANIC CARBON, PROGRAMMED PYROLYSIS DATA

Weatherford LABORATORIES

Well Name : Shales from Ness and Ellis County							Operator :						State :								Project No. :	
							API # :						County :									BH-49951 / BH-49951	

Client ID	Depth (ft) Top	Bottom	Median	Formation	Sample Type	Sample Prep	*	Leco TOC	S1	RE S2	S3	Tmax (°C)	±	Ro,%	HI	OI	S2/S3	S1/TOC	PI	Notes Checks	Pyrogram	Lab ID
15-051-25233	3216	3220	3218	LKC	Cutting	NOPR		10.57	4.75	36.68	2.10	419			347	20	17.4	45	0.11		n	3401866544
15-135-24314	3855	3860	3857.5	LKC	Cutting	NOPR		2.34	0.48	6.38	0.93	429			273	40	6.8	20	0.07	RE	n	3401866546
15-135-2425	3925	3930	3927.5	LKC	Cutting	NOPR		1.93	0.33	2.51	0.79	428			130	41	3.2	17	0.12		n	3401866548
15-135-24253	4020	4024	4022	LKC	Cutting	NOPR		3.20	0.76	7.18	1.19	425			225	37	6.1	24	0.10		n	3401866550
15-135-24186	4212	4218	4215	Lobette	Cutting	NOPR		10.75	4.45	52.79	1.32	424		0.59	491	12	39.9	41	0.08	TOC	n	3401866562
15-135-24314	4232	4237	4234.5	Cherokee	Cutting	NOPR		4.92	0.96	18.49	1.17	429			376	24	15.9	20	0.05	TOC	n	3401866564
15-135-23895	4235	4240	4237.5	Cherokee	Cutting	NOPR		1.26	0.28	1.53	1.29	434			121	102	1.2	22	0.16		n	3401866566
15-051-25316	3440	3450	3445	LKC	Cutting	NOPR		13.33	5.26	55.49	1.79	413			416	13	30.9	39	0.09		n	3401866569
15-135-24254	4226	4232	4229	Lobette	Cutting	NOPR		1.80	0.26	2.55	0.82	429			142	46	3.1	15	0.09	TOC	n	3401866571
15-135-24253	4275	4280	4277.5	Lobette	Cutting	NOPR		4.44	0.90	9.79	0.96	434			220	22	10.2	20	0.08		n	3401866573
15-051-25825	3546	3549	3547.5	LKC	Cutting	NOPR		2.27	0.52	3.71	0.98	431		0.56	164	43	3.8	23	0.12		n	3401866575
15-051-25316	3660	3672	3666	Arbuckle	Cutting	NOPR		5.21	1.71	18.49	0.72	427		0.59	355	14	25.5	33	0.08		n	3401866577
15-051-25825	3576	3580	3578	LKC	Cutting	NOPR		2.81	0.65	10.14	0.83	427			360	29	12.3	23	0.06	TOC RE	n	3401866579
15-051-25316	3725		3725	Arbuckle	Cutting	NOPR		5.88	2.04	22.84	1.17	430			388	20	19.5	35	0.08		n	3401866581

Notes:
-1 = not measured or invalid value for Tmax
TOC - Total Organic Carbon, wt %
S1 - volatile hydrocarbon (HC) content, mg HC/ g rock
S2 - remaining HC generative potential, mg HC/ g rock
S3 - carbon dioxide content, mg CO2/ g rock

* - comments regarding contamination
** - low S2, Tmax is unreliable
Meas. *Ro - measured vitrinite reflectance
HI - Hydrogen index = S2 x 100 / TOC, mg HC/ g TOC
OI - Oxygen Index = S3 x 100 / TOC, mg CO2/ g TOC
PI - Production Index = S1 / (S1+S2)

Program:
f - flat S2 peak
n - normal
ltSsh - low temperature S2 shoulder
htSsh - high temperature S2 shoulder
ltSp - low temperature S2 peak
htSp - high temperature S2 peak

LECO - TOC on Leco Instrument
RE - Programmed pyrolysis on TOC on Rock-Eval instrument
SRA - Programmed pyrolysis by SRA Instrument
EXT - Extracted Rock
NOPR - Normal Preparation

Table 3. Summary of data obtained by TOC and Rock-Eval analyses of the selected samples, for the first set of analyses.

Figure 34. Vitrinite reflectance histogram for 4212-4218 ft. interval in well 15-135-24186.


Figure 35. Vitrinite reflectance histogram for 3546-3549 ft. interval in well 15-051-25825.

Figure 36. Vitrinite reflectance histogram for 3660-3672 ft. interval in well 15-051-25316.

Sample	County	API	Formation	Depths	Sample Type	Analysis Run
1	Comanche	15-033-21470	LKC	4595-4599	Cuttings	RE/TOC
2	Comanche	15-033-21470	Stark	4745-4755	Cuttings	RE/TOC/Ro
3	Comanche	15-033-21470	Stark	4786-4792	Cuttings	RE/TOC
4	Comanche	15-033-21470	Cherokee	5012-5016	Cuttings	RE/TOC
5	Comanche	15-033-21470	Cherokee	5046-5050	Cuttings	RE/TOC
6	Meade	15-119-21194	Swope	5080-5084	Cuttings	RE/TOC/Ro
7	Meade	15-119-21194	Fort Scott	5309-5313	Cuttings	RE/TOC/Ro
8	Meade	15-119-21194	Cherokee	5346-5350	Cuttings	RE/TOC/Ro
9	Meade	15-119-21194	Cherokee	5414-5418	Cuttings	RE/TOC
10	Meade	15-119-21194	Morrow	5668-5671	Cuttings	RE/TOC/Ro

Table 4. Second set of data analyzed.

TOTAL ORGANIC CARBON, PROGRAMMED PYROLYSIS DATA

Company : Shales from Meade and Comanche counties

Project No. : BH-50594 / BH-50594

Client ID	Well Name	Operator	Top Depth (ft)	Bottom Depth (ft)	Median Depth (ft)	Formation	Sample Type	Sample Prep	*	SRA TOC	S1	S2	S3	Tmax (°C)	±	Meas. %Ro	HI	OI	S2/S3	S1/TO C*100	PI	Notes Checks	Pyrogram	LAB ID
LKL Shale #1	15-033-21470		4595	4599	4597		Cutting	NCPR		10.40	2.54	11.45	3.24	422			110	31	3.53	24	0.18		multiple main	340192883 6
Stark Shale #2	15-033-21470		4745	4755	4750		Cutting	NCPR		12.85	3.60	77.79	1.14	423		0.44	605	9	68.24	28	0.04		n	340192883 8
Stark Shale #3	15-033-21470		4788	4792	4789		Cutting	NCPR		10.37	3.98	58.74	0.96	425			566	9	61.19	38	0.06		n	340192884 0
Cherokee Shale #4	15-033-21470		5012	5016	5014		Cutting	NCPR		6.30	2.44	24.06	1.01	425			382	16	23.82	39	0.09		n	340192884 2
Cherokee Shale #5	15-033-21470		5046	5050	5048		Cutting	NCPR		6.93	2.58	33.64	0.79	428			485	11	42.58	37	0.07		n	340192884 4
Swope Shale #1	15-119-21194		5080	5084	5082		Cutting	NCPR		6.99	2.41	36.85	0.88	427		0.59	527	13	41.88	34	0.06		n	340192882 6
Fr. Scott Shale #2	15-119-21194		5309	5313	5311		Cutting	NCPR		2.42	0.50	5.67	0.65	432		0.58	234	27	8.72	21	0.08		n	340192882 8
Cherokee Shale #3	15-119-21194		5346	5350	5348		Cutting	NCPR		4.16	1.05	15.52	0.67	432		0.58	373	16	23.16	25	0.06		n	340192883 0
Cherokee Shale #4	15-119-21194		5414	5418	5416		Cutting	NCPR		4.27	0.95	17.71	0.61	431		0.63	414	14	29.03	22	0.05		n	340192883 2
Morrow Shale #5	15-119-21194		5668	5671	5669.5		Cutting	NCPR		2.81	0.40	5.09	0.56	440		0.65	181	20	9.09	14	0.07		n	340192883 4

Notes:

"<" - not measured or invalid value for T_max

TOC - Total Organic Carbon, wt. %
S1 - volatile hydrocarbon (HC) content, mg HC/g rock
S2 - remaining HC-generative potential, mg HC/g rock
S3 - carbon dioxide content, mg CO₂/g rock

"*" - comments regarding contamination
"<" - low S2, Tmax is unreliable
Meas. %Ro - measured vitrinite reflectance
HI - Hydrogen Index = S2 x 100 / TOC, mg HC/g TOC
OI - Oxygen Index = S3 x 100 / TOC, mg CO₂/g TOC
PI - Production Index = S1 / (S1+S2)

Pyrogram:
n   : normal
f   : flat S2 peak
lS2sh : low temperature S2 shoulder
lS2p : low temperature S2 peak
hS2p : high temperature S2 peak
hS2sh : high temperature S2 shoulder

RE   - Programmed pyrolysis on Rock-Eval Instrument
EXT   - Extracted Rock
NCPR - Normal Preparation

**Table 5. Summary of data obtained by TOC and Rock-Eval analyses of the selected samples, for the second set of analyses.**

44
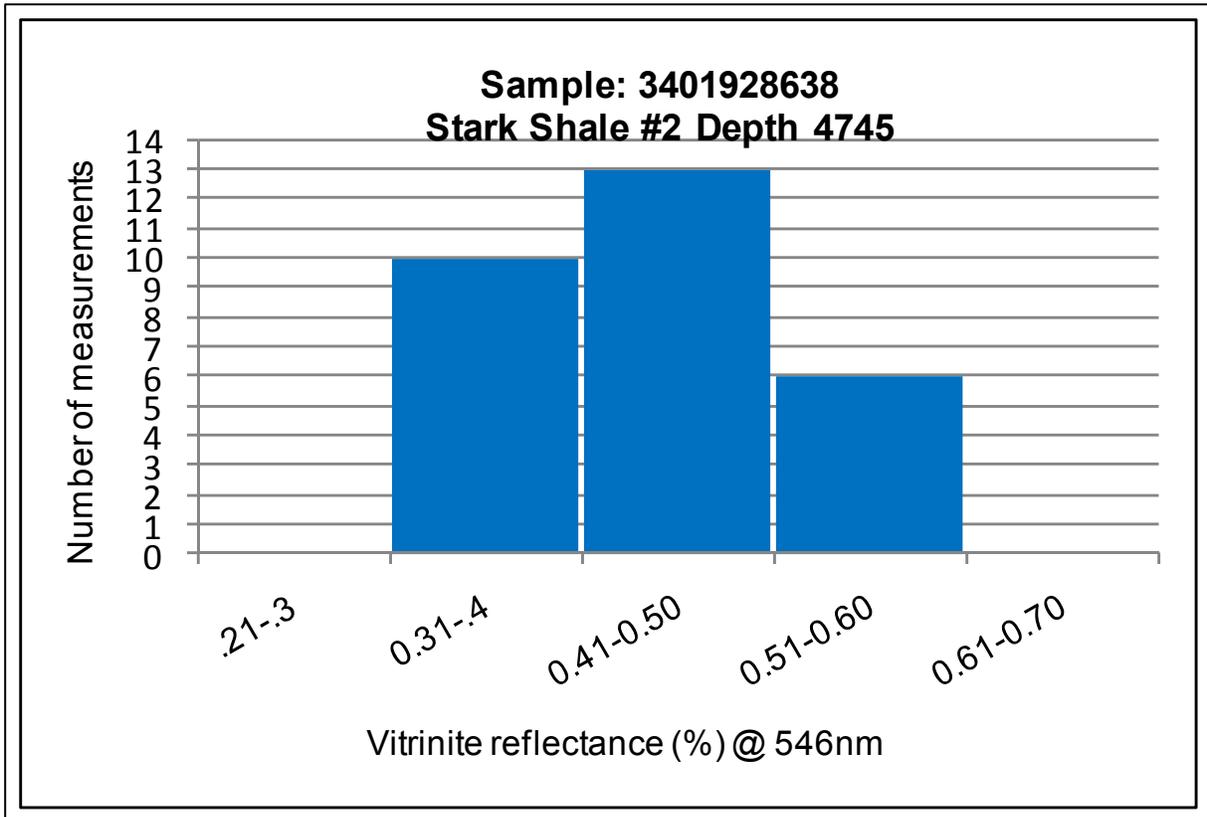
Figure 37. Vitrinite reflectance histogram for 4745-4755 ft. interval in well 15-033-21470.
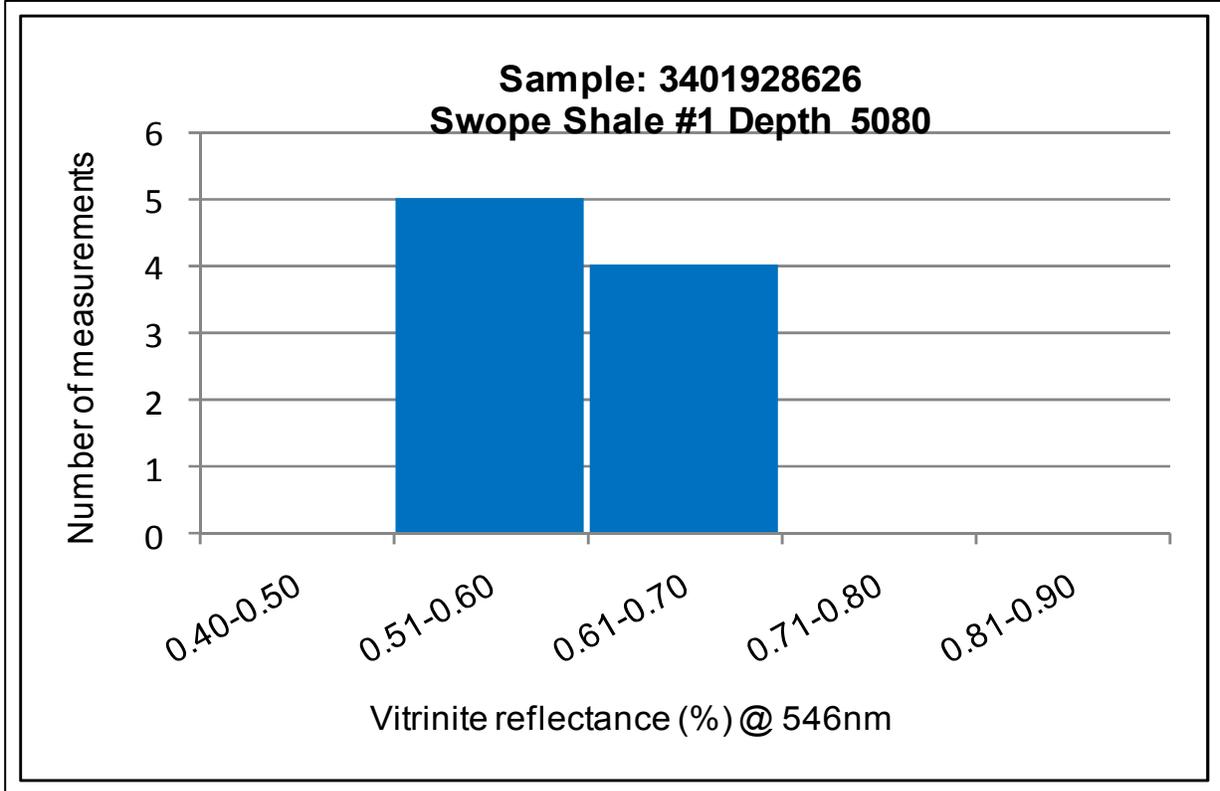
Figure 38. Vitrinite reflectance histogram for 5080-5084 ft. interval in well 15-119-21194.

