The Relationship between Specific Reservoir Characteristics and the Gas Productive Coals and Carbonaceous Mudstones in the Cherokee Basin*

Steven Tedesco[1]

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[1]Running Foxes Petroleum Inc., Centennial, CO, USA (s.a.tedesco14@runningfoxes.com)

Abstract

The Cherokee Basin is a shallow intracratonic basin that has significant gas production from the Desmoinesian and Atokan age Cherokee Formation coals and carbonaceous mudstones at less than 2,000 feet. The Cherokee Group's coals in the Cherokee Basin were deposited on an abandoned deltaic surface in a coastal setting. Only specific coals, the Mulky, Weir-Pittsburgh, Rowe and Riverton and the Excello Shale within the Cherokee Formation are generally productive whereas the remaining seams and carbonaceous shale are not productive. The basin was subject to thermal maturation in late Pennsylvanian and Permian time caused by expulsion of low temperature hydrothermal fluids from the Anadarko, Ardmore and Arkoma basins that migrated north through the Cherokee Basin into the Forest City Basin. Proximate analysis of the coals indicates that select seams are gas productive due to higher sulfur contents, which allowed hydrocarbon generation at lower temperatures. The Excello Shale is productive because it has over 50% quartz-carbonate minerals making it more brittle allowing hydraulic fracturing stimulation to be effective. The main productive area is in the central part of the basin and is related to the apex of the Silurian-Devonian age Chautauqua Arch. By mapping sulfur trends in coals and quartz-carbonate percentage content trends in carbonaceous mudstones allows a more definitive method to identify areas that will be gas productive.

Selected References

Adler, F.J., 1971, Future petroleum provinces of the Mid-Continent: in I. H. Cram, ed., Future petroleum provinces of the United States—their geology and potential: AAPG Memoir 15, v. 2, p. 985–1042.

Tedesco, S.A., 2014, Reservoir characterization and geology of the coals and carbonaceous shales of the Cherokee Group in the Cherokee Basin, Kansas, Missouri and Oklahoma, U.S.A.: Ph.D. Dissertation, Colorado School of Mines, Golden, CO.

The relationship between specific reservoir characteristics and the gas productive coals and carbonaceous mudstones in the Cherokee Basin

By: Dr. Steven A. Tedesco

Running Foxes Petroleum Inc.

Centennial, CO 80112

www.runningfoxes.com

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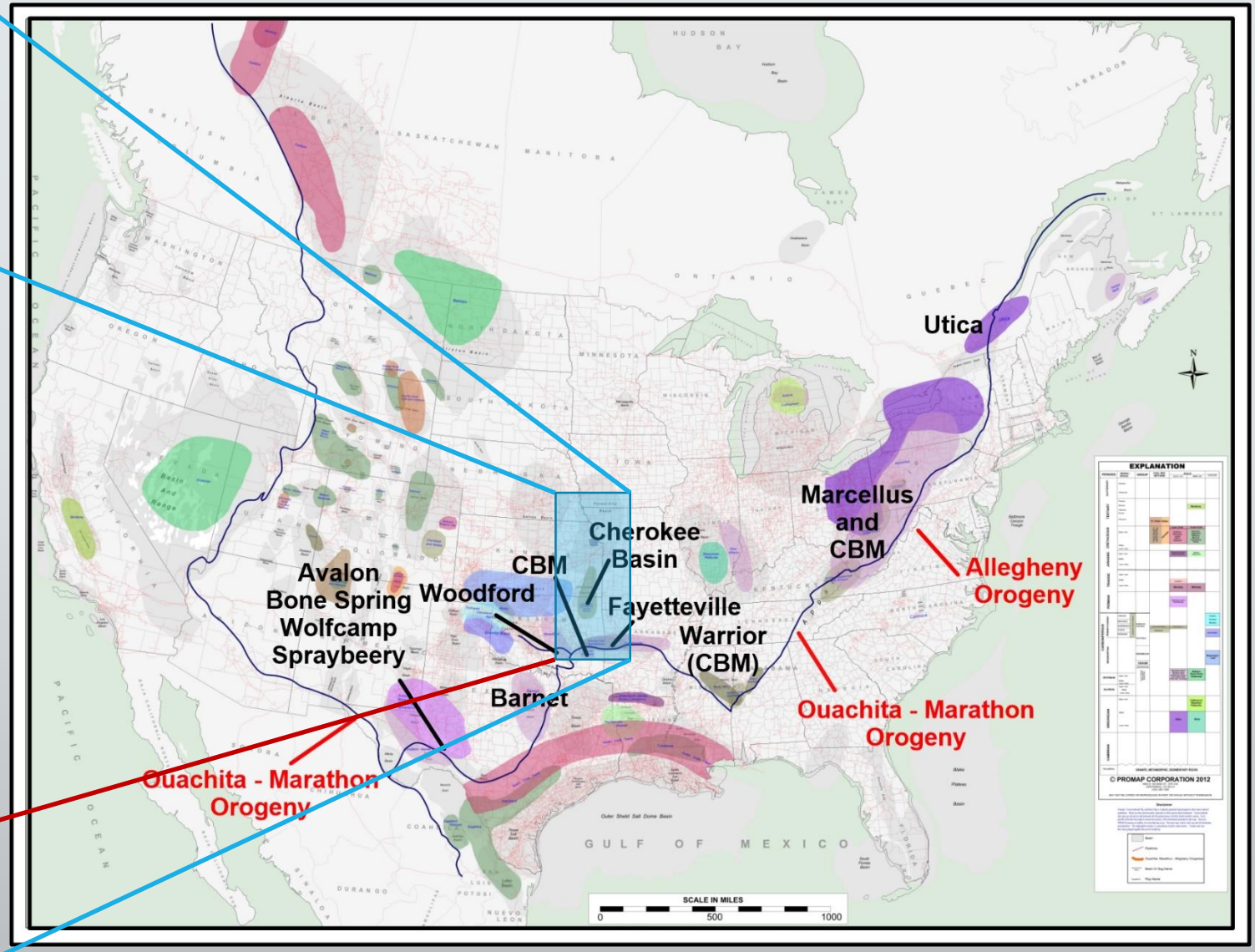
THE ART OF DISCOVERY

Abstract

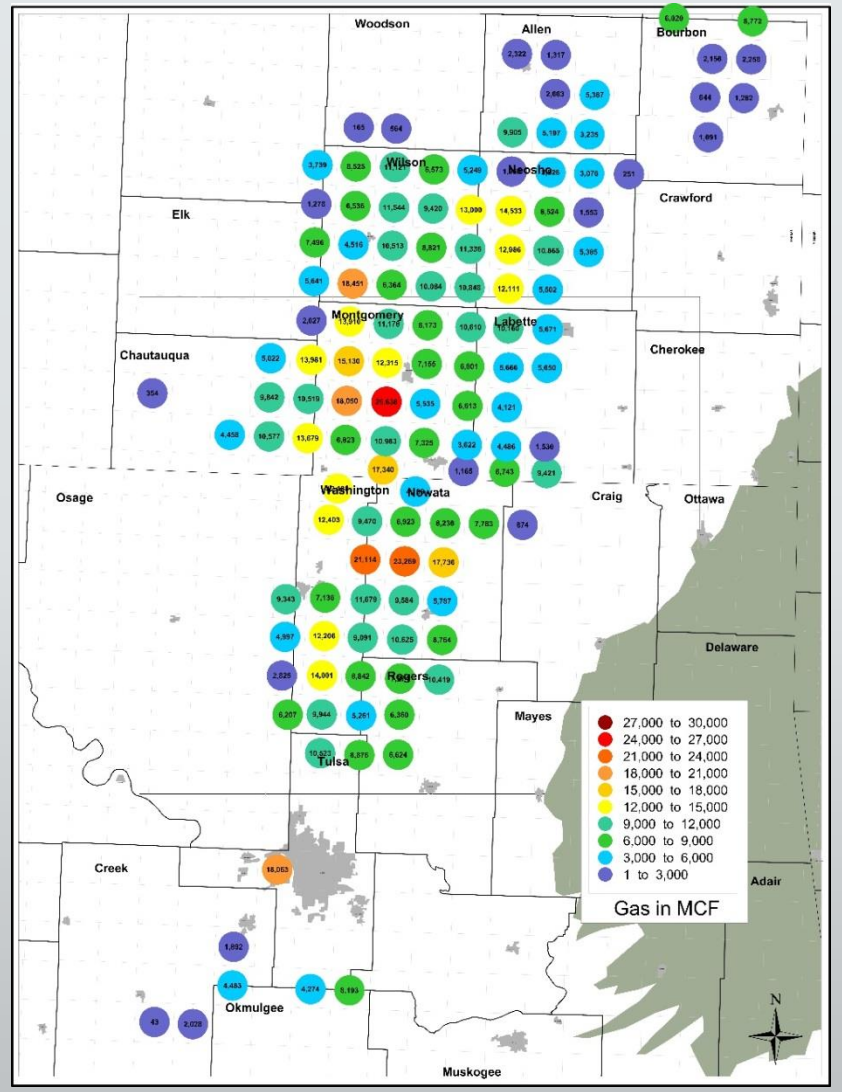
The Cherokee Basin is a shallow intracratonic basin that has significant gas production from the Desmoinesian and Atokan age Cherokee Formation coals and carbonaceous mudstones at less than 2,000 feet. The Cherokee Group's coals in the Cherokee Basin were deposited on an abandoned deltaic surfaces in a coastal setting. Only specific coals, the Mulky, Weir-Pittsburgh, Rowe and Riverton and the Excello Shale within the Cherokee Formation are generally productive whereas the remaining seams and carbonaceous shale are not productive. The basin was subject to thermal maturation in late Pennsylvanian and Permian time caused by expulsion of low temperature hydrothermal fluids from the Anadarko, Ardmore and Arkoma basins that migrated north through the Cherokee Basin into the Forest City Basin. Proximate analysis of the coals indicates that select seams are gas productive due to higher sulfur contents, which allowed hydrocarbon generation at lower temperatures. The Excello Shale is productive because it has over 50% quartz-carbonate minerals making it more brittle allowing hydraulic fracturing stimulation to be effective. The main productive area is in the central part of the basin and is related to the apex of the Silurian-Devonian age Chautauqua Arch. By mapping sulfur trends in coals and quartz-carbonate percentage content trends in carbonaceous mudstones allows a more definitive method to identify areas that will be gas productive.

