MAPPING AND GEOCHEMICAL ANALYSIS OF THE CHATTANOOGA SHALE AS A POTENTIAL SOURCE ROCK FOR KANSAS OIL

by

AUSTIN MCCOLLOCH

B.S., Kansas State University, 2013

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Geology
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2016

Approved by:

Major Professor
Matthew Totten

Copyright

AUSTIN MCCOLLOCH

2016

Abstract

Organic-rich shales were deposited over a large part of what is now North America during the Late Devonian. The Devonian-Mississippian Chattanooga (Woodford) shale is known to be an important petroleum source rock in many intracratonic basins of the Midcontinent (Lambert, 1993). North America in the late Devonian was located in the tropics (Woodrow et al., 1973), possibly in low southerly latitudes (Heckel and Witzke, 1979; Witzke and Heckel, 1988; Streel et al., 1990). This environment creates an organic-rich shale that is an important source of hydrocarbons throughout the Midcontinent.

Geochemical analysis of the Chattanooga shale using various techniques will provide additional information on oil-source rock correlations. This will provide insight on the potential of the Chattanooga Shale as a viable option for unconventional drilling. Handheld XRF analysis was conducted on well cuttings samples, Loss on Ignition was performed on a subset of those samples and mapping of the organic matter results of the two methods was completed.

Handled XRF still has the prospect for providing quick analysis on organic matter to be used as a determination of the quality of source rock. Although slightly reduced correlation has been found within this study compared to Willey (2015), the method has still proven viable for fracking targets to be determined on site and in a more efficient manner. Loss on Ignition results have correlated with TOC data better then XRF results making this method the better option for evaluating source rock potential. Mapping of these results provide the first known source rock potential map across Kansas and can be used by the industry for future exploration.

Table of Contents

List of Figures v
List of Tables vii
Acknowledgements viii
Dedication ix
Chapter 1 - Introduction 1
1.1 – Significance 2
1.2 - Geologic Setting 3
1.3 - Previous Work 6
Chapter 2 - Methodology 7
2.1 – Sample Selection 7
2.2 – Whole Rock XRF Analysis 8
2.3 – Loss on Ignition 9
2.4 – Petra Software 10
Chapter 3 – Results 11
3.1 – Whole Rock XRF Analysis 11
3.2 – Loss on Ignition 15
3.3 – Rock-Eval Pyrolysis 16
Chapter 4 – Discussion 22
4.1 - XRF: A Proxy for Organic Matter 22
4.2 – Loss on Ignition 24
4.3 – Total Organic Carbon 25
4.4 – Petra Mapping 27
Chapter 5 – Conclusions 34
Chapter 6 – Further Research 35
References 36
Appendix A - GeoMark Methodology 38
Appendix B - Full XRF Data Tables 40
Appendix C - Additional Figures 44

List of Figures

Figure 1 - Ongoing shale plays in the continental United States. 1
Figure 2 - Generalized cross-section showing stratigraphic relationships from the Chauauqua Arch into the North Kansas Basin modified from Amsden et al., (1967) 4
Figure 3 – Correlation chart comparing Kansas and Oklahoma Devonian strata modified from Hilpman (1967). 5
Figure 4 – Kansas State map showing sample locations and well identification symbols. 8
Figure 5 – Diagram showing Loss on Ignition technique modified from Dean (1974) 10
Figure 6 – Graph depicting the major element weight percent distribution among the 30 subset Chattanooga samples. 14
Figure 7 - Graph depicting the major element weight percent distribution among the 30 subset Chattanooga samples. 14
Figure 8 – Pyrogram showing low intensity S2 curve, representative of a majority of samples.. 17
Figure 9 – Pyrogram showing high intensity S2 curve, representative of two samples. (Wall, 2015) 17
Figure 10 – S2 Values vs. Depth and their evaluated potential as a source rock. 18
Figure 11 – Hydrogen Index Values (S2/TOC) vs. Depth and their evaluated source rock type. 19
Figure 12 – Oxygen Index vs. Hydrogen Index and predicted kerogen type. 20
Figure 13 – TOC vs. S2 and predicted kerogen index. 21
Figure 14 – Graph depicting strong correlation between Inverse Si/Al and TOC..... 23
Figure 15 - Graph depicting strong correlation between LOI % and TOC. 24
Figure 16 - Hydrogen Index vs. Tmax, showing kerogen type for all samples. 26
Figure 17 – Contour map of Chattanooga tops data. 28
Figure 18 – Isopach map showing thickness of Chattanooga shale..... 29
Figure 19 – Contour map representing Organic Matter distribution (constructed from XRF Inverse data.) Note – All data multiplied by a factor of 100 to contour in Petra Software. . 31
Figure 20 – Contour map representing Organic Matter distribution (constructed from LOI data). Note – All data multiplied by a factor of 100 to contour in Petra Software. 33
Figure 21 – TOC Evaluation. Modified from McCarthy (2011) 44

Figure 22- TOC Evaluation. Modified from Peters (2006) 44
Figure 23 – Pyrograms of all samples for TOC results. 45

List of Tables

Table 1 – Major Element XRF data on 30/90 samples tested..... 12
Table 2 - Trace Element XRF data on 30/90 samples tested..... 13
Table 3 – Results of Loss on Ignition testing. 15
Table 4 – GeoMark LECO OC and other pyrolysis results..... 16
Table 5 – Major XRF Data Index Samples 1-45 40
Table 6 – Major XRF Index Samples 46-90..... 41
Table 7 – Trace XRF Index Samples 1-45..... 42
Table 8 - Trace XRF Index Samples 46-90. 43

Acknowledgements

I would like to thank Dr. Matt Totten for sparking my interest in this field of study and taking me on as a graduate student. I would like to think Dr. Sambhudas Chaudhuri for all of his knowledge on clay mineralogy he has passed on. Also thanks to Pamela Kempton for letting me use the XRF. Finally, my family for their support while I was at Kansas State for both undergraduate and graduate school.

Dedication

I would like to dedicate this work to Linda and Patrick.

Chapter 1 - Introduction

The advances in completing low permeability shales into unconventional reservoirs have initiated an increased interest in shales, particularly organic-rich black shales. Major exploration plays are ongoing in many parts of the United States (Figure 1). Until recently, shales were regarded almost exclusively as organic-rich source and seal mudstones that were understudied relative to other sedimentary rocks (Potter, 1980). The Woodford shale of Oklahoma and Texas is a major player in unconventional shale production. This study is the evaluation of the potential of the correlative Chattanooga shale in Kansas. The Chattanooga Shale has potential to play a significant role in further understanding the relationship that local shales have on the petroleum system in Kansas.

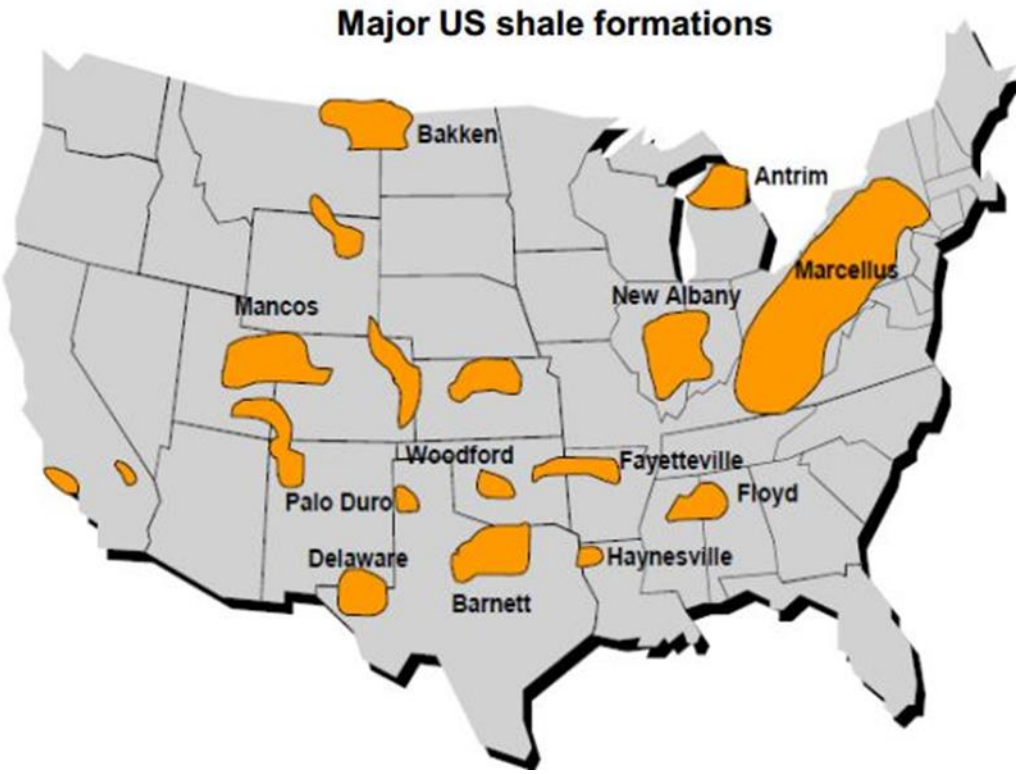


Figure 1 - Ongoing shale plays in the continental United States.

The Devonian-Mississippian Chattanooga (Woodford) Shale is known to be an important petroleum source rock in many intracratonic basins of the Midcontinent (Lambert, 1993). Philp (2011) has estimated that 90% of the petroleum in Oklahoma was sourced by the Woodford. It is currently unknown where the petroleum production in Kansas is sourced. The most cited model holds that Kansas oil is migrating north from Woodford sources in Oklahoma. An alternative model for local sources has been proposed, although it is not clear how adequate thermal maturity is achieved in shallow buried rocks in Kansas. A recent study by Wall (2015) gives strong evidence that the Chattanooga is a viable source for Mississippian oil in southern Kansas. Hill (2011) showed the potential for other organic-rich shales in western Kansas. McIntire (2014) suggested that Lansing/Kansas City oils in Rooks County, Kansas were locally sourced.

In this study, the Chattanooga Shale in Kansas has been investigated for its potential as a source rock for producing Kansas oil. Its distribution throughout Kansas has been mapped using various techniques including XRF, Rock-Eval and Loss on Ignition. This will be of interest to companies within the Kansas petroleum industry because it has shown that the Chattanooga shale is a viable target for unconventional drilling techniques.

1.1 – Significance

Until recently, shales were regarded almost exclusively as organic-rich source and seal mudstones that were understudied relative to other sedimentary rocks (Potter, 1980). The advances in completing low permeability shales into unconventional reservoirs have initiated an increased interest in shales, particularly organic-rich black shales. The Woodford shale of Oklahoma is a major player in unconventional shale production. It is the purpose of this study to evaluate the potential of the correlative Chattanooga shale in Kansas. The Chattanooga Shale has potential to

play a significant role in further understanding the relationship that local shales have on the petroleum system in Kansas.

The results of this research have impacts on both a local and regional scale for the petroleum industry. Kansas oil and gas has limited its exploration to only searching for reservoirs instead of potential self-sourcing units. Changing this assessment affects industry performance on a local level. Providing further evidence on the Chattanooga source rock potential will gain regional implications on how hydrocarbons are distributed throughout the Midwest.

The impact this research could have on the petroleum industry is both the advancement and confirmation of innovative sampling technique as well as providing new proven data about the Chattanooga as a formation. The sampling technique in question is the use of X-Ray Fluorescence (XRF) with regards to handheld XRF data as a proxy for %organic matter. Building off of Willey (2015) research, this will help investigate Handheld XRF as a viable option for %organic matter analysis.

1.2 - Geologic Setting

The Devonian-Mississippian Chattanooga shale is present across multiple sates with varying thickness and nomenclature. Structural features that were present in the Midcontinent, more specifically Kansas, during deposition of the Chattanooga shale include major basins and uplifts. Basins such as the Oklahoma and Iowa Basins provided and topographically negative area. Topographically positive areas include the Central Kansas Uplift and Chautauqua Arch. North America in the late Devonian was located in the tropics (Woodrow et al., 1973), possibly in low southerly latitudes (Heckel and Witzke, 1979; Witzke and Heckel, 1988; Streel et al., 1990). This creates an environment resulting in an organic-rich shale that is an important source of hydrocarbons throughout the Midcontinent.

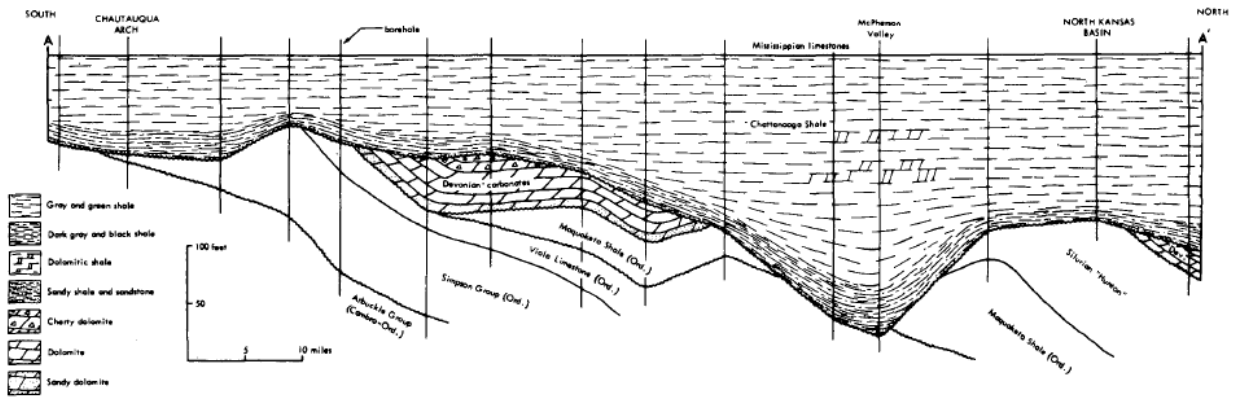


Figure 2 - Generalized cross-section showing stratigraphic relationships from the Chauauqua Arch into the North Kansas Basin modified from Amsden et al., (1967)

The Chattanooga ranges in thickness from a feather-edge at its margins to more the 280 feet in the deeper portions of the North Kansas basin (Figure 2). It can be divided into three distinct members, Lower, Middle, and Upper Shale Members. All three are present in Kansas, although the lower shale member is restricted to the south-central part of the state, and the upper shale member is not present in extreme northern Kansas. The radioactivity of each shale member decreases to the north (Lambert, 1993). There is a progressive color change in subsurface samples of the Chattanooga Shale of Kansas, from black in the southern part of the state to lighter colors in the north. (Lee, 1956). The least areally widespread of the shale members, the lower shale member is present only in the southern part of Kansas. The middle shale member of the Chattanooga (Woodford) Shale has the greatest areal extent of any shale member, and is found throughout northwestern Oklahoma and eastern Kansas. The upper shale member is not as areally widespread as the middle shale member but more than the lower member (Lambert, 1993).

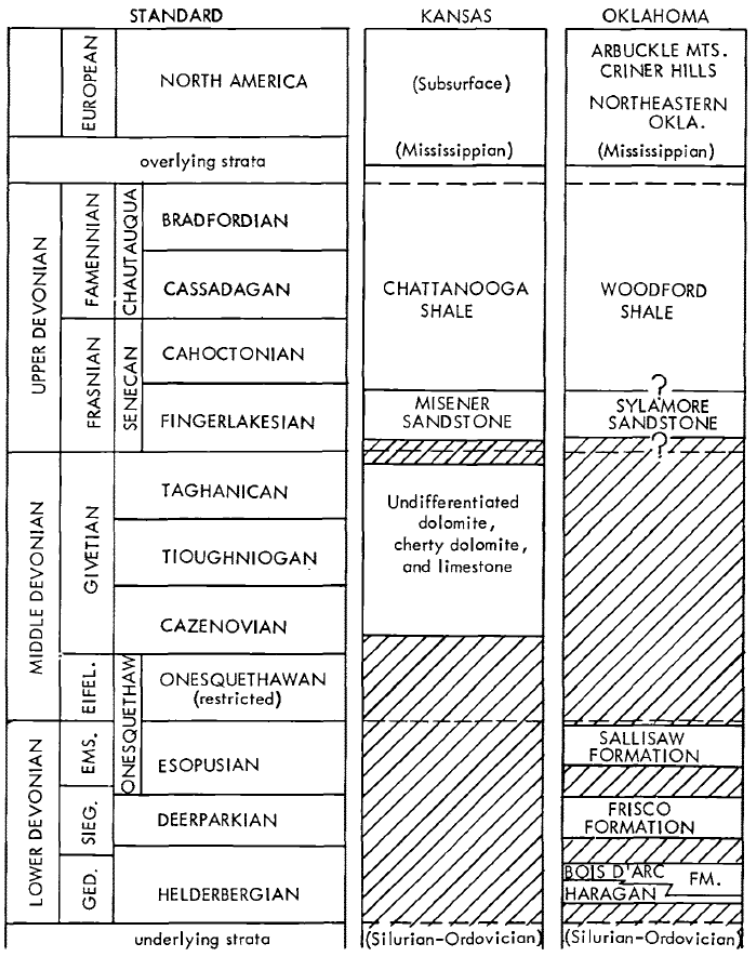


Figure 3 – Correlation chart comparing Kansas and Oklahoma Devonian strata modified from Hilpman (1967).

1.3 - Previous Work

Meagan Wall (2015) conducted a study on the oil-source rock correlation examining the potential of the Chattanooga shale as a source rock for oil. This was done within the Spivey-Grabs-Basil field in Kingman and Harper counties, Kansas. Gas Chromatography Mass Spectrometry (GC-MS) and Rock-Eval Pyrolysis tests were conducted on samples from the Chattanooga that apply to this study. Results showed that all of the samples in the study have values that fall within the parameters for both a history of hydrocarbon generation and high potential for hydrocarbon production as set forth by McCarthy (2011). Data was used from this study and expanded on to further investigate the Chattanooga shale and its oil source rock correlation.

Tyler Willey (2015) conducted a study on the use of handheld XRF as a proxy for onsite evaluation of unconventional targets. Results showed a strong inverse correlation is observed between organic matter weight present and the Si/Al and Si/K ratios. The strong inverse correlation observed shows that the handheld XRF has the potential to provide quick data on Si/Al ratios that can be used as a proxy for organic matter estimates. This study takes this initial finding and implements it on a much greater scale for further investigation on to its validity.

Tyler Hill (2011) examined possible source rocks and their potential productivity and oil-generative properties in various regions of western Kansas. His use of pyrolysis, and his investigation of TOC and vitrinite reflectance, although not directly applied to this study it provides excellent comparative data. His dataset revealed exceptional TOC numbers ranging up to 13.33%, and immature Tmax values of 428^{0}C average. His vitrinite reflectance values proved thermally immature in most samples, which is traditionally thought on Kansas' source potential. However, two samples fell over 0.6% value which categorically defines them as ideally mature,

or within the oil generative window. His study prompted Wall (2015) study, which in turn supplied data for this project.

Ramirez-Caro (2013) obtained TOC values for the stratigraphically equivalent Woodford shale in north-central Oklahoma, which is a known oil source rock. He also analyzed the organic fraction of his rocks for REE and other trace elements, which can be compared to the Chattanooga shale. Again it is not directly applied in this study, but provides excellent comparative data.

Chapter 2 - Methodology

2.1 – Sample Selection

The samples for this study were chosen by availability and quality. All samples were obtained from the Kansas Geological Survey (KGS) Wichita Well Sample Library located in Wichita, KS. Out of 565 wells within Kansas that report penetrating the Chattanooga shale, 106 well cuttings were available for testing. Visual examination of these cuttings determined that 90 samples would be suitable for X-ray Fluorescence (XRF), Loss on Ignitio (LOI) and Rock-Eval testing. The 90 wells are located throughout nineteen counties in Kansas, and come from various depths ranging from approximately 900 feet to 7,000 feet (Figure 4).

The process by which GeoMark laboratories extracted the TOC data for Rock-Eval Pyrolysis can be found in Appendix A.

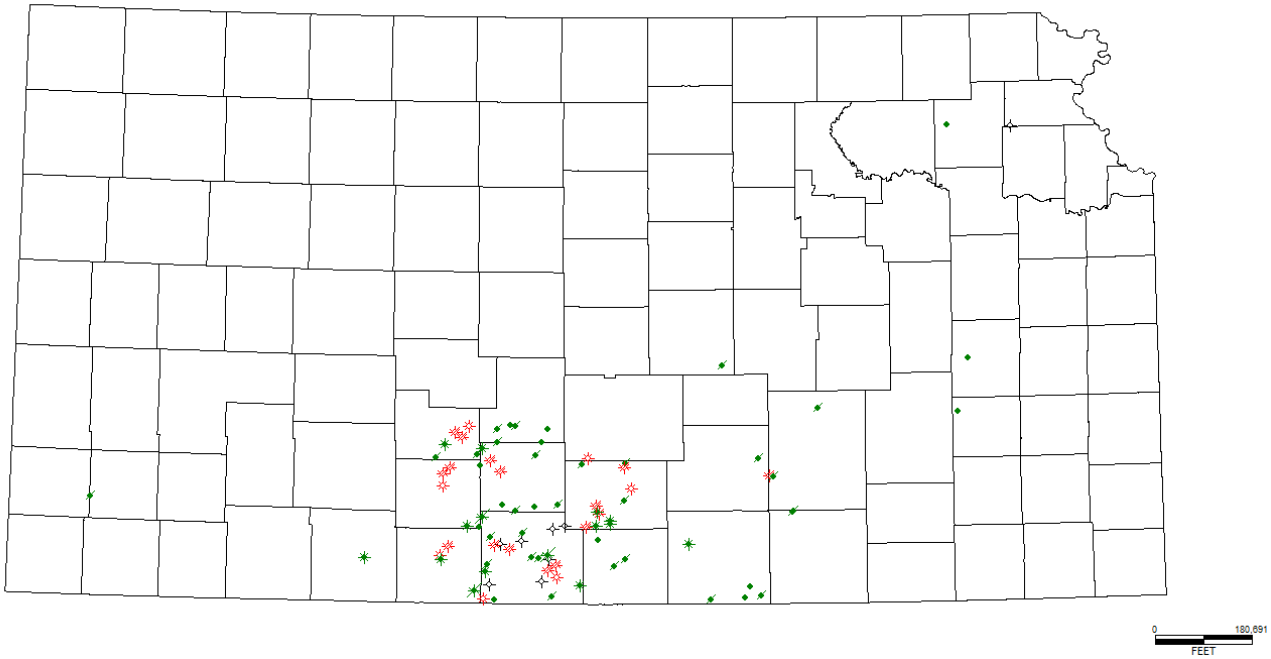


Figure 4 – Kansas State map showing sample locations and well identification symbols.

2.2 – Whole Rock XRF Analysis

X-ray Fluorescence (XRF) was performed on the 90 well cuttings to obtain bulk elemental composition using a Bruker Tracer III handheld XRF. Usually there would be no sample preparation and this method would be nondestructive, however for this project some sample preparation was implemented to ensure quality. The well cuttings were crushed into powder using mortar and pestle to minimize air pockets and maximize surface area for the XRF to examine. This also limited the dispersing effect of air that causes the XRF to not be able to read lighter elements (atomic weight < 24.305 u). Once ground into powder the samples were placed into SpectroMicro XRF sample cups (30.5 mm O. D. x 1 mm HIGH x 20 mm ID Aperture) and sealed with SpectroMembrane Mylar Thin-Film, both provided by Chemplex Industries, Inc.

Trace element analysis was conducted on the samples using the Bruker mudrock calibration. A yellow filter (12 mil Al + 1 mil Ti) was required along with the machine settings at

40kV, 12.4 μA at 60 second intervals. Five intervals, each at different surface locations, were conducted on all 90 samples to represent the average bulk chemical makeup. Using the S1PXRF program, relative weight percentages for each element were calculated from peaks generated during testing. When averaged among all five intervals, bulk trace element composition can be assigned to each sample.

Major element analysis was conducted on the samples using the same mudrock calibration. Without the yellow filter the Bruker Tracer III handheld XRF was connected to a vacuum to remove any air between the XRF sensor window and the x-ray detector. The machine settings were altered to 15kV, 25 μA at 180 second intervals. Again, five intervals at different surface locations were recorded for each sample. Using the S1PXRF program, relative weight percentages for each element were calculated from peaks generated during testing. When averaged among all five intervals, bulk major element composition can be assigned to each sample.

This data was used to generate proxies for significant minerals expected in organic-rich shales, as well as the percentage of organic matter in each sample. Both plots and maps were generated to better understand the Chattanooga throughout Kansas and its potential oil-source rock correlation.