45
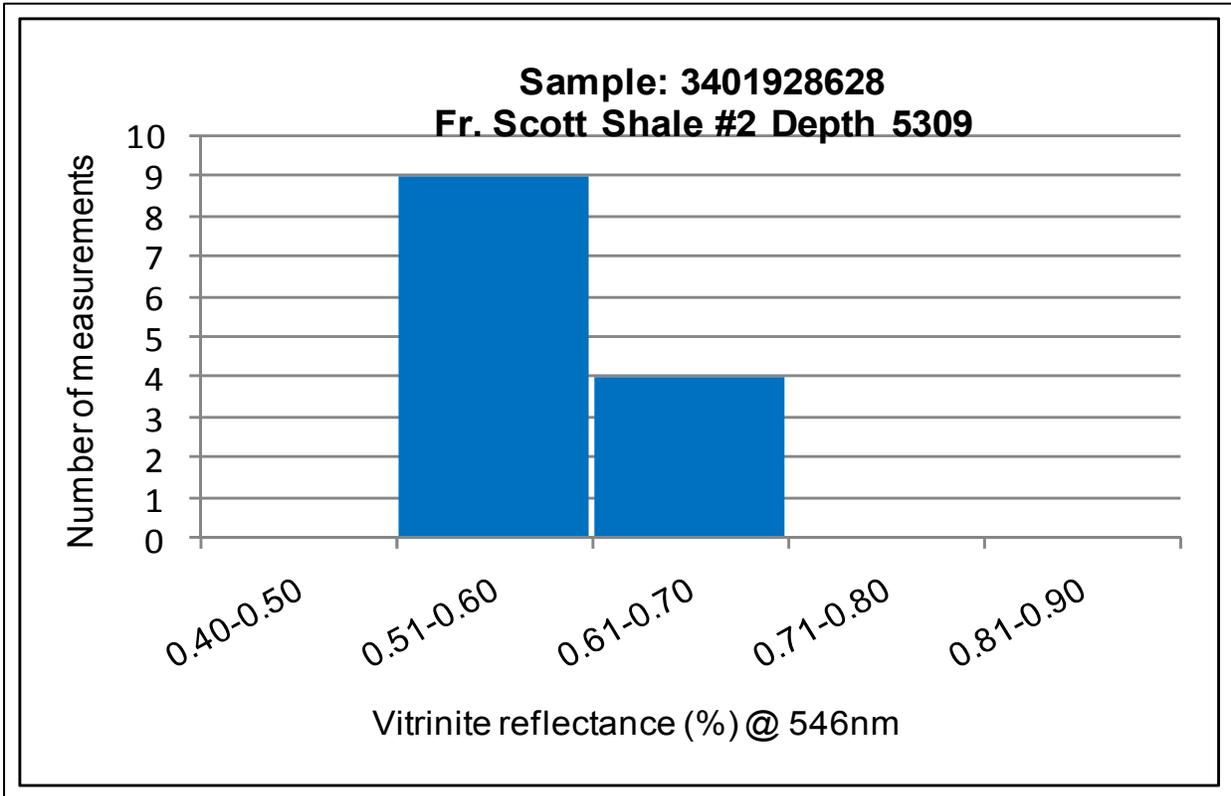
Figure 39. Vitrinite reflectance histogram for 5309-5313 ft. interval well 15-119-21194.
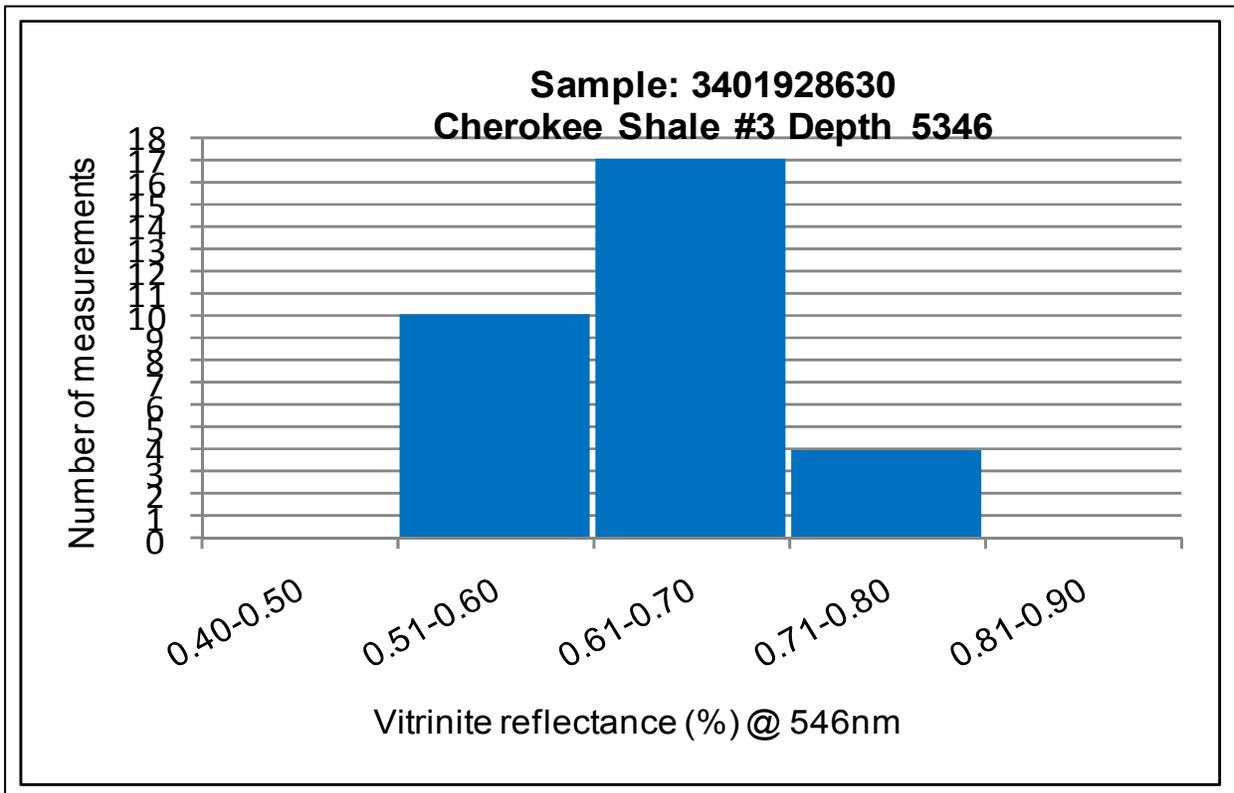
Figure 40. Vitrinite reflectance histogram for 5346-5350 ft. interval in well 15-119-21194.
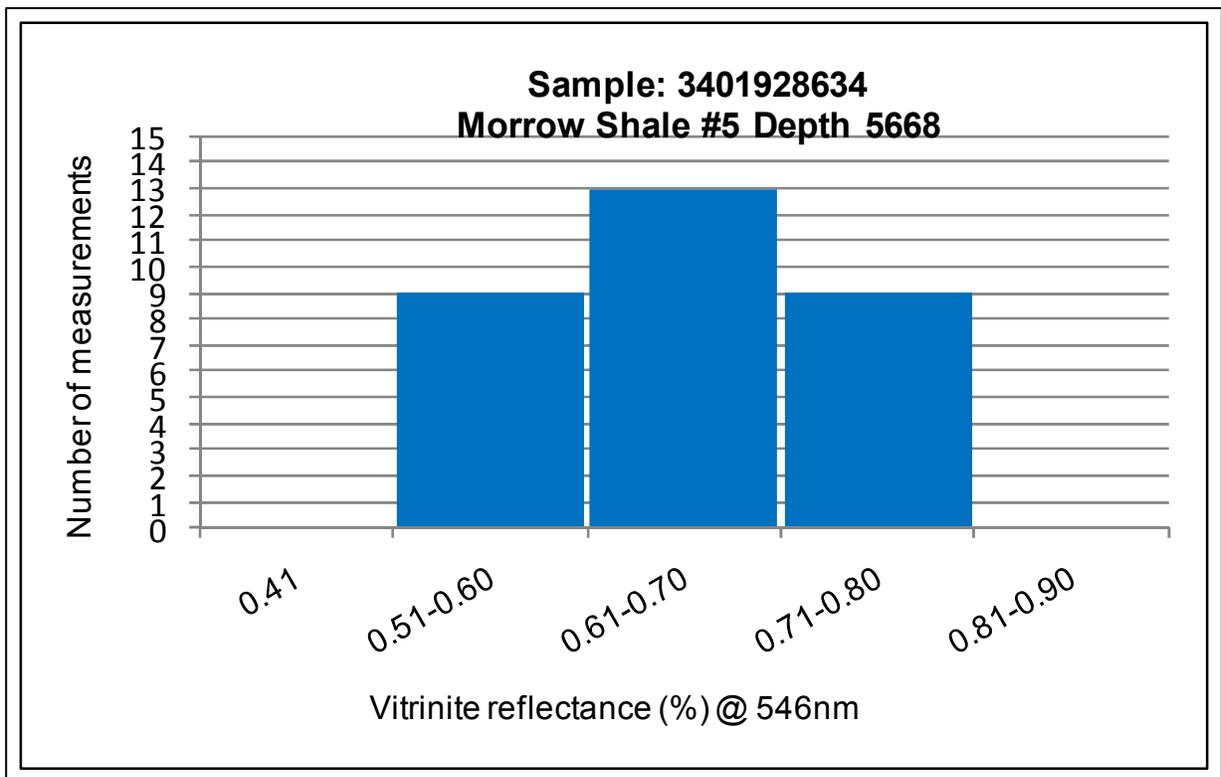
Figure 41. Vitrinite reflectance histogram for 5668-5671 ft. interval in well 15-119-21194.

CHAPTER 4 – DISCUSSION

4.1 Kansas Shale Properties

The following sections outline in detail the geochemical characteristics of the shales that were analyzed in this study. Studying the organic shales in depth will provide evidence that will show whether or not they have the potential for being a source rock. The organic richness, hydrocarbon potential, thermal maturity, and burial history are the analyses that were employed in this study that should give a good indication for the possibility of producing oil in this area.