Location of the Cherokee Basin

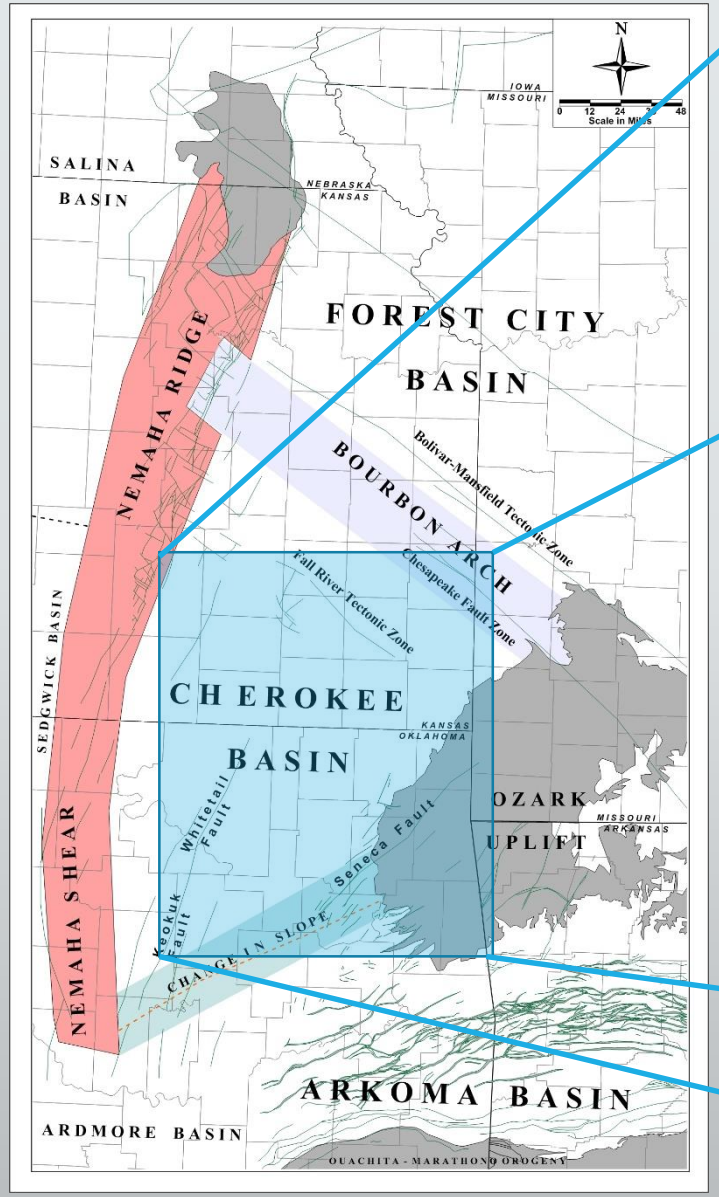


Promap, 2012

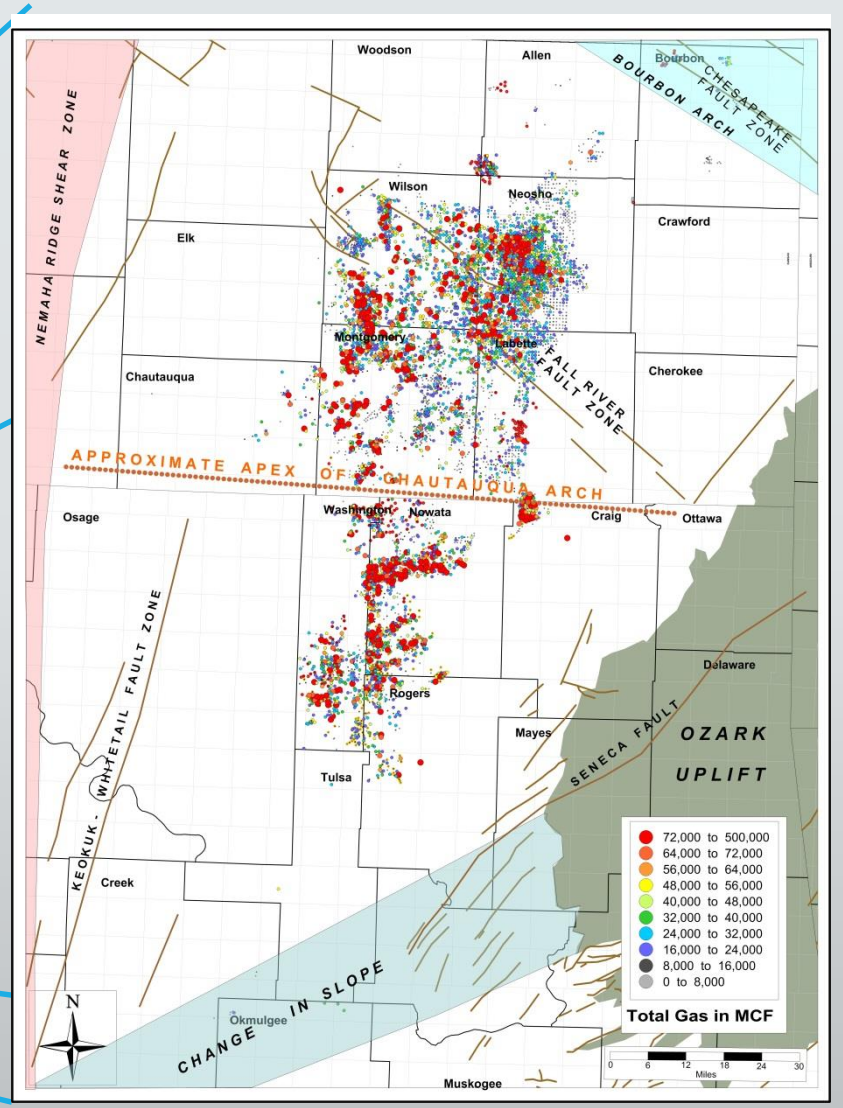
Cumulative Production up to 2011



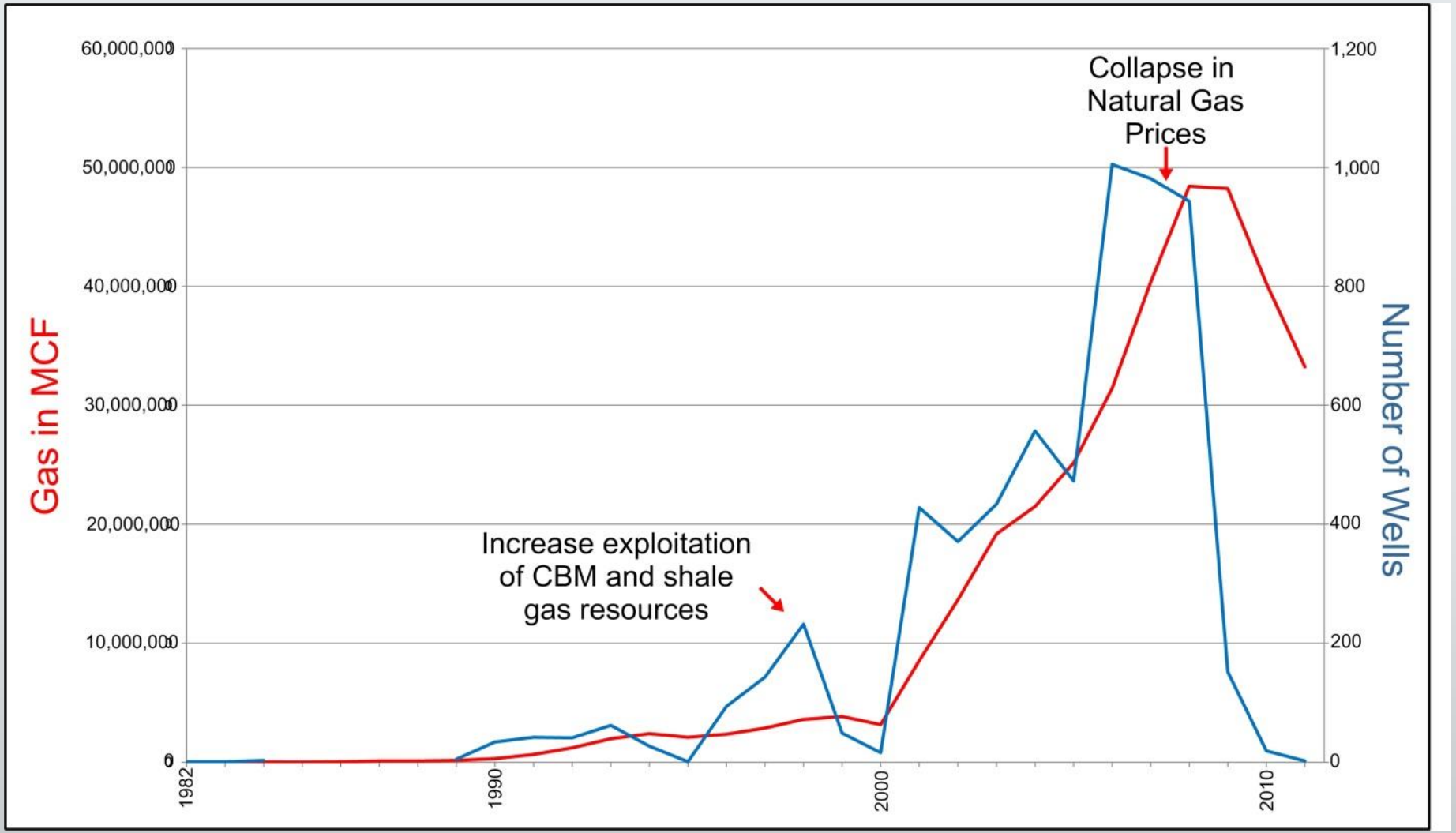
Total gas production for the 2nd, 3rd and 4th years on a township basis.