2.3 – Loss on Ignition

A loss on ignition technique was performed on a third of the samples to determine the amount of organic content in the samples. Differential thermal analysis (DTA) thermograms show that when a dried, powdered sample containing organic material and calcium carbonate is heated in a muffle furnace, the organic material begins to ignite at about 200 ° C and is completely ignited by the time the furnace temperature has reached approximately 550 ° C (Dean, 1974). The procedure implemented in this technique is described as follows. The samples were powdered and

placed in a furnace set at 90-100° C for one hour. After cooling to room temperature in a desiccator, the sample is weighed. This gives the dry weight of the sample which is the basis for all weight loss calculations. The sample and crucible are then placed in a muffle furnace and heated to 550 ° C for one hour. After cooling to room temperature, the sample is again weighed. The difference between this weight and the dry weight is the amount of organic carbon ignited.

This data was used as an additional source of organic content readings to compare with other methods. Both plots and maps were generated to better understand the Chattanooga throughout Kansas and the potential confirmation of XRF proxies.

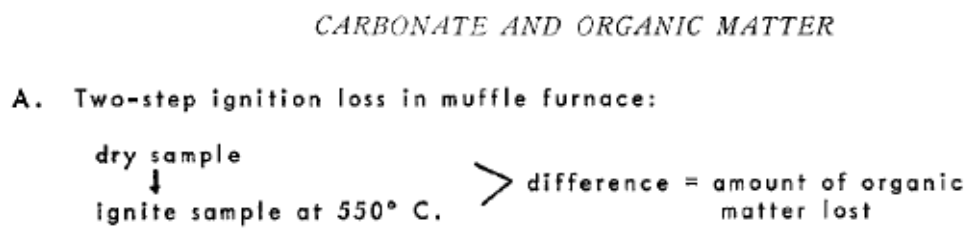


Figure 5 – Diagram showing Loss on Ignition technique modified from Dean (1974)

2.4 – Petra Software

The Petra software program was used as a visualization tool for better interpretation and conclusions about the raw data obtained from other methods. All 565 wells within Kansas that report penetrating the Chattanooga shale have been imported. Attributes connected to the wells imported include: Location (Lat. / Long.), API number, Datum Elevation, Well symbol, Chattanooga formation tops. This information provides a regional structure map of the Chattanooga shale in Kansas. Using data collected by XRF and Loss on Ignition, 90 wells will have additional geochemical data attributes. These geochemical attributes include: Si/Al ratios, K/AL ratios, Al/Si ratios, TOC (wt. %) and LOI organic carbon readings. This information provides the only map of source rock potential across Kansas.

Chapter 3 – Results

3.1 – Whole Rock XRF Analysis

Whole rock XRF analysis was performed on 90 well cutting samples in the form of trace and major elemental analysis. A subset example (30) results for both major and trace elements are presented in Tables 1 and 2. Where the full data table sets can be found in Appendix B. For better visual depiction of the data, charts were created to provide elemental variations within the samples (Figure 6 and 7). The subset samples were chosen based off the amount of data attributes associated to those samples. There are 90 samples with XRF data however, only 30 have LOI data and only 20 of those have Rock-Eval Pyrolysis accompanying the XRF.

1	KID	API_NUMBER	LONGITUDE	LATITUDE	Well Type	County	Na	Mg	Al	Si	P	S	K	Ca	Ti	Fe	Inverse	Si/Al	Si/K	K/Al
2																				
3	1036762743	15-207-27134	-95.9192108	37.9705398	OIL	Woodson		0.542394018	6.024287021	16.6870368	0.070719599	0.449120821	2.548991284	0.733404768	0.489876582	4.62276266	0.361015985	2.769960452	6.54652564	0.423119163
4	1002898254	15-031-20318	-95.8486892	38.2423623	OIL	Coffey	0.611797716	0.545044171	5.807676409	16.39498958	0.045817555	0.546584004	3.205730818	1.315965354	0.426097656	3.417196926	0.354234834	2.822986067	5.114275189	0.551981652
5	1002885127	15-005-20013	-95.53394	39.4219332	D&A	Atchison	0.623401988	0.441386803	4.810599825	13.60173194	0.072447152	0.594127051	2.88246967	8.004599188	0.331698929	4.035264022	0.353675535	2.827450305	4.718777124	0.599191322
6	1002922710	15-085-19008	-95.9544247	39.4354882	OIL	Jackson	0.616158011	0.486505749	5.368587317	16.50805592	0.069893415	0.727682446	2.73652625	2.587584585	0.423643275	3.837769142	0.325210149	3.074934791	6.032485862	0.509729299
7	1001254637	15-113-04525	-97.4503794	38.2164384	PAOW	McPherson	0.626080136	0.498056814	4.327146847	14.55089973	0.06669821	0.544819291	2.286088476	5.305479745	0.370062093	3.628664916	0.29738002	3.3627007	6.364976633	0.528313126
8	1037992735	15-015-19814	-97.1223889	37.6494133	PAOW	Butler	0.614019347	0.441083992	4.31499423	13.90068134	0.085465684	0.484332256	2.161986967	8.731009651	0.348496955	3.817509455	0.310416024	3.221483181	6.429586094	0.501040523
9	1036145571	15-015-19584	-97.149404	37.6548239	PAGW	Butler	0.619677326	0.440912287	4.188633535	14.51561818	0.080568329	0.620436827	2.115398407	7.645137023	0.361083045	3.615823551	0.288560465	3.465478194	6.861883857	0.505033059
10	1002950836	15-191-00090	-97.2729574	37.0881488	OIL	Sumner	0.618819568	0.447746994	4.571937881	15.79276573	0.083000719	0.661138187	2.437624058	5.289637134	0.358502037	3.458894662	0.289495707	3.454282656	6.478753636	0.533170861
11	1001321439	15-185-11043	-98.61757	37.82514	OIL	Stafford	0.623052313	0.440229905	3.765658973	12.99528936	0.079365188	0.610990042	1.974316076	10.06247347	0.301217519	3.039427371	0.289771075	3.451000066	6.582172692	0.524294975
12	1002885310	15-007-00129	-98.4656904	37.3976393	D&A	Barber	0.581531673	0.431907201	2.458046767	8.374827014	0.075999733	0.411706316	1.308805	18.9348143	0.219805854	2.348872819	0.293504184	3.407106459	6.398834823	0.532457323
13	1002907392	15-047-00034	-99.2967424	37.7418344	PAOW	Edwards	0.609155625	0.481244641	3.308522232	13.17855403	0.135585577	2.816171265	1.642883544	8.964363347	0.278719804	2.824504386	0.251053509	3.983214591	8.021599629	0.496561132
14	1002885295	15-007-00116	-98.6123226	37.1103958	D&A	Barber	0.617052242	0.43619986	3.17430425	10.88747651	0.088640284	0.546606399	1.449633258	13.72327016	0.292144048	2.869647777	0.291555554	3.429878063	7.51050409	0.456677478
15	1006013462	15-007-00651	-98.9629328	37.2001261	PAOW	Barber	0.599546185	0.444998614	2.864346691	9.846996953	0.094874132	1.016966054	1.58718116	15.67017417	0.25011	2.655512351	0.290885303	3.437781112	6.204078778	0.554116289
16	1002925921	15-097-00140	-99.08992	37.3924798	O&G	Kiowa	0.614179085	0.435771888	2.588775426	10.37904893	0.090252071	0.622555494	1.396307449	14.43794092	0.245871749	2.713307496	0.249423184	4.009250407	7.433211747	0.539369864
17	1006065035	15-067-20952	-101.5236865	37.4988561	PAOW	Grant	0.623381233	0.438953844	2.695025724	11.70502417	0.103783462	0.552865079	1.334791466	13.0945553	0.22938525	2.351753759	0.230245208	4.343195714	8.769178163	0.495279675
18	1002920159	15-077-00123	-98.2474119	37.3252281	OIL	Harper	0.473859926	0.493930452	1.023013827	5.52190063	0.084675384	0.438709394	0.712570104	26.63543614	0.115354949	1.268039493	0.185264802	5.39767937	0.696540051	0.696540051
19	1002924738	15-095-00030	-98.2666625	37.3959455	O&G	Kingman	0.626088655	0.438669469	3.735160386	14.11657412	0.089531444	1.087401703	2.136936797	8.224061821	0.331330589	2.793454246	0.26459397	3.779375625	0.572113799	0.572113799
20	1002924931	15-095-00201	-98.1708206	37.424623	O&G	Kingman	0.627751424	0.465005546	3.812138799	12.96316522	0.076483282	0.23030496	1.465927875	9.433100621	0.384936717	2.765147971	0.29407469	3.400496652	0.384542104	0.384542104
21	1002925147	15-095-00394	-98.3296599	37.3931085	PAGW	Kingman	0.601169475	0.444706131	3.047776453	11.6544355	0.092584924	0.659579966	1.481472056	13.61001015	0.278707424	2.520636249	0.261512147	3.823914149	0.486082913	0.486082913
22	1002925152	15-095-00399	-98.1751767	37.4069085	O&G	Kingman	0.61263252	0.440439894	3.344462191	11.32374318	0.100838514	1.451049049	1.605006033	12.02571727	0.302685693	2.741223335	0.295349527	3.385818865	0.47989959	0.47989959
23	1006013102	15-007-00100	-98.5428353	37.3824925	D&A	Barber	0.625951052	0.439653709	3.344202703	12.44838836	0.082467382	0.861486485	1.740203692	10.29788809	0.283239297	2.688689732	0.268645435	3.722378534	7.153408772	0.520364298
24	1006013408	15-007-00616	-98.63061	37.23149	PAOW	Barber	0.601638999	0.436250526	2.148721586	8.50639376	0.097507874	1.299652884	1.228976622	16.60602373	0.202789977	2.344819095	0.252600767	3.958816171	6.921526095	0.571957126
25	1006015927	15-007-21286	-98.945753	37.3385684	PAOW	Barber	0.522326721	0.461694778	1.52483019	6.668441149	0.075814221	0.234965847	1.193584499	24.95955723	0.146847324	1.54236976	0.228663665	4.373235258	5.586903278	0.782765522
26	1030455527	15-007-22792	-98.57051	37.24864	PAOGW	Barber	0.494405091	0.475976907	1.125403709	6.267683964	0.085696404	0.124934962	0.625557865	25.25070702	0.12053194	1.305817627	0.17955655	5.569276088	10.01935124	0.555851967
27	1006774561	15-035-70316	-96.9963305	37.4739559	PAOW	Cowley	0.620717691	0.440189428	2.871172069	10.78901719	0.08427222	1.124248702	1.573186982	12.82944521	0.263656074	2.683758552	0.26611989	3.757704844	6.858064121	0.547925009
28	1002924767	15-095-00057	-98.0732847	37.7179741	PAOW	Kingman	0.474452885	0.464511566	1.076585169	4.639044513	0.058148512	0.278306944	0.507961436	26.9309988	0.127596084	1.37088022	0.232070455	4.309036244	9.132670683	0.471826522
29	1002925494	15-095-10066	-98.08443	37.6978962	PAGW	Kingman	0.575011454	0.438167185	2.108157533	7.574440235	0.081504574	0.203264111	0.898291458	19.95650675	0.208962407	2.036139095	0.278325192	3.592919464	8.432051944	0.426102625
30	1006081782	15-095-20841	-98.3543054	37.7115981	PAOW	Kingman	0.603426942	0.437249292	1.724517629	8.190787175	0.066538615	0.477933913	1.057692009	18.17329569	0.173299296	1.881390433	0.210543577	4.749610579	7.744019149	0.613326296
31	1006112725	15-151-21355	-98.6568559	37.4932243	OIL	Pratt	0.576905931	0.441010456	2.084926952	8.415615322	0.082101462	0.662728082	1.203913595	19.09506632	0.189247486	1.808099326	0.24774504	4.036407757	6.990215378	0.577436823
32	1006159662	15-191-20047	-97.2070476	37.0369518	PAOW	Sumner	0.617129218	0.459402866	4.189984987	16.39140022	0.072484598	0.434133338	2.140216453	5.086878615	0.355773149	3.373466016	0.255620931	3.912042708	0.510793347	0.510793347

Table 1 – Major Element XRF data on 30/90 samples tested.

1	KID	API_NUMBER	LONGITUDE	LATITUDE	Well Type	County	Ca	Ba	Mn	Rb	Sr	Zr	Zn	Nb	Mo	Sn	Sb	Ti	Cr	Fe	Co	Ni	Cu	As	Pb	Th	U	Y
2																												
3	1036762743	15-207-27134	-95.9192108	37.9705398	OIL	Woodson	1.4022198	0.14113348	0.1002453	0.0131667	0.0145344	0.017688	0.0050626	0.0012171	0.0006679	0.0002476	0.0008375	0.5485266	0.0043645	4.8723038	0.0022057	0.0075739	0.00136603	0.0012763	0.0017333	0.0011223	2.0145E-05	0.0033497
4	1002898254	15-031-20318	-95.8486892	38.2423623	OIL	Coffey	1.3387611	0.07850533	0.0301509	0.0185722	0.018536	0.0145718	0.0100554	0.0014538	0.00273106	0.0002547	0.0008099	0.4790056	0.0065512	3.7270386	0.0018477	0.0061802	0.00176323	0.0010846	0.0015875	0.0014181	0.00075224	0.0024827
5	1002885127	15-005-20013	-95.53394	39.4219332	D&A	Atchison	9.4616394	-0.0449738	0.0429847	0.0154161	0.0121317	0.0115567	0.0062916	0.0011435	0.00087408	0.0002683	0.0008595	0.3930488	0.0090004	4.55716	0.0021064	0.0044658	0.0011721	0.0003929	0.001662	0.0011915	0.00012867	0.0025248
6	1002922710	15-085-19008	-95.9544247	39.4354882	OIL	Jackson	3.3959157	0.13783544	0.0437293	0.0155316	0.0167494	0.0157094	0.0103643	0.001227	0.00121763	0.0002428	0.0006247	0.4535508	0.0092322	4.1503455	0.0019921	0.006067	0.0019528	0.000943	0.0015212	0.0012357	0.00025638	0.0027619
7	1001254637	15-113-04525	-97.4503794	38.2164384	PAOW	McPherson	6.4132826	0.11384907	0.0310226	0.0135045	0.0335023	0.0150971	0.0076606	0.001163	0.00046216	0.0002401	0.0005786	0.395994	0.0082199	3.3410143	0.0017188	0.0060109	0.00111036	0.0004681	0.0010865	0.0010946	0.00051597	0.0027939
8	1037992735	15-015-19814	-97.1223889	37.6494133	PAOW	Butler	10.552393	0.04115607	0.0475343	0.0135254	0.0239225	0.0135021	0.0074325	0.0011498	0.00068358	0.0002345	0.0005786	0.3786454	0.0082748	4.2545026	0.0021321	0.0049641	0.00138934	0.0016019	0.0018631	0.001122	0.00024658	0.0028312
9	1036145571	15-015-19584	-97.149404	37.6548239	PAGW	Butler	9.182155	0.06075083	0.0395913	0.0128161	0.041651	0.0126862	0.0060605	0.001073	0.00073308	0.0002604	0.0007797	0.3771151	0.0112785	4.1196762	0.0020135	0.0049982	0.00193037	0.0004512	0.0013083	0.0010513	0.00010289	0.0024907
10	1002950836	15-191-00090	-97.2729574	37.0881488	OIL	Sumner	5.8102276	0.11442499	0.0384318	0.0144791	0.0236107	0.0134033	0.0076384	0.0011306	0.00264054	0.0002322	0.0005467	0.3871287	0.01016	4.0213355	0.0026289	0.0064902	0.00130744	0.0007558	0.0014346	0.0011637	-0.0002095	0.0028984
11	1001321439	15-185-11043	-98.61757	37.82514	OIL	Stafford	11.821342	0.07091483	0.0345735	0.0115833	0.0367022	0.012297	0.0065065	0.001053	0.00018478	0.0002225	0.0001548	0.3341667	0.0073471	3.5380989	0.0021845	0.0048091	0.00080993	0.0004045	0.0010939	0.0009977	-0.0004491	0.0033381
12	1002885310	15-007-00129	-98.4656904	37.3976393	D&A	Barber	21.928144	-0.0230856	0.0426121	0.00928	0.0383875	0.0088175	0.0058181	0.0008737	-0.0001734	0.0002418	0.0006555	0.2423639	0.0048641	2.526651	0.0011758	0.0039551	0.00065565	0.000375	0.0010613	0.0008015	0.00047753	0.002403
13	1002907392	15-047-00034	-99.2967424	37.7418344	PAOW	Edwards	9.4410466	0.03224501	0.0282709	0.0094635	0.0436614	0.0108304	0.0039287	0.0009136	0.0003251	0.0002319	0.000525	0.3083635	0.0054804	2.9724551	0.0013402	0.0047504	0.00015729	0.0003001	0.0010664	0.0008432	0.00022083	0.0024356
14	1002885295	15-007-00116	-98.6123226	37.1103958	D&A	Barber	17.028322	-0.0603725	0.0408917	0.0097035	0.0329659	0.0106445	0.005592	0.0009126	0.00018429	0.0002491	0.0008612	0.3248328	0.0036941	3.1670319	0.0014881	0.0048334	0.00093478	0.0004239	0.0012082	0.0008674	-0.0002343	0.0027892
15	1006013462	15-007-00651	-98.9629328	37.2001261	PAOW	Barber	18.306815	-0.0324545	0.0410613	0.0098165	0.0287287	0.0111399	0.0063883	0.0008794	0.00013574	0.0002392	0.0006823	0.2885576	0.0035082	2.8364012	0.0012859	0.0040811	0.00059021	0.0004405	0.0011488	0.0008644	-3.235E-06	0.0026043
16	1002925921	15-097-00140	-99.08992	37.3924798	D&G	Kiowa	17.375942	0.00107083	0.0511246	0.0082778	0.0322648	0.0105825	0.0068247	0.0009273	0.00076529	0.0002515	0.0007683	0.2738071	0.004317	3.165485	0.0013752	0.0043297	0.00071594	0.0007131	0.001361	0.0007925	0.00024173	0.0030309
17	1006065035	15-067-20952	-101.5236865	37.4988561	PAOW	Grant	14.433663	-0.0220557	0.0332281	0.0071296	0.0509229	0.0093683	0.0083738	0.0008408	0.00043117	0.0002319	0.0006165	0.2563512	0.0056055	2.4338133	0.0008885	0.0039747	0.00051374	0.0004848	0.0010534	0.0006854	0.00075328	0.0026026
18	1002920159	15-077-00123	-98.2474119	37.3252281	OIL	Harper	29.300024	0.03550668	0.0482574	0.0043549	0.0296281	0.0059783	0.0044355	0.0005738	-0.0006254	0.00024	0.0005623	0.1283063	0.001224	1.2660071	0.0008023	0.0028806	-4.759E-05	0.0003452	0.0009635	0.0005068	-0.0001174	0.0025486
19	1002924738	15-095-00030	-98.2666625	37.3959455	D&G	Kingman	9.1885195	0.06415183	0.0387802	0.0112417	0.0307736	0.013894	0.1310385	0.0009708	0.00036387	0.0002388	0.000573	0.3507808	0.0036403	3.0028668	0.001727	0.0050451	0.01308716	0.0057415	0.0012544	0.0009437	4.921E-05	0.0027939
20	1002924931	15-095-00201	-98.1708206	37.424623	D&G	Kingman	11.030504	0.05688826	0.026203	0.0061501	0.0157349	0.0166326	0.0119927	0.0007648	0.00050552	0.0002331	0.000559	0.3728402	0.0072504	3.0483992	0.0017032	0.0068232	0.000884	0.0006631	0.0009705	0.0006549	-0.0003643	0.0036989
21	1002925147	15-095-00394	-98.3296599	37.3931085	PAGW	Kingman	16.213464	0.02514338	0.0361542	0.0074573	0.0650388	0.0098947	0.0057431	0.0008201	-2.326E-06	0.000254	0.0005952	0.281987	0.0040757	2.8143643	0.0014532	0.0045844	0.00446094	0.0004084	0.0010193	0.0007041	0.00042423	0.0024445
22	1002925152	15-095-00399	-98.1751767	37.4069085	D&G	Kingman	13.910283	0.04818651	0.0311218	0.0077574	0.0450242	0.0113821	0.0133478	0.0007551	8.5865E-05	0.0002434	0.0006831	0.3202701	0.0045854	3.0873639	0.0017136	0.00517	0.00104185	0.0007486	0.0011718	0.0007269	-0.0001568	0.0029076
23	1006013102	15-007-00100	-98.5428353	37.3824925	D&A	Barber	11.146124	0.05444377	0.0408945	0.0106713	0.0388722	0.0108008	0.8601698	0.0003963	0.00047287	0.0002254	0.0006636	0.3112459	0.0077866	2.8447358	0.0015917	0.007305	0.08484892	0.0368759	0.0012878	0.0009053	0.00063982	0.0024715
24	1006013408	15-007-00616	-98.63061	37.23149	PAOW	Barber	19.746117	0.02747563	0.0427464	0.0080088	0.0372217	0.0087876	0.0160214	0.000839	0.00063338	0.000262	0.000737	0.2267625	0.0046341	2.6054192	0.0011419	0.0042292	0.00118473	0.0041863	0.0022032	0.0008362	-0.0004307	0.0025105
25	1006015927	15-007-21286	-98.945753	37.3385684	PAOW	Barber	27.306374	-0.0023107	0.0407099	0.0063636	0.0193232	0.0077009	0.0036677	0.0006921	-0.0001109	0.0002356	0.0004933	0.1668777	0.0028868	1.6407502	0.0007801	0.0031468	-0.0001529	0.0002805	0.0010585	0.0006463	-0.0002192	0.0026293
26	1030455527	15-007-22792	-98.57051	37.24864	PAOGW	Barber	27.914593	0.02619196	0.0433625	0.0032373	0.051572	0.0053316	0.0050074	0.0006163	-6.77E-05	0.000248	0.0005452	0.1305872	0.0030628	1.3022123	0.0005987	0.0033048	3.4637E-05	0.0005111	0.0013274	0.0004953	-0.0001453	0.0024162
27	1006774561	15-035-70316	-96.9963305	37.4739559	PAOW	Cowley	16.232502	-0.0418447	0.0385285	0.0089127	0.0682823	0.010098	0.0045591	0.0009337	-0.0004804	0.0002388	0.0005543	0.2993462	0.0032464	2.7675184	0.0012084	0.0037578	0.00019805	0.0003268	0.0010495	0.0008322	0.00044397	0.0019005
28	1002924767	15-095-00057	-98.0732847	37.7179741	PAOW	Kingman	32.275619	0.00149675	0.0336639	0.0029246	0.0412491	0.0067239	0.0052426	0.000563	-0.0005333	0.0002493	0.0006263	0.145267	0.0039389	1.5972326	0.0009096	0.0031017	-0.0001516	0.0003876	0.0011835	0.0004506	-7.147E-05	0.0026681
29	1002925494	15-095-10066	-98.08443	37.6978962	PAGW	Kingman	24.895366	-0.0294055	0.0318414	0.0053122	0.0296817	0.0097637	0.0061373	0.0006867	2.2143E-05	0.0002447	0.0007431	0.2314237	0.0050821	2.355872	0.001343	0.0039133	0.00036826	0.0004131	0.0009818	0.0005883	-0.0002551	0.0027725
30	1006091782	15-095-20841	-98.3543054	37.7115981	PAOW	Kingman	21.870292	-0.005345	0.0574733	0.007811	0.0457272	0.0105238	0.0083638	0.0008726	-0.0001206	0.0002512	0.0006406	0.2038372	0.0023986	2.0198758	0.0008881	0.0031702	0.00052891	0.0005289	0.001293	0.00074	0.00074402	0.0023777
31	1006112725	15-151-21355	-98.6568559	37.4932243	OIL	Pratt	21.913883	-0.016143	0.0478582	0.0075976	0.0807791	0.0080513	0.0028754	0.0009359	-0.0007105	0.0002413	0.0003936	0.2194038	0.0020295	1.8750348	0.0007619	0.0046358	-0.0002472	0.0002543	0.001037	0.0007353	0.00034649	0.0023587
32	1006159662	15-191-20047	-97.2070476	37.0369518	PAOW	Sumner	5.3482409	0.06785384	0.0359577	0.0129329	0.0226318	0.0161507	0.0101633	0.0011676	0.00066441	0.0002313	0.0005568	0.3951108	0.0069767	3.6870939	0.0016987	0.0050957	0.00133257	0.0005784	0.0012356	0.0010769	0.00034065	0.0029314

Table 2 - Trace Element XRF data on 30/90 samples tested.