The TOC values that were analyzed in this study proved to be sufficient enough for hydrocarbon generation potential. The leanest 1.26% by weight (Table 3) still falls within the category of "Good" according to Peters et al (2006). The values ranged overall "Good to Excellent" with the highest being 13.33% by weight (Table 3). The bulk of the values fell within the category of "Very Good to Excellent". A significant amount of values fell within the "Excellent" range. The high TOC values were not from a single formation, but rather were spread throughout all of the different formations. Out of the eight formations that were analyzed only two of the samples fell below the range of "Excellent", with the formations being the Ft. Scott and Morrow Shales. There was an abundance of TOC within this study for hydrocarbon generation. The next step was to look at kerogens, and thermal maturity.

The results for pyrolysis can be seen in Tables (3 and 5). Peak S1 plotted very low on a majority of the formations sampled, indicating that there has been little to no hydrocarbons produced. Peak S2 plotted very high indicating that there is still a lot of hydrocarbon left to be produced. When comparing S1/S2 from this study, all of the analyses fell within the category of "Poor to Excellent" (Figure 11). Most of the samples that did fall into the "Excellent" range

were however not mature enough to have produced hydrocarbons. There are two samples that did however fall within this range of "Excellent", and coupled with the other results may have produced some hydrocarbons.

The shales that have been analyzed can be put into several different graphs that aid in their interpretation. The Geochemical Logs (Figures 42 and 43) show a variety of different characteristics of each shale. This shows several different values, with each one plotted against depth. The first log is TOC, showing the range from good to excellent based on a percent. The next log is hydrocarbon potential (S2), which plots the remaining hydrocarbons within the shale. The next log is organic matter type (I, II, III, IV), which plot at type II and III. The last log that is plotted shows normalized oil content, which all plot as low maturity source rock.
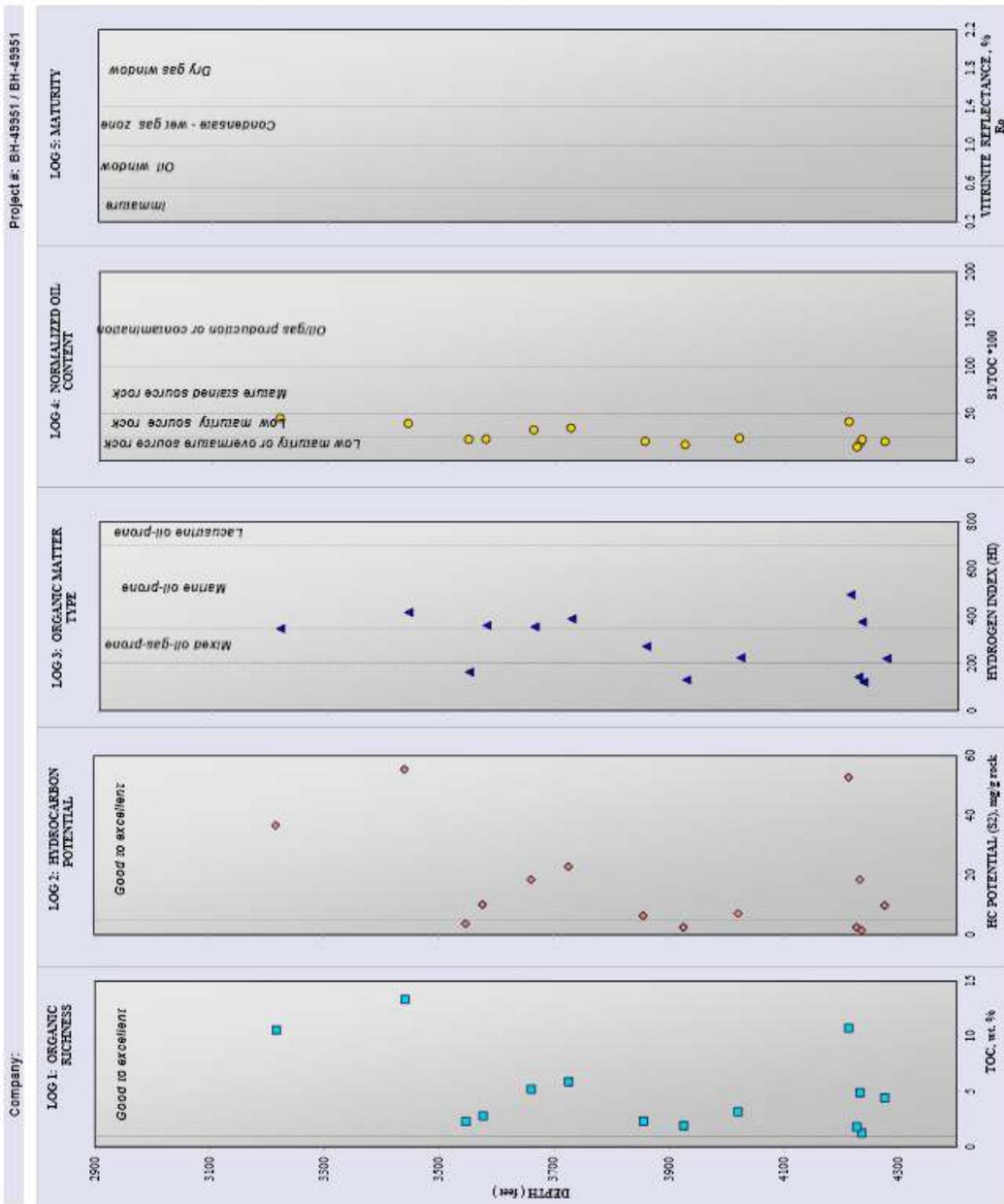
Figure 42. Geochemical Log of TOC, remaining potential (S2), kerogen type (HI), normalized oil content, and calculated vitrinite reflectance. Analyses from Ness and Ellis counties.
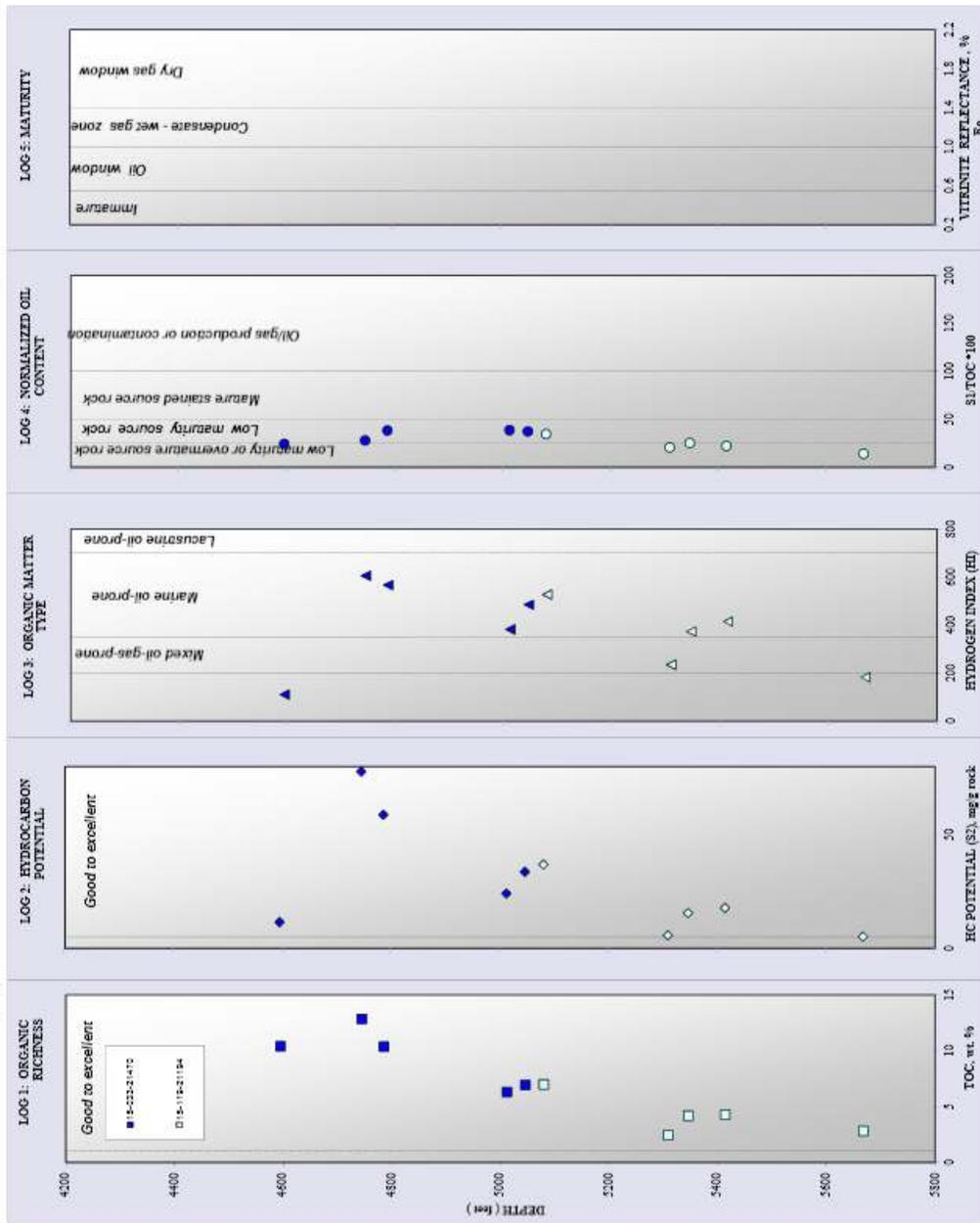
Figure 43. Geochemical Log of TOC, remaining potential (S2), kerogen type (HI), normalized oil content, and calculated vitrinite reflectance. Analyses from Meade and Comanche counties.