Tedesco, 2014



Total gas production per well.



Gas Production through 2011

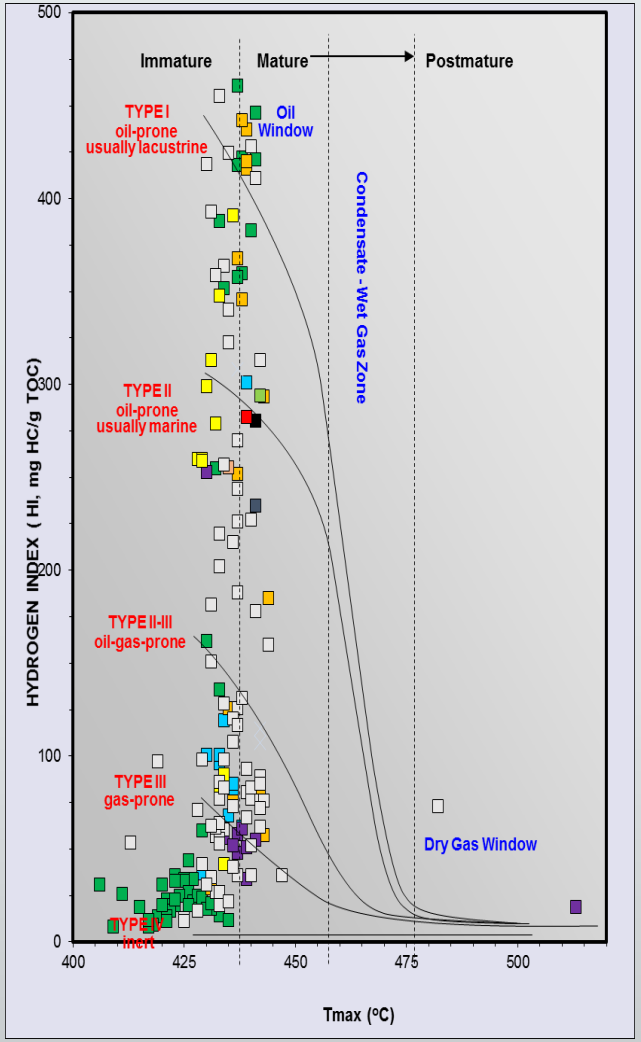
Since 2010 to 2015 there has been no CBM drilling in the basin. Several companies have gone out of business, been sold or have reduce production significantly.

Source Rock

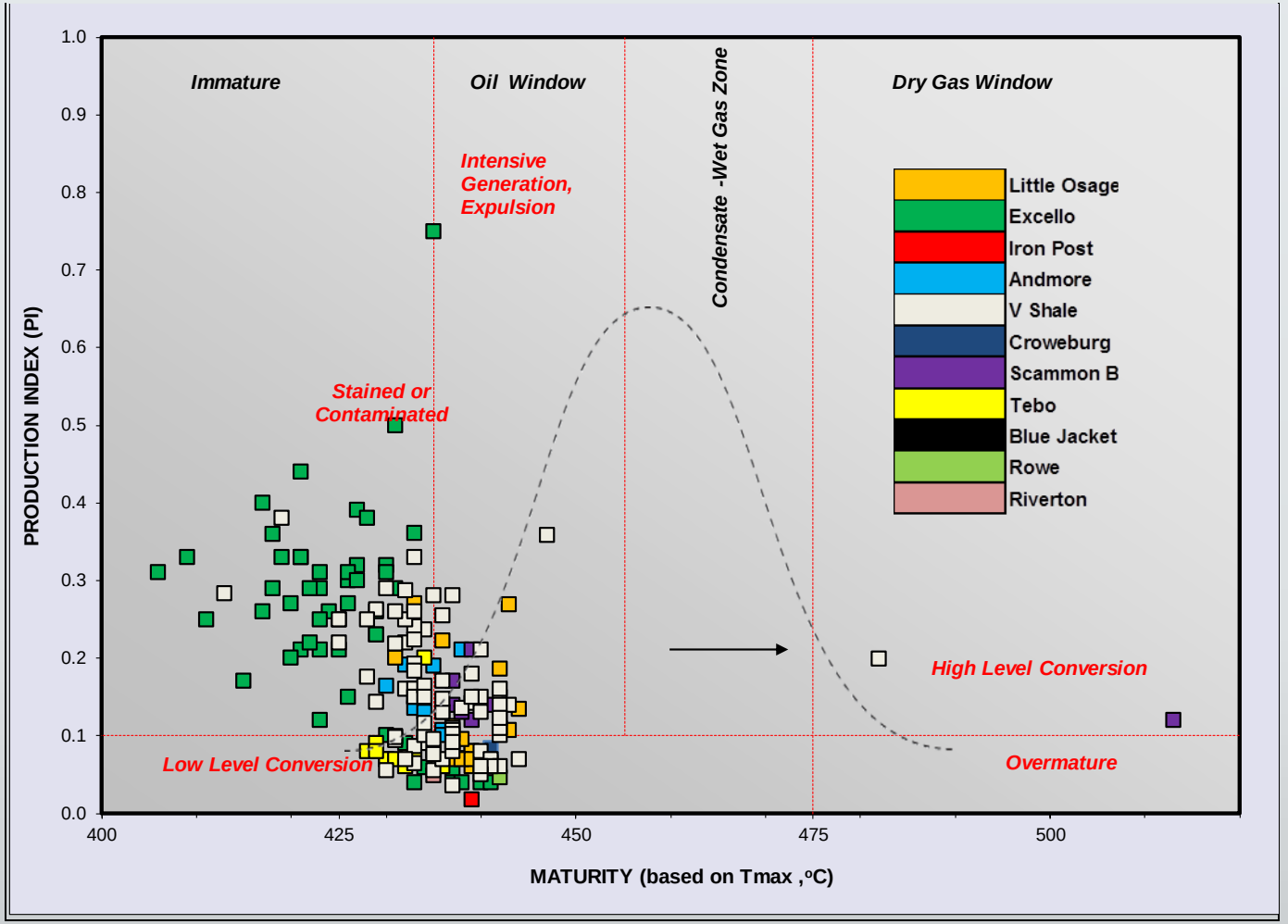
1) Coals based on ASTM methods are High Volatile A Bituminous to Medium Volatile Bituminous (Proximate analysis). When compared to the reflectance scale used in petroleum the coals and carbonaceous shales they are in the oil window; This is supported by reflectance data done on Pennsylvanian carbonaceous shales and the Devonian-Mississippian Chattanooga Shale.

2) The basin history, related to depths the coal and carbonaceous shales were buried were never buried more than 6,000 feet - not in agreement with ASTM rank and reflectance data;

3) A different mechanism for their maturity has to be found.



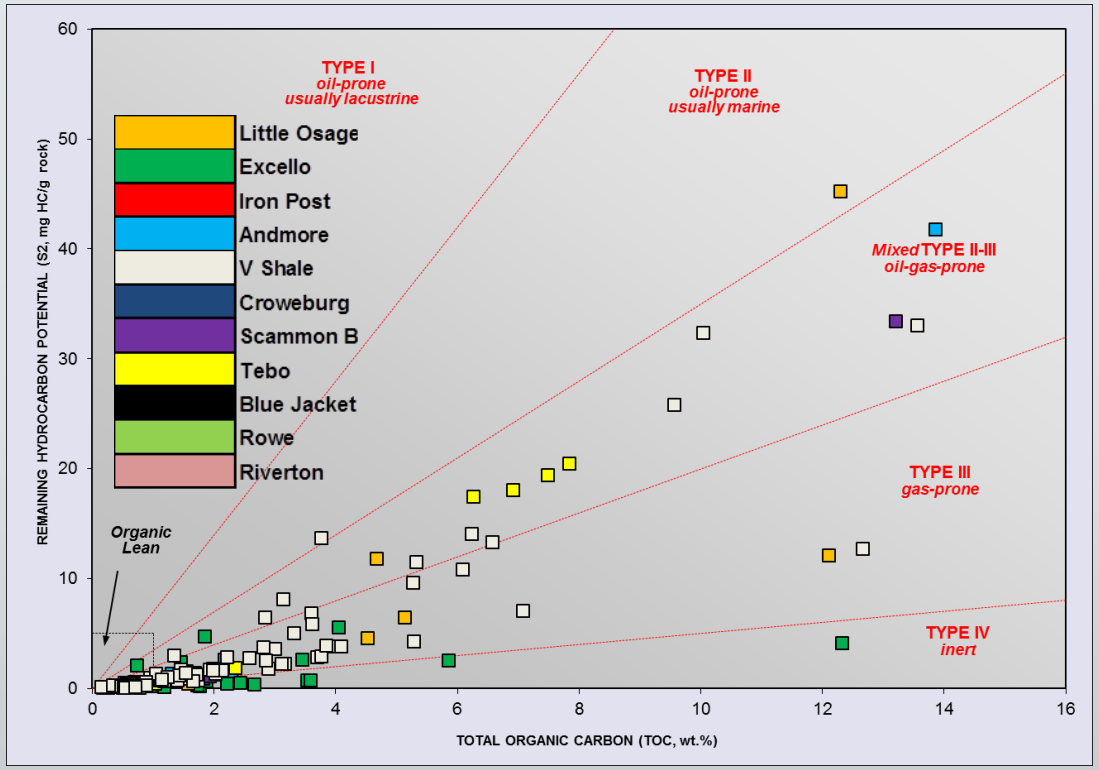
The Hydrogen Index versus and T_{max} indicating the source rocks are immature to marginally mature. The Little Osage and V shales are in the oil window. The Excello Shale overall is immature. However, recent work in other basins suggests that the presence of high sulfur content can allow early generation and expulsion of petroleum. The sulfur content in the Pennsylvanian carbonaceous mudstones and coals is greater than 2%.