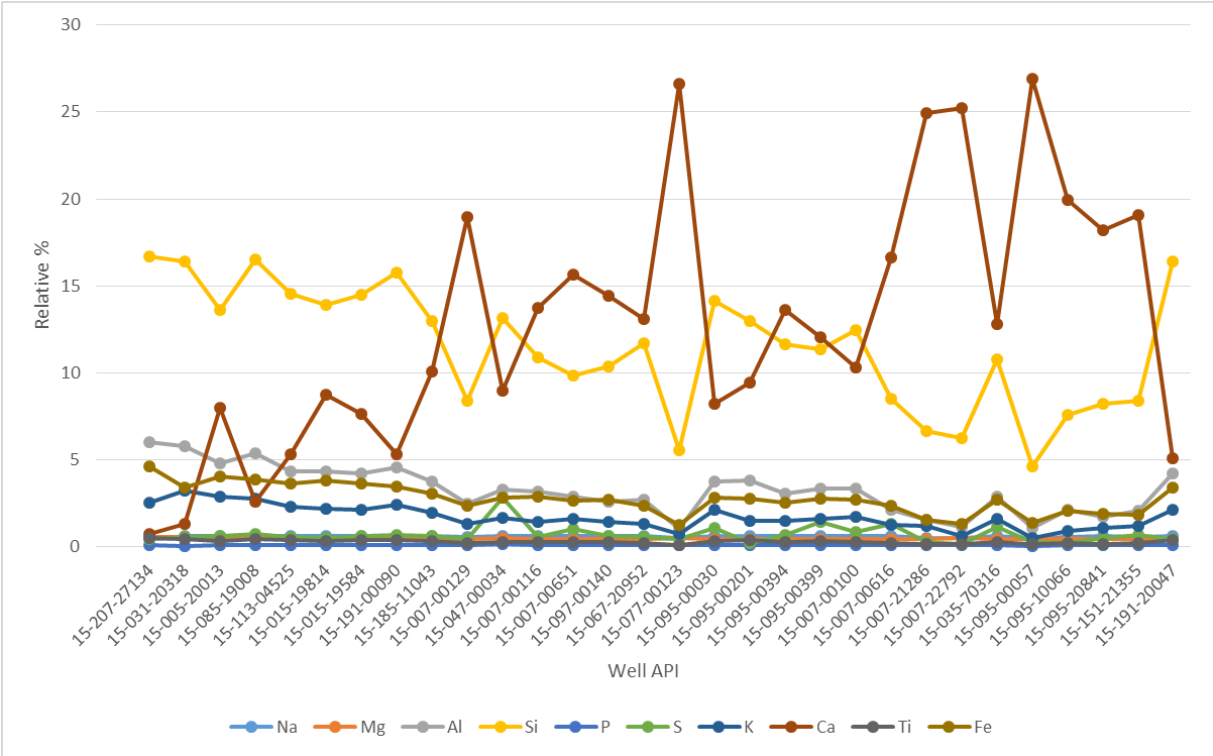


Figure 6 – Graph depicting the major element weight percent distribution among the 30 subset Chattanooga samples.

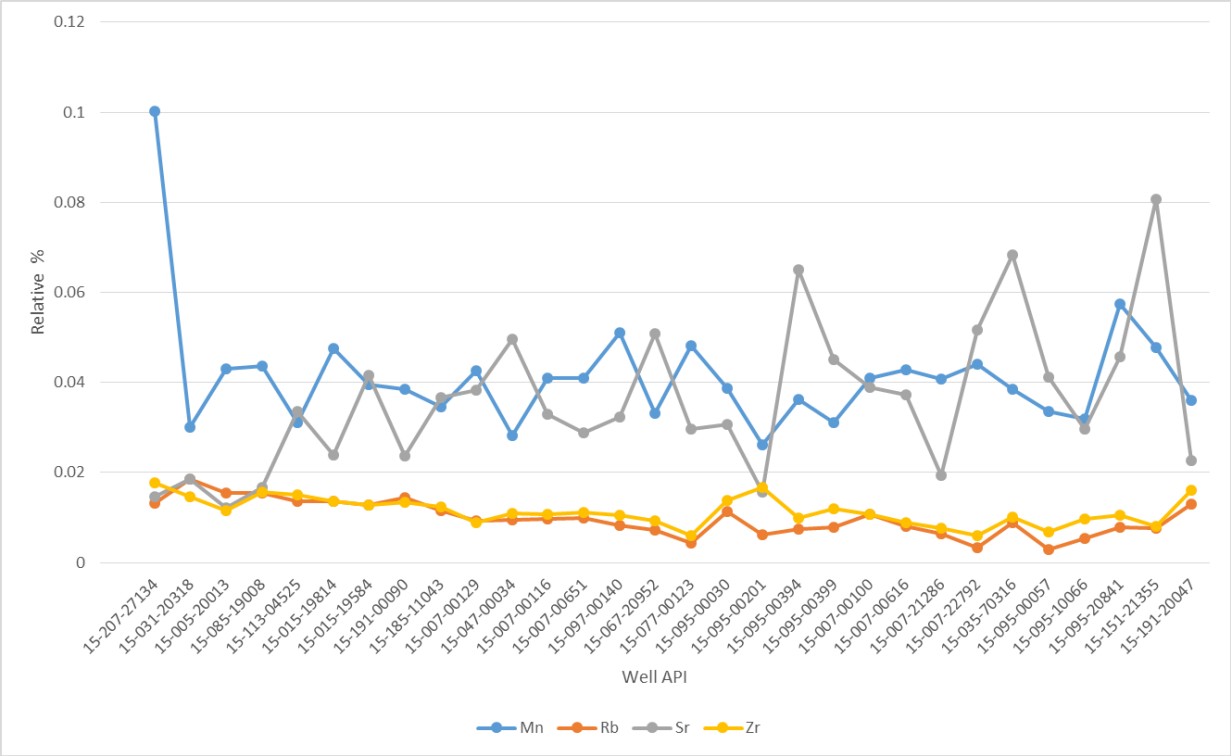


Figure 7 - Graph depicting the major element weight percent distribution among the 30 subset Chattanooga samples.

3.2 – Loss on Ignition

The initial results of the 30 samples tested by loss on ignition procedure are presented in Table 3. Determination of organic matter in geologic materials by loss on ignition is a well-tested and proven technique. It is rapid and requires equipment found in most laboratories. Although this procedure requires several hours to complete, only a portion of this time actually requires the operator to be present since most of the time involved is heating and cooling of samples.

1	KID	API_NUMBER	LONGITUDE	LATITUDE	Well Type	County	LOI Before	LOI After	LOI Difference	LOI %
2							(grams)	(grams)	(grams)	(% loss)
3	1036762743	15-207-27134	-95.9192108	37.9705398	OIL	Woodson	2.459	2.341	0.118	4.798698658
4	1002898254	15-031-20318	-95.8486892	38.2423623	OIL	Coffey	1.232	1.197	0.035	2.840909091
5	1002885127	15-005-20013	-95.53394	39.4219332	D&A	Atchison	6.965	6.877	0.088	1.263460158
6	1002922710	15-085-19008	-95.9544247	39.4354882	OIL	Jackson	6.488	6.338	0.15	2.311960543
7	1001254637	15-113-04525	-97.4503794	38.2164384	PAOW	McPherson	7.172	6.955	0.217	3.025655326
8	1037992735	15-015-19814	-97.1223889	37.6494133	PAOW	Butler	7.992	7.784	0.208	2.602602603
9	1036145571	15-015-19584	-97.149404	37.6548239	PAGW	Butler	4.26	4.16	0.1	2.34741784
10	1002950836	15-191-00090	-97.2729574	37.0881488	OIL	Sumner	3.62	3.524	0.096	2.651933702
11	1001321439	15-185-11043	-98.61757	37.82514	OIL	Stafford	4.954	4.855	0.099	1.998385143
12	1002885310	15-007-00129	-98.4656904	37.3976393	D&A	Barber	4.627	4.547	0.08	1.728982062
13	1002907392	15-047-00034	-99.2967424	37.7418344	PAOW	Edwards	5.169	5.094	0.075	1.450957632
14	1002885295	15-007-00116	-98.6123226	37.1103958	D&A	Barber	3.579	3.478	0.101	2.822017323
15	1006013462	15-007-00651	-98.9629328	37.2001261	PAOW	Barber	6.826	6.735	0.091	1.333138002
16	1002925921	15-097-00140	-99.08992	37.3924798	O&G	Kiowa	7.819	7.735	0.084	1.074306177
17	1006065035	15-067-20952	-101.5236865	37.4988561	PAOW	Grant	7.925	7.808	0.117	1.476340694
18	1002920159	15-077-00123	-98.2474119	37.3252281	OIL	Harper	2.761	2.741	0.02	0.724375226
19	1002924738	15-095-00030	-98.2666625	37.3959455	O&G	Kingman	5.172	5.069	0.103	1.991492653
20	1002924931	15-095-00201	-98.1708206	37.424623	O&G	Kingman	4.382	4.316	0.066	1.50616157
21	1002925147	15-095-00394	-98.3296599	37.3931085	PAGW	Kingman	1.436	1.414	0.022	1.532033426
22	1002925152	15-095-00399	-98.1751767	37.4069085	O&G	Kingman	6.201	6.047	0.154	2.483470408
23	1006013102	15-007-00100	-98.5428353	37.3824925	D&A	Barber	6.391	6.157	0.234	3.661398842
24	1006013408	15-007-00616	-98.63061	37.23149	PAOW	Barber	8.128	7.963	0.165	2.030019685
25	1006015927	15-007-21286	-98.945753	37.3385684	PAOW	Barber	5.254	5.237	0.017	0.323563
26	1030455527	15-007-22792	-98.57051	37.24864	PAOGW	Barber	6.152	6.066	0.086	1.397919376
27	1006774561	15-035-70316	-96.9963305	37.4739559	PAOW	Cowley	9.325	9.108	0.217	2.327077748
28	1002924767	15-095-00057	-98.0732847	37.7179741	PAOW	Kingman	6.502	6.398	0.104	1.599507844
29	1002925494	15-095-10066	-98.08443	37.6978962	PAGW	Kingman	4.716	4.607	0.109	2.311280746
30	1006081782	15-095-20841	-98.3543054	37.7115981	PAOW	Kingman	7.845	7.742	0.103	1.312938177
31	1006112725	15-151-21355	-98.6568559	37.4932243	OIL	Pratt	7.341	7.256	0.085	1.157880398
32	1006159662	15-191-20047	-97.2070476	37.0369518	PAOW	Sumner	6.571	6.373	0.198	3.013239994

Table 3 – Results of Loss on Ignition testing.

3.3 – Rock-Eval Pyrolysis

Rock-Eval Pyrolysis was conducted by GeoMark Laboratories on 20 well cutting samples. These samples were chosen based on initial results of the XRF data and data provided by Wall, 2015. Methodology for data extraction can be found in Appendix A. Tables and images are supplied by GeoMark and represent the results of the Rock-Eval Pyrolysis testing. Table 4 is the combined data, this study and Wall, 2015, from GeoMark Leco TOC Rock-Eval testing. The pyrograms (Figure 8 and 9) supplied by GeoMark depict a majority with low intensity S2 curves, implying a history of hydrocarbon generation. Whereas two depict high intensity S2 values, implying high potential for hydrocarbon production. (McCarthy et al., 2011). However, only 12 of the 20 samples have Tmax values ranging from 428 ° C to 445 ° C.

	Source Rock Analyses											
API Number	Percent Carbonate (wt%)	Leco TOC (wt%)	Rock-Eval-2 S1 (mg HC/g)	Rock-Eval-2 S2 (mg HC/g)	Rock-Eval-2 S3 (mg CO2/g)	Rock-Eval-2 Tmax (°C)	Calculated %Ro (RE TMAX)	Hydrogen Index (S2x100/TOC)	Oxygen Index (S3x100/TOC)	S2/S3 Conc. (mg HC/mg CO2)	S1/TOC Norm. Oil Content	Production Index (S1/(S1+S2)
15-207-27134	13.12	2.74	0.32	2.01	0.72	440	0.76	73	26	3	12	0.14
15-031-20318	8.02	1.61	0.26	3.15	0.63	440	0.76	196	39	5	16	0.08
15-005-20013	29.81	0.54	0.07	0.55	0.51	443	0.81	103	95	1	13	0.11
15-085-19008	12.93	0.76	0.04	0.40	0.43	443	0.81	53	57	1	5	0.09
15-113-04525	20.30	0.37	0.05	0.24	0.28	440	0.76	65	76	1	14	0.17
15-015-19814	29.46	0.44	0.05	0.27	0.51	445	0.85	61	116	1	11	0.16
15-015-19584	24.62	0.34	0.06	0.16	0.72	0	0.00	47	214	0	18	0.27
15-191-00090	25.37	0.82	0.08	0.50	0.58	440	0.76	61	71	1	10	0.14
15-185-11043	33.12	0.23	0.04	0.18	0.37	0	0.00	78	159	0	17	0.18
15-007-00129	53.35	0.17	0.05	0.08	0.39	0	0.00	48	235	0	30	0.38
15-047-00034	27.62	0.23	0.08	0.22	0.28	0	0.00	96	122	1	35	0.27
15-007-00116	39.69	0.25	0.05	0.05	0.51	0	0.00	20	203	0	20	0.50
15-007-00651	27.24	0.14	0.02	0.07	0.32	0	0.00	51	235	0	15	0.22
15-097-00140	33.88	0.15	0.08	0.16	0.35	0	0.00	104	227	0	52	0.33
15-067-20952	31.15	0.41	0.07	0.18	0.72	0	0.00	44	177	0	17	0.28
15-095-00030	11.57	0.72	0.32	0.98	0.39	430	0.69	403	11	37	37	0.08
15-077-00123	4.64	3.55	1.33	14.32	0.39	436	0.58	136	54	3	44	0.25
15-095-00201	22.75	0.88	0.22	1.25	0.34	440	0.76	142	39	4	25	0.15
15-095-00394	15.73	0.80	0.20	0.42	0.52	428	0.54	53	65	1	25	0.32
15-095-00399	10.22	3.95	1.22	15.69	0.47	439	0.74	397	12	33	31	0.07

Table 4 – GeoMark LECO OC and other pyrolysis results.

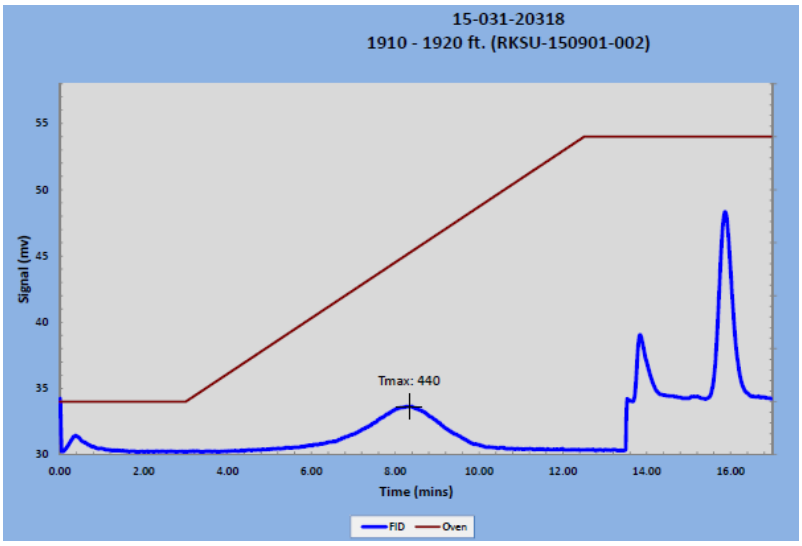


Figure 8 – Pyrogram showing low intensity S2 curve, representative of a majority of samples.

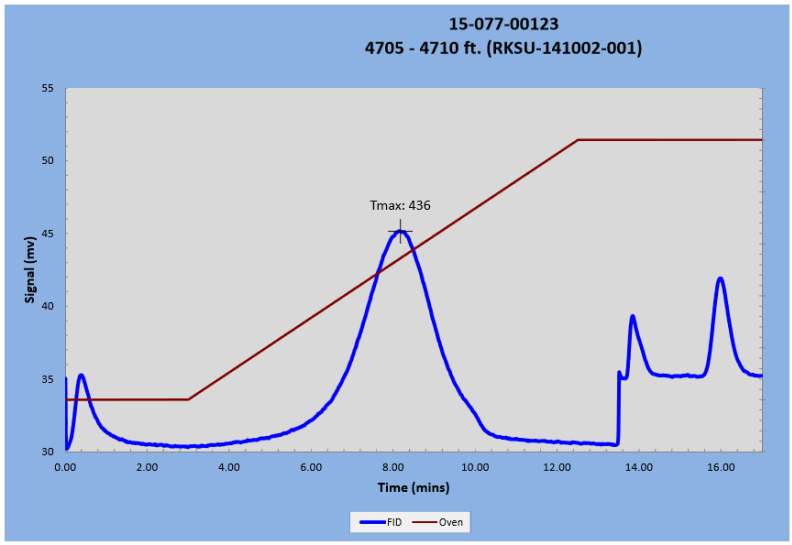


Figure 9 – Pyrogram showing high intensity S2 curve, representative of two samples. (Wall, 2015)

Figure 10 is a modified graph where all samples have been plotted onto the same graph for comparison. It depicts the S2 value vs. Depth and their evaluated potential as a source rock. Four samples fall in the fair/ Good-Excellent category. Whereas, the majority of samples display an S2 value within the poor category.

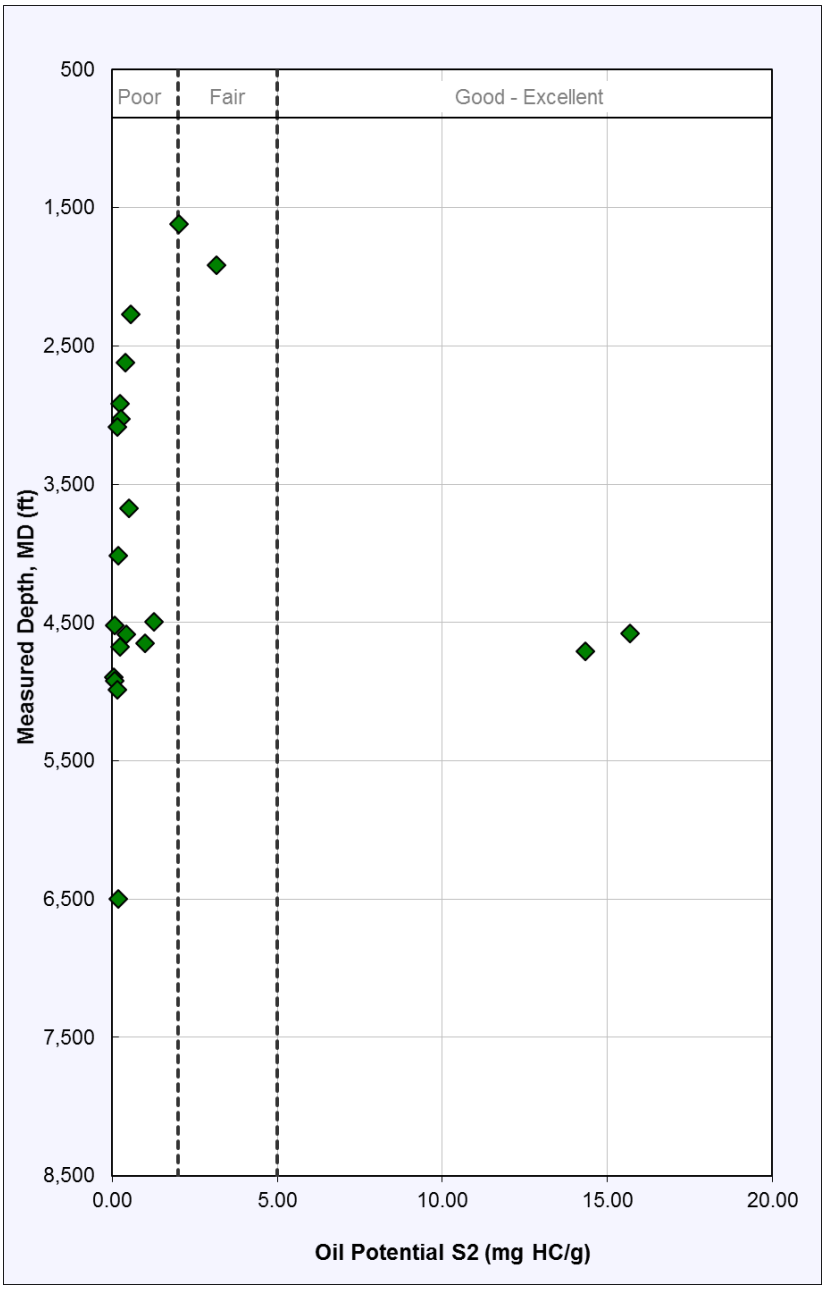


Figure 10 – S2 Values vs. Depth and their evaluated potential as a source rock.

Figure 11 is a modified graph where all samples have been plotted onto the same graph for comparison. It depicts the Hydrogen Index values (S2/TOC) vs. Depth and their evaluated source rock type. Two samples indicate a Type II kerogen, which is ideal for oil production. Whereas, the other 18 samples display a Hydrogen Index intensity much lower. One shows a mixed gas/ type II kerogen nature and the others have Hydrogen Index designated to gas.

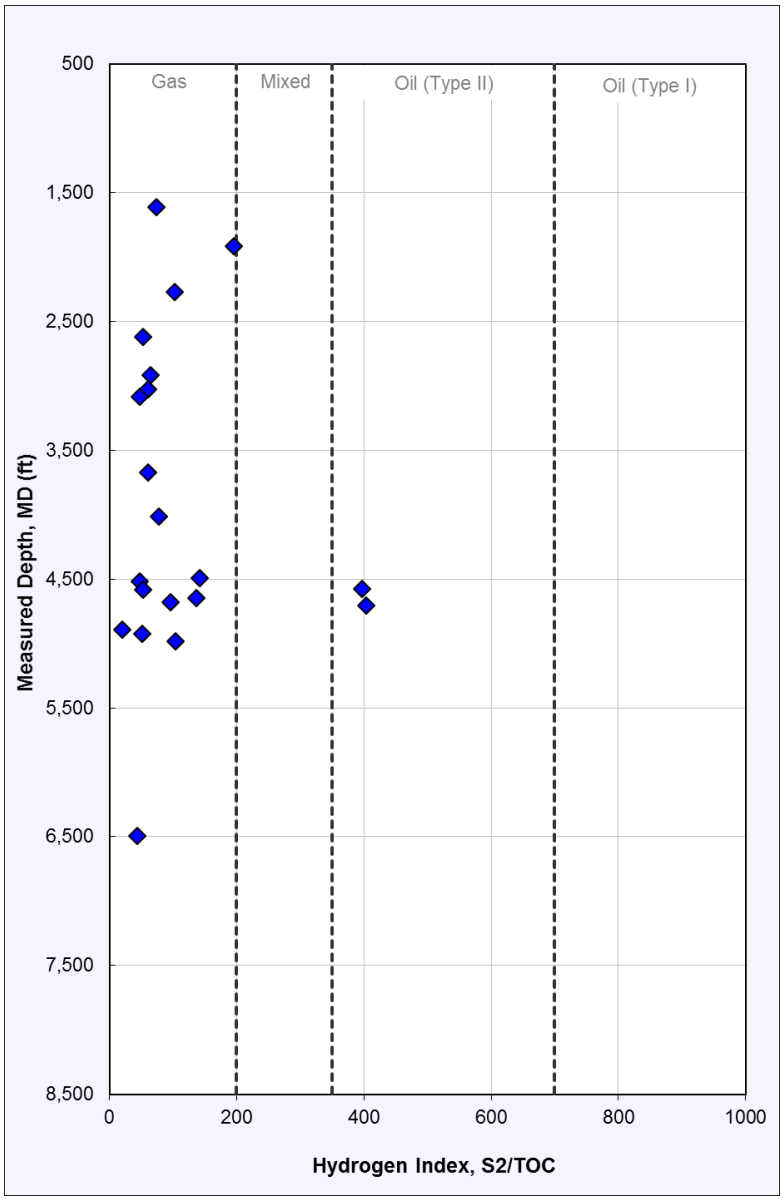


Figure 11 – Hydrogen Index Values (S2/TOC) vs. Depth and their evaluated source rock type.

Another general indicator for kerogen type is Oxygen Index vs. Hydrogen Index over TOC. Figure 12 depicts this information showing the majority (10) of samples in Type II and IV kerogen or gas prone, while a minority (5) display Type I and II kerogen or oil prone parameters.