Tmax can also be plotted in several different ways that show maturity of the sample versus the type of kerogens (Figures 44-47). This is another useful plot for determining whether or not the kerogens are mature enough to have produced hydrocarbons. These graphs are plotted in two different ways. The first is HI versus Tmax (Figures 44 and 45). This graph shows what type of kerogens that are present (Type II and III in this study), plotted against Tmax, to show whether or not they were mature or not. In the case of this study, they were not mature enough in most cases. The second plot (Figure 46 and 47) is Production Index (PI) which is S1/(S1+S2), versus Tmax. This indicates the average oil produced, with remaining potential left, plotted against Tmax to show its maturity. These all plot within the immature range, with one exception. The majority of the Tmax values fall into the "Immature" category (Figure 12). This indicates that the formations sampled are not mature enough to have produced hydrocarbons.
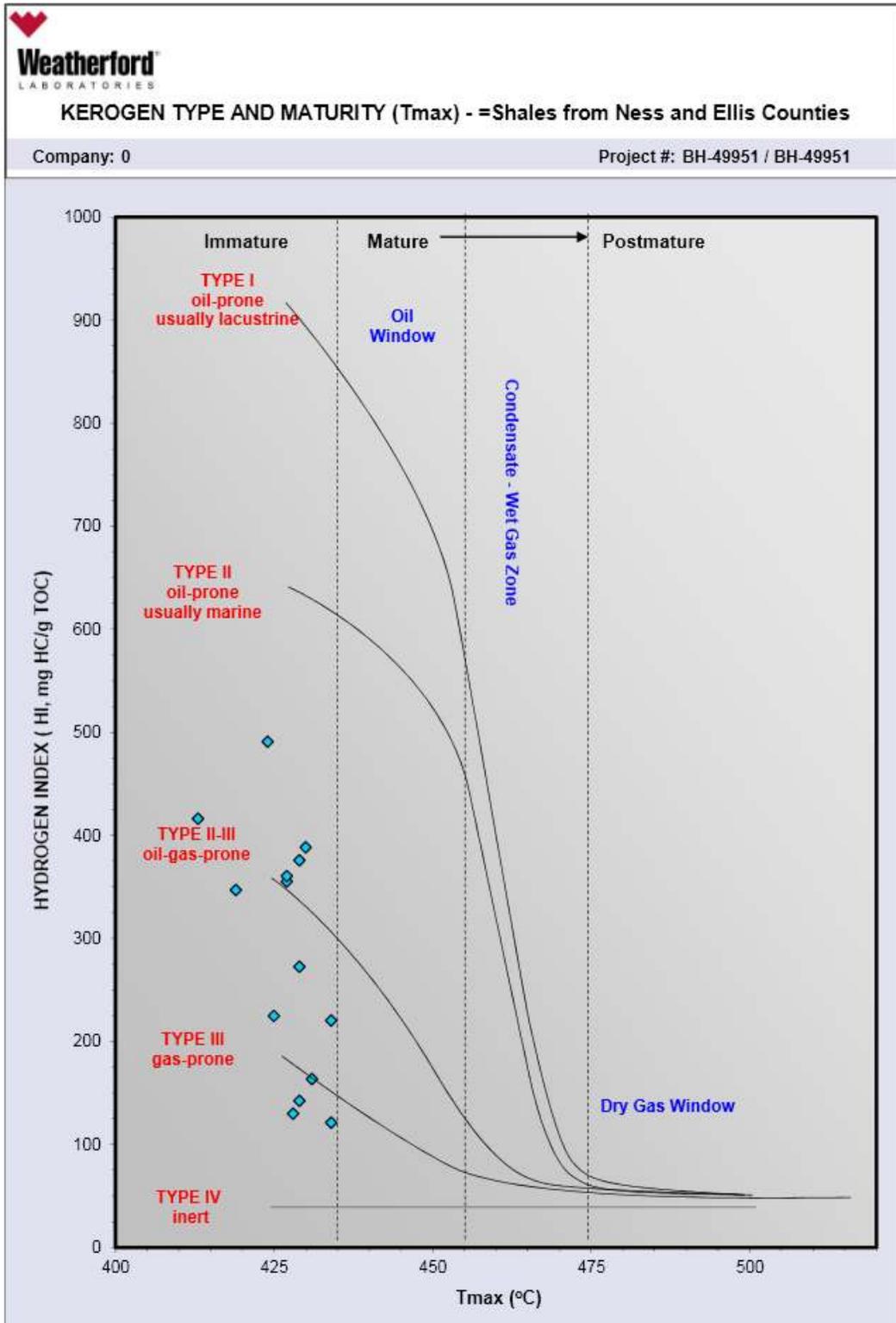
Figure 44. Kerogen type and maturity. Analyses from Ness and Ellis counties.
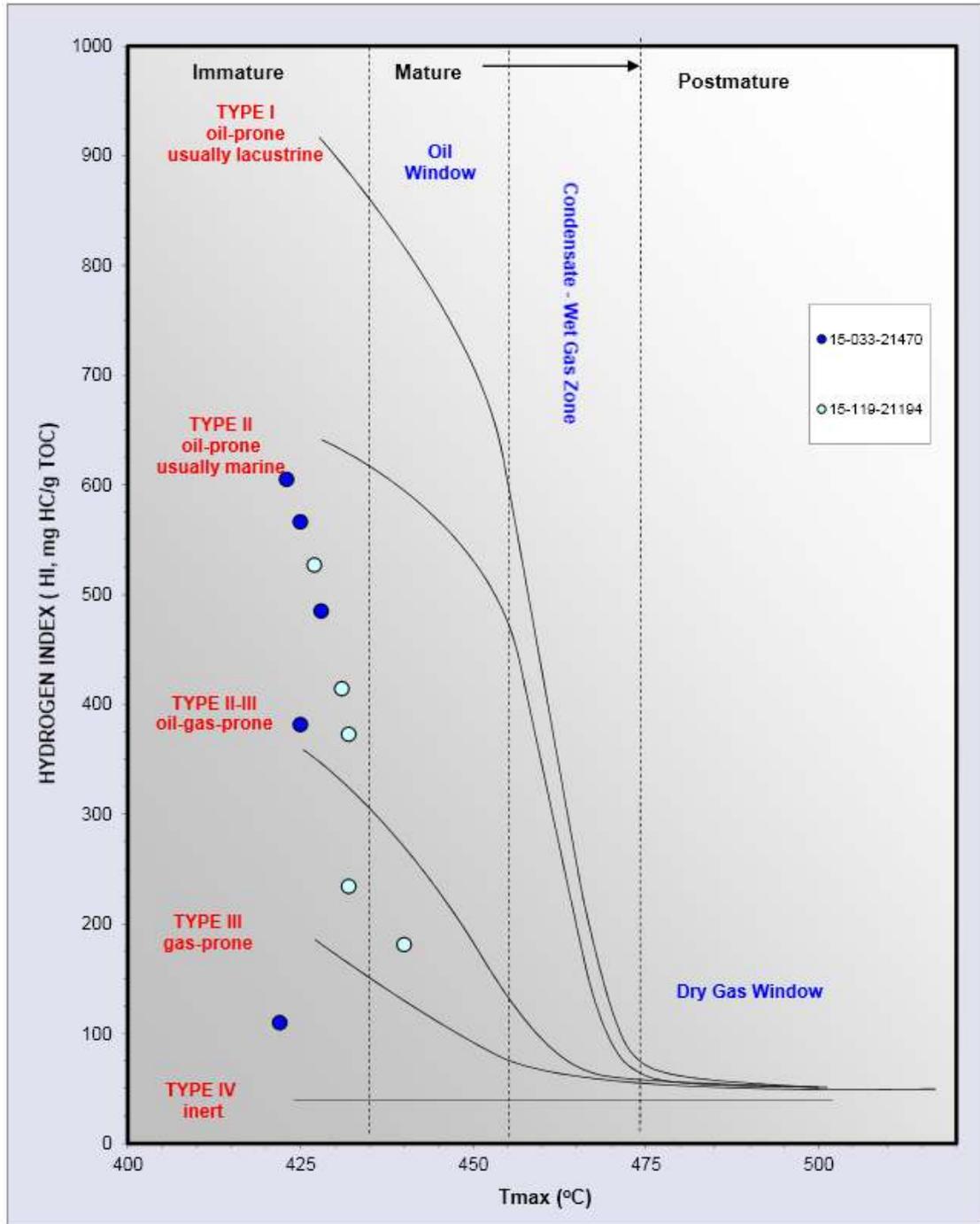
Figure 45. Kerogen type and maturity. Analyses from Meade and Comanche counties.
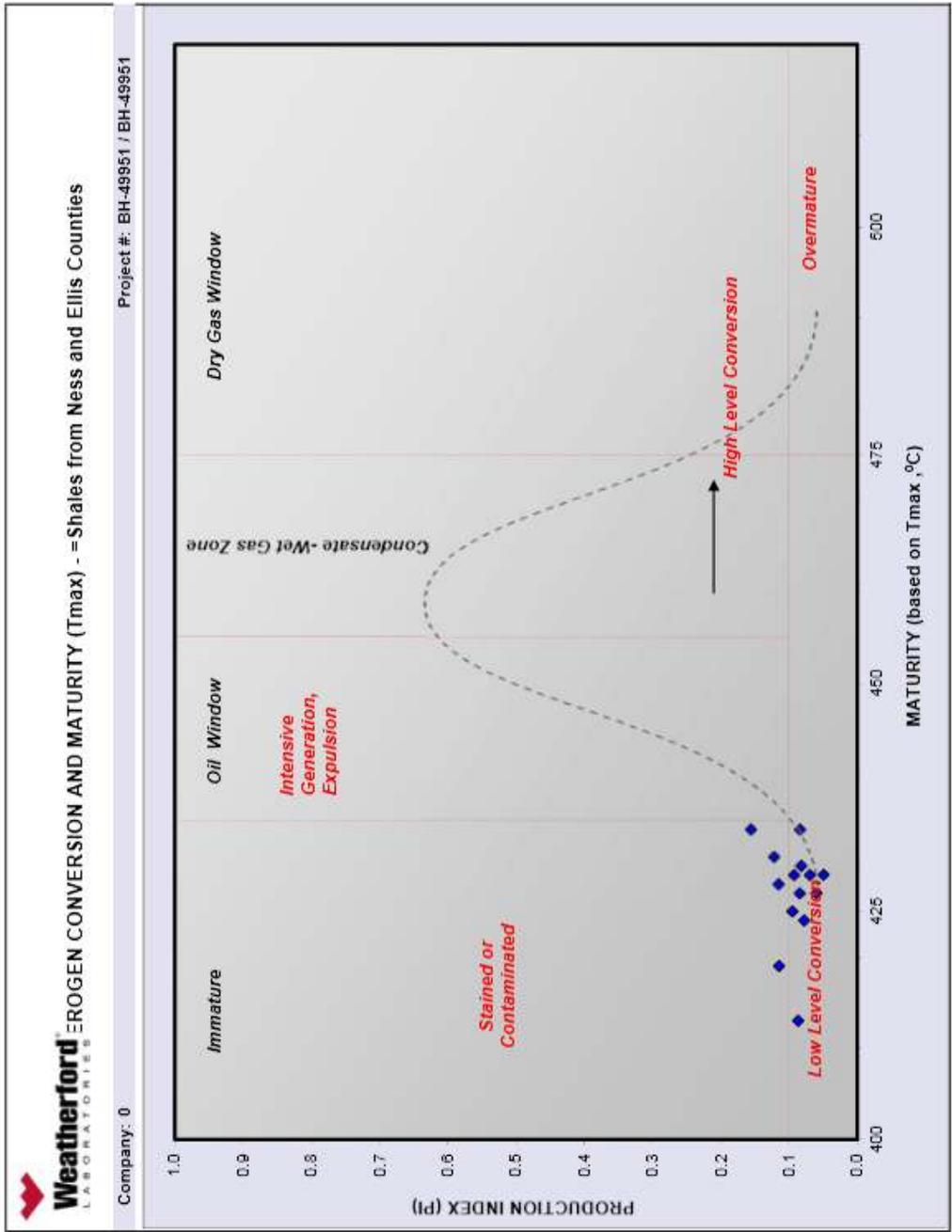
Figure 46. Kerogen conversion and maturity. Analyses from Ness and Ellis counties.

Figure 47. Kerogen conversion and maturity. Analyses from Ness and Ellis counties.