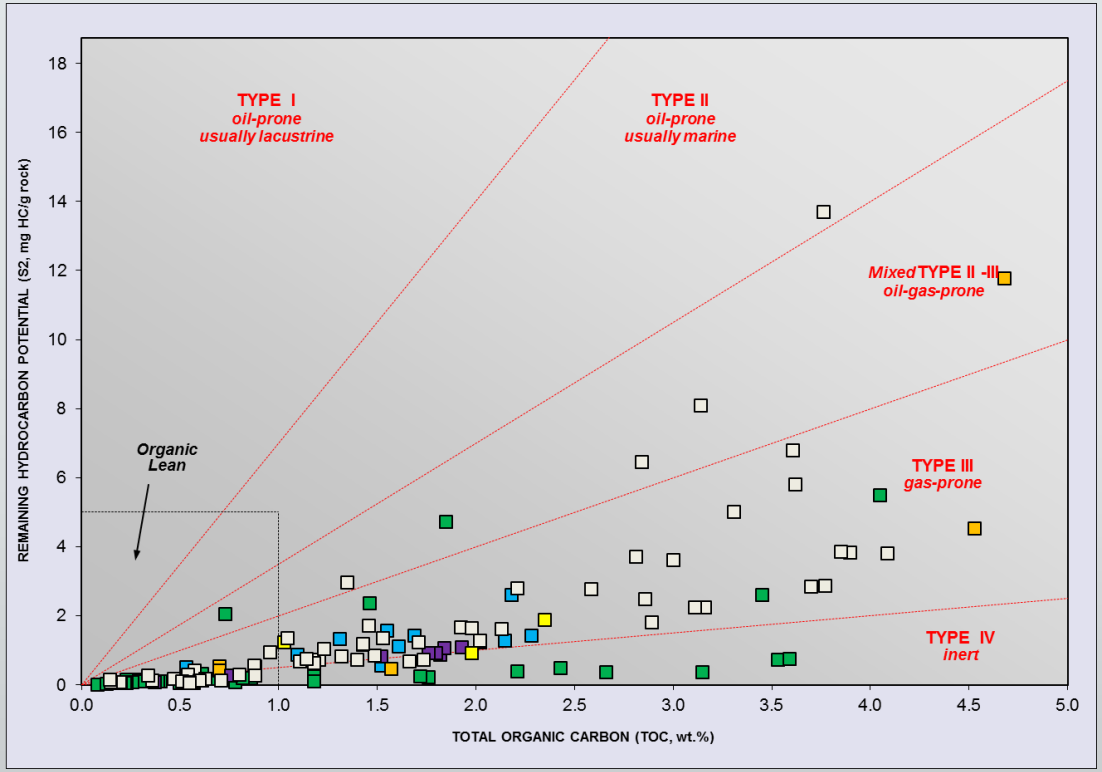
The Production Index (S1/(S1+S2) versus T_{max} indicates that the source rocks in the Pennsylvanian rocks are immature to marginally mature. The Little Osage and V shales are overall mature and the Excello Shale is immature.

Maturity of the Pennsylvanian Carbonaceous Mudstones

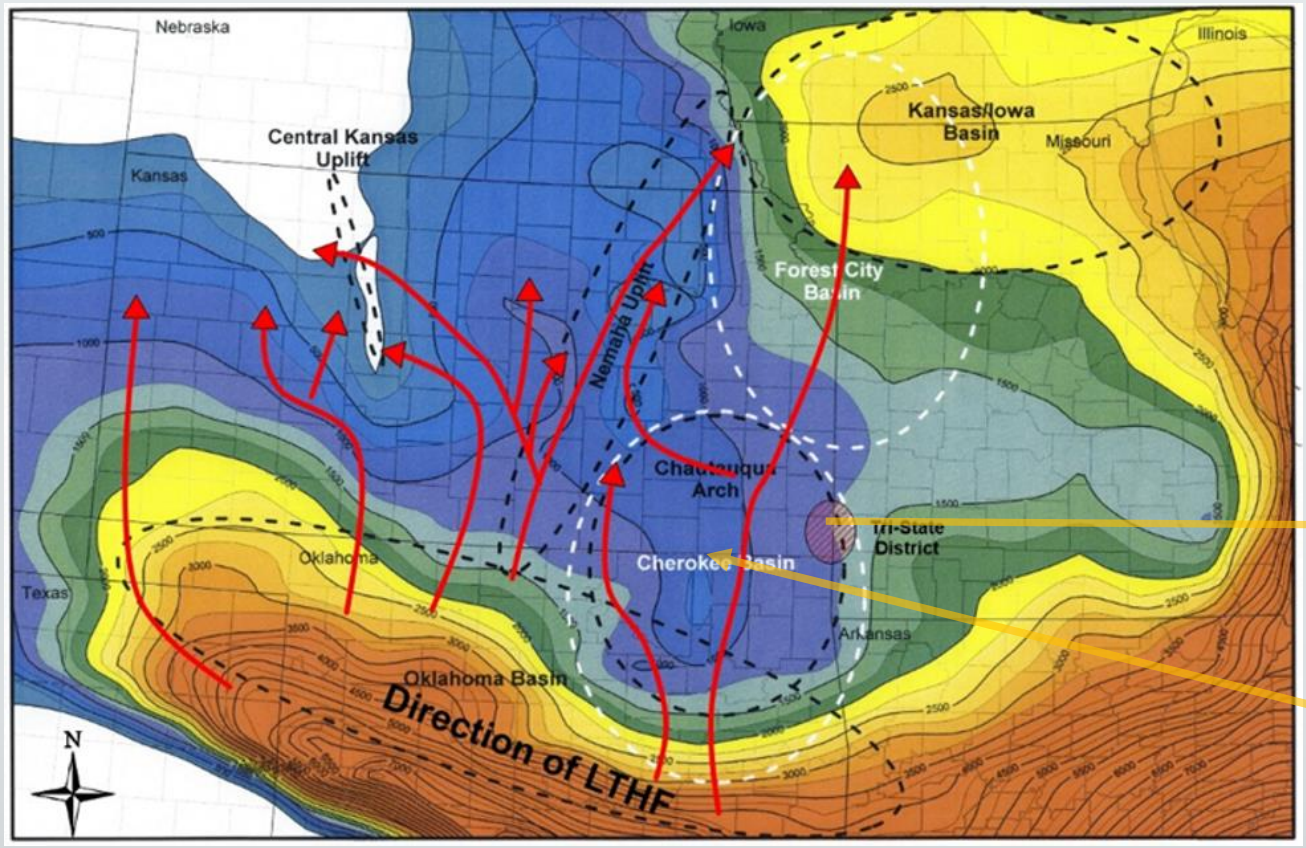
Maturity of the Pennsylvanian Carbonaceous Mudstones



Kerogen quality plotted as remaining hydrocarbon potential (S2) versus TOC.



The majority of samples are Type III the V and Tebo shales are in the Type II-III category.