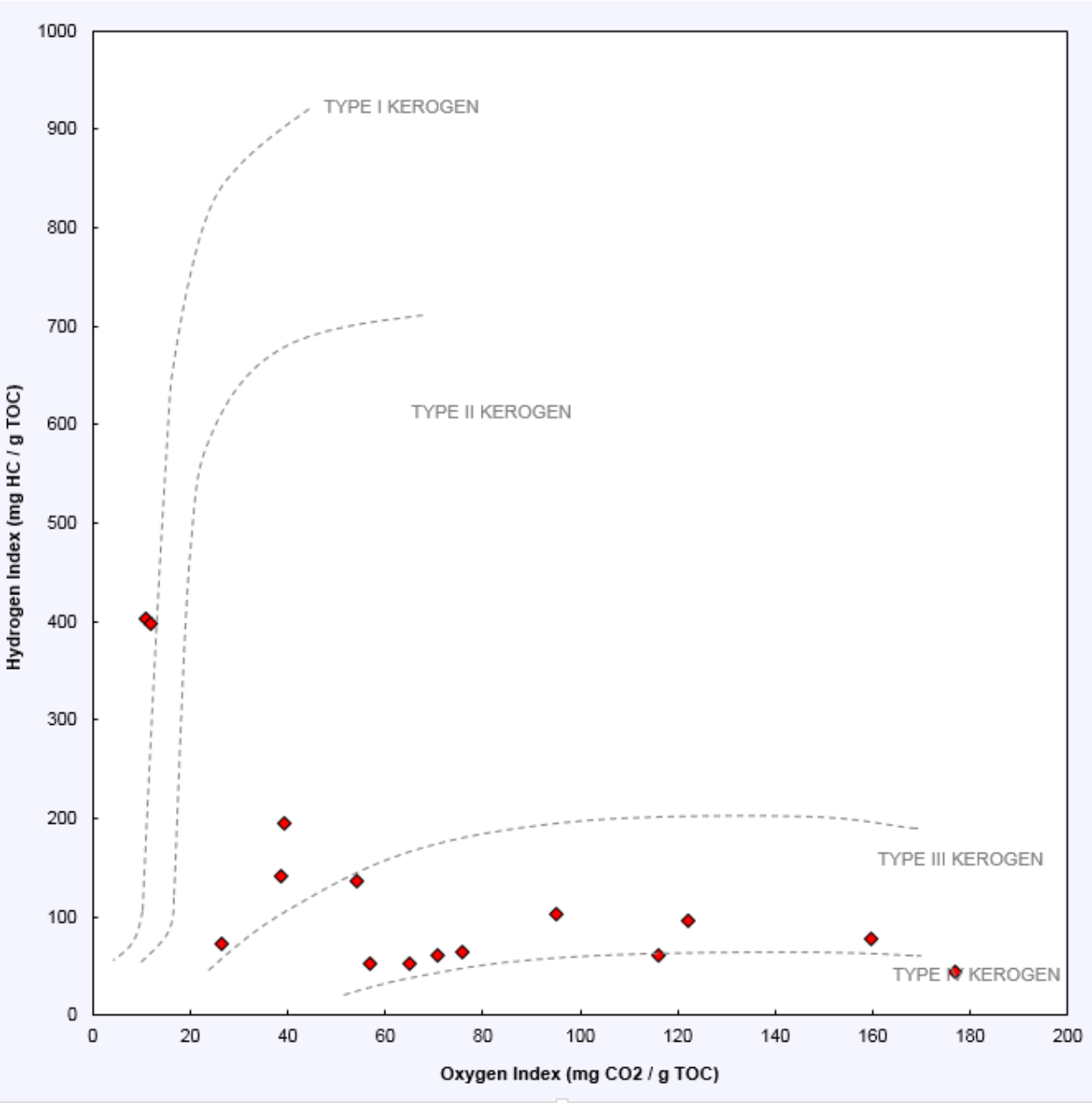


Figure 12 – Oxygen Index vs. Hydrogen Index and predicted kerogen type.

Finally, S2 curves and TOC and be used to display kerogen type arrangements for further visual representation of data. Figure 13 helps highlight the fact that there are two oil generative samples outlying the rest of the gas prone samples.

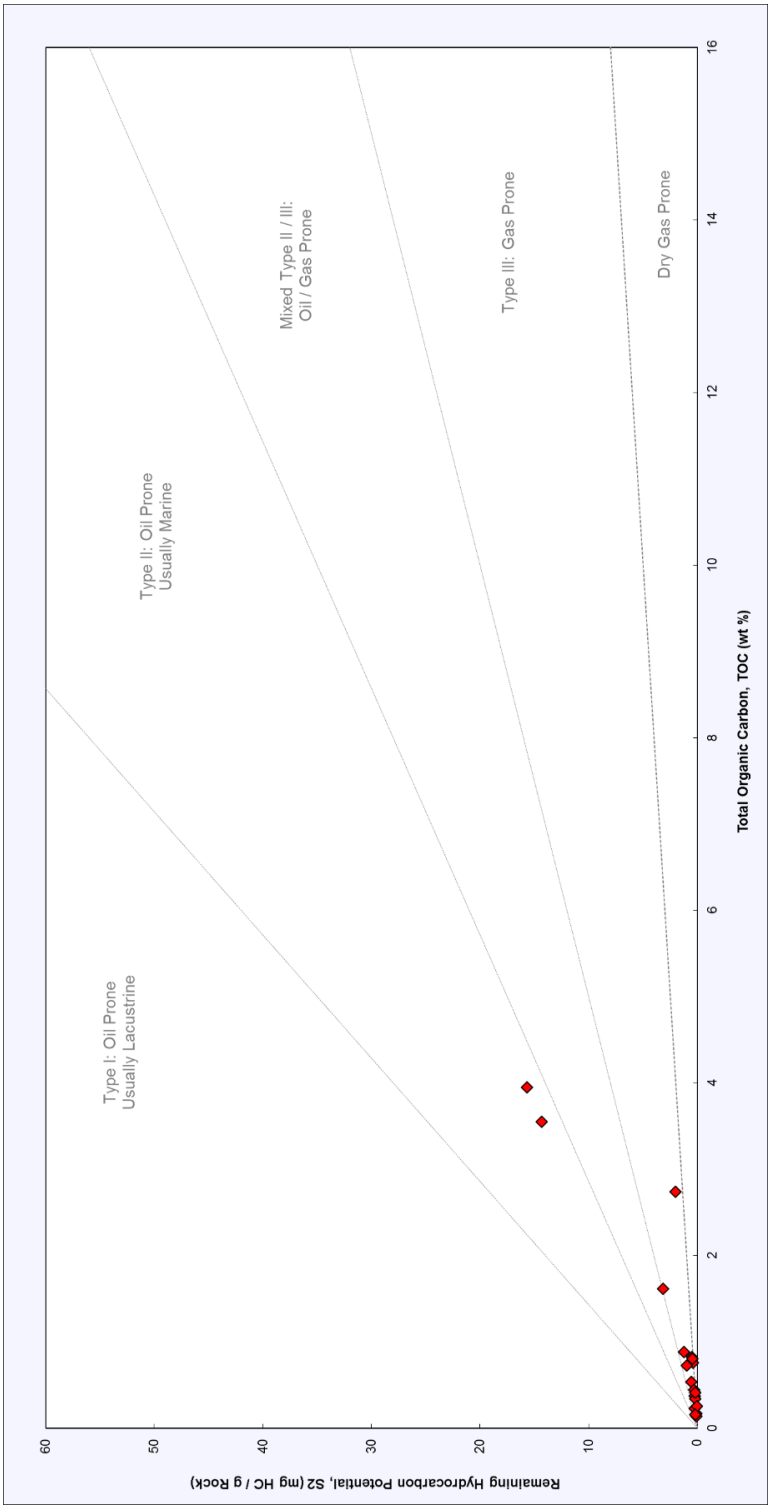


Figure 13 – TOC vs. S2 and predicted kerogen index.

Chapter 4 – Discussion

4.1 - XRF: A Proxy for Organic Matter

Handheld XRF has become an established instrument for quick analysis in the field. It is used to analyze ratios between element weight percentages to provide onsite determination of sample constituents. This study applies these principles to well cuttings for onsite evaluation of organic matter. Drawbacks include slight XRF difficulty in detecting lighter elements (Al, Si) without the use of a controlled atmosphere that doesn't fringe the x-ray penetration power. However, due to the portable nature of the Handheld XRF the use of a controlled atmosphere in the field will likely never be used. A past study by Willey (2015) concluded that the generic mudrock calibration provided by Bruker for analysis can provide precise readings in the field without the requirement of a helium purge.

Following the initial results reported by Willey (2015), Handheld XRF was tested as a viable proxy for organic matter. Willey (2015) identified a strong inverse correlation between organic matter weight percent and the Si/Al ratios. This is believed to be accurate due to the fact that samples with higher organic content in shale, the less chert and clay minerals it can contain. Within this study a similar principle and conclusion can be found as the inverse Si/Al ratios compared to Rock-Eval Pyrolysis TOC are observed. 15 samples can be graphed (Figure 14) with a correlation coefficient, r= .6748. When regarded in percentage of variation (r^2), a value of 45.54% is observed. R-squared is a statistical measure of how close the data are to the fitted regression line. Willey (2015) had an r value of r = .8827, which statistically is better than the values observed in this study. Possible explanations for this difference is the smaller sample size Willey (2015) had as well as the samples being comprised of the Woodford shale and not the Chattanooga. Another explanation can be Willey (2015) acquired OM% values from Ion Coupled Plasma Atomic

Emission Spectrometer (ICP-AES) provided by Ramirez (2013) whereas TOC values were calculated from Rock-Eval Pyrolysis in this study. Willey (2015) also reported a gap between 5 and 15% organic matter, whereas this study has a gap of only .15 and 2.74 % TOC.

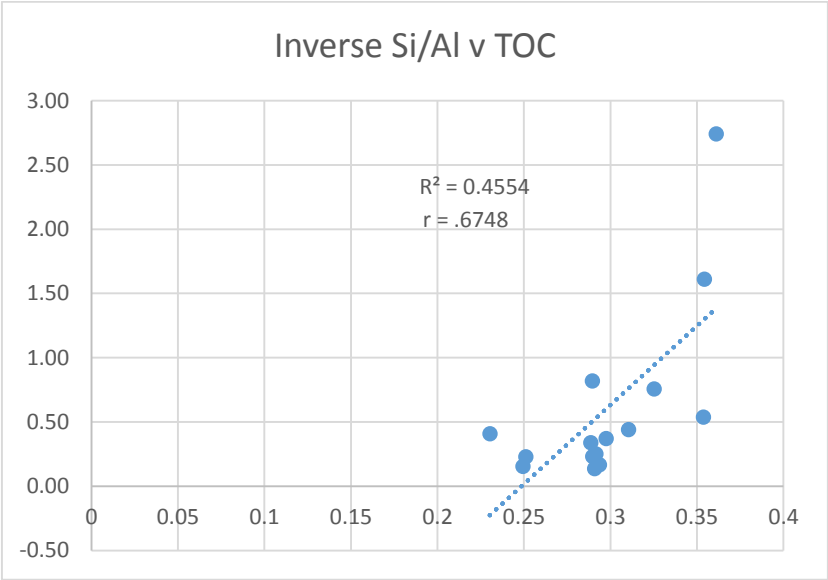


Figure 14 – Graph depicting strong correlation between Inverse Si/Al and TOC.

This method for quick on site analysis to estimate organic matter has the potential to greatly impact the petroleum industry. Si/Al ratios as a proxy for organic matter, although less confirmed in this study compared to Willey (2015), still has the prospect to provide a time and money saving option for contractors. Further study into this method is required to confirm or deny the validity that XRF can be used for onsite evaluation. In terms of the Chattanooga shale as an unconventional reservoir, organic matter values are important to the industry as an assessment of the quality of source rock productivity. Although slightly demonstrated to be less useful in this study this method for onsite organic matter evaluation can still provide an inexpensive preliminary result alternative for companies.

4.2 – Loss on Ignition

Differential thermal analysis (DTA) thermograms show that when a dried, powdered sample containing organic material is heated in a muffle furnace, the organic material begins to ignite at about 200 ° C and is completely ignited by the time the furnace temperature has reached approximately 550 ° C (Dean, 1974). . The difference between this weight and the dry weight is the amount of organic carbon ignited. Although this procedure requires several hours to complete, only a portion of this time actually requires the operator to be present since most of the time involved is heating and cooling of samples.

The results of this method (Table 3) can be given in weight percentage loss and can be compared to TOC values provided by Rock-Eval Pyrolysis. 15 samples can be graphed (Figure 15) with a correlation coefficient, r= .7957. When regarded in percentage of variation (r^2), a value of 63.32% is observed. R-squared is a statistical measure of how close the data are to the fitted regression line. With this correlation coefficient the validity of the loss on ignition method as a test for TOC is confirmed.

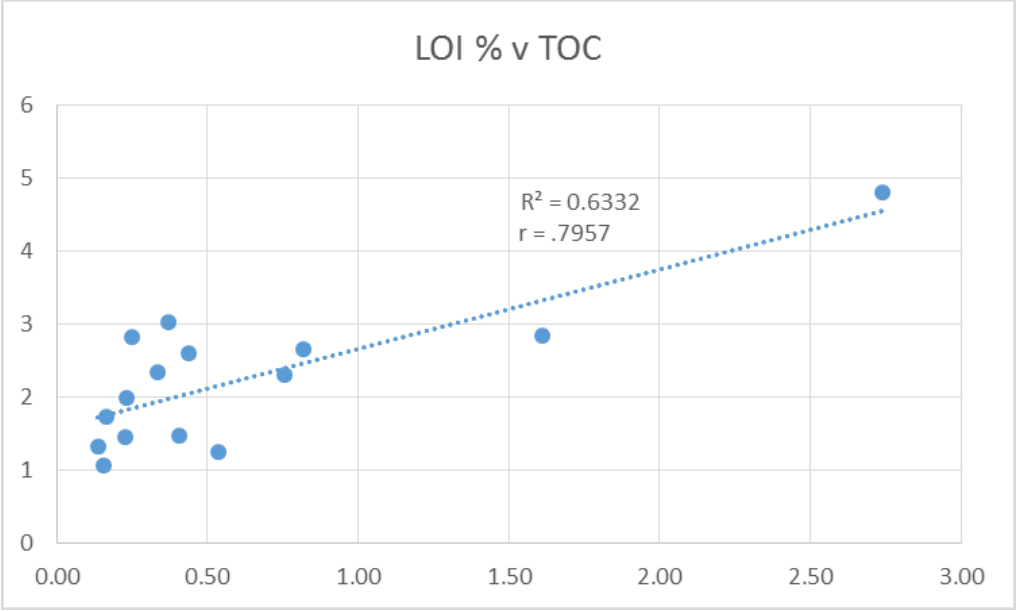


Figure 15 - Graph depicting strong correlation between LOI % and TOC.

Further testing should be performed on the remaining 60 samples to complete a full organic matter database on the Chattanooga shale in Kansas. This will provide more data to incorporate into the investigation of the Chattanooga shale as a potential source rock. Possible inaccuracies with this method are due on part with the laboratory settings. Heating and transport of samples in a non-vacuum environment could lead to water reentering the samples after they have been dried. This can provide false readings of before and after weights of the samples causing non-representative percentages of organic matter. However, precautions were taken in this study to provide the best possible conditions and the degree of error should be minimal and not undermine the validity of this method.

4.3 – Total Organic Carbon

The total organic carbon in this study (Table 4) was performed by GeoMark Laboratories providing an accurate measure of the organic richness in the Chattanooga shale. Data attained from this study and provided by Wall (2015) provide an insight to the organic richness of the Chattanooga shale on both a basin level and regional state wide level. A majority of samples have a low intensity S2 curves, implying a history of hydrocarbon generation. While two depict high intensity S2 values, implying high potential for hydrocarbon production based on parameters set by McCarthy (2011) (Figure 21). Figure 10 shows the S2 values, or oil potential, measured against depth. The two samples with high intensity S2 values can be found in the Spivey-Grabs-Basil field, a well producing basin that has demonstrated to contain the best example of the Chattanooga as a source rock. However, only 12 of the 20 samples have Tmax values ranging from 428 ° C to 445 ° C. These parameters are reflected in the TOC weight percent totals of the samples. 10 samples have TOC % values of < .5 (none), 6 samples have TOC % values of .5 to 1 (poor), and 4 samples have TOC % values of 1 or higher (fair/good). Another approach to determine maturation and

generation within a sample is the % Ro value, or percent of reflected light immersed in oil. Based off of Peters (2006) (Figure 22) parameters, 12 of the samples have a peak maturity value and early-mature Tmax values while the rest could not be determined. The definitive divide within the samples and their maturation index could be attributed to location, depth and if the samples were picked at the richest part of the Chattanooga for that well. Figure 16 shows kerogen type and Ro values with Tmax, type II kerogen samples are located in the Spivey-Grabs-Basil where samples located throughout the rest of Kansas can be found in type III. Given the location of the Spivey-Grabs-Basil field being closer to the Anadarko Basin the result is explained.

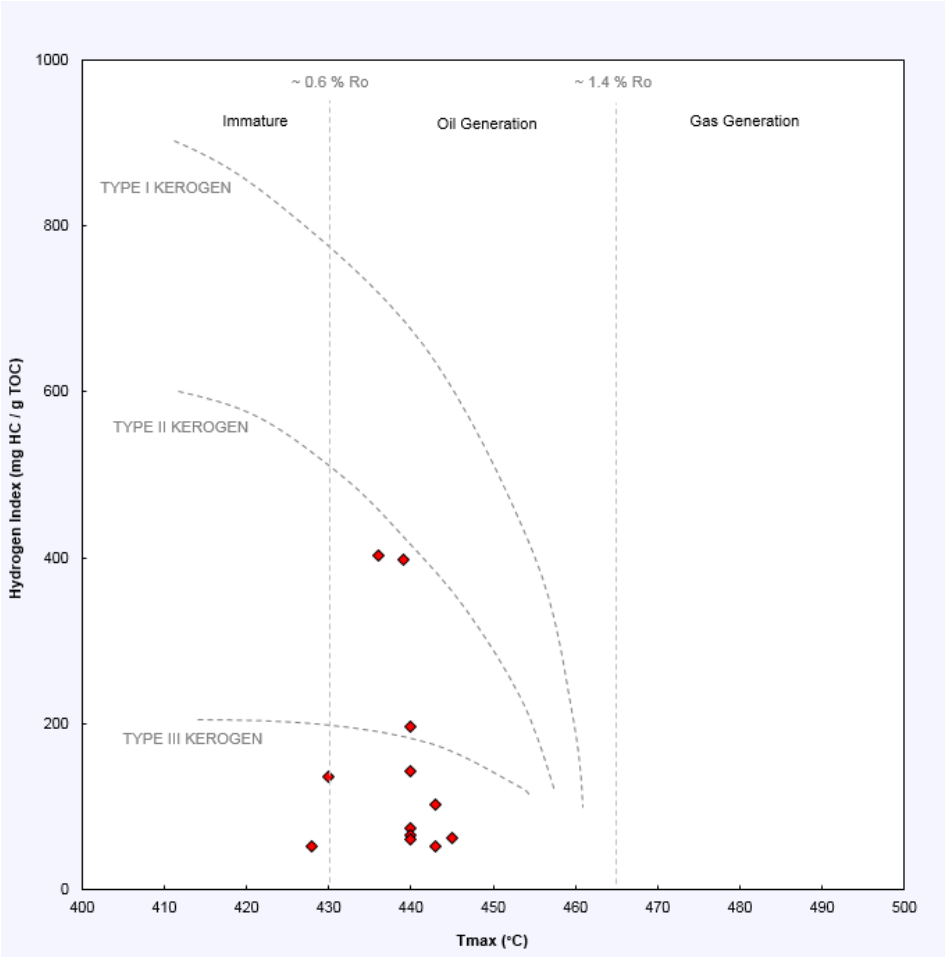


Figure 16 - Hydrogen Index vs. Tmax, showing kerogen type for all samples.

Comparing this data to two other studies, Ramirez-Caro (2013) and Hill (2011), the argument for the Chattanooga shale as a viable source rock in some parts of Kansas is improved. Ramirez-Caro (2013) TOC results from the Woodford shale in Oklahoma shows ranges of .36 to 11.5 wt. %. Hill (2011) TOC results from multiple shales in Kansas shows ranges of 1.8 to 13.3 wt. %. Chattanooga shale TOC values (from Wall, 2015) in the Spivey-Grabs-Basil field in Kansas have a range between .72 and 3.95 wt. %. Other Chattanooga shale samples that can be found in Woodson, Coffey, Jackson and Sumner counties in Kansas have TOC values ranging from .76 to 2.74 wt. %. All Chattanooga samples defined above fits into the range of values from the Woodford, a known commercially producing unit, well enough to conclude the Chattanooga as a viable source rock in some parts of Kansas.

4.4 – Petra Mapping

The use of advanced software programs, such as Petra, to map these locations with subsea formation top data has been used to create regional structure maps of the Chattanooga shale in Kansas. Understanding structures is the key to interpreting geological events that have shaped the present terrain. Structures can indicate potential locations of oil and gas reserves by characterizing both the underlying subsurface geometry of rock units and the amount of crustal deformation and stress experienced in a certain region. In addition, data from XRF and LOI testing has been mapped to show organic matter or source rock potential throughout Kansas. Figure 17 is a contour map comprised of 565 wells throughout Kansas reporting reaching the Chattanooga shale. Figure 18 is an Isopach map illustrating thickness distribution of the Chattanooga shale throughout Kansas.

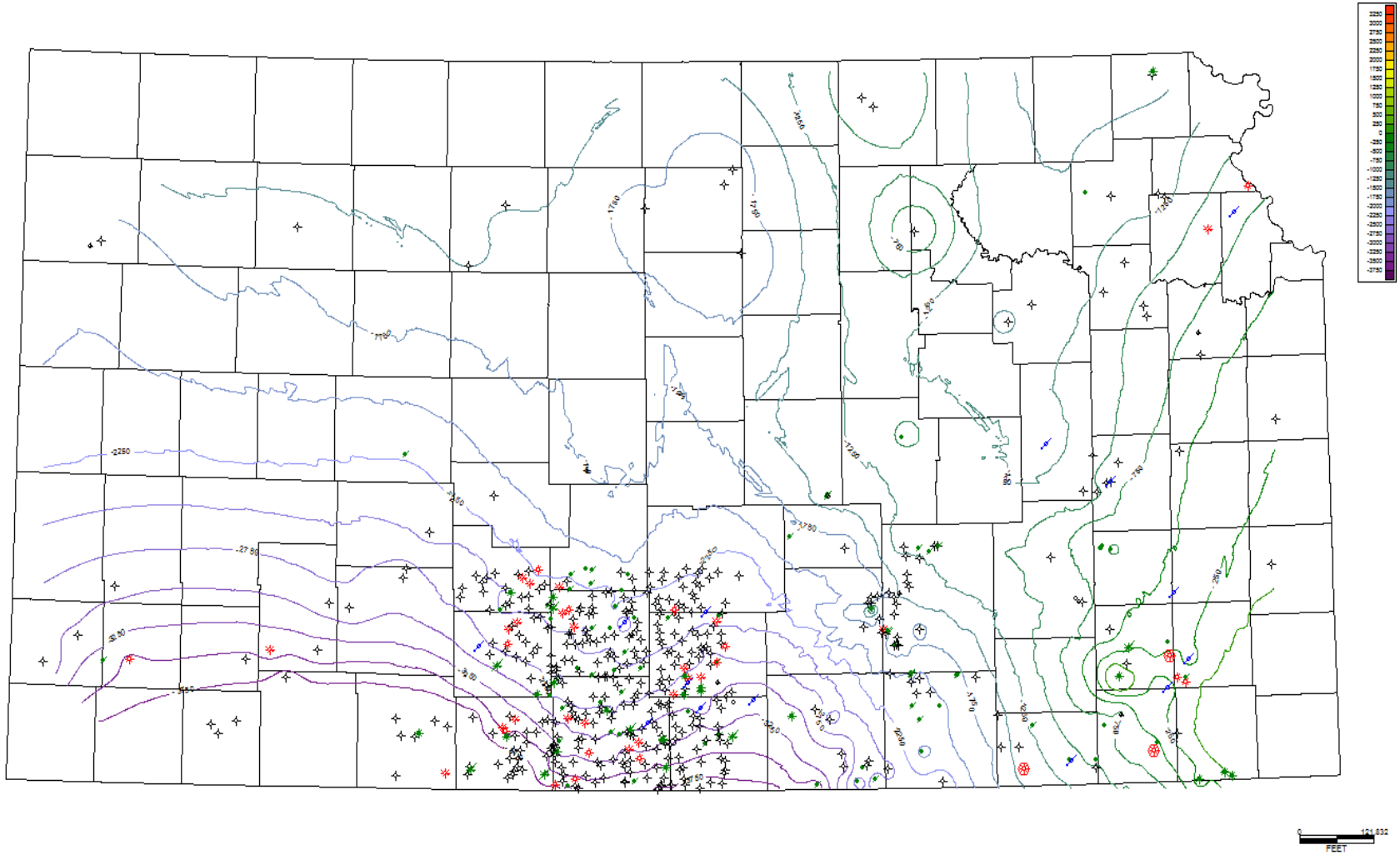


Figure 17 – Contour map of Chattanooga tops data.