On the van Krevelen diagram, the kerogens plot in Type II and III (Figures 48 and 49). These types are oil prone, and gas prone. On the S2 versus TOC diagram (Figures 50 and 51) the kerogens plot in Types II and III, which also indicates that they are oil prone, and gas prone. The S2 versus TOC diagram is a better way to look at the depositional environment so that the points are not scattered as much, like they are in the standard van Krevelen plots. This puts all of the samples within the depositional range of anoxic-oxic marine or laucustrine to, mildly oxic and coal swamp deposition. They are also mixed marine, and terrestrial.
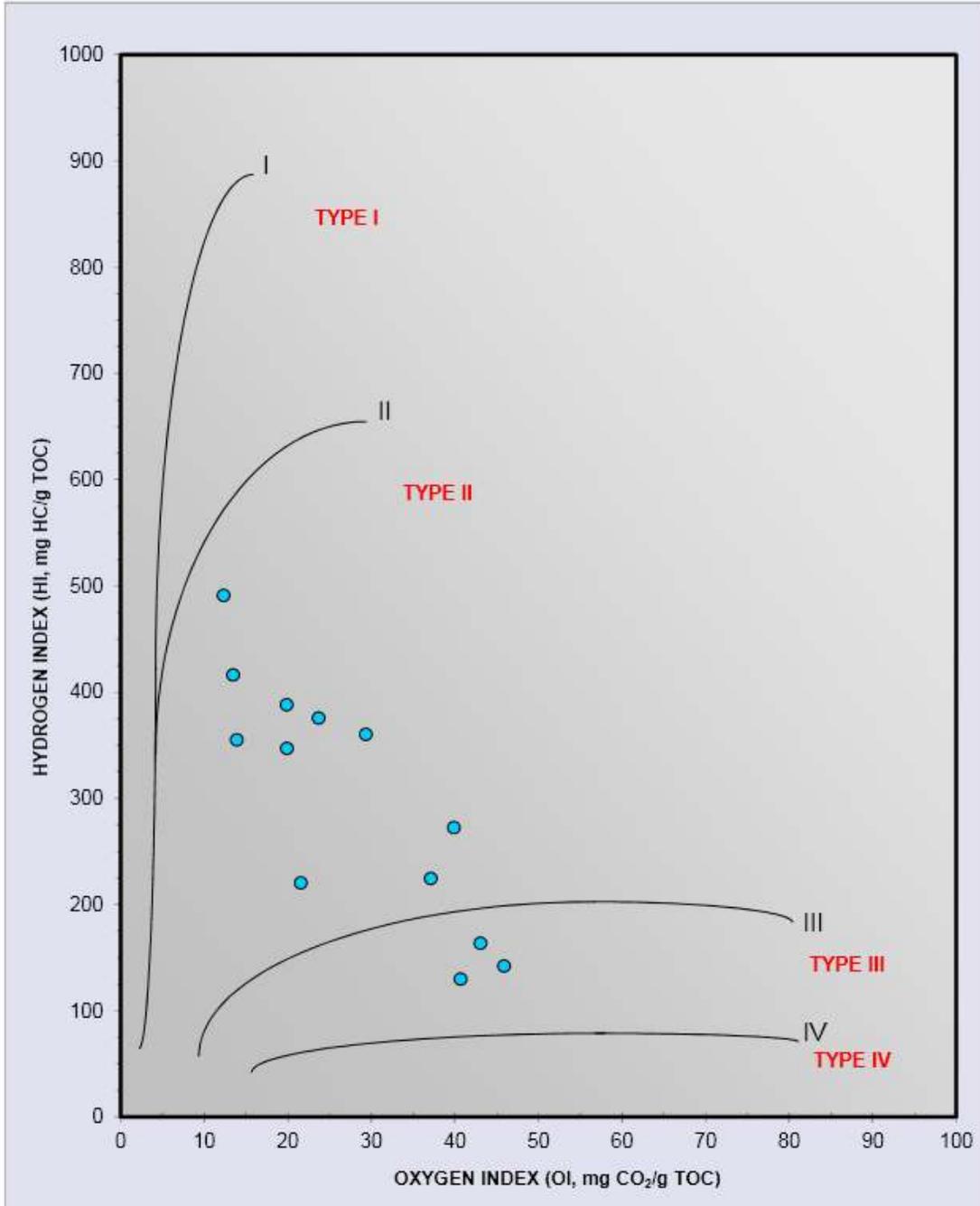
Figure 48. Kerogen type. Analyses from Ness and Ellis counties.
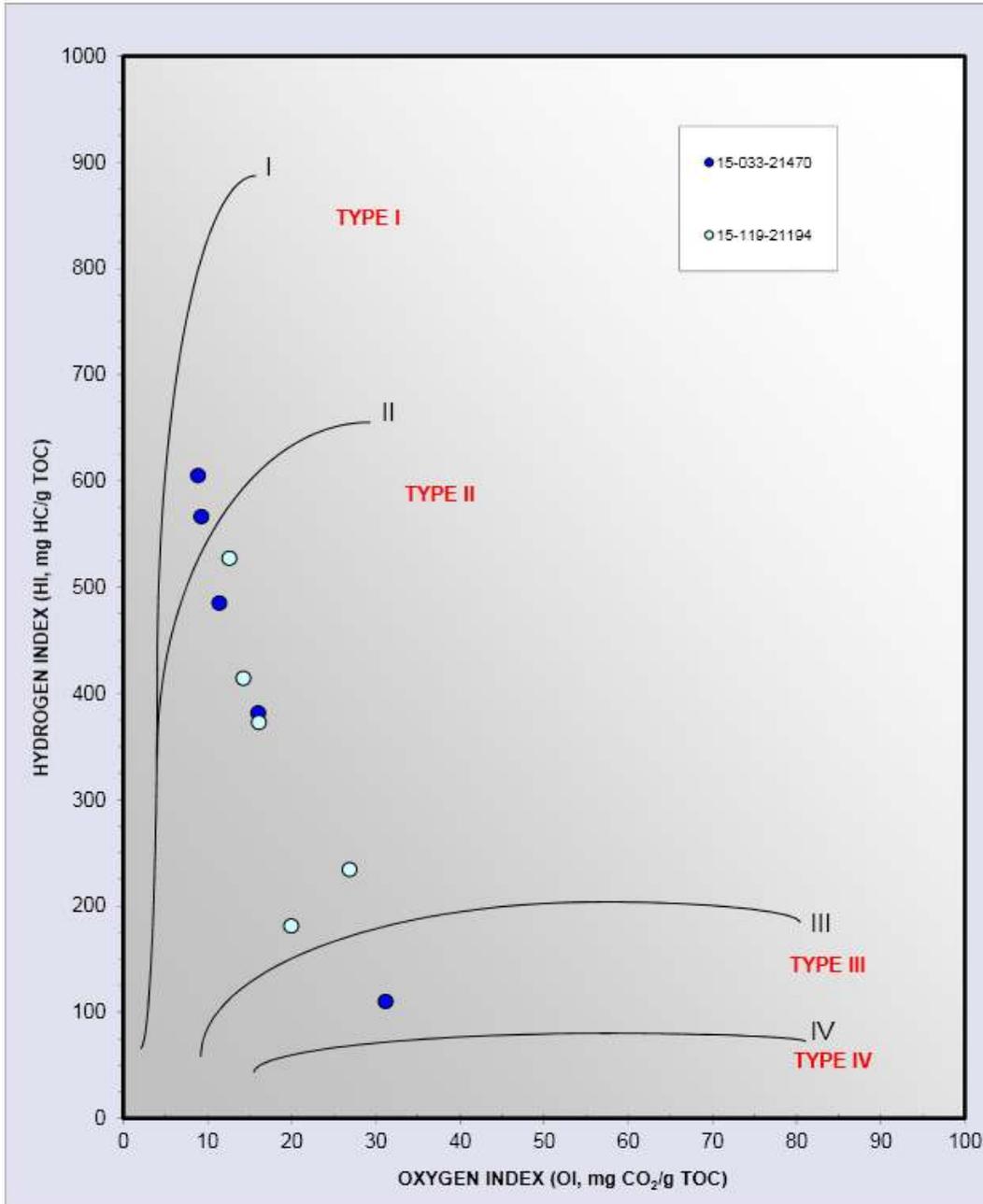
Figure 49. Kerogen type. Analyses from Meade and Comanche counties.
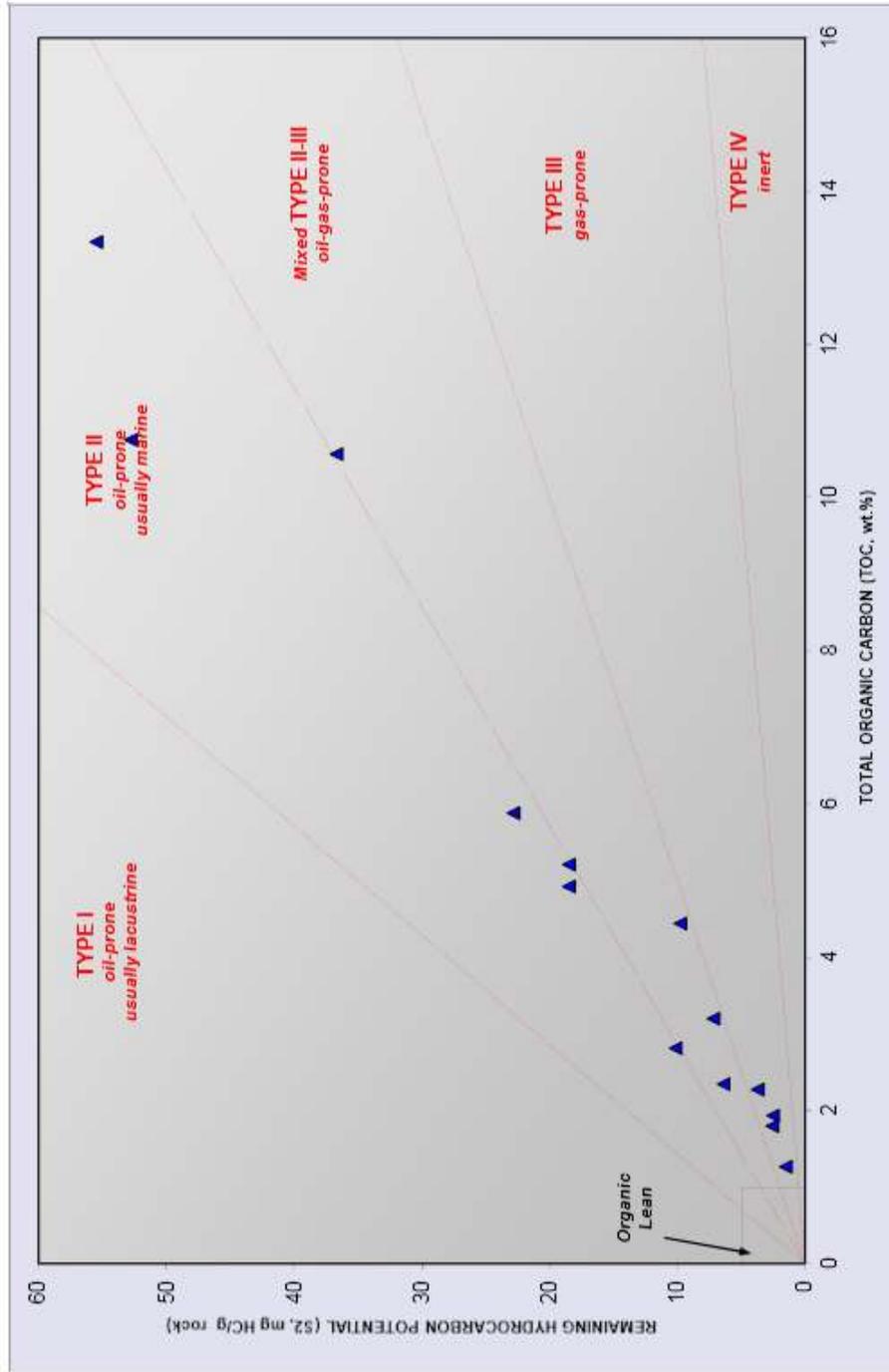
Figure 50. Kerogen quality. Analyses from Ness and Ellis counties.
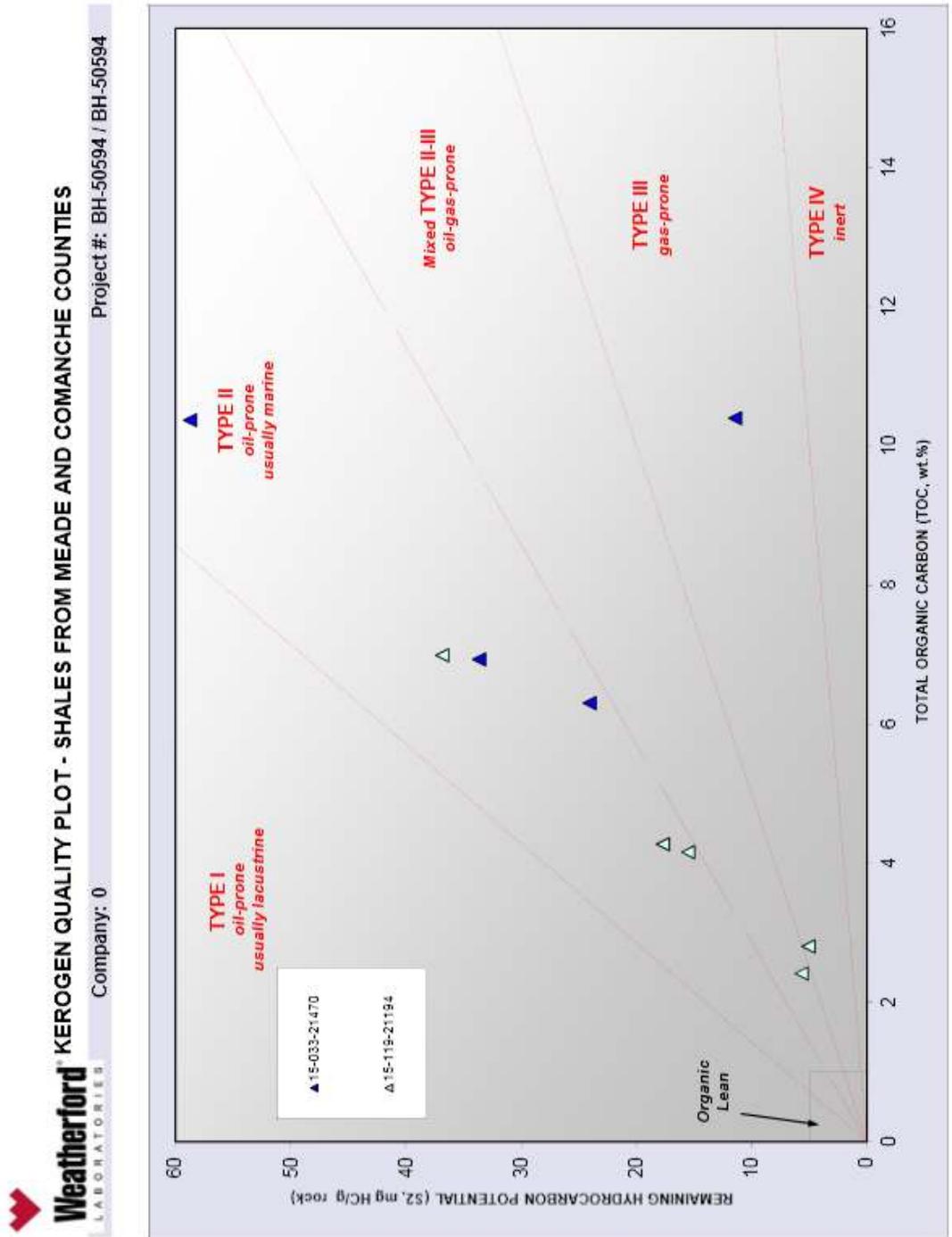
Figure 51. Kerogen quality. Analyses from Meade and Comanche counties.

Vitrinite reflectance can be broken into different categories depending on its percentage (Figure 12). Eight samples were analyzed for their vitrinite reflectance for this study (Figures 34-41). Out of the eight that were analyzed, only two fall within the category of "Mature" according to Peters et al (2006). The other six samples fall within the "Immature" category. The two samples that fall within the "Mature" range are early mature, and are just at the beginning peak of the oil generation window.