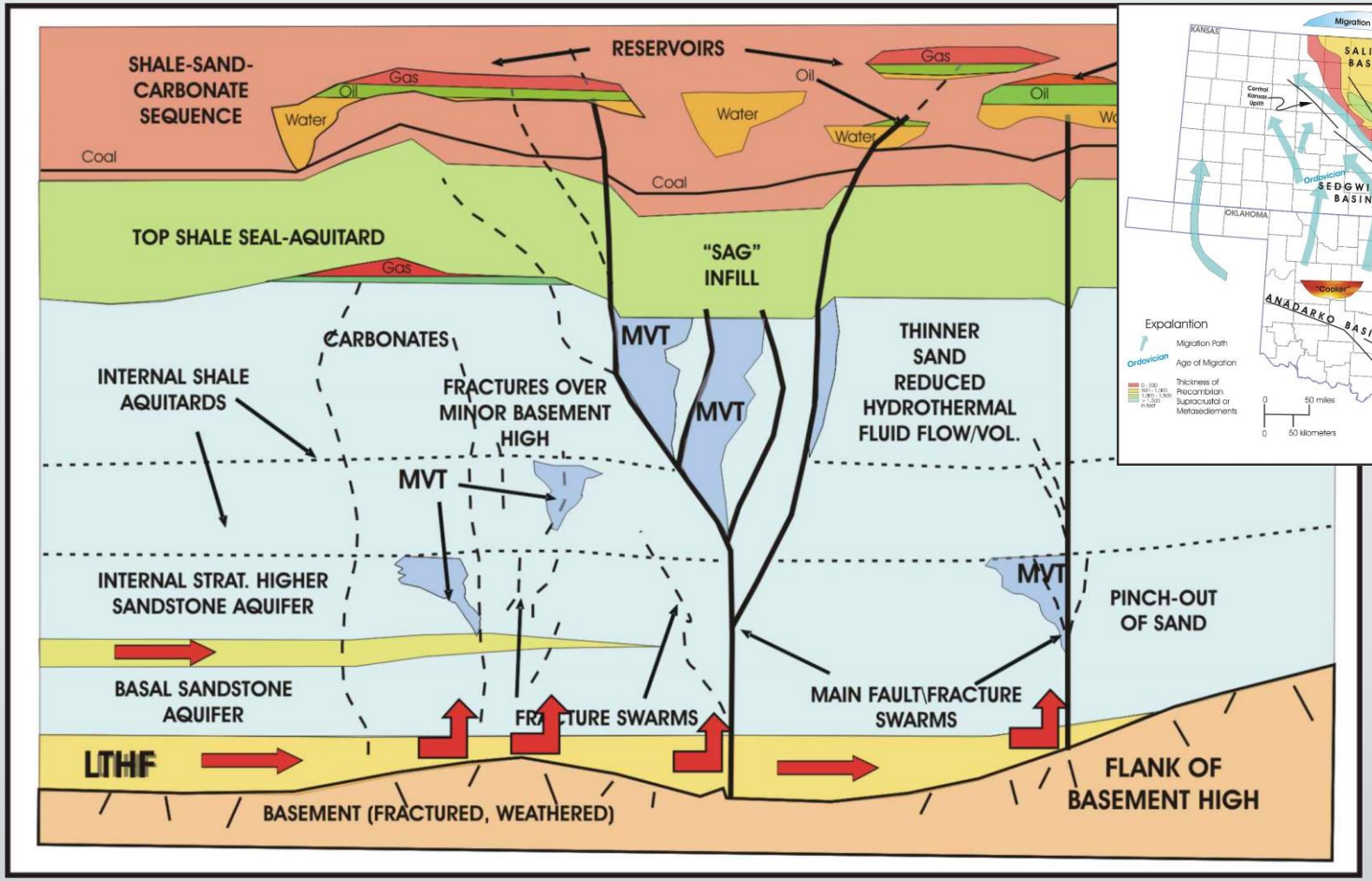
LTHF

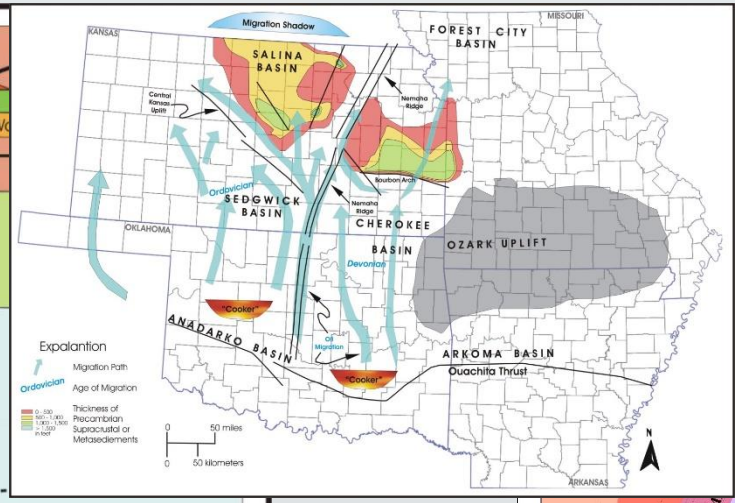
Chautauqua Arch (Cherokee Basin)

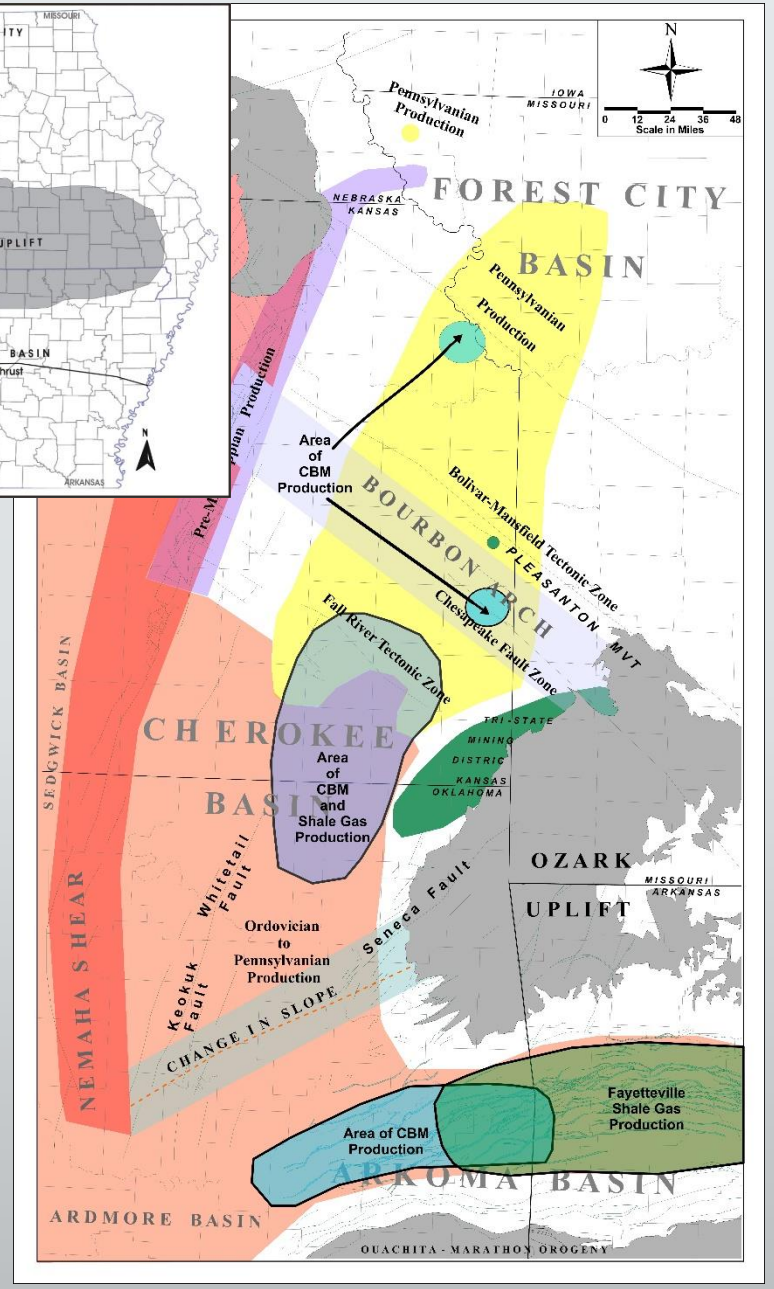
Migration of Low temperature hydrothermal fluids (LTHF) from the deep Anadarko, Ardmore and Arkoma basins migrated northward into Kansas. These fluids both carried petroleum as well as locally matured Ordovician, Devonian-Mississippian and Pennsylvanian age carbonaceous shales and mudstones;

Importance of thinness the Pre-Pennsylvanian overburden in the Cherokee Basin allowed widespread heating of overlying Pennsylvanian rocks;

The presence of LTHF is supported in the Cherokee Basin as well as the Forest City Basin to the north by the presence of numerous Mississippi Valley Type Deposits (lead-zinc accumulations).