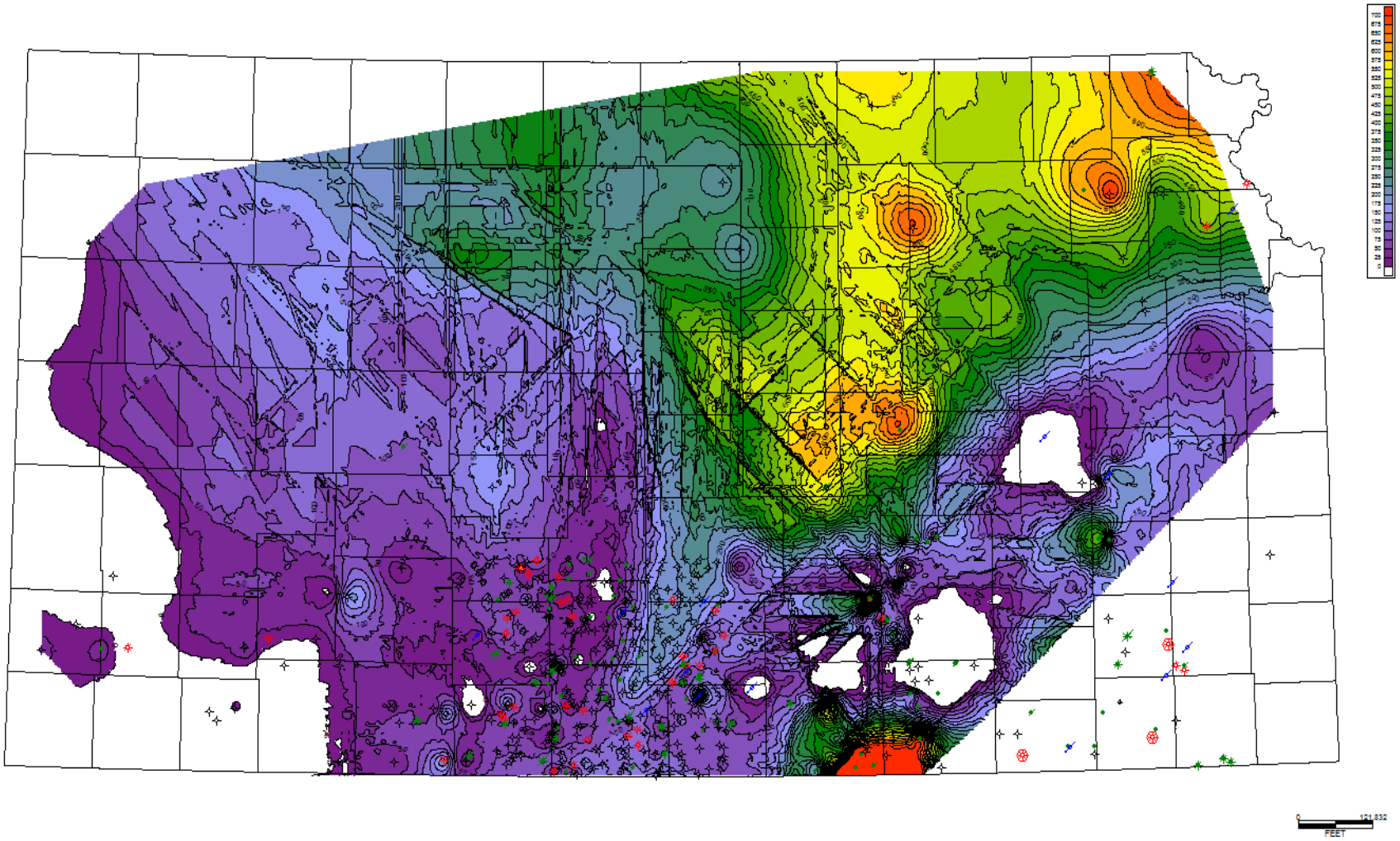


Figure 18 – Isopach map showing thickness of Chattanooga shale.

From this contour map of Chattanooga top data, there is an undeniable trend that the southwest portion of Kansas contains deeper tops of the Chattanooga and increases heading east-northeast. This is a long-established understanding of the Chattanooga and reflects its depositional environment conveyed by Woodrow (1973). Both the contour map and Isopach map acts in accordance with distribution of the three distinct members described by Lambert (1993). The least aerially widespread of the shale members, the lower shale member is present only in the southern part of Kansas. The middle shale member of the Chattanooga shale has the greatest areal extent of any shale member, and is found throughout northwestern Oklahoma (termed Woodford) and eastern Kansas. The upper shale member is not as aerially widespread as the middle shale member but more than the lower member (Lambert, 1993).

Figure 19 is a contour map depicting XRF Al/Si, or Inverse, data. This is a preliminary map of organic matter or source rock potential across Kansas. Willey (2015) used Si/Al ratios to approximate the chert to clay-mineral distribution in Woodford samples, and the inverse of this ratio correlated to the percentage of organic matter. Form this map there is a clear trend of lower Inverse ratios in the southwest and increases as you go northeast. This trend could be a possible product of sample selection and distribution. More samples are present in the southwest providing a more detailed contour while samples are scarce in the northeast possibly misrepresenting the region. Despite this fact, this contour map is the only available foundation to show source rock potential throughout Kansas.

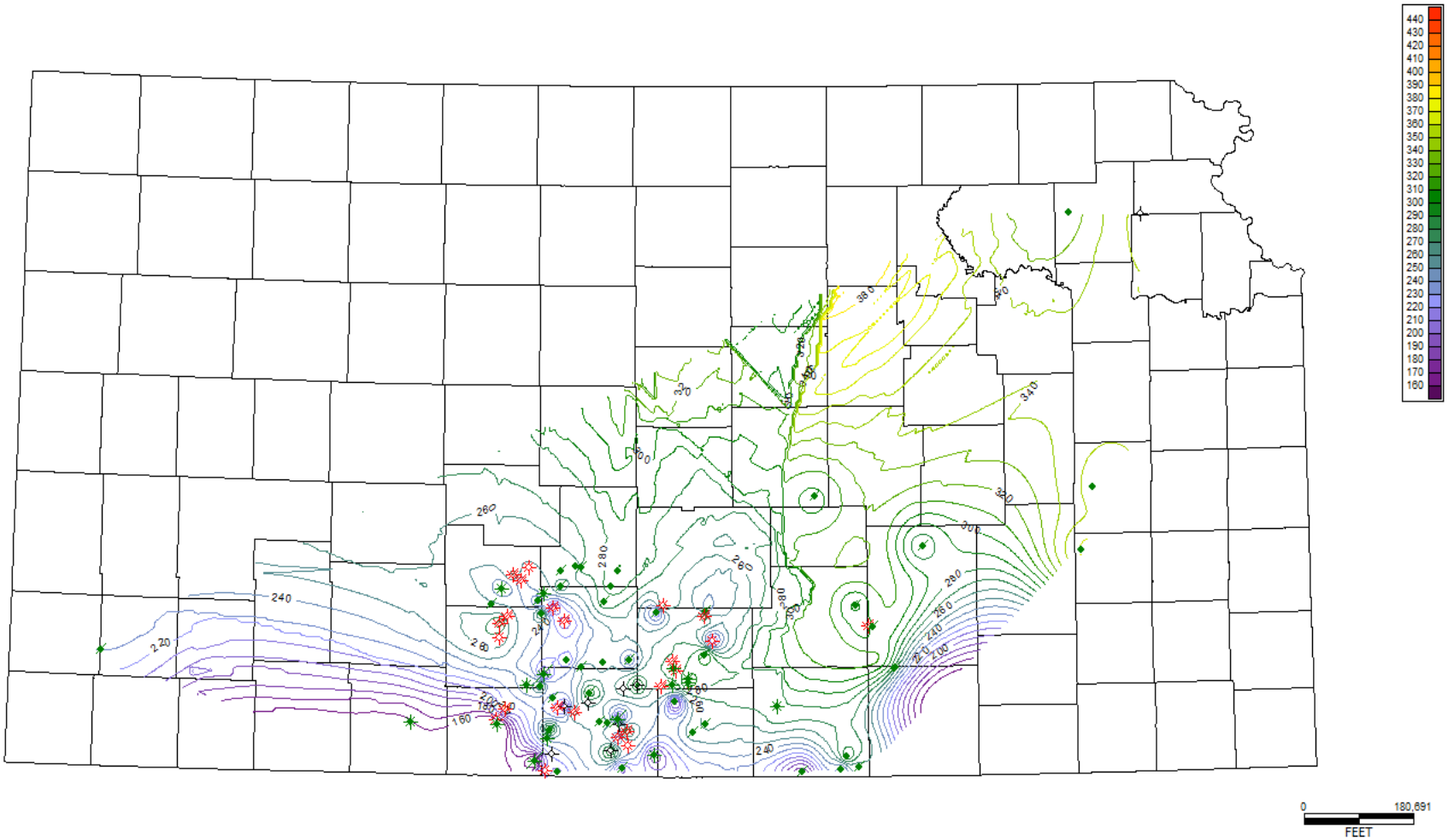


Figure 19 – Contour map representing Organic Matter distribution (constructed from XRF Inverse data.) Note – All data multiplied by a factor of 100 to contour in Petra Software.

Figure 20 is a contour map depicting Loss on Ignition data. Based off of correlation results with TOC data, this method provides a more accurate representation of source rock potential across Kansas. In reasonable concurrence with the XRF Inverse data, there is a clear trend of lower organic matter content in the west and increase to the east. Again, this trend could be a possible product of sample selection and distribution. More samples are present in the southwest providing a more detailed contour while samples are scarce in the northeast possibly misrepresenting the region. With only 30 of the 90 XRF samples tested by LOI method further testing should be done to obtain a more accurate map of organic matter distribution.

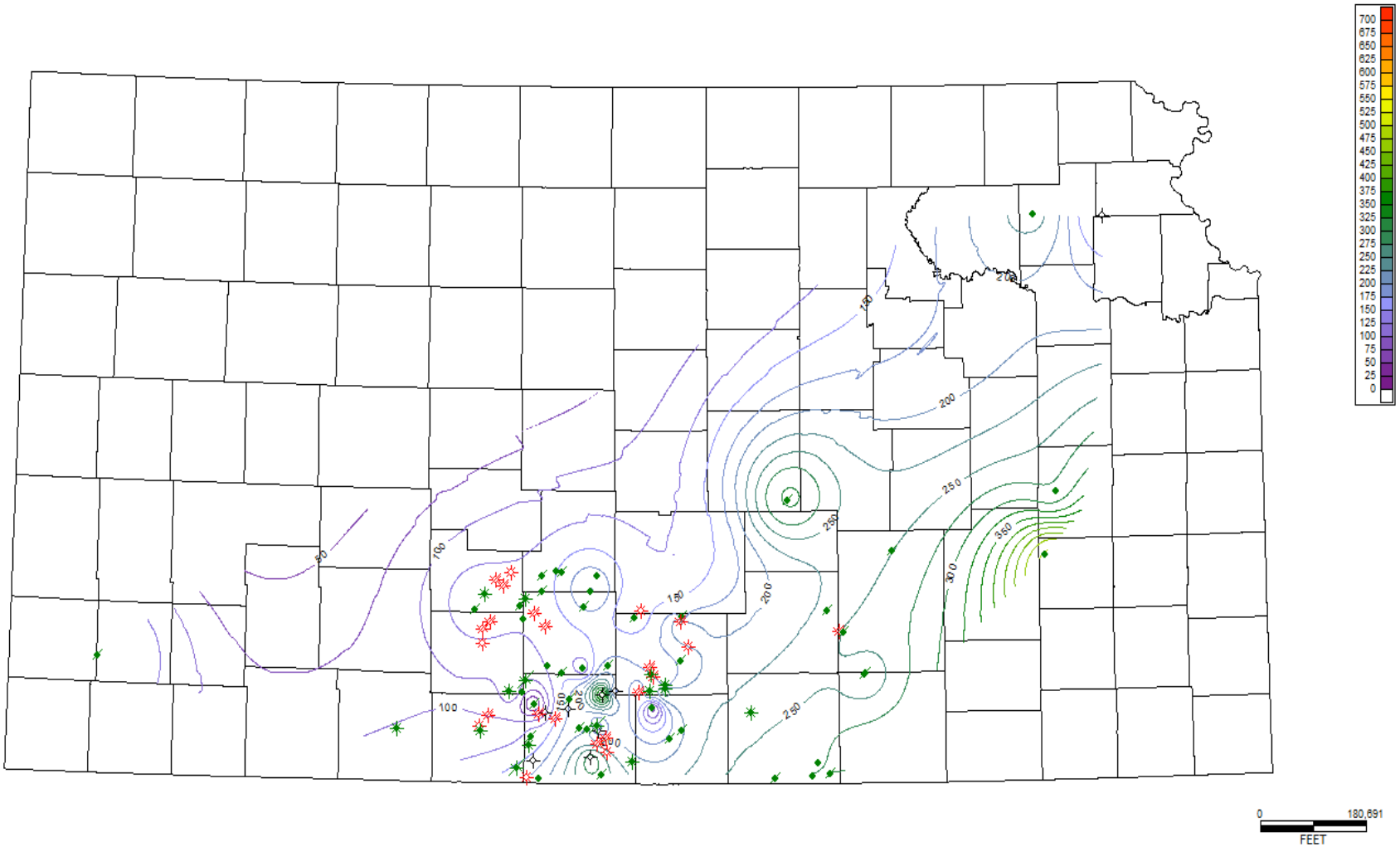


Figure 20 – Contour map representing Organic Matter distribution (constructed from LOI data). Note – All data multiplied by a factor of 100 to contour in Petra Software.

Chapter 5 – Conclusions

Handled XRF still has the prospect for providing quick analysis on organic matter to be used as a determination of the quality of source rock. Although slightly reduced correlation has been found within this study compared to Willey (2015), the method has still proven viable for fracking targets to be determined on site and in a more efficient manner. It has also been instrumental in providing preliminary results and data to the only map of source rock potential across Kansas.

Loss on Ignition results have correlated with TOC data better then XRF results making this method the better option for evaluating source rock potential. Its contour map has shown similar conclusions as the XRF method, however more testing should be done to gain an improved representation of source rock potential throughout Kansas. Even with little operator time involved the overall time it takes to evaluate organic content cannot compare with the XRF method when preforming onsite evaluation.

The source rock potential map can best be applied to the Midwest Kansas region as the quantity of samples are greater there. The clear trend of lower organic matter content in the west and increase to the east could be attributed to this fact. These results provide the first known source rock potential map across Kansas and can be used by the industry for future exploration.

Chapter 6 – Further Research

Upon completion of this study, further research is suggested to help validate the results found.

1. Create a specific Chattanooga shale calibration on the handheld XRF for better accuracy.
2. Complete the LOI testing on the remaining Chattanooga samples to compile a more comprehensive source rock potential map.
3. Additional oil-source rock correlations across Kansas to confirm or deny source rock potential mapping.

References

Amsden, T. W., *et al.*, 1967, Devonian of the Southern Midcontinent Area, United States. 1967 Intl. Symposium of the Devonian system: Papers, Volume I, 913-932.

Cardott, B., and Lambert, M., 1985, Thermal maturation by vitrinite reflectance of Woodford Shale, Anadarko basin, Oklahoma: AAPG Bulletin, v. 69, p. 1982-1998.

Dean, W., Determination of Carbonate and Organic Matter in Calcareous Sediments and Sedimentary Rocks by Loss on Ignition: Comparison With Other Methods. 1974 Journal of Sedimentary Petrology, Volume 44, No. 1, p. 242-248.

Heckel, P., and Witzke, B., 1979, Devonian world palaeogeography determined from distribution of carbonates and related lithic palaeoclimatic indicators, in M. House, C. Scrutton, and M. Bassett, eds., The Devonian System: Special Papers in Palaeontology 23, p. 99-123.

Hill, Tyler (2011). POTENTIAL SOURCE ROCKS IN THE WESTERN KANSAS PETROLEUM PROVINCE. Thesis. Kansas State University Graduate School, 2011. Manhattan. Kansas State University.

Hilpman, P. L. (1967). DEVONIAN STRATIGRAPHY IN KANSAS; A PROGRESS REPORT. TULSA GEOLOGICAL SOCIETY DIGEST, Vol. 35, 88-98.

Lambert, M. W. (1993). Internal Stratigraphy and Organic Facies of the Devonian-Mississippian Chattanooga (Woodford) Shale in Oklahoma and Kansas: Chapter 11. SG 37: Source Rocks in a Sequence Stratigraphic Framework, p. 163-176.

Lambert, M.W., (1990). Internal Stratigraphy of the Chattanooga Shale in Kansas and Oklahoma, in Johnson, K.S. and B.J. Cardott (eds.) Source Rocks in the Southern Midcontinent, 1990 symposium: Oklahoma Geological Society Circular 93, 94-103.SOCIETY DIGEST, Vol. 35, 88-98.

Lee, W., 1956, Stratigraphy and structural development of the Salina basin area: Kansas Geological Survey Bulletin 121,167 p.

McCarthy, K., Neimann, M., & Palmowski, D. P. (2011). Basic Petroleum Geochemistry for Source Rock Evaluation. Oilfield Review, v. 23, No. 2, 32-43.

McIntire, Michael (2012). RARE EARTH ELEMENTS (REE) IN CRUDE OIL IN THE LANSING-KANSAS CITY FORMATIONS IN CENTRAL KANSAS; POTENTIAL INDICATIONS ABOUT THEIR SOURCES, LOCALLY DERIVED OR LONG-DISTANCE DERIVED. Thesis. Kansas State University Graduate School, 2012. Manhattan. Kansas State University.

Peters, K. E., Walters, C. C., & Moldowan, J. M. (2006). *The Biomarker Guide: p. 72-118.* New York: Cambridge University Press.

Potter, P.E., Maynard, J.B., and Pryor, W.A. (1980). Sedimentology of Shale. Springer Verlag, New York.

Lee, W., 1956, Stratigraphy and structural development of the Salina basin area: Kansas Geological Survey Bulletin 121,167 p.

Ramirez-Caro, D. (2013). Rare Earth Elements (REE) as Geochemical Clues to Reconstruct Hydrocarbon Generation History. Thesis. Kansas State University Graduate School, 2013. Manhattan. Kansas State University.

Tissot, B., and Welte, D., 1984, Petroleum formation and occurrence: Springer-Verlag, New York, 699 p.

Totten, M.W., Dean, M.C., and Falster, A.U., 1995, Separation of Heavy Minerals from Mudrocks, Journal of Sedimentary Research, v. 65, p.563-566.

Wall, Meagan (2015). An Oil-Source Rock Correlation Examining the Potential of the Chattanooga Shale as a Source Rock for Oil within the Spivey-Grabs-Basil Field, Kingman and Harper Counties, Kansas. Thesis. Kansas State University Graduate School, 2015. Manhattan. Kansas State University.

Willey, Tyler (2015). HANDHELD XRF AS A PROXY FOR ONSITE EVALUATION OF UNCONVENTIONAL TARGETS: AN INVESTIGATION OF THE WOODFORD SHALE, ANADARKO BASIN, OKLAHOMA. Thesis. Kansas State University Graduate School, 2015. Manhattan. Kansas State University.Survey Bulletin 121,167 p.

Witzke, B., and Heckel, P., 1988, Paleoclimatic indicators and inferred Devonian paleolatitudes of Euramerica, in N. McMillan, A. Embry, and D. Glass, eds., Devonian of the world: proceedings of the second international symposium on the Devonian system, v. 3: Canadian Society of Petroleum Geologists, p. 49-63.

Woodrow, D., Fletcher, F., and Ahrnsbrak, W., 1973, Paleogeography and paleoclimate at the deposition sites of the Devonian Catskill and Old Red Sandstone Facies: Geological Society of America Bulletin, v. 84, p. 3051-3064.

Appendix A - GeoMark Methodology

PYROLYSIS

1. Sample Requirements for a Typical Geochemical Program

For geochemical analysis a teaspoon (ca. 10 g.) of sample material is needed when TOC, Rock-Eval, vitrinite reflectance and residual hydrocarbon fluid fingerprinting is to be completed. If possible, a tablespoon is preferred. However, it is possible to complete a detailed program with even less sample, although there is dependency on the sample characteristics (e.g., organic richness, abundance of vitrinite, amount of staining).

2. Total Organic Carbon (TOC) – LECO C230 instrument

Leco TOC analysis requires decarbonation of the rock sample by treatment with hydrochloric acid (HCl). This is done by treating the samples with Concentrated HCL for at least two hours. The samples are then rinsed with water and flushed through a filtration apparatus to remove the acid. The filter is then removed, placed into a LECO crucible and dried in a low temperature oven (110° C) for a minimum of 4 hours. Samples may also be weighed after this process in order to obtain a % Carbonate value based on weight loss.

The LECO C230 instrument is calibrated with standards having known carbon contents. This is completed by combustion of these standards by heating to 1200°C in the presence of oxygen. Both carbon monoxide and carbon dioxide are generated and the carbon monoxide is converted to carbon dioxide by a catalyst. The carbon dioxide is measured by an IR cell. Combustion of unknowns is then completed and the response of unknowns per mass unit is compared to that of the calibration standard, thereby the TOC is determined.
Standards are analyzed as unknowns every 10 samples to check the variation and calibration of the analysis. Random and selected reruns are done to verify the data. The acceptable standard deviation for TOC is 3% variation from established value.

3. Rock Eval

Approximately 100 milligrams of washed, ground (60 mesh) whole rock sample is analyzed in the Rock-Eval II instrument. Organic rich samples are analyzed at reduced weights whenever the S2 value exceeds 40.0 mg/g or TOC exceeds 7-8%. Samples must be re-analyzed at lower weights when these values are obtained at 100 mg.

RE-II Operating Conditions

S1: 300°C for 3 minutes
S2: 300°C to 550°C at 25$_{o}$C/min;
hold at 550°C for 1 minute
S3: trapped between 300 to 390°

RE-VI Operating Conditions

S1: 300°C for 3 minutes
S2: 300°C to 600°C at 25°C/min;
hold at 600°C for 1 minute
S3: measured between 300 to 400°

HAWK Operating Conditions

S1: 300°C for 3 minutes
S2: 300°C to 650°C at 25°C/min;
hold at 650°C for 0 minute
S3: measured between 300 to 400°

Measurements from Rock-Eval are:

S1: free oil content (mg HC/g rock)
S2: remaining generation potential (mg HC/g rock)
Tmax: temperature at maximum evolution of S2 hydrocarbons (°C)
S3: organic carbon dioxide yield (mg CO_2/ g rock)

Several useful ratios are also utilized from Rock-Eval and TOC data. These are:

Hydrogen Index (HI):	S2/TOC x 100 (in mg HC/g TOC)
Oxygen Index (OI):	S3/TOC x 100 (in mg CO2/g TOC)
Normalized Oil Content:	S1/TOC x 100 (in mg HC/g TOC)
S2/S3:	
Production Index (PI):	S1/ (S1+S2)

Instrument calibration is achieved using a rock standard. Its values were determined from a calibration curve to pure hydrocarbons of varying concentrations. This standard is analyzed every 10 samples as an unknown to check the instrument calibration. If the analysis of the standard ran as an unknown does not meet specifications, those preceding data are rejected, the instrument recalibrated, and the samples analyzed again. However, normal variations in the standard are used to adjust any variation in the calibration response. The standard deviation is considered acceptable under the following guidelines:

Tmax: ± 2°C
S1: 10% variation from established value
S2: 10% variation from established value
S3: 20% variation from established value

Analytical data are checked selectively and randomly. Selected and random checks are completed on approximately 10% of the samples. A standard is analyzed as an unknown every 10 samples.

4. Turnaround Time:

The standard turnaround time for sample orders over the past 12 months is approximately 2 to 3 weeks, depending on number of samples in the order.