4.1.1 Stevens Unit 'SMU'

While most of the shales analyzed fall within the immature range, there are two shales that are close to being mature enough to produce hydrocarbons. The Stevens Unit 'SMU' 316 (15-119-21194) in Meade county did have adequate vitrinite reflectance numbers to have potentially produced hydrocarbons. Within the Cherokee formation, the TOC was 4.16, S1 was 1.05, S2 was 15.52, Tmax was 432 degrees C, and the vitrinite reflectance was 0.63%. According to Peters et al (2006) these numbers put this Cherokee shale in the range of early mature, except for the Tmax value. Had the Tmax value been 3 degrees C higher, then it would have been mature enough to produce hydrocarbons according to Peters (2006). This is such an insignificant difference that it is still probably mature to early mature. I still believe that this shale formation did produce some hydrocarbons, adding to the oil that was already there. This may not have been commercial amounts produced out of this shale, but the evidence is very strong towards it being a source. The only way to actually prove this would be to check biomarkers within the oil.

The Morrow Shale in the same well also had high vitrinite reflectance numbers, suggesting its maturity. Within the shale formation, the TOC was 2.81, S1 was 0.40, S2 was 5.09, Tmax was 440 degrees C, and the vitrinite reflectance was 0.65%. According to Peters et

al (2006) these numbers put this shale in the range of early mature to peak mature. The only value that sets this shale back, is the S1 with a "Poor" value. The rest of the values do however suggest that this was a mature source rock, and that it did produce some oil. This is along the same lines as the Cherokee shale though, where it probably did not produce commercial amounts of hydrocarbons, and probably just added to what was already there. Again the only way to check for sure would to analyze the biomarkers.

Even with the hydrocarbons that were generated from the Stevens Unit 'SMU', the second hypothesis of oil migration from the Anadarko basin in Oklahoma proved to be correct. There are a significant amount of commercial hydrocarbons in Kansas, and they did not come from the source rocks that are currently there. The migration northward from Oklahoma is credible, considering the amount of time that the hydrocarbons had to travel, which is at least several hundred million years.

4.1.2 Discussion of Bostick's Figure.

According to Bostick's (1979) figure from Chapter 1 (Figure 14), the source rocks within the study area could have potentially reached thermal maturity. The source rocks are shallow, however they are old enough, and could have potentially reached high enough maturity to produce hydrocarbons. The source rocks range in age from 440 ma to 290 ma. Early Permian source rocks could have been subjected to much lower temperatures for a significant amount of time, and still have produced hydrocarbons.

This figure was part of the basis for which we came up with the hypothesis for potential source rocks within western Kansas. Geologically the study area fit into the model perfectly. There was more than enough time for the organic shales to be subjected to enough heat to make them thermally mature.

Vitrinite reflectance values did not reach 0.7% in this study. They were within the early mature range for hydrocarbon generation. There were several that were close to Bostick's (1979) range for hydrocarbon generation window, but did not quite reach high enough temperatures.

The results of the study do not support Bostick's model for maturity to be reached at lower temperatures if enough time is available. Because vitrinite reflectance mirrors hydrocarbon generation, time must not be an important factor. Temperature remains the key factor in hydrocarbon generation. According to the results from vitrinite reflectance, most of the shales were right on the verge of being thermally mature. Had the temperatures been higher, then there is a good possibility that the Kansas organic shales could have sourced significant hydrocarbons.

CHAPTER 5 – SUMMARY AND CONCLUSIONS

This study shows one of the many benefits of combining geochemistry and subsurface mapping in basin evaluation. The shales analyzed in this study are dark-gray to black, organic-rich, and were deposited in anoxic-oxic water conditions. They range in age from Cambrian-Ordovician through the Permian. Their depositional environments are similar, in that they are marine and deposited several hundred feet deep. Their current stratigraphic depths range from 3,500-4,500 ft. deep in Ellis and Ness Counties. In Meade and Comanche Counties, their depths range from 4,500-5,600 ft. deep. The average shale is five to twenty feet thick.

The shales in Ellis and Ness proved to be extremely organic-rich, however they were thermally immature. TOC values ranged from 1.26% up to 13.33%, which is very high for the average source rock. Tmax values ranged from 413 degrees C to 434 degrees C, making them immature. Vitrinite Reflectance values were 0.56%, 0.59%, and 0.59%, confirming that they were thermally immature. All of these values combined can make a definite answer that the oil in the reservoirs did migrate northward from the Anadarko basin of Oklahoma.

The shales in Meade and Comanche proved to be extremely organic-rich, the maturity of some of the source rocks is on the verge of potentially producing some hydrocarbons. TOC values ranged from 2.41% up to 12.85%, which is also very high for the average source rock. Tmax values ranged from 422 degrees C to 440 degrees C, making the majority of them immature, however some of them did reach temperatures high enough to make them mature. Vitrinite Reflectance values were (0.44%, 0.58%, 0.59%, 0.63%, and 0.65%). The first three values are thermally immature, but the last two values are early mature to peak mature, respectively. The last two values are of great interest in this study. It is probably safe to say that these two shales (Cherokee and Morrow) did produce some hydrocarbons. When looking at the

kerogens from these two shales, they fall into type II and III, making the hydrocarbon generation gas-oil. The next step to analyzing their oil and gas generation potentials would be to check for biomarkers within the oil.

There is an obvious, and much expected general increase in thermal maturity of the shales from the north to the south in western Kansas. This can be expected because of the deepening of the shales towards the south, and the Anadarko basin. In the northern counties within this study (Ness and Ellis), the rocks are on average about a thousand feet shallower compared to the southern counties (Meade and Comanche). The shales in the southern counties did exhibit higher Tmax values, as well as higher vitrinite reflectance values. These counties are very close to the Anadarko basin, and may have been subjected to higher temperatures coming out of the basin.

This study proves that the hypothesis concerning the migration of oil from the Anadarko basin in Oklahoma is correct. The shales in Ness and Ellis are not thermally mature enough to produce hydrocarbons. Most of the shales in Meade and Comanche are also thermally immature. This study also proves that the hypothesis concerning hydrocarbon generation from shales currently present within western Kansas is also correct. There was probably not a commercial amount of hydrocarbons that were produced, but the amount of evidence from analyses shows that there was some generation of hydrocarbons.

This study is important to other petroleum geologist's investigating similar basins to western Kansas. If there are no other deep, organic, hydrocarbon rich basins surrounding the basin being evaluated, then there would probably not be any need to explore in that area. The bulk of the oil in Kansas did migrate north, and it has been enough to make Kansas a valuable

economic region. Even though western Kansas did produce hydrocarbons, they were minimal and could not prove to be economical.

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Appendix A - FID Responses

Lab ID: 3401866550, Client ID: 15-135-24253, Prep: NOPR
Well Name: Shale No. 1, Depths: 4020.00-4024.00

S1: 0.76
S2: 7.18
S3: 1.19
Tmax: 425
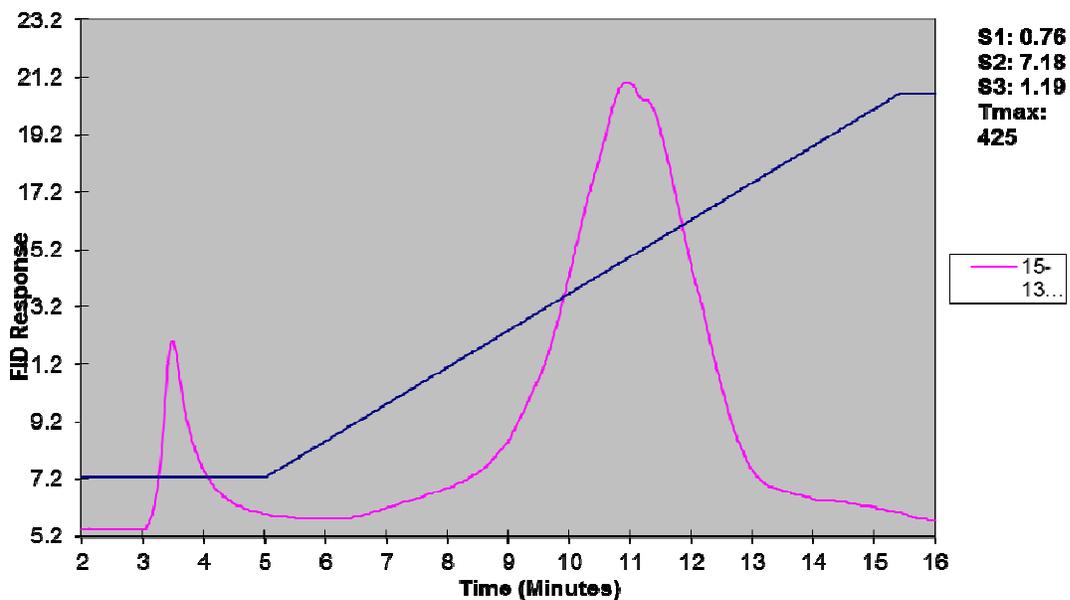
Lab ID: 3401866544, Client ID: 15-051-25233, Prep: NOPR
Well Name: Shale No. 1, Depths: 3216.00-3220.00

S1: 4.75
S2: 36.68
S3: 2.10
Tmax:
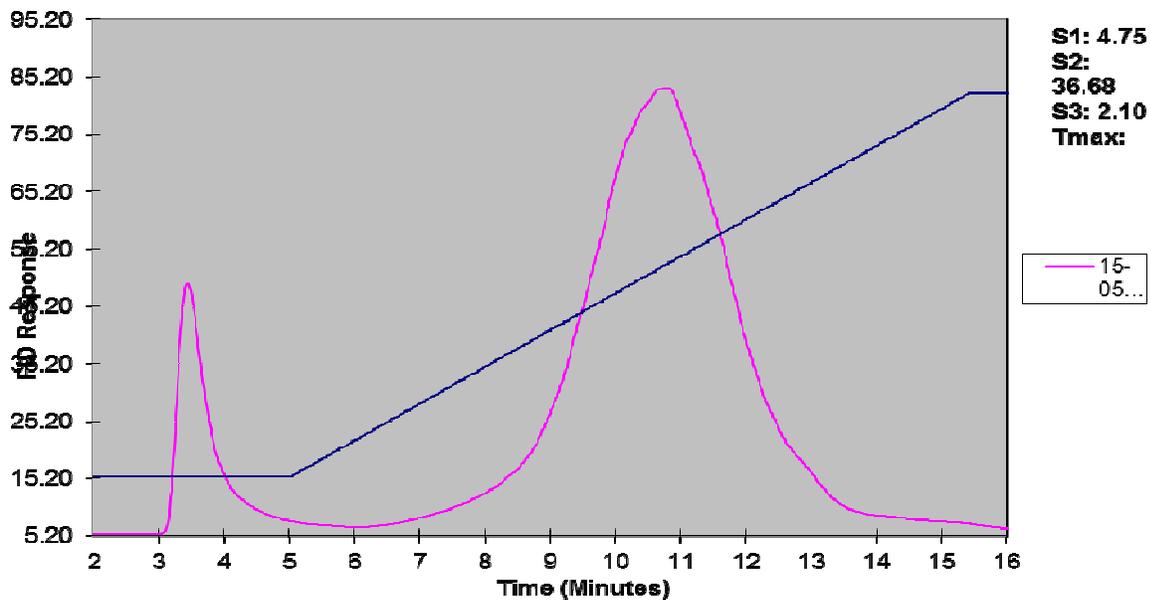
Lab ID: 3401866546, Client ID: 15-135-24314, Prep: NOPR
Well Name: Shale No. 1, Depths: 3855.00-3860.00

S1: 0.48
S2: 6.38
S3: 0.93
Tmax: 429
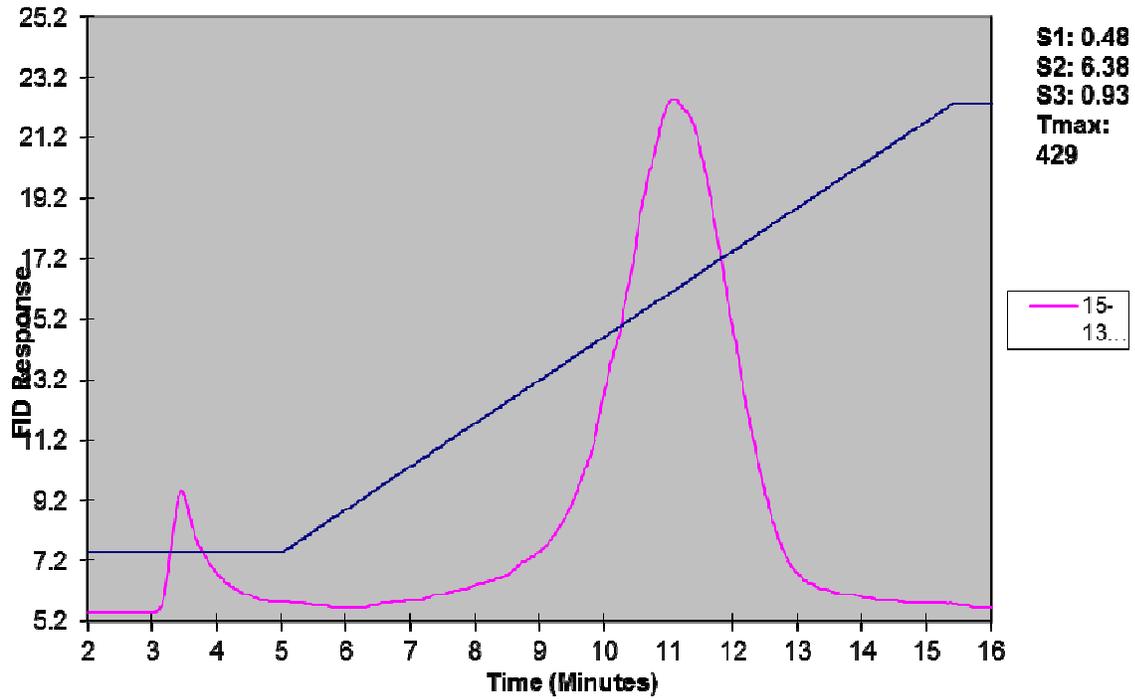
15-13…