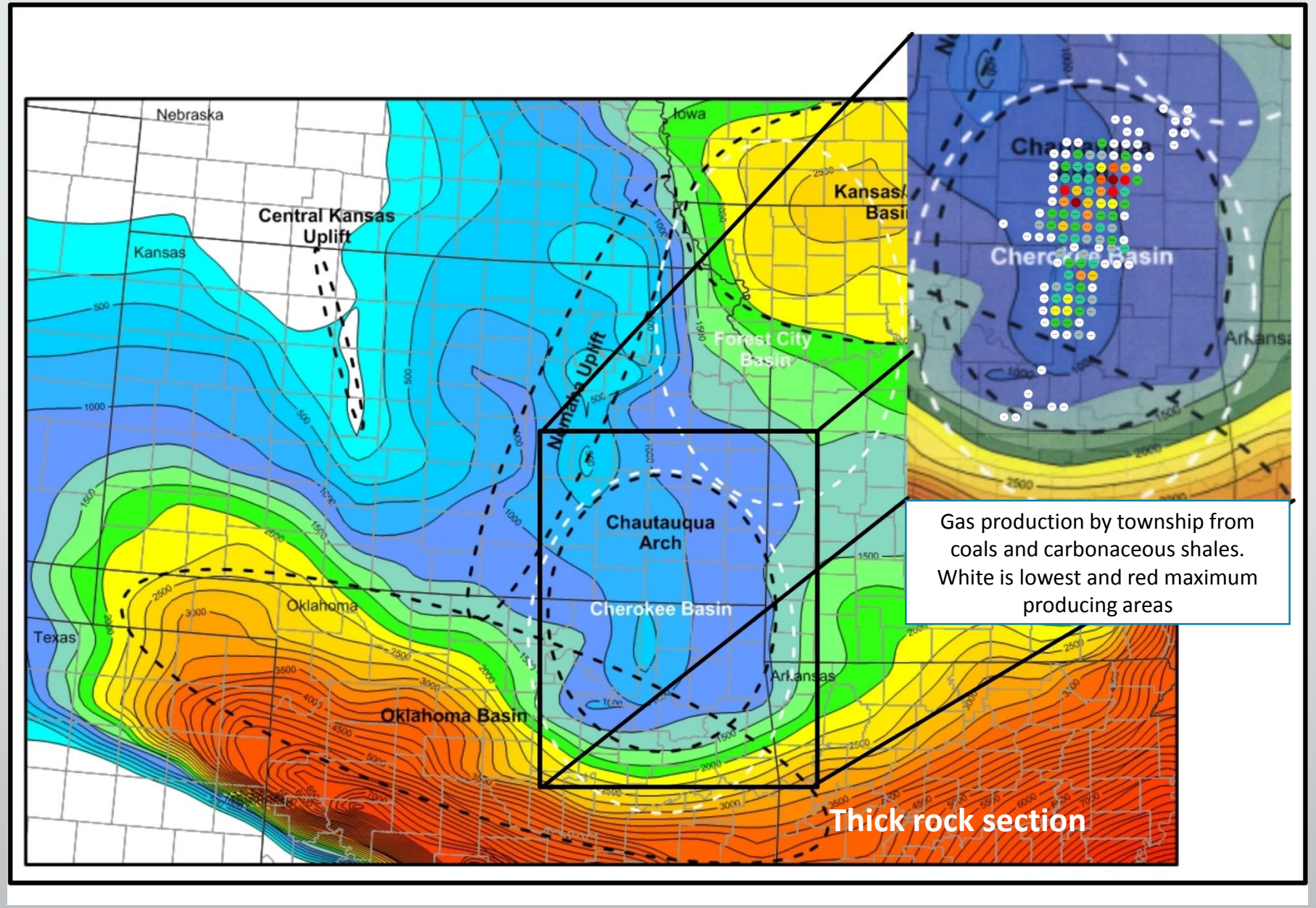




LTHF migration pathways with associated elements including Mississippi Valley Type Deposits (MVT) and filling of hydrocarbon-bearing reservoirs as these LTHF's migrate in and through the Cherokee Basin (modified from Davies and Smith, 2006).

Petroleum and MVT deposits

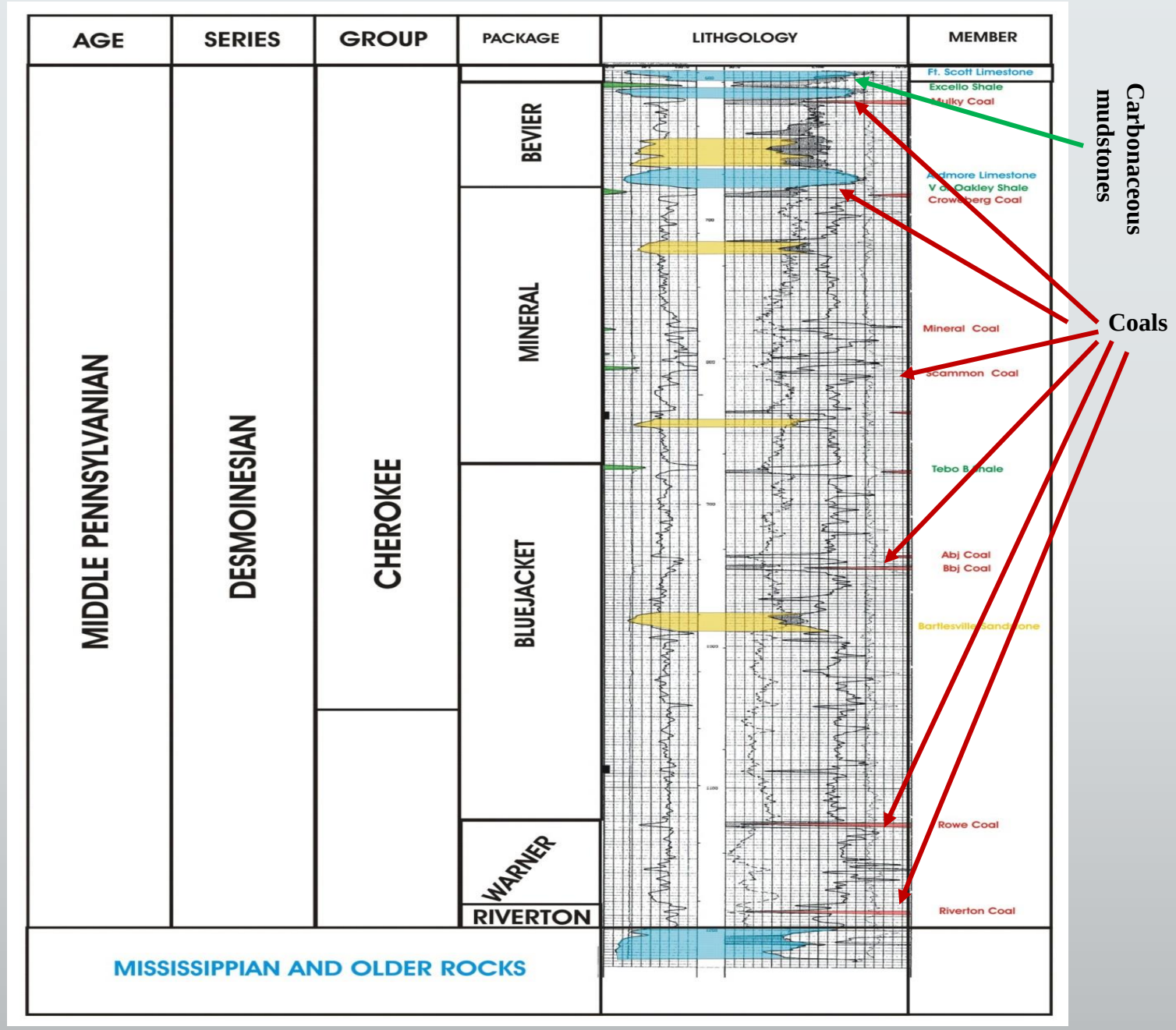
Coal and Carbonaceous Mudstone Gas Production



Adler et al., 1971 and Tedesco, 2014

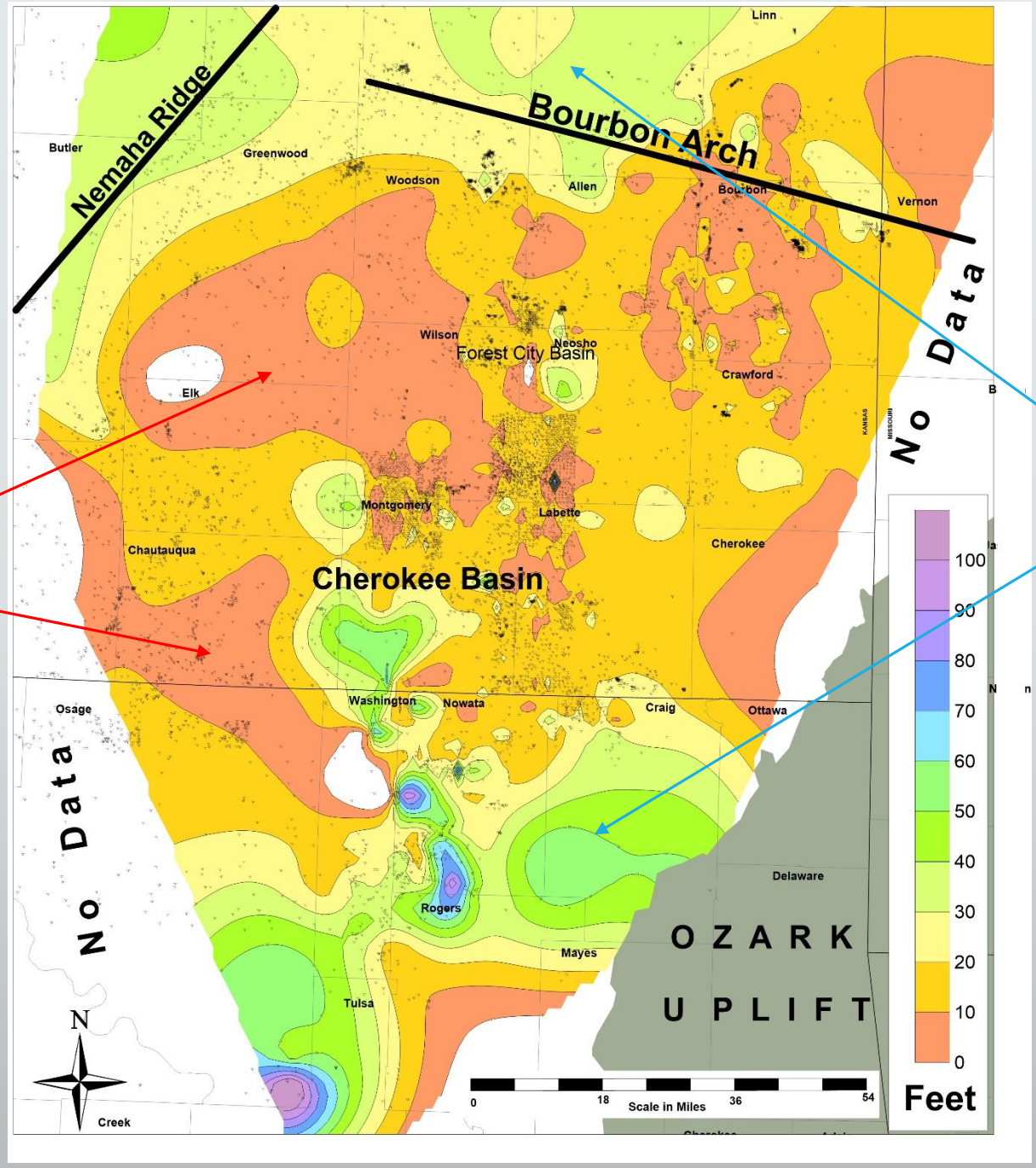
Typical Log for the Cherokee Basin

- Coals found in the Cherokee Group
- Depths - surface to 2,600 feet
- High sulfur coals
- Rank - High Volatile A Bituminous coal
- Coals contain thin ash lamination – 5 to 50%



Tedesco, 2014

Map of the Riverton Interval



Coal and Carbonaceous Mudstones Reservoir Characteristics

Coal
- Thin 1 to 2 feet thick;
- High Volatile B to Medium Volatile;
- Poor vitrinite content: 65% to 85%;
- Friable;
- Poorly cleated;
- Bright to dull;
- Laminated;
- High Inertinite and Fusinite;
- High Ash;
- High sulfur;
- No de-watering.