Appendix B - Full XRF Data Tables

API_NUMBER	LONGITUDE	LATITUDE	Well Type	County	Na	Mg	Al	Si	P	S	K	Ca	Ti	Fe	Inverse	Si/Al	K/Al
15-005-20013	-95.53394	39.4219332	D&A	Atchison	0.62340199	0.4413868	4.81059982	13.6017319	0.07244715	0.59412705	2.88246967	8.00459919	0.33169893	4.03526402	0.35368	2.82745	0.59919
15-007-00023	-98.5672558	37.2280028	D&A	Barber	0.62367888	0.44850716	3.78407144	14.7670802	0.12018985	0.69486412	2.49838343	6.83657545	0.32664416	3.58187131	0.25625	3.90243	0.66024
15-007-00026	-98.8765778	37.3024544	D&A	Barber	0.5057007	0.4569885	1.07118664	5.71581877	0.07684489	0.22047155	0.77853891	25.8663436	0.12459824	1.33041718	0.18741	5.33597	0.7268
15-007-00044	-98.7421836	37.3206795	D&A	Barber	0.61809791	0.44034578	3.29109048	12.4423901	0.11135861	1.86594129	1.89785729	10.4729847	0.27768092	2.85003608	0.21304	4.69395	0.79984
15-007-00100	-98.5428353	37.3824925	D&A	Barber	0.62595105	0.43965371	3.3442027	12.4483884	0.08246738	0.86148648	1.74020369	10.2978881	0.2832393	2.68868973	0.26451	3.78063	0.57667
15-007-00115	-98.9489251	37.0949374	D&A	Barber	0.61854288	0.43875357	3.33983225	15.0045433	0.07435194	0.67673225	1.79962051	8.62649243	0.29798682	2.89137588	0.26865	3.72238	0.52036
15-007-00116	-98.6123226	37.1103958	D&A	Barber	0.61705224	0.43619986	3.17430425	10.8874765	0.08864028	0.5466064	1.44963326	13.7232702	0.29214405	2.86964778	0.22259	4.4926	0.53884
15-007-00129	-98.4656904	37.3976393	D&A	Barber	0.58153167	0.4319072	2.45804677	8.37482701	0.07599973	0.41170632	1.308805	18.9348143	0.21980585	2.34887282	0.29156	3.42988	0.45668
15-007-00314	-98.5738415	37.1683964	PAGW	Barber	0.54041151	0.43922493	1.50265823	6.77038255	0.07883239	0.42226482	0.78446007	22.7372403	0.17622744	1.96303786	0.2935	3.40711	0.53246
15-007-00345	-98.9194516	37.2953998	PAGW	Barber	0.4903221	0.45547025	1.18707567	5.57206825	0.07747396	0.13367885	0.94946712	26.8706601	0.13172681	1.44992752	0.22195	4.5056	0.52205
15-007-00522	-98.6779888	37.2384066	PAOW	Barber	0.53287417	0.46837943	1.86968808	7.34828504	0.08672661	0.39572136	1.00867669	22.3870733	0.17474669	1.82613471	0.25444	3.93022	0.53949
15-007-00523	-98.8224457	37.2756755	PAGW	Barber	0.55956307	0.45724012	2.199672	8.32387966	0.10664957	0.83218514	1.22424596	19.7578536	0.19908852	2.23830826	0.26426	3.78415	0.55656
15-007-00533	-98.5232768	37.1969482	PAGW	Barber	0.58607135	0.44732757	2.69142863	9.55392007	0.12351221	1.22884907	1.35187028	16.2772797	0.24074697	2.40322395	0.28171	3.54976	0.50229
15-007-00537	-98.9130662	37.0185588	OIL	Barber	0.5745441	0.44859654	1.98090347	9.59466526	0.08367765	0.51632755	1.16757369	18.7178862	0.19452031	1.97031368	0.20646	4.84358	0.58941
15-007-00616	-98.63061	37.23149	PAOW	Barber	0.601639	0.43625053	2.14872159	8.50639376	0.09750787	1.29965288	1.22897662	16.6060237	0.20278998	2.3448191	0.2526	3.95882	0.57196
15-007-00651	-98.9629328	37.2001261	PAOW	Barber	0.59954619	0.44499861	2.86434669	9.84699695	0.09487413	1.01696605	1.58718116	15.6701742	0.25011	2.65551235	0.29089	3.43778	0.55412
15-007-01167	-98.7341036	37.3597508	PAOW	Barber	0.59070056	0.44477503	2.88828214	10.0253534	0.11701668	1.40525321	1.58408941	15.2682135	0.25052709	2.51604495	0.2881	3.47104	0.54845
15-007-01816	-98.5137	37.13163	GAS	Barber	0.61063185	0.45416336	3.40289099	13.900011	0.11624091	1.93370956	1.67658587	8.69794517	0.29574098	2.91928841	0.24481	4.08477	0.49269
15-007-20361	-98.5464045	37.0349265	PAOW	Barber	0.5953812	0.42720439	3.42865767	17.2201279	0.08347551	0.50884152	1.7695381	7.90814534	0.27754254	2.80699694	0.19911	5.02241	0.5161
15-007-21286	-98.945753	37.3385684	PAOW	Barber	0.52232672	0.46169478	1.52483019	6.66844115	0.07581422	0.23496585	1.1935845	24.9595572	0.14684732	1.54236976	0.22866	4.37324	0.78277
15-007-21596	-98.9945421	37.4428116	PAOGW	Barber	0.51484802	0.45585284	1.23698378	6.45799431	0.0910331	0.05758095	0.76535332	24.7205879	0.138008	1.5510882	0.19154	5.22076	0.61873
15-007-21630	-98.3668934	37.0950894	O&G	Barber	0.61005983	0.43930258	2.53112334	13.6608222	0.08416346	0.49396015	1.19761348	11.4013899	0.24046046	2.44710517	0.18528	5.39714	0.47315
15-007-22662	-98.9741814	37.1595907	O&G	Barber	0.57362724	0.43790391	2.2157413	9.31457809	0.08964309	0.38527509	1.16175714	19.0781997	0.20748895	2.01040456	0.23788	4.20382	0.52432
15-007-22792	-98.57051	37.24864	PAOGW	Barber	0.49440509	0.47597691	1.12540371	6.26768396	0.0856964	0.12493496	0.62555786	25.250707	0.12053194	1.30581763	0.17956	5.56928	0.55585
15-007-30268	-98.9840064	37.0218131	GAS	Barber	0.48918116	0.49215221	1.39710826	6.46410158	0.10553536	1.05494263	0.85498131	24.0873386	0.13012167	2.02145559	0.21613	4.62677	0.61196
15-015-19584	-97.149404	37.6548239	PAGW	Butler	0.61967733	0.44091229	4.18863353	14.5156182	0.08056833	0.62043683	2.11539841	7.64513702	0.36108305	3.61582355	0.28856	3.46548	0.50503
15-015-19814	-97.1223889	37.6494133	PAOW	Butler	0.61401935	0.44108399	4.31499423	13.9006813	0.08546568	0.48433226	2.16198697	8.73100965	0.34849696	3.81750945	0.31042	3.22148	0.50104
15-015-22303	-96.8303772	37.9976575	PAOW	Butler	0.61959168	0.44375817	3.40306348	12.4058652	0.10959686	0.40873661	1.63861812	11.1501871	0.31898741	3.07395563	0.27431	3.6455	0.48151
15-025-20688	-99.7494855	37.2260253	O&G	Clark	0.59289294	0.45630825	2.41414789	15.1854215	0.09316051	1.03337377	1.29702846	10.8226907	0.21912002	2.21076227	0.15898	6.29018	0.53726
15-031-20318	-95.8486892	38.2423623	OIL	Coffey	0.61179772	0.54504417	5.80767641	16.3949896	0.04581756	0.546584	3.20573082	1.31596535	0.42609766	3.41719693	0.35423	2.82299	0.55198
15-033-00035	-99.2621002	37.2429628	GAS	Comanche	0.56117916	0.64377109	1.20422139	7.38886741	0.13831004	1.6554273	0.71356215	17.5315933	0.11208456	1.74512345	0.16298	6.1358	0.59255
15-033-10035	-99.2121034	37.2903828	PAGW	Comanche	0.60387312	0.51002325	2.87071048	12.7781705	0.14493119	2.99317879	1.49024296	9.29979177	0.26480064	2.71720727	0.22466	4.45122	0.51912
15-033-20108	-99.0427181	37.0655094	PAOGW	Comanche	0.59973383	0.4259406	2.57507514	17.6319205	0.08582755	0.50763618	1.28209968	7.5756922	0.25059275	2.35919191	0.14605	6.84715	0.49789
15-033-20628	-99.259338	37.2192333	O&G	Comanche	0.59997313	0.43770733	1.92464096	15.7561028	0.09561723	0.59144666	1.03838947	10.8577758	0.18217303	1.74215334	0.12215	8.18652	0.53952
15-035-70311	-96.999347	37.4664483	PAOW	Cowley	0.61448094	0.43850299	4.18649382	16.1537417	0.0829616	1.01089579	3.2448598	4.74815725	0.32783902	3.70737575	0.25917	3.85854	0.77508
15-035-70312	-97.0016835	37.4681515	PAOW	Cowley	0.60277008	0.5293202	4.91734647	17.3347153	0.06156239	0.69573455	2.56982422	1.85911555	0.43754244	3.0557848	0.28367	3.52522	0.5226
15-035-70313	-96.9971674	37.4680921	PAOW	Cowley	0.61287147	0.43935039	3.42575679	13.2983913	0.09964626	0.74838726	2.17027201	10.2945642	0.29304873	3.17004743	0.25761	3.88188	0.63352
15-035-70316	-96.9963305	37.4739559	PAOW	Cowley	0.62071769	0.44018943	2.87117207	10.7890172	0.08427222	1.1242487	1.57318698	12.8294452	0.26365607	2.68375855	0.26612	3.7577	0.54793
15-047-00034	-99.2967424	37.7418344	PAOW	Edwards	0.60915562	0.48124464	3.30852223	13.178554	0.13558558	2.81617126	1.64288354	8.96436335	0.2787198	2.82450439	0.25105	3.98321	0.49656
15-047-00042	-99.0325628	37.7611681	PAOW	Edwards	0.60171894	0.45159558	3.82611541	18.0625409	0.0727327	0.60134683	1.75382771	4.06691452	0.34106289	3.34400961	0.21183	4.72086	0.45838
15-047-00052	-99.089484	37.9062923	GAS	Edwards	0.62584219	0.43507595	2.69566465	10.8375784	0.08396994	0.64341079	1.42471244	13.0257305	0.26998477	2.6296368	0.24873	4.02037	0.52852
15-047-00087	-99.1334153	37.8497141	PAGW	Edwards	0.60588326	0.50585416	4.00837966	17.1212326	0.06180248	0.34682993	1.52206026	3.18620187	0.39639638	3.43009216	0.23412	4.27136	0.37972
15-047-00227	-99.2395247	37.8126847	O&G	Edwards	0.61527713	0.44166151	2.90926874	12.7232891	0.10208491	1.66121057	1.52273951	10.0949094	0.27467104	2.86069383	0.22866	4.37336	0.52341
15-047-20921	-99.1756593	37.8755499	PAGW	Edwards	0.63283531	0.44166848	3.44369348	13.1212485	0.07100611	0.49332454	1.56760351	8.42850488	0.33097587	3.21949604	0.26245	3.81023	0.45521

Table 5 – Major XRF Data Index Samples 1-45

API_NUMBER	LONGITUDE	LATITUDE	Well Type	County	Na	Mg	Al	Si	P	S	K	Ca	Ti	Fe	Inverse	Si/Al	K/Al
15-067-20952	-101.5236865	37.4988561	PAOW	Grant	0.62338123	0.43895384	2.69502572	11.7050242	0.10378346	0.55286508	1.33479147	13.0945553	0.22938525	2.35175376	0.23025	4.3432	0.49528
15-077-00043	-98.1490326	37.1899519	PAOW	Harper	0.62466683	0.4464499	3.62646819	14.2177973	0.0864014	1.18257824	1.80067548	7.08532647	0.32796655	3.16876195	0.25507	3.92056	0.49654
15-077-00123	-98.2474119	37.3252281	OIL	Harper	0.47385993	0.49393045	1.02301383	5.52190063	0.08467538	0.43870939	0.7125701	26.6354361	0.11535495	1.26803949	0.18526	5.39768	0.69654
15-077-00125	-98.0741552	37.2255194	PAOW	Harper	0.60960684	0.43849627	3.16416173	12.0392477	0.09738598	0.81838519	1.57392852	12.3833888	0.27579204	2.76462323	0.26282	3.80488	0.49742
15-085-19008	-95.9544247	39.4354882	OIL	Jackson	0.61615801	0.48650575	5.36858732	16.5080559	0.06989342	0.72768245	2.73652625	2.58758459	0.42364327	3.83776914	0.32521	3.07493	0.50973
15-095-00030	-98.2666625	37.3959455	O&G	Kingman	0.62608865	0.43866947	3.73516039	14.1165741	0.08953144	1.0874017	2.1369368	8.22406182	0.33133059	2.79345425	0.26459	3.77938	0.57211
15-095-00056	-98.2441316	37.4628585	PAGW	Kingman	0.60991103	0.43833723	2.89937255	10.6322166	0.08133989	0.3688752	1.36364539	14.4591302	0.29184297	2.68340788	0.2727	3.66707	0.47032
15-095-00057	-98.0732847	37.7179741	PAOW	Kingman	0.47445288	0.46451157	1.07658517	4.63904451	0.05814851	0.27830694	0.50796144	26.9309988	0.12759608	1.37088022	0.23207	4.30904	0.47183
15-095-00201	-98.1708206	37.424623	O&G	Kingman	0.62775142	0.46500555	3.8121388	12.9631652	0.07648328	0.23030496	1.46592787	9.43310062	0.38493672	2.76514797	0.29407	3.4005	0.38454
15-095-00306	-98.0817586	37.5255233	PAOW	Kingman	0.61681937	0.43632462	3.40384979	11.3487645	0.08481884	0.68718869	1.31312315	12.3517448	0.31228554	2.78529079	0.29993	3.3341	0.38578
15-095-00391	-98.2601499	37.4720626	O&G	Kingman	0.62588744	0.44205153	3.7054837	13.2408047	0.08038241	0.95134825	1.93221013	8.73291274	0.32928689	3.1237478	0.27985	3.5733	0.52145
15-095-00394	-98.3296599	37.3931085	PAGW	Kingman	0.60116948	0.44470613	3.04777645	11.6544355	0.09258492	0.65957997	1.48147206	13.6100102	0.27870742	2.52063625	0.26151	3.82391	0.48608
15-095-00399	-98.1751767	37.4069085	O&G	Kingman	0.61263252	0.44043989	3.34446219	11.3237432	0.10083851	1.45104905	1.60500603	12.0257173	0.30268569	2.74122334	0.29535	3.38582	0.4799
15-095-10066	-98.08443	37.6978962	PAGW	Kingman	0.57501145	0.43816719	2.10815753	7.57444023	0.08150457	0.20326411	0.89829146	19.9565067	0.20896241	2.0361391	0.27833	3.59292	0.4261
15-095-20431	-98.2648108	37.501407	PAGW	Kingman	0.61103245	0.43529011	2.84606707	10.4596981	0.07055325	0.22066781	1.38931359	15.0918103	0.28294909	2.48896289	0.2721	3.67514	0.48815
15-095-20841	-98.3543054	37.7115981	PAOW	Kingman	0.60342694	0.43724929	1.72451763	8.19078717	0.06653861	0.47793391	1.05769201	18.1732957	0.1732993	1.88139043	0.21054	4.74961	0.61333
15-095-21226	-98.0376407	37.5914586	GAS	Kingman	0.49463365	0.46016816	1.12920492	5.35168573	0.0681332	0.09838677	0.60012864	26.5765665	0.12236332	1.26044962	0.211	4.73934	0.53146
15-097-00123	-99.018006	37.3896867	OIL	Kiowa	0.61249062	0.45546281	3.20351743	11.8002795	0.08573792	1.08931844	1.69740197	12.1826016	0.28941931	2.79244058	0.27148	3.68354	0.52986
15-097-00140	-99.08992	37.3924798	O&G	Kiowa	0.61417908	0.43577189	2.58877543	10.3790489	0.09025207	0.62255549	1.39630745	14.4379409	0.24587175	2.7133075	0.24942	4.00925	0.53937
15-097-00151	-99.2504778	37.6594352	PAGW	Kiowa	0.62538579	0.44173403	3.94973085	13.8400137	0.0848297	0.99647136	2.06781619	7.39137931	0.34694296	3.32435193	0.28538	3.50404	0.52353
15-097-00153	-99.2059212	37.6905412	PAGW	Kiowa	0.62439709	0.45375781	3.65659032	14.4335476	0.08544676	0.79499665	1.62426632	7.36539693	0.33324949	3.29802317	0.25334	3.94727	0.4442
15-097-00156	-99.25405	37.6004	GAS	Kiowa	0.60830465	0.44208141	2.92189791	10.9495363	0.10518685	1.01632716	1.36068076	13.5468826	0.29036213	2.44617165	0.26685	3.74741	0.46568
15-113-04525	-97.4503794	38.2164384	PAOW	McPherson	0.62608014	0.49805681	4.32714685	14.5508997	0.06669821	0.54481929	2.28608848	5.30547975	0.37006209	3.62866492	0.29738	3.3627	0.52831
15-151-10614	-98.6551267	37.7595683	PAOW	Pratt	0.62304041	0.43892107	3.53714892	12.7886842	0.08767351	1.25865728	1.72710056	9.46735675	0.31473032	3.10744241	0.27658	3.61553	0.48827
15-151-20010	-98.50892	37.5044067	PAOW	Pratt	0.57078219	0.45091555	2.06257238	9.28796543	0.09472121	0.66690069	1.00860574	17.8869963	0.18715657	2.44859259	0.22207	4.5031	0.489
15-151-20285	-98.7814357	37.4758723	PAOW	Pratt	0.60895654	0.43919406	2.81387989	11.1220356	0.07625827	0.66133905	1.58374123	13.9006461	0.27168525	2.58969469	0.253	3.95256	0.56283
15-151-20479	-99.0033797	37.7939429	O&G	Pratt	0.58777626	0.45956135	2.43989943	9.83667201	0.09659949	1.19924453	1.24058293	15.4790929	0.22421345	2.41023026	0.24804	4.03159	0.50846
15-151-20998	-98.8809825	37.6721397	PAGW	Pratt	0.58076859	0.44416688	2.11435196	10.4139161	0.11885968	0.52693293	1.09253425	17.3329607	0.18165936	1.86899152	0.20303	4.92535	0.51672
15-151-21000	-99.0118202	37.7052014	OIL	Pratt	0.61733604	0.43740325	3.06743825	11.0755034	0.05652027	0.31333214	1.49059007	12.3603538	0.27912081	3.33286955	0.27696	3.61067	0.48594
15-151-21256	-98.8644724	37.5040842	OIL	Pratt	0.59286061	0.44430309	2.14207131	10.1561587	0.09521786	0.4655251	1.07647462	17.2657184	0.19410921	1.94338134	0.21091	4.74128	0.50254
15-151-21339	-98.9466497	37.7311843	PAGW	Pratt	0.53098823	0.455525	1.45629979	7.75360519	0.07739265	0.17613101	0.66217786	22.6012902	0.1405057	1.4911423	0.18782	5.32418	0.4547
15-151-21355	-98.6568559	37.4932243	OIL	Pratt	0.57690593	0.44101046	2.08492695	8.41561532	0.08210146	0.66272808	1.20391359	19.0950663	0.18924749	1.80809933	0.24775	4.03641	0.57744
15-155-00079	-98.3202588	37.7459476	GAS	Reno	0.62144077	0.44340014	3.62927387	13.4136479	0.08777031	0.70411082	1.92120853	8.94108272	0.28941993	3.39842043	0.27057	3.69596	0.52936
15-173-00053	-97.2145467	37.7422464	PAOW	Sedgwick	0.57821278	0.45801311	2.67313614	9.28631691	0.09019944	0.590232	1.34145946	18.0382326	0.22687899	2.22408646	0.28786	3.47394	0.50183
15-185-00271	-98.58029	37.89216	OIL	Stafford	0.5748862	0.46160377	3.07852171	10.6769259	0.1024579	1.28677995	1.48590779	14.5705005	0.2515302	3.33030174	0.28833	3.4682	0.48267
15-185-00477	-98.8171035	37.9116942	OIL	Stafford	0.60977045	0.43840028	3.23368258	12.9139627	0.07871852	1.01396238	1.59308458	9.2320733	0.27396323	4.72295002	0.2504	3.99358	0.49265
15-185-11043	-98.61757	37.82514	OIL	Stafford	0.62305231	0.44022991	3.76565897	12.9952894	0.07936519	0.61099004	1.97431608	10.0624735	0.30121752	3.03942737	0.28977	3.451	0.52429
15-185-19138	-98.904156	37.8899811	PAOW	Stafford	0.62032805	0.46402155	3.87514155	15.3074669	0.06608992	0.27137685	1.9722583	6.07162675	0.3436306	3.21941106	0.25315	3.95017	0.50895
15-185-20435	-98.9062359	37.8262299	PAOW	Stafford	0.62859592	0.45426957	4.16349524	15.3576873	0.05742904	0.71129766	2.11545556	4.93118182	0.3956449	3.20182074	0.2711	3.68865	0.5081
15-185-30110	-98.7849389	37.906127	PAOW	Stafford	0.6172998	0.44035963	3.61116364	13.0007944	0.0733248	0.67648931	1.7998633	10.4912197	0.31742297	2.99600449	0.27776	3.60017	0.49842
15-191-00090	-97.2729574	37.0881488	OIL	Sumner	0.61881957	0.44774699	4.57193788	15.7927657	0.08300072	0.66113819	2.43762406	5.28963713	0.35850204	3.45889466	0.2895	3.45428	0.53317
15-191-20047	-97.2070476	37.0369518	PAOW	Sumner	0.61712922	0.45940287	4.18998499	16.3914002	0.0724846	0.43413334	2.14021645	5.08687862	0.35577315	3.37346602	0.25562	3.91204	0.51079
15-191-21739	-97.529412	37.020385	PAOW	Sumner	0.612995	0.44537453	2.44633295	14.1587445	0.09376248	0.56655705	1.22382249	11.1532279	0.22445345	2.05011389	0.17278	5.78774	0.50027
15-191-22156	-97.3060104	37.0321451	OIL	Sumner	0.60611943	0.43896434	3.13731273	13.7638058	0.1136396	0.43082261	1.55372097	11.5603648	0.25375728	2.51124712	0.22794	4.38713	0.49524
15-191-22456	-97.6680792	37.3045177	O&G	Sumner	0.61632878	0.45512894	4.23591843	15.2374821	0.08158844	0.38598971	1.72316882	7.07862482	0.36724019	2.91442265	0.27799	3.59721	0.4068
15-207-27134	-95.9192108	37.9705398	OIL	Woodson		0.54239402	6.02428702	16.6870368	0.0707196	0.44912082	2.54899128	0.73340477	0.48987658	4.62276266	0.36102	2.76996	0.42312