Lab ID: 3401866548, Client ID: 15-135-2425, Prep: NOPR
Well Name: Shale No. 1, Depths: 3925.00-3930.00
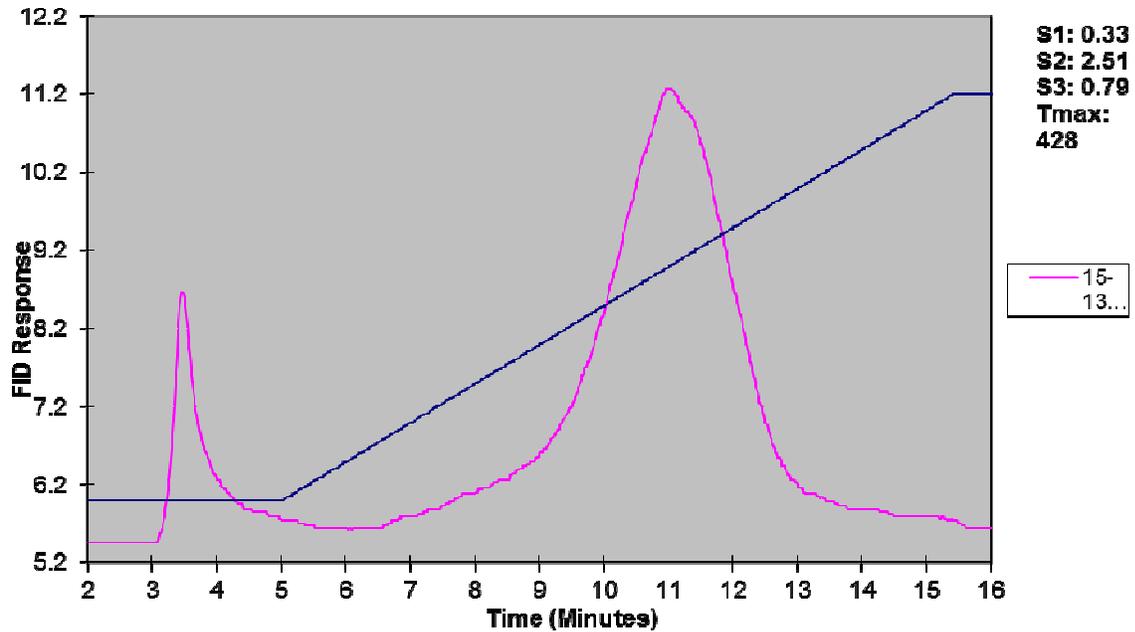

S1: 0.33
S2: 2.51
S3: 0.79
Tmax: 428

15-13…

Lab ID:3401928626, Client ID:Swope Shale #1, Prep:NOPR
Well Name:15-119-21194, Depth:5080.00
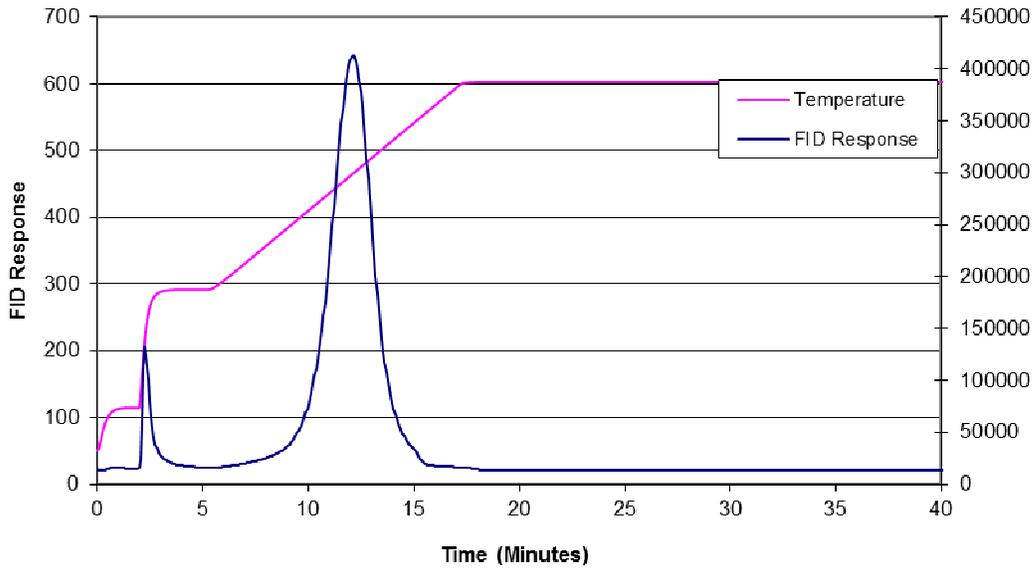
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Well Name:15-119-21194, Depth:5080.00
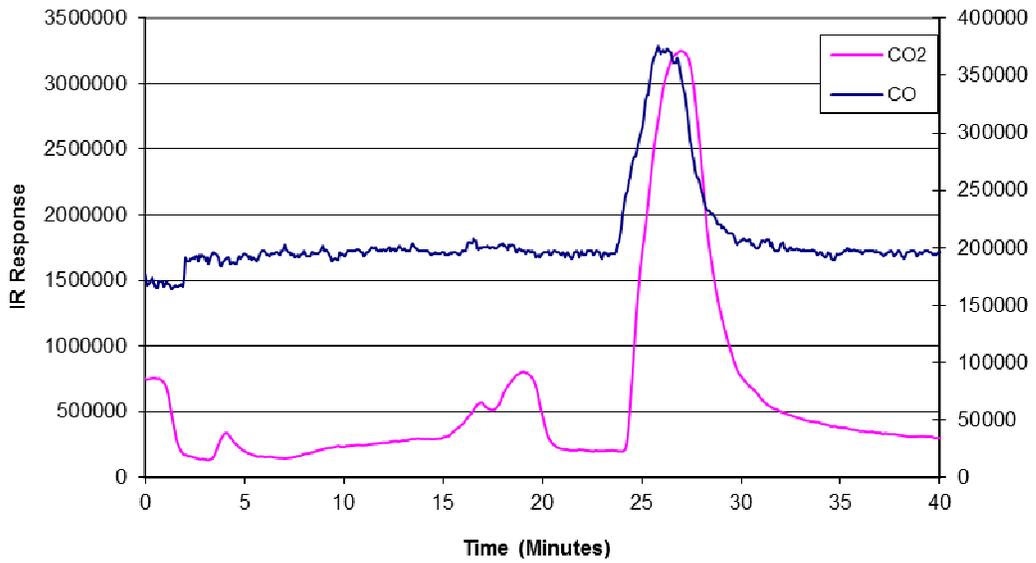
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Well Name:15-119-21194, Depth:5309.00
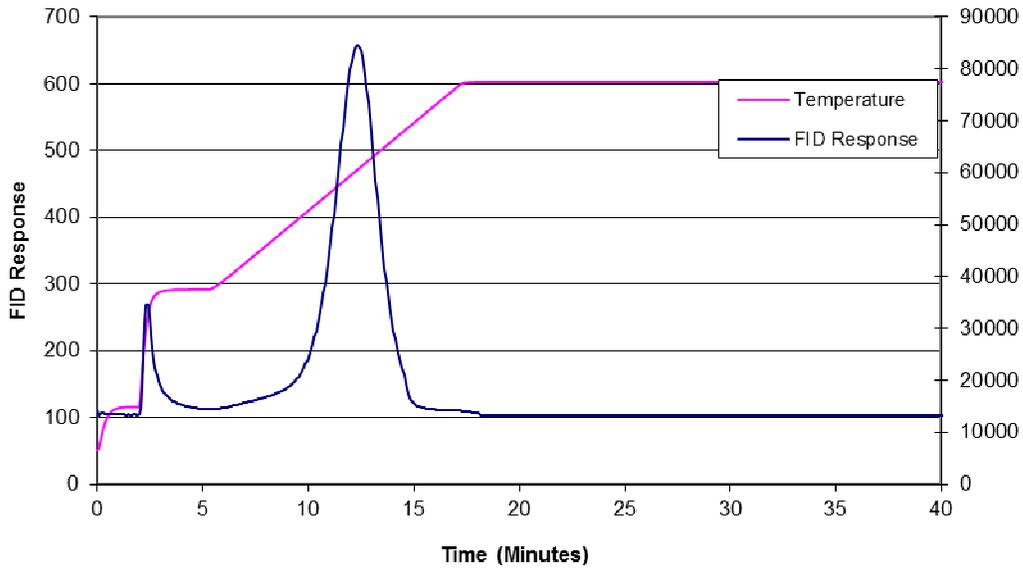
Lab ID:3401928628, Client ID:Fr. Scott Shale #2, Prep:NOPR
Well Name:15-119-21194, Depth:5309.00
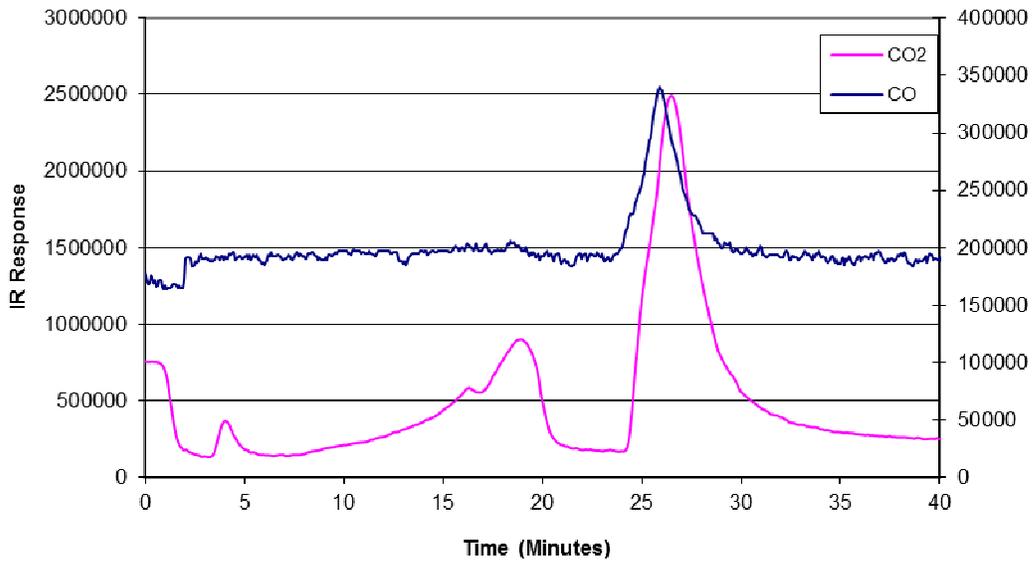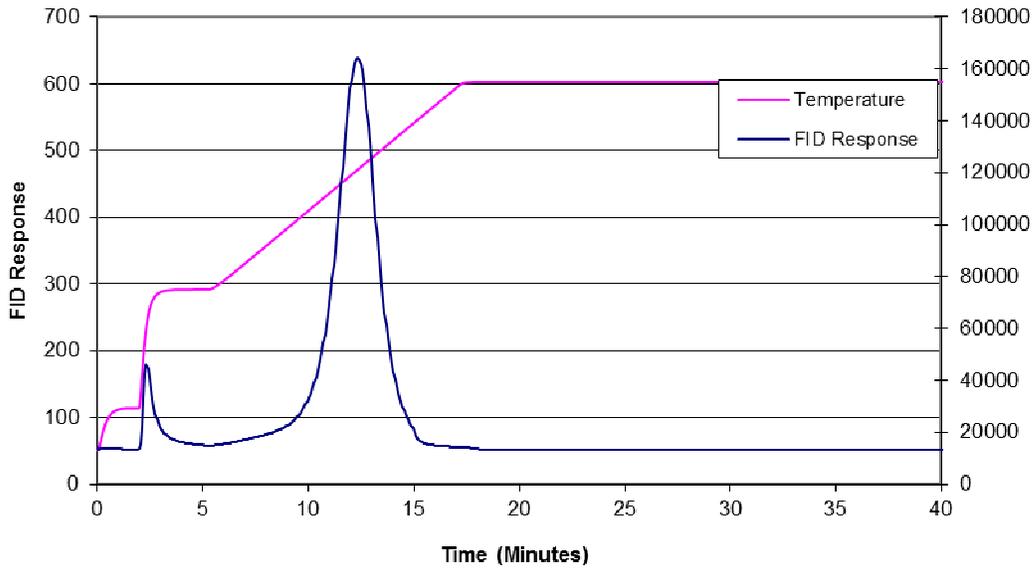
Lab ID:3401928630, Client ID:Cherokee Shale #3, Prep:NOPR
Well Name:15-119-21194, Depth:5346.00