Carbonaceous Mudstone
- Thin 1 to 10 feet thick;
- R_o 0.45 to 0.76;
- Marine to terrestrial;
- Quartz and carbonate <50% except Excello Shale;
- Laminated;
- No de-watering.

Cherokee Basin
- Underpressured, 0.34 gradient;
- Lack of depth of burial;
- Maturation related to thin Pre-Pennsylvanian Paleozoic cover and migrating low temperature hydrothermal fluids.

Productive Coals and Carbonaceous Mudstones Proximate Analysis

Mulky
Weir- Pittsburg
Drywood – Rowe
Riverton

Productive Mudstones
Excello

Moisture	No. of Samples	Average	Median	Standard Deviation
Little Osage	27	4.0	3.6	1.4
Excello	67	3.8	3.1	2.1
V	17	3.3	3.2	1.1
Tebo & Tebo B	9	3.7	3.8	1.5
Other Shales	12	3.5	3.5	1.2
Mulky	6	2.8	1.9	1.7
Bevier	5	3.1	2.6	2.0
Croweberg	6	3.0	2.7	1.1
Mineral	18	3.9	3.6	1.6
Scammon	7	5.0	5.0	1.5
Weir-Pittsburg	8	2.8	2.1	2.1
Drywood	17	3.5	3.4	1.3
Rowe	59	3.3	2.9	2.2
Aw	22	4.1	4.2	1.8
Riverton	118	3.1	2.6	1.8
Other Coals	23	3.6	3.8	1.4

Ash	No. of Samples	Average	Median	Standard Deviation
Little Osage	27	73.0	75.1	11.1
Excello	67	61.1	74.5	28.2
V	17	61.6	72.8	23.2
Tebo & Tebo B	9	49.8	48.4	24.8
Other Shales	12	75.9	82.7	19.0
Mulky	6	17.6	15.8	7.9
Bevier	5	35.9	32.7	18.4
Croweberg	6	30.1	22.9	25.4
Mineral	18	41.7	32.3	28.0
Scammon	7	45.9	34.6	18.1
Weir-Pittsburg	8	29.9	18.1	27.3
Drywood	17	30.4	23.3	25.2
Rowe	59	22.1	17.7	14.3
Aw	22	21.0	18.8	16.5
Riverton	118	23.7	17.2	19.5
Other Coals	23	37.5	23.9	27.0

Sulfur	No. of Samples	Average	Median	Standard Deviation
Little Osage	27	1.6	1.5	1.1
Excello	67	2.2	2.0	1.6
V	17	1.8	1.4	1.3
Tebo & Tebo B	9	4.6	3.4	3.6
Other Shales	12	2.3	1.3	3.0
Mulky	6	5.1	4.2	3.8
Bevier	5	2.1	2.0	0.5
Croweberg	6	2.4	2.7	0.9
Mineral	18	3.4	3.1	2.0
Scammon	7	4.5	5.5	2.7
Weir-Pittsburg	8	5.6	4.8	3.1
Drywood	17	5.2	4.6	3.2
Rowe	59	5.4	5.3	2.2
Aw	22	6.5	5.6	3.7
Riverton	118	7.2	6.2	5.3
Other Coals	23	5.3	5.5	3.7

Producing

Non-producing

Volatile Matter	No. of Samples	Average	Median	Standard Deviation
Little Osage	27	15.0	14.7	6.2
Excello	67	17.4	12.3	12.1
V	17	20.1	18.5	8.4
Tebo & Tebo B	9	21.4	20.1	9.7
Other Shales	12	11.3	7.3	9.8
Mulky	6	36.9	36.4	6.7
Bevier	5	27.8	27.1	9.8
Croweberg	6	30.9	35.0	11.4
Mineral	18	23.3	27.8	21.5
Scammon	7	25.3	26.0	11.0
Weir-Pittsburg	8	30.1	35.8	10.9
Drywood	17	30.0	32.0	10.4
Rowe	59	32.4	33.7	6.8
Aw	22	32.7	34.1	7.5
Riverton	118	32.1	34.1	8.8
Other Coals	23	29.0	32.3	10.8

Fixed Carbon	No. of Samples	Average	Median	Standard Deviation
Little Osage	27	8.2	7.9	6.6
Excello	67	17.6	10.3	17.1
V	17	12.9	8.5	13.9
Tebo & Tebo B	9	24.4	22.7	13.9
Other Shales	12	8.5	5.1	11.3
Mulky	6	42.0	43.8	4.6
Bevier	5	33.2	32.4	9.4
Croweberg	6	35.9	41.2	15.4
Mineral	18	29.9	33.4	21.5
Scammon	7	23.9	28.9	12.9
Weir-Pittsburg	8	37.3	42.6	17.6
Drywood	17	36.1	41.1	15.4
Rowe	59	42.1	44.5	8.9
Aw	22	42.3	43.7	10.6
Riverton	118	41.1	44.7	12.5
Other Coals	23	29.0	32.3	10.8

Heating Value in BTU/lb DAF	No. of Samples	Average	Median	Standard Deviation	Rank (Median)
Little Osage	27	10,247	10,876	3,323	Not Applicable
Excello	67	10,484	11,831	5,113	Not Applicable
V	17	10,060	11,541	4,820	Not Applicable
Tebo & Tebo B	9	13,254	13,170	1,552	Not Applicable
Other Shales	12	11,908	10,710	14,888	Not Applicable
Mulky	6	15,149	14,932	401	High Volatile A
Bevier	5	14,219	14,298	917	High Volatile A
Croweberg	6	14,666	15,241	1,458	High Volatile A
Mineral	18	11,963	14,458	4,672	High Volatile A
Scammon	7	13,281	14,829	2,643	High Volatile A
Weir-Pittsburg	8	14,219	15,143	1,838	High Volatile A
Drywood	17	13,488	15,086	3,941	High Volatile A
Rowe	59	14,574	14,929	1,799	High Volatile A
Aw	22	14,479	14,985	2,401	High Volatile A
Riverton	118	14,332	14,994	2,032	High Volatile A
Other Coals	23	13,387	14,327	2,761	High Volatile A

Over 40%

Proximate analysis summary for the coals and carbonaceous shale in this study. All numbers other than BTU are in percentage of rock volume. BTU: British Thermal Units per pound. DAF: dry, ash free.

Sulfur and petroleum generation

Most Productive Reservoirs:

Excello Shale

Weir-Pittsburg Coal

Rowe Coal

Riverton Coal

Sulfur present is high compared to Pennsylvanian coals in other basins.

Sulfur source for coals is likely from highly organic marine sediments immediately overlying coals.

Unit	No. of Samples	Ro Mean	Ro Median	Ro Standard Deviation	Sulfur Mean	Sulfur Median	Sulfur Standard Deviation	Rock Type
Labette	7	0.71	0.71	0.07	3.17	1.46	0.53	Carbonaceous Shale
Little Osage	23	0.65	0.63	0.20	1.83	1.22	1.81	Carbonaceous Shale
Excello	47	0.68	0.63	0.19	2.53	2.60	2.13	Carbonaceous Shale
Iron Post	11	0.64	0.62	0.04	4.11	4.11	ND	Coal
Bevier	14	0.66	0.64	0.12	2.18	2.09	0.64	Coal
V	20	0.66	0.67	0.06	3.46	2.40	1.94	Carbonaceous Shale
Croweberg	14	0.62	0.61	0.10	2.58	2.28	0.86	Coal
Mineral	41	0.72	0.72	0.07	4.17	5.75	1.95	Coal
Scammon	20	0.71	0.71	0.10	5.32	7.12	3.55	Coal
Tebo\Tebo B	22	0.67	0.67	0.10	ND	ND	ND	Carbonaceous Shale
Weir-Pittsburg	19	0.73	0.74	0.07	4.17	5.75	1.95	Coal
Abj	4	0.66	0.66	0.06	ND	ND	ND	Coal
Cbj	5	0.72	0.76	0.14	1.35	1.35	ND	Coal
Drywood	19	0.78	0.79	0.09	6.03	4.61	3.33	Coal
Rowe	63	0.71	0.68	0.09	5.64	5.59	2.06	Coal
Aw	18	0.72	0.70	0.10	7.30	7.33	3.28	Coal
Bw	5	0.67	0.66	0.14	6.34	6.34	2.14	Coal
Riverton	137	0.71	0.70	0.08	6.99	6.29	4.34	Coal