Table 6 – Major XRF Index Samples 46-90

1	API_NUMBE	LONGITUDE	LATITUDE	Well Type	County	Ca	Ba	Ti	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Pb	Th	Rb	U	Sr	Y	Zr	Nb	Mo	Sn	Sb
2	15-005-20013	-95.53394	39.421933	D&A	Atchison	9.46169937	-0.04497378	0.39304877	0.00900044	0.04298474	4.55716003	0.00210641	0.00446578	0.0011721	0.00623164	0.00039289	0.00166202	0.00119145	0.01541608	0.00012867	0.0121917	0.00252477	0.0115567	0.00114347	0.00087408	0.00026889	0.0008595
3	15-007-00023	-98.5672558	37.228003	D&A	Barber	7.79134027	0.02160906	0.36856107	0.00692599	0.04488041	3.7661938	0.0017651	0.00573566	0.00190957	0.01659232	0.00087051	0.00130589	0.00105535	0.01303824	0.00068842	0.02437998	0.00269348	0.0131044	0.00115098	0.00144751	0.0002517	0.00072175
4	15-007-00026	-98.8765778	37.302454	D&A	Barber	28.9644306	-0.0056131	0.14374813	0.00227233	0.0343425	1.38114789	0.00050284	0.00282662	0.00022356	0.00092818	0.00021579	0.00094115	0.00048341	0.00394007	4.3044E-05	0.02766802	0.00254429	0.00602204	0.00060045	-0.00028132	0.00024732	0.00078348
5	15-007-00044	-98.7421836	37.32068	D&A	Barber	11.6744219	0.08317508	0.23590344	0.00560866	0.03773195	3.01348193	0.00127898	0.00470138	0.00073607	0.00787675	0.00049374	0.00115238	0.00095045	0.01122851	0.00033069	0.0432023	0.00238259	0.01151639	0.00100765	0.0001701	0.00024429	0.00072515
6	15-007-00100	-98.5428353	37.382493	D&A	Barber	11.1461245	0.05444977	0.31124586	0.00778663	0.04089448	2.84473575	0.0053165	0.00730436	0.08484832	0.86016381	0.03687588	0.00128785	0.00090526	0.0106713	0.00069382	0.03887221	0.00247146	0.01080083	0.0009963	0.00047287	0.0002254	0.00066362
7	15-007-00115	-98.9489251	37.094937	D&A	Barber	3.40834246	0.02567993	0.32527174	0.00484209	0.0281965	3.00598984	0.00113268	0.00415955	3.4366E-05	0.00607151	0.00040611	0.00111976	0.00085888	0.00384368	7.2397E-06	0.02265681	0.00281321	0.01178198	0.00087792	0.00045187	0.00022561	0.0005792
8	15-007-00116	-98.6123226	37.110396	D&A	Barber	17.0283223	-0.06037254	0.32483277	0.00369414	0.04083167	3.16703187	0.00148808	0.00483342	0.00099478	0.00559196	0.00042387	0.00120816	0.00086737	0.00970345	-0.00023488	0.0329659	0.00278916	0.01064452	0.00091265	0.00018429	0.00024311	0.00086119
9	15-007-00129	-98.4656904	37.397639	D&A	Barber	21.928144	-0.02308564	0.24236385	0.00486408	0.0426121	2.52685098	0.00117579	0.0039551	0.00065565	0.0058181	0.00037502	0.00106127	0.00080154	0.00927998	0.00047753	0.03838754	0.00240293	0.00881748	0.00087374	-0.0001734	0.00024184	0.00065551
10	15-007-00314	-98.5738415	37.168396	PAGW	Barber	26.7750194	-0.00641011	0.19226749	0.00356264	0.0420897	2.3028504	0.00094298	0.00422254	0.00024202	0.00786431	0.00345452	0.00226504	0.00058128	0.00398668	-0.00069574	0.03517226	0.00277334	0.00827797	0.00060843	-0.00031508	0.00026262	0.00088434
11	15-007-00345	-98.9194516	37.2954	PAGW	Barber	29.8120713	0.01352041	0.14556632	0.00341189	0.03438818	1.52448677	0.00075632	0.00265635	0.00058325	0.01168144	0.00066376	0.00093017	0.00057581	0.00528309	0.0001041	0.02385724	0.00231594	0.00643169	0.00065726	-0.00027577	0.00024716	0.00057089
12	15-007-00522	-98.6779888	37.238407	PAOW	Barber	25.2816093	0.02288712	0.17392604	0.00398295	0.03739917	2.04544464	0.00098169	0.00393824	0.00073683	0.01501991	0.00075403	0.00108881	0.0006145	0.00603072	4.424E-05	0.02754347	0.00241721	0.00803494	0.00068003	1.3449E-05	0.00025987	0.00060198
13	15-007-00523	-98.8224457	37.275676	PAGW	Barber	22.8121384	-0.02565587	0.22421548	0.00539388	0.03825229	2.50600148	0.0010045	0.00420008	0.00096348	0.00837053	0.00043863	0.00107602	0.00071563	0.00763346	0.00033264	0.04257377	0.00237227	0.00751603	0.00079377	-7.9566E-05	0.00023827	0.00056303
14	15-007-00533	-98.5232768	37.196948	PAGW	Barber	18.0917638	0.06504236	0.2370526	0.0040858	0.03775637	2.47838509	0.00107177	0.00412633	0.0030875	0.03001425	0.0014198	0.00104456	0.00075555	0.00834014	0.00063383	0.05028863	0.00242984	0.00880994	0.00083046	-1.0745E-05	0.0002675	0.00075174
15	15-007-00537	-98.9130662	37.018559	OIL	Barber	20.5027537	-0.02638734	0.21531077	0.00322746	0.04043351	2.06268506	0.00092944	0.00334068	0.00065773	0.00665511	0.00040352	0.001078	0.0006825	0.00706316	-8.1288E-05	0.02372434	0.00274743	0.00867637	0.00074318	0.00011456	0.00023364	0.00058073
16	15-007-00616	-98.63061	37.23149	PAOW	Barber	19.746117	0.02747563	0.22676246	0.00469411	0.04274638	2.60541321	0.00114131	0.00422915	0.00118473	0.01602137	0.00418629	0.00220324	0.00083618	0.00800884	-0.00043074	0.03722167	0.0025105	0.00878759	0.00083303	0.00069338	0.00026197	0.00073697
17	15-007-00651	-98.9629328	37.200126	PAOW	Barber	18.3068155	-0.03245454	0.28855759	0.00350822	0.04106132	2.83640123	0.00128593	0.0040811	0.00059021	0.00638888	0.0004405	0.00114882	0.00086437	0.00981649	-3.2353E-06	0.02872866	0.00260427	0.01113388	0.00087942	0.00013574	0.0002392	0.0006823
18	15-007-01167	-98.7341036	37.359751	PAOW	Barber	16.6063095	0.01750848	0.26216323	0.00808409	0.03403453	2.77460025	0.00132083	0.00587569	0.00064837	0.00885098	0.00055082	0.00127205	0.00092044	0.01076841	0.00061117	0.07213937	0.00318374	0.00932407	0.0011124	-0.0002941	0.00024587	0.00060639
19	15-007-01816	-98.5137	37.13163	GAS	Barber	9.44561788	0.00801959	0.31481536	0.00685773	0.02964311	3.01246395	0.00138641	0.00440074	0.00237182	0.01873719	0.00092933	0.00113775	0.00086912	0.01021974	0.0004368	0.0444373	0.00251173	0.01152787	0.00093103	0.00052302	0.0002376	0.00060299
20	15-007-20361	-98.5464045	37.034927	PAOW	Barber	7.88634243	0.08753082	0.28067257	0.00457245	0.04128557	2.83523325	0.00133697	0.00331009	0.00065495	0.0093352	0.00051824	0.0011203	0.00086994	0.01006586	-1.717E-06	0.02455168	0.00266338	0.00946278	0.00083111	0.00077474	0.00023216	0.00031523
21	15-007-21286	-98.945753	37.338568	PAOW	Barber	27.3063744	-0.00231073	0.16687773	0.00288681	0.04070387	1.64075023	0.00078007	0.00314684	-0.00015292	0.00366772	0.00028054	0.00105853	0.00064633	0.00636356	-0.00021919	0.01932322	0.00262934	0.00770086	0.00063206	-0.00011087	0.00023562	0.00049333
22	15-007-21596	-98.9945421	37.442812	PAOGW	Barber	27.7854332	0.00415508	0.15319147	0.00170105	0.05131822	1.5978906	0.00083051	0.00344839	-0.00034639	0.00213357	0.00027163	0.00094535	0.00048854	0.00416817	0.00035132	0.0310554	0.00265335	0.00645204	0.00062621	-0.00025534	0.00023796	0.00056721
23	15-007-21630	-98.3668934	37.095089	O&G	Barber	12.3606774	-0.02107574	0.25520413	0.00507026	0.03467834	2.5014797	0.00111788	0.00337528	5.8935E-05	0.00598561	0.02777632	0.00464319	0.00080154	0.00526758	-0.00130345	0.02169397	0.00292842	0.01085504	0.0006934	0.00081946	0.00024626	0.00071212
24	15-007-22662	-98.9741814	37.159591	O&G	Barber	21.6127871	-0.03269516	0.22429344	0.00349734	0.0319157	2.10816511	0.00088952	0.00321391	-9.547E-05	0.0029757	0.00058645	0.00146642	0.00066653	0.00633038	-0.00045104	0.03208653	0.00255291	0.00850368	0.00067306	9.7029E-05	0.00024967	0.0005607
25	15-007-22792	-98.57051	37.24864	PAOGW	Barber	27.3145927	0.02619136	0.13058718	0.00306276	0.04398253	1.30221228	0.00053871	0.00330477	3.4637E-05	0.00500737	0.0005111	0.00132743	0.00049526	0.0032373	-0.00014593	0.05157201	0.00241624	0.00593164	0.00061689	-6.77E-05	0.00024801	0.00054518
26	15-007-30268	-98.9840064	37.021813	GAS	Barber	27.4810604	-0.01101941	0.16146107	0.00604806	0.04430504	2.41621952	0.00109332	0.00278428	0.00043407	0.0035325	0.00041124	0.001359	0.00057666	0.00524518	-7.7015E-05	0.0277526	0.00250263	0.00627019	0.00063442	-9.9808E-06	0.00024931	0.00073308
27	15-015-19584	-97.149404	37.654824	PAGW	Butler	9.18215437	0.06075083	0.37711512	0.01127855	0.03953131	4.11967616	0.0020135	0.00439824	0.00133037	0.00606054	0.00045124	0.00130833	0.00105151	0.01281606	0.00010289	0.04165098	0.00243073	0.01268623	0.00107299	0.00073308	0.0002604	0.00077963
28	15-015-19814	-97.1223889	37.649413	PAOW	Butler	10.5523926	0.04115607	0.37864542	0.00827479	0.04753435	4.25450265	0.00213215	0.00436412	0.00138934	0.00743255	0.00160188	0.00186312	0.00112201	0.0135254	0.00024658	0.02392251	0.00283119	0.01350211	0.00114976	0.00068358	0.00023443	0.00057858
29	15-015-22303	-96.8303772	37.997658	PAOW	Butler	13.2016645	-0.0014534	0.35590254	0.00140371	0.07166705	3.20204982	0.00097747	0.00383474	0.00198436	0.00818361	0.0006359	0.00134573	0.00079553	0.00887682	0.0018233	0.14052904	0.00187425	0.0107521	0.00106907	-0.00111262	0.00030536	0.00132837
30	15-025-20688	-99.7494855	37.226025	O&G	Clark	10.8388979	0.06172186	0.2253923	0.00372746	0.03083869	2.28222045	0.00092955	0.00284966	0.00146713	0.02105368	0.00103997	0.0009864	0.00067521	0.00727901	0.0001627	0.02111027	0.00274989	0.00917958	0.00071578	0.00042909	0.00021536	0.00040775
31	15-031-20318	-95.8498892	38.242362	OIL	Coffey	1.93876106	0.07850533	0.47900564	0.00655116	0.03015088	3.7270386	0.0018477	0.00618016	0.00176923	0.01005537	0.00108462	0.00158747	0.00141809	0.01857221	0.00075224	0.01853598	0.0024827	0.01457182	0.00145378	0.00279106	0.00025467	0.00080394
32	15-033-00035	-99.2621002	37.242963	GAS	Comanche	19.4932821	0.0297963	0.15032116	0.00347263	0.04258062	1.86623078	0.0007841	0.00201321	-0.00046316	0.0038426	0.00032211	0.00115514	0.00043002	0.00364578	0.00011431	0.02863045	0.0020683	0.00551965	0.00054268	0.00076291	0.0002191	0.00046245
33	15-033-10035	-99.2121034	37.290383	PAGW	Comanche	9.76081363	0.02560079	0.28275867	0.00563863	0.02978036	2.77707175	0.00113729	0.00442013	0.00122396	0.01283805	0.00067436	0.00107967	0.00076471	0.00840428	0.00177798	0.15229738	0.00163162	0.00862195	0.00100671	-0.00083636	0.00026662	0.00072646
34	15-033-20108	-99.0427181	37.065509	PAOGW	Comanche	7.67379189	0.02296406	0.25365497	0.00385487	0.02735395	2.46327711	0.00106889	0.00339836	0.00028888	0.01023124	0.00058202	0.00097229	0.00066462	0.00725462	0.00021873	0.01622329	0.00272499	0.00942644	0.00067215	0.0010636	0.00022181	0.00045001
35	15-033-20628	-99.259338	37.219233	O&G	Comanche	10.8611434	0.01386231	0.20092335	0.00220094	0.0265282	1.84053646	0.00075666	0.00238512	-0.00036814	0.004323	0.00035203	0.00093218	0.00059663	0.0057836	0.00034626	0.02243632	0.00230283	0.00766431	0.00065237	0.00094359	0.00021731	0.00038703
36	15-035-70311	-96.999347	37.466448	PAOW	Cowley	5.12645798	0.16571839	0.35882519	0.0067836	0.04777247	4.17651465	0.00210452	0.00435944	0.00201516	0.00528778	0.00127048	0.0018029	0.00112073	0.01373406	0.00108748	0.03013466	0.00220128	0.01388648	0.00121078	0.00298039	0.00025103	0.00063889
37	15-035-70312	-97.0016835	37.468152	PAOW	Cowley	2.50378268	0.06024312	0.45602667	0.0052456	0.02427179	3.44248254	0.00189405	0.00571455	0.00180015	0.00440087	0.00084214	0.00160425	0.00131512	0.01651283	0.00010547	0.02289046	0.00244577	0.01178147	0.00127085	0.00163917	0.00023246	0.00058197
38	15-035-70313	-96.9971674	37.468092	PAOW	Cowley	11.7095267	0.08422447	0.3293847	0.00483274	0.05428632	3.48477668	0.00153013	0.00429448	0.00140094	0.00693575	0.00088673	0.00155209	0.00096384	0.01145709	0.00025201	0.03832932	0.00268262	0.01246164	0.0010323	0.00073143	0.00026237	0.00070772
39	15-035-70316	-96.9963305	37.473956	PAOW	Cowley	16.232502	-0.04184468	0.29934624	0.00324641	0.03852846	2.76751836	0.00120841	0.0037578	0.00019805	0.00455306	0.00032681	0.00104943	0.00083219	0.00891274	0.00044997	0.06828235	0.00190052	0.01003802	0.00093372	-0.00048035	0.00023885	0.00055427
40	15-047-00034	-99.2967424	37.741834	PAOW	Edwards	9.44104658	0.03224501	0.30836949	0.00548036	0.02827089	2.9724551	0.00134021	0.0047504	0.00015729	0.00332871	0.00030007	0.00106641	0.00084317	0.0094695	0.00022083	0.04966145	0.0024356	0.01083044	0.00091364	0.0003251	0.00023187	0.00052495
41	15-047-00042	-99.0325628	37.761168	PAOW	Edwards	4.70270108	0.00963385	0.36728409	0.00816584	0.02643352	3.64570415	0.00172195	0.00581238	0.00036136	0.00888113	0.00056637	0.00122802	0.00083108	0.00924021	0.00019551	0.02104493	0.00364057	0.01348153	0.00095515	0.00093833	0.0002196	0.00055433
42	15-047-00052	-99.089484	37.906292	GAS	Edwards	10.5092084	-0.05160114	0.23619303	0.00064018	0.0286257	2.17819805	0.00107681	0.00246457	-0.0022193	0.01722479	3.74533904	0.04353801	0.00253652	-0.00660104	-0.01751617	0.02196077	0.00531181	0.00471953	0.00052708	0.00133781	0.00043451	0.00303453
43	15-047-00087	-99.1334153	37.849714	PAGW	Edwards	3.33816576	0.09523008	0.39172628	0.0096551	0.02239541	3.76441027	0.00180095	0.00584338	0.00025196	0.00558183	0.00040246	0.00114364	0.00076108	0.00734563	-0.00042352	0.02055702	0.0034894	0.0143922	0.00087482	0.00110499	0.00022302	0.00036028
44	15-047-00227	-99.2395247	37.812685	O&G	Edwards	11.3482888	0.07210565	0.29089876	0.00636145	0.02704466	3.04128368	0.0014342	0.0053094	0.00766109	0.00242185	0.00026879	0.0010074	0.00077598	0.00827638	0.00067883	0.07924757	0.00216683	0.01111454	0.00091253	-0.00022893	0.0002262	0.0003748
45	15-047-20921	-99.1756593	37.87555	PAGW	Edwards	10.1213133	0.10343485	0.34485092	0.00869207	0.03232795	3.43963706	0.00196317	0.00483966	0.00019416	0.00586263	0.00037651	0.00113012	0.0008075	0.00861477	-0.00023243	0.04818785	0.00274149	0.01466045	0.00084458	0.00042082	0.00023703	0.00050803

Table 7 – Trace XRF Index Samples 1-45.