Lab ID:3401928630, Client ID:Cherokee Shale #3, Prep:NOPR
Well Name:15-119-21194, Depth:5346.00

74
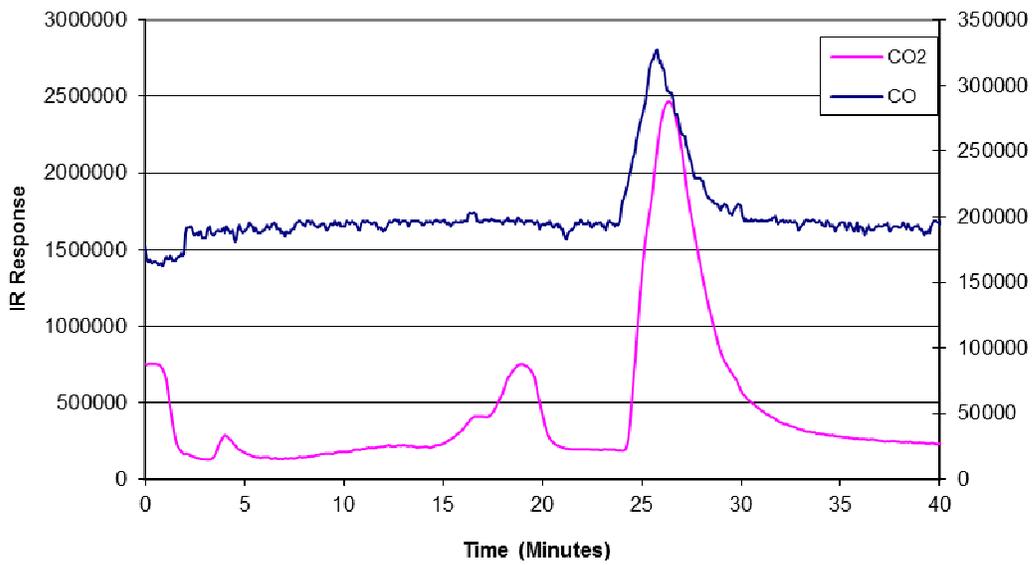
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Well Name:15-119-21194, Depth:5414.00

Lab ID:3401928632, Client ID:Cherokee Shale #4, Prep:NOPR
Well Name:15-119-21194, Depth:5414.00
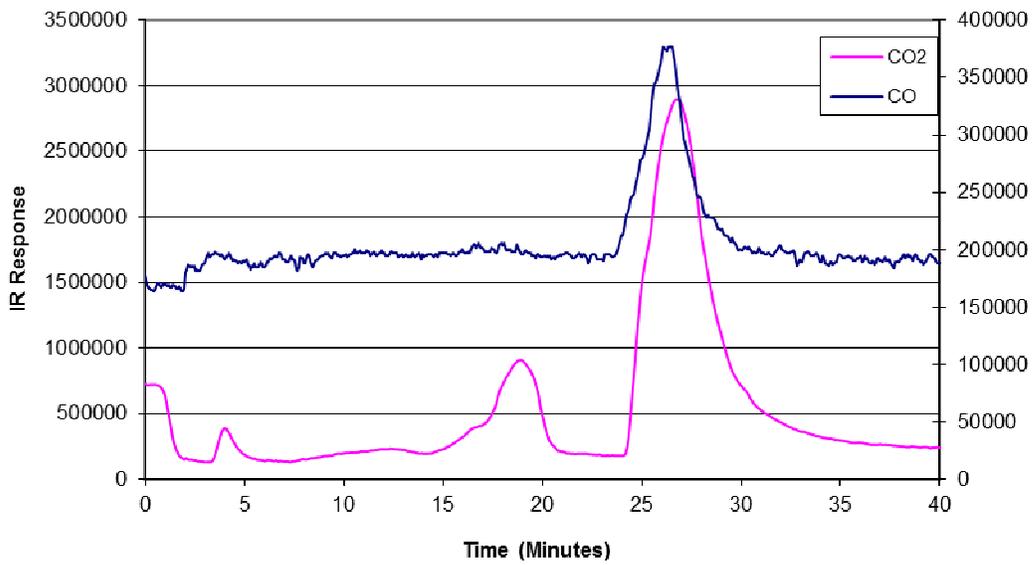
Lab ID:3401928634, Client ID:Morrow Shale #5, Prep:NOPR
Well Name:15-119-21194, Depth:5668.00
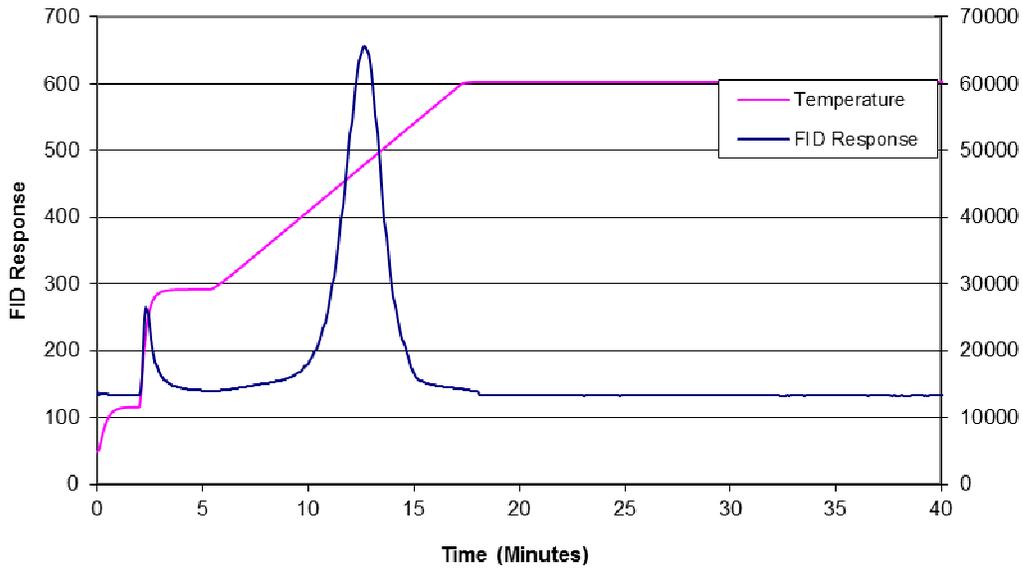
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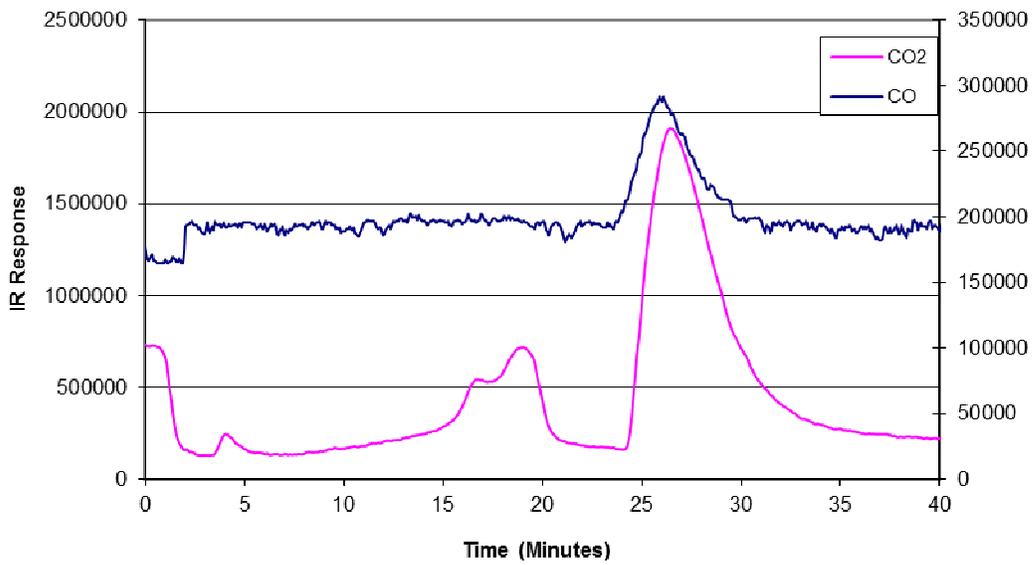
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Well Name:15-033-21470, Depth:4595.00
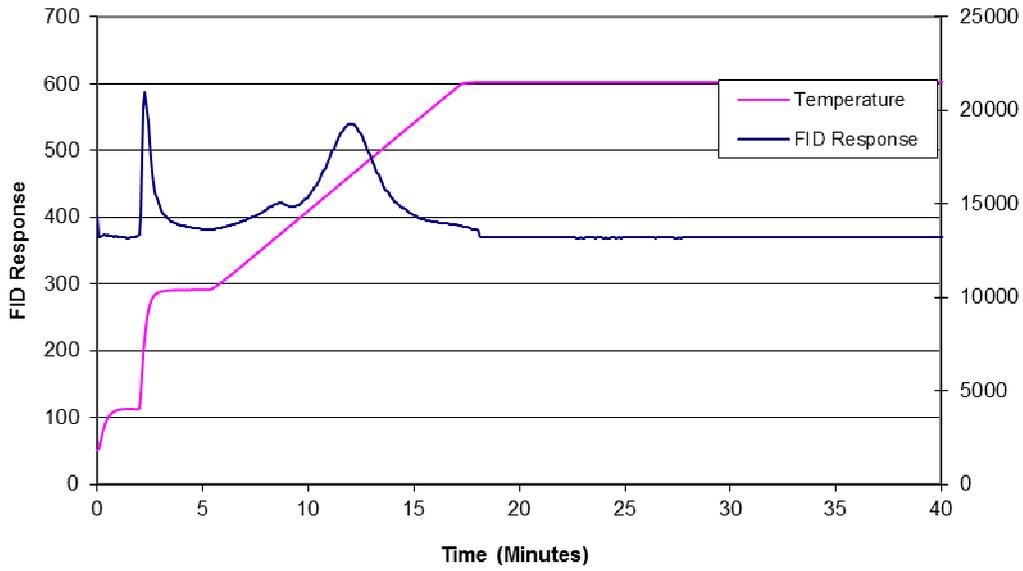
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Well Name:15-033-21470, Depth:4595.00
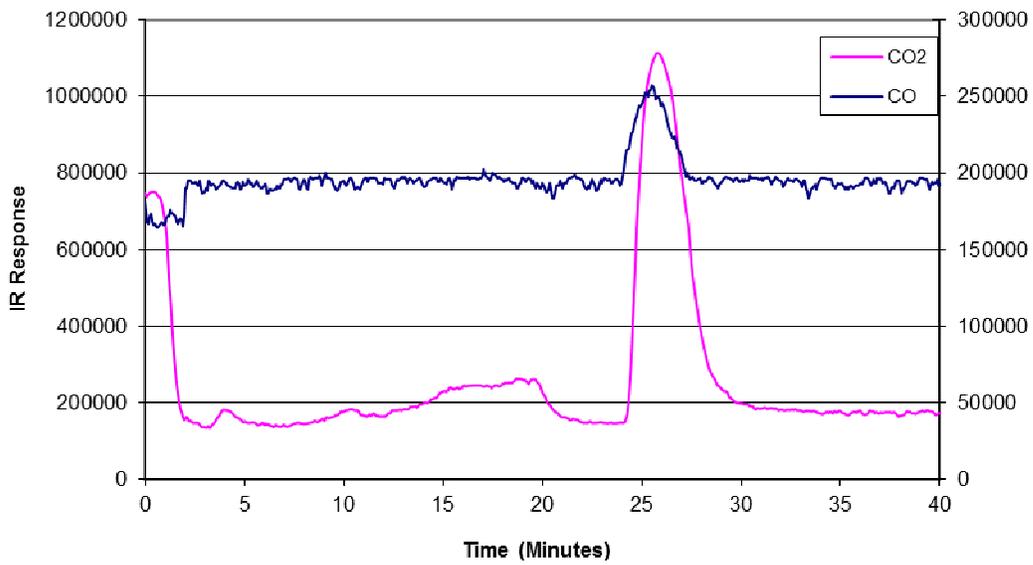
Lab ID:3401928638, Client ID:Stark Shale #2, Prep:NOPR
Well Name:15-033-21470, Depth:4745.00

Lab ID:3401928638, Client ID:Stark Shale #2, Prep:NOPR
Well Name:15-033-21470, Depth:4745.00