Reservoirs are saturated to over saturated in the prime producing areas

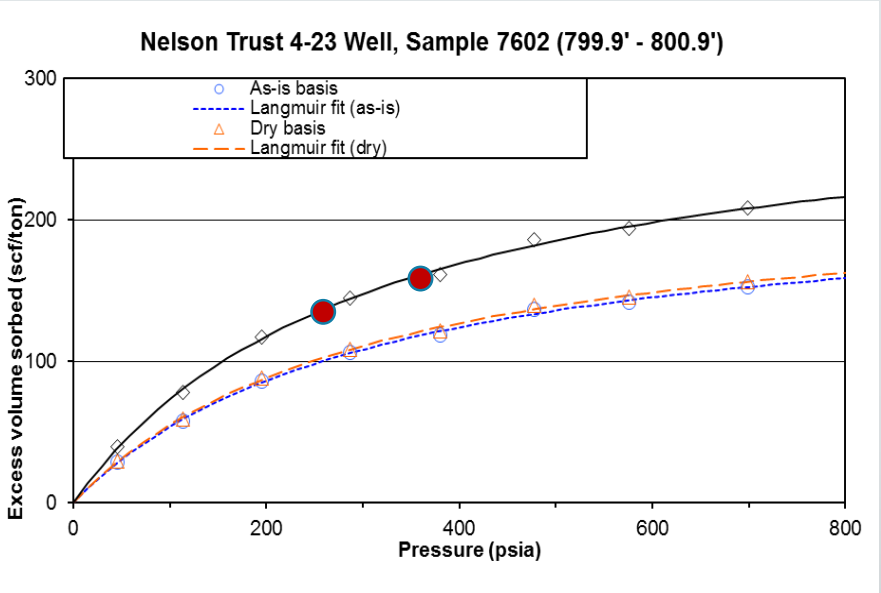
Most productive unconventional reservoirs

USBM Total Gas (scf) DAF

Unit	No. of Samples	Average	Median	Standard Deviation
Little Osage	34	149	119	116
Excello	71	141	98	122
V	20	140	103	124
Tebo & Tebo B	17	75	56	50
Other Shales	139	140	103	116
Mulky	7	134	139	58
Bevier	5	118	131	54
Croweberg	9	163	130	136
Mineral	18	218	173	222
Scammon	9	106	107	51
Weir-Pittsburg	8	149	98	98
Drywood	17	188	150	122
Rowe	60	132	124	80
Aw	22	122	122	63
Riverton	120	135	122	73
All Coals	311	138	120	95

Desorption results in Scf per ton dry ash free

Adsorption data both raw and dry, ash, free (DAF) in both SCF/ton and standard cm3/g at 0.34 and 0.44 psi/ft.



Adsorption for a Riverton Coal sample from the Nelson Trust 4-23 well in Labette County, Kansas, Riverton coal. This well is productive from the Riverton Coal.

Calc. Adsorption Based on 0.44 psi/ft (scf/ton) Raw

Unit	No. of Samples	Average	Median	Standard Deviation
Little Osage	15	39.9	34.3	31.8
Excello	33	43.5	43.1	57.1
V	14	38.6	33.0	26.6
All Shales	67	41.0	29.5	37.8
Bevier	3	126.4	114.3	47.6
Mineral	10	86.7	68.3	66.1
Scammon	3	66.1	40.4	67.1
Weir-Pittsburg	3	118.8	134.6	72.3
Drywood	12	109.4	110.5	59.8
Rowe	16	143.3	123.7	70.6
Aw	14	66.4	61.1	56.4
Riverton	37	131.3	126.6	38.4
All Coals	112	128.6	127.9	63.6

Calc. Adsorption Based on 0.44 psi/ft (scf/ton) DAF

Unit	No. of Samples	Average	Median	Standard Deviation
Little Osage	15	163.1	161.2	59.0
Excello	33	188.8	188.3	82.4
V	14	129.8	148.8	63.5
All Shales	67	164.8	148.8	84.2
Bevier	3	244.3	235.8	22.2
Mineral	10	159.2	137.9	54.9
Scammon	3	169.1	146.4	92.4
Weir-Pittsburg	3	223.6	224.9	8.9
Drywood	12	167.9	151.8	39.0
Rowe	16	188.1	176.0	64.6
Aw	14	134.0	137.1	25.0
Riverton	37	173.0	173.2	32.5
All Coals	112	190.0	181.7	56.9

Comparison of Adsorption to Desorption	Unit	Desorption No. of Samples	Adsorption No. of Samples	Desorption scf\ton Raw	Desorption scf\ton DAF	Adsorption scf\ton Raw at 0.44 psi/ft	Adsorption scf\ton DAF at 0.44 psi/ft	Adsorption scf\ton Raw at 0.34 psi/ft	Adsorption scf\ton DAF at 0.34 psi/ft
	Little Osage	34	15	30	149	40	163	35	142
	Excello	71	33	37	141	43	189	39	174
	V	20	14	35	140	39	130	34	115
	Tebo & Tebo B	17	0	39	75	No Data	No Data	No Data	No Data
	All Shales	139	67	34	140	41	165	35	148
	Mulky	7	0	106	134	No Data	No Data	No Data	No Data
	Bevier	5	3	73	118	126	244	116	224
	Croweberg	9	0	131	163	No Data	No Data	No Data	No Data
	Mineral	18	10	94	218	87	159	70	139
	Scammon	9	3	53	106	66	169	51	135
	Weir-Pittsburg	8	3	99	149	119	224	109	200
	Drywood	17	12	125	188	109	168	97	148
	Rowe	60	16	99	132	143	188	128	169
	Aw	22	14	86	122	66	134	57	115
	Riverton	120	37	96	135	131	173	118	155
	All Coals	311	112	93	138	129	190	114	167

Comparison of desorption to adsorption data for two different pressure regimes. The red color indicates whether the adsorption or desorption is greater than the other.

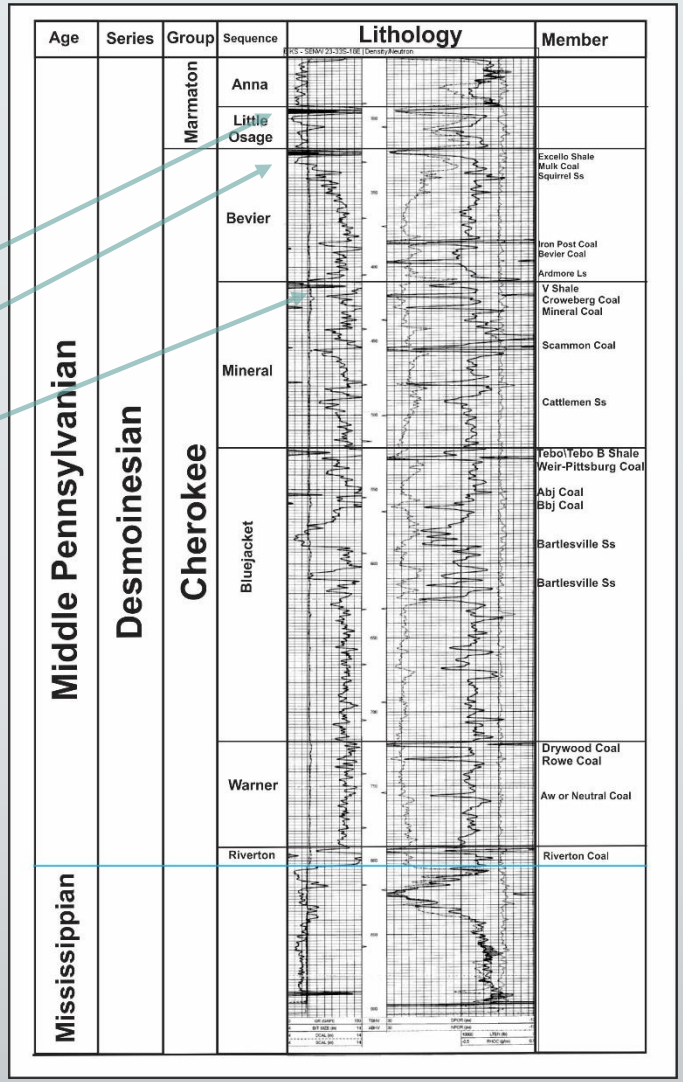
Desorption higher than adsorption suggesting these reservoirs are over saturated with gas.

Carbonaceous Shales

Little Osage

Excello

V



Unit	Average Porosity	Average Permeability
All samples	10.04	0.154
Little Osage Shale	8.5	0.010
Excello Shale	11.45	0.245
V Shale	7.3	0.023

Unit	Clays %	Silica \ Carbonates %	Other %
All samples	39.7	50.2	10.1
Little Osage shale	45.6	45.4	9.0
Excello shale	35.6	59.2	10.1
V shale	40.7	47.9	11.4

Significantly higher permeability
Due to increase brittleness of rock due to > 50% quartz and carbonates

Summary

The primary coals that produce gas are:

Coals with over 5% and carbonaceous shales with over 2.5% sulfur (Proximate analysis. Sulfur, because of weaker bonds with carbon allows for generation of hydrocarbons at lower temperatures than normal ;

When low temperature fluids migrated through the area the higher sulfur in certain coals and carbonaceous shales caused maturation and early onset of petroleum generation and expulsion;

Fixed carbon is higher in productive coals (proximate analysis) and also have higher vitrinite macerals, lower ash and inertinite contents;

Reflectance values can be suppressed by the high sulfur contents causing the coals and carbonaceous shales to be misinterpreted as immature;

Structure, thickness of the reservoir and localized thickness of the Cherokee Group do not seem to be related to gas productive areas;

Thank you for coming