46	API_NUMBE	LONGITUDE	LATITUDE	Well Type	County	Ca	Ba	Ti	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Pb	Th	Rb	U	Sr	Y	Zr	Nb	Mo	Sn	Sb
47	15-067-20952	-101.523687	37.498856	PAOW	Grant	14.4336633	-0.02205567	0.25635123	0.00560554	0.0332281	2.43381326	0.00088654	0.00397474	0.00051374	0.00837382	0.00048481	0.00105342	0.00068542	0.00712961	0.00075328	0.05032294	0.00260255	0.0093689	0.00084083	0.00043117	0.00023192	0.00061646
48	15-077-00043	-98.1490326	37.189952	PAOW	Harper	8.22372497	0.03777589	0.36100776	0.00840243	0.03024714	3.41931702	0.0016224	0.0052031	0.00089734	0.01655064	0.00083125	0.00111532	0.00084361	0.00951201	0.00051351	0.02940407	0.00260888	0.01385907	0.00094988	0.00052669	0.00024085	0.00069539
49	15-077-00123	-98.2474119	37.325228	OIL	Harper	29.9000241	0.03550668	0.12890695	0.00122401	0.04825738	1.26600714	0.00080226	0.00288056	-4.7592E-05	0.00443547	0.00034524	0.00036951	0.00050684	0.0043549	-0.0001174	0.02962809	0.00254862	0.00597829	0.00057383	-0.00062541	0.00024001	0.00056225
50	15-077-00125	-98.0741552	37.225519	PAOW	Harper	14.0503468	0.03186398	0.27725235	0.00633631	0.04186684	3.08435736	0.00172336	0.00521159	0.00117685	0.01260047	0.00066346	0.00113539	0.00083165	0.00893772	-0.0006193	0.02277693	0.0029374	0.01167324	0.0008362	0.00043621	0.00022783	0.00035095
51	15-085-19008	-95.9544247	39.435488	OIL	Jackson	3.39591567	0.13789544	0.45355083	0.00923225	0.04372926	4.15034545	0.00199211	0.00606701	0.0019528	0.01036429	0.00094303	0.0015212	0.00123572	0.01553162	0.00025638	0.0167494	0.0027819	0.01570944	0.00122699	0.00121769	0.00024279	0.00062474
52	15-095-00030	-98.2666625	37.395946	O&G	Kingman	9.18851949	0.06415183	0.35078078	0.00364027	0.03878016	3.00286683	0.00172701	0.00504508	0.01308716	0.1310385	0.00574154	0.00125439	0.00094312	0.01124171	4.321E-05	0.03077363	0.00273987	0.01389405	0.00097079	0.00036387	0.00023877	0.00057305
53	15-095-00056	-98.2441216	37.462859	PAGW	Kingman	16.5737433	0.07000513	0.28874158	0.00881571	0.03380874	3.07054091	0.00160527	0.00500509	0.00286433	0.03513207	0.00163795	0.00101203	0.00065033	0.0062199	-0.0005087	0.01975106	0.0032885	0.01215302	0.00071363	0.00085233	0.00023276	0.00059633
54	15-095-00057	-98.0732847	37.717974	PAOW	Kingman	32.2756192	0.00149675	0.14526702	0.00393887	0.03366393	1.59723258	0.00090965	0.00310169	-0.00015161	0.00524264	0.00038759	0.00118348	0.0004506	0.00292465	-7.1469E-05	0.04124315	0.00266806	0.00672394	0.00056298	-0.00053332	0.00024928	0.00062625
55	15-095-00201	-98.1708206	37.424623	O&G	Kingman	11.0305043	0.05688826	0.37284023	0.00725041	0.02620297	3.04833918	0.0017032	0.00682318	0.000884	0.01193268	0.0006631	0.00097049	0.00065489	0.00615007	-0.00036491	0.0157343	0.00363886	0.01663263	0.0007648	0.00050552	0.00023305	0.00055303
56	15-095-00306	-98.0817586	37.525523	PAOW	Kingman	14.5395778	0.04985507	0.32001984	0.00798007	0.03517023	3.23586908	0.00177063	0.0048213	-0.00014291	0.00518315	0.00035671	0.00107411	0.00074307	0.00785432	-0.0002453	0.02297568	0.00441267	0.01298974	0.00092299	0.00024763	0.0002454	0.00064211
57	15-095-00391	-98.2601499	37.472063	O&G	Kingman	9.90050949	0.04834458	0.35131587	0.00763557	0.02972937	3.53341151	0.00168148	0.0071383	0.00020437	0.00723149	0.0004388	0.00108619	0.00092809	0.01112575	-4.5368E-05	0.03381034	0.00287199	0.01390605	0.00094559	0.00041379	0.00024785	0.00083897
58	15-095-00394	-98.3296599	37.393109	PAGW	Kingman	16.2134644	0.02514336	0.28198703	0.00407568	0.03615418	2.81436435	0.0014532	0.00458442	0.00446034	0.00574311	0.00040837	0.00101932	0.00070408	0.00745786	0.00042429	0.06503879	0.00244452	0.00989473	0.00082006	-2.3258E-06	0.00025404	0.00059515
59	15-095-00399	-98.1751767	37.406909	O&G	Kingman	13.9102828	0.04816651	0.32027006	0.00458536	0.03112184	3.08736388	0.00171364	0.00517001	0.00104185	0.01394775	0.00074859	0.00117178	0.00072688	0.00775738	-0.00015684	0.04502424	0.00290761	0.01198211	0.00075512	8.5865E-05	0.00024938	0.00068308
60	15-095-10066	-98.08443	37.697896	PAGW	Kingman	24.8953663	-0.02940545	0.23142371	0.00508208	0.03184145	2.35587196	0.00134298	0.00391326	0.00036826	0.00613733	0.00041313	0.00036179	0.00058685	0.00531224	-0.00025508	0.02368173	0.00277243	0.00976366	0.00068673	2.2143E-05	0.00024475	0.00074309
61	15-095-20431	-98.2648108	37.501407	PAGW	Kingman	17.926614	0.0213774	0.28857451	0.00636583	0.03117321	2.90958565	0.00157781	0.00470662	0.00259209	0.0023478	0.00025582	0.00102017	0.00074614	0.00773639	-0.0002372	0.02505122	0.00306463	0.01390204	0.00080833	0.00023439	0.00022278	0.00045493
62	15-095-20841	-98.3543054	37.711598	PAOW	Kingman	21.870292	-0.00534497	0.20383721	0.00239856	0.05747329	2.01987584	0.00088809	0.00317017	0.00052691	0.00896384	0.00052887	0.00129297	0.00073997	0.00781105	0.00074402	0.04572718	0.00237771	0.01052385	0.00087257	-0.00012058	0.00025117	0.00064064
63	15-095-21226	-98.0376407	37.591459	GAS	Kingman	29.6886628	0.02851023	0.1350398	0.00192253	0.0383865	1.33454815	0.00078605	0.00309151	-0.00050062	0.00183963	0.00021934	0.0003882	0.00043571	0.00358278	5.8277E-05	0.02092894	0.00265465	0.00703288	0.00043607	-0.0002126	0.00026019	0.00065248
64	15-097-00123	-99.018006	37.389687	OIL	Kiowa	14.4640261	0.12151732	0.23883011	0.00606936	0.0321818	3.03981972	0.00167218	0.00421672	0.00021045	0.00388748	0.00028537	0.00113811	0.00085276	0.00924756	-0.00039442	0.03485598	0.00275415	0.01270685	0.00088736	0.00014581	0.00022751	0.00055513
65	15-097-00140	-99.08992	37.39248	O&G	Kiowa	17.3759418	0.00107083	0.27380713	0.00431703	0.05112459	3.16548501	0.00137517	0.00432968	0.00071534	0.00682467	0.0007131	0.00136097	0.0007925	0.00827777	0.00024179	0.03226477	0.00303088	0.01058253	0.00092725	0.00076529	0.0002515	0.00076834
66	15-097-00151	-99.2504778	37.659435	PAGW	Kiowa	8.03283656	0.08336383	0.35293309	0.0066673	0.02761372	3.57039831	0.00206078	0.00442453	2.0577E-05	0.00485342	0.00068346	0.0015163	0.00091184	0.01145215	5.6609E-05	0.03058283	0.00268685	0.012177	0.0008431	0.0005715	0.00027486	0.00091173
67	15-097-00153	-99.2059212	37.690541	PAGW	Kiowa	8.69376445	0.02176643	0.36127328	0.00698316	0.0268871	3.41538273	0.00135729	0.00485356	0.00022002	0.00435563	0.00030327	0.00110346	0.00070046	0.00685061	-0.00028277	0.02438309	0.00292209	0.01083069	0.00072911	0.00119406	0.00019741	0.00039877
68	15-097-00156	-99.25405	37.6004	GAS	Kiowa	15.9832433	0.12335155	0.27516197	0.00696337	0.04332263	2.68043153	0.00157401	0.00786319	0.00044384	0.01118308	0.00059789	0.00107553	0.00074271	0.00796025	-0.00045764	0.02864092	0.00403058	0.01291406	0.00085823	0.0003848	0.00023188	0.00051608
69	15-113-04525	-97.4503794	38.216438	PAOW	McPherso	6.4132826	0.11384907	0.33539404	0.00821985	0.03102257	3.34101427	0.00171884	0.0060109	0.00111036	0.00766063	0.00046809	0.00108654	0.00109459	0.01350449	0.00051597	0.0335023	0.00273388	0.01509709	0.00116305	0.00046216	0.00024013	0.00057859
70	15-151-10614	-98.6551267	37.759568	PAOW	Pratt	11.0247241	0.09398404	0.32813461	0.00650998	0.03445072	3.48173669	0.0018976	0.00653478	0.0045664	0.00414098	0.00032591	0.001092	0.00081876	0.0091103	0.00025077	0.050886	0.00314829	0.01225882	0.00095275	0.00024877	0.00022852	0.00052417
71	15-151-20010	-98.50892	37.504407	PAOW	Pratt	21.2628228	-0.01586248	0.22084231	0.00408247	0.0571739	2.97368567	0.0014852	0.00522155	0.00018066	0.00722117	0.00044187	0.00102145	0.00060525	0.00574874	-8.2339E-05	0.03917002	0.00266865	0.00837887	0.00068632	9.6086E-05	0.00023646	0.00043395
72	15-151-20285	-98.7814357	37.475872	PAOW	Pratt	15.5344302	0.0385223	0.28816063	0.00434609	0.04125362	2.88923294	0.00162552	0.00438222	0.0012887	0.00752965	0.00073328	0.00146681	0.00081302	0.00865476	-0.00025164	0.02679282	0.00278983	0.01215778	0.00081478	0.00029506	0.00022917	0.00065825
73	15-151-20479	-99.0033797	37.793943	O&G	Pratt	17.700414	0.04197824	0.23673275	0.00452629	0.03391355	2.69741036	0.00140433	0.00387503	0.00092802	0.01345063	0.00112268	0.00149416	0.00068564	0.00609284	-0.00040502	0.0640524	0.0026241	0.0067785	0.00078111	-0.00032533	0.00024663	0.00048067
74	15-151-20998	-98.8809825	37.67214	PAGW	Pratt	19.3130088	0.05711056	0.19123529	0.00282625	0.06673465	2.02029179	0.0011407	0.00372657	0.00026626	0.00573966	0.00037779	0.00102879	0.00063043	0.00564677	-8.1082E-05	0.03633045	0.00292123	0.00997398	0.00074792	0.00013325	0.00021102	0.00037317
75	15-151-21000	-99.0118202	37.705201	OIL	Pratt	14.317605	0.05544686	0.30660738	0.00636619	0.06206836	4.08191802	0.00218224	0.0046169	0.00025309	0.00431483	0.01529604	0.00376913	0.00091403	0.00761248	-0.00180103	0.01965577	0.00367702	0.01227836	0.0008286	0.0004775	0.00023687	0.00043499
76	15-151-21256	-98.8644724	37.504084	OIL	Pratt	19.7515126	0.00794055	0.21429134	0.00316707	0.03743743	2.17681543	0.0012156	0.00384746	-0.00044728	0.00213763	0.00025585	0.00093141	0.00066952	0.00674369	0.0001164	0.02896538	0.00261239	0.00933643	0.00074325	0.00019401	0.00022251	0.00034347
77	15-151-21339	-98.9466497	37.731184	PAGW	Pratt	26.064885	0.03148563	0.1505172	0.00329555	0.04039253	1.67676377	0.00096872	0.00308223	-0.00036756	0.00187826	0.00188302	0.00196628	0.00054432	0.00354677	-0.00054817	0.03296753	0.00241172	0.00702231	0.00058144	4.8029E-05	0.00024101	0.00052985
78	15-151-21355	-98.6568559	37.493224	OIL	Pratt	21.9138828	-0.01614302	0.2194038	0.00202952	0.0478582	1.87503482	0.00076167	0.00463578	-0.0002472	0.00287538	0.00025434	0.001037	0.00073533	0.00759761	0.00094649	0.08077913	0.0023587	0.00805125	0.00093586	-0.00071048	0.00024133	0.0003936
79	15-155-00079	-98.3202588	37.745948	GAS	Reno	10.1360379	0.06030823	0.31960529	0.00925486	0.03798841	4.01213573	0.00241386	0.00475207	0.00171882	0.00742327	0.00045829	0.00117903	0.00090011	0.01040544	-0.00012723	0.0423715	0.00267907	0.01086567	0.00093309	0.00051568	0.00023327	0.00058233
80	15-173-00053	-97.2145467	37.742246	PAOW	Sedgwick	21.0510433	0.06866938	0.23357358	0.00568638	0.03385223	2.54153155	0.00151552	0.00375098	6.4017E-05	0.002034	0.00021147	0.0010676	0.00077572	0.0080356	0.00132193	0.15151795	0.00156477	0.00811378	0.00103252	-0.00183603	0.0002451	0.00079493
81	15-185-00271	-98.58029	37.89216	OIL	Stafford	17.7755176	0.02931299	0.2862192	0.00958803	0.0406337	4.11902564	0.00218815	0.00609331	0.00075216	0.00923818	0.00051737	0.00114297	0.00081456	0.0093608	0.00020058	0.03530983	0.00403343	0.01033668	0.00102677	-0.00025563	0.00023507	0.00054653
82	15-185-00477	-98.8171035	37.911694	OIL	Stafford	12.345933	-0.03908454	0.3735896	0.01423538	0.05613947	6.46822936	0.00359457	0.00439519	0.00147174	0.00428218	0.00093317	0.00164528	0.00081172	0.0079505	-0.00109606	0.03741115	0.00328894	0.01080965	0.00083223	0.00028907	0.00024197	0.00066212
83	15-185-11043	-98.61757	37.82514	OIL	Stafford	11.8213415	0.07091489	0.33416673	0.00734714	0.03457348	3.53809885	0.00218454	0.00480911	0.00080933	0.00650649	0.00040446	0.00109332	0.00093766	0.01158389	-0.00044909	0.03670221	0.00333811	0.01229702	0.00105299	0.00018478	0.00022248	0.00015484
84	15-185-19138	-98.9041156	37.889981	PAOW	Stafford	7.3427765	0.11716836	0.36843709	0.00812764	0.02761644	3.70380988	0.00226553	0.00434123	0.00117969	0.00385766	0.00034427	0.00116751	0.00089314	0.00988509	-0.00050234	0.02043767	0.00320632	0.01380942	0.00088864	0.00078451	0.00021251	0.00040194
85	15-185-20435	-98.9062359	37.82623	PAOW	Stafford	6.11541406	0.16360324	0.40190687	0.00742834	0.02264827	3.74895525	0.00237048	0.00624442	-0.00057161	0.00407186	0.00030412	0.00121202	0.00088314	0.00999589	-0.00043839	0.0206795	0.0036616	0.01642782	0.00091152	0.00063205	0.00021147	0.00046581
86	15-185-30110	-98.7843389	37.906127	PAOW	Stafford	12.1462379	0.08407744	0.3302211	0.00540964	0.03065526	3.47364742	0.00227502	0.00600502	0.00572042	0.04738422	0.00219108	0.00120295	0.00082228	0.00866166	-0.00030292	0.0502859	0.00339363	0.01222337	0.00093151	0.00028378	0.00022874	0.00058494
87	15-191-00090	-97.2729574	37.088149	OIL	Sumner	5.8102276	0.11442439	0.38712868	0.01016002	0.03843177	4.02133554	0.00262887	0.00643025	0.00130744	0.00763841	0.00075562	0.00143463	0.00116365	0.01447903	-0.0002095	0.02361067	0.00283842	0.01340332	0.0011306	0.00264054	0.00023216	0.00054669
88	15-191-20047	-97.2070476	37.036952	PAOW	Sumner	5.94824088	0.06785384	0.39511077	0.0069767	0.03595712	3.68709393	0.00163673	0.0050957	0.00133257	0.01016333	0.00057836	0.00123561	0.0010769	0.01293291	0.00034065	0.02263181	0.00293136	0.01615073	0.00116764	0.00066441	0.00023132	0.00055676
89	15-191-21739	-97.529412	37.020385	PAOW	Sumner	11.9782827	0.04112631	0.24208324	0.00386815	0.0397291	2.40604356	0.00157134	0.00358366	0.00015917	0.00164465	0.00040063	0.00124539	0.0006651	0.0066253	-0.00014843	0.02069361	0.00328983	0.01156539	0.00072433	0.00126018	0.00022426	0.00023262
90	15-191-22156	-97.3060104	37.032145	OIL	Sumner	12.3000368	0.10167153	0.25957365	0.00436922	0.04891398	2.87512016	0.0017638	0.00354839	0.00038117	0.00478191	0.00107317	0.0017214	0.00082959	0.00881421	-0.00045391	0.02579093	0.00337436	0.01181043	0.00086448	0.00070459	0.00021671	0.00048602
91	15-191-22456	-97.6680792	37.304518	O&G	Sumner	8.02219575	0.08754881	0.37835143	0.00463911	0.04649204	3.3231981	0.00214173	0.00524932	0.0008336	0.00651276	0.00040958	0.00115764	0.00082015	0.00847928	-0.00074268	0.02429685	0.00341555	0.01674024	0.00083741	0.00058132	0.00020816	0.00048698
92	15-207-27134	-95.9192108	37.97054	OIL	Woodson	1.40221981	0.14113348	0.54852659	0.0049645	0.1002459	4.87230376	0.0022057	0.00757385	0.00136603	0.00506258	0.00127632	0.0011333	0.0011223	0.01316667	2.0145E-05	0.01453438	0.00334367	0.01768799	0.00121708	0.0006679	0.0002476	0.00083748

Table 8 - Trace XRF Index Samples 46-90.

Appendix C - Additional Figures

Source rock quality	TOC, %	Pyrolysis S2, mg hydrocarbons/g rock	EOM weight, %	Hydrocarbons, ppm
None	< 0.5	< 2	< 0.05	< 200
Poor	0.5 to 1	2 to 3	0.05 to 0.1	200 to 500
Fair	1 to 2	3 to 5	0.1 to 0.2	500 to 800
Good	2 to 5	5 to 10	> 0.2	> 1,200
Very good	> 5	> 10		

Product type	Hydrogen index
Gas	50 to 200
Gas and oil	200 to 300
Oil	> 300

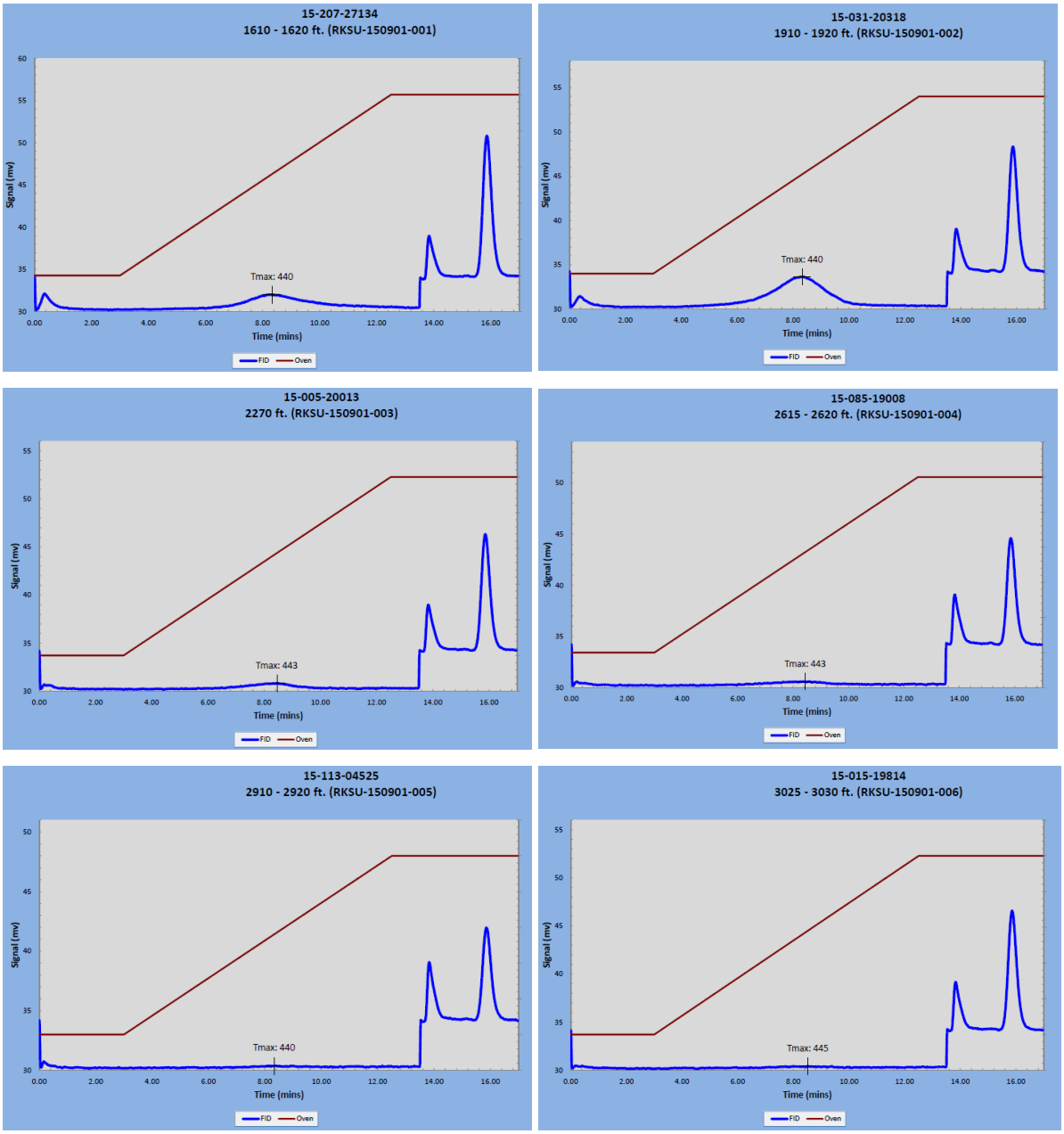
Stage	T_{max}
Onset of oil	
Type I kerogen	~445°C
Type II kerogen	~435°C
Type III kerogen	~440°C
Onset of gas	~460°C

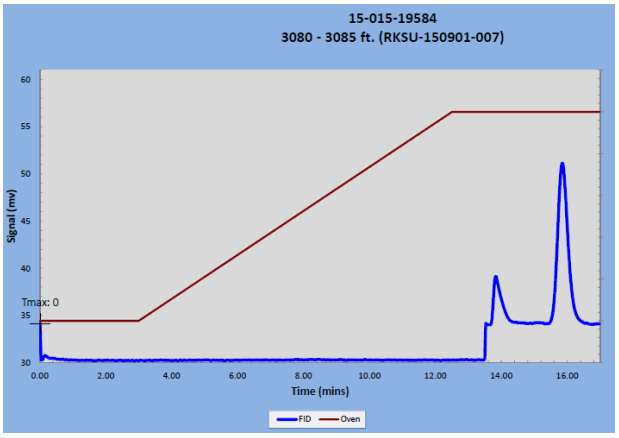
Figure 21 – TOC Evaluation. Modified from McCarthy (2011)

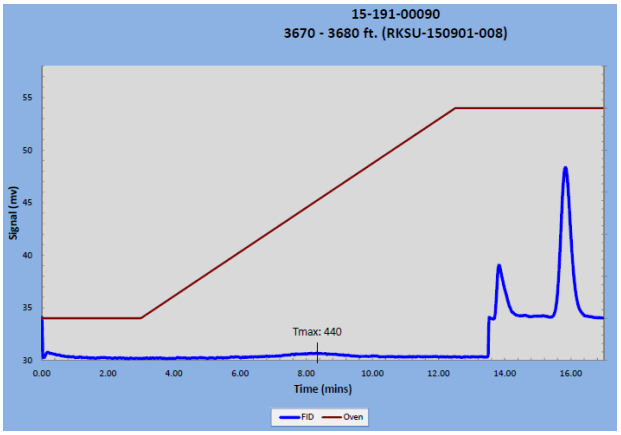
	Maturation			Generation		
Maturity	R_o (%)	T_{max} (°C)	TAI	Bitumen/TOC*	Bitumen (mg/g rock)	Production index (S1/(S1+S2))
Immature	0.20–0.60	<435	1.5–2.6	<0.05	<50	<0.10
Mature						
Early	0.60–0.65	435–445	2.6–2.7	0.05–0.10	50–100	0.10–0.15
Peak	0.65–0.90	445–450	2.6–2.7	0.15–0.25	150–250	0.25–0.40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

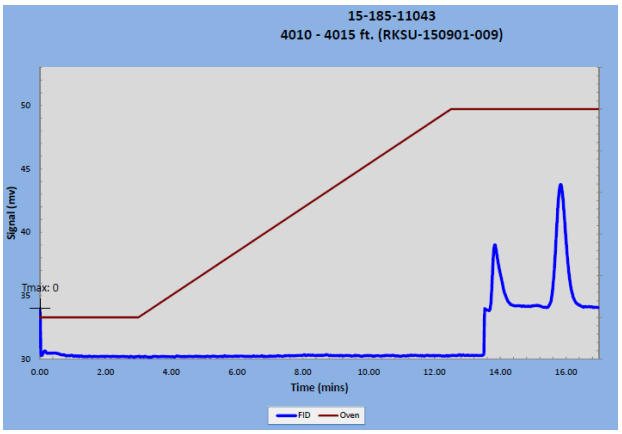
Figure 22- TOC Evaluation. Modified from Peters (2006)

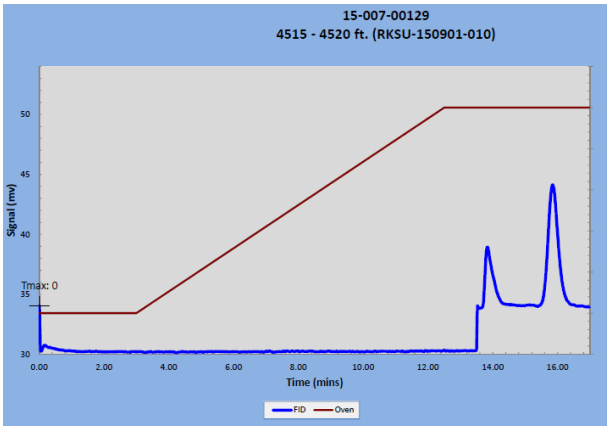
Figure 23 – Pyrograms of all samples for TOC results.

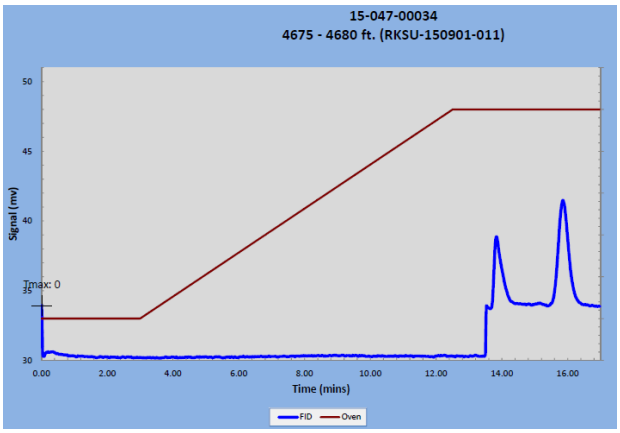


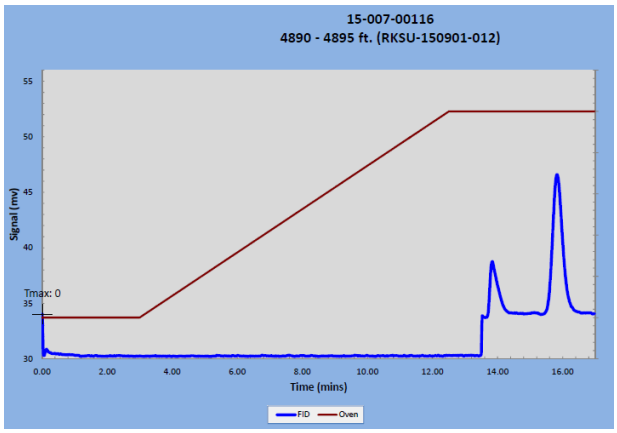

15-015-19584
3080 - 3085 ft. (RKSU-150901-007)
Signal (mv)
Time (mins)
Tmax: 0
FID
Oven

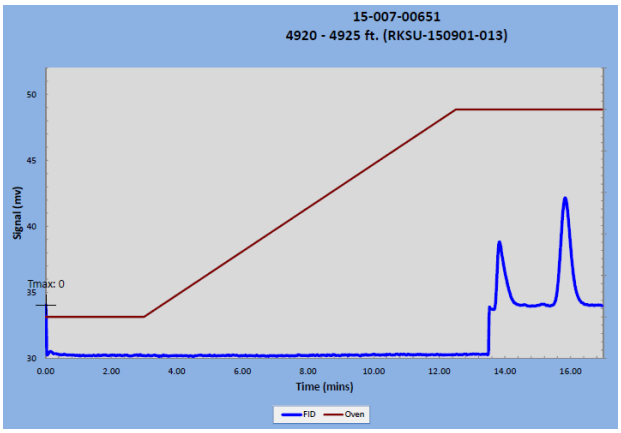

15-191-00090
3670 - 3680 ft. (RKSU-150901-008)
Signal (mv)
Time (mins)
Tmax: 440
FID
Oven

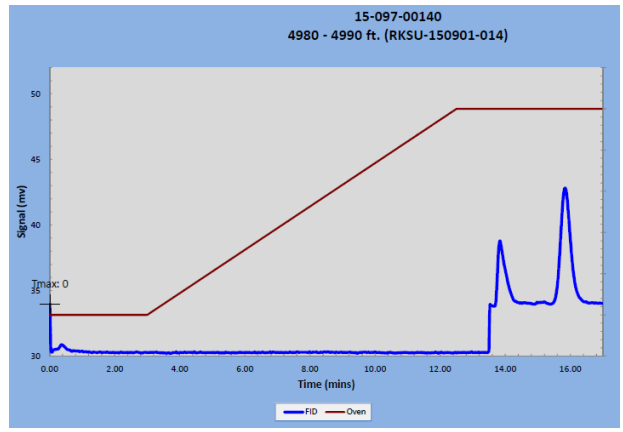

15-185-11043
4010 - 4015 ft. (RKSU-150901-009)
Signal (mv)
Time (mins)
Tmax: 0
FID
Oven

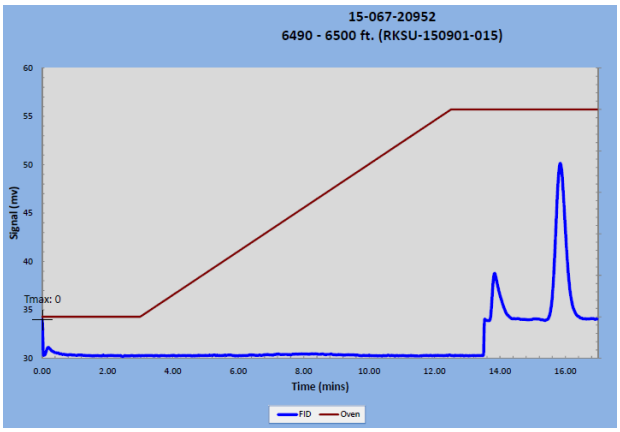

15-007-00129
4515 - 4520 ft. (RKSU-150901-010)
Signal (mv)
Time (mins)
Tmax: 0
FID
Oven


15-047-00034
4675 - 4680 ft. (RKSU-150901-011)
Signal (mv)
Time (mins)
Tmax: 0
FID
Oven


15-007-00116
4890 - 4895 ft. (RKSU-150901-012)
Signal (mv)
Time (mins)
Tmax: 0
FID
Oven


15-007-00651
4920 - 4925 ft. (RKSU-150901-013)
Signal (mv)
Tmax: 0
Time (mins)
FID
Oven


15-097-00140
4980 - 4990 ft. (RKSU-150901-014)
Signal (mv)
Tmax: 0
Time (mins)
FID
Oven


15-067-20952
6490 - 6500 ft. (RKSU-150901-015)
Signal (mv)
Tmax: 0
Time (mins)
FID
Oven